Natural Gas & Propane Technician Textbook

Canadian Standards - TSSA G2/G3 Qualification & CSA B149 Compliance

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TEXTBOOK STRUCTURE OVERVIEW

Target Audience: Apprentice gas technicians, vocational students, TSSA G2/G3 candidates **Estimated Length:** 600-800 pages **Level:** Introductory to intermediate **Compliance:** CSA B149.1-25, CSA B149.2, TSSA regulations, National Building Code

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SECTION 1: FOUNDATIONS (Chapters 1-3)

CHAPTER 1: Introduction to the Gas Industry in Canada

Estimated: 30-40 pages

1.1 History of Gas Utilities in Canada

- Development of natural gas infrastructure
- Propane industry evolution
- Regional distribution systems

1.2 The Canadian Regulatory Framework

- Technical Standards and Safety Authority (TSSA)
- Provincial regulatory bodies across Canada
- CSA standards overview (B149.1, B149.2, B149.5)
- National codes and standards hierarchy

1.3 Career Pathways and Certifications

- G3 Certificate (Propane)
- G2 Certificate (Natural Gas & Propane)
- G1 Certificate (Gas Fitter)
- Continuing education requirements
- Trade certification vs. gas licensing

1.4 Industry Best Practices

- Professional conduct
- Customer relations
- Documentation requirements
- Quality assurance

Chapter Review:

- Key terms glossary
- Review questions (20)
- Case studies (3)
- Practical exercises

CHAPTER 2: Safety Fundamentals

Estimated: 50-60 pages

2.1 Personal Protective Equipment (PPE)

- Required PPE for gas work
- Proper selection and maintenance
- When and where to use specific PPE
- CSA standards for safety equipment

2.2 Hazard Recognition

- Flammability and explosive ranges
- Asphyxiation hazards
- Carbon monoxide awareness
- Confined space dangers
- Electrical hazards
- Physical hazards on job sites

2.3 Emergency Procedures

- Gas leak response protocols
- Evacuation procedures
- First aid for gas exposure
- Fire safety and extinguisher use
- Emergency contact procedures
- Incident reporting requirements

2.4 Workplace Safety Regulations

- Provincial occupational health and safety acts
- WHMIS 2015 (GHS)
- Safety data sheets (SDS)
- Lockout/tagout procedures
- Working at heights
- Trenching and excavation safety

2.5 Gas Leak Detection and Response

- Sensory detection methods
- Electronic detection equipment
- Leak investigation procedures
- Building evacuation criteria
- Emergency shut-off procedures
- Documentation and reporting

2.6 Carbon Monoxide Safety

- Sources and dangers
- Detection methods
- Symptoms of CO poisoning
- Prevention strategies
- CSA B149.1 ventilation requirements

- CO alarm requirements per code

Chapter Review:

- Safety scenarios (10)
- Hazard identification exercises
- Emergency response simulations
- PPE selection quiz

CHAPTER 3: Tools and Equipment

Estimated: 45-55 pages

3.1 Hand Tools

- Wrenches (pipe, adjustable, basin)
- Pipe cutters and reamers
- Flaring and swaging tools
- Tube benders
- Threading equipment
- Measuring tools
- Proper use and maintenance

3.2 Power Tools

- Drills and drivers
- Reciprocating and band saws
- Threading machines
- Grinders
- Safety considerations
- Maintenance requirements

3.3 Testing and Measurement Equipment

- Manometers (digital and analog)

- Pressure gauges
- Multimeters
- Combustion analyzers
- Gas leak detectors (electronic)
- Clamp meters
- Thermometers and psychrometers
- Calibration requirements

3.4 Piping Tools

- Pipe threading dies and stocks
- Fusion welding equipment
- Mechanical joint tools
- Support and hanging equipment

3.5 Specialized Gas Equipment

- Purging equipment
- Pressure testing apparatus
- Valve exercising tools
- Regulator adjustment tools

3.6 Tool Safety and Maintenance

- Inspection procedures
- Preventive maintenance schedules
- Safe storage practices
- Manufacturer specifications

Chapter Review:

- Tool identification exercises
- Proper use demonstrations
- Maintenance checklists

- Safety assessments

SECTION 2: GAS PROPERTIES & SCIENCE (Chapters 4-5)

CHAPTER 4: Properties of Natural Gas

Estimated: 40-50 pages

4.1 Composition and Characteristics

- Chemical makeup (methane content)
- Physical properties
- Specific gravity
- Heating values (BTU content)
- Wobbe Index
- Regional variations in Canada

4.2 Natural Gas Behavior

- Pressure-volume relationships
- Temperature effects
- Flow characteristics
- Gas laws applicable to field work

4.3 Combustion Principles

- Complete vs. incomplete combustion
- Air-fuel ratios
- Primary and secondary air
- Flame characteristics
- Products of combustion
- Excess air requirements

4.4 Natural Gas Distribution

- Pipeline systems in Canada

- Pressure levels (high, medium, low)
- Odorization requirements
- Quality standards (CSA standards)
- Measurement and billing

4.5 Environmental Considerations

- Greenhouse gas impact
- Natural gas vs. other fuels
- Efficiency considerations
- Methane emissions reduction

Chapter Review:

- Calculations exercises
- Combustion analysis problems
- Property comparison charts
- Case studies

CHAPTER 5: Properties of Propane (LP Gas)

Estimated: 40-50 pages

5.1 Composition and Characteristics

- Chemical structure
- Liquid vs. vapor states
- Specific gravity (liquid and vapor)
- Heating value
- Vapor pressure
- Temperature-pressure relationships

5.2 Propane Behavior

- Vaporization process

- Effects of temperature on pressure
- Tank sizing considerations
- Vapor withdrawal rates
- Weathering and HD-5 specifications

5.3 Propane vs. Natural Gas

- Comparative properties
- Appliance conversion considerations
- Orifice sizing differences
- Installation differences
- Code requirements (B149.1 vs B149.2)

5.4 Propane Storage and Handling

- Tank types and capacities
- DOT/TC cylinder specifications
- Fill limits (80% rule)
- Pressure relief devices
- Tank installation requirements per CSA B149.2
- Setback distances
- Underground vs. aboveground installations

5.5 Propane Distribution Systems

- Bulk plant operations
- Transportation regulations (TDG)
- Cylinder exchange programs
- Delivery procedures
- Safety protocols

5.6 Two-Stage vs. Single-Stage Systems

- System design differences

- Pressure regulation requirements
- Advantages and applications

Chapter Review:

- Vapor pressure calculations
- Tank sizing exercises
- Conversion problems
- Storage requirement assessments

SECTION 3: PIPING & INSTALLATION (Chapters 6-8)

CHAPTER 6: Gas Piping Materials and Methods

Estimated: 60-70 pages

6.1 Approved Piping Materials

- Black steel pipe
- Corrugated stainless steel tubing (CSST)
- Polyethylene (PE) pipe
- Copper tubing (where permitted)
- Aluminum pipe
- Material selection criteria per CSA B149

6.2 Pipe Sizing Principles

- Pressure drop calculations
- Flow rate requirements
- Longest run method
- Branch length method
- Using CSA B149 sizing tables
- Equivalent length of fittings
- Specific gravity corrections

6.3 Steel Pipe Installation

- Threading procedures
- Joint compound specifications
- Proper support spacing
- Expansion considerations
- Protection from damage
- Sleeving requirements

6.4 CSST Installation

- Manufacturer specifications
- Support requirements
- Bonding and grounding (CSA B149.1 clause 7.11)
- Protection from physical damage
- Arc-fault protection
- Termination methods
- Jacket vs. non-jacketed systems

6.5 Polyethylene Pipe Installation

- Fusion joining techniques
- Burial depth requirements
- Tracer wire installation
- Protection from rocks and debris
- Transitioning to steel
- Pressure testing requirements

6.6 Underground Piping

- Minimum cover requirements
- Corrosion protection
- Marking and identification

- Crossing utilities
- Service entrance requirements
- Locate requirements

6.7 Above-Ground Piping

- Support and anchoring
- Protection from weather
- Painting requirements
- Identification and labeling
- Clearances from electrical
- Seismic considerations

Chapter Review:

- Pipe sizing calculations (15)
- Installation planning exercises
- Code compliance checklists
- Material selection scenarios

CHAPTER 7: Gas Meters and Regulators

Estimated: 50-60 pages

7.1 Gas Meters

- Diaphragm meter operation
- Rotary meter principles
- Turbine meters
- Meter reading and capacity
- Installation requirements
- Meter set assemblies
- Inlet and outlet pressure requirements

7.2 Service Regulators

- Purpose and function
- First-stage regulators
- Second-stage regulators
- Line pressure regulators
- Appliance regulators
- Spring vs. diaphragm design

7.3 Regulator Selection and Sizing

- Capacity calculations
- Inlet pressure considerations
- Outlet pressure requirements
- Lock-up pressure
- Droop characteristics
- Manufacturer ratings

7.4 Regulator Installation

- Location requirements per code
- Venting requirements (vent limiting devices)
- Support and orientation
- Protection from elements
- Access requirements
- Pressure testing considerations

7.5 Regulator Adjustment and Testing

- Outlet pressure verification
- Lock-up pressure testing
- Vent operation testing
- Maintenance procedures

- Troubleshooting common problems
- Documentation requirements

7.6 Overpressure Protection

- Overpressure protection devices (OPD)
- Relief valve requirements
- Monitoring regulators
- Series regulation

Chapter Review:

- Regulator selection exercises
- Pressure testing procedures
- Installation scenarios
- Troubleshooting case studies

CHAPTER 8: Pressure Testing and Purging

Estimated: 35-45 pages

8.1 Pressure Testing Requirements

- CSA B149.1 test pressure requirements
- Test medium (air, nitrogen, inert gas)
- Test duration requirements
- Documentation and record keeping
- Test gauge requirements
- Temperature compensation

8.2 Testing Procedures

- System preparation
- Isolating appliances and devices
- Pressure application methods

- Acceptable pressure drop
- Leak detection procedures
- Failed test procedures
- Re-testing requirements

8.3 Purging Procedures

- Purpose of purging
- Purge gas requirements
- Volume calculations
- Outdoor purging methods
- Indoor purging (special provisions)
- Verification of complete purge
- Safety considerations

8.4 New Construction vs. Existing Systems

- Initial system testing
- Modification testing requirements
- Adding to existing systems
- Partial system testing

8.5 Special Testing Situations

- CSST systems
- PE piping
- High-pressure systems
- Medical gas considerations

Chapter Review:

- Pressure test calculations
- Procedure checklists
- Documentation exercises

- Safety scenario assessments

SECTION 4: APPLIANCES & EQUIPMENT (Chapters 9-13)

CHAPTER 9: Introduction to Gas Appliances

Estimated: 45-55 pages

9.1 Appliance Categories

- Heating equipment
- Water heaters
- Cooking appliances
- Clothes dryers
- Pool and spa heaters
- Specialty appliances

9.2 Venting Categories

- Category I (draft hood equipped)
- Category II (non-condensing, forced draft)
- Category III (condensing, natural draft)
- Category IV (condensing, forced draft)
- Direct vent appliances
- Power vented appliances

9.3 Certification and Approval

- CSA certification marks
- AGA/CGA approval
- ANSI standards
- Canadian vs. U.S. appliances
- Serial plate information
- De-rating requirements

9.4 Input Rating and Efficiency

- Gross vs. net input
- AFUE (Annual Fuel Utilization Efficiency)
- Thermal efficiency
- Combustion efficiency
- De-rating for altitude
- De-rating for propane conversion

9.5 Appliance Installation Fundamentals

- Clearances to combustibles
- Combustion air requirements
- Accessibility for service
- Gas connection requirements
- Electrical connections
- Condensate drainage (where applicable)

9.6 Appliance Inspection and Commissioning

- Pre-start checks
- Initial firing procedures
- Combustion analysis requirements
- Documentation and reporting
- Owner instruction requirements

Chapter Review:

- Appliance identification exercises
- Rating plate interpretation
- Installation planning scenarios
- Code compliance reviews

CHAPTER 10: Burners and Combustion Systems

Estimated: 50-60 pages

10.1 Atmospheric Burners

- Natural draft principles
- Venturi mixing
- Primary and secondary air
- Flame characteristics
- Port loading
- Burner orifices

10.2 Power Burners

- Forced draft design
- Premix burners
- Modulating burners
- Proportional air/gas mixing
- Applications and advantages

10.3 Burner Orifices

- Sizing calculations
- Drill number sizing
- Natural gas vs. propane orifices
- Altitude compensation
- Pressure requirements
- Replacement procedures

10.4 Ignition Systems

- Standing pilot
- Intermittent pilot (spark ignition)
- Direct spark ignition (DSI)

- Hot surface ignition (HSI)
- Safety considerations per system
- Troubleshooting procedures

10.5 Flame Sensing

- Thermocouple operation
- Thermopile systems
- Flame rectification
- Optical flame sensors
- Proper flame characteristics
- Flame signal troubleshooting

10.6 Combustion Air Requirements

- Calculating air requirements per CSA B149.1
- Confined space definitions
- Unconfined space provisions
- Mechanical ventilation
- Outdoor combustion air
- Make-up air considerations
- Common venting complications

10.7 Combustion Analysis

- Oxygen (O_2) readings
- Carbon dioxide (CO_2) readings
- Carbon monoxide (CO) limits
- Stack temperature
- Draft measurements
- Efficiency calculations
- Correction factors

Chapter Review:

- Orifice sizing calculations
- Combustion air calculations
- Flame analysis exercises
- Troubleshooting scenarios

CHAPTER 11: Gas Valves and Safety Controls

Estimated: 55-65 pages

11.1 Manual Gas Valves

- Ball valves
- Plug valves
- Gate valves
- Applications and limitations
- Installation requirements
- Identification and labeling

11.2 Automatic Gas Valves

- Solenoid valves
- Diaphragm valves
- Redundant valve systems
- Slow-opening valves
- Pressure regulating valves
- Combination gas valves

11.3 Safety Shut-Off Systems

- Manual reset requirements
- 100% shut-off criteria
- Proving systems

- Redundancy requirements per code
- Pilot safety valves

11.4 Limit Controls

- Temperature limits
- High limit vs. operating limit
- Pressure limits
- Spill switches
- Blocked vent switches
- Manual vs. automatic reset

11.5 Flame Safeguard Controls

- Thermocouple systems (millivolt)
- Thermopile systems
- Flame rectification systems
- Electronic flame safeguard modules
- Sequence of operation
- Lockout conditions

11.6 Pressure and Air Flow Switches

- Differential pressure switches
- Air proving switches
- Draft safeguard switches
- Installation and adjustment
- Testing procedures

11.7 Sequence of Operations

- Pre-purge requirements
- Ignition trial timing
- Main flame establishment

- Post-purge requirements
- CSA B149.1 timing requirements
- Safety lockout conditions

Chapter Review:

- Valve identification exercises
- Wiring diagram interpretation
- Sequence timing problems
- Troubleshooting scenarios

CHAPTER 12: Venting Systems

Estimated: 60-70 pages

12.1 Venting Principles

- Natural draft operation
- Stack effect
- Available draft
- Factors affecting draft
- Spillage and backdrafting

12.2 Venting Materials

- Type B gas vent
- Type BW (water heater vent)
- Category II, III, IV materials
- PVC/CPVC for condensing appliances
- Stainless steel systems
- Material selection per appliance category

12.3 Venting System Design

- Sizing vents per CSA B149.1 tables

- Single appliance venting
- Common venting requirements
- Maximum vent length
- Offsets and elbows
- Termination requirements
- Clearances to air intakes

12.4 Type B Vent Installation

- Assembly requirements
- Support spacing
- Clearances to combustibles
- Slope requirements
- Connector sizing and length
- Termination height and location
- Cap requirements

12.5 Direct Vent Systems

- Concentric vent design
- Horizontal terminations
- Vertical terminations
- Clearance requirements
- Manufacturer specifications
- Installation in cold climates

12.6 Power Venting

- Induced draft systems
- Forced draft systems
- Vent materials and sizing
- Electrical interlocks

- Condensate handling
- Safety controls

12.7 Condensate Management

- Condensate production
- Drain requirements
- Neutralization (where required)
- Freeze protection
- Trap requirements
- Testing condensate systems

12.8 Troubleshooting Venting Problems

- Spillage detection and correction
- Draft measurement
- Condensation issues
- Blockage identification
- Carbon monoxide production
- Corrective actions

Chapter Review:

- Vent sizing calculations (20)
- Installation planning exercises
- Code compliance assessments
- Problem diagnosis scenarios

CHAPTER 13: Heating Systems

Estimated: 70-80 pages

13.1 Forced Air Furnaces

- System components

- Airflow principles
- Heat exchanger types
- Condensing vs. non-condensing
- Efficiency ratings
- Multi-stage and modulating systems

13.2 Furnace Installation

- Location requirements
- Clearances per code
- Return air considerations
- Filter access
- Gas piping connections
- Electrical connections
- Combustion air provisions
- Venting installation

13.3 Furnace Controls and Sequences

- Thermostat operation
- Blower control sequences
- Limit switch operation
- Ignition control modules
- Integrated furnace controls
- Communication protocols (when applicable)

13.4 Hydronic Heating Systems

- Hot water boilers
- System components (circulators, expansion tanks, zone valves)
- Piping configurations
- Temperature controls

- Boiler installation requirements
- CSA B149.1 specific requirements for boilers

13.5 Radiant Heating

- In-floor heating systems
- Panel radiators
- Unit heaters
- Installation considerations
- Control strategies

13.6 Heat Pump Systems (Dual Fuel)

- Integration with gas furnaces
- Changeover controls
- Efficiency considerations

13.7 Commissioning Heating Systems

- Start-up procedures
- Temperature rise checks
- Combustion testing requirements
- Airflow verification
- Control verification
- Documentation requirements

13.8 Troubleshooting Heating Systems

- No heat calls
- Inadequate heat
- Short cycling
- Noisy operation
- Safety lockouts
- Systematic diagnostic approach

Chapter Review:

- System design exercises
- Installation planning
- Combustion analysis interpretation
- Diagnostic scenarios (15)

SECTION 5: ELECTRICAL FUNDAMENTALS (Chapters 14-15)

CHAPTER 14: Electricity for Gas Technicians

Estimated: 55-65 pages

14.1 Basic Electrical Theory

- Voltage, current, and resistance
- Ohm's Law applications
- AC vs. DC power
- Power calculations (watts)
- Series and parallel circuits

14.2 Electrical Safety

- Electrical hazards in gas work
- Safe working practices
- Lockout/tagout procedures
- Canadian Electrical Code basics
- Personal protective equipment
- Arc flash awareness

14.3 Electrical Measurement

- Using multimeters
- Voltage testing
- Continuity testing

- Resistance measurement
- Current measurement (using clamp meters)
- Safety precautions

14.4 Electrical Components in Gas Systems

- Transformers (24V control circuits)
- Relays and contactors
- Switches (limit, pressure, flow)
- Thermostats
- Solenoids
- Motors (blower, inducer, circulator)
- Capacitors

14.5 Control Circuits

- 24V control systems
- 115V circuits
- Line voltage vs. low voltage
- Safety circuits (series wiring)
- Operating circuits (parallel wiring)
- Common vs. hot wiring

14.6 Reading Wiring Diagrams

- Ladder diagrams
- Pictorial diagrams
- Schematic symbols
- Following circuit paths
- Identifying components
- Troubleshooting with diagrams

14.7 Thermostats and Control Devices

- Mechanical thermostats
- Electronic thermostats
- Programmable and smart thermostats
- Heat-only vs. heat-cool
- Multi-stage controls
- Proper installation and wiring

14.8 Motors and Motor Controls

- Blower motors (PSC, ECM)
- Inducer motors
- Circulator pumps
- Motor protection devices
- Troubleshooting motor problems

Chapter Review:

- Ohm's Law calculations
- Circuit analysis exercises
- Wiring diagram interpretation (10)
- Component testing procedures
- Troubleshooting scenarios

CHAPTER 15: Control Systems and Sequences

Estimated: 45-55 pages

15.1 Basic Control Logic

- On-off control
- Staged control
- Modulating control
- Setpoint and differential

- Anticipation

15.2 Heating Control Sequences

- Simple thermostat call for heat
- Ignition sequences per CSA B149.1
- Blower control (heating mode)
- Limit control operation
- Safety lockout procedures

15.3 Combination Systems

- Heating and cooling integration
- Furnace with air conditioning
- Heat pump with gas backup
- Changeover controls
- Emergency heat

15.4 Zone Control Systems

- Multiple zone damper systems
- Multiple circulator systems
- Control strategies
- Bypass requirements (air systems)

15.5 Advanced Controls

- Outdoor reset controls
- Boiler management systems
- Building automation basics
- Communication protocols (basic overview)

15.6 Troubleshooting Control Systems

- Systematic approach
- Using wiring diagrams

- Voltage tracing techniques
- Component verification
- Sequence verification
- Common failure modes

Chapter Review:

- Sequence of operation exercises
- Control system design scenarios
- Troubleshooting case studies (10)
- Wiring problem diagnosis

SECTION 6: WATER HEATING & APPLIANCES (Chapters 16-17)

CHAPTER 16: Water Heaters

Estimated: 50-60 pages

16.1 Water Heater Types

- Atmospheric storage tank
- Power vent storage tank
- Direct vent storage tank
- Tankless (instantaneous)
- Condensing storage
- Commercial water heaters
- Indirect water heaters

16.2 Water Heater Components

- Tank construction
- Anode rods
- Dip tubes
- Temperature and pressure relief valves

- Gas control valves
- Thermostats
- Burner assemblies
- Venting components

16.3 Water Heater Installation

- Location requirements per code
- Clearances to combustibles
- Combustion air provisions
- Gas piping connections
- Venting requirements per category
- Temperature and pressure relief valve discharge
- Earthquake strapping (where required)
- Drain pan requirements

16.4 Water Heater Sizing

- First hour rating (FHR)
- Recovery rate
- Storage capacity
- Calculating hot water demand
- Tankless flow rate requirements
- Temperature rise considerations

16.5 Tankless Water Heater Installation

- Location considerations
- Venting (concentric vs. separate)
- Gas line sizing (high input rates)
- Water flow requirements
- Freeze protection

- Filtration requirements
- Condensate drainage

16.6 Temperature and Pressure Relief Valves

- Purpose and operation
- Sizing requirements
- Installation position
- Discharge piping requirements
- Testing procedures
- Replacement criteria

16.7 Water Heater Maintenance

- Anode rod inspection/replacement
- Tank flushing
- Combustion chamber inspection
- Burner cleaning
- Vent system inspection
- Relief valve testing

16.8 Troubleshooting Water Heaters

- No hot water
- Insufficient hot water
- Temperature issues
- Pilot outage problems
- Burner problems
- Vent spillage
- Relief valve discharge
- Noise and odor issues

Chapter Review:

- Sizing calculations
- Installation planning exercises
- Code compliance checks
- Diagnostic scenarios (12)

CHAPTER 17: Other Gas Appliances

Estimated: 40-50 pages

17.1 Cooking Appliances

- Ranges and cooktops
- Wall ovens
- Commercial cooking equipment
- Installation requirements
- Clearances and ventilation
- Anti-tip devices
- Troubleshooting common issues

17.2 Clothes Dryers

- Residential dryers
- Commercial dryers
- Installation requirements
- Exhaust venting requirements
- Make-up air considerations
- Troubleshooting procedures

17.3 Fireplaces and Log Sets

- Vented decorative appliances
- Vent-free appliances (where permitted)
- Installation requirements per CSA codes

- Clearances and hearth extensions
- Glass door requirements
- Annual inspection requirements

17.4 Pool and Spa Heaters

- Installation location requirements
- Clearances to combustibles
- Venting provisions
- Outdoor installations
- Freeze protection
- Troubleshooting

17.5 Unit Heaters

- Separated combustion unit heaters
- Installation and mounting
- Venting requirements
- Clearances
- Applications and limitations

17.6 Construction Heaters

- Temporary heating devices
- Safety requirements
- Proper ventilation
- Code restrictions on use
- Carbon monoxide awareness

17.7 Infrared Heaters

- Vented vs. unvented
- Installation requirements
- Applications

- Safety considerations

Chapter Review:

- Appliance identification
- Installation requirement summaries
- Code compliance exercises
- Application selection scenarios

SECTION 7: SPECIALIZED TOPICS (Chapters 18-21)

CHAPTER 18: Propane Systems and Installations

Estimated: 55-65 pages

18.1 Propane System Design

- Single-stage vs. two-stage systems
- Vapor withdrawal systems
- Liquid withdrawal systems
- System component selection
- Pressure requirements at appliances

18.2 Propane Tanks and Cylinders

- DOT/TC cylinder specifications
- ASME tank specifications
- Tank sizing methods
- Fill limits and ullage
- Tank placement requirements per CSA B149.2
- Setback distances from buildings and property lines
- Underground tank installations

18.3 Propane Regulators

- First-stage regulators (high pressure to 10 psi)

- Second-stage regulators (10 psi to 11" W.C.)
- Integral two-stage regulators
- Automatic changeover regulators
- Relief valve requirements
- Regulator venting

18.4 Propane Piping

- Material selection per CSA B149.2
- Sizing propane piping
- Specific gravity correction factors
- Vapor piping vs. liquid piping
- Installation requirements
- Protection from damage

18.5 Propane Appliance Conversion

- Natural gas to propane conversion
- Orifice changes
- Pressure adjustments
- Vent system evaluation
- Combustion testing post-conversion
- Labeling requirements

18.6 Cylinder Storage and Handling

- Storage requirements
- Transportation regulations (TDG)
- Cylinder filling procedures
- Exchange programs
- Safety in handling

18.7 Propane System Commissioning

- Leak testing procedures
- Pressure testing requirements
- Purging procedures
- Appliance adjustment
- Documentation

Chapter Review:

- System design exercises
- Tank sizing calculations
- Piping calculations with corrections
- Installation planning scenarios
- Conversion procedures

CHAPTER 19: Troubleshooting and Diagnostics

Estimated: 50-60 pages

19.1 Systematic Troubleshooting Approach

- Gathering information
- Understanding normal operation
- Isolating the problem
- Testing hypotheses
- Making repairs
- Verification
- Documentation

19.2 Diagnostic Tools and Their Use

- Multimeters
- Manometers
- Combustion analyzers

- Temperature measurement
- Amp meters
- Gas leak detectors

19.3 Common Heating System Problems

- No heat calls
- Insufficient heat
- Short cycling
- Blower problems
- Ignition failures
- Flame sensor issues
- Limit switch trips
- Inducer motor problems

19.4 Common Water Heater Problems

- No hot water
- Inadequate hot water
- Pilot problems
- Burner issues
- Relief valve discharge
- Temperature control problems

19.5 Gas Supply Problems

- Low gas pressure
- High gas pressure
- Regulator failures
- Piping restrictions
- Meter problems

19.6 Venting Problems

- Spillage and backdrafting
- Condensation issues
- Inadequate draft
- Blocked vents
- Improper terminations

19.7 Control System Failures

- Thermostat problems
- Limit switch issues
- Pressure switch failures
- Valve problems
- Sensor failures
- Wiring issues

19.8 Using Wiring Diagrams for Troubleshooting

- Following circuit paths
- Voltage tracing
- Identifying open circuits
- Finding short circuits
- Component verification

19.9 Advanced Diagnostic Techniques

- Sequence of operation verification
- Timing measurements
- Current draw analysis
- Temperature differential testing
- Combustion analysis interpretation

19.10 When to Refer Work

- Scope of practice limitations

- Electrical work requiring electrician
- HVAC system modifications
- Structural issues
- Code authority involvement

Chapter Review:

- Troubleshooting case studies (20)
- Diagnostic procedure exercises
- Tool use demonstrations
- Problem identification scenarios

CHAPTER 20: Maintenance and Service

Estimated: 40-50 pages

20.1 Preventive Maintenance Programs

- Importance of regular maintenance
- Seasonal maintenance tasks
- Manufacturer recommendations
- Creating maintenance schedules
- Documentation and record keeping

20.2 Furnace Maintenance Procedures

- Annual inspection checklist
- Burner cleaning and adjustment
- Heat exchanger inspection
- Blower maintenance
- Filter replacement schedules
- Control testing
- Combustion analysis

- Safety device testing

20.3 Water Heater Maintenance

- Inspection procedures
- Anode rod service
- Tank flushing
- Burner and combustion chamber cleaning
- Vent system inspection
- Relief valve testing
- Control verification

20.4 Boiler Maintenance

- Inspection procedures
- Cleaning procedures
- Control testing
- Water treatment
- Circulator maintenance
- Safety device testing

20.5 Seasonal Start-Up and Shut-Down

- Pre-season equipment checks
- Start-up procedures
- End-of-season procedures
- System winterization (where applicable)

20.6 Combustion Testing and Adjustment

- When testing is required
- Using combustion analyzers
- Interpreting results
- Making adjustments

- Documentation requirements

20.7 Maintenance Contracts

- Types of agreements
- Scope of services
- Pricing considerations
- Customer communication
- Legal considerations

Chapter Review:

- Maintenance checklist creation
- Procedure documentation
- Service planning exercises
- Customer communication scenarios

CHAPTER 21: Codes, Standards, and Regulations

Estimated: 45-55 pages

21.1 Canadian Regulatory Framework

- Federal regulations
- Provincial regulations by province
- Municipal bylaws
- Enforcement authorities
- TSSA and provincial equivalents

21.2 CSA B149.1 - Natural Gas and Propane Installation Code

- Scope and application
- Key definitions
- General requirements
- Installation requirements by section

- Testing and purging requirements
- Using code tables
- Updates and amendments

21.3 CSA B149.2 - Propane Storage and Handling Code

- Scope and application
- Container requirements
- Installation requirements
- Setback distances
- Marking and identification
- Filling procedures

21.4 CSA B149.5 - Installation Code for Propane Fuel Systems and Tanks on Highway Vehicles

- Vehicle installations
- Mobile applications
- Safety requirements

21.5 National Building Code of Canada

- Relationship to gas codes
- Combustion air requirements
- Venting requirements
- Clearances to combustibles

21.6 Canadian Electrical Code (CEC)

- Electrical requirements for gas appliances
- Grounding and bonding
- CSST bonding requirements
- Wiring methods

21.7 Other Relevant Standards

- NFPA standards (reference)
- ANSI standards
- UL/ULC standards
- Manufacturer standards

21.8 Permit and Inspection Requirements

- When permits are required
- Application process
- Inspection procedures
- Rough-in inspections
- Final inspections
- Dealing with failed inspections
- Record retention

21.9 Liability and Insurance

- Professional liability
- Gas contractor licensing
- Insurance requirements
- Record keeping for liability protection

21.10 Staying Current

- Code updates
- Continuing education
- Industry publications
- Professional associations
- TSSA bulletins and directives

Chapter Review:

- Code reference exercises
- Permit application practice

- Code interpretation scenarios
- Compliance verification exercises

SECTION 8: PROFESSIONAL PRACTICE (Chapters 22-23)

CHAPTER 22: Business Practices

Estimated: 35-45 pages

22.1 Starting a Gas Contracting Business

- Licensing requirements
- Business structure options
- Insurance needs
- Bonding requirements
- Business planning

22.2 Estimating and Quoting

- Material takeoff
- Labor estimation
- Overhead and profit
- Written quotes
- Change orders

22.3 Customer Relations

- Professional conduct
- Communication skills
- Managing expectations
- Handling complaints
- Building repeat business

22.4 Documentation and Record Keeping

- Work orders

- Invoicing
- Warranty information
- Permit documentation
- Inspection records
- Customer files
- Retention requirements

22.5 Legal and Ethical Considerations

- Contract basics
- Lien legislation
- Code of ethics
- Scope of practice
- Confidentiality
- Conflicts of interest

22.6 Marketing and Growth

- Marketing strategies
- Online presence
- Reputation management
- Hiring and training
- Business development

Chapter Review:

- Business planning exercises
- Estimating practice problems
- Customer scenario responses
- Documentation examples

CHAPTER 23: Environmental and Energy Efficiency

Estimated: 30-40 pages

23.1 Energy Efficiency Fundamentals

- AFUE ratings
- Energy Star standards
- Efficiency vs. cost considerations
- Payback period calculations

23.2 High-Efficiency Equipment

- Condensing furnaces and boilers
- Modulating burners
- Variable-speed blowers
- Smart controls
- Benefits and considerations

23.3 System Optimization

- Proper sizing
- Zone control
- Setback thermostats
- Maintenance for efficiency

23.4 Renewable Energy Integration

- Solar thermal with gas backup
- Hybrid systems
- Future trends

23.5 Environmental Considerations

- Greenhouse gas emissions
- Carbon footprint
- Refrigerant management (when applicable)
- Disposal of old equipment

- Recycling programs

23.6 Energy Auditing Basics

- Home energy assessments
- Identifying improvements
- Working with other trades
- Grants and rebates

Chapter Review:

- Efficiency calculations
- System comparison exercises
- Payback analysis
- Environmental impact assessments

APPENDICES

APPENDIX A: Reference Tables

- Gas properties
- Pipe sizing tables
- Vent sizing tables
- Conversion factors
- Orifice drill sizes
- Pressure conversion charts
- BTU content by fuel
- Specific gravity values

APPENDIX B: Code Reference Quick Guide

- CSA B149.1 key sections
- CSA B149.2 key sections
- Common clearances

- Testing requirements
- Combustion air calculations

APPENDIX C: Electrical Symbols and Diagrams

- Standard symbols
- Sample wiring diagrams
- Troubleshooting flowcharts

APPENDIX D: Formulas and Calculations

- Gas law formulas
- Pressure drop calculations
- Heat content calculations
- Orifice sizing formulas
- Vent sizing formulas
- Electrical calculations

APPENDIX E: Troubleshooting Charts

- Symptom-based diagnostics
- Component testing procedures
- Common failure modes

APPENDIX F: Safety Data Sheets

- Natural gas
- Propane
- Pipe dope compounds
- Cleaning chemicals

APPENDIX G: TSSA Exam Preparation

- Study tips
- Sample questions by topic
- Practice exams

- Resources for further study

APPENDIX H: Glossary

- Comprehensive terminology
- Acronyms and abbreviations

APPENDIX I: Index

PEDAGOGICAL FEATURES

Throughout Each Chapter:

- **Learning Objectives** - Clear goals for each chapter
- **Key Terms** - Highlighted and defined
- **Safety Alerts** - Critical safety information boxes
- **Code References** - Direct citations to applicable codes
- **Examples** - Worked problems and real-world applications
- **Photos and Diagrams** - Visual learning aids
- **Pro Tips** - Industry best practices
- **Common Mistakes** - What to avoid
- **Chapter Summary** - Key points recap
- **Review Questions** - Multiple choice, true/false, short answer
- **Practical Exercises** - Hands-on activities
- **Case Studies** - Real-world scenarios

Supplementary Materials:

- **Instructor's Manual**
    - Lesson plans
    - PowerPoint presentations
    - Answer keys
    - Test banks

- Lab exercises with solutions
- **Student Workbook**
  - Practice problems
  - Worksheets
  - Lab sheets
  - Self-assessment tools
- **Online Resources**
  - Video demonstrations
  - Interactive diagrams
  - Supplementary readings
  - Code updates
  - Practice quizzes

WRITING STANDARDS

Technical Accuracy:

- All content aligned with current CSA B149.1-25, B149.2
- TSSA requirements integrated throughout
- Cross-referenced with National Building Code
- Technical review by certified G1 gas fitters
- Code authority review

Reading Level:

- Grade 10-12 reading level
- Technical terminology introduced gradually
- Plain language explanations
- Metric and imperial units (with conversion emphasis on metric)

Canadian Focus:

- All measurements in metric (with imperial reference)
- Canadian code references exclusively
- Provincial variations noted where applicable
- Canadian supplier and manufacturer information
- Temperature in Celsius (Fahrenheit in parentheses)

Visual Design:

- Full-color printing
- High-quality photographs
- Clear technical drawings
- Standardized symbols per CSA
- Consistent formatting
- Durable binding for shop use

REVISION CYCLE

- **Major Revisions:** Every 5 years (aligned with code cycles)
- **Minor Updates:** Annual (bulletins, corrections)
- **Online Supplements:** Continuous updates for code changes
- **Errata:** Published online as needed

ESTIMATED DEVELOPMENT TIMELINE

Phase 1 - Planning and Outline (Complete)

- 3 months: Curriculum mapping, learning objectives, code alignment

Phase 2 - First Draft

- 12-18 months: Chapter drafting by subject matter experts

Phase 3 - Technical Review

- 3-4 months: Review by certified gas fitters, code officials, educators

Phase 4 - Editing and Design

- 4-6 months: Professional editing, layout, photography, illustration

Phase 5 - Pilot Testing

- 6 months: Classroom testing with feedback collection

Phase 6 - Revision and Finalization

- 3-4 months: Incorporate feedback, final edits

Phase 7 - Production and Launch

- 2-3 months: Printing, distribution setup, instructor training

Total Timeline: Approximately 3 years from start to publication

CHAPTER 1

Introduction to the Gas Industry in Canada

Learning Objectives

Upon completion of this chapter, students will be able to:

1. Describe the historical development of natural gas and propane infrastructure in Canada
2. Identify the key regulatory bodies governing gas installations across Canada
3. Explain the hierarchy of Canadian gas codes and standards
4. Differentiate between G3, G2, and G1 certification levels and their scopes of work
5. Describe the career pathways available in the gas industry
6. Understand the importance of professional conduct and continuing education
7. Identify provincial variations in gas regulations across Canada

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1.1 History of Gas Utilities in Canada

The Early Years (1850s-1900s)

The gas industry in Canada began in the mid-1800s with manufactured gas (coal gas) used primarily for street lighting and commercial applications. Montreal became the first Canadian city to implement gas street lighting in 1837, followed by Toronto in 1841. These early systems used coal gasification plants to produce combustible gas, which was distributed through cast iron pipes to customers.

Natural gas was first discovered in Canada in 1859 near Petrolia, Ontario—the same year as the famous oil discovery in Pennsylvania. However, it would take decades before natural gas became a primary fuel source. The gas was initially considered a nuisance byproduct of oil drilling and was often flared off or vented to the atmosphere.

The Natural Gas Era (1900s-1950s)

The discovery of the Turner Valley gas field in Alberta in 1914 marked the beginning of western Canada's natural gas industry. However, the lack of pipeline infrastructure meant most of this gas was flared. It wasn't until after World War II that large-scale natural gas transmission became economically viable.

Key developments included:

- **1947**: The Leduc oil discovery in Alberta reignited interest in Alberta's petroleum resources
- **1951**: The Alberta Gas Trunk Line (later NOVA, now part of TC Energy) was established
- **1957**: The Trans-Canada Pipeline (now TC Energy) completed, connecting Alberta to eastern Canadian markets
- **1958**: Westcoast Transmission (now part of TC Energy) began delivering natural gas from northeastern BC to Vancouver

This infrastructure development transformed natural gas from a regional fuel to a national energy source.

Modern Era (1960s-Present)

The 1960s and 1970s saw explosive growth in natural gas use:

- Residential and commercial conversions from manufactured gas and oil
- Industrial applications expansion
- Development of provincial distribution networks
- Establishment of comprehensive safety codes and regulations

The **National Energy Program (NEP)** of the 1980s, while controversial, led to increased Canadian ownership of energy resources and infrastructure. The subsequent deregulation in the 1990s opened markets to competition while maintaining strict safety oversight.

Today, Canada has one of the most extensive natural gas pipeline networks in the world, with over 700,000 km of transmission and distribution pipelines serving millions of customers.

Propane Industry Development

The propane (liquefied petroleum gas) industry developed alongside natural gas, serving areas beyond pipeline infrastructure. Propane gained popularity in rural Canada where natural gas pipelines were not economically feasible.

The Canadian Propane Association (CPA), founded in 1962, helped establish industry standards and safety protocols. Today, propane serves approximately 4 million Canadians in residential, agricultural, commercial, and industrial applications.

1.2 The Canadian Regulatory Framework

Canada's gas industry operates under a comprehensive regulatory framework designed to ensure public safety, environmental protection, and reliable energy supply. Understanding this framework is essential for anyone working in the gas industry.

Federal Level

While natural gas distribution and propane are primarily regulated provincially, several federal agencies have jurisdiction:

Natural Resources Canada (NRCan)

- Energy policy development
- National energy statistics
- Research and development support
- International energy agreements

Transport Canada

- Transportation of dangerous goods (TDG) regulations
- Propane cylinder transportation
- Pipeline crossing regulations for federal lands

National Research Council (NRC)

- Development of national codes through the Canadian Commission on Building and Fire Codes
- Research on gas technologies and safety

Provincial and Territorial Level

Each province and territory has authority over gas installation, distribution, and safety within its borders. This has led to variations in regulatory approaches across Canada.

Ontario - Technical Standards and Safety Authority (TSSA)

The TSSA is one of the most comprehensive gas regulatory bodies in Canada and serves as a model often referenced in other jurisdictions.

- Delegated administrative authority under the Technical Standards and Safety Act, 2000
- Issues gas technician licenses (G3, G2, G1)
- Conducts inspections and enforcement
- Maintains public registry of licensed gas contractors
- Investigates incidents and accidents
- Provides education and compliance support

British Columbia - Technical Safety BC

- Similar mandate to TSSA
- Issues gas fitting certificates (Class A, B)
- Regulates under the Safety Standards Act

- Province-wide jurisdiction

Alberta - Alberta Municipal Affairs (Safety Codes Council)

- Accreditation-based system using Safety Codes Officers
- Certificate of Competency for gas fitters
- Permits issued by municipalities or accredited agencies
- Emphasis on municipal enforcement

Quebec - Régie du bâtiment du Québec (RBQ)

- Licenses gas contractors and workers
- Unique classification system
- Bilingual regulatory framework
- Integration with provincial construction regulations

Other Provinces and Territories

Each jurisdiction has established regulatory bodies or frameworks:

- **Saskatchewan**: Technical Safety Authority of Saskatchewan (TSASK)
- **Manitoba**: Manitoba Office of the Fire Commissioner
- **Atlantic Provinces**: Individual provincial authorities
- **Territories**: Territorial governments with federal oversight

Key Principle: Harmonization Efforts

While regulations vary by province, efforts continue toward harmonization through:

- Adoption of CSA standards across all jurisdictions
- Interprovincial mobility agreements for certified technicians
- Shared incident data and lessons learned
- National working groups on emerging technologies

1.3 CSA Standards Overview

The **Canadian Standards Association (CSA Group)** develops and maintains the technical standards that form the foundation of gas regulations across Canada. While CSA is a private organization, its standards are adopted by provincial authorities and given force of law through regulation.

CSA B149.1 - Natural Gas and Propane Installation Code

This is the primary standard governing gas installations in Canada. The current edition is **CSA B149.1-25** (2025 edition).

Scope:

- Installation of natural gas and propane piping systems
- Installation of natural gas and propane appliances
- Conversion of appliances between gas types
- Testing and purging requirements
- Venting systems
- Combustion air requirements

Key Features:

- Prescriptive and performance-based requirements
- Detailed sizing tables for piping and venting
- Safety requirements for all installation types
- Requirements for both residential and commercial applications

Updates: Revised on a 5-year cycle with interim amendments as needed. Always verify you are working with the current edition adopted in your jurisdiction.

CSA B149.2 - Propane Storage and Handling Code

Governs the storage, handling, and distribution of propane (LP gas).

Scope:

- Propane container specifications
- Installation location requirements
- Setback distances from buildings and property lines
- Filling and transfer procedures
- Bulk plant operations
- Transportation requirements
- Cylinder exchange programs

Application: Any installation using propane containers from small BBQ cylinders to large bulk tanks.

CSA B149.3 - Code for the Field Approval of Fuel-Related Components on Appliances and Equipment

Provides requirements for field modifications to gas appliances when manufacturers' components are not available.

CSA B149.5 - Installation Code for Propane Fuel Systems and Tanks on Highway Vehicles

Covers propane installations on vehicles, including:

- Automotive conversions
- Forklifts and material handling equipment
- Recreational vehicles
- Mobile equipment

Related CSA Standards

CSA B139 - Installation Code for Oil-Burning Equipment

- Important when working on combination systems
- Oil-to-gas conversions

CSA B365 - Installation Code for Solid-Fuel-Burning Appliances and Equipment

- Clearances and installation principles applicable to gas work

CSA B140.12 - Installation of Propane Fuel Systems in Motor Homes, Travel Trailers, Park Trailers, and Similar Vehicles

- Recreational vehicle applications

1.4 National Building Code and Other Codes

National Building Code of Canada (NBC)

The NBC, developed by the National Research Council, provides model building regulations adopted by provinces and territories. Gas installation requirements in the NBC reference CSA B149 standards but also include:

Part 3 - Fire Protection, Occupant Safety and Accessibility

- Appliance room requirements
- Fire separation requirements
- Accessibility provisions

Part 6 - Heating, Ventilating and Air-Conditioning

- Combustion air requirements

- Mechanical ventilation integration
- System design requirements

Part 9 - Housing and Small Buildings

- Simplified requirements for residential construction
- References to CSA B149 standards
- Clearances to combustibles

Provincial Building Codes

Most provinces adopt the NBC with provincial modifications:

- Ontario Building Code (OBC)
- BC Building Code (BCBC)
- Alberta Building Code (ABC)
- Quebec Construction Code (QCC) - significantly different structure

National Fire Code of Canada (NFC)

Addresses fire safety aspects of gas installations:

- Appliance location in relation to fire separations
- Storage of combustible materials near gas equipment
- Emergency procedures
- Inspection and maintenance requirements

1.5 Career Pathways and Certifications

The gas industry offers diverse career opportunities with clear advancement pathways. Certification requirements ensure competency and public safety.

Certification Levels (Ontario TSSA Model)

G3 Certificate - Propane Fitter

Scope of Work:

- Install, alter, repair, and service propane appliances
- Install propane piping systems
- Install propane containers and associated equipment
- Work only with propane (LP gas), not natural gas
- Typically covers residential and light commercial applications

Requirements:

- Minimum 18 years of age
- Successfully complete approved training program or demonstrate equivalent experience
- Pass G3 certification examination
- Maintain continuing education requirements

Typical Entry Level: Ideal for those entering the trades or specializing in propane-only installations, particularly in rural areas.

G2 Certificate - Gas Technician 2

Scope of Work:

- Everything included in G3 certification
- Install, alter, repair, and service natural gas appliances
- Install natural gas piping systems
- Work with both natural gas and propane
- Residential and light commercial installations up to 400,000 BTU/hr input

Requirements:

- Possess G3 certificate or demonstrate equivalent competency
- Complete approved training program
- Pass G2 certification examination
- Practical experience requirements
- Continuing education

Career Stage: Most common certification for residential HVAC technicians and service professionals.

G1 Certificate - Gas Fitter 1

Scope of Work:

- Unlimited scope for all gas installations
- Commercial and industrial applications
- Complex systems and high-input appliances
- Gas train assembly and testing
- Supervision of G2 and G3 technicians
- Commercial kitchen equipment
- Boiler installations
- Industrial burners

Requirements:

- Possess G2 certificate
- Extensive experience (typically 3-5 years minimum)
- Complete advanced training
- Pass comprehensive G1 examination
- Demonstrated competency in commercial/industrial applications

Career Stage: Senior technician, commercial specialist, business owner, project manager.

Equivalent Certifications in Other Provinces

British Columbia (Technical Safety BC):

- **Class B Gas Fitter**: Similar to Ontario G3/G2, residential and commercial to 400,000 BTU/hr
- **Class A Gas Fitter**: Similar to Ontario G1, unlimited scope

Alberta:

- **Gas Fitter Certificate of Competency**: Based on Red Seal requirements
- Levels correspond to complexity of work (apprentice, journeyperson)

Quebec (RBQ):

- **Gas Installation Contractor License**: Various subclasses
- Separate licensing for contractors vs. workers
- Unique classification system

Red Seal Program: The **Interprovincial Red Seal Program** provides national certification for gas fitters, facilitating mobility across provinces:

- **Gas Fitter - Red Seal**: Recognized nationally
- Requires apprenticeship completion and examination
- Promotes consistency in training standards

Continuing Education Requirements

All provinces require ongoing education to maintain certification:

- Code update training (when new editions released)
- Safety training refreshers
- New technology training
- Minimum hours per renewal period (varies by province)
- Documentation of training activities

1.6 Industry Career Paths

Service Technician

Role: Diagnose and repair residential and commercial gas equipment

Typical Progression:

- Apprentice/Helper → G3 Certified → G2 Certified → Lead Technician → Service Manager

Skills Required:

- Troubleshooting expertise
- Customer service
- Time management
- Tool proficiency
- Continuing technical education

Work Environment: Service trucks, residential and commercial buildings, variable schedules including emergency calls

Installation Technician/Gas Fitter

Role: Install new gas systems and appliances in new construction and renovations

Typical Progression:

- Helper → G3 Installer → G2 Installer → G1 Fitter → Foreman/Supervisor

Skills Required:

- Blueprint reading
- Layout and planning
- Piping skills
- Coordination with other trades
- Quality workmanship

Work Environment: Construction sites, new homes, commercial buildings, renovation projects

Commercial/Industrial Gas Fitter (G1)

Role: Install and service complex commercial and industrial gas systems

Specializations:

- Boiler systems
- Commercial kitchen equipment
- Industrial burners and processes
- Institutional buildings (hospitals, schools)
- Multi-residential buildings

Skills Required:

- Advanced technical knowledge
- Project management
- Safety systems expertise
- Supervision and mentoring
- Code expertise

Business Owner/Contractor

Role: Operate gas contracting business

Requirements:

- Appropriate gas certification (typically G2 minimum, G1 preferred)
- Business licenses and insurance
- Financial management skills
- Marketing and customer relations
- Employee management

Business Types:

- Residential HVAC companies
- Propane service companies
- Commercial mechanical contractors
- Service-only businesses
- Installation-focused businesses

Utility Company Technician

Role: Work for natural gas utility maintaining distribution systems

Responsibilities:

- Meter installation and maintenance
- Service line installation
- Leak investigation
- Emergency response
- System maintenance

Requirements:

- Company-specific training programs
- Gas certification (requirements vary)
- CDL/commercial driving (often required)
- Emergency response training

Inspector/Regulatory Officer

Role: Conduct inspections and enforce gas codes for regulatory authority

Qualifications:

- Extensive field experience (typically 5-10 years)
- G1 certification (usually required)
- Code expertise
- Communication skills
- Investigative abilities

Employers:

- Provincial regulatory bodies (TSSA, Technical Safety BC, etc.)
- Municipal building departments
- Insurance companies

Educator/Trainer

Role: Teach gas technology in colleges, trade schools, or training centers

Qualifications:

- Journeyperson certification
- Extensive industry experience
- Teaching certification or adult education training
- Current with industry trends

Settings:

- Community colleges
- Trade schools
- Union training centers
- Industry associations
- Private training companies

Sales and Technical Support

Role: Product representation for manufacturers and distributors

Backgrounds:

- Field experience as technician
- Product knowledge expertise
- Customer relationship skills

Positions:

- Manufacturer's representative
- Technical sales
- Application engineering
- Product training specialist

1.7 Industry Best Practices

Professional Conduct

Gas technicians work in customers' homes and businesses, often unsupervised. Professional conduct is essential for public safety and industry reputation.

Core Principles:

1. **Safety First**
   - Never compromise safety for speed or convenience
   - When in doubt, consult code, manufacturer, or authority
   - Report unsafe conditions
   - Refuse to perform work beyond your competency
2. **Honesty and Integrity**
   - Provide accurate information to customers
   - Disclose all findings, even if costly to repair
   - Don't sell unnecessary services or equipment
   - Honor warranties and commitments
3. **Competency**
   - Work only within your certified scope
   - Maintain current knowledge through continuing education
   - Seek guidance on unfamiliar equipment or situations
   - Practice skills regularly
4. **Respect**
   - Treat customer property with care
   - Use floor protection, drop cloths
   - Clean up thoroughly
   - Respect customer's time and schedule

5. **Communication**
    - Explain work to be performed
    - Provide clear, written estimates
    - Document findings with photos where appropriate
    - Listen to customer concerns
    - Follow up on completed work

Documentation Requirements

Proper documentation protects both the technician and the customer:

Installation Documentation:

- Permit applications and approvals
- Material specifications and approvals
- Installation date and technician identification
- Test results (pressure tests, combustion analysis)
- Manufacturer's installation instructions compliance
- Photos of critical installations
- Customer sign-off

Service Documentation:

- Service call reports
- Diagnostic findings
- Parts replaced
- Test results
- Recommendations for future work
- Safety concerns identified
- Customer acknowledgment

Record Retention:

- Most jurisdictions require 7 years minimum
- Some installations require permanent records
- Digital backup recommended
- Organized filing system essential

Quality Assurance

Quality work is essential for safety, customer satisfaction, and business success:

Installation Quality:

- Follow manufacturer's instructions exactly
- Use proper materials and approved components

- Test all work thoroughly before leaving job
- Verify proper operation and safety
- Provide customer education on equipment operation

Service Quality:

- Diagnose thoroughly before recommending repairs
- Use OEM or approved replacement parts
- Test after repairs to verify proper operation
- Check related systems for potential issues
- Document all findings

Self-Inspection:

- Review your work before calling for inspection
- Use checklists for complex installations
- Double-check measurements and calculations
- Verify code compliance
- Test thoroughly

Customer Relations

Positive customer interactions lead to repeat business and referrals:

Communication Skills:

- Introduce yourself professionally
- Explain what you'll be doing
- Provide realistic time estimates
- Update customer on progress
- Explain findings in understandable terms
- Avoid unnecessary technical jargon
- Listen to concerns and questions

Problem Solving:

- Offer options with pros and cons
- Provide written estimates
- Don't pressure for immediate decisions
- Be honest about limitations
- Follow through on commitments

Professionalism:

- Arrive on time or call if delayed
- Present professional appearance

- Use proper language
- Respect customer's home/business
- Handle complaints professionally
- Thank customers for their business

1.8 Provincial Variations in Gas Regulations

While CSA B149 standards provide consistency, each province implements regulations differently. Understanding these variations is crucial for technicians working across provincial boundaries.

Licensing and Certification

Province	Regulatory Body	License Types	Key Differences
Ontario	TSSA	G3, G2, G1	Three-tier system, most detailed
BC	Technical Safety BC	Class B, Class A	Two-tier system
Alberta	Safety Codes Council	Certificate of Competency	Municipal permit system
Quebec	RBQ	Multiple subclasses	Contractor vs. worker licenses
Saskatchewan	TSASK	Gas Fitter levels	Similar to BC model
Manitoba	Fire Commissioner	Permit required	Combined with plumbing

Permit Requirements

Ontario: Permit required for all installations, alterations, obtained through TSSA

British Columbia: Permit through local authority having jurisdiction (AHJ) or Technical Safety BC

Alberta: Permit through municipality or accredited agency, Safety Codes Officer inspection

Quebec: Permit through RBQ or delegated municipal authority

Inspection Protocols

Ontario: TSSA inspectors conduct final inspections, rough-in inspections on new construction

Alberta: Safety Codes Officers (SCO) can be municipal employees or accredited private agencies

BC: Authority Having Jurisdiction (AHJ) determines inspection requirements, may delegate to Technical Safety BC

Appliance Regulations

Most provinces allow CSA or AGA certified appliances, but some differences exist:

- Quebec requires specific certifications for some equipment
- Some provinces restrict vent-free appliances
- Variations in requirements for appliance replacement vs. new installation

Code Adoption Timelines

Provinces adopt new editions of CSA B149 at different times:

- Some adopt immediately upon publication
- Others have transition periods
- Check with local authority for current edition in force
- Previous edition may be permitted for work started before new edition adoption

Interprovincial Work

Red Seal Certification facilitates mobility but consider:

- Provincial licensing still required in most jurisdictions
- Temporary work permits may be available
- Local code variations must be understood
- Insurance and liability considerations
- Business licensing separate from technician certification

1.9 Industry Resources and Associations

Canadian Standards Association (CSA Group)

- **Website:** www.csagroup.org
- Standards development and sales
- Training programs
- Certification services

Technical Standards and Safety Authority (TSSA) - Ontario

- **Website:** www.tssa.org
- Licensing information

- Code interpretations
- Safety bulletins
- Incident reports

Technical Safety BC

- **Website:** www.technicalsafetybc.ca
- Similar resources for BC

Canadian Propane Association (CPA)

- **Website:** www.propane.ca
- Industry advocacy
- Training resources
- Safety information
- Market data

Heating, Refrigeration and Air Conditioning Institute of Canada (HRAI)

- **Website:** www.hrai.ca
- Training and certification
- Industry standards
- Contractor resources
- Conferences and education

Canadian Institute of Plumbing & Heating (CIPH)

- **Website:** www.ciph.com
- Industry association
- Educational programs
- Advocacy

Provincial Associations

Each province has gas contractor associations providing:

- Networking opportunities
- Continuing education
- Advocacy
- Business resources
- Insurance programs

Chapter Summary

The Canadian gas industry has evolved from early manufactured gas systems to today's sophisticated natural gas and propane distribution networks. A comprehensive regulatory framework ensures public safety through provincial authorities like TSSA, Technical Safety BC, and others, all working with CSA standards as the technical foundation.

Career opportunities range from entry-level G3 propane fitters to G1 gas fitters handling complex commercial installations. Success requires technical competency, commitment to safety, professional conduct, and ongoing education. While provincial variations exist in licensing and regulation, CSA B149 standards provide consistency across Canada.

Understanding the regulatory framework, certification requirements, and professional expectations forms the foundation for a successful career in the gas industry.

Review Questions

Multiple Choice

1. In what year was the Trans-Canada Pipeline completed, connecting Alberta natural gas to eastern markets?
   - a) 1947
   - b) 1951
   - c) 1957
   - d) 1962
2. Which CSA standard governs the installation of natural gas and propane piping and appliances?
   - a) CSA B139
   - b) CSA B149.1
   - c) CSA B149.2
   - d) CSA B149.5
3. An Ontario G2 gas technician is qualified to work on installations up to:
   - a) 200,000 BTU/hr
   - b) 400,000 BTU/hr
   - c) 600,000 BTU/hr
   - d) Unlimited
4. Which of the following is NOT within the scope of a G3 certificate holder?
   - a) Installing propane piping
   - b) Servicing propane appliances
   - c) Installing natural gas piping
   - d) Installing propane containers
5. The National Building Code of Canada is developed by:
   - a) Canadian Standards Association

  - b) National Research Council
  - c) Natural Resources Canada
  - d) Provincial regulatory authorities

True or False

6. CSA standards are mandatory in all Canadian provinces.
7. The Red Seal Program eliminates the need for provincial gas licensing.
8. CSA B149.2 governs propane storage and handling.
9. All provinces use the same three-tier certification system (G3, G2, G1).
10. Documentation of gas installations must be retained for a minimum of 7 years in most jurisdictions.

Short Answer

11. List three key responsibilities of provincial regulatory authorities like TSSA. (3 marks)
12. Explain the difference between CSA B149.1 and CSA B149.2. (4 marks)
13. What is the Red Seal Program and how does it benefit gas technicians? (3 marks)
14. List four professional conduct principles important for gas technicians. (4 marks)
15. Why is it important to verify which edition of CSA B149.1 is adopted in your jurisdiction? (3 marks)

Long Answer

16. Describe the typical career progression from entry-level to senior gas technician, including certification levels and types of work performed at each stage. (10 marks)
17. Explain why provincial variations in gas regulations exist despite the national CSA standards. Discuss the benefits and challenges this creates for the industry. (10 marks)

Practical Exercises

Exercise 1: Regulatory Research

Research the gas regulatory authority in your province. Identify:

- The authority's name and website
- Certification levels offered
- How to apply for certification
- Continuing education requirements
- Where to obtain permit applications

Exercise 2: Code Familiarization

Obtain access to CSA B149.1-25 (through library, employer, or purchase). Locate the following sections:

- Definitions section
- Piping materials requirements
- Appliance installation requirements
- Testing and purging procedures Familiarize yourself with how the code is organized.

Exercise 3: Career Planning

Create a 5-year career plan including:

- Certification goals
- Required training and experience
- Skills to develop
- Potential employers or business opportunities
- Continuing education plans

Case Studies

Case Study 1: Regulatory Compliance

Scenario: A homeowner has hired you to replace their 20-year-old natural gas furnace. They mention their neighbor's son "does this kind of work" and offered to do it for half your price without bothering with permits.

Questions:

1. What are the risks of unpermitted gas work?
2. How would you explain the importance of proper licensing to the homeowner?
3. What are the potential consequences for both the homeowner and the unlicensed worker?
4. What would you do if you discovered unlicensed work in a home you were servicing?

Case Study 2: Scope of Practice

Scenario: You hold a G2 certificate and are asked by a customer to install a 500,000 BTU/hr commercial boiler at their small manufacturing facility.

Questions:

1. Is this within your scope of practice?
2. What should you tell the customer?
3. What steps could you take to eventually be qualified for this work?

4. What are the risks of working beyond your certification level?

Case Study 3: Interprovincial Work

Scenario: Your company, based in Ontario, has been asked to provide service at a customer's vacation property in British Columbia.

Questions:

1. Can you legally perform gas work in BC with an Ontario license?
2. What research would you need to do before accepting this work?
3. What are the regulatory requirements for working in another province?
4. How might code requirements differ between Ontario and BC?

Key Terms

Authority Having Jurisdiction (AHJ): The organization, office, or individual responsible for enforcing code requirements, issuing permits, and conducting inspections.

Canadian Standards Association (CSA): Organization that develops technical standards for gas installations and equipment in Canada.

Certificate of Competency: Document issued by regulatory authority confirming an individual's qualifications to perform gas work.

Code: A body of regulations and standards adopted by law.

G1 Certificate: Highest level of gas certification in Ontario, allows unlimited scope of gas work.

G2 Certificate: Mid-level gas certification in Ontario, allows natural gas and propane work up to 400,000 BTU/hr.

G3 Certificate: Entry-level gas certification in Ontario, allows propane-only work.

Harmonization: Efforts to align regulations and standards across different jurisdictions.

Interprovincial Mobility: Ability to work across provincial boundaries with recognized qualifications.

Red Seal: Interprovincial certification program for skilled trades, including gas fitters.

Regulatory Authority: Provincial body responsible for gas safety and licensing (e.g., TSSA, Technical Safety BC).

Scope of Practice: The types of work an individual is legally qualified to perform based on their certification level.

Technical Standards and Safety Authority (TSSA): Ontario's regulatory authority for gas, fuels, elevating devices, boilers, and pressure vessels.

End of Chapter 1

CHAPTER 2

Safety Fundamentals

Learning Objectives

Upon completion of this chapter, students will be able to:

1. Select and properly use personal protective equipment (PPE) for gas work
2. Identify and assess hazards associated with natural gas and propane
3. Explain flammability limits and explosive ranges for natural gas and propane
4. Describe proper emergency response procedures for gas leaks and fires
5. Apply WHMIS 2015 requirements to gas industry work
6. Use gas detection equipment properly and interpret readings
7. Recognize symptoms of carbon monoxide exposure and understand prevention strategies
8. Implement lockout/tagout procedures for equipment servicing
9. Apply confined space entry procedures when required
10. Understand provincial occupational health and safety regulations

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2.1 Personal Protective Equipment (PPE)

Personal protective equipment is the last line of defense against workplace hazards. While engineering controls and safe work practices are preferred, PPE is essential when hazards cannot be eliminated.

Head Protection

Hard Hats/Safety Helmets

Required in construction environments and when overhead hazards exist.

Types:

- **Type 1:** Top impact protection (most common in construction)
- **Type 2:** Top and lateral impact protection
- **Class E (Electrical):** Up to 20,000 volts protection
- **Class G (General):** Up to 2,200 volts protection
- **Class C (Conductive):** No electrical protection, lightweight

When Required:

- New construction sites
- Commercial/industrial installations
- Working near overhead hazards
- Working below others
- Confined spaces with vertical access
- Utility work

Proper Use:

- Inspect before each use for cracks, dents, or wear
- Replace after impact, even if damage not visible
- Adjust suspension for secure, comfortable fit
- Don't modify (drilling holes, painting weakens protection)
- Replace every 5 years or per manufacturer recommendation
- Don't wear backwards unless designed for reverse wear

CSA Standard: CSA Z94.1 - Industrial Protective Headwear

Eye and Face Protection

Gas work involves multiple eye hazards: flying debris, chemical splash, UV radiation from flames, and particles from drilling or cutting.

Safety Glasses

Minimum eye protection for all work sites.

Requirements:

- CSA Z94.3 certified
- Side shields required
- Impact-resistant lenses
- Available in prescription
- Anti-fog coating recommended

When Required:

- All work sites (minimum protection)
- Using hand tools
- Working around others using power tools
- General service work

Safety Goggles

Provide better protection against impact, dust, and chemical splash.

Types:

- Direct vented (impact protection)
- Indirect vented (chemical splash and impact)
- Non-vented (maximum chemical protection)

When Required:

- Using chemicals (pipe dope, cleaners)
- Cutting or grinding operations
- Dusty environments
- Working with refrigerants or other pressurized liquids

Face Shields

Full face protection for high-risk operations.

When Required:

- Brazing or welding operations
- Grinding
- Using chemical cleaners
- Battery work
- Combined with safety glasses (face shield alone insufficient)

Proper Use:

- Clean lenses regularly
- Replace scratched or damaged lenses
- Store in protective case
- Don't wear on top of head (contaminates lenses)
- Ensure proper fit (no gaps)

Hearing Protection

Types:

Disposable Foam Earplugs

- Single use
- Noise Reduction Rating (NRR) 29-33 dB
- Must be inserted properly (roll, pull ear up and back, insert)
- Inexpensive, convenient

Reusable Earplugs

- Washable
- Pre-molded designs
- Various materials (silicone, rubber)
- More comfortable for extended wear
- Must be cleaned regularly

Earmuffs

- NRR 20-30 dB
- Quick on/off
- Work over glasses and hard hats
- More expensive but more durable
- Can be combined with earplugs for extreme noise

When Required:

- Operating power tools
- Working near loud equipment (boilers, compressors)
- Construction environments
- Generally required when noise exceeds 85 dBA for 8 hours
- Requirements vary by exposure time and intensity

Proper Use:

- Check NRR rating adequate for noise level
- Insert earplugs properly
- Ensure earmuff seal around ears
- Don't lift one side to hear (defeats protection)
- Replace foam plugs when dirty or compressed
- Clean reusable protection regularly

CSA Standard: CSA Z94.2 - Hearing Protection Devices

Hand Protection

Hands are most frequently injured body part in gas work. Proper gloves protect against cuts, burns, chemical exposure, and cold.

Work Gloves - General Purpose

Leather gloves:

- Abrasion and cut resistance
- Heat resistant (moderate temperatures)

- Good dexterity
- General installation work

Synthetic/fabric gloves:

- Cut-resistant materials (Kevlar, Dyneema)
- Good dexterity
- Some chemical resistance
- ANSI cut levels: A1-A9 (A9 highest protection)

When to Use:

- Handling pipe and fittings
- Using hand tools
- Working with sheet metal
- General construction work

Chemical-Resistant Gloves

Nitrile gloves:

- Excellent chemical resistance
- Puncture resistant
- Good dexterity
- Resistant to petroleum products, oils, pipe dope

Neoprene gloves:

- Broad chemical resistance
- Moderate temperature resistance
- Less dexterity than nitrile

When to Use:

- Applying pipe dope or sealants
- Handling chemicals
- Fuel oil work
- Cleaning with solvents

Insulated Gloves

When to Use:

- Cold weather work
- Handling extremely cold propane lines
- Working with cryogenic fluids

Electrical-Rated Gloves

When Required:

- Working on energized electrical circuits
- Must be rated for voltage being worked on
- Regular inspection and testing required
- Usually worn with leather outer protectors

Important: Most gas technicians are NOT qualified for electrical work beyond low-voltage thermostats. Electrical-rated gloves are mentioned for awareness but should only be used by qualified electricians.

Proper Selection:

- Choose gloves appropriate for hazard
- Ensure proper fit (too large reduces dexterity, too small restricts movement)
- Inspect before each use
- Replace when damaged, contaminated, or worn
- Never use damaged gloves
- Consider dexterity requirements vs. protection level

Foot Protection

Safety Boots/Shoes

Requirements:

- CSA Z195 certified
- Steel toe or composite toe (minimum 125 joules/90 pounds impact)
- Puncture-resistant sole plate (where required)
- Slip-resistant sole
- Ankle support
- Electrical hazard rated (where required)

Grade 1 (Green Triangle):

- Sole puncture protection with plate
- Toe protection
- Required on most construction sites

Grade 2 (Yellow Triangle):

- Toe protection only (no plate)
- Suitable for many service environments

Additional Features:

- Metatarsal guards (additional top-of-foot protection)
- Electrical hazard (EH) rating
- Slip-resistant soles (oil, chemical resistant)
- Waterproof construction
- Insulation for cold weather

When Required:

- All construction sites
- Commercial/industrial installations
- Where heavy objects handled
- Provincial requirements vary but generally required for gas work

Proper Use:

- Ensure proper fit and support
- Lace/fasten completely
- Replace when soles worn
- Keep clean and dry
- Break in gradually to prevent blisters
- Replace safety toe if impact occurs

CSA Standard: CSA Z195 - Protective Footwear

Respiratory Protection

Gas technicians may encounter situations requiring respiratory protection, though this is less common than in some other trades.

Types:

Dust Masks (N95, N99)

- Filters particulates only
- No protection against gases or vapors
- Single use
- Must be fit tested
- Required for dusty environments

Half-Face Respirators

- Filters or cartridges for specific contaminants
- Must be fit tested annually
- Requires medical clearance

- Various cartridge types:
  - Organic vapor (for solvents)
  - Acid gas (for combustion products)
  - Combination cartridges
  - Particulate filters

Full-Face Respirators

- Better protection than half-face
- Includes eye protection
- Same cartridge options
- Required medical clearance and fit testing

Supplied-Air Respirators (SAR)

- External air source
- Required for IDLH (Immediately Dangerous to Life or Health) atmospheres
- Confined space entry
- Special training required

Self-Contained Breathing Apparatus (SCBA)

- Carried air supply
- Emergency/rescue use
- Fire department equipment
- Extensive training required

When Required:

- Confined spaces with inadequate oxygen
- Presence of toxic gases above acceptable limits
- Environments with unknown air quality
- Specific operations identified in risk assessment
- Asbestos abatement (specialized protection)

Important Considerations:

- Facial hair prevents proper seal (clean-shaven required)
- Medical clearance needed
- Annual fit testing required
- Cartridges have limited life span
- Must understand limitations
- Provincial regulations strictly govern respiratory protection

CSA Standard: CSA Z94.4 - Selection, Use and Care of Respirators

High-Visibility Clothing

When Required:

- Working near traffic or moving vehicles
- Construction sites with equipment operation
- Utility work
- Low-light conditions
- Often required by site safety rules

Classes:

- **Class 1:** Low-risk environments, parking areas
- **Class 2:** Medium-risk, traffic under 50 km/h
- **Class 3:** High-risk, highway work, high-speed traffic

Types:

- Safety vests
- Traffic jackets
- Full rain suits with reflective striping

CSA Standard: CSA Z96 - High-Visibility Safety Apparel

Other PPE Considerations

Knee Pads:

- Protect knees during prolonged kneeling
- Install low appliances, water heaters
- Types: strap-on or built into work pants

Back Support Belts:

- Controversial effectiveness
- Not substitute for proper lifting technique
- May provide reminder to lift correctly
- Should not be relied upon for protection

Fall Protection:

- Required when working above 3 meters (10 feet) in most provinces
- Full-body harness required (not belt-type)
- Must be trained in use
- Anchorage point calculations required
- Rescue plan must be in place

- Specialized training required - discussed further in working at heights

Sun Protection:

- Sunscreen for outdoor work
- Wide-brimmed hats
- UV-protective clothing
- Important for all-day outdoor installations

2.2 Hazard Recognition

Recognizing hazards is the first step in preventing accidents. Gas work involves multiple hazard types that must be identified and controlled.

Flammability Hazards

Flammable Range (Explosive Limits)

Both natural gas and propane will only burn within specific concentration ranges in air.

Natural Gas (Methane):

- **Lower Explosive Limit (LEL):** 5% by volume in air
- **Upper Explosive Limit (UEL):** 15% by volume in air
- **Flammable Range:** 5% to 15%

Propane:

- **Lower Explosive Limit (LEL):** 2.1% by volume in air
- **Upper Explosive Limit (UEL):** 9.5% by volume in air
- **Flammable Range:** 2.1% to 9.5%

Understanding the Ranges:

Below LEL (Too Lean):

- Not enough fuel to burn
- Will not ignite
- Still dangerous as concentration can increase

Within Flammable Range:

- EXPLOSION HAZARD
- Any ignition source can cause fire or explosion

- Most dangerous condition

Above UEL (Too Rich):

- Too much fuel, not enough oxygen
- Will not ignite in this state
- Will explode as it mixes with air and enters flammable range
- Still extremely dangerous

Critical Safety Point: Propane's wider flammable range (2.1%-9.5%) compared to natural gas (5%-15%) means propane creates explosive mixtures more easily. Propane's LEL of 2.1% means only small amounts create explosive conditions.

Ignition Sources

Gas will not burn without an ignition source. Common ignition sources on job sites:

Open Flames:

- Pilot lights
- Matches, lighters
- Cutting/welding torches
- Space heaters
- Smoking materials

Electrical:

- Sparks from switches, outlets
- Static electricity
- Power tools (brushed motors)
- Electrical arcs
- Lightning
- Faulty wiring

Mechanical:

- Grinding sparks
- Metal striking metal
- Friction heating
- Hot surfaces

Other:

- Hot work (soldering, brazing)
- Vehicle exhaust systems
- Furnace combustion chambers

- Any surface above auto-ignition temperature

Auto-Ignition Temperatures:

- Natural Gas: 540°C (1,004°F)
- Propane: 493-549°C (920-1,020°F)

Any surface at or above these temperatures will ignite the gas without spark or flame.

Asphyxiation Hazards

Both natural gas and propane displace oxygen. In confined spaces or enclosed areas, this can create asphyxiation hazards.

Normal Atmospheric Oxygen: 20.9%

Effects of Oxygen Deficiency:

Oxygen %	Effects
19.5%	Minimum acceptable level (regulatory limit)
15-19%	Decreased ability to work, early symptoms
12-15%	Deeper breathing, faster heartbeat, poor coordination
10-12%	Very poor judgment, blue lips, nausea
8-10%	Unconsciousness, brain damage likely
6-8%	Death within 6-8 minutes
Below 6%	Death within seconds

High-Risk Scenarios:

- Confined spaces (tanks, vaults, crawlspaces)
- Trenches and excavations
- Unventilated rooms
- Basements with gas accumulation
- Tanks or vessels being purged with inert gas

Warning: Natural gas is lighter than air and rises; propane is heavier than air and settles in low areas. Both displace oxygen and can create asphyxiation hazards.

Carbon Monoxide (CO) Hazards

Carbon monoxide is produced by incomplete combustion of any carbon-based fuel. It is the leading cause of death from gas equipment in Canada.

Properties of CO:

- Colorless
- Odorless
- Tasteless
- Cannot be detected by human senses
- Slightly lighter than air (will mix throughout space)
- Toxic at very low concentrations

Sources in Gas Work:

- Improperly adjusted burners
- Blocked or inadequate venting
- Insufficient combustion air
- Cracked heat exchangers
- Spillage from draft hood appliances
- Backdrafting conditions
- Running vehicles in confined spaces
- Unvented or vent-free appliances

CO Toxicity:

Carbon monoxide binds to hemoglobin 200-250 times more readily than oxygen, preventing oxygen transport in blood.

Symptoms of CO Exposure:

CO Level (ppm)	Exposure Time	Symptoms
35 ppm	8 hours	CSA B149.1 maximum for continuous exposure
70 ppm	1-4 hours	Headache, fatigue
150 ppm	1.5 hours	Dizziness, nausea
400 ppm	1 hour	Headache, nausea, confusion
800 ppm	45 min	Unconsciousness
1,600 ppm	20 min	Death
3,200 ppm	5-10 min	Death
6,400 ppm	1-2 min	Death

Early Symptoms (often mistaken for flu):

- Headache
- Dizziness
- Nausea
- Fatigue
- Confusion
- Shortness of breath

Severe Symptoms:

- Vomiting
- Chest pain
- Loss of consciousness
- Seizures
- Death

High-Risk Situations:

- Combustion testing in confined spaces
- Working on equipment with suspected problems
- Multiple appliances in small mechanical rooms
- Start-up and commissioning
- Troubleshooting no-heat calls (equipment may be running improperly)

Protection Strategies:

- Always use combustion analyzer
- Never work in unventilated spaces with running equipment
- Use personal CO monitors
- Ensure adequate ventilation
- Test CO levels before and during work
- Evacuate at dangerous levels

Physical Hazards

Lifting Injuries:

- Gas equipment often heavy (furnaces 200+ lbs, water heaters 150+ lbs)
- Piping and fittings
- Proper lifting technique essential
- Use mechanical aids when possible

Cuts and Lacerations:

- Sharp sheet metal edges
- Pipe threading chips
- Cutting tools
- Proper gloves and handling techniques required

Burns:

- Hot pipes and equipment during service
- Soldering and brazing operations
- Steam and hot water in hydronic systems

- Contact with heat exchangers
- Propane cold burns (rapid expansion)

Struck-By Hazards:

- Falling objects on construction sites
- Swinging pipe or materials
- Tools dropped from heights
- Hard hat required in construction environments

Slips, Trips, and Falls:

- Wet or icy surfaces
- Cluttered work areas
- Ladders and scaffolds
- Working at heights
- Leading cause of workplace injuries

Electrical Hazards

Gas technicians frequently work with electrical systems and must understand electrical hazards.

Shock Hazards:

- 115V and 230V circuits at appliances
- 24V control circuits (generally safe but can startle)
- Potential contact with higher voltages in electrical rooms

Arc Flash:

- Explosive release of energy during electrical fault
- Can cause severe burns, hearing damage, blindness
- Requires specialized PPE and training
- Gas technicians should not work on high-voltage systems

Electrocution:

- Current through body can stop heart
- As little as 75 mA can be fatal
- Wet conditions increase risk
- Damaged cords and tools

CSST Bonding:

- Corrugated stainless steel tubing must be bonded per CSA B149.1
- Lightning strikes or electrical faults can arc through CSST causing rupture

- Bonding reduces this risk
- Electrical contractor may be required for bonding

Safe Practices:

- Assume all circuits are live until proven otherwise
- Use voltage tester before touching
- De-energize circuits when possible
- Use insulated tools
- Work in dry conditions
- GFCI protection on power tools
- Never bypass safety devices

Trench and Excavation Hazards

Gas service line installation involves trenching and excavation with significant hazards.

Cave-In Hazards:

- Soil failure is leading cause of excavation deaths
- Can occur suddenly without warning
- Cubic meter of soil weighs 1,500-2,000 kg
- Fatal burial can occur in seconds

Protection Required:

- Slope walls to safe angle (typically 1:1 or flatter)
- Shore with timber or aluminum supports
- Use trench box or shield
- Requirements depend on depth, soil type, water presence

Minimum Requirements (typical):

- Excavations 1.2m (4 ft) or deeper require protection
- Competent person must inspect daily
- Ladder required every 7.5m (25 ft) of trench
- Soil and materials kept 1m (3 ft) from edge

Underground Utilities:

- Contact provincial one-call service before digging (Ontario: ON1Call)
- Allow 3-5 business days for locates
- Mark planned excavation
- Hand dig near marked utilities
- Assume unmarked utilities present
- Report any strikes immediately

Atmospheric Hazards in Excavations:

- Oxygen deficiency
- Toxic gases (sewer lines, contaminated soil)
- Test atmosphere before entry if over 1.2m deep
- Ensure adequate ventilation

Water Accumulation:

- Reduces soil stability
- Drowning hazard
- Pump continuously if present
- Never enter water-filled excavations

Confined Space Hazards

Definition: A confined space is an enclosed or partially enclosed space that:

- Is not designed or intended for continuous human occupancy
- Has restricted entry or exit
- May contain or accumulate hazardous substances

Examples in Gas Work:

- Meter vaults
- Crawlspaces
- Attics with limited access
- Boiler rooms with inadequate ventilation
- Tanks and vessels
- Manholes and utility vaults

Hazards:

- Oxygen deficiency or enrichment
- Flammable atmospheres
- Toxic gases
- Engulfment
- Configuration (inability to escape)
- Temperature extremes

Entry Requirements:

- Confined space program required by employer
- Atmospheric testing before and during entry
- Continuous ventilation
- Permit system

- Attendant outside
- Communication system
- Rescue plan and equipment
- Specialized training

Never enter confined space without:

- Proper authorization and permit
- Atmospheric testing showing safe conditions
- Required PPE and equipment
- Established rescue plan
- Attendant present

2.3 Emergency Procedures

Every gas technician must know how to respond to emergencies. Quick, appropriate action can prevent injuries and save lives.

Gas Leak Response

Immediate Actions:

1. **Evacuate the Area**
   - Get everyone out immediately
   - Don't stop to gather belongings
   - Evacuate to safe distance (minimum 100m/300ft for large leaks)
   - Account for all occupants
2. **Eliminate Ignition Sources**
   - DON'T operate electrical switches (on or off)
   - DON'T use phones inside building (including cell phones)
   - DON'T start vehicles
   - DON'T use flashlights (unless explosion-proof)
   - No smoking, matches, lighters
3. **Stop Gas Flow (if safe to do so)**
   - Shut manual valve at meter or tank
   - Only if valve is accessible without entering hazard area
   - Don't risk life to shut off gas
4. **Call for Help**
   - Call 911 from safe location outside
   - Call gas utility emergency number (natural gas)
   - Call propane supplier emergency number (propane)
   - Provide clear information:
     - Nature of emergency
     - Address and location

        - Number of people involved
        - Injuries (if any)
        - Your callback number
5. **Ventilate (if safe)**
    - Open doors and windows from outside if possible
    - Don't enter building to ventilate
    - Natural ventilation only (don't use fans which could create sparks)
6. **Prevent Re-Entry**
    - Keep everyone away from building
    - Warn approaching people
    - Wait for utility or fire department clearance

What NOT to Do:

- Don't search for leak source in emergency
- Don't try to repair leak immediately
- Don't re-enter building until cleared by authorities
- Don't turn utilities back on yourself

After Emergency:

- Don't operate gas system until repaired and tested
- Proper repair by licensed technician required
- Testing and inspection required before restart
- Document incident
- Report to regulatory authority if required

Fire Response

If Fire Involves Gas Equipment:

1. **Evacuate Immediately**
    - Sound alarm
    - Get everyone out
    - Close doors behind you (don't lock)
    - Don't use elevators
2. **Call 911**
    - From safe location
    - Provide clear location and details
    - State gas is involved
    - Report any injuries
3. **Shut Off Gas (only if safe)**
    - Only if you can do so without risk
    - Shut exterior valve or tank valve
    - Don't enter burning building

Small Fire (if safe to fight):

- Use appropriate extinguisher (Class B or ABC)
- Only fight fire if:
  - You have been trained
  - You have proper extinguisher
  - Fire is small and contained
  - You have clear escape route
  - You are not risking your safety
- If fire grows or you feel unsafe, evacuate immediately

Never attempt to extinguish:

- Gas leak fire (unless you can shut off gas first)
- Large or spreading fires
- Fires in occupied areas
- Fires blocking escape routes

After Fire:

- Gas system must be professionally inspected
- Damaged components must be replaced
- Complete testing before restart
- Document for insurance and authorities

Carbon Monoxide Emergency

Symptoms Present:

1. **Evacuate Immediately**
   - Get all occupants outside into fresh air
   - Leave doors and windows open for ventilation
2. **Call 911**
   - Report suspected CO poisoning
   - Number and condition of affected people
   - Address and location
3. **Seek Medical Attention**
   - Anyone with symptoms needs medical evaluation
   - CO exposure causes delayed effects
   - Blood test can confirm CO exposure
4. **Don't Re-Enter**
   - Wait for emergency responders
   - Building not safe until source identified and corrected

High CO Readings (no symptoms yet):

1. **Shut Down Equipment**
    - Turn off all gas appliances
    - Shut off gas supply if possible
2. **Ventilate**
    - Open windows and doors
    - Leave building if levels high (>100 ppm)
3. **Call Utility or Service Provider**
    - Report dangerous condition
    - Request emergency service
4. **Test and Monitor**
    - Use CO detector to monitor levels
    - Ensure levels decreasing
    - Document readings

Don't restart equipment until:

- Source identified and corrected
- Complete combustion test performed
- Safe CO levels confirmed
- Written clearance provided

Electrical Emergency

Shock Victim:

1. **Don't Touch Victim** if still in contact with electricity
2. **Shut Off Power**
    - Breaker or disconnect
    - If not possible, call 911
3. **Once Safe:**
    - Check breathing and pulse
    - Perform CPR if trained and necessary
    - Call 911 if not already done
    - Keep victim warm and calm
    - Wait for emergency responders

Electrical Fire:

- Use Class C extinguisher
- Shut off power if possible
- Don't use water
- Evacuate if fire not controlled immediately

Personal Injury

Serious Injury:

- Call 911 immediately
- Don't move victim unless in immediate danger
- Control bleeding with pressure
- Keep victim warm
- Stay with victim until help arrives
- Document incident

Minor Injury:

- Administer first aid
- Clean and bandage wounds
- Report to supervisor
- Document incident
- Seek medical attention if any doubt

First Aid:

- Know location of first aid kit
- Maintain current first aid certification
- Standard First Aid with CPR Level C recommended

Evacuation Procedures

Know Before You Need It:

- Location of exits
- Evacuation routes
- Assembly points
- Emergency equipment locations
- Emergency contact numbers

During Evacuation:

- Follow established routes
- Assist others if safe to do so
- Don't use elevators
- Close doors behind you
- Report to assembly point
- Account for everyone
- Don't re-enter until cleared

Incident Reporting

Required Reports:

- All injuries (no matter how minor)

- Near misses (could have caused injury)
- Property damage
- Gas releases
- Fires
- Dangerous conditions

Report To:

- Employer/supervisor (immediately)
- Regulatory authority (as required)
- Workers' compensation board (injuries)
- Customer (incidents at their property)

Documentation:

- Date, time, and location
- People involved
- Witnesses
- Sequence of events
- Contributing factors
- Corrective actions
- Photos if appropriate

2.4 Workplace Safety Regulations

Provincial Occupational Health and Safety Acts

Every province has occupational health and safety legislation governing workplace safety. While specifics vary, common principles include:

Employer Responsibilities:

- Provide safe workplace
- Provide safe equipment and procedures
- Provide training and supervision
- Provide PPE at no cost to worker
- Establish safety programs
- Investigate incidents
- Report serious incidents to authorities

Worker Responsibilities (3 Rights and 1 Duty):

Right to Know:

- Hazards in workplace
- Safe work procedures
- How to protect yourself

Right to Participate:

- In safety programs
- Through health and safety committees
- In workplace inspections

Right to Refuse:

- Unsafe work
- Without penalty
- With investigation of concern

Duty to:

- Use PPE as required
- Follow safe work procedures
- Report hazards and incidents
- Work safely

Supervisor Responsibilities:

- Ensure workers follow procedures
- Provide instruction and training
- Monitor workplace for hazards
- Investigate incidents
- Enforce safety rules

Internal Responsibility System (IRS)

Everyone shares responsibility for workplace safety:

- Management provides resources and leadership
- Supervisors ensure compliance
- Workers work safely and report hazards
- Joint health and safety committees facilitate cooperation

WHMIS 2015 (Workplace Hazardous Materials Information System)

WHMIS is Canada's hazard communication standard for workplace chemicals. It aligns with the Globally Harmonized System (GHS).

Three Key Elements:

1. Labels

All hazardous products must have labels with:

- Product identifier (name)
- Supplier identifier
- Hazard pictograms
- Signal word (Danger or Warning)
- Hazard statements
- Precautionary statements

Pictograms (standardized symbols in red diamond):

- Flame (flammable)
- Flame over circle (oxidizer)
- Gas cylinder (compressed gas)
- Corrosion (corrosive)
- Skull and crossbones (acute toxicity)
- Health hazard (serious health effects)
- Exclamation mark (irritant, less serious health effects)
- Environment (aquatic toxicity)
- Exploding bomb (explosive)

2. Safety Data Sheets (SDS)

16-section standardized documents providing detailed hazard and safety information:

- **Section 1:** Identification
- **Section 2:** Hazard identification
- **Section 3:** Composition/information on ingredients
- **Section 4:** First-aid measures
- **Section 5:** Fire-fighting measures
- **Section 6:** Accidental release measures
- **Section 7:** Handling and storage
- **Section 8:** Exposure controls/personal protection
- **Section 9:** Physical and chemical properties
- **Section 10:** Stability and reactivity
- **Section 11:** Toxicological information
- **Section 12:** Ecological information
- **Section 13:** Disposal considerations
- **Section 14:** Transport information
- **Section 15:** Regulatory information
- **Section 16:** Other information

Employer must:

- Obtain SDS for all hazardous products
- Make SDS readily available to workers
- Update SDS regularly (every 3 years or when new information available)

3. Worker Education

All workers must receive WHMIS training:

- Before working with hazardous products
- When new hazards introduced
- Regular refresher training

Training must cover:

- How to read labels and SDS
- Safe handling, storage, and disposal
- Emergency procedures
- Health effects
- PPE requirements

Common Hazardous Products in Gas Work:

- Pipe thread compounds (pipe dope)
- Cleaning solvents
- Adhesives and sealants
- Compressed gases
- Refrigerants
- Oils and lubricants
- Primers and cleaners for plastic pipe

2.5 Gas Leak Detection and Response

Proper gas leak detection is fundamental to gas technician work. Every installation must be tested, and technicians must be able to locate leaks quickly and safely.

Detection Methods

1. Odor Detection

Natural gas and propane are odorized with mercaptan (smells like rotten eggs or sulfur) for safety.

Advantages:

- No equipment required
- Immediate detection
- Wide area sensing

Limitations:

- Not reliable for small leaks
- Olfactory fatigue (nose becomes desensitized)
- Some people have reduced sense of smell
- Odor can fade in some situations (scrubbing)
- Cannot quantify leak size
- Not acceptable as sole leak test method

Never rely on odor alone for leak testing.

2. Soap Bubble Solution

Most reliable method for pinpointing small leaks.

Procedure:

- Mix leak detection solution (commercially available or mild dish soap and water)
- Apply to suspected leak points
- Bubbles indicate leak
- Brush or spray application

Advantages:

- Highly sensitive
- Visual confirmation
- Inexpensive
- Safe
- Accepted by code and inspectors

Disadvantages:

- Time consuming for large systems
- Requires access to joint
- Messy
- Not practical for entire system testing
- Freezes in cold weather

Best Use:

- Verifying specific joints
- Final inspection of test points

- Small systems
- Verification after electronic detection

3. Electronic Combustible Gas Detectors

Use sensors to detect combustible gases and display concentration.

Types:

Catalytic Bead Sensors:

- Oxidizes gas on heated element
- Measures temperature change
- Reads % LEL (Lower Explosive Limit)
- Requires oxygen to function
- Can be poisoned by silicones or sulfur

Infrared Sensors:

- Detects gas by light absorption
- More stable than catalytic
- Works without oxygen
- More expensive
- Less sensitivity to low concentrations

Semiconductor Sensors:

- Changes electrical resistance in presence of gas
- Very sensitive
- Less specific (responds to many gases)
- Lower cost
- Faster recovery

Reading and Interpreting:

- Usually display % LEL
- 10% LEL = 10% of concentration needed for explosion
- Some display ppm (parts per million)
- Understanding scale critical

Example:

- Natural gas LEL = 5% by volume = 50,000 ppm
- Detector reading 10% LEL = 0.5% gas in air = 5,000 ppm
- Detector reading 100% LEL = explosive mixture present

Using Electronic Detectors:

- Calibrate per manufacturer instructions
- Zero in fresh air before use
- Move probe slowly (2-3 cm/sec)
- Hold near suspected leak
- Work methodically
- Check all joints and connections
- Document results

Advantages:

- Fast screening of large systems
- Quantitative results
- Can detect very small leaks
- Immediate response
- Records for documentation

Disadvantages:

- Requires maintenance and calibration
- Battery dependent
- Can give false readings (other chemicals)
- Must be used properly to be effective
- More expensive than bubble test

Best Use:

- Surveying installed systems
- Emergency response
- System commissioning
- Routine inspections
- Finding general leak area (then pinpoint with bubbles)

4. Pressure Testing

Most reliable method for new installations or after modifications.

Procedure (covered in detail in Chapter 8):

- Isolate section to be tested
- Cap appliances or close valves
- Apply test pressure per code
- Monitor pressure over time
- Acceptable pressure drop per CSA B149.1

Advantages:

- Tests entire system
- Quantifies system tightness
- Required by code
- Documented results
- High confidence

Disadvantages:

- Requires equipment
- Takes time (test duration)
- May not pinpoint leak location
- Must isolate appliances

Best Use:

- New installations
- Modifications and additions
- After repairs
- Regulatory requirement
- Quality assurance

Leak Investigation Procedure

Systematic approach prevents missing leaks:

1. Gather Information

- Where odor detected?
- When first noticed?
- Any recent work on system?
- Any changes in operation?
- Building alterations?

2. Safety First

- Eliminate ignition sources
- Ensure adequate ventilation
- Use intrinsically safe equipment
- Evacuate if concentration high
- Call utility if major leak

3. Trace Gas System

- Start at meter/tank

- Follow piping systematically
- Check all connections
- Include all branches
- Don't skip areas

4. Check Common Leak Points

- Threaded connections
- Union fittings
- Valves and regulators
- Flexible connectors
- Appliance connections
- Meter connections
- Tank connections
- Damaged piping

5. Use Multiple Methods

- Electronic detector to locate area
- Bubble test to pinpoint
- Pressure test to verify repair

6. Document

- Location of leak
- Apparent cause
- Repair method
- Verification test results
- Photos if appropriate

7. Verify Repair

- Pressure test after repair
- Bubble test specific repair
- Monitor for period of time
- Provide documentation

Leak Classification and Response

Minor Leak:

- Small concentration
- Not immediately hazardous
- Can be repaired on normal schedule
- Monitor until repaired

Action:

- Tag and document
- Schedule repair
- Advise customer
- Ensure adequate ventilation

Major Leak:

- Significant gas release
- Potentially hazardous
- Requires immediate action

Action:

- Shut off gas
- Evacuate if necessary
- Eliminate ignition sources
- Ventilate
- Emergency repair
- Don't restore service until safe

Emergency Leak:

- Immediate danger
- Evacuation required
- Fire/explosion risk

Action:

- Evacuate immediately
- Call 911
- Call utility/supplier
- Shut off gas from outside if possible
- Establish safety perimeter
- Wait for emergency responders

2.6 Carbon Monoxide Safety

Carbon monoxide kills more people than any other product of combustion. Every gas technician must understand CO production, detection, and prevention.

Sources of Carbon Monoxide

Incomplete Combustion Causes:

1. Insufficient Air

- Blocked air intakes
- Insufficient combustion air openings
- Negative building pressure
- Sealed buildings

2. Poor Air-Fuel Mixture

- Improper orifice size
- Wrong gas pressure
- Dirty or maladjusted burners
- Incorrect conversion (natural gas to propane)

3. Flame Impingement

- Burner misalignment
- Flame contact with cool surfaces
- Deposits on burners

4. Venting Problems

- Blocked vents
- Undersized vents
- Backdrafting
- Spillage
- Corroded vents
- Improper termination

5. Equipment Problems

- Cracked heat exchangers
- Failed heat exchangers
- Deteriorated gaskets
- Warped components

6. Other Sources

- Vehicle exhaust (attached garages)
- Portable generators
- Unvented space heaters
- Barbecues used indoors
- Construction heaters

Detection and Measurement

CO Alarms (Residential):

- Required by code in dwellings with fuel-burning appliances
- CSA 6.19 certified
- Installed per manufacturer instructions
- Near sleeping areas
- Not in mechanical rooms (delayed alarm)
- Replace per manufacturer (typically 5-7 years)
- Not substitute for proper equipment maintenance

Professional CO Analyzers:

- Used by technicians for combustion testing
- Electrochemical sensors
- Measure CO in ppm
- Also measure O_2, CO_2, flue temperature
- Calculate efficiency
- Essential tool for gas technicians

Measurement Points:

- Flue gas (combustion products)
- Ambient air (room where appliance located)
- Near appliances
- In living spaces

Acceptable Levels per CSA B149.1:

- Ambient air (continuous): 35 ppm maximum
- Flue gas: 100 ppm air-free maximum for most appliances
- Some appliances have different limits (check manufacturer specifications)

Taking Measurements:

- Allow analyzer warm-up period
- Zero in fresh air
- Insert probe into flue per manufacturer instructions
- Wait for stable reading
- Record all measurements
- Document ambient CO before and during testing

Prevention Strategies

Installation:

- Proper combustion air provisions per code
- Correct venting per manufacturer and code
- Proper appliance sizing
- Quality workmanship
- Complete testing before leaving job

Maintenance:

- Annual inspection and cleaning
- Burner cleaning and adjustment
- Venting inspection
- Combustion testing
- Heat exchanger inspection
- Air intake inspection

Customer Education:

- Importance of maintenance
- CO alarm requirements
- Symptoms of CO exposure
- Never ignore CO alarm
- Proper appliance ventilation
- Dangers of unvented appliances
- Vehicle idling in garages

Building Considerations:

- Adequate combustion air
- Proper make-up air
- Understanding house depressurization
- Exhaust fan coordination
- Sealed combustion appliances in tight buildings

Response to CO

CO Alarm Activation:

1. Evacuate building immediately
2. Call 911 or fire department
3. Get fresh air
4. Seek medical attention if symptoms present
5. Don't re-enter until building cleared
6. Professional inspection required before restart

High CO Readings During Testing:

1. Shut down equipment immediately
2. Determine source
3. Check for spillage
4. Ventilate area
5. Do not restart until corrected
6. Complete combustion test after correction

Symptoms in Occupants:

1. Evacuate to fresh air
2. Call 911
3. Medical evaluation required
4. Don't re-enter building
5. Professional investigation required

Documentation

Every service call should document:

- Ambient CO level
- Flue gas CO level
- O_2 and CO_2 levels
- Temperature
- Calculated efficiency
- Any concerns or corrections
- Signature and date

This protects:

- Customer (proof of proper service)
- Technician (proof of proper procedures)
- Company (liability protection)
- Future technicians (baseline data)

2.7 Confined Space Safety

Gas technicians occasionally need to enter confined spaces. This requires specialized training and procedures.

Confined Space Definition

A confined space:

- Is enclosed or partially enclosed

- Is not designed for continuous occupancy
- Has restricted entry or exit
- May contain hazards to health or safety

Examples:

- Meter vaults
- Manholes
- Tanks and vessels
- Crawlspaces (some)
- Trenches over 1.2m deep
- Attics with restricted access
- Small mechanical rooms

Confined Space Program Requirements

Employers must:

- Identify all confined spaces
- Assess hazards
- Develop entry procedures
- Provide training
- Provide equipment
- Maintain entry permits
- Conduct rescue drills

Before Entry:

- Permit required
- Atmospheric testing
- Hazard control
- Entry procedures established
- Rescue plan in place
- Equipment checked

Atmospheric Hazards

Testing Required For:

1. **Oxygen level** - must be 19.5% to 23%
2. **Flammable gases** - must be below 10% LEL
3. **Toxic gases** - must be below exposure limits (CO, H_2S, etc.)

Test:

- Before entry

- Continuously during occupancy (if required)
- After breaks in occupancy
- If conditions change

Ventilation:

- Forced ventilation usually required
- Continuous during occupancy
- Cannot rely on natural ventilation
- Exhaust to safe location

Entry Procedures

Required Elements:

1. **Entry permit** documenting:
    - Space identification
    - Atmospheric test results
    - Hazards present
    - Control measures
    - Entry team
    - Duration
    - Signatures
2. **Attendant:**
    - Remains outside
    - Maintains contact with entrants
    - Monitors conditions
    - Initiates rescue if needed
    - Cannot enter to rescue
3. **Communication:**
    - Continuous contact
    - Method established (voice, radio, signals)
    - Check-in schedule
4. **Equipment:**
    - Atmospheric monitor
    - Ventilation equipment
    - PPE as required
    - Retrieval equipment
    - Lighting (explosion-proof if needed)
    - Rescue equipment
5. **Rescue Plan:**
    - Cannot rely on 911 response time
    - Self-rescue or non-entry rescue preferred
    - Retrieval equipment required
    - Trained rescue team
    - Regular drills

Training Requirements

All entrants, attendants, and supervisors must be trained in:

- Hazard recognition
- Testing procedures
- Entry procedures
- Emergency procedures
- Equipment use
- Rescue procedures

Training must be:

- Before first entry
- When conditions change
- When procedures change
- Annually (minimum)
- Documented

Most Common Fatal Mistake

Untrained rescue attempts kill more people than initial incidents.

Never enter confined space to rescue without:

- Proper training
- Proper equipment
- Atmospheric monitoring
- SCBA or SAR
- Backup personnel
- Call 911 immediately in emergency

2.8 Lockout/Tagout Procedures

Lockout/tagout (LOTO) prevents equipment from starting unexpectedly during service.

When Required

- Servicing equipment with stored energy
- Clearing blockages
- Working on electrical systems
- Any time unexpected start could cause injury

Energy Sources to Control

Electrical:

- Disconnect and lock out
- Verify de-energized
- Discharge capacitors

Gas:

- Close and lock valve
- Relieve pressure
- Verify no flow

Mechanical:

- Block moving parts
- Relieve springs
- Support suspended components

Hydraulic/Pneumatic:

- Isolate pressure sources
- Relieve pressure
- Block cylinders

Thermal:

- Allow cooling
- Drain hot fluids
- Block steam lines

Gravity:

- Block suspended loads
- Support before disconnect

Lockout Procedure

1. **Notify affected people**
2. **Identify energy sources**
3. **Shut down equipment normally**
4. **Isolate energy sources**
5. **Apply lockout devices**
6. **Verify isolation** (test equipment)
7. **Relieve stored energy**

Lockout Devices

Locks:

- Each worker applies own lock
- Unique key (no duplicate for same lock)
- Only worker who applied can remove

Tags:

- Identify who locked out
- Date and time
- Reason for lockout
- Contact information
- "Do Not Operate"

Devices:

- Circuit breaker lockouts
- Valve lockouts
- Plug lockouts
- Various adapters for different equipment

Tagout

Tagout alone is acceptable only if lockout not physically possible. Tags must:

- Be substantial (won't tear easily)
- Be standardized
- Identify person
- Warn against operation

Removing Lockout

Only worker who applied lock can remove it

Before removing:

1. Ensure work complete
2. Tools and materials removed
3. Covers and guards replaced
4. All personnel clear
5. Notify affected people

Special case: If worker unavailable (shift change, etc.):

- Supervisor may remove with authorization
- Verify work complete
- Verify area safe
- Document reason
- Notify worker

Group Lockout

When multiple workers on same equipment:

- Each worker applies own lock
- Supervisor may coordinate
- All locks must be removed before restart

Stored Energy

Always relieve or block stored energy:

- Capacitors (electrical)
- Springs (mechanical)
- Compressed gas (pneumatic)
- Hydraulic pressure
- Elevated components (gravity)
- Rotating masses (inertia)

Chapter Summary

Safety is the foundation of professional gas work. Personal protective equipment, hazard recognition, and emergency response procedures protect workers and the public. Natural gas and propane have specific properties that create flammability, asphyxiation, and carbon monoxide hazards that must be understood and controlled.

Provincial workplace safety legislation establishes rights and responsibilities through the Internal Responsibility System. WHMIS 2015 provides hazard communication for chemical products. Proper gas leak detection uses multiple methods including electronic detectors and bubble solutions. Carbon monoxide prevention requires proper installation, maintenance, and testing.

Specialized procedures govern confined space entry, lockout/tagout, and excavation work. Every technician must maintain current knowledge through regular training and practice of emergency procedures. Safe work practices, proper PPE use, and thorough hazard assessment prevent accidents and ensure successful careers in the gas industry.

Review Questions

Multiple Choice

1. Natural gas has a Lower Explosive Limit (LEL) of:
    - a) 2.1%
    - b) 5%
    - c) 10%
    - d) 15%
2. At what oxygen concentration must work stop in a confined space?
    - a) 23%
    - b) 20.9%
    - c) 19.5%
    - d) 18%
3. According to CSA B149.1, the maximum continuous ambient CO level is:
    - a) 9 ppm
    - b) 35 ppm
    - c) 70 ppm
    - d) 100 ppm
4. Which CSA standard governs protective footwear?
    - a) Z94.1
    - b) Z94.3
    - c) Z195
    - d) Z96
5. Propane's flammable range is:
    - a) 2.1% to 9.5%
    - b) 5% to 15%
    - c) 1% to 5%
    - d) 10% to 20%
6. Electronic gas detectors typically display readings in:
    - a) ppm only
    - b) % LEL only
    - c) Either % LEL or ppm depending on model
    - d) % by volume
7. The most reliable method for pinpointing small gas leaks is:
    - a) Odor detection
    - b) Electronic detector
    - c) Soap bubble solution
    - d) Pressure testing
8. WHMIS pictograms appear in what color?
    - a) Red diamond with black symbol
    - b) Yellow triangle with black symbol
    - c) Orange circle with black symbol
    - d) Blue square with white symbol
9. A confined space attendant must:
    - a) Enter if rescue needed

- b) Remain outside at all times
- c) Perform atmospheric testing
- d) Supervise the work inside

10. Excavations ______ or deeper typically require cave-in protection:
    - a) 0.6m (2 ft)
    - b) 1.2m (4 ft)
    - c) 1.8m (6 ft)
    - d) 2.4m (8 ft)

True or False

11. Propane is heavier than air and will settle in low areas.
12. Face shields can be worn alone without safety glasses.
13. An employer can remove a worker's lockout device if the worker is unavailable.
14. Carbon monoxide alarms in homes eliminate the need for annual appliance maintenance.
15. Soap bubble solution must be applied to all joints during pressure testing.

Short Answer

16. List the three worker rights under occupational health and safety legislation. (3 marks)
17. Explain why you should never rely on odor alone to detect gas leaks. (3 marks)
18. What are the three key elements of WHMIS 2015? (3 marks)
19. List four common sources of carbon monoxide in gas appliance installations. (4 marks)
20. Explain the difference between LEL and UEL. (4 marks)

Long Answer

21. Describe the complete procedure for responding to a suspected gas leak in a residential home. Include safety considerations, evacuation procedures, and steps to secure the situation. (10 marks)
22. Explain why carbon monoxide is so dangerous to human health. Include how it affects the body, typical symptoms at different exposure levels, and why it cannot be detected by human senses. Discuss prevention strategies for gas technicians. (12 marks)
23. A homeowner calls you to service their furnace that is "making them feel sick." When you arrive, you notice the occupants have headaches and nausea. What are your immediate actions and concerns? Detail your systematic approach to this call including safety considerations, testing procedures, and recommendations to the homeowner. (12 marks)

Practical Exercises

Exercise 1: PPE Selection

For each scenario, identify all required PPE:

1. Installing furnace in new construction
2. Servicing water heater in residential basement
3. Pressure testing gas piping system
4. Working in mechanical room with running equipment
5. Digging trench for gas service line

Exercise 2: Gas Detector Calibration and Use

Using an electronic combustible gas detector:

1. Review manufacturer's instructions
2. Perform calibration check
3. Zero in fresh air
4. Test response with leak source
5. Practice systematic leak survey technique
6. Document findings

Exercise 3: Emergency Response Drill

Role-play the following scenarios with proper procedures:

1. Customer calls reporting gas odor in house
2. You detect high CO levels during service call
3. You discover active gas leak while working
4. You find unconscious person in mechanical room

Exercise 4: SDS Review

Obtain Safety Data Sheets for:

1. Pipe thread compound (pipe dope)
2. PVC primer and cement
3. Cleaning solvent used in shop Review each SDS and identify:

- Health hazards
- Fire hazards
- Required PPE
- First aid measures
- Storage requirements

Exercise 5: Confined Space Assessment

Inspect your training facility and identify:

1. Spaces meeting confined space definition
2. Hazards present in each space
3. Required atmospheric testing
4. Required permits and procedures
5. Entry equipment needed
6. Rescue procedures

Case Studies

Case Study 1: The Hidden Danger

Scenario: A technician responds to a no-heat call. The furnace is in a small mechanical room with a closed door. The homeowner mentions they keep the door closed to reduce noise. The technician enters, starts diagnostics, and begins feeling dizzy and nauseous after 10 minutes.

Questions:

1. What is the likely problem?
2. What should the technician do immediately?
3. What safety equipment should have been used?
4. What might be wrong with the furnace?
5. What recommendations should be made to the homeowner?
6. How could this situation have been prevented?

Case Study 2: The Shortcut

Scenario: An experienced technician needs to replace a gas valve on a commercial boiler. The electrical disconnect is in a locked electrical room, and the maintenance person with the key won't be available for two hours. The technician decides to just close the gas valve, replace the valve, and test operation. While testing, sparks occur and the technician receives a minor shock.

Questions:

1. What procedure was violated?
2. What injuries could have occurred?
3. What is the proper procedure?
4. What if lockout was impossible?
5. What would you document?
6. What are the potential legal consequences?

Case Study 3: Trench Collapse

Scenario: Two workers are installing a gas service line in a 1.5m (5 ft) deep trench. The soil is sandy and the trench walls are vertical. One worker is in the trench connecting pipe while the other is on the surface. The walls suddenly collapse, partially burying the worker in the trench.

Questions:

1. What regulations were violated?
2. What is the immediate response?
3. What protection should have been provided?
4. Who can perform the rescue?
5. What notifications are required?
6. How could this be prevented?

Case Study 4: Multiple Gas Alarms

Scenario: You respond to a home where the CO alarm has activated twice in the past week. The homeowner reset it both times because "nothing seemed wrong." They have a forced-air furnace and gas water heater, both about 15 years old. Current CO reading in the living room is 45 ppm with all equipment operating.

Questions:

1. Is this an emergency situation?
2. What are your immediate actions?
3. What equipment and testing will you use?
4. What are possible causes?
5. What will you tell the homeowner?
6. What if you can't find the source?
7. What documentation is required?

Case Study 5: Right to Refuse

Scenario: You are sent to install a furnace in a new home. When you arrive, the basement is partially flooded with 30 cm of water. Other trades are working in the water wearing rubber boots. The general contractor tells you "everyone else is working, just put on boots and get it done."

Questions:

1. What are the hazards?
2. Can you refuse this work?
3. What is the proper procedure for refusal?
4. What if your supervisor insists you proceed?
5. What protections do you have?
6. What would be required to make this work safe?

Key Terms

Asphyxiation: Condition caused by lack of oxygen, leading to unconsciousness and death.

Auto-ignition Temperature: Temperature at which a substance will spontaneously ignite without external ignition source.

Carbon Monoxide (CO): Colorless, odorless toxic gas produced by incomplete combustion.

Combustible Gas Indicator (CGI): Electronic device that detects presence of flammable gases.

Confined Space: Enclosed or partially enclosed space not designed for continuous occupancy with restricted entry/exit.

Explosive Range: Concentration range between LEL and UEL where gas-air mixture can ignite.

Internal Responsibility System (IRS): Workplace safety system where everyone shares responsibility.

LEL (Lower Explosive Limit): Minimum concentration of gas in air that will burn.

Lockout/Tagout (LOTO): Procedure to isolate energy sources during equipment service.

Mercaptan: Sulfur-containing odorant added to natural gas and propane for leak detection.

NIOSH: National Institute for Occupational Safety and Health (U.S. research organization).

Olfactory Fatigue: Reduced ability to detect odors after prolonged exposure.

PPE: Personal Protective Equipment - equipment worn to reduce exposure to hazards.

SDS: Safety Data Sheet - standardized document providing chemical hazard information.

UEL (Upper Explosive Limit): Maximum concentration of gas in air that will burn.

WHMIS: Workplace Hazardous Materials Information System - Canada's hazard communication standard.

End of Chapter 2

CHAPTER 3

Tools and Equipment

Learning Objectives

Upon completion of this chapter, students will be able to:

1. Identify and properly use hand tools common to gas fitting work
2. Select appropriate tools for specific tasks
3. Operate power tools safely and effectively
4. Use testing and measurement equipment accurately
5. Perform basic tool maintenance and calibration checks
6. Apply proper safety procedures for all tools and equipment
7. Select piping tools appropriate for different materials
8. Interpret measurements from test instruments
9. Maintain tools to ensure accuracy and longevity
10. Understand quality tool selection criteria

3.1 Hand Tools

Hand tools form the foundation of a gas technician's toolkit. Quality tools, properly maintained and correctly used, increase efficiency, safety, and work quality.

Wrenches

Pipe Wrenches (Stillson Wrenches)

The most essential tool for gas pipe work.

Description:

- Adjustable jaw with toothed gripping surfaces
- Angled jaw design for leverage
- Heel jaw (fixed) and hook jaw (adjustable)
- Available in multiple sizes

Common Sizes:

- 10" (250 mm) - Small piping, tight spaces
- 14" (350 mm) - General purpose, most common
- 18" (450 mm) - Larger pipe, more leverage
- 24" (600 mm) - Large commercial pipe
- 36" (900 mm) and larger - Industrial applications

Proper Use:

- Direction of force opens jaw (self-tightening)
- Always pull, never push when possible
- Use two wrenches on threaded joints (one to hold, one to turn)
- Adjust jaw tension properly (not too loose or too tight)
- Position wrench to maximize leverage
- Keep jaws parallel to pipe
- Use appropriate size (wrench should fit 2/3 of jaw on pipe)

Safety Considerations:

- Pulling reduces risk of injury if wrench slips
- If must push, use open palm
- Stand with stable footing
- Worn or damaged jaws can slip
- Don't extend with cheater bars (use larger wrench)
- Don't use on nuts or finished surfaces (will damage)

Maintenance:

- Clean jaws after use
- Light oil on moving parts
- Keep adjustment nut free
- Replace if jaws worn smooth
- Check for cracks in handle

Adjustable Wrenches (Crescent Wrenches)

Open-end wrench with adjustable jaw.

Common Sizes:

- 6" (150 mm)
- 8" (200 mm)
- 10" (250 mm)
- 12" (300 mm)

Proper Use:

- Turn adjustment to fit snugly
- Apply force to fixed jaw side
- Position jaw flush against flats
- Don't use if jaw loose
- Use for hex fittings, union nuts, flare nuts

Applications in Gas Work:

- Flare fittings
- Union nuts
- Gas valve packing nuts
- Regulator connections
- Meter connections

Basin Wrench

Specialized wrench for confined spaces.

Description:

- Long shaft (10-17")
- Pivoting jaw at end
- Spring-loaded gripper
- T-handle at top

Applications:

- Water heater connections in tight spaces
- Under-sink connections
- Any fitting in confined space
- Coupling nuts behind fixtures

Proper Use:

- Jaw pivots to grip in either direction
- Spring maintains grip
- Long handle provides access
- Limited torque capability

Strap Wrenches

Flexible strap for gripping round objects without damage.

Types:

- Rubber strap with metal handle

- Chain with handle
- Heavy-duty nylon strap

Applications:

- Chrome-plated pipe
- Plastic pipe (ABS, PVC where permitted)
- Fragile fittings
- Polished surfaces
- Removing filter canisters

Socket Sets and Ratchets

While primarily automotive tools, useful for gas work.

Common Uses:

- Gas valve operators
- Mounting bolts
- Control brackets
- Equipment assembly
- Appliance service

Types:

- Standard (imperial) - common in North America
- Metric - some imported equipment
- Deep sockets - for recessed nuts
- Universal joints - for angles

Key sizes for gas work:

- 7/16" (11mm) - common gas valve size
- 1/2" (13mm) - mounting bolts
- 9/16" (14mm) - larger valves
- 3/8" and 1/4" drive - most versatile

Box-End and Open-End Wrenches

Fixed-size wrenches for hex fittings.

When to Use:

- More torque than adjustable
- Better fit prevents rounding
- Two wrenches for unions

- Flare fitting assembly
- Critical torque applications

Combination Wrenches:

- Box end one side, open end other
- Same size both ends
- Most versatile

Torque Wrenches

Measure and limit applied torque.

Types:

- Click-type (most common)
- Beam-type
- Digital

Applications in Gas Work:

- Flare fittings (prevent over-tightening)
- Union connections
- Critical gas valve connections
- Manufacturer specifications

Common Torque Values:

- 1/4" flare: 10-12 ft-lbs
- 3/8" flare: 15-18 ft-lbs
- 1/2" flare: 25-30 ft-lbs
- 5/8" flare: 35-40 ft-lbs
- (Always verify manufacturer specifications)

Cutting Tools

Pipe Cutters (Wheel-Type)

Standard tool for cutting steel pipe.

Components:

- Cutting wheel (hardened steel)
- Pressure rollers (2 or 3)
- Adjustment knob
- Frame

Sizes:

- 1/8" to 2" (most common)
- Heavy-duty models to 4"
- Close-quarters models (short handle)

Proper Use:

1. Mark cut line on pipe
2. Open jaws and position cutter
3. Tighten until wheel contacts pipe firmly
4. Rotate cutter around pipe once
5. Tighten slightly (1/4 to 1/2 turn)
6. Continue rotating and tightening gradually
7. Don't over-tighten (damages wheel, deforms pipe)

Benefits:

- Clean, square cut
- No sparks (safe around gas)
- Minimal burr
- Quiet operation
- Works in confined spaces

Maintenance:

- Replace cutting wheel when dull
- Keep rollers clean
- Oil pivot points
- Don't drop (damages wheel)

Internal Pipe Reamer

Removes burr from inside of pipe after cutting.

Types:

- Cone-style (most common)
- Folding pocket style
- Spiral design

Importance:

- Burrs restrict gas flow
- Can catch debris
- Create turbulence

- Required for quality installation

Use:

- Insert and rotate after each cut
- Remove burr completely
- Don't over-ream (weakens pipe end)
- Clean shavings from pipe

Hacksaws

Backup cutting method or for materials pipe cutter can't handle.

Frame Types:

- Fixed frame
- Adjustable length
- Close-quarters (short)

Blade Specifications:

- 14, 18, 24, 32 teeth per inch (TPI)
- 18 TPI most versatile for pipe
- 24-32 TPI for thin wall tubing
- Bi-metal blades most durable

Proper Use:

- Install blade with teeth forward
- Tension blade properly
- Support pipe adequately
- Use steady, full-stroke cuts
- Let blade do the work
- Cuts on push stroke

When to Use:

- CSST or corrugated tubing (where cutting allowed)
- Plastic pipe (where permitted)
- Materials that damage pipe cutter wheels
- Where pipe cutter won't fit
- Emergency situations

Tubing Cutters

Smaller version for copper and thin-wall tubing.

Sizes:

- 1/8" to 1-1/8" common range
- Mini-cutters for tight spaces

Features:

- Smaller cutting wheel
- Built-in reamer (triangular point)
- Roller guide bearings

Applications:

- Copper tubing (where permitted for gas)
- Control tubing
- Sensing lines
- Small diameter piping

Threading Tools

Threading pipe is essential for black iron installations.

Pipe Threading Dies

Create external threads on pipe.

Components:

- Die head with cutting teeth
- Guide teeth (first threads)
- Cutting teeth (main threads)
- Sizing teeth (final pass)

Types:

- Drop-head dies (receding)
- Solid dies (fixed)
- Ratcheting dies

Thread Standards:

- NPT (National Pipe Taper) - standard for gas pipe
- NPTF (Fuel) - tighter tolerance, not required for gas
- Tapered 3/4" per foot
- Threads seal on taper, not thread bottom

Die Sizes:

- 1/8" through 2" in hand sets
- Larger sizes machine-powered

Stocks and Handles

Hold dies and provide leverage.

Types:

- Ratcheting stocks (most efficient)
- Solid stocks
- Power drive adapters

Sizes:

- Small stock: 1/8" to 1/2"
- Medium stock: 1/2" to 1-1/4"
- Large stock: 1-1/2" to 2"

Proper Threading Procedure:

1. **Cut Pipe to Length**
   - Measure accurately
   - Cut square
   - Ream thoroughly
2. **Secure Pipe**
   - Use pipe vise
   - Adequate support
   - End close to vise (minimize deflection)
3. **Apply Cutting Oil**
   - Generously on die teeth
   - Continuously during threading
   - Threading oil, not motor oil
   - Lubricates and cools
4. **Start Die**
   - Align die square to pipe
   - Push firmly while turning
   - Die should bite and advance
   - If slipping, check die condition
5. **Thread Pipe**
   - Turn clockwise (standard right-hand thread)
   - Use steady pressure
   - Back off 1/4 turn periodically to break chips
   - Apply oil frequently

    - Thread until proper length
6. **Thread Length:**
    - Must engage fitting completely
    - Follow table in CSA B149.1
    - General guide: thread length = 1/2 to 2/3 of fitting depth
    - 1/2" pipe: approximately 10 threads
    - 3/4" pipe: approximately 10 threads
    - 1" pipe: approximately 10-11 threads
7. **Inspect Threads**
    - Clean threads
    - Check for damage
    - Threads should be sharp and clean
    - Test-fit in fitting (hand tight should start easily)

Threading Problems and Solutions:

Problem	Cause	Solution
Die won't start	Dull die, no oil, not square	Sharpen/replace die, add oil, realign
Threads rough	Insufficient oil, die worn	Add more oil, replace die
Threads taper wrong	Damaged die	Replace die
Threads galled	No oil, forcing	Use plenty of oil, reduce pressure
Pipe bends	Inadequate support	Better support, closer to vise

Die Maintenance:

- Clean after use
- Store in cases
- Oil lightly for storage
- Sharpen or replace when dull
- Keep guide teeth sharp (critical for starting)

Pipe Vises

Hold pipe securely for threading and assembly.

Types:

Chain Vise:

- Portable
- Mounts to table or stand
- Chain wraps around pipe
- Self-tightening
- Various chain lengths for different pipe sizes

Yoke Vise:

- Bench-mounted or stand
- Fixed or hinged design
- Very strong grip
- Best for threading
- Supports pipe well

Tripod Vise (Portable):

- Three-leg stand
- Chain vise at top
- Portable for field work
- Less stable than fixed vise
- Adequate for small pipe

Proper Use:

- Secure pipe near working end
- Jaws/chain tight enough to prevent rotation
- Don't over-tighten (can damage pipe)
- Support long pipe sections
- Vise at comfortable working height

Flaring and Swaging Tools

Used for copper tubing connections (where permitted for gas).

Flaring Tool

Creates a 45° flare on tubing end for flare fittings.

Components:

- Flaring bar (clamp)
- Flaring cone
- Screw mechanism

Procedure:

1. Cut tubing square
2. Ream inside and outside
3. Slide flare nut on tubing
4. Clamp tubing in bar (extends slightly above)
5. Center cone over tubing
6. Turn screw to form flare

7. Check for cracks or unevenness
8. Lubricate flare before assembly

Quality Flare Characteristics:

- Smooth, even surface
- No cracks
- Proper angle (45°)
- Concentric to tubing

Common Problems:

- Uneven flare - tubing not perpendicular in bar
- Cracked flare - over-formed or dirty tubing
- Rough surface - insufficient reaming or dirty cone

Swaging Tool

Expands tube end to accept another tube.

Types:

- Punch-type (hammer-driven)
- Lever-type
- Hydraulic

Use in Gas Work:

- Limited applications
- Some older systems
- Generally not used in modern installations

Tube Bending Tools

Hand Benders (Lever-Type)

Create smooth bends without kinking tubing.

Sizes:

- 1/4", 3/8", 1/2", 5/8" common
- Specific to tubing size

Proper Use:

- Mark bend location

- Insert tubing fully in bender
- Make bend slowly and smoothly
- Don't exceed minimum bend radius
- Check for kinks or flattening

Minimum Bend Radius:

- 1/4": 2"
- 3/8": 3"
- 1/2": 4"
- 5/8": 5" (Generally 6-8 times tube diameter)

Spring-Type Benders

Flexible spring slips over tubing to prevent kinking.

Use:

- Gentle bends
- Small tubing
- Limited control
- Better for soft copper

Applications:

- Control tubing
- Thermocouple leads
- Small sensing lines

Measuring and Layout Tools

Tape Measures

Essential for all measurements.

Sizes:

- 25' (7.6m) most common
- 16' (4.9m) convenient carry
- 35' (10.6m) for longer runs

Features:

- Metric and imperial markings
- Locking mechanism
- Belt clip

- Magnetic tip (some models)

Reading Measurements:

- To nearest 1/16" typically
- Metric to nearest mm
- Account for hook at end (moves to compensate for inside/outside measurement)

Proper Use:

- Hook securely on edge
- Keep tape flat and straight
- Read perpendicular to tape
- For inside measurements, add case width if printed on case
- Don't drop (damages return spring and hook)

Levels

Ensure proper pipe slope and appliance installation.

Types:

Torpedo Level (9-12"):

- Compact
- Magnetic models stick to pipe
- Most versatile for gas work
- 3 vials (level, plumb, 45°)

Box Level (24-48"):

- Longer span for accuracy
- Check appliance level
- Verify long pipe runs
- More accurate over distance

Digital Levels:

- Electronic reading
- Displays degree of slope
- More expensive
- Batteries required

Proper Use:

- Clean surface before placing

- Read bubble centered in vials
- Check calibration periodically
- Protect from damage (vials fragile)

Squares

Check and mark right angles.

Types:

- Combination square (most versatile)
- Speed square (rafting square)
- Try square

Uses:

- Mark cut lines
- Check square cuts
- Layout offsets
- Mark angles

Chalk Lines

Mark long straight lines.

Use:

- Layout pipe runs
- Mark support locations
- Straight reference lines
- Wall and ceiling marks

Markers and Pencils

- Carpenter's pencils (don't roll)
- Soapstone markers (metal)
- Permanent markers (plastic)
- Silver markers (dark surfaces)

3.2 Power Tools

Power tools increase efficiency but require additional safety considerations and training.

Drills

Corded Drills

Constant power for demanding applications.

Advantages:

- Unlimited runtime
- More power than battery
- Consistent torque
- Lower cost

Disadvantages:

- Requires electrical outlet
- Cord management
- Limited mobility
- GFCI protection required in damp locations

Battery-Powered Drills

Most common for service work.

Advantages:

- Portability
- No cord management
- Safer in damp locations
- Quick setup

Disadvantages:

- Limited runtime
- Battery weight
- Battery replacement cost
- Power decreases as battery depletes

Voltage and Power:

- 12V - Light duty, compact
- 18V - Standard for most work
- 20V - Heavy duty (note: marketing voltage, 18V nominal)

Features:

Clutch Settings:

- Numbered settings (1-20 typical)
- Limit torque to prevent over-driving screws
- Drill setting for full power
- Use appropriate setting for task

Two-Speed Gearbox:

- Low speed/high torque (0-400 RPM)
- High speed/low torque (0-1500 RPM)
- Select based on application

Chuck Size:

- 3/8" adequate for most gas work
- 1/2" for larger bits and heavy duty
- Keyless chucks most convenient
- Metal chuck more durable than plastic

Safety:

- Remove chuck key before starting (keyed chucks)
- Secure work piece
- Don't wear gloves (can catch)
- Maintain balance
- Eye protection required
- Keep cord clear of bit

Common Applications:

- Drilling pilot holes
- Mounting brackets
- Installing appliances
- Driving screws
- Mixing (with paddle attachment)

Drill Bits:

Twist Bits:

- General purpose
- Metal, wood, plastic
- High-speed steel (HSS) for metal
- Titanium-coated for longer life
- Cobalt for hard metals

Masonry Bits:

- Carbide tip
- For concrete, brick, block
- Use hammer drill mode if available
- Keep cool, withdraw frequently

Spade Bits:

- Flat blade for wood
- Quick rough holes
- Sizes 1/4" to 1-1/2"
- Not for metal

Hole Saws:

- Cut large diameter holes
- Arbor with pilot bit
- Various diameters
- For gas line penetrations
- Wood and metal versions

Step Bits (Unibit):

- Cone-shaped, stepped
- Multiple diameters in one bit
- Excellent for sheet metal
- Self-starting
- More expensive but versatile

Reciprocating Saws (Sawzalls)

Versatile cutting for demolition and rough work.

Uses in Gas Work:

- Cutting out old equipment
- Demo work
- Access holes
- Cutting steel (with proper blade)
- Emergency repairs

Blades:

- Metal cutting (bi-metal, 18-24 TPI)
- Wood cutting (6-10 TPI)
- Demo blades (mixed materials)
- Match blade to material

Safety:

- Maintain firm grip (vibration)
- Let blade stop before setting down
- Keep blade clear of body
- Check for utilities before cutting
- Eye protection essential
- Hearing protection recommended

Threading Machines

Power threading for larger production or commercial work.

Types:

Portable Threaders:

- RIDGID 300 series common
- Thread 1/8" to 2"
- Transportable to job site
- Oiler system

Stationary Machines:

- Shop installations
- Larger capacities
- Better support
- Higher production

Components:

- Drive motor
- Chuck (pipe grip)
- Die head
- Oiling system
- Reamer

Operation:

1. **Secure Pipe:**
    - Insert in chuck
    - Tighten firmly
    - Support long sections
2. **Select Die:**
    - Correct size for pipe
    - Install per manufacturer

    - Check die condition
3. **Set Up Oiler:**
    - Fill with threading oil
    - Adjust flow rate
    - Aim at die head
4. **Thread:**
    - Start machine
    - Engage die head
    - Monitor progress
    - Machine stops at proper length automatically (if equipped)
    - Or count turns for manual machine
5. **Retract and Shut Down:**
    - Open die head
    - Reverse to clear
    - Stop machine
    - Remove pipe

Safety:

- Training required before use
- Guards in place
- Loose clothing secured
- No gloves
- Eye protection
- Hearing protection
- Emergency stop accessible
- Proper electrical grounding

Grinders

Angle Grinders (4-1/2" most common)

Uses:

- Cutting steel
- Grinding welds (if welding done)
- Removing rust
- Sharpening tools
- Cutting bolts

Discs:

- Cutting discs (thin, reinforced)
- Grinding discs (thicker)
- Wire wheels (rust removal)
- Match to material and task

Safety:

- Most dangerous portable power tool
- Face shield required (plus safety glasses)
- Hearing protection
- Gloves for grip (but aware of catch hazard)
- Secure work piece
- Keep disc guard in place
- Check disc for cracks before use
- Don't exceed rated RPM
- Sparks fly long distance (fire hazard)
- Extreme kickback potential

When to Use in Gas Work:

- Limited applications
- Cutting in demolition
- Emergency situations
- Generally avoid if possible

Hammer Drills

Combines rotation with hammering action.

Use:

- Drilling masonry
- Installing anchors
- Concrete penetrations
- Service line entry

Types:

- Regular hammer drill (light duty)
- Rotary hammer (heavy duty, larger holes)
- SDS bits and chucks (heavier models)

Proper Use:

- Hammer mode for masonry only
- Drill mode for metal and wood
- Let tool do work (don't force)
- Withdraw frequently to clear dust
- Use proper bit type

3.3 Testing and Measurement Equipment

Accurate testing and measurement are critical for safety, code compliance, and proper system operation.

Manometers

Measure gas pressure and draft.

Types:

U-Tube Manometer (Water Column)

Traditional liquid-filled manometer.

Construction:

- Clear tube bent in U-shape
- Filled with water or oil
- Scale marked in inches
- Reference marks at zero

Reading:

- Measures pressure difference
- One side to pressure, other to reference
- Read height difference
- Typically inches of water column ("W.C. or in. W.C.)

Range:

- 0-15" W.C. typical
- Suitable for low-pressure gas (< 14" W.C.)
- Not for high pressure

Advantages:

- Simple, reliable
- No batteries
- Accurate
- Low cost

Disadvantages:

- Breakable
- Water can spill

- Slower response
- Less convenient

Digital Manometer

Electronic pressure measurement.

Features:

- LCD display
- Multiple pressure units (in. W.C., PSI, kPa, mbar)
- Auto-ranging
- Hold function
- Min/max recording
- Backlight
- Data logging (some models)

Ranges:

- Dual range typical
- Low: 0-60" W.C.
- High: 0-35 PSI (some models higher)
- Select appropriate range for measurement

Advantages:

- Durable
- Fast response
- Easy to read
- Records data
- Multiple measurements

Disadvantages:

- Requires batteries
- More expensive
- Can drift (requires calibration)
- Electronic failure possible

Common Measurements:

Manifold Pressure:

- Gas pressure at appliance
- Natural gas: typically 3.5" W.C.
- Propane: typically 10" W.C.

- Verify in appliance specifications

Inlet Pressure (Supply Pressure):

- Pressure entering appliance or building
- Natural gas: typically 5-7" W.C.
- Propane (residential dwelling): typically 11" W.C.
- Propane (mobile home): typically 13" W.C.
- Propane 1st stage outlet (where 2-stage): typically 10 PSI

Regulator Lock-Up:

- Maximum pressure when no flow
- Should not exceed rating
- Test per CSA B149.1

Draft:

- Negative pressure in vent
- Induced draft: -0.01 to -0.10" W.C.
- Natural draft: -0.02 to -0.04" W.C.

Using a Manometer:

1. **Select Appropriate Range/Port:**
   - Low range for "W.C. measurements
   - High range for PSI measurements
2. **Connect Hose:**
   - Secure to port
   - Other end to pressure point
   - Use probe or adapters as needed
3. **Zero (Digital):**
   - Both ports open to atmosphere
   - Zero or tare function
   - Verify zero reading
4. **Take Measurement:**
   - Connect to pressure source
   - Allow stabilization
   - Read display
   - Record reading
5. **Safety:**
   - Don't exceed range
   - Watch for leaks at connections
   - Relieve pressure before disconnecting
   - Follow manufacturer procedures

Maintenance:

- Calibrate annually (digital)
- Replace batteries as needed
- Protect from impact
- Store in case
- Keep clean and dry
- Check hoses for leaks

Pressure Gauges

Measure higher pressures.

Types:

Bourdon Tube Gauges:

- Mechanical, no power required
- Curved tube straightens under pressure
- Moves pointer via linkage
- Various ranges available

Common Ranges for Gas Work:

- 0-15 PSI (propane first stage, test pressure)
- 0-30 PSI (test gauge)
- 0-100 PSI (high-pressure systems)

Test Gauge:

- High accuracy (1% or better)
- Used for pressure testing
- Calibrated regularly
- Large dial for precision
- Often 0-30 or 0-60 PSI

Accuracy Classes:

- Grade A: ±1% (test instruments)
- Grade B: ±2% (general use)
- Grade C: ±3-4% (indication only)

Using Pressure Gauges:

- Select appropriate range (reading in middle third most accurate)
- Install per manufacturer (typically vertical)

- Check for damage before use
- Isolate before removing
- Don't exceed range
- Calibrate periodically

Multimeters (Digital Multimeter - DMM)

Measure electrical properties.

Functions:

Voltage (V):

- AC voltage (VAC) - household power
- DC voltage (VDC) - batteries, control circuits
- Ranges: typically 0-600V

Current (A):

- AC and DC current
- milliamps (mA) for control circuits
- Amps for loads
- Usually requires different meter connection

Resistance (Ω):

- Ohms
- Tests continuity
- Checks components
- Must de-energize circuit

Continuity:

- Beeps when resistance low
- Tests for complete circuit
- Quick testing
- Wire and switch testing

Features to Look For:

- Auto-ranging (selects scale automatically)
- Backlit display
- Hold function
- Min/max recording
- True RMS (for AC measurements with variable frequency)
- CAT rating (safety for voltage level)

CAT Ratings (Safety):

- CAT I: Low voltage, protected circuits
- CAT II: Outlets and appliances (residential gas work)
- CAT III: Distribution panels
- CAT IV: Service entrance

Common Uses in Gas Work:

Testing Voltage:

- 24VAC thermostat circuit
- 115VAC appliance power
- Transformer output
- Control board voltage

Testing Continuity:

- Limit switches
- Pressure switches
- Thermostat contacts
- Wiring connections
- Fuses

Testing Resistance:

- Igniter resistance (HSI typically 40-120 ohms)
- Thermocouple output (millivolts)
- Sensor circuits
- Ground continuity

Safe Use:

- Set correct function before connecting
- Start with highest range if manual ranging
- Connect black lead to common (COM)
- Red lead to appropriate jack
- Don't measure voltage with leads in current jacks
- Assume all circuits live until proven otherwise
- One hand operation in live panels
- Don't exceed meter ratings

Maintenance:

- Test against known voltage regularly
- Replace batteries when low

- Check test leads for damage
- Calibrate if accuracy questionable
- Store in case

Clamp Meters

Measure current without breaking circuit.

Function:

- Clamp around single conductor
- Measures current via magnetic field
- No electrical contact needed
- Safe and convenient

Types:

- AC only (most common, least expensive)
- AC/DC (more expensive)

Uses in Gas Work:

Motor Current:

- Blower motors
- Inducer motors
- Circulator pumps
- Compare to nameplate rating
- Diagnose motor problems

Total Current:

- Appliance amp draw
- Verify circuit capacity
- Diagnose electrical loads

Taking Measurements:

1. Set meter to AC amps
2. Select appropriate range
3. Clamp around ONE conductor only
4. Hot wire only (not neutral)
5. Center conductor in jaw
6. Read stabilized value

Common Measurements:

- Induced draft motor: 0.5-1.5 amps typical
- PSC blower motor: 3-8 amps typical
- ECM blower: 0.5-3 amps typical
- Igniter: 3-4 amps typical

Important Notes:

- Clamping both hot and neutral gives zero (cancels out)
- Must clamp only one conductor
- Accuracy decreases with small currents
- Position conductor in center of jaw

Combustion Analyzers

Essential for verifying proper combustion and carbon monoxide levels.

Functions:

Oxygen (O_2):

- Percentage in flue gas
- Indicates excess air
- Normal range: 5-9%

Carbon Dioxide (CO_2):

- Percentage in flue gas
- Indicates combustion completeness
- Natural gas: 8-10% typical
- Propane: 10-12% typical

Carbon Monoxide (CO):

- Parts per million (ppm)
- Air-free measurement (adjusted)
- CSA B149.1 limit: 100 ppm air-free
- Lower is better

Stack Temperature:

- Temperature of flue gases
- Indicates heat exchanger efficiency
- Used in efficiency calculations

Calculated Values:

- Efficiency (combustion efficiency)
- Excess air percentage
- Air-free CO (corrected for O_2)

Types:

Basic Analyzers:

- O_2 and CO sensors
- Stack temperature
- Calculate efficiency
- Print capability (some models)

Advanced Analyzers:

- Add CO_2 sensor
- Draft measurement
- Multiple probe capability
- Data logging
- Bluetooth connectivity
- More accurate

Sensor Types:

Electrochemical Cells:

- O_2, CO, and toxic gas sensors
- Limited lifespan (typically 2-3 years)
- Require periodic replacement
- Environmental conditions affect life
- Most accurate

NDIR (Non-Dispersive Infrared):

- CO_2 measurement
- Longer life
- More stable
- More expensive

Using a Combustion Analyzer:

Preparation:

1. Fresh air calibration (bump test)
2. Verify sensors within life
3. Install probe and sampling hose

4. Allow warm-up period

Measurement:

1. Insert probe in flue per manufacturer (typically 1-2 pipe diameters downstream of appliance)
2. Allow readings to stabilize (1-2 minutes)
3. Record all readings
4. Print or document
5. Interpret results

Acceptable Readings (General Guidelines):

- O_2: 5-9% (lower indicates less excess air, higher efficiency)
- CO: < 100 ppm air-free (CSA B149.1), ideally < 50 ppm
- CO_2: Natural gas 8-10%, Propane 10-12%
- Stack temp: Varies by appliance (typically 300-500°F for non-condensing)
- Efficiency: 78-83% non-condensing, 90-98% condensing

Common Problems Indicated:

High CO:

- Insufficient combustion air
- Improper burner adjustment
- Flame impingement
- Heat exchanger problems
- Venting problems

Low O_2 (High CO_2):

- Insufficient air
- Can cause high CO
- Incomplete combustion risk

High O_2 (Low CO_2):

- Excess air
- Lower efficiency
- Proper combustion but wasteful

Low Stack Temperature:

- Condensing in non-condensing appliance
- Vent sizing issues
- May indicate backdrafting

High Stack Temperature:

- Dirty heat exchanger
- Poor heat transfer
- Lower efficiency

Maintenance:

- Replace sensors per schedule
- Calibrate annually
- Fresh air bump test before each use
- Clean probe regularly
- Replace filters
- Store properly
- Protect from moisture

Documentation:

- Record readings on every service call
- Compare to baseline or previous readings
- Note any corrections made
- Provide copy to customer
- Maintain records per regulatory requirements

Gas Leak Detectors

Electronic detection of combustible gases.

Types:

Combustible Gas Indicator (CGI):

- Detects all combustible gases
- Displays as % LEL
- Not specific to natural gas or propane
- Most common type

Heated Diode (Semiconductor):

- Fast response
- Very sensitive
- Less expensive
- Responds to many gases (less specific)

Catalytic Bead:

- Burns gas on heated catalyst
- Measures temperature change
- Requires oxygen
- Can be "poisoned" by silicones

Infrared:

- Detects by light absorption
- Specific to hydrocarbon gases
- More stable
- More expensive
- No poisoning

Using Gas Detectors:

1. **Calibrate:**
    - Per manufacturer schedule
    - With known gas concentration
    - Document calibration
2. **Zero:**
    - In fresh air
    - Before each use
    - Verify zero reading
3. **Warm Up:**
    - Allow specified time
    - Typically 30-60 seconds
    - Critical for accuracy
4. **Survey:**
    - Move probe slowly (2-3 cm/sec)
    - Work systematically
    - Check all connections
    - Check from multiple angles
5. **Response:**
    - Audible alarm at preset level (typically 10-20% LEL)
    - Visual indication
    - Quantitative reading

Limitations:

- Other gases can trigger alarm (solvents, etc.)
- Require calibration and maintenance
- Sensors have limited life
- Wind and ventilation affect readings
- Not substitute for bubble test

Maintenance:

- Replace sensors per schedule
- Calibrate regularly
- Keep probe clean
- Protect from moisture
- Test functionality regularly
- Store properly

Thermometers

Types:

Dial Thermometers:

- Bi-metal coil
- No batteries
- Slower response
- Durable

Digital Thermometers:

- Fast response
- Easy to read
- Min/max functions
- Various probe types

Infrared Thermometers:

- Non-contact
- Surface temperature
- Laser pointer
- Quick spot checks

Pipe Thermometers:

- Clamp or strap to pipe
- Read surface temperature
- Boiler piping
- Temperature verification

Uses in Gas Work:

Temperature Rise (Furnace):

- Supply vs. return air temperature
- Verify proper operation
- Compare to rating plate

Boiler Supply Temperature:

- Verify control setpoints
- Check for overheating
- Aquastat function

Flue Temperature:

- Part of combustion analysis
- Efficiency indicator
- Verify proper operation

Ambient Temperature:

- Room conditions
- Combustion air temperature
- Documentation

Proper Use:

- Allow time for stabilization
- Shield from radiant heat (for air temp)
- Ensure probe contact (surface measurements)
- Calibrate periodically (check ice water = 32°F/0°C)

3.4 Specialized Gas Equipment

Purging Equipment

Purge Point Adapters:

- Install at pipe test points
- Allow controlled purging
- Various fitting sizes
- Hose connections

Purge Volume Calculation:

- 3 times system volume minimum
- CSA B149.1 requirements
- Verify complete purge

Vent Extensions:

- Direct purge gas outside safely
- Prevent indoor accumulation
- Extend purge point to exterior

Piping Tools and Accessories

Pipe Support Installation:

- Pipe strap cutters
- Ceiling anchor installation tools
- J-hook installation tools
- Clevis hanger tools

CSST Tools:

Cutters:

- Specific for CSST
- Clean, square cut
- Don't use standard pipe cutters

Strikers (Manifold Tools):

- Install fittings on CSST
- Compress fitting
- Manufacturer-specific tools
- Critical for proper installation

Bonding Clamps:

- Install grounding per code
- Proper electrical connection
- CSA B149.1 requirement
- Various sizes for different CSST

Polyethylene Pipe Tools:

Fusion Equipment:

- Heat plate
- Clamps and jigs
- Temperature control
- Cooling fixtures

Scraper:

- Clean pipe before fusion
- Remove oxidation
- Critical for proper joint

3.5 Tool Safety and Maintenance

General Tool Safety

Before Each Use:

- Inspect for damage
- Check operation
- Verify guards in place
- Test safety features
- Ensure proper accessories

During Use:

- Use for intended purpose only
- Maintain focus
- Keep work area clean
- Proper body position
- Adequate lighting
- Secure work piece
- Proper PPE

After Use:

- Clean tools
- Inspect for damage
- Store properly
- Report problems
- Charge batteries
- Organize storage

Power Tool Safety

Electrical:

- Inspect cords before use
- GFCI protection in damp areas
- Don't carry by cord
- Unplug before adjustments
- Three-prong or double-insulated

- Proper voltage

Battery Tools:

- Use manufacturer's batteries
- Charge per instructions
- Store batteries properly
- Don't short terminals
- Remove before adjustments
- Don't use damaged batteries

Guarding:

- Keep guards in place
- Don't disable safety features
- Replace missing guards
- Verify operation

Tool Maintenance

Hand Tools:

- Clean after use
- Light oil on metal
- Keep cutting edges sharp
- Tighten loose handles
- Replace damaged tools
- Proper storage (toolbox, organized)

Power Tools:

- Follow manufacturer maintenance schedule
- Keep air vents clear
- Lubricate per instructions
- Replace brushes (brushed motors)
- Inspect cords
- Professional repair for major issues

Testing Equipment:

Calibration:

- Manometers: annually
- Combustion analyzers: annually
- Gas detectors: per manufacturer (often 6 months)
- Test gauges: annually

- Multimeters: verify function regularly

Sensor Replacement:

- Combustion analyzer sensors: 2-3 years
- Gas detector sensors: per manufacturer
- Mark installation date
- Track hours of use
- Replace before end of life

Documentation:

- Calibration certificates
- Service records
- Sensor replacement dates
- Maintain equipment log

Tool Organization

Benefits:

- Save time
- Prevent loss
- Easier inventory
- More professional appearance
- Know what you have
- Identify missing tools

Methods:

Toolbox:

- Organized compartments
- Heavy items on bottom
- Frequently used items accessible
- Secure latches
- Weatherproof if outdoor use

Tool Bags:

- Lighter weight than toolbox
- Open-top access
- Multiple pockets
- Shoulder strap
- Canvas or nylon

Rolling Carts:

- Large capacity
- Organized drawers
- Mobile
- Locks
- Work surface
- Shop/van use

Shadow Boards:

- Wall-mounted
- Tool outline
- Quick visual inventory
- Shop organization
- Shows missing tools

Service Vehicles:

- Secure storage
- Organized shelving
- Parts inventory
- Equipment protection
- Accessible layout

Chapter Summary

Quality tools properly used and maintained are essential for professional gas work. Hand tools including wrenches, cutters, and threading equipment form the foundation of the gas fitter's toolkit. Power tools increase efficiency but require additional safety training and precautions.

Testing and measurement equipment ensures safe, code-compliant installations. Manometers measure gas pressure and draft, while combustion analyzers verify proper combustion and detect carbon monoxide. Multimeters and clamp meters diagnose electrical problems.

Proper tool maintenance includes regular cleaning, inspection, calibration, and documentation. Safety practices including inspection before use, appropriate PPE, and proper storage prevent injuries and extend tool life. Organized tool storage saves time, prevents loss, and presents a professional image.

Investment in quality tools pays dividends through better work quality, increased efficiency, fewer callbacks, and enhanced reputation. Understanding tool selection, use, and maintenance separates professional gas technicians from amateurs.

Review Questions

Multiple Choice

1. When using a pipe wrench, you should:
   - a) Always push the wrench
   - b) Always pull the wrench when possible
   - c) Use a cheater bar for more leverage
   - d) Tighten the jaw as tight as possible
2. The proper TPI (teeth per inch) for a hacksaw blade when cutting steel pipe is:
   - a) 14 TPI
   - b) 18 TPI
   - c) 24 TPI
   - d) 32 TPI
3. When threading pipe, you should:
   - a) Use motor oil as lubricant
   - b) Back off 1/4 turn periodically while threading
   - c) Thread continuously without stopping
   - d) Use maximum pressure to speed up threading
4. Digital manometers should be calibrated:
   - a) Weekly
   - b) Monthly
   - c) Annually
   - d) Only when they appear inaccurate
5. Natural gas manifold pressure is typically:
   - a) 3.5" W.C.
   - b) 7" W.C.
   - c) 11" W.C.
   - d) 5 PSI
6. When using a combustion analyzer, acceptable air-free CO for most appliances per CSA B149.1 is:
   - a) Under 35 ppm
   - b) Under 100 ppm
   - c) Under 200 ppm
   - d) Under 400 ppm
7. A clamp meter measures current by clamping around:
   - a) Both hot and neutral wires together
   - b) The ground wire only
   - c) A single conductor
   - d) The entire cable
8. Pipe threads per NPT standard taper:
   - a) 1/4" per foot
   - b) 1/2" per foot
   - c) 3/4" per foot

- d) 1" per foot

9. The most dangerous common portable power tool is:
    - a) Drill
    - b) Reciprocating saw
    - c) Angle grinder
    - d) Circular saw
10. Combustion analyzer sensors typically need replacement every:
    - a) 6 months
    - b) 1 year
    - c) 2-3 years
    - d) 5 years

True or False

11. A basin wrench is designed for working in tight spaces under sinks and fixtures.
12. You should use gloves when operating a threading machine.
13. Pipe thread compound should be applied to both male and female threads.
14. A manometer reading of 3.5" W.C. is the same as 0.125 PSI.
15. Flare fittings should be tightened to maximum torque without a torque wrench.

Short Answer

16. List four safety considerations when using an angle grinder. (4 marks)
17. Explain the proper procedure for threading 1/2" steel pipe. Include the steps from securing the pipe through inspecting the finished threads. (6 marks)
18. What is the difference between a catalytic bead sensor and an infrared sensor in gas detectors? (4 marks)
19. List the four primary measurements taken by a combustion analyzer and explain what each indicates. (8 marks)
20. Explain why threading oil is important and what problems occur when it is not used properly. (4 marks)

Long Answer

21. You are setting up a job to install 50 feet of 3/4" black iron pipe in a commercial building. List all the tools and equipment you would need, organized by category (hand tools, power tools, testing equipment, etc.). Explain why each tool is necessary. (12 marks)
22. A combustion analyzer shows the following readings on a natural gas furnace: O_2 = 4%, CO = 250 ppm air-free, CO_2 = 11%, Stack temp = 425°F. Interpret these readings. What do they indicate about the furnace operation? What are the likely problems? What would you check or adjust? (12 marks)
23. Describe a complete tool maintenance program for a service technician's toolkit. Include daily, weekly, monthly, and annual tasks. Discuss calibration requirements for testing equipment and how to document maintenance activities. (15 marks)

Practical Exercises

Exercise 1: Tool Identification

Instructor provides 20 common gas fitting tools. Students must:

1. Identify each tool by name
2. State primary use
3. Identify safety considerations
4. Demonstrate proper use (selected tools)

Exercise 2: Pipe Threading

Under supervision, students will:

1. Cut pipe to specified length
2. Ream pipe end
3. Secure in vise
4. Thread pipe to proper length
5. Inspect threads
6. Document thread count and quality
7. Test-fit in coupling

Exercise 3: Manometer Use

Students will:

1. Set up digital manometer
2. Perform zero calibration
3. Measure manifold pressure on test appliance
4. Measure inlet pressure
5. Calculate pressure drop
6. Document all readings
7. Compare to specifications

Exercise 4: Combustion Analysis

On operating appliance, students will:

1. Set up combustion analyzer
2. Perform fresh air calibration
3. Insert probe properly
4. Record all measurements

5. Interpret readings
6. Determine if appliance within specifications
7. Document findings with printed results

Exercise 5: Electrical Testing

Using multimeter on trainer or de-energized equipment:

1. Measure voltage (AC and DC)
2. Test continuity on switches
3. Measure resistance of components
4. Identify proper meter settings
5. Practice safe procedures
6. Document findings

Exercise 6: Gas Leak Detection

On test piping system with known leak:

1. Use electronic gas detector to locate general area
2. Use soap solution to pinpoint exact leak location
3. Document leak location
4. Estimate leak severity
5. Recommend repair method

Case Studies

Case Study 1: The Wrong Tool

Scenario: An apprentice is asked to tighten a flare nut on a water heater gas connection. Unable to find an appropriate wrench, he uses a pipe wrench. The fitting is damaged, begins leaking, and must be replaced.

Questions:

1. What tool should have been used?
2. Why is a pipe wrench inappropriate for this application?
3. What damage likely occurred?
4. What safety risks were created?
5. What is the proper way to tighten flare fittings?
6. How could this situation have been prevented?

Case Study 2: Combustion Testing Reveals Problems

Scenario: During annual maintenance, you perform combustion testing on a 10-year-old induced draft furnace. Your combustion analyzer shows: O_2 = 11%, CO = 450 ppm air-free, CO_2 = 6%, Stack temp = 525°F. The customer mentions they've had frequent headaches this winter.

Questions:

1. What do these readings indicate?
2. Is this an emergency situation?
3. What are the immediate actions required?
4. What are the likely causes of these readings?
5. What diagnostic steps would you perform?
6. What would you tell the customer?
7. What documentation is required?
8. Could the headaches be related? How?

Case Study 3: Calibration Matters

Scenario: A technician uses his manometer to test manifold pressure on a furnace. The reading shows 4.2" W.C., which seems high. He adjusts the gas valve down to 3.5" W.C. The furnace now operates poorly with incomplete combustion. He learns later that his manometer has been reading 0.7" W.C. high due to lack of calibration.

Questions:

1. What was the actual manifold pressure before adjustment?
2. What is it after adjustment?
3. What problems will this cause?
4. How often should manometers be calibrated?
5. How can you verify a manometer is reading correctly?
6. What are the consequences of inaccurate testing equipment?
7. Who is liable for problems caused by this error?

Case Study 4: Threading Machine Accident

Scenario: An experienced technician is threading 1" pipe on a power threading machine. His loose shirt sleeve catches on the rotating chuck. He attempts to pull free but is drawn toward the machine. A co-worker hits the emergency stop before serious injury occurs.

Questions:

1. What safety rules were violated?
2. What injuries could have occurred?
3. What is proper attire for threading machine operation?
4. What other safety features should be present?
5. What should happen after this incident?
6. How could this be prevented in future?

7. What training should be provided?

Case Study 5: Tool Investment Decision

Scenario: A newly licensed G2 technician is starting service work for a large company. The employer provides a service van and major testing equipment but expects the technician to provide personal hand tools. The technician must decide between:

- Option A: Budget tool set ($500) - basic tools, lower quality, 1-year warranty
- Option B: Professional tool set ($2,000) - high quality, lifetime warranty, complete selection
- Option C: Build gradually - Buy tools as needed over first year

Questions:

1. What are the advantages and disadvantages of each option?
2. What tools are absolutely essential to start?
3. What tools can wait?
4. How does tool quality affect work quality and efficiency?
5. What is the true cost of cheap tools?
6. What would you recommend and why?
7. What financing options might be available?

Key Terms

Basin Wrench: Specialized wrench with long shaft and pivoting jaw for tight spaces.

Bourdon Tube: Curved tube that straightens under pressure, used in mechanical pressure gauges.

CAT Rating: Safety category rating for electrical test equipment indicating voltage level safely measured.

Chuck: Gripping device on drill or threading machine that holds bit or pipe.

Combustion Analyzer: Electronic device measuring flue gas composition and calculating efficiency.

Die: Cutting tool that creates external threads on pipe.

Electrochemical Sensor: Chemical cell that generates electrical signal in presence of specific gas.

Flaring Tool: Tool that creates 45° flare on tube end for flare fittings.

LEL (Lower Explosive Limit): Minimum gas concentration that will ignite (natural gas 5%, propane 2.1%).

Manometer: Device for measuring gas pressure, typically in inches of water column.

NPT (National Pipe Taper): Standard tapered pipe thread used in North America (3/4" per foot taper).

Pipe Wrench: Adjustable wrench with toothed jaws for gripping pipe.

Reamer: Tool that removes burrs from inside of cut pipe.

Stock: Handle that holds threading die and provides leverage.

Threading Oil: Specialized lubricant for cutting threads, provides cooling and lubrication.

Torque Wrench: Wrench that measures and limits applied torque.

TPI (Teeth Per Inch): Measurement of hacksaw blade tooth density (18 TPI common for pipe).

True RMS: Multimeter feature providing accurate AC measurements with varying waveforms.

Water Column (W.C.): Pressure measurement unit; inches of water column height (natural gas typically 3.5" W.C.).

End of Chapter 3

CHAPTER 4

Properties of Natural Gas

Learning Objectives

Upon completion of this chapter, students will be able to:

1. Describe the chemical composition of natural gas and its components
2. Explain the physical properties of natural gas including specific gravity, heating value, and Wobbe Index
3. Apply basic gas laws to understand pressure-temperature-volume relationships
4. Distinguish between complete and incomplete combustion
5. Calculate air requirements for proper combustion
6. Understand primary and secondary air concepts
7. Identify products of combustion and their significance
8. Explain natural gas distribution systems in Canada
9. Describe odorization requirements and safety considerations
10. Compare environmental impacts of natural gas versus other fuels

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4.1 Composition and Characteristics

Chemical Composition

Natural gas is a fossil fuel formed over millions of years from decomposed organic matter under heat and pressure deep within the earth. It is found in underground rock formations, often associated with petroleum deposits.

Primary Component: Methane (CH_4)

Natural gas consists primarily of methane, the simplest hydrocarbon molecule containing one carbon atom and four hydrogen atoms.

Typical Composition of Natural Gas in Canada:

Component	Chemical Formula	Percentage (typical)
Methane	CH_4	85-98%
Ethane	C_2H_6	1-10%

Component	Chemical Formula	Percentage (typical)
Propane	C_3H_8	0-3%
Butane	C_4H_{10}	0-1%
Pentanes+	C_5H_{12}+	0-0.5%
Nitrogen	N_2	0-5%
Carbon Dioxide	CO_2	0-2%
Hydrogen Sulfide	H_2S	0-0.02%
Water Vapor	H_2O	trace

Regional Variations:

Natural gas composition varies by source and location across Canada:

Western Canada (Alberta, BC):

- High methane content (90-98%)
- Lower inert gases
- "Dry" gas (minimal heavier hydrocarbons)
- Consistent heating value

Eastern Canada:

- Some variation in composition
- May contain higher nitrogen content in some fields
- Generally consistent after processing

Processing:

Raw natural gas undergoes processing before distribution:

- Remove water vapor (prevents corrosion and freezing)
- Remove hydrogen sulfide (toxic "sour gas" to "sweet gas")
- Remove carbon dioxide (non-combustible)
- Extract heavier hydrocarbons (propane, butane for separate sale)
- Result: pipeline-quality "dry" natural gas

Hydrocarbons Series:

Understanding the hydrocarbon series helps explain natural gas properties:

- **Methane (CH_4):** 1 carbon, simplest
- **Ethane (C_2H_6):** 2 carbons
- **Propane (C_3H_8):** 3 carbons (LP gas)
- **Butane (C_4H_{10}):** 4 carbons (LP gas)

- **Pentane+ (C_5H_{12}+):** 5+ carbons (liquids)

As molecular size increases:

- Heating value per unit volume increases
- Boiling point increases
- Specific gravity increases
- Changes from gas to liquid at room temperature (butane+)

Physical Properties

State of Matter:

- Gas at standard temperature and pressure
- Remains gaseous at normal atmospheric conditions
- Does not liquefy unless extreme cold or high pressure

Color:

- Colorless in pure form
- No visual indication of presence
- Requires odorization for safety

Odor:

- Naturally odorless
- Mercaptan added for leak detection
- Distinctive "rotten egg" smell
- Odorant concentration: approximately 1 pound per 10,000 cubic feet

Toxicity:

- Non-toxic (methane itself not poisonous)
- Asphyxiant (displaces oxygen)
- Carbon monoxide produced by incomplete combustion is highly toxic
- Hydrogen sulfide (if present in raw gas) is extremely toxic

Flammability:

- Highly flammable within explosive range
- Lower Explosive Limit (LEL): 5% by volume in air
- Upper Explosive Limit (UEL): 15% by volume in air
- Auto-ignition temperature: 540°C (1,004°F)

Weight Relative to Air:

- Lighter than air
- Rises and disperses in open areas
- Can accumulate in enclosed spaces at ceiling level
- Important for leak detection and safety

4.2 Specific Gravity

Specific gravity compares the weight of a gas to the weight of an equal volume of air.

Definition: Specific gravity = Weight of gas / Weight of equal volume of air

Air = 1.0 (reference standard)

Natural Gas Specific Gravity: 0.60 to 0.70 (typically 0.60)

Interpretation:

- Natural gas is about 60% as heavy as air
- 0.60 specific gravity means natural gas weighs 60% of what air weighs
- Therefore, natural gas is lighter than air and rises

Why Specific Gravity Matters:

1. Buoyancy and Leak Behavior:

- Natural gas rises when released
- Accumulates at high points
- Disperses upward in open areas
- Ventilation considerations

2. Piping System Design:

- Affects pressure drop calculations
- Different from propane (which is heavier)
- Influences vent termination requirements

3. Orifice Sizing:

- Gas flow through orifices depends on specific gravity
- Conversion between natural gas and propane requires recalculation
- Affects appliance performance

4. Pressure Drop in Piping:

- Lighter gas = less pressure drop for same flow
- Piping sizing tables based on specific gravity
- Must correct calculations if actual specific gravity differs from table values

Calculating for Different Specific Gravity:

If piping tables assume specific gravity of 0.60 and actual gas is 0.65:

Correction Factor = $\sqrt{(0.60 / \text{Actual SG})}$

Example: CF = $\sqrt{(0.60 / 0.65)} = \sqrt{0.923} = 0.96$

Multiply table values by correction factor to get actual capacity.

Comparison to Other Gases:

Gas	Specific Gravity	Relative to Air
Natural Gas	0.60	Lighter - rises
Air	1.00	Reference
Propane	1.52	Heavier - sinks
Carbon Monoxide	0.97	Similar to air
Carbon Dioxide	1.52	Heavier - sinks

4.3 Heating Value

Heating value is the amount of heat energy released when gas burns completely.

Gross Heating Value vs. Net Heating Value

Gross Heating Value (Higher Heating Value - HHV):

- Total heat released including latent heat of water vapor condensation
- Assumes water vapor in combustion products condenses
- Used in Canada for rating gas appliances
- Higher number

Net Heating Value (Lower Heating Value - LHV):

- Heat available when water vapor remains as vapor
- Does not include latent heat
- Used in some countries
- Lower number (about 10% less than gross)

Canadian Standard: Gross (Higher) Heating Value

Units of Measurement

British Thermal Unit (BTU):

- Amount of heat to raise 1 pound of water 1°F
- Common in North America
- Natural gas rated in BTU per cubic foot

Joules and Megajoules (MJ):

- SI (metric) unit
- 1 BTU = 1.055 kJ
- 1 MJ = 948 BTU
- Some Canadian references use MJ

Common Usage:

- Appliance input ratings: BTU/hr or MBH (thousands of BTU/hr)
- Gas billing: cubic meters
- Heating value: BTU/cubic foot or MJ/m^3

Natural Gas Heating Value

Standard Heating Value:

- **1,000 BTU per cubic foot** (approximate, commonly used for calculations)
- Actual range: 950-1,150 BTU/ft^3
- Depends on composition

Metric:

- **37.3 MJ per cubic meter** (approximate)
- Range: 35-43 MJ/m^3

Regional Variations:

Western Canadian natural gas (high methane):

- 1,000-1,050 BTU/ft^3
- Higher heating value
- More consistent

Some eastern sources:

- May be slightly lower if higher inert content
- Generally standardized through blending

Why Heating Value Matters:

1. Appliance Input Rating:

- Determines appliance capacity
- Input (BTU/hr) = Flow rate (ft^3/hr) × Heating value (BTU/ft^3)
- Must match appliance requirements

2. Orifice Sizing:

- Orifice delivers specific heat input
- Based on heating value
- Different heating values require different orifice sizes

3. Billing:

- Utilities bill by volume (cubic meters or cubic feet)
- Energy content varies slightly
- Some utilities adjust billing for heating value

4. Efficiency Calculations:

- Output BTU / Input BTU = Efficiency
- Must use consistent heating value

Example Calculation:

A furnace rated 100,000 BTU/hr input:

- Heating value = 1,000 BTU/ft^3
- Gas flow required = 100,000 BTU/hr ÷ 1,000 BTU/ft^3 = 100 ft^3/hr

If heating value is actually 1,050 BTU/ft^3:

- Gas flow required = 100,000 ÷ 1,050 = 95.2 ft^3/hr
- Slightly less gas needed for same heat input

Heating Value of Components

Individual hydrocarbon heating values:

Component	Heating Value (BTU/ft^3)
Methane (CH_4)	1,013

Component	Heating Value (BTU/ft³)
Ethane (C_2H_6)	1,783
Propane (C_3H_8)	2,590
Butane (C_4H_{10})	3,373

Observation:

- Heavier hydrocarbons have higher heating values per unit volume
- Natural gas becomes "richer" with more heavier hydrocarbons
- Processing removes heavier components, making gas "leaner" but more consistent

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4.4 Wobbe Index

The Wobbe Index (or Wobbe Number) is a critical parameter for gas interchangeability.

Definition

Wobbe Index = Heating Value / √(Specific Gravity)

Purpose

The Wobbe Index determines whether different gas compositions will produce similar heat output through the same orifice at the same pressure.

Key Principle:

- Gases with similar Wobbe Index are interchangeable
- Appliances will produce similar heat output
- No adjustment needed to orifices or pressure

Why It Works:

- Heating value determines energy content
- Specific gravity affects flow rate through orifice
- The ratio predicts actual heat delivery

Calculation Example

Natural Gas:

- Heating Value: 1,000 BTU/ft³
- Specific Gravity: 0.60

- Wobbe Index = 1,000 / √0.60 = 1,000 / 0.775 = 1,291

Different Natural Gas Source:

- Heating Value: 1,050 BTU/ft³
- Specific Gravity: 0.64
- Wobbe Index = 1,050 / √0.64 = 1,050 / 0.800 = 1,312

Interpretation:

- Wobbe Index difference = 21 (1.6%)
- Very similar - gases are interchangeable
- No appliance adjustment needed
- Similar heat output through same orifice

Wobbe Index Ranges

Natural Gas in Canada:

- Typical range: 1,250-1,400
- Relatively consistent across country
- Utilities blend to maintain consistent Wobbe Index

Propane:

- Wobbe Index: approximately 2,100
- Much higher than natural gas
- NOT interchangeable without appliance conversion
- Different orifices required

Standard Tolerance:

- Utilities maintain Wobbe Index within ±4-5%
- Ensures appliances operate properly
- Prevents need for field adjustments

Practical Application

Gas Source Changes: When utility changes gas source or supplier:

- Check Wobbe Index compatibility
- If within acceptable range, no action needed
- If significantly different, appliances may need adjustment
- Utilities responsible for maintaining compatible gas

Blending: Utilities may blend gases from different sources:

- Maintain consistent Wobbe Index
- Mix lean gas with rich gas
- Add inert gases if needed
- Ensures customer appliances work properly

Appliance Certification:

- Appliances tested with specific Wobbe Index range
- Certified for natural gas meeting Canadian standards
- Important for imported appliances

4.5 Combustion Principles

Understanding combustion is fundamental to gas work. Proper combustion ensures safety, efficiency, and equipment longevity.

The Combustion Reaction

Complete Combustion of Methane:

$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O + \text{Heat}$

One molecule methane + Two molecules oxygen → One molecule carbon dioxide + Two molecules water + Heat energy

In Words: Methane combines with oxygen to produce carbon dioxide, water vapor, and heat.

Requirements for Combustion:

1. **Fuel** (natural gas/methane)
2. **Oxygen** (from air)
3. **Ignition source** (spark, pilot, hot surface)
4. **Proper mixture** (within flammable range)

Remove any element and combustion stops - this is the principle behind safety controls.

Stoichiometric Combustion

Stoichiometric combustion means perfect combustion with exactly the right amount of oxygen - no excess, no deficiency.

Theoretical Air Requirement:

For methane (CH_4):

- 2 molecules O_2 required per molecule CH_4
- Air is approximately 21% oxygen, 79% nitrogen
- Therefore need approximately 9.5 molecules of air per molecule CH_4

Volume Basis (practical calculation):

For complete combustion of 1 cubic foot of natural gas:

- **Theoretical air required: 9.5 cubic feet**
- This is the absolute minimum
- Real appliances require more (excess air)

Why Excess Air is Needed:

Perfect mixing impossible in practice:

- Some air doesn't contact fuel
- Flame temperature variations
- Physical limitations of burner design
- Safety margin

Typical Excess Air:

Appliance Type	Excess Air	Total Air/Fuel Ratio
Atmospheric burner	40-60%	13-15:1
Power burner	15-30%	11-12:1
Sealed combustion	30-50%	12-14:1

Example:

- Theoretical air: 9.5 ft^3
- 50% excess air: $9.5 \times 1.5 = 14.25$ ft^3
- Total air needed: 14.25 ft^3 per ft^3 of gas

Primary and Secondary Air

Gas burners use two air sources:

Primary Air:

- Mixed with gas BEFORE combustion
- Drawn through venturi by gas jet
- Creates air-gas mixture

- Amount controlled by air shutter
- Typically 40-60% of total air (atmospheric burners)

Secondary Air:

- Drawn into flame during combustion
- Comes from surrounding burner area
- Completes combustion
- No control mechanism
- Must be available from room/combustion air supply

Primary Air Adjustment:

Too Little Primary Air:

- Yellow, lazy flame
- Flame lifting possible
- Incomplete combustion
- Soot formation
- Carbon monoxide production
- Lower efficiency

Too Much Primary Air:

- Sharp blue flame
- Flame lifting (blows off ports)
- Noisy combustion (roaring)
- Flashback possible
- Cooler flame (heat loss)

Correct Primary Air:

- Stable blue flame
- Soft flame, not lifting
- Minimal yellow tipping
- Complete combustion
- Maximum efficiency

Power Burners:

- Fan forces air into combustion chamber
- Air and gas premixed
- Precise control of air-fuel ratio
- Higher efficiency possible
- Less dependent on secondary air
- Better combustion control

Complete vs. Incomplete Combustion

Complete Combustion:

$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$ + Heat

Products:

- Carbon dioxide (CO_2) - colorless, non-toxic gas
- Water vapor (H_2O) - condensation in flue
- Heat energy - useful output
- Nitrogen (from air) - passes through unchanged

Characteristics:

- Blue flame
- Maximum heat output
- Safe products
- No visible smoke or soot

Incomplete Combustion:

$2CH_4 + 3O_2 \rightarrow 2CO + 4H_2O$ + Heat (less heat than complete)

Or even less complete: $CH_4 + O_2 \rightarrow C + 2H_2O$ + Heat (even less heat)

Products:

- Carbon monoxide (CO) - highly toxic, colorless, odorless
- Free carbon (C) - soot, visible smoke
- Unburned hydrocarbons
- Water vapor
- Less heat released

Characteristics:

- Yellow or orange flame
- Visible smoke or soot
- Lower heat output
- Dangerous products

Causes of Incomplete Combustion:

1. **Insufficient Air:**
    - Blocked air intakes
    - Inadequate combustion air supply

    - Poor primary air adjustment
    - Negative building pressure
2. **Poor Mixing:**
    - Dirty burners
    - Improper burner adjustment
    - Damaged burner ports
    - Wrong orifice size
3. **Flame Quenching:**
    - Flame contact with cold surfaces
    - Heat exchanger too close to flame
    - Deposits on heat exchanger
4. **Excess Gas Pressure:**
    - Too much gas through orifice
    - Overwhelms available air
    - Rich mixture
5. **Venting Problems:**
    - Backdrafting
    - Products recirculate
    - Depletes oxygen

Carbon Monoxide Production:

Even small amounts of CO are dangerous:

- 35 ppm continuous exposure limit (CSA B149.1)
- 70 ppm causes headaches in 1-4 hours
- 400 ppm dangerous in 1 hour
- 1,600 ppm fatal in 20 minutes

This is why combustion testing is critical on every service call.

Flame Characteristics

Proper Flame (Natural Gas):

- Clear blue color
- Inner cone distinct
- Stable, not lifting
- Minimal yellow tips at outer edge
- Soft, quiet combustion
- No soot formation

Flame Zones:

1. **Primary Combustion Zone (inner cone):**
    - Light blue

    - Hottest part (1,980°C / 3,600°F for methane)
    - Primary air combustion
2. **Secondary Combustion Zone (outer mantle):**
    - Darker blue/purple
    - Secondary air completes combustion
    - Slightly cooler

Problem Flames:

Yellow Flame:

- Insufficient air
- Incomplete combustion
- Soot formation
- CO production
- Needs adjustment

Floating/Lifting Flame:

- Flame not on port
- Hovers above burner
- Excessive primary air
- Wrong orifice size
- Possible ignition failure

Flashback:

- Flame burns inside burner
- Excessive primary air
- Gas velocity too low
- Dangerous condition
- Shut off immediately

Impingement:

- Flame contacts surfaces
- Incomplete combustion
- CO production
- Equipment damage
- Misaligned burner or damaged heat exchanger

4.6 Products of Combustion

Understanding combustion products is essential for safety and proper venting.

Normal Products (Complete Combustion)

1. Carbon Dioxide (CO_2)

Properties:

- Colorless, odorless gas
- Non-toxic at low concentrations
- Heavier than air (SG = 1.52)
- Normal atmospheric level: 400 ppm (0.04%)

In Flue Gas:

- Natural gas: 8-10% CO_2 (complete combustion)
- Propane: 10-12% CO_2
- Higher CO_2 indicates better combustion (less excess air)
- Maximum practical: about 11-12% for natural gas

Significance:

- Indicates combustion efficiency
- High CO_2 = less excess air = higher efficiency
- Too high may indicate insufficient air
- Measured by combustion analyzer

2. Water Vapor (H_2O)

Properties:

- Colorless (visible as steam when condensed)
- Non-toxic
- Lighter than air as vapor

Quantity Produced:

- About 1 gallon of water per 100,000 BTU burned
- 100,000 BTU/hr furnace produces 1 gallon/hr
- Significant moisture load

Significance:

- Must be vented (prevents condensation damage)
- Condensing furnaces extract latent heat from water vapor
- Non-condensing vents must stay above dew point
- Source of "steam" visible from flues in cold weather

3. Nitrogen (N_2)

Properties:

- Inert gas
- Passes through combustion unchanged
- Makes up 79% of air

Significance:

- Dilutes combustion products
- No harmful effects
- Affects vent sizing (volume of products)

4. Heat Energy

- Useful output (approximately 1,000 BTU per ft^3 natural gas)
- Transferred to heat exchanger
- Remaining heat exits via flue

Harmful Products (Incomplete Combustion)

1. Carbon Monoxide (CO)

Properties:

- Colorless, odorless, tasteless
- Highly toxic
- Slightly lighter than air (SG = 0.97)
- Cannot be detected by human senses

Toxicity:

- Binds to hemoglobin 200-250 times more readily than oxygen
- Prevents oxygen transport in blood
- Accumulative effect
- Fatal at high concentrations
- Symptoms: headache, nausea, confusion, death

Acceptable Levels:

- Ambient air: 35 ppm maximum continuous (CSA B149.1)
- Flue gas: 100 ppm air-free maximum (most appliances)
- Lower is always better
- Goal: < 50 ppm in flue gas

Production:

- Any incomplete combustion
- Insufficient air
- Flame impingement
- Poor mixing
- Backdrafting

Prevention:

- Adequate combustion air
- Proper burner adjustment
- Clean heat exchangers
- Proper venting
- Regular maintenance
- Combustion testing

2. Soot (Free Carbon)

Properties:

- Fine black particles
- Unburned carbon
- Deposits on surfaces

Effects:

- Insulates heat exchanger (reduces efficiency)
- Blocks flue passages
- Dirty appearance
- Indicates combustion problems
- Often accompanies CO production

Causes:

- Insufficient air
- Improper adjustment
- Dirty burners
- Over-firing

3. Unburned Hydrocarbons

Properties:

- Organic compounds that didn't combust
- Can include methane, formaldehyde, others

- Some may be irritants

Significance:

- Indicates incomplete combustion
- Energy loss
- Potential health concerns
- Usually accompanies CO and soot

4. Nitrogen Oxides (NOx)

Properties:

- Formed at high combustion temperatures
- Includes NO and NO_2
- Respiratory irritants
- Contribute to smog formation

Significance:

- Environmental concern
- Low-NOx burners available
- Trade-off with efficiency
- Generally lower concern in residential equipment

5. Sulfur Dioxide (SO_2)

Properties:

- Produced if sulfur in fuel
- Highly corrosive
- Respiratory irritant
- Distinctive sharp odor

Significance:

- Modern natural gas highly desulfurized
- Primarily concern with oil or untreated gas
- Can corrode venting
- Minimal in Canadian natural gas

Measuring Combustion Products

Combustion Analyzer Measurements:

Oxygen (O_2):

- Indicates excess air
- Higher O_2 = more excess air
- Typical: 5-9%

Carbon Dioxide (CO_2):

- Indicates combustion completeness
- Higher CO_2 = less excess air (more efficient)
- Natural gas: 8-10%
- Propane: 10-12%

Carbon Monoxide (CO):

- Indicates incomplete combustion
- Measured in ppm
- Air-free reading (corrected for O_2)
- Must be < 100 ppm (ideally < 50 ppm)

Stack Temperature:

- Temperature of flue gases
- Indicates heat exchanger efficiency
- Used in efficiency calculations
- Typical: 300-500°F non-condensing

Calculated Efficiency:

- Based on O_2, stack temperature, ambient temperature
- Combustion efficiency (flue loss)
- Not same as AFUE (seasonal efficiency)

4.7 Natural Gas Distribution in Canada

Production and Processing

Major Production Regions:

Western Canada Sedimentary Basin:

- Alberta: largest producer (>70% of Canadian production)
- British Columbia: significant producer
- Saskatchewan: smaller production
- Conventional and unconventional sources

Other Regions:

- Nova Scotia: offshore production (Sable Island)
- Ontario: small production
- Newfoundland: offshore (Hibernia)
- Northwest Territories: potential development

Processing Steps:

1. **Extraction:**
    - Wells drilled to gas formations
    - Natural pressure drives gas to surface
    - Associated gas (with oil) or non-associated
2. **Field Separation:**
    - Remove water and condensate
    - Initial processing at wellhead
3. **Gas Processing Plant:**
    - Remove hydrogen sulfide (sweetening)
    - Remove CO_2
    - Remove water vapor (dehydration)
    - Extract natural gas liquids (ethane, propane, butane)
    - Result: pipeline-quality natural gas
4. **Compression:**
    - Increase pressure for transmission
    - Multiple compressor stations along pipeline

Transmission System

Transmission Pipelines:

High-Pressure Long-Distance:

- 400-1,000 PSI typical
- Large diameter (36-48" common)
- Carbon steel pipe
- Welded construction
- Cathodic protection against corrosion
- Right-of-way through rural areas

Major Canadian Pipelines:

- **TC Energy (formerly TransCanada):** Transcontinental system
- **Enbridge:** Ontario and Quebec
- **Alliance Pipeline:** Western Canada to US
- **Westcoast Energy:** BC system
- Many regional systems

Compressor Stations:

- Located every 60-100 km
- Maintain pressure along pipeline
- Gas turbine or electric motor driven
- Remote monitoring

Regulation:

- **National Energy Board (NEB):** Federal oversight
- Provincial regulators
- Safety standards
- Environmental protection

Distribution System

Pressure Reduction:

Gas pressure reduced in stages:

1. **Transmission Pressure:** 400-1,000 PSI
2. **High-Pressure Distribution:** 60-200 PSI
    - Steel pipe
    - Serves large loads
    - Industrial/commercial customers
    - Gate stations reduce from transmission pressure
3. **Medium-Pressure Distribution:** 15-60 PSI
    - Steel or polyethylene pipe
    - Residential and commercial areas
    - District regulator stations reduce pressure
4. **Low-Pressure Distribution:** 5-15 PSI (typical 7" W.C.)
    - Steel or PE pipe in street
    - Service regulators at each customer
    - Legacy systems in some older cities
5. **Customer Service Pressure:** 5-7" W.C. (typical)
    - Regulator at meter
    - Delivers gas at appliance pressure
    - Individual service line to building

Distribution Piping Materials:

Steel Pipe:

- Mains in streets
- Coated for corrosion protection
- Cathodic protection

- Legacy systems

Polyethylene (PE) Pipe:

- Modern standard for distribution
- Corrosion-proof
- Flexible
- Fused joints (no leaks)
- Yellow jacket for easy identification
- Depth requirements in CSA B149

Service Lines:

Connection to Main:

- Tap into distribution main
- Corporation stop or tapping valve
- Transition from PE to steel often at property line

Materials:

- PE pipe most common
- Steel if required by utility or code
- Must be traceable (yellow tracer wire if PE)

Installation:

- Minimum depth per code (typically 18" below frost line)
- Protected from damage
- Marked at surface
- Clear of other utilities

Utility Responsibilities vs. Customer Responsibilities

Utility Owns and Maintains:

- All mains
- Service line to meter (typically)
- Meter and regulator
- Emergency response
- Pressure maintenance

Customer Owns and Maintains:

- Piping downstream of meter
- All appliances

- Interior installations
- Must use licensed contractor for work

Meter Set:

- Transition point
- Service line enters
- Meter measures consumption
- Regulator reduces pressure
- Shut-off valve(s)
- Utility access required

4.8 Odorization

Natural gas is naturally odorless - odorization is required for safety.

Odorant Characteristics

Mercaptan (Methyl Mercaptan or Ethyl Mercaptan):

- Chemical formula: CH_3SH (methyl) or C_2H_5SH (ethyl)
- Sulfur-containing compound
- Extremely distinctive odor
- "Rotten egg" or "sulfur" smell
- Detectable at very low concentrations

Detection Threshold:

- Humans can detect at 1-2 parts per billion
- Well below LEL (50,000 ppm)
- Provides early warning
- Can smell gas long before dangerous concentration

Concentration:

- Approximately 1 pound per 10,000 cubic feet of gas
- Higher concentration in winter (gas more compressed)
- Sufficient to detect 1/5 of LEL

Odorization Requirements

CSA Z662 (Oil and Gas Pipeline Systems):

- Requires odorization of gas distributed to public
- Must be distinctive and unpleasant
- Detectable at 1/5 LEL (1% by volume for natural gas)

Purpose:

- Early leak detection
- Public safety
- Required by regulation

Injection Points:

- City gate stations (where gas enters distribution)
- Processing plants
- Automatically controlled
- Monitored for consistency

Odor Fade

Definition:

- Loss of odorant over time or conditions
- Gas becomes less odorous

Causes:

1. **Adsorption:**
    - Odorant absorbed by pipe walls
    - New pipe particularly susceptible
    - Rusty pipe
    - Condensate in pipe
2. **Oxidation:**
    - Odorant reacts with oxygen
    - Rust in pipe
    - Contamination
3. **Dilution:**
    - Mixing with unodorized gas
    - Air infiltration

Significance:

- Rare in modern systems
- Could delay leak detection
- More common in old systems
- PE pipe minimizes this issue

Industry Monitoring:

- Regular odor intensity tests
- Maintain adequate odorant levels
- Adjust injection rates as needed

Public Education

Utilities Promote:

- "Smell gas? Act fast!"
- Recognition of gas odor
- Proper response procedures
- Annual reminders
- Bill inserts

Some People Can't Smell:

- Olfactory impairment
- Medical conditions
- Smoking effects
- Age-related changes
- Cannot rely solely on odor

This is why:

- Electronic detection needed professionally
- CO alarms supplement but don't detect gas
- Multiple safety layers important
- Education on other signs (hissing, dead vegetation, etc.)

4.9 Environmental Considerations

Greenhouse Gas Emissions

Carbon Dioxide (CO_2) Production:

Complete combustion of methane:

- Produces CO_2 and H_2O
- 117 pounds CO_2 per million BTU (approximately)
- Lower than coal or oil per unit energy
- Still contributes to greenhouse gas emissions

Methane (CH_4) as Greenhouse Gas:

- Potent greenhouse gas (25-30x more potent than CO_2 over 100 years)
- Leaks from production, transmission, distribution
- Industry efforts to minimize fugitive emissions
- Pipeline maintenance
- Leak detection programs

Natural Gas vs. Other Fuels

CO_2 Emissions Comparison (per million BTU):

Fuel	CO_2 Produced (lbs)	Relative
Coal	220	100% (highest)
Oil	160	73%
Natural Gas	117	53% (cleanest fossil fuel)

Other Emissions:

- Lower sulfur oxides (SOx) than oil or coal
- Lower nitrogen oxides (NOx) than oil or coal
- Lower particulate matter
- No ash or solid waste

Efficiency Advantage:

- Modern gas furnaces: 90-98% efficient
- Modern boilers: 85-95% efficient
- Combined cycle power generation: up to 60% efficient
- Less waste = fewer emissions per useful energy

Environmental Benefits

Compared to Other Fossil Fuels:

- Cleanest burning fossil fuel
- No on-site storage (no spill risk)
- No soot or ash disposal
- Reliable supply
- Efficient combustion

Air Quality:

- Minimal particulate emissions
- Lower smog precursors

- Reduced acid rain contribution
- Cleaner indoor air

Infrastructure:

- Underground distribution (minimal visual impact)
- Established pipeline network
- High safety record
- Efficient delivery system

Role in Energy Transition

Current Role:

- Reliable baseload energy
- Backup for renewable intermittency
- Heating in cold climates
- Industrial processes
- Electricity generation

Future Considerations:

- Bridge fuel during transition
- Renewable natural gas (RNG) potential
- Hydrogen blending research
- Carbon capture technology
- Continued infrastructure use

Renewable Natural Gas (RNG):

- Produced from organic waste
- Chemically identical to natural gas
- Can use existing infrastructure
- Reduces net greenhouse gas emissions
- Growing in Canada

4.10 Gas Quality Standards

Quality Specifications

Gas utilities must deliver gas meeting specifications:

Heating Value:

- Must fall within specified range
- Typically 950-1,100 BTU/ft^3
- Consistent heating value
- Appliances designed for range

Wobbe Index:

- Maintained within narrow range
- Ensures appliance compatibility
- ±4-5% typical tolerance

Pressure:

- Consistent delivery pressure
- 5-7" W.C. typical at customer meter
- Within appliance operating range

Contaminants:

- Minimal water vapor
- No hydrogen sulfide
- Low nitrogen and CO_2
- No solids or liquids

Dewpoint:

- Water dewpoint below ambient temperature
- Prevents condensation in pipes
- Prevents freezing
- Prevents corrosion

Monitoring and Testing

Utility Responsibilities:

- Regular gas quality testing
- Monitor heating value
- Check odorant levels
- Verify pressure delivery
- Respond to quality issues

Records:

- Maintain quality data
- Available to regulators
- Document variations

- Trend analysis

Customer Impact:

- Consistent appliance performance
- No field adjustments needed
- Appliance efficiency maintained
- Safety assured

Chapter Summary

Natural gas is primarily methane (CH_4) with small amounts of heavier hydrocarbons and inerts. Its physical properties include specific gravity of 0.60 (lighter than air), heating value of approximately 1,000 BTU/ft^3, and a Wobbe Index of 1,250-1,400. These properties determine appliance performance, piping requirements, and safety considerations.

Complete combustion requires proper air-fuel mixture producing carbon dioxide, water vapor, and heat. Incomplete combustion produces dangerous carbon monoxide, requiring adequate combustion air, proper burner adjustment, and effective venting. The stoichiometric air requirement is 9.5:1, with practical installations using 40-60% excess air.

Natural gas is distributed through extensive pipeline networks from western Canadian production to customers nationwide. Pressure is reduced in stages from transmission (400-1,000 PSI) to customer service (5-7" W.C.). Odorization with mercaptan provides leak detection, and quality standards ensure consistent appliance performance.

As the cleanest-burning fossil fuel, natural gas produces lower emissions than coal or oil. Modern high-efficiency equipment and proper combustion further reduce environmental impact. Understanding gas properties enables safe, efficient installations and effective troubleshooting.

Review Questions

Multiple Choice

1. The primary component of natural gas is:
   - a) Propane
   - b) Ethane
   - c) Methane
   - d) Butane
2. Natural gas has a specific gravity of approximately:
   - a) 0.60

- b) 1.00
- c) 1.52
- d) 2.00

3. The gross heating value of natural gas is approximately:
   - a) 500 BTU/ft^3
   - b) 1,000 BTU/ft^3
   - c) 2,500 BTU/ft^3
   - d) 5,000 BTU/ft^3
4. The Wobbe Index is calculated by:
   - a) Heating value × Specific gravity
   - b) Heating value ÷ Specific gravity
   - c) Heating value ÷ √(Specific gravity)
   - d) √(Heating value) ÷ Specific gravity

CHAPTER 5

Properties of Propane (LP Gas)

Learning Objectives

Upon completion of this chapter, students will be able to:

1. Describe the chemical composition and structure of propane
2. Explain the relationship between liquid and vapor states of propane
3. Understand vapor pressure and its relationship to temperature
4. Calculate vapor withdrawal rates for propane tanks
5. Compare propane properties to natural gas properties
6. Explain appliance conversion requirements between natural gas and propane
7. Understand propane storage requirements including the 80% fill rule
8. Describe DOT and TC cylinder specifications
9. Differentiate between single-stage and two-stage pressure regulation
10. Apply safety considerations specific to propane installations

---

5.1 Composition and Characteristics

Chemical Structure

Propane: C_3H_8

Propane is a three-carbon hydrocarbon molecule:

- 3 carbon atoms
- 8 hydrogen atoms
- Molecular weight: 44.1
- Member of the paraffin series (alkanes)
- Saturated hydrocarbon (single bonds only)

Structural Formula:

```
    H   H   H
    |   |   |
H - C - C - C - H
    |   |   |
    H   H   H
```

Three carbon atoms in a chain, each surrounded by hydrogen atoms.

LP Gas vs. Propane

LP Gas (Liquefied Petroleum Gas):

- Generic term for propane, butane, or mixtures
- In Canada and USA, "LP gas" typically means propane or propane-dominant mixtures
- Commercial propane may contain small amounts of other hydrocarbons

HD-5 Propane (Standard Grade):

- Minimum 90% propane
- Maximum 5% propylene (C_3H_6)
- Maximum 2.5% butane and heavier
- Remainder: ethane and lighter
- Standard for appliance fuel in North America
- Consistent properties for equipment operation

Commercial Propane:

- May vary slightly in composition
- Still meets minimum standards
- Primarily propane with minor components

Propane vs. Butane:

Property	Propane (C_3H_8)	Butane (C_4H_{10})
Molecular Weight	44.1	58.1
Boiling Point	-42°F (-42°C)	32°F (0°C)
Vapor Pressure (70°F)	127 PSIG	17 PSIG
Use in Canada	Year-round	Limited (freezes in winter)

Why Propane in Canada:

- Low boiling point allows winter use
- Adequate vapor pressure in cold weather
- Butane unusable below freezing
- Propane standard for all seasons

Physical Properties

State at Normal Conditions:

- Liquid when under moderate pressure or refrigerated

- Gas when released to atmospheric pressure
- Transitions easily between states
- Stored as liquid, used as vapor

Color:

- Colorless as liquid
- Colorless as vapor
- No visual indication of presence

Odor:

- Naturally odorless (like natural gas)
- Ethyl mercaptan added as odorant
- Distinctive "rotten egg" smell
- Required for safety

Toxicity:

- Non-toxic (propane itself not poisonous)
- Asphyxiant (displaces oxygen)
- Anesthetic effect at high concentrations
- Carbon monoxide from incomplete combustion is highly toxic

Flammability:

- Highly flammable within explosive range
- Lower Explosive Limit (LEL): 2.1% by volume in air
- Upper Explosive Limit (UEL): 9.5% by volume in air
- Auto-ignition temperature: 920-1,020°F (493-549°C)
- Wider flammable range than natural gas (more easily explosive)

Weight Relative to Air:

- **Heavier than air**
- Specific gravity: 1.52 (vapor at 60°F)
- **Sinks and accumulates in low areas**
- Critical safety consideration
- Different behavior than natural gas

5.2 Liquid vs. Vapor States

Understanding propane's dual nature is fundamental to working with LP gas systems.

Liquid Propane Properties

Density:

- Liquid propane weighs approximately 4.24 lbs per gallon at 60°F
- Changes with temperature (expands when heated)
- Less dense than water (water = 8.34 lbs/gallon)
- Floats on water

Volume:

- 1 gallon of liquid = 36.39 cubic feet of vapor at 60°F
- Approximately 270:1 expansion ratio (liquid to vapor)
- Small liquid leak creates large vapor volume
- This is why propane is stored as liquid (efficiency)

Temperature Effects on Liquid:

- Liquid expands significantly when heated
- Approximately 1.5% volume increase per 10°F
- Must not completely fill containers (ullage space required)
- Pressure increases with temperature in closed container

Boiling Point:

- -42°F (-42°C) at atmospheric pressure
- Boiling point increases with pressure
- In pressurized tank, remains liquid above -42°F

Vapor Propane Properties

Specific Gravity (Vapor):

- 1.52 relative to air
- Heavier than air
- Sinks to lowest point
- Accumulates in basements, pits, low areas

Vapor Density:

- 0.1162 lbs per cubic foot at 60°F
- Air = 0.0765 lbs per cubic foot
- About 1.5 times heavier than air

Behavior:

- Released vapor sinks
- Flows like water seeking lowest level
- Does not readily disperse upward
- Can travel long distances at ground level
- Critical for leak response and ventilation

Heating Value (Vapor):

- Approximately 2,500 BTU per cubic foot of vapor
- About 2.5 times more than natural gas
- 91,500 BTU per gallon of liquid
- High energy density

Vaporization Process

How Liquid Becomes Vapor:

1. **Heat Absorption:**
   - Liquid propane absorbs heat from surroundings
   - Heat energy breaks molecular bonds
   - Molecules escape liquid surface as vapor
   - This is evaporation/vaporization
2. **Latent Heat of Vaporization:**
   - 184 BTU per pound required to vaporize propane
   - Heat must come from somewhere (air, ground, water)
   - Vaporization cools the remaining liquid
   - Tank surface may frost in high-demand situations
3. **Continuous Process:**
   - As vapor withdrawn, liquid vaporizes to replace it
   - Tank pressure maintained (if vaporization rate adequate)
   - Heat continuously absorbed from environment

Factors Affecting Vaporization Rate:

1. **Temperature:**
   - Warmer = faster vaporization
   - Colder = slower vaporization
   - Winter = reduced capacity
   - Critical in northern Canada
2. **Tank Surface Area:**
   - Larger surface = more vaporization
   - Liquid level affects surface area (less liquid = less surface)
   - Tank design affects capacity
   - Horizontal tanks better than vertical for vaporization
3. **Tank Size:**
   - Larger tanks have more surface area

    - But also store more liquid
    - Proper sizing critical
4. **Demand Rate:**
    - High demand may exceed vaporization rate
    - Causes pressure drop
    - May cause "freeze-up"
    - Requires proper tank sizing

Weathering:

- As propane vaporizes, heavier components remain
- Butane and heavier hydrocarbons stay liquid longer
- Over time, liquid becomes "heavier"
- Affects heating value and vapor pressure
- Eventually may not vaporize properly in cold weather
- Reason to refill rather than "use to empty"

5.3 Vapor Pressure and Temperature Relationships

Vapor pressure is the pressure exerted by propane vapor in a closed container.

Understanding Vapor Pressure

Definition:

- Pressure of vapor in equilibrium with liquid
- In closed tank, vapor and liquid coexist
- Pressure depends on temperature
- Independent of tank size (full or partially full)

Key Concept:

- Propane vapor pressure is ONLY dependent on temperature
- 10% full tank has same pressure as 90% full tank (at same temperature)
- Pressure gauge shows temperature, not quantity

Temperature-Pressure Relationship

Propane Vapor Pressure Table:

Temperature	Vapor Pressure	Temperature	Vapor Pressure
-40°F (-40°C)	5 PSIG	50°F (10°C)	71 PSIG
-30°F (-34°C)	9 PSIG	60°F (16°C)	91 PSIG

Temperature	Vapor Pressure	Temperature	Vapor Pressure
-20°F (-29°C)	14 PSIG	70°F (21°C)	112 PSIG
-10°F (-23°C)	20 PSIG	80°F (27°C)	135 PSIG
0°F (-18°C)	27 PSIG	90°F (32°C)	161 PSIG
10°F (-12°C)	35 PSIG	100°F (38°C)	189 PSIG
20°F (-7°C)	44 PSIG	110°F (43°C)	219 PSIG
30°F (-1°C)	54 PSIG	120°F (49°C)	252 PSIG
40°F (4°C)	66 PSIG	130°F (54°C)	287 PSIG

PSIG = Pounds per Square Inch Gauge (pressure above atmospheric)

Observations:

- Pressure increases rapidly with temperature
- Non-linear relationship (exponential)
- Approximately 10 PSI increase per 10°F rise
- At -42°F (boiling point), pressure = 0 PSIG
- At 130°F, pressure approaches 300 PSIG

Practical Implications

Winter Operation:

- Cold temperatures = lower pressure
- May be inadequate for appliance operation
- Vaporization rate reduced
- Tank may "freeze up" (frost formation)
- Larger tanks or vaporizers may be needed

Summer Operation:

- High temperatures = high pressure
- Increased vaporization
- Relief valve may operate if excessive
- Adequate capacity for demand

System Design:

- First-stage regulator inlet pressure varies with temperature
- Must design for coldest expected temperature
- Appliance regulators see constant pressure after regulation
- Second-stage typically delivers 11" W.C. (residential) or 13" W.C. (mobile home)

Safety Considerations:

- Pressure relief valve required on all tanks
- Typically set at 250-375 PSIG
- Vents if temperature causes excessive pressure
- Prevents tank rupture
- Never block or plug relief valve

Tank Pressure as Temperature Indicator:

- Gauge reading indicates approximate temperature
- Cannot determine liquid level from pressure
- Common misconception
- Use gauge or weight to determine quantity

5.4 Propane vs. Natural Gas

Understanding differences between propane and natural gas is essential for conversions and proper installations.

Property Comparison

Property	Natural Gas	Propane
Chemical Formula	CH_4 (primarily)	C_3H_8
Specific Gravity (vapor)	0.60	1.52
Heating Value	~1,000 BTU/ft³	~2,500 BTU/ft³
Wobbe Index	1,250-1,400	~2,100
Weight Relative to Air	Lighter (rises)	Heavier (sinks)
LEL	5%	2.1%
UEL	15%	9.5%
Auto-ignition Temp	1,004°F	920-1,020°F
Storage	Gas in pipes	Liquid in tanks
Supply Pressure (typical)	5-7" W.C.	11" W.C. (residential)
Manifold Pressure (typical)	3.5" W.C.	10" W.C.

Orifice Sizing Differences

Appliances require different orifices for natural gas vs. propane:

Why Different:

- Propane has 2.5× higher heating value
- Need less propane flow for same BTU input

- Smaller orifice required
- Specific gravity affects flow rate
- Wobbe Index difference is significant

Example: 40,000 BTU/hr Burner

Natural Gas:

- Flow needed: 40,000 BTU/hr ÷ 1,000 BTU/ft³ = 40 ft³/hr
- Larger orifice
- Lower pressure (3.5" W.C. manifold)

Propane:

- Flow needed: 40,000 BTU/hr ÷ 2,500 BTU/ft³ = 16 ft³/hr
- Smaller orifice (typically 60% of natural gas orifice size)
- Higher pressure (10" W.C. manifold)

Conversion Requirements:

- Change all orifices
- Adjust or change gas valve spring (for proper manifold pressure)
- Verify primary air adjustment
- Update appliance labeling
- Document conversion
- Some appliances have conversion kits; others not convertible

Drill Number Sizes:

- Natural gas orifice might be #42 drill (0.0935")
- Propane orifice might be #54 drill (0.0550")
- Always verify manufacturer specifications
- Never guess or estimate

Combustion Differences

Air Requirements:

Natural Gas:

- Stoichiometric: 9.5:1 (air:gas)
- Practical: 13-15:1 with excess air

Propane:

- Stoichiometric: 23.8:1 (air:gas)

- Practical: 30-35:1 with excess air
- Requires 2.5× more air per unit volume

Flame Characteristics:

Natural Gas:

- Blue flame
- Higher flame speed
- Less luminous

Propane:

- Blue flame with slight luminosity
- Slower flame speed
- May show slight yellow tipping (acceptable if minimal)
- Higher flame temperature potential

Products of Combustion:

Complete Combustion (Propane): $C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$ + Heat

Propane produces:

- More CO_2 per unit volume of fuel (3 molecules vs. 1 for methane)
- More water vapor (4 molecules vs. 2 for methane)
- More flue gas volume per unit fuel
- Slightly higher CO_2 percentage in ideal combustion (10-12% vs. 8-10%)

Venting Differences

Generally Similar Requirements:

- Same vent categories apply
- Same clearances
- Same sizing principles

Differences:

- Propane produces more flue gas per BTU input
- May require slightly larger vents (check tables)
- Same vent material specifications
- Higher water vapor production (more condensation in condensing appliances)

Safety Differences

Natural Gas:

- Lighter than air (rises)
- Disperses upward
- Accumulates at ceiling level
- Easier to ventilate

Propane:

- **Heavier than air (sinks) - CRITICAL**
- Flows to lowest point
- Accumulates in basements, pits, crawlspaces
- Harder to disperse
- Can travel long distances at ground level
- Greater explosion risk in confined low areas

Installation Implications:

- No propane tanks in below-grade areas
- No propane appliances in pits without special ventilation
- Floor drains may need sealing
- Ventilation must be from floor level (not ceiling)
- Leak response more critical

5.5 Propane Storage and Handling

Tank Types and Sizes

ASME Tanks (Stationary):

- Built to American Society of Mechanical Engineers code
- Permanent installation
- Above-ground or underground
- Various capacities

Common Residential Sizes:

- **120 gallon (420 lb):** Small homes, seasonal
- **250 gallon (880 lb):** Small homes, backup heat
- **500 gallon (1,760 lb):** Average home, primary heat
- **1,000 gallon (3,520 lb):** Large homes, high demand
- Larger for commercial/agricultural

Tank Capacity Ratings:

- "Water capacity" = total internal volume
- **NOT the usable propane capacity**
- Actual fill limited to 80% (discussed below)

Example: 500 Gallon Tank

- 500 gallons = water capacity
- 500 × 0.80 = 400 gallons maximum propane fill
- 400 gal × 4.24 lbs/gal = 1,696 lbs propane capacity

DOT/TC Cylinders (Portable):

- Department of Transportation (USA) or Transport Canada specifications
- Portable, movable
- Various sizes
- Must be transported upright
- Subject to re-certification requirements

Common Cylinder Sizes:

- **20 lb (5 gallon):** BBQ cylinders, most common
- **30 lb (7.5 gallon):** RVs, larger portable
- **40 lb (10 gallon):** Forklifts
- **100 lb (25 gallon):** Temporary construction heat
- Larger cylinders for special applications

Cylinder Markings (typical):

- DOT or TC specification (e.g., DOT-4BA240)
- Date of manufacture (month/year)
- Re-test date (every 10-12 years typically)
- Tare weight (empty weight)
- Water capacity
- Service pressure rating

The 80% Fill Rule

Propane expands significantly when heated. Tanks must have space for expansion.

Why 80%:

- Liquid propane expands about 1.5% per 10°F temperature rise
- From 0°F to 130°F = 19.5% expansion
- 80% fill allows adequate expansion space (20% ullage)
- Prevents overfilling
- Allows for pressure relief valve to handle temperature extremes

Maximum Fill (by weight):

For any container:

- Water capacity (gallons) × 4.24 lbs/gal × 0.80 = Maximum fill (lbs)

Example: 500 Gallon ASME Tank

- 500 gal × 4.24 lbs/gal × 0.80 = 1,696 lbs maximum
- Never exceed this amount
- Typically filled to 80% by volume or 42% by gauge

Fixed Liquid Level Gauge:

- Indicates when tank is 80% full
- Bleeder valve
- Opens when liquid reaches 80%
- Liquid (not vapor) sprays out when 80% reached
- Filling stops
- Required on all ASME tanks

Percentage Gauges:

- Dial gauge showing 0-100%
- Indicates liquid level
- Reading of 80% = full by volume
- Actually about 42% by weight (due to ullage space at top)
- Common on residential tanks

Overfill Prevention Device (OPD):

- Required on portable cylinders (DOT/TC)
- Prevents filling beyond 80%
- Triangular hand wheel identifies OPD valve
- Float mechanism inside valve
- Automatically stops fill at 80%

Consequences of Overfilling:

- No room for expansion
- Excessive pressure
- Relief valve operates
- Propane venting (waste and hazard)
- Potential tank damage
- Illegal and dangerous

Tank Installation Requirements (CSA B149.2)

Setback Distances (Minimum):

Distances from ASME tanks to buildings, property lines, and other features per CSA B149.2:

From Buildings:

- Water capacity < 2,000 L (530 gal): 3 meters (10 ft) minimum
- Larger tanks: Increased distances
- From doors, windows, and ventilation openings: minimum 3 meters
- From above-ground non-fireproof structure: minimum 3 meters

From Property Line:

- Minimum 3 meters (10 ft) to adjoining property
- Greater if larger tank
- Consider neighboring buildings

From Other Features:

- Sources of ignition: 3 meters minimum
- Air conditioning equipment: 3 meters
- Heat pumps: 3 meters
- Other propane containers: specified distances

Relief Valve Discharge:

- Must point vertically upward for above-ground
- Must terminate away from buildings
- Minimum heights specified
- Away from openings
- Unobstructed

Underground Installation:

- Minimum depth of cover
- Corrosion protection required
- Must be locatable
- Electrical bonding requirements
- Fill and gauge access above grade

Cylinder Storage:

- Outdoor only (except during use)
- Upright position

- Protected from tampering
- Away from heat sources
- Secure from falling
- Minimum distances from buildings

Tank Sizing Considerations

Factors in Sizing:

1. **Total Appliance Load:**
    - Sum of all appliance inputs (BTU/hr)
    - Consider simultaneous operation
    - Peak demand conditions
2. **Vaporization Capacity:**
    - Tank must vaporize enough propane to meet demand
    - Depends on tank size, surface area, and temperature
    - Critical in cold climates
3. **Refill Frequency:**
    - How often customer accepts delivery
    - Storage capacity between fills
    - Winter consumption higher than summer
4. **Ambient Temperature:**
    - Coldest expected temperature
    - Reduced vaporization in cold weather
    - May need larger tank or multiple tanks
5. **Delivery Access:**
    - Truck access
    - Hose reach
    - Terrain considerations

Vaporization Rates (Approximate):

BTU/hr continuous capacity at various temperatures:

Tank Size	-20°F	0°F	20°F	40°F
120 gal	50,000	85,000	130,000	190,000
250 gal	90,000	150,000	230,000	340,000
500 gal	140,000	240,000	370,000	550,000
1,000 gal	210,000	370,000	570,000	850,000

(Values are approximations; actual varies with tank design and conditions)

Observation:

- Capacity drops dramatically in cold weather

- 500-gallon tank at -20°F provides only 140,000 BTU/hr continuously
- Same tank at 40°F provides 550,000 BTU/hr
- Winter sizing critical in Canada

Rule of Thumb:

- Tank should provide 2-3 times peak demand at coldest temperature
- Prevents pressure drop
- Prevents "freeze-up"
- Maintains system pressure

Multiple Tanks:

- Manifolding tanks increases vaporization capacity
- Two 500-gal tanks provide nearly double capacity
- Common for high-demand applications
- Must be properly manifolded and regulated

Vaporizers:

- Electric or indirect-fired
- Supplement natural vaporization
- Required for very high demands
- Commercial/industrial applications
- Add heat to increase vaporization rate

5.6 Pressure Regulation

Propane systems require pressure regulation to deliver gas at proper pressure to appliances.

Single-Stage vs. Two-Stage Systems

Single-Stage System:

- One regulator reduces tank pressure directly to appliance pressure
- Simple, fewer components
- Less common in modern installations
- Used for small loads only

Two-Stage System:

- First-stage regulator at tank reduces to intermediate pressure (typically 10 PSI)
- Second-stage regulator at building reduces to appliance pressure (11" W.C. residential or 13" W.C. mobile home)

- Modern standard
- Better pressure control
- Protects against tank pressure variations

First-Stage Regulation

Location:

- At or near tank
- Often integral with tank service valve
- Protected from weather

Function:

- Reduces tank pressure (varies with temperature) to constant 10 PSI
- Handles varying inlet pressure (20-250+ PSIG depending on temperature)
- Outlet pressure constant regardless of inlet

Outlet Pressure:

- **10 PSI (27.7" W.C.) typical**
- Sometimes 15 PSI for longer runs
- Allows piping to second stage with smaller pipe
- Higher pressure means less pressure drop in piping

Relief Valve:

- Integral or separate
- Vents to atmosphere if over-pressure
- Protects piping downstream
- Must point away from building

Lock-Up Pressure:

- Pressure when no flow
- Should not exceed 20 PSI (approximately)
- Test requirement

Second-Stage Regulation

Location:

- At or just outside building
- Before entering structure
- Protected from weather
- Accessible for service

Function:

- Reduces 10 PSI to appliance pressure
- Final pressure control
- Protects appliances

Outlet Pressure:

- **11" W.C. (0.40 PSI) for residential dwellings**
- **13" W.C. (0.47 PSI) for mobile/manufactured homes**
- Constant pressure to appliances
- Appliance regulators further reduce to manifold pressure (10" W.C.)

Vent:

- Second-stage regulators are vented
- Vent to atmosphere
- Must terminate outside (except for Vent Limiting Devices)
- Minimum distances from openings per code
- Protected from insects and weather

Lock-Up Pressure:

- Pressure when no flow
- Should not exceed 14" W.C. (residential) or 16" W.C. (mobile home)
- Test requirement per CSA B149.2

Automatic Changeover Regulators

For Cylinder Systems:

- Automatically switches between two cylinders
- Continuous supply when one cylinder empties
- Indicator shows which cylinder in use
- Common for cylinder installations

Operation:

- Regulates from cylinder supplying gas
- When that cylinder empties (pressure drops), automatically switches to full cylinder
- Indicator moves to show switchover
- Allows empty cylinder replacement without interrupting service

First-Stage Function:

- Integral first-stage regulation

- Reduces cylinder pressure to 10 PSI
- Requires second-stage at building

Line Pressure Regulators

Two-Stage Integral:

- Single device combining first and second stage
- Mounted at tank or on building
- Direct reduction to appliance pressure
- Simpler installation
- Common on smaller systems

Installation Considerations:

- Cannot have excessive pressure drop between regulator and appliances
- Piping must be sized adequately
- Limited run length
- Not suitable for complex piping systems

Regulator Venting

Why Regulators Vent:

- Diaphragm-operated regulators use atmospheric pressure as reference
- Internal chamber must be vented to atmosphere
- Vent allows regulator to sense outlet pressure correctly
- Small gas amounts may vent during operation

Vent Location Requirements (CSA B149.2):

- **Outdoors**
- Minimum 3 meters (10 ft) from any source of ignition
- Minimum 1.5 meters (5 ft) from mechanical ventilation intakes
- Minimum 3 meters (10 ft) from doors, windows, and ventilation openings
- Protected from precipitation
- Screened against insects

Vent Limiting Devices (VLD):

- Special internal vent design
- Allows indoor installation of second-stage regulator in some cases
- Limits gas release if diaphragm fails
- Must meet specific standards
- Not common in Canada

5.7 Propane Piping

Materials

Approved Materials (per CSA B149.2):

- Black steel pipe (most common)
- Brass pipe
- Copper tubing (Type K or L, properly joined)
- Corrugated stainless steel tubing (CSST)
- Polyethylene (PE) for underground only, with proper transitions
- Flexible appliance connectors (approved lengths)

Not Approved:

- Galvanized steel pipe (internal coating flakes off)
- PVC, ABS, or other plastics above ground
- Aluminum (except specific appliance components)
- Copper soft tubing (for permanent piping)

Sizing Considerations

Propane vs. Natural Gas:

- Propane has higher specific gravity (1.52 vs. 0.60)
- More pressure drop for same pipe size and flow
- Must use propane-specific sizing tables
- Cannot use natural gas tables directly

Correction Factor:

- If using natural gas table: CF = $\sqrt{(0.60 \div 1.52)} = 0.628$
- Multiply natural gas capacity by 0.628 to get propane capacity
- Or use propane-specific tables in CSA B149.2

Example:

- 1/2" pipe, 20 ft, 0.5" W.C. drop
- Natural gas capacity from table: 175 ft^3/hr (CFH)
- Propane capacity: $175 \times 0.628 = 110$ CFH
- In BTU: $110 \times 2{,}500 = 275{,}000$ BTU/hr

Pressure Drop:

- Higher pressure = less percentage drop
- 11" W.C. supply (vs. 7" W.C. for natural gas) helps
- Still must calculate pressure drop
- CSA B149.2 tables account for this

Underground Piping

Polyethylene (PE):

- Yellow jacket (propane identification)
- Minimum depth per code (typically 18" below frost)
- Protected from rocks and sharp objects
- Installed on sand bed if rocky soil
- Tracer wire for locating
- Transition to steel above grade

Steel Pipe Underground:

- Coated and wrapped
- Cathodic protection may be required
- More expensive than PE
- Higher maintenance
- Less common for new installations

Transitions:

- PE to steel transition above grade (minimum 12" above)
- Proper fittings
- Dielectric union may be required
- Accessible for inspection

5.8 Appliance Conversion

Converting appliances between natural gas and propane is common but must be done correctly.

Conversion Requirements

When Conversion Allowed:

- Appliance manufacturer provides conversion kit or instructions
- Appliance designed for conversion
- Proper documentation available

When Conversion NOT Allowed:

- No manufacturer conversion kit available
- Appliance not designed for conversion
- Instructions unavailable
- Appliance too old (parts unavailable)
- Sealed combustion chamber (some models)

Conversion Procedure

1. Verify Convertibility:

- Check manufacturer specifications
- Obtain proper conversion kit
- Review conversion instructions
- Verify appliance model compatibility

2. Change Orifices:

- Turn off gas supply
- Remove burner orifices
- Install orifices for new gas type
- Typically smaller for propane
- ALL orifices must be changed (including pilot)

3. Adjust/Replace Gas Valve:

- Change gas valve spring (if required)
- Some valves need complete replacement
- Adjust manifold pressure to:
    - Natural gas: 3.5" W.C.
    - Propane: 10" W.C.

4. Adjust Primary Air:

- May require adjustment
- Propane needs more air per unit volume
- Verify proper flame characteristics

5. Verify Venting:

- Check vent sizing (may be adequate for both)
- Verify clearances unchanged
- Confirm proper draft

6. Test and Adjust:

- Pressure test all connections

- Light appliance and verify operation
- Check manifold pressure
- Perform combustion analysis
- Adjust burner for proper flame
- Verify all safeties operate

7. Update Labeling:

- Remove old gas type label
- Install new gas type label
- CSA requires proper labeling
- Include conversion date
- Technician identification

8. Document:

- Record conversion in service records
- Provide customer with documentation
- Include new operating specifications
- List converted components

Common Conversion Mistakes

Incomplete Orifice Change:

- Missing pilot orifice change
- Missing one burner
- Results in improper combustion

Wrong Manifold Pressure:

- Using natural gas pressure with propane orifices (too rich)
- Using propane pressure with natural gas orifices (too lean)
- Both dangerous

Missing Pressure Adjustment:

- Forgot to adjust gas valve
- Incorrect pressure
- Poor combustion or over-firing

Inadequate Testing:

- Skipping combustion analysis
- Not checking all safety controls
- Assuming conversion successful without verification

Improper Labeling:

- Confuses future service technicians
- May lead to incorrect service
- Code violation

5.9 Safety Considerations

Heavier Than Air

Critical Safety Difference from Natural Gas:

- Propane sinks to lowest point
- Accumulates in basements, crawlspaces, pits, low areas
- Does not readily disperse
- Can travel long distances along ground
- Remains concentrated longer

Installation Implications:

- No propane tanks in below-grade locations
- No cylinders in basements
- Appliances in basements require adequate ventilation
- Floor drains may need traps or sealing
- Ventilation from floor level (not ceiling)

Leak Response:

- Evacuate immediately
- Ventilate from low areas
- Propane may have traveled far from source
- Check all low areas
- Use gas detector from floor level up

Cold Burns

Liquid propane is extremely cold:

- Boils at -42°F
- Contact causes frostbite instantly
- Skin damage similar to thermal burns
- Eye exposure can cause blindness

When Risk Exists:

- Rapid liquid releases (line breaks)
- Tank overfilling
- Relief valve discharge
- Connecting/disconnecting fittings
- Filling operations

Protection:

- Safety glasses (always)
- Gloves when handling connections
- Proper clothing
- Know emergency procedures
- First aid for cold exposure

Tank Safety

Relief Valve:

- Never plug, cap, or block
- Operates at 250-375 PSIG typically
- Vents excess pressure
- Must discharge upward and away from people
- Check operation during tank inspection

Fire Exposure:

- Tanks exposed to fire can rupture catastrophically (BLEVE)
- Extremely dangerous
- Call fire department immediately
- Evacuate far distance (1/2 mile recommended)
- Never approach tank involved in fire

Physical Damage:

- Inspect tanks for damage (dents, rust, cracks)
- Damaged tanks may fail
- Report damage to supplier
- Never use damaged tank

Overfilling:

- Strictly enforce 80% rule
- Never override safety devices
- Overfilled tank is extreme hazard
- Relief valve will vent (waste and danger)

Leak Detection

Electronic Detectors:

- Most effective for propane
- Check from floor level upward
- Propane specific detectors available
- More sensitive than human nose

Soap Solution:

- Works well for pinpointing
- Bubbles show leak location
- Safe method
- Apply to all connections

Odor:

- Mercaptan provides warning
- But never rely on odor alone
- Some people cannot smell
- Odorant can fade
- Always use detection equipment

Leak Response Protocol:

1. Evacuate building
2. Call fire department (911) and propane supplier
3. Shut off tank if safe to do so
4. Keep people away
5. No ignition sources
6. Ventilate (open doors/windows from outside)
7. Do not re-enter until cleared
8. Professional leak investigation required

Chapter Summary

Propane (C_3H_8) is stored as a liquid and used as a vapor, with properties significantly different from natural gas. With specific gravity of 1.52, propane is heavier than air and sinks to low areas—a critical safety consideration. The heating value of approximately 2,500 BTU/ft^3 is 2.5 times higher than natural gas, requiring smaller orifices and different manifold pressure (10" W.C. vs. 3.5" W.C.).

Vapor pressure increases with temperature, varying from about 27 PSIG at 0°F to 189 PSIG at 100°F. The 80% fill rule prevents dangerous overfilling, allowing space for liquid expansion. Tank sizing must account for vaporization capacity, which decreases dramatically in cold weather.

Two-stage pressure regulation is standard: first stage at tank reduces to 10 PSI, second stage at building reduces to 11" W.C. (residential) or 13" W.C. (mobile home). Conversion between natural gas and propane requires changing all orifices, adjusting manifold pressure, testing combustion, and updating labeling.

Safety considerations include propane's tendency to accumulate in low areas, cold burn hazards from liquid propane, proper tank setbacks per CSA B149.2, and appropriate emergency response procedures. Understanding propane's unique properties enables safe, efficient installations and effective troubleshooting.

Review Questions

Multiple Choice

1. Propane has the chemical formula:
    - a) CH_4
    - b) C_2H_6
    - c) C_3H_8
    - d) C_4H_{10}
2. The specific gravity of propane vapor is approximately:
    - a) 0.60
    - b) 1.00
    - c) 1.52
    - d) 2.50
3. One gallon of liquid propane produces approximately how many cubic feet of vapor?
    - a) 9.5 ft^3
    - b) 36.4 ft^3
    - c) 92.0 ft^3
    - d) 270 ft^3
4. Propane tanks are filled to a maximum of what percentage?
    - a) 60%
    - b) 70%
    - c) 80%
    - d) 90%
5. The typical manifold pressure for propane appliances is:
    - a) 3.5" W.C.
    - b) 7" W.C.
    - c) 10" W.C.
    - d) 11" W.C.

6. A first-stage propane regulator typically reduces tank pressure to:
   - a) 11" W.C.
   - b) 5 PSI
   - c) 10 PSI
   - d) 20 PSI
7. The second-stage outlet pressure for a residential dwelling is typically:
   - a) 7" W.C.
   - b) 10" W.C.
   - c) 11" W.C.
   - d) 13" W.C.
8. The Lower Explosive Limit (LEL) for propane is:
   - a) 1.5%
   - b) 2.1%
   - c) 5.0%
   - d) 9.5%
9. When converting from natural gas to propane, the orifice size must be:
   - a) Increased
   - b) Decreased
   - c) Kept the same
   - d) Removed entirely
10. Propane is heavier than air, which means it will:
    - a) Rise and disperse quickly
    - b) Mix evenly with air
    - c) Sink and accumulate in low areas
    - d) Float on water

True or False

11. Propane and natural gas have the same Wobbe Index and are directly interchangeable.
12. The 80% fill rule exists because liquid propane expands significantly when heated.
13. Propane tank pressure indicates how much propane is in the tank.
14. A 500-gallon propane tank can safely hold 500 gallons of liquid propane.
15. Second-stage propane regulators must be vented to the outdoors.

Short Answer

16. Explain why propane is stored as a liquid but used as a vapor. Include the expansion ratio and its significance. (4 marks)
17. Describe the difference between single-stage and two-stage pressure regulation systems for propane. (4 marks)
18. Why is propane's heavier-than-air property a critical safety consideration? List three specific implications. (5 marks)
19. Explain the relationship between temperature and vapor pressure in propane tanks. Why does this matter for system design? (5 marks)
20. What is "weathering" in propane tanks and why does it matter? (3 marks)

Long Answer

21. A customer wants to install a propane furnace rated at 100,000 BTU/hr input in a location where winter temperatures can drop to -20°F. Explain how you would determine the proper tank size. Include:
    - Calculation of propane consumption rate
    - Vaporization capacity considerations
    - Temperature effects
    - Safety factors
    - Your recommendation with justification (12 marks)
22. Describe the complete procedure for converting a natural gas furnace to propane operation. Include:
    - Pre-conversion verification
    - All components that must be changed or adjusted
    - Testing procedures
    - Safety checks
    - Documentation requirements
    - Common mistakes to avoid (15 marks)
23. Compare and contrast propane and natural gas in terms of:
    - Physical properties (specific gravity, heating value, Wobbe Index)
    - Storage and distribution
    - Safety considerations
    - Appliance requirements
    - Environmental factors Explain why these differences require different installation practices and equipment. (15 marks)

Practical Exercises

Exercise 1: Vapor Pressure Calculations

Using the temperature-pressure table:

1. What is the tank pressure at -10°F?
2. What is the tank pressure at 70°F?
3. If tank pressure reads 91 PSIG, what is the approximate temperature?
4. Why can't you determine quantity from pressure alone?

Exercise 2: Tank Capacity Calculations

Calculate for various tank sizes:

1. Water capacity in gallons
2. Maximum fill at 80% (gallons)

3. Maximum fill weight (pounds)
4. Vapor volume at 60°F
5. Total BTU content

Exercise 3: Vaporization Rate Analysis

For a 500-gallon tank:

1. Find vaporization capacity at -20°F
2. Find vaporization capacity at 40°F
3. Calculate percentage reduction in cold weather
4. Determine if adequate for 150,000 BTU/hr furnace at each temperature
5. Explain implications for cold climate installations

Exercise 4: Piping Sizing for Propane

Using CSA B149.2 tables:

1. Size pipe for 200,000 BTU/hr, 50 ft run
2. Compare to natural gas sizing for same load
3. Calculate pressure drop
4. Verify adequate pressure at appliance
5. Document design

Exercise 5: Conversion Procedure

On training appliance (if available) or detailed written procedure:

1. Identify current gas type
2. List all components requiring change
3. Obtain proper orifices
4. Describe pressure adjustment procedure
5. Create step-by-step checklist
6. Describe combustion testing process
7. Prepare proper labeling
8. Complete documentation

Exercise 6: Leak Detection Practice

On test propane system with known leak:

1. Use electronic detector to locate general area
2. Use soap solution to pinpoint exact leak
3. Estimate leak severity
4. Recommend repair method
5. Document findings

6. Describe safety procedures followed

Exercise 7: Tank Setback Calculations

Given site plan:

1. Identify proposed tank location
2. Measure distances to building, property lines, ignition sources
3. Verify compliance with CSA B149.2
4. Identify any violations
5. Recommend compliant location if needed
6. Document with sketches

Case Studies

Case Study 1: Winter Freeze-Up

Scenario: A customer calls in February complaining their furnace "keeps shutting down" and they "can't keep the house warm." Outdoor temperature is -25°F. They have a 250-gallon propane tank that shows 40% on the gauge. The 125,000 BTU/hr furnace runs for a few minutes, then shuts down on limit. When you arrive, you notice frost on the lower half of the propane tank.

Questions:

1. What is causing this problem?
2. Why is there frost on the tank?
3. What is the tank's vaporization capacity at -25°F?
4. Is 40% adequate liquid level? Why or why not?
5. Why does the furnace shut down on limit?
6. What immediate solution can you provide?
7. What long-term solutions would you recommend?
8. How do you explain this to the customer?

Case Study 2: Improper Conversion

Scenario: You respond to a "no heat" call. The customer just had their natural gas furnace "converted to propane" by an unlicensed friend. The furnace won't light. You find:

- Natural gas orifices still installed
- Natural gas label still on furnace
- Gas valve spring not changed
- No combustion testing performed

- Manifold pressure measures 10" W.C.

Questions:

1. Why won't the furnace light?
2. What's wrong with the manifold pressure?
3. What could happen if it did light with this configuration?
4. What components are incorrect?
5. What is the proper manifold pressure for propane?
6. What is required to properly convert this furnace?
7. What do you tell the customer?
8. What are the safety and legal implications?

Case Study 3: Tank Location Violation

Scenario: You're asked to perform a routine inspection on a propane installation. You find a 500-gallon tank located:

- 2 meters (6.5 ft) from the house
- 1.5 meters (5 ft) from the property line
- Adjacent to the neighbor's heat pump (3 meters away)
- Relief valve pointing toward the house

Questions:

1. What CSA B149.2 violations exist?
2. What are the required minimum setbacks?
3. Why are these distances required?
4. What is wrong with the relief valve orientation?
5. Where should the tank be located?
6. Who is responsible for correction?
7. What if correction is impossible on this property?
8. What documentation/notification is required?

Case Study 4: Basement Accumulation

Scenario: Homeowners smell propane in their basement. They have a propane furnace and water heater in the basement. You arrive and detect propane concentration of 8,000 ppm (0.8%) at floor level in one corner, decreasing with height. No odor at ground level outside. All appliances are off.

Questions:

1. What is the immediate action?
2. Why is propane only in the basement?
3. Why higher concentration at floor level?

4. What is 0.8% in relation to LEL?
5. How would this differ if it were natural gas?
6. What is the likely leak source?
7. How do you locate the leak safely?
8. What ventilation strategy do you use?
9. What recommendations prevent future accumulation?

Case Study 5: Vaporization Capacity

Scenario: A customer wants to add a propane pool heater (400,000 BTU/hr) to their existing 250-gallon tank that supplies their home (furnace: 80,000 BTU/hr, water heater: 40,000 BTU/hr, range: 65,000 BTU/hr). They live in an area where winter temperatures reach -10°F. Current tank shows 60% full.

Questions:

1. What is the peak simultaneous load?
2. What is the tank's vaporization capacity at -10°F?
3. Is the existing tank adequate? Why or why not?
4. What happens if vaporization capacity is exceeded?
5. What solutions are available?
6. Would a larger tank solve the problem?
7. What about two tanks manifolded together?
8. What would you recommend and why?
9. How do summer conditions affect this analysis?

Case Study 6: Overfilled Tank

Scenario: You're called to a home where the propane tank is venting from the relief valve. It's a hot summer day (95°F). The customer mentions the delivery driver "really filled it up good - said he wanted to make sure I had plenty." The gauge reads 95%. Liquid is spraying from the relief valve.

Questions:

1. What has happened?
2. Why is the relief valve operating?
3. What is the immediate danger?
4. What immediate actions are required?
5. How did this occur?
6. What should the maximum fill be?
7. What prevents this normally?
8. How is the problem corrected?
9. Who should be notified?
10. What could happen if the relief valve were blocked?

Key Terms

ASME Tank: Stationary propane tank built to American Society of Mechanical Engineers standards.

Auto-Ignition Temperature: Temperature at which propane ignites spontaneously without external ignition (920-1,020°F).

BLEVE (Boiling Liquid Expanding Vapor Explosion): Catastrophic tank failure when liquid rapidly vaporizes, typically from fire exposure.

DOT Cylinder: Portable propane cylinder meeting Department of Transportation specifications.

First-Stage Regulator: Reduces tank pressure to intermediate pressure (typically 10 PSI).

HD-5 Propane: Standard grade propane containing minimum 90% propane.

LEL (Lower Explosive Limit): Minimum propane concentration in air that will ignite (2.1%).

LP Gas (Liquefied Petroleum Gas): Generic term for propane, butane, or mixtures thereof.

OPD (Overfill Prevention Device): Valve preventing propane cylinder from being filled beyond 80%.

Second-Stage Regulator: Reduces intermediate pressure to appliance supply pressure (11" W.C. residential, 13" W.C. mobile home).

Specific Gravity: Weight of propane vapor relative to equal volume of air (1.52).

TC Cylinder: Portable propane cylinder meeting Transport Canada specifications.

UEL (Upper Explosive Limit): Maximum propane concentration in air that will ignite (9.5%).

Ullage: Space in tank above liquid level; required for liquid expansion (20% minimum).

Vapor Pressure: Pressure exerted by propane vapor in closed container; varies with temperature.

Vaporization: Process of liquid propane converting to vapor by absorbing heat.

Weathering: Preferential vaporization of lighter components, leaving heavier components in liquid.

Wobbe Index: Heating value divided by square root of specific gravity (propane ≈ 2,100).

End of Chapter 5

CHAPTER 6

Gas Piping Materials and Methods

Learning Objectives

Upon completion of this chapter, students will be able to:

1. Identify approved piping materials for natural gas and propane installations
2. Select appropriate piping materials for different applications
3. Calculate pipe sizes using CSA B149.1 sizing tables
4. Apply pressure drop calculations for gas piping systems
5. Install black steel pipe with proper threading and joint compound
6. Install corrugated stainless steel tubing (CSST) per manufacturer specifications
7. Install polyethylene (PE) pipe for underground applications
8. Understand support spacing and protection requirements
9. Apply proper bonding and grounding for CSST systems
10. Install gas piping in compliance with CSA B149.1 requirements

---

6.1 Approved Piping Materials

CSA B149.1 specifies approved materials for gas piping. Selection depends on application, location (indoor/outdoor, above/below ground), and local requirements.

Black Steel Pipe

Most Common Material for Indoor Gas Piping

Specifications:

- ASTM A53, Grade B or ASTM A106, Grade B
- Seamless or welded
- Black finish (not galvanized)
- Threaded connections (NPT threads)
- Standard wall thickness (Schedule 40)

Sizes:

- 1/8" through 12" (larger for commercial/industrial)

- Residential typically 1/2" through 1-1/4"
- Nominal sizes (not actual dimensions)

Advantages:

- Strong and durable
- Widely available
- Proven track record
- Long service life
- High pressure rating
- Familiar to installers

Disadvantages:

- Requires threading
- Heavier than alternatives
- Can corrode (especially underground without protection)
- Rigid (difficult in tight spaces)
- Labor-intensive installation

Applications:

- Indoor piping (primary use)
- Above-ground outdoor (with protection)
- Exposed piping
- Commercial/industrial
- High-pressure applications

Why Not Galvanized:

- Galvanizing (zinc coating) flakes off over time
- Flakes can plug orifices, damage regulators
- Prohibited by CSA B149.1
- Black pipe only for gas

Corrugated Stainless Steel Tubing (CSST)

Flexible Alternative to Black Steel

Description:

- Thin-wall stainless steel tubing
- Corrugated (accordion-like) for flexibility
- Yellow or black jacket (PE coating)
- Factory lengths with fittings attached or field-installed fittings
- Various manufacturers (TracPipe, Gastite, WarFlex, etc.)

Sizes:

- Designated by inside diameter flow capacity
- 3/8", 1/2", 5/8", 3/4", 1", 1-1/4" nominal
- Must use manufacturer's sizing charts

Advantages:

- Flexible (bends around obstacles)
- Faster installation than threaded pipe
- Lighter weight
- No threading required
- Long continuous runs (reduces fittings)
- Corrosion resistant

Disadvantages:

- More expensive than black steel
- Requires special tools (striker/crimping tool)
- Must use manufacturer's fittings
- Can be damaged by physical impact
- Requires bonding/grounding (electrical safety)
- Not all jurisdictions permit
- Must be protected from damage

Installation Requirements:

- Follow manufacturer's instructions exactly
- Use manufacturer's fittings only
- Support per manufacturer specifications (typically 4-6 ft)
- Protect from physical damage
- **MUST be bonded per CSA B149.1 Clause 7.11**
- Cannot contact sharp edges
- Cannot be buried underground (in most cases)
- Jacketed CSST may be run through walls

Bonding and Grounding:

- Required by CSA B149.1
- Protects against lightning strikes and electrical faults
- Bonding clamp at CSST entry point
- Conductor to electrical ground
- #6 AWG copper minimum
- Electrician may be required
- Critical safety requirement

Applications:

- Residential installations
- Light commercial
- Retrofit installations (easier routing)
- Where flexibility needed
- Indoor installations primarily

Polyethylene (PE) Pipe

Underground Gas Piping

Specifications:

- PE 2708 or PE 4710 rated for gas
- Yellow color (gas identification)
- Various pressure ratings
- SDR 11 (Standard Dimension Ratio) common for gas

Sizes:

- 1/2" through 6" CTS (Copper Tube Size) for gas distribution
- Larger for transmission lines
- Size marking on pipe

Advantages:

- Corrosion-proof
- Flexible
- Long continuous lengths
- Heat-fused joints (no leaks)
- Lightweight
- Lower cost than steel underground
- Excellent for underground service lines

Disadvantages:

- Underground use only (except approved cases)
- Requires fusion equipment
- Training required for proper fusion
- Can be damaged by rocks during backfill
- Must transition to steel above ground
- Requires tracer wire (not detectable by metal detector)

Installation Requirements:

- Yellow jacket (gas identification)
- Minimum depth per code (typically 18" below frost line)
- Sand bedding if rocky soil
- Protected from sharp objects
- Tracer wire (copper) for locating
- Transition to steel minimum 12" above grade
- Cannot be threaded (heat fusion only)
- Test per code requirements

Heat Fusion:

- Butt fusion (pipe to pipe)
- Socket fusion (pipe to fitting)
- Electrofusion (fitting with built-in heater)
- Proper temperature and time critical
- Visual inspection required
- Training and certification recommended

Applications:

- Underground service lines
- Distribution mains
- Residential gas services
- Farm gas lines
- Where corrosion is concern

Copper Tubing

Limited Use in Gas Installations

Specifications:

- Type K or Type L (wall thickness)
- ACR (Air Conditioning & Refrigeration) quality
- Hard-drawn or annealed

Approved Joining Methods:

- Brazed joints (silver alloy, not soft solder)
- Flared fittings (mechanical)
- Compression fittings (limited applications)
- **NOT soft-soldered** (solder melts at low temperature)

Limitations:

- Not permitted in some jurisdictions

- Natural gas may cause copper corrosion in some conditions
- Limited pressure rating
- More expensive than steel
- Requires brazing skills

Applications (where permitted):

- Propane installations (more common)
- Above-ground only
- Protected locations
- Short runs
- Appliance connections

CSA B149.1 Requirements:

- Type K or L only (Type M not permitted)
- Properly joined (brazed or flared)
- Protected from physical damage
- Limited to specific applications per local code

Flexible Appliance Connectors

Short Connections to Moveable Appliances

Description:

- Flexible metal hose
- Corrugated or smooth wall
- Various lengths (typically 2-6 feet maximum)
- Factory-installed fittings
- Listed and approved for gas

Specifications:

- CSA certified for gas use
- Length limitations per code
- Cannot pass through walls, floors, ceilings
- Must be visible and accessible

Applications:

- Ranges and cooktops
- Dryers
- Other moveable appliances
- Where appliance must be moved for service

Installation Requirements:

- Maximum length per code (typically 6 ft)
- Must be accessible for inspection
- Cannot be concealed
- Proper support
- Not subject to damage
- Shut-off valve at rigid piping

Prohibited Uses:

- Permanent connections
- Connections through walls
- Underground
- Long runs
- As substitute for rigid piping

Prohibited Materials

Materials NOT Approved for Gas Piping:

- **Galvanized steel pipe** (zinc flakes plug orifices)
- **PVC, ABS, and plastic pipes** (above ground)
- **Copper soft solder joints** (solder melts)
- **Aluminum pipe** (except specific applications)
- **Cast iron pipe** (brittle, old systems only)
- **Rubber or vinyl hose** (except approved appliance connectors)
- **Garden hose** (obviously unsafe)
- **Unapproved flexible connectors**

6.2 Pipe Sizing Principles

Proper pipe sizing ensures adequate gas flow at correct pressure. Undersized pipe causes pressure drop; oversized pipe is wasteful.

Factors Affecting Pipe Size

1. Gas Flow Rate (Demand):

- Total BTU/hr input of all appliances
- Determines cubic feet per hour (CFH) needed
- Must size for maximum simultaneous demand

2. Pipe Length:

- Longer run = more friction = larger pipe needed
- Measure from meter/regulator to farthest appliance
- "Longest run" method or branch lengths

3. Allowable Pressure Drop:

- Maximum pressure loss allowed in system
- Inlet pressure minus minimum appliance requirement
- Typical: 0.5" W.C. for low pressure systems
- More drop allowed in higher pressure systems

4. Specific Gravity:

- Natural gas: 0.60
- Propane: 1.52
- Different tables for each
- Affects flow calculations

5. Supply Pressure:

- Inlet pressure at meter/regulator
- Natural gas: typically 7" W.C.
- Propane: typically 11" W.C.
- Higher pressure = smaller pipe possible

Calculating Gas Demand

Step 1: List All Appliances and Inputs

Example residence:

- Furnace: 100,000 BTU/hr
- Water heater: 40,000 BTU/hr
- Range: 65,000 BTU/hr
- Dryer: 35,000 BTU/hr

Step 2: Determine Simultaneous Demand

Not all appliances operate at once continuously:

- Furnace and water heater: likely simultaneous
- Range: intermittent use
- Dryer: intermittent use

Conservative Approach: Size for all appliances Total = 100,000 + 40,000 + 65,000 + 35,000 = 240,000 BTU/hr

Alternative: Engineering judgment for intermittent loads (Less conservative, not recommended for residential)

Step 3: Convert to Cubic Feet per Hour

For Natural Gas (1,000 BTU/ft³): CFH = BTU/hr ÷ 1,000 CFH = 240,000 ÷ 1,000 = 240 CFH

For Propane (2,500 BTU/ft³): CFH = BTU/hr ÷ 2,500 CFH = 240,000 ÷ 2,500 = 96 CFH

Using CSA B149.1 Sizing Tables

Table Selection:

- Natural gas or propane
- Supply pressure (e.g., 7" W.C. inlet)
- Allowable pressure drop (e.g., 0.5" W.C.)
- Specific gravity (if different from table)

Table Format:

- Rows: Pipe sizes (1/2", 3/4", 1", etc.)
- Columns: Pipe lengths (10', 20', 30', etc.)
- Values: Maximum capacity in cubic feet per hour (CFH)

Example Natural Gas Table Excerpt (7" W.C. inlet, 0.5" W.C. drop, 0.60 SG):

Pipe Size	10 ft	20 ft	30 ft	40 ft	50 ft	60 ft
1/2"	132	92	73	63	56	50
3/4"	278	190	152	130	115	105
1"	520	360	285	245	215	195
1-1/4"	1,050	730	580	500	440	400

(Values are approximate examples; always use current CSA B149.1 tables)

Longest Run Method

Most Common Sizing Method:

Step 1: Identify Longest Run

- Measure from meter to farthest appliance
- Include all pipe, fittings, valves
- Fittings add equivalent length

Step 2: Determine Total Demand

- Sum all appliance inputs on system

Step 3: Select Pipe Size

- Use table for longest run length
- Find pipe size that handles total demand
- Use next larger size if between sizes

Example:

System:

- Longest run: 45 ft
- Total demand: 240,000 BTU/hr = 240 CFH (natural gas)
- Supply: 7" W.C., Allowable drop: 0.5" W.C.

From table:

- 45 ft falls between 40 ft and 50 ft columns
- Interpolate or use 50 ft to be conservative
- At 50 ft: 3/4" pipe handles 115 CFH (too small)
- At 50 ft: 1" pipe handles 215 CFH (too small)
- At 50 ft: 1-1/4" pipe handles 440 CFH (adequate)

Answer: Use 1-1/4" pipe for entire run

Advantages:

- Simple
- Conservative (safe)
- Required by many jurisdictions

Disadvantages:

- May oversize near meter
- More material cost
- Not optimized

Branch Length Method

More Efficient for Complex Systems:

Size each section based on the demand it serves and its length.

Procedure:

1. **Draw System:**
   - Sketch piping layout
   - Mark all appliances
   - Measure each section length
2. **Calculate Section Loads:**
   - Start at farthest appliance
   - Work back toward meter
   - Each section carries load of all appliances downstream
3. **Size Each Section:**
   - Use appropriate length and load
   - May have different sizes in different sections

Example:

```
Meter --- 20ft (1") --- A (Tee)
                          |
                          +-- 30ft (3/4") --- Water Heater (40 MBTUH)
                          |
                          +-- 40ft --- B (Tee)
                                       |
                                       +-- 10ft (1/2") --- Range (65 MBTUH)
                                       |
                                       +-- 20ft (1/2") --- Furnace (100 MBTUH)
```

Section Sizing:

Furnace Branch (20 ft from B):

- Load: 100,000 BTU = 100 CFH
- Length: 20 ft
- 1/2" pipe @ 20 ft = 92 CFH (adequate)

Range Branch (10 ft from B):

- Load: 65,000 BTU = 65 CFH
- Length: 10 ft
- 1/2" pipe @ 10 ft = 132 CFH (adequate)

Section B to A (40 ft):

- Load: 100 + 65 = 165 CFH
- Length: 40 ft
- 3/4" pipe @ 40 ft = 130 CFH (too small)
- 1" pipe @ 40 ft = 245 CFH (adequate)

Wait - Need to reconsider: Actually measure 40 ft from meter, not from B. **From meter to B: 20 + 40 = 60 ft**

Section from Meter through A to B (60 ft):

- Load: All appliances = 100 + 65 + 40 = 205 CFH
- Length: 60 ft
- 1" pipe @ 60 ft = 195 CFH (too small)
- 1-1/4" pipe @ 60 ft = 400 CFH (adequate)

Water Heater Branch (30 ft from A):

- Load: 40,000 BTU = 40 CFH
- **Length from meter: 20 + 30 = 50 ft**
- 1/2" pipe @ 50 ft = 56 CFH (adequate)

Revised Sizing:

- Meter to A: 1-1/4" (20 ft, carries all appliances)
- A to B: 1-1/4" (40 ft, carries furnace and range)
- A to water heater: 1/2" (30 ft, carries water heater only)
- B to range: 1/2" (10 ft)
- B to furnace: 1/2" (20 ft)

Advantages:

- Optimized sizing
- Lower material cost
- Still meets code

Disadvantages:

- More complex calculations
- More prone to errors
- Requires accurate measurements

Equivalent Length of Fittings

Fittings add friction/resistance. Add equivalent length to straight pipe.

Typical Equivalent Lengths:

Fitting	Equivalent Length (ft)
90° Elbow	3 ft
45° Elbow	1.5 ft
Tee (flow through)	1.5 ft
Tee (flow through branch)	5 ft
Gate valve	0.5 ft

Fitting	Equivalent Length (ft)
Plug valve	3 ft

Example:

Straight pipe: 40 ft Plus: 3 elbows @ 3 ft each = 9 ft Plus: 2 tees @ 5 ft each = 10 ft Plus: 1 valve @ 3 ft = 3 ft **Total equivalent length: 40 + 9 + 10 + 3 = 62 ft**

Use 62 ft (or 60 ft column) in sizing table.

Specific Gravity Corrections

If actual gas specific gravity differs from table, apply correction factor.

Correction Factor:

CF = √(Table SG ÷ Actual SG)

Example:

Natural gas table based on 0.60 SG Actual gas has 0.65 SG

CF = √(0.60 ÷ 0.65) = √0.923 = 0.96

Multiply table values by 0.96 to get actual capacity.

If table shows 200 CFH capacity: Actual = 200 × 0.96 = 192 CFH

For propane: Use propane tables (SG = 1.52), not natural gas tables with corrections.

6.3 Steel Pipe Installation

Black steel pipe is the traditional and most common gas piping material.

Threading Pipe

Proper Threading is Critical for Leak-Free Joints

Thread Standard:

- NPT (National Pipe Taper)
- Tapered 3/4" per foot
- 1/16" taper per inch of length

- Seals on tapered threads, not thread bottom

Threading Procedure: (Review Chapter 3 for detailed threading steps)

1. Cut pipe square
2. Ream inside burr
3. Secure in vise
4. Apply threading oil generously
5. Start die square to pipe
6. Thread to proper length
7. Back off periodically to break chips
8. Add oil continuously
9. Inspect threads

Thread Length:

Must engage fitting properly:

Pipe Size	Thread Length (approximate)
1/2"	3/4" (9-10 threads)
3/4"	3/4" (9-10 threads)
1"	1" (10-11 threads)
1-1/4"	1" (11-12 threads)
1-1/2"	1" (11-12 threads)
2"	1" (11-12 threads)

Too little: Won't engage properly, weak joint Too much: Bottoms out before sealing

Thread Inspection:

Good threads:

- Sharp and clean
- No torn or ragged edges
- Uniform taper
- Start easily in fitting by hand
- Tighten with moderate force

Pipe Joint Compound (Pipe Dope)

Purpose:

- Lubricates threads for assembly
- Fills minor imperfections
- Creates seal

Types Approved for Gas:

- Paste compounds (most common)
- Teflon tape (with compound)
- Never use unapproved sealants

Application:

Male threads only:

- Apply to male threads
- Cover first 2-3 threads completely
- Brush or finger application
- Moderate coating (not excessive)
- **Never apply to female threads**

Why only male threads:

- Prevents compound from being forced into pipe
- Compound in pipe can contaminate regulators, pilots
- Keeps compound in joint, not system

Assembly:

1. Apply compound to male threads
2. Start fitting by hand (should thread easily)
3. Tighten with wrenches:
   - Wrench on fitting
   - Wrench on pipe
   - Turn fitting, hold pipe
4. Tighten until firm:
   - Typically 2-3 turns past hand tight
   - Not excessive force
   - Fitting should not turn easily
   - Don't crack fitting

Common Mistakes:

- Compound on female threads
- Insufficient compound
- No compound (will leak)
- Over-tightening (cracks fitting)
- Wrong compound (not gas-rated)

Pipe Support and Spacing

Support Requirements:

CSA B149.1 specifies maximum support spacing:

Horizontal Pipe:

Pipe Size	Maximum Support Spacing
1/2"	6 ft (1.8 m)
3/4" - 1"	8 ft (2.4 m)
1-1/4" and larger	10 ft (3 m)

Vertical Pipe:

- Support at each floor
- Maximum 10 ft intervals

Support Types:

- Pipe straps (most common)
- Clevis hangers
- Pipe hooks (J-hooks)
- Brackets
- Must not damage pipe

Installation:

- Support from structure (not hanging from other piping)
- Proper size for pipe
- Allow for expansion
- Don't over-tighten (can deform pipe)
- At changes in direction

Protection from Damage

Physical Protection Required:

In Walls:

- Steel plates if pipe closer than 1-1/4" (32 mm) from surface
- Prevents nails, screws from penetrating
- 1/16" (1.6 mm) minimum thickness
- Extends beyond pipe

In Concrete:

- Sleeve or wrap pipe
- Prevents concrete contact
- Allows for expansion
- Protects from chemical reaction

Exterior:

- Protect from physical damage
- Paint if desired (identification)
- Guard from vehicles if required
- Minimum height above grade

Underground (coated steel):

- Coating systems
- Wrapping
- Cathodic protection for larger systems
- Typically use PE pipe instead

Expansion and Flexibility

Thermal Expansion:

- Pipe expands/contracts with temperature
- 100 ft of steel pipe expands 1" over 100°F change
- Allow for movement in long runs

Methods:

- Loops or offsets
- Expansion joints (commercial)
- Flexible sections
- Proper support allows sliding

6.4 CSST Installation

Corrugated Stainless Steel Tubing requires specific installation practices.

Manufacturer Requirements

Critical: Follow manufacturer instructions exactly

- Each manufacturer has specific requirements

- Use only manufacturer's fittings
- Use manufacturer sizing charts
- Installation variations between brands
- Certification may be required

System Design

Manifold System:

- Central manifold near gas meter
- Individual CSST runs to each appliance
- "Home run" configuration
- Minimizes fittings
- Easy to trace

Trunk and Branch:

- Main CSST line (trunk)
- Branches to appliances
- More fittings
- More complex

Installation Steps

1. Planning:

- Measure runs carefully
- Add length for routing
- Select proper CSST size
- Account for fittings
- Plan support locations

2. Cutting CSST:

- Use proper CSST cutter (not hacksaw)
- Cut square
- Don't crush tubing
- Remove burrs if any

3. Installing Fittings:

- Use manufacturer's striker tool
- Insert CSST fully into fitting
- Strike/crimp per instructions
- Verify proper engagement
- Visual inspection

4. Routing:

- Avoid sharp bends
- Minimum bend radius per manufacturer
- Protect from damage
- Support properly
- Keep accessible where possible

5. Support:

- Spacing per manufacturer (typically 4-6 ft horizontal)
- Use proper support clips/hangers
- Don't over-tighten
- Allow for movement
- Each floor level (vertical)

6. Protection:

- Protect from physical damage
- Can run through walls if jacketed
- Steel plates if near surface
- Cannot contact sharp edges
- Guard from abrasion

7. Bonding:

- **REQUIRED per CSA B149.1 Clause 7.11**
- Bonding clamp at CSST entry to structure
- #6 AWG copper conductor minimum
- Connect to electrical grounding system
- Electrician may be required
- Document bonding installation

Bonding and Grounding (Critical)

Why Required:

- Lightning strike protection
- Electrical fault protection
- Prevents arcing through CSST wall
- Arc can rupture CSST causing gas release

Bonding Requirements:

Clamp Location:

- First fitting where CSST enters structure
- On rigid piping before CSST
- Listed bonding clamp

Bonding Conductor:

- Minimum #6 AWG copper
- Connect to electrical grounding electrode system
- May connect to electrical panel ground
- Follow electrical code
- Electrician typically performs

Testing:

- Verify bonding connection
- Check continuity
- Proper clamp installation
- Document

Inspection:

- Required by code
- Verify bonding present
- Failed inspection if not bonded

CSST Sizing

Use Manufacturer Tables:

- Different from steel pipe tables
- Based on CSST diameter designation
- Consider pressure drop
- Account for fittings

Example Sizing:

- Appliance: 100,000 BTU/hr
- Run length: 50 ft
- Natural gas
- Manufacturer table indicates: 3/4" CSST

Don't assume same size as steel pipe equivalent

6.5 Polyethylene Pipe Installation

PE pipe is standard for underground gas service lines.

Material Selection

PE 2708 or PE 4710:

- Yellow jacket (gas service)
- Pressure rating adequate for application
- SDR 11 common (Standard Dimension Ratio)
- Size marking on pipe

Tracer Wire:

- Copper wire
- Locatable by wire locator
- Run alongside or attached to pipe
- Brought to surface at access points

Fusion Joining

Heat Fusion is ONLY Approved Method:

Butt Fusion (Pipe to Pipe):

1. Square pipe ends
2. Heat fusion plate to proper temperature
3. Heat both pipe ends
4. Remove plate, join pipes
5. Hold until cooled
6. Proper bead formation indicates good fusion

Socket Fusion (Pipe to Fitting):

1. Insert pipe into heated socket fitting
2. Hold until cooled
3. Verify proper depth

Electrofusion:

- Special fittings with built-in heating element
- Electrical power melts fitting to pipe
- Indicator shows complete fusion
- More expensive but reliable

Critical Factors:

- Proper temperature
- Clean surfaces (scrape oxidation)
- Proper heating time
- Proper cooling time (don't disturb)
- Visual inspection of bead

Underground Installation

Trenching:

- Minimum depth per code (typically 18" below frost line)
- Width adequate for bedding and backfill
- Locate other utilities
- Shore if required (depth over 4 ft)

Bedding:

- 4-6" sand or fine soil
- Level bottom
- No rocks or sharp objects
- Uniform support

Pipe Installation:

- Lay pipe on bedding
- No tension (slight snake pattern)
- Allows for expansion/contraction
- Attach tracer wire
- Bring tracer wire to surface at terminations

Backfill:

- 6-12" clean fill over pipe first
- Hand compact gently
- Protects pipe from rocks
- No heavy equipment over pipe until adequate cover
- Verify no damage during backfill

Marking:

- Warning tape 12" above pipe
- "Caution Gas Line Below"
- Bright yellow
- Continuous over pipe route

Transition to Steel

Requirements:

- Minimum 12" above grade
- Accessible for inspection
- Proper transition fitting
- No stress on connection
- Support both PE and steel

Transition Fittings:

- Compression fitting to PE
- NPT threads to steel
- Listed for purpose
- Proper installation

Protection:

- Guard from damage
- Identify as gas line
- Paint yellow (identification)
- Support steel pipe

6.6 Above-Ground Piping

Indoor Installation

General Requirements:

- Accessible for inspection
- Protected from damage
- Proper support
- Identified where required
- No conflicts with other trades

Routing:

- Neat and workmanlike
- Minimize fittings
- Adequate clearances
- Away from heat sources
- Consider appearance

Concealed Piping:

- Allowed in walls, ceilings, floors
- Must be continuous (no fittings in concealed spaces preferred)
- Accessible at appliances
- Test before concealing

Identification:

- Not required in dwellings (single family)
- Required in multi-residential and commercial
- Yellow paint or yellow marking
- "Gas" or "Fuel Gas"

Outdoor Installation

Protection:

- Paint or coat (rust prevention)
- Support adequately
- Protect from physical damage
- Guard from vehicles if required
- Not in direct soil contact

Clearances:

- From buildings per code
- From other utilities
- From ignition sources
- Minimum height above grade

Corrosion Prevention:

- Paint (if desired)
- Coating systems
- Proper drainage (no water pockets)
- Inspect regularly

6.7 Piping Through Structures

Penetrations

Through Walls and Floors:

Steel Pipe:

- Can pass directly through
- Sleeve recommended (protection and access)
- No tight contact with structure
- Allow for expansion

CSST:

- Can pass through if jacketed
- Use proper sleeve/grommet
- Protect from abrasion
- No sharp edges

PE Pipe:

- Underground only
- Transition to steel above grade before penetration

Sleeves:

- Larger than pipe
- Sealed at one end (exterior)
- Open at interior (allows leak detection)
- Proper size for pipe plus expansion

Clearances

From Electrical:

- Minimum separation per code
- Typically 6" from electrical panels
- Adequate separation from conduit
- CSST bonding addresses this

From Other Utilities:

- Adequate clearance
- No interference
- Identify all piping
- Coordinate with other trades

From Heat Sources:

- Adequate distance from flues
- Away from heat-producing equipment
- Consider radiant heat
- May require insulation or shields

Chapter Summary

Gas piping materials include black steel (most common indoors), CSST (flexible alternative), polyethylene (underground), and copper tubing (limited use). Material selection depends on application, location, and local requirements. Each material has specific installation requirements and limitations.

Proper pipe sizing uses CSA B149.1 tables based on gas demand (BTU/hr converted to CFH), pipe length, allowable pressure drop, and specific gravity. The longest run method sizes entire system for worst case; branch length method optimizes each section. Equivalent length must be added for fittings.

Black steel installation requires proper threading to NPT standards, pipe joint compound on male threads only, adequate support spacing, and protection from damage. CSST installation requires manufacturer-specific procedures, proper fittings and tools, adequate support, and CRITICAL bonding per CSA B149.1 Clause 7.11.

Polyethylene pipe for underground use requires heat fusion joining, proper trenching and bedding, tracer wire, and transition to steel above grade. All piping must be tested per CSA B149.1 before placing in service.

Review Questions

Multiple Choice

1. Which material is NOT approved for gas piping?
    - a) Black steel pipe
    - b) Galvanized steel pipe
    - c) CSST
    - d) Polyethylene pipe
2. Pipe joint compound should be applied to:
    - a) Female threads only
    - b) Male threads only
    - c) Both male and female threads
    - d) No threads (use Teflon tape only)
3. The maximum support spacing for 3/4" steel pipe installed horizontally is:
    - a) 4 feet
    - b) 6 feet
    - c) 8 feet
    - d) 10 feet
4. CSST must be bonded per CSA B149.1 using minimum:

- a) #10 AWG copper
    - b) #8 AWG copper
    - c) #6 AWG copper
    - d) #4 AWG copper
5. Polyethylene pipe for gas service must be:
    - a) White
    - b) Black
    - c) Orange
    - d) Yellow
6. When sizing pipe using CSA B149.1 tables, the total appliance load should be converted to:
    - a) PSI
    - b) Cubic feet per hour (CFH)
    - c) Gallons per hour
    - d) Inches of water column
7. NPT pipe threads taper:
    - a) 1/4" per foot
    - b) 1/2" per foot
    - c) 3/4" per foot
    - d) 1" per foot
8. PE pipe joints must be made using:
    - a) Threaded connections
    - b) Compression fittings
    - c) Heat fusion
    - d) Glued joints
9. The minimum depth for underground PE gas pipe (below frost line) is typically:
    - a) 6 inches
    - b) 12 inches
    - c) 18 inches
    - d) 24 inches
10. CSST is primarily used for:
    - a) Underground installations
    - b) Indoor installations
    - c) High-pressure transmission
    - d) Water service lines

True or False

11. Galvanized steel pipe can be used for gas piping if it's new pipe.
12. CSST can be buried underground for service lines.
13. Propane requires larger pipe than natural gas for the same BTU/hr load.
14. Tracer wire must be installed with underground PE gas pipe.
15. Flexible appliance connectors can pass through walls if properly supported.

Short Answer

16. Explain why galvanized pipe is not permitted for gas piping. (3 marks)
17. List four advantages of CSST compared to black steel pipe. (4 marks)
18. Why must pipe joint compound be applied only to male threads and not female threads? (3 marks)
19. What is the purpose of bonding CSST systems, and what are the minimum bonding requirements? (5 marks)
20. Describe the proper procedure for transitioning from underground PE pipe to above-ground steel pipe. (4 marks)

Long Answer

21. You need to size gas piping for a residential natural gas installation with the following:
    - Furnace: 100,000 BTU/hr
    - Water heater: 40,000 BTU/hr
    - Range: 65,000 BTU/hr
    - Longest run from meter: 55 feet
    - Supply pressure: 7" W.C.
    - Allowable pressure drop: 0.5" W.C.

    Show all calculations and determine the required pipe size using the longest run method. (10 marks)

22. Describe the complete procedure for installing black steel gas pipe, from cutting and threading through final assembly. Include:
    - Threading requirements
    - Pipe joint compound application
    - Assembly procedure
    - Support requirements
    - Protection requirements (12 marks)
23. Compare CSST and black steel pipe for residential gas piping. Include:
    - Material characteristics
    - Installation procedures
    - Advantages and disadvantages of each
    - Cost considerations
    - Code requirements specific to each
    - When you would choose one over the other (15 marks)

Practical Exercises

Exercise 1: Pipe Threading Practice

Thread various sizes of pipe:

1. Cut pipe to specified length

2. Ream inside burr
3. Thread to proper length
4. Inspect threads for quality
5. Test-fit in coupling
6. Measure thread length
7. Document quality

Exercise 2: Pipe Sizing Calculations

Using CSA B149.1 tables, size piping for:

1. Given appliance loads
2. Measured pipe lengths
3. Specified pressure drops
4. Both natural gas and propane
5. Document all calculations
6. Justify pipe size selections

Exercise 3: System Layout Design

Design complete gas piping system:

1. Draw floor plan with appliance locations
2. Plan pipe routing
3. Measure all sections
4. Size each section
5. Calculate equivalent length with fittings
6. Prepare material list
7. Create installation drawing

Exercise 4: CSST Installation

Install CSST practice system:

1. Measure and cut CSST
2. Install fittings using striker tool
3. Route and support properly
4. Install bonding per code
5. Pressure test system
6. Document installation

Exercise 5: Pipe Assembly

Assemble gas piping system:

1. Thread all connections

2. Apply pipe dope correctly
3. Assemble system
4. Install supports
5. Verify all joints tight
6. Pressure test
7. Check for leaks

Exercise 6: PE Pipe Fusion

Practice PE pipe fusion:

1. Square cut pipe ends
2. Scrape oxidation
3. Heat fusion machine to proper temperature
4. Heat pipe ends
5. Join pipes
6. Verify proper bead formation
7. Test joint strength

Case Studies

Case Study 1: Undersized Piping

Scenario: A customer complains that when they turn on their gas dryer while the furnace is running, the furnace flames get very small and the furnace shuts down on limit. You measure gas pressure at the furnace and find it drops from 7" W.C. to 3" W.C. when the dryer starts. The system has 1/2" pipe for 80 feet from the meter.

Questions:

1. What is causing this problem?
2. Why does the furnace shut down?
3. Is 3" W.C. adequate for the furnace?
4. What pressure drop has occurred?
5. How would you verify the pipe is undersized?
6. What size pipe should have been installed?
7. What are the correction options?
8. How do you prevent this on future installations?

Case Study 2: CSST Without Bonding

Scenario: During an inspection, you discover a 3-year-old CSST installation with no bonding to the electrical ground system. The system appears otherwise properly installed. The homeowner says there's never been a problem.

Questions:

1. Is this a code violation?
2. What is the safety risk?
3. Can the system remain in service?
4. Who is responsible for correction?
5. How should it be corrected?
6. What if the homeowner refuses to correct it?
7. What documentation is required?
8. Could insurance be affected?

Case Study 3: Wrong Pipe Compound

Scenario: A recent gas piping installation is experiencing multiple leaks at threaded joints. Upon investigation, you find the installer used general-purpose Teflon tape without pipe dope, and applied it to both male and female threads. Some joints are also under-tightened.

Questions:

1. What are the problems with this installation?
2. Why is Teflon tape alone inadequate?
3. What's wrong with applying sealant to female threads?
4. How should joints have been sealed?
5. How tight should joints be?
6. What correction is required?
7. What testing is needed after correction?
8. What training does the installer need?

Case Study 4: PE Pipe Installation Error

Scenario: During inspection of an underground gas line installation, you find PE pipe installed with compression fittings instead of heat fusion. The installer says "compression fittings are approved for water, so they should work for gas too."

Questions:

1. Is this installation acceptable?
2. What is the proper joining method for PE gas pipe?
3. Why are compression fittings not acceptable?
4. What are the risks of this installation?
5. Can any of the installed pipe be salvaged?
6. What is the proper correction?

7. What testing is required?
8. What notification to authorities is required?

Case Study 5: Pipe Size Calculation Error

Scenario: You're reviewing plans for a gas installation. The designer sized the piping for the furnace (100,000 BTU) and water heater (40,000 BTU) but didn't include the range (65,000 BTU) or dryer (35,000 BTU) in the calculations. The piping is sized as 3/4" for the entire 45-foot run from meter.

Questions:

1. What is the error in the design?
2. What is the total system demand?
3. Is 3/4" pipe adequate for this installation?
4. What size should be used?
5. What would happen with the undersized pipe?
6. How would you explain this to the customer?
7. What is the cost impact of the correct sizing?
8. What if the piping is already installed?

Case Study 6: Mixed Materials

Scenario: You find an installation where galvanized pipe was used for the first 10 feet from the meter, then transitioned to black pipe for the remainder of the system. The installer thought galvanized was "better" near the meter because it's outdoors.

Questions:

1. Is this installation compliant with CSA B149.1?
2. What problems does galvanized pipe cause?
3. When are the problems likely to manifest?
4. What correction is required?
5. Can the black pipe portion be retained?
6. What if galvanized shows no problems currently?
7. How do you explain this to the property owner?
8. What are the liability implications?

Key Terms

Branch Length Method: Pipe sizing method that sizes each section based on its specific load and length.

CSST (Corrugated Stainless Steel Tubing): Flexible stainless steel tubing for gas piping, requires bonding.

Equivalent Length: Additional length added to account for friction in fittings.

Heat Fusion: Joining method for polyethylene pipe using heat to melt and fuse pipe together.

Longest Run Method: Pipe sizing method using longest distance from meter to appliance for entire system.

NPT (National Pipe Taper): Standard tapered thread for pipe, seals on taper.

PE Pipe (Polyethylene): Plastic pipe approved for underground gas piping, must be yellow.

Pipe Joint Compound (Pipe Dope): Sealant applied to male threads for gas-tight joints.

SDR (Standard Dimension Ratio): Ratio of pipe diameter to wall thickness for PE pipe.

Specific Gravity (SG): Weight of gas compared to equal volume of air (natural gas 0.60, propane 1.52).

Tracer Wire: Copper wire installed with PE pipe to allow electronic locating.

Water Column (W.C.): Pressure measurement unit; inches of water column height.

End of Chapter 6

CHAPTER 7

Gas Meters and Regulators

Learning Objectives

Upon completion of this chapter, students will be able to:

1. Identify different types of gas meters and explain their operation
2. Read gas meters accurately and calculate consumption
3. Understand meter capacity ratings and sizing
4. Describe service regulator types and their functions
5. Explain the difference between first-stage and second-stage regulation
6. Select appropriate regulators for different applications
7. Adjust regulator outlet pressure correctly
8. Test regulator lock-up pressure per code requirements
9. Diagnose common regulator problems
10. Understand overpressure protection requirements

7.1 Gas Meters

Gas meters measure the volume of gas consumed for billing purposes and provide information about system capacity.

Purpose of Gas Meters

Primary Functions:

1. **Billing:** Measure consumption for customer billing
2. **Capacity:** Indicate maximum flow rate available
3. **System monitoring:** Track usage patterns
4. **Leak detection:** Unusual consumption indicates leaks

Ownership:

- Utility owns meter (natural gas)
- Propane supplier may own or lease meter
- Customer never owns utility meter
- Tampering with meter is illegal

Diaphragm Meters (Displacement Meters)

Most Common Type for Residential and Small Commercial

Construction:

- Metal case housing
- Internal diaphragms (flexible chambers)
- Valves directing gas flow
- Mechanical counter (register)
- Inlet and outlet connections

Operation:

1. Gas enters meter
2. Valves direct gas into first chamber
3. Diaphragm expands, filling chamber with measured volume
4. Valve switches, directs gas to second chamber
5. First chamber empties through outlet
6. Cycle repeats continuously
7. Each cycle = specific volume
8. Mechanical linkage counts cycles
9. Register displays total volume

Advantages:

- Accurate
- Reliable
- No power required
- Long service life (20-30 years)
- Wide range of sizes
- Proven technology

Disadvantages:

- Moving parts (diaphragms, valves)
- Can freeze if moisture present
- Requires periodic recalibration
- Size/weight for large capacities
- Pressure drop through meter

Capacity Range:

- Residential: 175-250 CFH (1.75-2.5 m^3/h) typical
- Small commercial: Up to 10,000 CFH
- Larger for industrial applications

Reading Diaphragm Meters:

Dial Configuration:

- Multiple dials (typically 4-6)
- Each dial represents place value
- Rightmost = ones
- Next left = tens, hundreds, thousands, etc.
- Some dials rotate clockwise, others counterclockwise

Reading Procedure:

1. Start with leftmost (largest value) dial
2. Read each dial from left to right
3. If pointer between numbers, use lower number
4. Record all digits
5. Note units (cubic feet, cubic meters)

Example:

```
[1000s] [100s] [10s] [1s]
   4       7     3    6
```

Reading: 4,736 cubic feet (or cubic meters, depending on meter)

Test Dials:

- Some meters have test dials
- Complete rotation = specific volume (e.g., 1/2 cubic foot)
- Used for leak testing
- Useful for monitoring small flows

Rotary Meters

Used for Larger Commercial/Industrial Applications

Construction:

- Rotating impellers/vanes
- Precision-machined case
- Electronic or mechanical register
- Larger capacity than diaphragm meters

Operation:

- Gas flow turns impellers

- Rotation speed proportional to flow rate
- Counter records rotations
- More compact than large diaphragm meters

Advantages:

- Higher capacity
- Smaller size for capacity
- Lower pressure drop
- More accurate at high flows

Disadvantages:

- More expensive
- May require filtration
- More maintenance
- Not as common in residential

Capacity Range:

- 3,000 to 100,000+ CFH
- Commercial and industrial applications

Turbine Meters

High-Capacity Applications

Construction:

- Turbine wheel in gas stream
- Electronic sensor counts rotations
- Digital register
- High-flow, low pressure drop

Operation:

- Gas flow spins turbine
- Speed proportional to flow rate
- Electronic counter
- Very accurate at design flow

Applications:

- Large commercial
- Industrial facilities
- High-volume users

- Usually utility-specified

Ultrasonic Meters

Modern Technology

Operation:

- Sound waves measure gas velocity
- No moving parts
- Electronic measurement
- Very accurate

Advantages:

- No moving parts (no wear)
- Wide measurement range
- Low pressure drop
- Long service life
- Remote monitoring capable

Disadvantages:

- Expensive
- Requires power
- Complex technology

Applications:

- Large commercial/industrial
- Where accuracy critical
- Modern installations
- Growing in use

Meter Sizing and Capacity

Meter Capacity Rating:

- Maximum continuous flow rate
- Expressed in cubic feet per hour (CFH) or cubic meters per hour (m^3/h)
- Must handle peak demand
- Oversizing creates minimal penalty
- Undersizing causes pressure drop

Sizing Considerations:

Total Connected Load:

- Sum all appliance inputs
- Convert to CFH (BTU/hr ÷ heating value)
- Add safety factor (typically 25-50%)

Example:

- Connected load: 240,000 BTU/hr
- Natural gas: 240,000 ÷ 1,000 = 240 CFH
- Safety factor: 240 × 1.25 = 300 CFH
- Select meter: 250-400 CFH capacity

Utility Determination:

- Utilities typically size and install meters
- Based on connected load or projected usage
- May limit capacity to control costs
- Upgrades available if needed

Pressure Drop Through Meter:

- All meters create pressure drop
- Greater at higher flows
- Must account for in system design
- Typically 0.25-0.5" W.C. at rated capacity

Meter Installation Requirements

Location (CSA B149.1):

Outdoors Preferred:

- Protected from physical damage
- Accessible for reading and service
- Away from ignition sources
- Adequate clearances
- Protected from weather (overhead cover)

Indoors (where permitted):

- Well-ventilated space
- Accessible location
- Not in sleeping areas
- Not in bathrooms
- Away from electrical equipment

- Adequate clearances

Clearances (Minimum):

- 3 ft (1 m) from ignition sources
- 3 ft (1 m) from electric meters
- 3 ft (1 m) from building openings (below)
- 1 ft (0.3 m) from building openings (to side)
- 10 ft (3 m) from above-ground propane tank

Installation Details:

- Level and plumb
- Properly supported
- Protected from damage (vehicle guards if needed)
- Unions or flanges for removal
- Valves on both sides (utility typically installs)
- Proper venting if regulator integral
- Drip leg at inlet (condensation)

Meter Numbering:

- Each meter has unique serial number
- Used for billing and tracking
- Never remove or alter
- Record for documentation

Meter Reading and Consumption Calculation

Reading for Consumption:

1. Record initial reading: 4,736 cubic feet
2. Record final reading (1 month later): 5,921 cubic feet
3. Calculate consumption: 5,921 - 4,736 = 1,185 cubic feet
4. Convert to therms or GJ for billing:
    - 1 therm = 100,000 BTU = 100 cubic feet (approximately)
    - 1,185 cubic feet ÷ 100 = 11.85 therms

Temperature and Pressure Correction:

- Gas volume varies with temperature and pressure
- Utilities apply correction factors
- Billing at standard conditions
- Customer sees corrected usage

Estimating Appliance Consumption:

Example: Furnace

- Input: 100,000 BTU/hr
- Consumption: 100,000 ÷ 1,000 = 100 CFH when running
- Runs 8 hours per day average in winter
- Daily consumption: 100 × 8 = 800 cubic feet
- Monthly: 800 × 30 = 24,000 cubic feet

7.2 Service Regulators

Regulators reduce gas pressure and maintain constant outlet pressure despite varying inlet pressure or flow demand.

Regulator Function

Purpose:

- Reduce high pressure to usable pressure
- Maintain constant outlet pressure
- Protect appliances from over-pressure
- Compensate for supply pressure variations
- Allow proper appliance operation

How Regulators Work:

Basic Components:

1. **Diaphragm:** Flexible membrane sensing outlet pressure
2. **Spring:** Provides force to set outlet pressure
3. **Valve:** Opens/closes to control flow
4. **Vent:** Allows diaphragm to sense atmospheric pressure

Operation Principle:

1. Spring pushes diaphragm down
2. Diaphragm connected to valve
3. Valve opens, allowing gas flow
4. Outlet pressure builds
5. Outlet pressure pushes diaphragm up against spring
6. When outlet pressure = spring force, valve holds steady position
7. If outlet pressure drops (demand increases), spring pushes valve open more
8. If outlet pressure rises (demand decreases), pressure pushes valve closed
9. Self-regulating balance maintains setpoint

This is automatic and continuous - no external power needed.

Types of Service Regulators

Single-Stage Regulators

Function:

- Reduce pressure in one step
- From supply pressure directly to appliance pressure

Natural Gas Single-Stage:

- Inlet: 60 PSI to 5 PSI (varies by utility)
- Outlet: 5-7" W.C. (typically 7" W.C.)
- One regulator does entire pressure reduction

Propane Single-Stage:

- Inlet: Tank pressure (varies with temperature, 20-250+ PSIG)
- Outlet: 11" W.C. (residential) or 13" W.C. (mobile home)
- Handles wide inlet pressure variation

Advantages:

- Simple
- Fewer components
- Lower cost
- Adequate for many applications

Disadvantages:

- Outlet pressure varies with inlet pressure changes
- Less precise control
- Greater pressure drop under high flow
- Not ideal for large inlet pressure variations

Applications:

- Small propane systems (where not much better option)
- Natural gas where inlet pressure stable
- Simple installations
- Low-demand systems

Two-Stage Regulation

Modern Standard for Propane, Common for Natural Gas

First-Stage Regulator:

Location:

- At or near supply source
- Propane: at tank
- Natural gas: at meter or service entry

Function:

- Reduce high/variable pressure to intermediate pressure
- Buffer between supply and distribution

Propane First-Stage:

- Inlet: Tank pressure (20-250+ PSIG)
- Outlet: 10 PSI (27.7" W.C.) typical
    - Sometimes 15 PSI for long distribution runs
- Handles wide inlet variation
- Maintains constant intermediate pressure

Natural Gas First-Stage:

- Inlet: Utility delivery pressure (60 PSI or higher)
- Outlet: 2 PSI (55" W.C.) typical for larger systems
- Used in large commercial/industrial
- Allows higher-pressure distribution (smaller pipe)

Second-Stage Regulator:

Location:

- At or near building
- After first-stage reduction
- Just before entering structure

Function:

- Reduce intermediate pressure to appliance pressure
- Final pressure control
- Protects appliances

Second-Stage Outlet Pressures:

- Natural gas: 7" W.C. typical (appliances rated 7" or 7" ±)
- Propane (residential dwelling): **11" W.C.**
- Propane (mobile/manufactured home): **13" W.C.**

Why Two Stages:

- More stable outlet pressure
- Better flow characteristics
- Protects against first-stage failure
- Allows smaller distribution piping (higher intermediate pressure)
- Industry standard for quality installations

Line Pressure Regulators:

Definition:

- Integral two-stage in one body
- Or high-capacity single-stage line regulators
- Mounted at tank or building

Function:

- Single device, two-stage function internally
- Or robust single-stage design

Applications:

- Residential propane (common)
- Small commercial
- Simpler installation
- Where two separate regulators not desired

Limitations:

- Fixed capacity
- All pressure drop at one location
- Limited by piping downstream
- May not work for complex systems

Appliance Regulators

Built into Appliances:

- Most appliances have internal regulator
- Reduces supply pressure (7" W.C. or 11" W.C.) to manifold pressure
- Natural gas: 3.5" W.C. manifold typical

- Propane: 10" W.C. manifold typical
- Adjustable spring or fixed

Not All Appliances:

- Some rely on supply pressure being correct
- Check appliance specifications
- Conversion kits change appliance regulator

7.3 Regulator Selection and Sizing

Selecting the correct regulator ensures proper system operation and appliance performance.

Capacity Requirements

Calculate System Demand:

- Sum all appliance inputs (BTU/hr)
- Convert to CFH (natural gas ÷ 1,000, propane ÷ 2,500)
- Add safety factor (10-25%)

Example:

- Total load: 240,000 BTU/hr
- Natural gas: 240,000 ÷ 1,000 = 240 CFH
- With 20% safety factor: 240 × 1.20 = 288 CFH
- Select regulator rated ≥ 288 CFH

Manufacturer Ratings:

- Regulators rated in CFH at specific conditions
- Rating usually at outlet pressure setpoint
- Check capacity curves for flow vs. pressure

Oversizing Considerations:

- Moderate oversizing acceptable
- Excessive oversizing can cause instability
- Usually stay within 2-3 times required capacity
- Follow manufacturer recommendations

Inlet Pressure Requirements

First-Stage Regulators:

- Must handle maximum inlet pressure
- Propane: design for 250-300 PSIG minimum
- Natural gas: per utility supply pressure
- Check regulator rating

Second-Stage Regulators:

- Inlet matches first-stage outlet
- Typically 10 PSI for propane systems
- Must not exceed regulator inlet rating

Outlet Pressure Requirements

Match Appliance Requirements:

Natural Gas:

- Most appliances: 5-7" W.C. supply pressure
- Check appliance rating plate
- Standard: 7" W.C.

Propane:

- Residential dwellings: 11" W.C.
- Mobile/manufactured homes: 13" W.C.
- Appliances designed for these pressures

Adjustable vs. Fixed:

- Adjustable regulators: spring tension adjustable
- Fixed regulators: non-adjustable spring
- Adjustable allows field setup
- Fixed simpler but less flexible

Vent Requirements

Why Regulators Vent:

- Diaphragm chamber must be vented to atmosphere
- Allows diaphragm to sense atmospheric pressure
- Reference point for regulation
- Small amounts of gas may vent during operation or diaphragm failure

Vent Location (CSA B149.2 for Propane):

- Must terminate outdoors
- Minimum 3 m (10 ft) from ignition sources
- Minimum 3 m (10 ft) from building openings below vent
- Minimum 1.5 m (5 ft) from mechanical ventilation intakes
- Turn downward or screened to prevent insect/water entry
- Not obstructed

Vent Limiting Devices (VLD):

- Special internal vent design
- Limits gas release if diaphragm fails
- May allow indoor installation in some cases
- Must meet specific standards
- Not common in Canada

First-Stage Regulators:

- Vent at tank location
- Outdoor location typically
- Integrated with relief valve sometimes

Second-Stage Regulators:

- Must vent per code
- Often point of inspection failure
- Critical safety requirement

Special Applications

High-Capacity Regulators:

- Commercial/industrial
- May require pilot-operated designs
- Multiple regulators in parallel
- Consult with supplier/engineer

Overpressure Protection:

- Some applications require overpressure shutdown devices
- Monitors outlet pressure
- Shuts off flow if excessive
- Required by code in some jurisdictions for larger systems

7.4 Regulator Installation

Proper installation ensures safe, reliable operation.

Location Requirements

First-Stage (Propane at Tank):

- Attached to tank valve or nearby
- Outdoor location
- Accessible for service
- Protected from physical damage
- Vent properly oriented
- Relief valve outlet oriented correctly

Second-Stage (at Building):

- Exterior of building preferred
- Just before entering structure
- Protected from weather (overhang helpful)
- Accessible for service
- Vent properly terminated
- Upstream of building piping

Line Pressure (Integral Two-Stage):

- Can be at tank or building
- Outdoor location
- Adequate capacity for entire system
- Piping sized for supply pressure delivered

Mounting and Support

Support Requirements:

- Adequate support for weight
- No stress on connections
- Level installation
- Protected from vibration
- Rigid mounting

Connections:

- Proper pipe sizing inlet and outlet
- Unions for service removal
- No strain on regulator
- Valves for isolation
- Drip leg at inlet (if condensation possible)

Pressure Testing Considerations

Testing Around Regulators:

- Regulators can be damaged by excessive pressure
- May need isolation during testing
- Check manufacturer limits
- Remove or bypass for high-pressure tests
- Reinstall/reopen after testing

Test Plugs:

- Some regulators have test plugs for pressure measurement
- 1/8" NPT taps
- Use for setting and verifying pressure
- Seal properly after testing

7.5 Regulator Adjustment and Testing

Proper adjustment ensures correct outlet pressure for appliance operation.

Outlet Pressure Adjustment

Tools Required:

- Manometer (digital or U-tube)
- Screwdriver (for adjustment)
- Wrenches (if cover removal needed)

Procedure:

1. Preparation:

- Ensure appliances off or minimal load
- Connect manometer to test port (or downstream pressure tap)
- Manometer to sense outlet pressure

2. Access Adjustment:

- Some regulators: cap removal required
- Some regulators: external adjustment screw
- Note seal (may need inspector verification after adjustment)

3. Initial Reading:

- Start appliances to create flow (or note static pressure)
- Read outlet pressure
- Compare to target:
  - Natural gas: typically 7" W.C.
  - Propane residential: 11" W.C.
  - Propane mobile home: 13" W.C.

4. Adjustment:

- Turn adjustment screw:
  - Clockwise = increase pressure (tighten spring)
  - Counter-clockwise = decrease pressure (loosen spring)
- Small adjustments (1/4 turn at a time)
- Allow pressure to stabilize
- Check reading

5. Verification:

- Cycle appliances on/off
- Verify pressure stable
- Check at various loads (low and high)
- Verify no excessive droop (pressure drop under load)

6. Lock-Up Pressure Test:

- Turn off all appliances (no flow)
- Pressure rises slightly
- Should not exceed:
  - Natural gas: typically 10-12" W.C. maximum
  - Propane residential: typically 14" W.C. maximum
  - Propane mobile home: typically 16" W.C. maximum
- Excessive lock-up indicates regulator problem

7. Documentation:

- Record inlet pressure
- Record outlet pressure (no load and under load)
- Record lock-up pressure
- Date and technician signature

Lock-Up Pressure

Definition:

- Outlet pressure when no gas flows
- Regulator valve fully closed
- Normal for pressure to rise slightly

Acceptable Lock-Up:

- Should be close to setpoint
- CSA B149.1/B149.2 specify maximums:
    - Second-stage: typically no more than 2" W.C. above setpoint
    - First-stage: per manufacturer

Testing Procedure:

1. Set outlet pressure under flow
2. Close all appliance valves (no flow)
3. Wait for pressure to stabilize
4. Read and record maximum pressure
5. Verify within acceptable range

Excessive Lock-Up Causes:

- Regulator valve not seating properly
- Damaged valve seat
- Debris in valve
- Spring tension too high
- Regulator failure

Excessive Lock-Up Consequences:

- Over-fires appliances
- Damages appliance components
- Safety concern
- Failed inspection

Correction:

- Check for debris
- Clean if possible
- Replace regulator if damaged
- Do not attempt repair of sealed regulators
- Verify correction with retest

Common Adjustment Problems

Pressure Won't Adjust:

- Adjustment screw may be seized
- Limit of adjustment range reached
- Wrong regulator for application
- Internal failure

Pressure Unstable:

- Hunting (pressure oscillates)
- Regulator undersized
- Vent obstructed
- Diaphragm damage
- Debris in valve

Pressure Drops Under Load:

- Undersized regulator
- Restricted inlet
- Failing regulator
- Excessive demand

7.6 Regulator Testing and Maintenance

Regular testing ensures continued safe operation.

Periodic Testing

When to Test:

- Initial installation
- Annual maintenance
- After any repairs
- If performance issues
- Code-required intervals

Test Sequence:

1. Visual Inspection:

- Physical damage
- Corrosion
- Vent clear and properly oriented
- Connections tight
- No gas odor
- Diaphragm housing intact

2. Inlet Pressure:

- Measure and record
- Verify adequate for regulator
- Compare to expected

3. Outlet Pressure (Operating):

- With appliances running
- Various load conditions
- Record pressure

4. Outlet Pressure (Lock-Up):

- All appliances off
- Maximum no-flow pressure
- Record and verify acceptable

5. Droop Test:

- Pressure difference between lock-up and full load
- Should be minimal
- Excessive droop indicates undersizing or failure

6. Vent Operation:

- Verify vent clear
- Check for gas leakage at vent
- Slight venting normal during operation
- Excessive venting indicates diaphragm failure

Maintenance

Customer-Accessible Maintenance:

- None - regulators are sealed units
- Only technicians should service
- Never attempt repairs

Technician Maintenance:

- External cleaning
- Vent inspection and clearing
- Pressure testing and adjustment
- Leak testing connections
- Visual inspection

When to Replace:

- Excessive lock-up (unfixable)
- Unstable operation
- Physical damage
- Corrosion
- Vent damage
- Age (typically 15-20 years)
- Failed testing
- After fire exposure

Replacement Procedure:

1. Shut off gas supply
2. Relieve pressure downstream
3. Disconnect old regulator
4. Inspect piping
5. Install new regulator with proper orientation
6. Pressure test connections
7. Restore gas service
8. Set outlet pressure
9. Test lock-up pressure
10. Document replacement

7.7 Troubleshooting Regulators

Insufficient Gas Pressure/Flow

Symptoms:

- Appliances won't light or operate poorly
- Yellow flames
- Pilot outages
- Low heat output

Possible Causes:

1. Low Inlet Pressure:

- Empty propane tank
- Undersized first-stage regulator
- Restricted supply line
- Utility supply problem (natural gas)
- Check: Measure inlet pressure

2. Failed Regulator:

- Diaphragm rupture
- Spring failure
- Valve seat damage
- Frozen regulator (moisture/propane)
- Check: Measure outlet pressure, replace if low

3. Undersized Regulator:

- Insufficient capacity for demand
- Pressure drops under load
- Check: Calculate actual demand vs. regulator capacity

4. Obstructed Vent:

- Regulator cannot regulate properly
- Insects, ice, debris blocking vent
- Check: Inspect and clear vent

5. Restricted Piping:

- Downstream blockage
- Undersized piping creating excessive drop
- Check: Pressure at regulator vs. at appliances

Excessive Gas Pressure

Symptoms:

- Appliances over-fire
- Rollout or lockout
- Noisy combustion
- Excessive short cycling

Possible Causes:

1. Excessive Lock-Up:

- Regulator not closing valve completely
- Adjustment too high
- Failed valve seat
- Check: Lock-up pressure test

2. Wrong Regulator:

- Natural gas regulator on propane
- Wrong outlet pressure setting
- Check: Verify regulator specifications

3. Failed Regulator:

- Stuck open
- Spring failure
- Diaphragm damage
- Check: Outlet pressure under all conditions

4. First-Stage Failure (Two-Stage System):

- First stage not regulating
- Full tank pressure to second stage
- Second stage overwhelmed
- Check: Measure between stages

Pressure Fluctuations

Symptoms:

- Pressure varies during operation
- Appliances cycle
- Inconsistent performance

Possible Causes:

1. Hunting:

- Regulator oscillating
- Oversized regulator
- Vent problem
- Internal regulator issue
- Check: Observe pressure with continuous monitoring

2. Demand Changes:

- Normal slight variation
- Other appliances cycling
- May be normal if minor

3. Supply Variations:

- First-stage problem (two-stage system)
- Utility supply fluctuation (natural gas)

- Check: Monitor inlet pressure

Frozen Regulator

Propane Specific Problem:

Cause:

- High gas flow causes cooling (Joule-Thomson effect)
- Moisture in gas freezes at regulator
- Ice blocks regulator operation
- External moisture freezes on cold regulator body

Prevention:

- Proper tank sizing (adequate vaporization)
- Dry gas (proper processing)
- Regulator covers in cold weather
- Heating tape if necessary (commercial)

Symptoms:

- Pressure drop during operation
- Frost formation on regulator
- Appliances lose performance

Correction:

- Reduce demand or increase supply
- Allow regulator to thaw
- Address root cause (undersized tank, wet gas)

7.8 Overpressure Protection

Some installations require overpressure protection devices.

When Required

CSA B149.1 Requirements:

- Check current code edition
- Some larger commercial/industrial installations
- When specified by engineer

- Where failure creates excessive hazard
- Check local authorities

Purpose:

- Protect against regulator failure
- Prevent excessive pressure at appliances
- Additional safety layer

Types of Overpressure Devices

1. Overpressure Shut-Off Valve (OPSV):

- Monitors outlet pressure
- Automatically closes if pressure exceeds setpoint
- Requires manual reset
- Installed downstream of regulator

2. Relief Valves:

- Vents gas if pressure excessive
- Does not shut off flow
- Protects piping
- Required on propane tanks

3. Monitoring Regulator:

- Second regulator in series
- Normally wide open (no regulation)
- Closes if senses excessive pressure
- Backup to main regulator

4. Slam-Shut Device:

- Closes immediately if pressure excessive
- Protects downstream equipment
- Requires reset

Installation

Location:

- Downstream of main regulator
- Upstream of appliances
- Accessible for testing and reset
- Properly vented if device vents

Setting:

- Set above normal operating pressure
- Below appliance maximum rating
- Typical: 25-50% above normal
- Per manufacturer and code

Testing:

- Initial installation
- Annually
- After any system changes
- Simulate overpressure condition
- Verify operation and reset

Chapter Summary

Gas meters measure consumption for billing and indicate system capacity. Diaphragm meters are most common for residential use, with rotary and turbine meters for larger applications. Meters are sized based on total connected load plus safety factor, typically by the utility.

Service regulators reduce gas pressure and maintain constant outlet pressure for appliance operation. Single-stage regulators reduce pressure in one step, while two-stage regulation provides more stable pressure control. Modern propane installations use two-stage regulation: first stage at tank reduces to 10 PSI, second stage at building reduces to 11" W.C. (residential) or 13" W.C. (mobile home).

Regulator selection requires calculating system demand, verifying inlet pressure compatibility, and matching outlet pressure to appliance requirements. All regulators must be properly vented per code. Installation requires proper location, support, and orientation.

Regulator adjustment involves setting outlet pressure under load and verifying acceptable lock-up pressure. Excessive lock-up indicates regulator failure requiring replacement. Regular testing ensures continued safe operation. Common problems include insufficient pressure (undersized or failed regulator), excessive pressure (failed regulation), and pressure fluctuations (hunting or vent obstruction).

Review Questions

Multiple Choice

1. The most common type of gas meter for residential use is:
   - a) Rotary meter
   - b) Turbine meter
   - c) Diaphragm meter
   - d) Ultrasonic meter
2. A propane first-stage regulator typically reduces tank pressure to:
   - a) 11" W.C.
   - b) 7" W.C.
   - c) 10 PSI
   - d) 20 PSI
3. The outlet pressure for a propane second-stage regulator in a residential dwelling should be:
   - a) 7" W.C.
   - b) 10" W.C.
   - c) 11" W.C.
   - d) 13" W.C.
4. Lock-up pressure is measured when:
   - a) All appliances are operating
   - b) No gas is flowing
   - c) One appliance is operating
   - d) Gas is being delivered at maximum rate
5. To increase regulator outlet pressure, turn the adjustment screw:
   - a) Clockwise
   - b) Counter-clockwise
   - c) Either direction
   - d) Do not adjust - call manufacturer
6. Regulator vents must terminate:
   - a) Indoors for monitoring
   - b) In crawl space
   - c) Outdoors per code requirements
   - d) Back into gas supply
7. A frozen propane regulator is typically caused by:
   - a) Cold weather only
   - b) High flow causing cooling and moisture freezing
   - c) Defective regulator
   - d) Wrong gas type
8. When reading a diaphragm gas meter, if the pointer is between two numbers:
   - a) Use the higher number
   - b) Use the lower number
   - c) Estimate halfway
   - d) Round to nearest number
9. The outlet pressure for a propane second-stage regulator in a mobile home should be:
   - a) 7" W.C.
   - b) 10" W.C.
   - c) 11" W.C.
   - d) 13" W.C.

10. Excessive regulator lock-up pressure indicates:
    - a) Normal operation
    - b) Regulator needs adjustment
    - c) Regulator failure requiring replacement
    - d) Inlet pressure too high

True or False

11. Gas meters are owned by the customer in natural gas installations.
12. Two-stage regulation provides more stable outlet pressure than single-stage.
13. All gas appliance regulators require external venting to outdoors.
14. Lock-up pressure should be significantly higher than operating pressure.
15. Regulator adjustment should only be performed by qualified technicians.

Short Answer

16. Explain the difference between first-stage and second-stage regulation in a propane system. Include inlet and outlet pressures for each stage. (5 marks)
17. List four symptoms that would indicate a failed or undersized regulator. (4 marks)
18. Why must regulator vents terminate outdoors? Where must they be located relative to building openings? (4 marks)
19. Describe the procedure for testing regulator lock-up pressure. (4 marks)
20. What is regulator "hunting" and what causes it? (3 marks)

Long Answer

21. Describe the complete procedure for adjusting a propane second-stage regulator outlet pressure in a residential installation. Include:
    - Required tools and equipment
    - Safety precautions
    - Step-by-step adjustment procedure
    - Testing and verification
    - Acceptable pressure ranges
    - Documentation requirements (12 marks)
22. A customer complains that their furnace "doesn't heat well" and sometimes shuts down. You measure the gas pressure at the furnace and find it's 4" W.C. during operation (should be 7" W.C.). Describe your systematic troubleshooting approach. Include:
    - Possible causes of low pressure
    - Tests and measurements you would perform
    - How to isolate the problem
    - Likely solutions
    - How to verify correction (15 marks)
23. Compare single-stage and two-stage pressure regulation systems. Include:
    - How each system operates
    - Pressure levels at each stage
    - Advantages and disadvantages of each

- Applications where each is appropriate
- Why two-stage is preferred for modern propane installations
- Cost and complexity considerations (15 marks)

Practical Exercises

Exercise 1: Meter Reading

Practice reading various gas meters:

1. Dial-type meters (various configurations)
2. Record readings accurately
3. Calculate consumption between readings
4. Convert to therms or GJ
5. Estimate costs

Exercise 2: Regulator Pressure Testing

On training equipment or actual installation:

1. Connect manometer to test point
2. Measure inlet pressure
3. Measure outlet pressure (under load)
4. Measure lock-up pressure (no flow)
5. Calculate pressure droop
6. Document all readings
7. Determine if regulator acceptable

Exercise 3: Regulator Adjustment

Under supervision, adjust regulator:

1. Measure initial outlet pressure
2. Access adjustment screw
3. Make calculated adjustment
4. Verify new pressure
5. Test lock-up pressure
6. Cycle appliances to verify stability
7. Document final settings

Exercise 4: Regulator Capacity Calculation

Calculate and select regulator:

1. Given appliance loads
2. Calculate total CFH demand
3. Add safety factor
4. Select appropriate regulator from catalog
5. Verify capacity adequate
6. Document selection rationale

Exercise 5: Two-Stage System Testing

On propane two-stage system:

1. Measure tank pressure (inlet to first stage)
2. Measure between stages (outlet first stage / inlet second stage)
3. Measure final outlet pressure (outlet second stage)
4. Verify each stage operating correctly
5. Test lock-up at second stage
6. Document complete system pressures

Exercise 6: Troubleshooting Simulation

Given problem scenarios:

1. Low pressure at appliances
2. High pressure causing rollout
3. Pressure fluctuations
4. Frozen regulator

For each:

- List possible causes
- Describe diagnostic steps
- Identify most likely cause
- Recommend solution
- Verify correction method

Case Studies

Case Study 1: Undersized Regulator

Scenario: A homeowner complains that when they run hot water while cooking on the range, the furnace flame gets very small and sometimes shuts off on limit. Gas pressure measurement shows:

- At meter outlet: 11" W.C. (propane residential, correct)
- At furnace (with all appliances on): 6" W.C.
- Lock-up pressure at meter: 12" W.C. (acceptable)

The system has a line pressure (integral two-stage) regulator rated 300 CFH. Total connected load is 285,000 BTU (114 CFH propane).

Questions:

1. What is causing the low pressure at the furnace?
2. Is the regulator undersized based on BTU load?
3. What else could cause this pressure drop?
4. How do you diagnose further?
5. What is the solution?
6. How do you size the replacement regulator?
7. Could piping be the problem instead?
8. How do you verify the correction?

Case Study 2: Excessive Lock-Up

Scenario: During annual inspection, you test a propane second-stage regulator:

- Outlet pressure (under load): 11" W.C. (correct)
- Lock-up pressure (no flow): 18" W.C.
- Acceptable maximum: 14" W.C.

The homeowner says everything works fine and doesn't want to spend money on repairs.

Questions:

1. Is this a code violation?
2. What are the risks of excessive lock-up?
3. What could happen to the appliances?
4. Can you adjust the regulator to fix this?
5. What is the proper correction?
6. Can the system remain in service?
7. What do you tell the homeowner?
8. What documentation is required?
9. What if the homeowner refuses repairs?

Case Study 3: Wrong Regulator Installed

Scenario: You're called for a "furnace problem." You find:

- System is propane
- Building is a manufactured (mobile) home

- Second-stage outlet pressure: 11" W.C.
- Should be: 13" W.C. for mobile homes

The furnace is rated for 13" W.C. supply. It lights but doesn't produce full heat. The system was installed 6 months ago.

Questions:

1. What is wrong with this installation?
2. Why does the furnace light but not heat properly?
3. What pressure should be supplied to mobile home appliances?
4. Is this a code violation?
5. What correction is required?
6. Who is responsible (original installer, supplier, homeowner)?
7. Are other appliances affected?
8. How do you verify all appliances after correction?

Case Study 4: Frozen Regulator

Scenario: On a cold winter day (-25°C), a customer calls saying they have no heat. You arrive and find:

- Propane system
- 250-gallon tank, gauge shows 35%
- Heavy frost on regulator body
- No gas pressure at appliances
- System was working fine in warmer weather
- Total demand: 180,000 BTU (furnace 100,000, water heater 40,000, range 40,000)

Questions:

1. What is causing the frozen regulator?
2. Why does this happen in cold weather but not warm?
3. Is the tank too small?
4. Calculate approximate vaporization capacity at -25°C
5. What is the immediate solution?
6. What is the long-term solution?
7. Could a vaporizer help?
8. What do you tell the customer?

Case Study 5: Vent Obstruction

Scenario: You're called to investigate "strange pressure problems." You find:

- Second-stage regulator vent is blocked by wasp nest
- Outlet pressure fluctuates wildly (8-15" W.C.)

- Appliances operate erratically
- Sometimes cycling, sometimes over-firing
- Homeowner painted regulator and vent last summer

Questions:

1. How does a blocked vent affect regulator operation?
2. Why is the pressure unstable?
3. What damage could have occurred?
4. What is the immediate action?
5. Can the regulator be salvaged?
6. What testing is required after clearing vent?
7. How do you prevent recurrence?
8. What do you tell the homeowner about painting gas equipment?

Case Study 6: First-Stage Failure in Two-Stage System

Scenario: Multiple appliances over-firing and shutting down on high limit. You measure:

- Propane tank pressure: 150 PSIG (normal for temperature)
- Between first and second stage: 150 PSIG (should be 10 PSI)
- Second-stage outlet: Fluctuating 12-20" W.C. (should be stable 11")

Questions:

1. Which regulator has failed?
2. Why is the second stage unable to regulate properly?
3. Is this an emergency/safety issue?
4. Can the system operate safely?
5. What is the proper repair?
6. Could the second-stage regulator also be damaged?
7. What testing is required after replacement?
8. How do you prevent this type of failure?

Key Terms

Diaphragm Meter: Positive displacement meter using flexible chambers to measure gas volume.

Droop: Pressure decrease from lock-up to operating pressure under load.

First-Stage Regulator: Reduces high supply pressure to intermediate pressure (typically 10 PSI for propane).

Hunting: Regulator oscillation causing pressure fluctuations.

Line Pressure Regulator: Single device providing two-stage function or high-capacity single-stage regulation.

Lock-Up Pressure: Maximum outlet pressure when no gas flows; indicates regulator health.

Overpressure Shut-Off Valve (OPSV): Safety device that closes if pressure exceeds setpoint.

Regulator: Device that reduces gas pressure and maintains constant outlet pressure.

Relief Valve: Safety valve that vents gas if pressure excessive.

Rotary Meter: Gas meter using rotating impellers for high-capacity measurement.

Second-Stage Regulator: Reduces intermediate pressure to appliance supply pressure (11" W.C. or 13" W.C. for propane).

Single-Stage Regulator: Reduces pressure in one step from supply to appliance pressure.

Two-Stage Regulation: Pressure reduction in two steps for better control and stability.

Vent Limiting Device (VLD): Special regulator vent design limiting gas release during failure.

End of Chapter 7

CHAPTER 8

Pressure Testing and Purging

Learning Objectives

Upon completion of this chapter, students will be able to:

1. Explain the purpose and importance of pressure testing gas piping systems
2. Apply CSA B149.1 test pressure requirements for different installation types
3. Select appropriate test medium for various applications
4. Perform pressure tests and interpret results correctly
5. Calculate acceptable pressure drop over test duration
6. Locate and repair leaks detected during testing
7. Understand purging requirements and safety considerations
8. Calculate purge volume for gas piping systems
9. Execute safe outdoor and indoor purging procedures
10. Document testing and purging per code requirements

8.1 Purpose of Pressure Testing

Pressure testing verifies the integrity of gas piping systems before placing them in service.

Why Pressure Testing is Required

Safety:

- Detects leaks before introducing gas
- Prevents gas accumulation in structures
- Protects occupants and property
- Identifies workmanship defects
- Verifies system integrity

Code Compliance:

- Required by CSA B149.1 for all new installations
- Required for modifications and additions
- Required after repairs
- Inspection requirement

- Permits cannot be closed without test

Quality Assurance:

- Verifies proper installation
- Confirms material integrity
- Tests all joints and connections
- Identifies hidden problems
- Protects installer's reputation

Legal Protection:

- Documents system integrity
- Provides evidence of proper work
- Protects against liability
- Required for insurance
- Professional standard

When Pressure Testing is Required

New Installations:

- All new gas piping systems
- Before concealing any piping
- Before connecting appliances
- Before introducing gas

Modifications:

- Additions to existing systems
- Changes to piping configuration
- Replacement of sections
- May test new portion only or entire system

Repairs:

- After repairing leaks
- After replacing components
- After disturbing joints
- Verify repair successful

Existing Systems:

- When leak suspected
- As part of major service
- During renovations

- When required by authority

8.2 CSA B149.1 Test Requirements

CSA B149.1 specifies test pressures, duration, and acceptance criteria.

Test Pressure Requirements

Test Pressure Based on Operating Pressure:

CSA B149.1 specifies test pressure as multiple of maximum operating pressure (MOP):

For Operating Pressures:

Maximum Operating Pressure	Minimum Test Pressure
125 kPa (18 PSI) or less	1.5 times MOP, but not less than 10 kPa (1.5 PSI)
Over 125 kPa (18 PSI)	1.5 times MOP

Common Applications:

Low-Pressure Systems (Typical Residential):

- Operating pressure: 2 kPa (8" W.C. or 0.29 PSI)
- Minimum test pressure: 10 kPa (1.5 PSI or 41" W.C.)
- Common test pressure: 3.5 kPa (14" W.C. or 0.5 PSI)

Medium-Pressure Systems:

- Operating pressure: 2-35 kPa (0.29-5 PSI)
- Test pressure: 1.5 × operating pressure (minimum 10 kPa)

High-Pressure Systems:

- Operating pressure: above 35 kPa (5 PSI)
- Test pressure: 1.5 × operating pressure

Important Notes:

- **Never exceed pressure rating of any system component**
- Isolate or remove regulators if test pressure exceeds rating
- Check appliance shut-off valves - may not be rated for test pressure
- CSST systems have specific test pressure limitations
- Document actual test pressure used

Test Duration

Minimum Test Duration per CSA B149.1:

Standard Test:

- **Minimum 10 minutes** at test pressure
- Longer duration preferred (30-60 minutes typical)
- Extended test for large systems
- Observe for entire duration

For Systems Over 10 m³ (350 ft³):

- May require extended duration
- Check current code edition
- Follow authority requirements
- Engineer may specify longer tests

Practical Considerations:

- Longer tests more reliable
- Temperature stabilization time
- Allows careful inspection
- Industry standard often 30 minutes minimum

Acceptable Pressure Drop

Acceptance Criteria:

No Pressure Drop: Ideal result

- Pressure remains constant
- System is tight
- No leaks present

Allowable Pressure Drop:

- CSA B149.1 specifies allowable drop based on:
  - Test pressure
  - System volume
  - Test duration
  - Temperature effects

General Guideline:

- **No discernible pressure drop on test gauge**

- Any noticeable drop requires investigation
- Even small drops may indicate leaks
- Zero drop is goal

Factors Affecting Pressure:

- Temperature changes (air expands/contracts)
- Gauge accuracy
- System volume
- Test medium
- Pressure stabilization time

Temperature Compensation:

- Temperature drop = pressure drop
- Allow system to stabilize before starting timing
- Shield from sun and weather
- Account for temperature in acceptance decision

Example:

- 10-minute test at 14" W.C.
- Pressure drops to 13.8" W.C.
- Drop = 0.2" W.C. (1.4%)
- Investigation required - likely leak

8.3 Test Medium Selection

The medium used for testing affects safety and effectiveness.

Air Testing

Most Common Test Medium

Advantages:

- Readily available (free)
- Safe (non-toxic)
- Compressible (stores energy for test)
- Detects small leaks
- No contamination

Disadvantages:

- Contains moisture
- Temperature sensitive
- Supports combustion (if gas mixed)
- Must be completely removed before purging with gas

Equipment:

- Air compressor
- Pressure regulator
- Test gauge
- Connection fittings
- Relief valve (for over-pressure protection)

Precautions:

- Never exceed system component ratings
- Monitor pressure continuously
- Verify all appliances isolated
- Allow pressure stabilization
- Account for temperature changes

Nitrogen Testing

Inert Gas Testing

Advantages:

- Inert (won't support combustion)
- Dry (no moisture)
- More stable than air (less temperature sensitivity)
- Can remain in system during purging
- Professional standard

Disadvantages:

- Cost (cylinder rental and gas purchase)
- Requires regulator and equipment
- Cylinder handling
- Not readily available

When to Use:

- High-pressure tests
- Critical installations
- Where moisture concern
- When required by engineer or code

- Professional/commercial installations

Equipment:

- Nitrogen cylinder
- Two-stage regulator
- Test gauge
- Connection hoses
- Proper fittings

Safety:

- Nitrogen is asphyxiant
- Adequate ventilation required
- Never enter enclosed space with nitrogen
- Monitor oxygen levels
- Proper cylinder handling and storage

Other Test Media

Inert Gases (Argon, Helium, CO_2):

- Used in special circumstances
- Similar to nitrogen
- More expensive
- Rarely needed for gas piping

Natural Gas or Propane:

- **NEVER use gas for initial testing of new piping**
- Only used for testing operational systems
- Leak testing with gas requires special precautions
- Electronic detection only
- Not pressure testing

Water:

- Not used for gas piping (causes corrosion)
- Difficult to remove completely
- Freezing concern
- Mentioned only to prohibit its use

8.4 Testing Procedures

Proper procedure ensures accurate results and safety.

Pre-Test Preparation

System Preparation:

1. **Verify Piping Complete:**
    - All joints made up
    - All plugs and caps installed
    - All branches capped or valved
    - System ready for service (except appliances)
2. **Inspect Visually:**
    - Check all joints
    - Verify pipe supports
    - Look for obvious defects
    - Ensure protection in place
3. **Isolate Appliances:**
    - Close appliance shut-off valves
    - Verify valves tight
    - Or cap appliance connections
    - Protect appliance controls from over-pressure
4. **Isolate or Remove Regulators:**
    - Most regulators not rated for test pressure
    - Remove or isolate with valves
    - If testing through regulator, verify rating
    - Plan for regulator installation after test
5. **Install Test Equipment:**
    - Test gauge (accurate, readable)
    - Connection point (test tee or valve)
    - Pressure source connection
    - Relief valve (safety)
6. **Verify Gauge:**
    - Accurate and calibrated
    - Appropriate range for test pressure
    - Easy to read
    - Note starting pressure (atmospheric)

Test Execution

Step-by-Step Procedure:

1. Pressurize System Slowly:

- Apply pressure gradually
- Monitor all visible piping
- Listen for leaks

- Stop at test pressure
- Don't over-pressurize

2. Stabilization Period:

- Allow 5-10 minutes for stabilization
- Pressure may fluctuate initially
- Temperature equalization
- Compression settling
- Adjust to test pressure after stabilization

3. Mark Starting Pressure and Time:

- Note exact pressure
- Record time
- Note temperature if possible
- Start test duration timer

4. Monitor Throughout Test:

- Observe gauge continuously or frequently
- Watch for pressure drop
- Note any changes
- Listen for leaks
- Check visible joints

5. Record Final Pressure:

- Note pressure at end of test period
- Calculate pressure drop
- Note temperature change
- Document conditions

6. Evaluate Results:

- Compare to acceptance criteria
- Investigate any pressure drop
- Determine pass/fail

Leak Detection During Testing

If Pressure Drop Detected:

1. Soap Solution Method:

- Most effective for pinpointing leaks

- Apply to all joints systematically
- Bubbles indicate leak
- Mark leaks for repair
- Start at highest suspected points

2. Listen:

- Larger leaks audible
- Quiet environment helpful
- May hear hissing
- Follow sound to source

3. Electronic Detection:

- Combustible gas detector can detect compressed air in some cases
- Ultrasonic leak detectors (professional)
- Follow manufacturer instructions

4. Isolate Sections:

- If large system, isolate branches
- Test sections individually
- Narrow down leak location
- Systematic approach

5. Common Leak Locations:

- Threaded joints (most common)
- Unions
- Valves
- Caps and plugs
- Damage during installation
- Fittings

Repairing Leaks

Repair Procedure:

1. **Release Test Pressure:**
   - Depressurize system slowly
   - Vent to atmosphere safely
   - Ensure zero pressure before opening joints
2. **Repair Leak:**
   - Threaded joint: Re-make with fresh compound
   - Damaged pipe/fitting: Replace section
   - CSST: Re-strike fitting or replace

- Verify cause of leak

3. **Re-Test:**
   - Pressurize system again
   - Full test duration
   - Verify repair successful
   - May need multiple test cycles

Do Not:

- Attempt to tighten pressurized joints (dangerous)
- Apply sealant to pressurized joints
- Ignore small leaks
- Accept marginal results

Passing the Test

Acceptance:

- Pressure stable over test duration
- No discernible drop on gauge
- No leaks detected with soap solution
- All joints tight
- System ready for service

Documentation:

- Record test pressure
- Record test duration
- Record start and end pressure
- Note temperature
- Sign and date
- Provide copy to customer and inspector
- Retain in records

Failed Test

If Test Fails:

1. Do NOT put system in service
2. Locate and repair all leaks
3. Re-test entire system
4. Document repairs
5. Notify customer of delays
6. Don't conceal piping until passed

Common Reasons for Failure:

- Insufficient pipe dope
- Cross-threaded fittings
- Damaged threads
- Loose joints
- Damaged piping
- Poor workmanship

8.5 Special Testing Considerations

Different piping materials and situations require specific procedures.

Testing CSST Systems

Manufacturer Requirements:

- Follow manufacturer specifications exactly
- Maximum test pressure limits
- Some CSST limited to 15-20 PSI test pressure
- Do not exceed manufacturer maximum

Procedure:

- Lower test pressure acceptable if meets code minimum
- Extended duration may be required
- Visual inspection critical
- All fittings must be properly struck/crimped

Bonding:

- Verify bonding installed before test
- Test bonding continuity
- Document bonding compliance

Testing PE Pipe

Underground PE Piping:

Test Pressure:

- Follow CSA B149.1 requirements
- 1.5 × operating pressure minimum
- Typically 10 PSI or higher

Duration:

- Minimum 10 minutes
- 30-60 minutes recommended
- Allow stabilization time

Considerations:

- PE pipe is flexible - expands under pressure
- Longer stabilization time
- Temperature effects significant
- May show initial pressure drop (normal)
- Wait for stabilization before starting timer

Transition Points:

- Pay special attention to PE-to-steel transitions
- Common leak location
- Soap test thoroughly

Testing Existing Systems

Partial System Testing:

- May test new addition only
- Isolate new from existing with valve
- Or test entire system
- Code requires testing modified portions

Lower Test Pressure:

- Existing systems may have appliances connected
- May not be practical to isolate all appliances
- Can use lower test pressure if needed
- 3" W.C. (0.1 PSI) minimum with soap test
- Not as effective as proper pressure test

Operational Testing:

- With gas in system
- Using electronic detector or soap
- Start at meter and work downstream
- Check every joint
- Lower confidence than pressure test

8.6 Purging Procedures

Purging removes air from gas piping before introducing gas to appliances.

Purpose of Purging

Safety:

- Removes air from piping
- Prevents air-gas mixture (explosive)
- Ensures pure gas reaches appliances
- Required before appliance operation

Proper Appliance Operation:

- Air in system prevents ignition
- Appliances won't light with air
- Pilot lights difficult
- Main burners won't ignite

Code Requirement:

- CSA B149.1 requires purging
- Must purge completely before service
- Specific procedures required
- Documentation may be required

Volume Calculation

System Volume:

Need to calculate volume of piping to determine purge time:

Formula: Volume = $\pi \times r^2 \times L$

Where:

- $\pi = 3.14159$
- r = inside radius of pipe
- L = length of pipe

Easier Method - Use Table:

Pipe Size	Volume per Foot
1/2"	0.0106 ft^3/ft

Pipe Size	Volume per Foot
3/4"	0.0233 ft^3/ft
1"	0.0411 ft^3/ft
1-1/4"	0.0647 ft^3/ft
1-1/2"	0.0933 ft^3/ft
2"	0.1632 ft^3/ft

Example Calculation:

System:

- 50 ft of 3/4" pipe = 50 × 0.0233 = 1.165 ft^3
- 30 ft of 1/2" pipe = 30 × 0.0106 = 0.318 ft^3
- Total volume = 1.165 + 0.318 = 1.483 ft^3

Purge Volume Required:

- Minimum 3 times system volume (CSA B149.1)
- Better: 4-5 times for complete purge
- Example: 1.483 × 3 = 4.45 ft^3 minimum
- Preferred: 1.483 × 4 = 5.93 ft^3

Outdoor Purging

Safest and Preferred Method

When to Use:

- New installations
- Large systems
- Whenever practical
- Where gas can be safely vented outside

Procedure:

1. Preparation:

- Verify test passed and pressure released
- Close all appliance valves
- Select purge point (farthest from gas source)
- Prepare to vent gas outdoors
- Eliminate ignition sources nearby

2. Open Purge Point:

- Remove cap or open valve at purge point
- Attach hose if needed to direct gas outside
- Minimum 3 m (10 ft) from ignition sources
- Away from building openings
- Adequate ventilation

3. Open Gas Supply:

- Slowly open gas valve at meter/tank
- Gas flows through system
- Air pushed out purge point
- Monitor flow

4. Test for Gas:

- Use combustible gas indicator at purge point
- Or use flame test (match or lighter at purge opening)
  - Blue flame = gas present
  - Yellow/orange flame = still air
- Continue until pure gas

5. Verify Volume:

- Calculate time or volume
- Minimum 3× system volume
- Better to purge longer than minimum

6. Close Purge Point:

- Close valve or reinstall cap
- Remove purge hose
- Test joint with soap solution

7. Pressurize System:

- Allow pressure to build
- Check system pressure at meter
- Ready for appliance connection

Indoor Purging

Only When Outdoor Purging Not Practical

Requirements:

- Adequate ventilation critical

- Small volumes only
- Special provisions per code
- More hazardous than outdoor

When Allowed:

- Small additions to existing systems
- Very small system volumes
- Where outdoor purging impossible
- Follow code requirements strictly

Procedure:

1. Ensure Adequate Ventilation:

- Open windows and doors
- Mechanical ventilation if available
- Create air flow through space
- Monitor gas concentration
- Have combustible gas detector

2. Eliminate Ignition Sources:

- No smoking
- No open flames
- No pilot lights
- Electrical switches off
- Water heater pilots off
- Furnace pilots off

3. Notify Occupants:

- Building occupants must leave or be in safe area
- Post warning if needed
- Control access

4. Purge Small Volumes:

- Open purge point
- Open gas supply slowly
- Vent into room
- Monitor gas concentration
- Stop if concentration exceeds 25% LEL (1.25% for natural gas)
- Minimum volume required

5. Ventilate After Purging:

- Continue ventilation after purging complete
- Verify gas concentration drops to safe levels
- Allow adequate time
- Test with detector

6. Restore System:

- Close purge point
- Re-light pilots
- System ready for service

Critical Safety:

- Indoor purging is hazardous
- Must follow code exactly
- Emergency ventilation plan
- Gas detector required
- Trained personnel only

Purging with Inert Gas

Inert Gas Pre-Purge:

When Used:

- High-pressure systems
- Where air-gas mixture unacceptable
- Critical installations
- Where required by engineer

Procedure:

1. Pressure test with nitrogen (or other inert gas)
2. Leave nitrogen in system
3. Purge nitrogen with natural gas/propane
4. Reduces risk of explosive mixture
5. Never creates flammable mixture (nitrogen to gas)

Advantages:

- Safer (no air-gas mixture formed)
- Better for high-pressure systems
- Professional standard for critical applications

Disadvantages:

- Additional cost (nitrogen)
- Additional time
- Requires equipment

8.7 Appliance Connection and Initial Lighting

After purging, appliances can be connected and lit.

Connecting Appliances

Final Connections:

1. Remove caps from appliance branches
2. Connect appliances per manufacturer instructions
3. Use proper fittings and compounds
4. Flexible connectors where appropriate
5. Test all new connections with soap solution
6. Support piping properly

Initial Appliance Lighting

Systematic Approach:

1. Verify Gas Available:

- Check pressure at appliance
- Verify valve open
- Gas reaching appliance

2. Light Pilots:

- Follow manufacturer lighting instructions
- Purge air from pilot line
- May take time for gas to reach pilot
- Bleed air at pilot connection if needed

3. Test Main Burner:

- Call for heat/operation
- Verify ignition
- Check flame characteristics
- Adjust if needed

4. Test All Safeties:

- Verify controls operate
- Test limit switches
- Verify pressure switches
- Check all interlocks

5. Adjust and Fine-Tune:

- Manifold pressure
- Primary air
- Flame characteristics
- Combustion testing

Documentation

Required Records:

Pressure Test:

- Date and time
- Test pressure used
- Test duration
- Start and end pressure
- Pass/fail result
- Test medium used
- Technician name and license
- Inspector sign-off (if present)

Purge:

- System volume calculated
- Purge method (outdoor/indoor)
- Purge volume/time
- Verification method
- Date completed
- Technician name

Appliance Commissioning:

- Each appliance
- Pressure settings
- Combustion test results
- Adjustments made
- Date and technician

Provide Copies:

- Customer
- Inspector/authority
- Retain in company files
- Required retention: typically 7 years

8.8 Troubleshooting Test Problems

Cannot Achieve Test Pressure

Symptoms:

- Pressure builds slowly or not at all
- Gauge doesn't reach setpoint
- Compressor runs continuously

Possible Causes:

1. Large Leak:

- Major joint not made up
- Pipe damage
- Valve not closed
- Check: Listen for loud hissing
- Solution: Find and repair leak

2. Inadequate Pressure Source:

- Compressor too small
- Low inlet pressure
- Source not capable
- Check: Source gauge reading
- Solution: Larger compressor or higher pressure source

3. Gauge Problem:

- Incorrect gauge
- Broken gauge
- Wrong connection
- Check: Verify gauge with second gauge
- Solution: Replace or reconnect gauge

4. System Too Large:

- Volume exceeds source capacity
- Takes long time to pressurize
- Not actually a problem if eventually reaches pressure
- Solution: Patience, larger source, or section testing

Pressure Drops During Test

Symptoms:

- Pressure drops over test duration
- Fails acceptance criteria
- System leaking

Possible Causes:

1. Actual Leaks:

- Most common cause
- Threaded joints
- Damaged piping
- Solution: Find and repair all leaks

2. Temperature Drop:

- Air cooling causes pressure drop
- Outdoor testing in changing weather
- Sun to shade
- Can be significant
- Check: Temperature of piping/ambient
- Solution: Account for temperature in evaluation

3. Gauge Drift:

- Gauge reading changing
- Gauge inaccuracy
- Check: Use multiple gauges
- Solution: Better gauge

4. System Stabilization:

- Piping expanding under pressure (PE pipe especially)
- Pressure settling
- Should stabilize after initial period
- Check: Wait longer before starting timer
- Solution: Allow adequate stabilization time

Pressure Rises During Test

Symptoms:

- Pressure increases over test duration
- Unexpected result

Possible Causes:

1. Temperature Rise:

- Sun heating piping
- Ambient temperature increase
- Air expanding
- Most common cause
- Check: Temperature of piping
- Solution: Shield from sun, account for temperature

2. Continued Pressurization:

- Source still connected and flowing
- Relief valve not functioning
- Check: Isolate source
- Solution: Close source valve, check relief

3. Gauge Error:

- Gauge problem
- Reading incorrectly
- Check: Verify with second gauge
- Solution: Better gauge

Chapter Summary

Pressure testing verifies the integrity of gas piping systems before introducing gas. CSA B149.1 requires testing at 1.5 times maximum operating pressure for minimum 10 minutes, with no discernible pressure drop. Typical residential test pressure is 14" W.C. (3.5 kPa), though 10 kPa is code minimum. Air is the most common test medium, with nitrogen providing advantages for critical or high-pressure applications.

Testing procedure includes system preparation, gradual pressurization, stabilization period, monitoring throughout test duration, and documentation of results. Any pressure drop requires investigation and leak repair using soap solution, systematic inspection, or isolation techniques.

Special considerations apply to CSST (manufacturer pressure limits) and PE pipe (extended stabilization time).

Purging removes air from piping before gas introduction, requiring minimum three times system volume per CSA B149.1. Outdoor purging is preferred and safest; indoor purging requires special precautions and adequate ventilation. Volume calculations determine purge time, verified by gas detection or flame test at purge point.

Complete documentation includes test pressure, duration, results, purge method and volume, and appliance commissioning data. Proper testing and purging procedures ensure safe installations, code compliance, and system integrity for the life of the installation.

Review Questions

Multiple Choice

1. According to CSA B149.1, the minimum test pressure for a system with operating pressure under 18 PSI is:
   - a) 1.5 PSI
   - b) 3.5 kPa (14" W.C.)
   - c) 10 kPa (41" W.C.)
   - d) 15 PSI
2. The minimum test duration required by CSA B149.1 is:
   - a) 5 minutes
   - b) 10 minutes
   - c) 30 minutes
   - d) 60 minutes
3. The minimum purge volume required is:
   - a) Equal to system volume
   - b) Twice system volume
   - c) Three times system volume
   - d) Five times system volume
4. When purging indoors, gas concentration should not exceed:
   - a) 10% LEL
   - b) 25% LEL
   - c) 50% LEL
   - d) 100% LEL
5. The most common test medium for residential gas piping is:
   - a) Natural gas
   - b) Propane
   - c) Nitrogen
   - d) Air
6. If a test shows pressure drop, the first step is to:
   - a) Pass the test anyway

- b) Use soap solution to find leaks
- c) Reduce test pressure
- d) Ignore small drops

7. Outdoor purging should direct gas at least _____ from ignition sources:
   - a) 1 m (3 ft)
   - b) 3 m (10 ft)
   - c) 5 m (15 ft)
   - d) 10 m (30 ft)
8. During pressure testing, regulators should be:
   - a) Left in place always
   - b) Adjusted to maximum
   - c) Isolated or removed if test pressure exceeds rating
   - d) Tested at same pressure as piping
9. Temperature drop during testing will cause pressure to:
   - a) Increase
   - b) Decrease
   - c) Remain stable
   - d) Fluctuate randomly
10. After completing purging, before lighting appliances, you should:
    - a) Wait 24 hours
    - b) Test all connections with soap solution
    - c) Increase pressure
    - d) Call for inspection

True or False

11. Water can be used as a test medium for gas piping if below freezing temperatures.
12. Any pressure drop during testing, even small amounts, requires investigation.
13. Indoor purging is preferred over outdoor purging when practical.
14. CSST systems can always be tested at the same pressure as steel pipe.
15. Documentation of pressure testing is required for code compliance.

Short Answer

16. Explain why pressure testing is performed before introducing gas to a new piping system. (4 marks)
17. List four factors that can cause pressure to drop during a test even if there are no leaks. (4 marks)
18. Why is outdoor purging preferred over indoor purging? (3 marks)
19. Describe how to verify that purging is complete and pure gas is present at the purge point. (4 marks)
20. Why must the test pressure not exceed manufacturer ratings for CSST systems? (3 marks)

Long Answer

21. Describe the complete procedure for pressure testing a residential natural gas piping system. Include:
    - Pre-test preparation and system isolation
    - Test pressure selection
    - Step-by-step testing procedure
    - Acceptable results criteria
    - Actions if test fails
    - Documentation requirements (15 marks)
22. Calculate the purge volume for the following system and describe the complete outdoor purging procedure:
    - 40 feet of 3/4" pipe (0.0233 ft^3/ft)
    - 25 feet of 1/2" pipe (0.0106 ft^3/ft)
    - 15 feet of 1" pipe (0.0411 ft^3/ft)

Include: - Volume calculations - Minimum purge volume (3× system volume) - Complete purging procedure - Verification method - Safety considerations (12 marks)

23. Compare air testing and nitrogen testing for gas piping systems. Include:
    - Advantages and disadvantages of each
    - When each is appropriate
    - Safety considerations for each
    - Cost and equipment differences
    - Why nitrogen is preferred for critical applications
    - Which you would recommend for a typical residential installation and why (15 marks)

Practical Exercises

Exercise 1: Pressure Test Procedure

On training system or actual installation:

1. Prepare system for testing
2. Install test gauge and equipment
3. Pressurize to test pressure
4. Allow stabilization
5. Monitor for test duration
6. Document results
7. Interpret pass/fail
8. Complete test documentation

Exercise 2: Leak Detection

On system with known leak(s):

1. Perform pressure test
2. Detect pressure drop
3. Use soap solution systematically
4. Locate all leaks
5. Mark leak locations
6. Prioritize repairs
7. Plan correction strategy

Exercise 3: Volume Calculation

Given system drawings:

1. Measure all pipe runs
2. Calculate volume of each section
3. Sum total system volume
4. Calculate required purge volume
5. Estimate purge time at typical flow rate
6. Document calculations

Exercise 4: Outdoor Purging

On training system:

1. Calculate system volume
2. Set up purge point outdoors
3. Open gas supply
4. Monitor purge progress
5. Test for gas at purge point
6. Verify adequate volume purged
7. Close purge point
8. Test purge point connection
9. Document procedure

Exercise 5: Test Documentation

Practice completing:

1. Pressure test report forms
2. Required information
3. Calculations
4. Pass/fail determination
5. Signature and license number
6. Customer copy
7. Regulatory copy

Exercise 6: Failed Test Response

Simulate failed pressure test:

1. Identify pressure drop
2. Develop systematic leak search plan
3. Prioritize likely leak locations
4. Execute search procedure
5. Document findings
6. Plan repairs
7. Estimate time for correction

Case Studies

Case Study 1: Persistent Small Leak

Scenario: You perform a pressure test on a new residential installation. Test pressure is 14" W.C. After 30 minutes, pressure has dropped to 13.5" W.C. (0.5" W.C. drop, 3.6%). You soap test all visible joints - no bubbles found anywhere. Temperature has been constant. The system has 60 feet of exposed piping and 40 feet concealed in walls.

Questions:

1. Is this test acceptable?
2. Where could the leak be?
3. How can you isolate the problem?
4. What if the leak is in concealed piping?
5. Can you section test to narrow down location?
6. What if you can't find the leak?
7. Can you put the system in service?
8. What do you tell the customer?

Case Study 2: Temperature Effect

Scenario: You pressure test an outdoor gas line on a sunny morning. Initial pressure: 14.0" W.C. at 9:00 AM. You check after 20 minutes: 14.3" W.C. You wait another 10 minutes: 14.5" W.C. The pipe is in full sun and warm to the touch.

Questions:

1. Why is pressure increasing?
2. Is this acceptable?
3. How do you account for temperature effect?
4. Should you fail the test?
5. How can you minimize temperature effects?
6. What if clouds move in and temperature drops during test?

7. How do you determine if actual leaks present?
8. What do you document?

Case Study 3: CSST Pressure Limitation

Scenario: You're installing a CSST system. The manufacturer specifies maximum test pressure of 15 PSI. Your standard residential test is 14" W.C. (0.5 PSI) which is well under 15 PSI. However, the inspector wants you to test at 3.5 PSI (96" W.C.) which exceeds manufacturer limit.

Questions:

1. What is the code minimum test pressure?
2. What is your standard test pressure?
3. Can you test at 3.5 PSI?
4. What does the manufacturer restriction mean?
5. How do you handle the inspector's request?
6. What test pressure should you use?
7. Who has authority - code, manufacturer, or inspector?
8. How do you document this situation?

Case Study 4: Indoor Purging Gone Wrong

Scenario: An apprentice is adding a gas line for a dryer in a basement. The addition is 20 feet of 1/2" pipe (volume about 0.2 ft^3). Instead of purging outdoors, he opens the gas valve in the basement "to save time." The water heater pilot light is still burning. Within seconds, you smell gas heavily and see the apprentice still at the open purge point.

Questions:

1. What immediate actions do you take?
2. What dangers exist?
3. What procedure violations occurred?
4. How should this have been done?
5. What if outdoor purging truly impossible?
6. What training does the apprentice need?
7. What safety protocols should be in place?
8. What if gas had ignited?

Case Study 5: Test Equipment Failure

Scenario: You're performing a pressure test using your digital manometer. Initial pressure: 14.0" W.C. After 15 minutes: 13.7" W.C. You suspect a leak and start soap testing. Your assistant checks your gauge with his mechanical gauge - it shows 14.1" W.C. and is stable. You realize your digital gauge is drifting.

Questions:

1. What is the actual test result?
2. How do you verify gauge accuracy?
3. Can you complete test with suspect gauge?
4. What if you'd repaired joints based on faulty gauge?
5. How often should gauges be calibrated?
6. What backup equipment should you have?
7. How do you document this situation?
8. Can you trust any readings from this gauge today?

Case Study 6: Incomplete Purge

Scenario: You purge a new system outdoors. After what you think is adequate purging (you heard gas coming out), you close the purge point and light the furnace pilot. The pilot lights but immediately goes out. Several attempts fail. You check gas pressure at furnace - it's correct at 7" W.C.

Questions:

1. What is the most likely problem?
2. How do you verify air still in system?
3. Did you purge adequately?
4. How should purging be verified?
5. What is the proper correction?
6. How much should you have purged?
7. Can you purge through the appliance pilot line?
8. How do you prevent this in future?

Case Study 7: Large System Test

Scenario: You're testing a commercial system with 500 feet of 2" pipe, 300 feet of 1-1/4" pipe, and multiple branches. Your small air compressor cannot build pressure above 5" W.C. even after 30 minutes. The system needs to test at 14" W.C.

Questions:

1. Why can't you achieve test pressure?
2. What is the system volume (approximately)?
3. What size compressor/air source needed?
4. Can you section-test instead?
5. What are advantages of section testing?
6. What are disadvantages?
7. How do you document section testing?
8. What if you must test entire system at once?

Key Terms

Acceptable Pressure Drop: Maximum pressure decrease allowed during test (generally zero for residential).

Air Testing: Using compressed air as test medium for pressure testing.

Inert Gas: Non-reactive gas such as nitrogen used for testing; won't support combustion.

LEL (Lower Explosive Limit): Minimum gas concentration that will ignite (natural gas 5%, propane 2.1%).

Lock-Up Pressure: Pressure in closed system with no flow; regulator testing term.

Maximum Operating Pressure (MOP): Highest pressure at which system normally operates.

Nitrogen Testing: Using nitrogen gas as test medium; professional standard for critical applications.

Outdoor Purging: Venting air/gas mixture outside building during purging; safest method.

Pressure Drop: Decrease in pressure during test; indicates leak if not due to temperature.

Purging: Process of removing air from gas piping by flowing gas through system.

Soap Solution: Mixture of water and soap for detecting gas leaks; creates bubbles at leak points.

Stabilization Period: Time allowed for pressure and temperature to equalize before starting test timing.

System Volume: Total internal volume of piping; determines purge volume required.

Test Duration: Time period pressure must be maintained during test (minimum 10 minutes per CSA B149.1).

Test Medium: Substance used for pressure testing (air, nitrogen, etc.).

Test Pressure: Pressure applied during test; typically 1.5× maximum operating pressure.

End of Chapter 8

CHAPTER 9

Introduction to Gas Appliances

Learning Objectives

Upon completion of this chapter, students will be able to:

1. Identify major categories of gas appliances and their applications
2. Interpret appliance rating plates and certification markings
3. Distinguish between venting categories and select appropriate venting
4. Calculate and apply input ratings, including de-rating requirements
5. Understand efficiency ratings (AFUE, thermal, combustion)
6. Apply clearance requirements to combustibles per CSA B149.1
7. Calculate combustion air requirements for appliances
8. Install appliances according to manufacturer instructions and code
9. Perform initial commissioning and testing of gas appliances
10. Document appliance installations properly

9.1 Appliance Categories

Gas appliances convert the chemical energy in natural gas or propane into useful heat for various applications.

Heating Equipment

Central Heating:

Forced Air Furnaces:

- Most common residential heating
- Heat exchanger plus blower
- Ducted air distribution
- 40,000 - 150,000 BTU/hr residential
- Up to millions BTU commercial
- Various efficiency levels (80-98% AFUE)

Boilers (Hydronic Heating):

- Heat water or produce steam
- Radiant heat distribution
- Baseboards, radiators, or in-floor
- 50,000 - 400,000 BTU/hr residential
- Larger for commercial/industrial
- 80-95%+ efficiency

Unit Heaters:

- Self-contained heating unit
- Direct space heating
- Common in garages, warehouses, shops
- 30,000 - 400,000 BTU/hr typical
- Vented or unvented (separated combustion)

Space Heaters:

Vented Space Heaters:

- Wall-mounted or floor-standing
- Direct vented or B-vented
- Zone heating
- 10,000 - 40,000 BTU/hr typical
- Supplemental heat

Vent-Free Space Heaters:

- No venting required
- Restrictions in Canada (limited or prohibited in some jurisdictions)
- Oxygen depletion sensor required
- Maximum size limitations
- CSA B149.1 restrictions

Infrared Heaters:

- Radiant heat
- High-intensity or low-intensity
- Industrial/commercial applications
- Outdoor heating (patios)
- Vented or unvented designs

Water Heating

Storage Tank Water Heaters:

- Most common residential

- 30-75 gallon capacity typical
- 30,000 - 75,000 BTU/hr input
- Various venting types
- Recovery rate important

Tankless (Instantaneous) Water Heaters:

- Heat water on demand
- No storage tank
- 120,000 - 199,000 BTU/hr residential
- Continuous hot water
- Higher efficiency potential
- Complex installation requirements

Commercial Water Heaters:

- Larger capacity storage
- Higher input rates
- Multiple units common
- Specialized applications

Indirect Water Heaters:

- Tank heated by boiler
- No direct gas burner
- Very efficient
- Common with hydronic systems

Cooking Appliances

Ranges:

- Combined cooktop and oven
- 30" and 36" widths common
- 65,000 - 75,000 BTU/hr typical total input
- Open burner or sealed burner

Cooktops:

- Counter-mounted burners only
- 4-6 burners typical
- 30,000 - 45,000 BTU/hr
- Various burner configurations

Wall Ovens:

- Built-in ovens separate from cooktop
- Single or double ovens
- 18,000 - 25,000 BTU/hr each
- Convection or conventional

Commercial Cooking Equipment:

- Ranges (heavy-duty)
- Griddles
- Fryers
- Ovens (standard and convection)
- Broilers
- Specialized equipment
- Much higher inputs than residential

Clothes Dryers

Residential Dryers:

- 30,000 - 35,000 BTU/hr input
- Vented to exterior
- Moisture removal
- Gas or electric ignition

Commercial Dryers:

- Laundromats and institutions
- Higher capacity
- 100,000+ BTU/hr
- Multiple units common

Other Appliances

Fireplaces and Fireplace Inserts:

- Decorative and/or heating
- Vented or vent-free (where permitted)
- Direct vent popular
- Gas logs in existing fireplaces
- 20,000 - 40,000 BTU/hr typical

Pool and Spa Heaters:

- Outdoor installation typical
- 100,000 - 400,000 BTU/hr
- Weatherproof construction

- Corrosion-resistant materials

Outdoor Appliances:

- Patio heaters
- Barbecues (built-in)
- Outdoor fireplaces
- Fire pits
- Weather-resistant construction

Generators (Standby):

- Emergency power
- Engine-driven
- Automatic start
- Whole-house or partial
- Varies greatly in size

9.2 Venting Categories

Appliances are classified by venting method, which affects installation requirements.

Category I Appliances

Characteristics:

- Draft hood equipped (natural draft)
- Non-positive vent static pressure
- Flue gas temperature > 140°F (60°C)
- Non-condensing
- Traditional design

Operation:

- Natural draft pulls combustion products through heat exchanger
- Draft hood dilutes flue gases with room air
- Creates negative pressure in vent
- Relies on buoyancy

Venting:

- Type B gas vent (double-wall)
- Single-wall vent connector (limited length)
- Vertical termination through roof

- Cannot use PVC or plastic
- Must terminate above roof per code

Efficiency:

- 78-82% AFUE typical
- Heat lost in flue gases
- Draft hood allows spillage potential

Examples:

- Older furnaces
- Atmospheric water heaters
- Standard boilers
- Most cooking appliances

Installation Considerations:

- Adequate combustion air critical
- Building depressurization can cause spillage
- Vent must be properly sized and installed
- Draft must be adequate
- Spillage testing required

Category II Appliances

Characteristics:

- Non-positive vent static pressure
- Flue gas temperature ≤ 140°F (60°C)
- May condense in vent
- Rarely seen (few manufacturers)

Venting:

- Special vent materials
- Corrosion-resistant
- Must handle condensation
- Specific to appliance

Notes:

- Uncommon category
- Mostly historical reference
- Check specific appliance requirements

Category III Appliances

Characteristics:

- Positive vent static pressure
- Flue gas temperature > 140°F (60°C)
- Forced or induced draft
- Non-condensing
- Power vented

Operation:

- Fan forces or induces draft
- Creates positive pressure in vent
- No draft hood
- More efficient than Category I

Venting:

- Special vent materials
- Single-wall metal or specific listed materials
- Can vent horizontally through wall
- Shorter vent runs possible
- Must withstand positive pressure

Examples:

- Some power-vented water heaters
- Older power-vented furnaces
- Commercial equipment

Installation:

- Follow manufacturer specifications exactly
- Electrical interlock required (vent fan)
- Vent material critical
- Termination specific to appliance

Category IV Appliances

Characteristics:

- Positive vent static pressure
- Flue gas temperature ≤ 140°F (60°C)
- Condensing
- High efficiency

- Forced or induced draft

Operation:

- Extracts maximum heat from combustion
- Flue gases cooled below water vapor condensation point
- Water vapor condenses in heat exchanger
- Latent heat recovered
- Fan creates positive vent pressure

Venting:

- PVC, CPVC, or ABS plastic (per manufacturer)
- Polypropylene
- Stainless steel
- Must resist condensate (acidic)
- Can vent horizontally through wall
- Direct vent option

Efficiency:

- 90-98% AFUE
- Highest efficiency category
- Condensate produced (must be drained)

Examples:

- High-efficiency furnaces (90%+)
- High-efficiency boilers
- Condensing tankless water heaters
- Modern residential equipment

Installation:

- Condensate drain required
- Must pitch for drainage
- PVC primer and cement per manufacturer
- Air intake often incorporated
- Specific termination requirements
- Electrical interlock

Condensate Management:

- Drain to floor drain, condensate pump, or outside
- May require neutralization (depending on local code)
- Trap required per manufacturer

- Cannot freeze
- Approximately 1 gallon per 100,000 BTU input

Direct Vent Appliances

Not a numbered category, but common design

Characteristics:

- Sealed combustion chamber
- Concentric vent (pipe within pipe)
- Combustion air drawn from outside
- Flue gases exhausted outside
- No room air used for combustion

Operation:

- Outer pipe brings combustion air in
- Inner pipe exhausts flue gases out
- Completely isolated from indoor air
- Can be Category III or IV

Venting:

- Horizontal through wall (most common)
- Vertical through roof (possible)
- Concentric termination
- Specific clearances to openings

Advantages:

- No combustion air from indoors (tight buildings)
- No spillage potential
- Can install in confined spaces
- More flexible installation

Examples:

- Direct vent fireplaces
- Direct vent water heaters
- Some furnaces
- Wall furnaces

Installation:

- Follow manufacturer termination requirements exactly

- Clearances to openings critical
- Must maintain slope for drainage
- Seal penetration properly

Power Vent vs. Direct Vent

Power Vent:

- Uses indoor air for combustion
- Vents through power vent fan
- Single pipe exhaust
- Separate combustion air from room

Direct Vent:

- Uses outdoor air for combustion
- Sealed combustion
- Concentric vent (usually)
- No room air involved

9.3 Certification and Approval

All gas appliances must be certified for use in Canada.

Certification Marks

CSA (Canadian Standards Association):

- Most common certification in Canada
- Blue CSA mark with flame logo
- Indicates compliance with Canadian standards
- Tested for safety
- Different marks for different products

AGA (American Gas Association) / CGA (Canadian Gas Association):

- Blue star seal
- Certifies performance
- Common on cooking appliances
- Now mostly replaced by CSA

UL/ULC (Underwriters Laboratories):

- Safety certification
- Both U.S. (UL) and Canadian (ULC) marks
- Some appliances carry both CSA and ULC

ANSI (American National Standards Institute):

- Standards reference
- Not certification mark itself
- Standards adopted by certifying bodies

Requirements:

- Must have recognized certification mark
- Installed per listing and manufacturer instructions
- Uncertified appliances not permitted
- Used appliances must retain certification marking

Rating Plate Information

Required Information on Rating Plate:

1. **Manufacturer Name and Model Number**
    - Identifies appliance
    - Required for service
    - Parts ordering
2. **Certification Mark**
    - CSA, AGA/CGA, ULC
    - Confirms approval
3. **Gas Type**
    - Natural gas or propane (LP)
    - May show both if convertible
    - Critical for proper operation
4. **Input Rating**
    - BTU/hr or kW
    - Manifold pressure
    - Orifice size (sometimes)
5. **Elevation (De-rating)**
    - Maximum elevation without de-rating
    - De-rating requirements if applicable
    - Important in mountainous areas
6. **Electrical Requirements**
    - Voltage (115V, 230V typical)
    - Amperage
    - Must match supply
7. **Venting Information**
    - Category (I, III, IV)

    - Vent material requirements
    - Vent diameter
    - Maximum/minimum vent length
8. **Clearances**
    - Minimum clearances to combustibles
    - Required for safe installation
9. **Serial Number**
    - Unique identifier
    - Manufacturing date (encoded)
    - Warranty reference
10. **Other:**
    - Efficiency rating (AFUE for furnaces/boilers)
    - For water heaters: recovery rate, first hour rating
    - Special instructions or warnings

Interpreting Rating Plates

Example Furnace Rating Plate:

```
Manufacturer: XYZ Heating Company
Model: ABC-100
Serial: 12345678

Certification: [CSA Logo]

Gas Type: Natural Gas (NAT) - Propane (LP) Field Convertible
Input: 100,000 BTU/hr NAT @ 3.5" W.C.
       100,000 BTU/hr LP @ 10" W.C.

Output: 95,000 BTU/hr (95% AFUE)

Electrical: 115V / 60Hz / 15A

Venting: Category IV, PVC Sch 40, 3" diameter
         Max Vent Length: 60 ft equivalent

Clearances:
  Front: 24" for service
  Sides: 3" to combustibles
  Rear: 1" to combustibles
  Top: 12" to combustibles
  Flue: 1" clearance

Elevation: Suitable for use up to 2000 ft (600 m)
           See manual for de-rating above 2000 ft

For installation and service, see manual provided
```

Reading This Plate:

- High-efficiency condensing furnace (Category IV, 95% AFUE)

- 100,000 BTU input, 95,000 BTU output
- Requires 3" PVC vent
- Can burn either natural gas or propane (with conversion)
- Different manifold pressures for each fuel
- Needs 115V electrical
- Specific clearances must be maintained
- De-rating required above 2000 feet elevation

9.4 Input Rating and Efficiency

Understanding input, output, and efficiency is essential for proper appliance selection and operation.

Input Rating

Definition:

- Rate at which appliance consumes fuel
- Measured in BTU/hr (or kW in metric)
- Based on heating value of gas
- Total energy entering appliance

Determining Input:

- Stamped on rating plate
- Can calculate: (gas flow in CFH) × (heating value)
- Natural gas: CFH × 1,000 BTU/ft^3
- Propane: CFH × 2,500 BTU/ft^3

Example:

- Gas flow: 100 ft^3/hr natural gas
- Heating value: 1,000 BTU/ft^3
- Input: 100 × 1,000 = 100,000 BTU/hr

MBH Notation:

- M = thousands (Roman numeral)
- BH = BTU/hr
- 100 MBH = 100,000 BTU/hr
- Common shorthand

Output Rating

Definition:

- Useful heat delivered by appliance
- Always less than input (losses occur)
- Measured in BTU/hr

Heat Losses:

- Up the vent (flue gases)
- Cycling losses
- Jacket losses (heat exchanger surface)
- Pilot light (standing pilot systems)

Example:

- Input: 100,000 BTU/hr
- Vent losses: 18,000 BTU/hr
- Cycling losses: 2,000 BTU/hr
- Output: 80,000 BTU/hr

Efficiency Ratings

AFUE (Annual Fuel Utilization Efficiency):

Used For:

- Furnaces
- Boilers
- Annual average efficiency

Includes:

- Steady-state efficiency
- Cycling losses
- Pilot light losses (if standing pilot)
- Jacket losses
- Real-world operation

Calculation:

- (Useful heat output / Energy input) × 100
- Seasonal average, not instantaneous

Ranges:

- Old atmospheric: 55-65% AFUE

- Standard efficiency: 78-82% AFUE
- Mid-efficiency: 83-89% AFUE
- High-efficiency: 90-98% AFUE

Interpretation:

- 80% AFUE = 80% of fuel energy becomes useful heat
- 20% lost up vent and through cycling
- Higher AFUE = lower operating costs

Thermal Efficiency:

Used For:

- Water heaters
- Commercial equipment
- Steady-state measurement

Definition:

- Efficiency during continuous operation
- Does not include cycling or standby losses

Calculation:

- Similar to AFUE but steady-state only
- (Output / Input) × 100

Ranges:

- Standard water heaters: 75-85%
- High-efficiency: 90-96%

Energy Factor (EF) for Water Heaters:

- Includes standby losses
- More comprehensive than thermal efficiency
- Replaced by Uniform Energy Factor (UEF) in newer ratings

Combustion Efficiency:

Definition:

- Efficiency of combustion process only
- Measured with combustion analyzer
- Stack loss calculation

Factors:

- Stack temperature
- Excess air (O_2 level)
- Fuel type

Use:

- Field measurement during service
- Verify proper combustion
- Tune-up indicator

Typical Values:

- Well-tuned atmospheric: 75-82%
- Power burners: 78-85%
- Condensing: 90-98%

Not Same as AFUE:

- AFUE includes cycling and other losses
- Combustion efficiency higher than AFUE
- Both important metrics

Capacity vs. Efficiency

Don't Confuse:

- Input (capacity) = size
- Efficiency = percentage of fuel converted to useful heat
- High efficiency doesn't mean high capacity
- Can have small high-efficiency or large low-efficiency

Example:

- Furnace A: 60,000 BTU input, 95% efficient = 57,000 BTU output
- Furnace B: 100,000 BTU input, 80% efficient = 80,000 BTU output
- B has higher output despite lower efficiency (because larger input)

9.5 De-rating Requirements

Appliances must be de-rated (reduced input) in certain situations.

Altitude De-rating

Why Required:

- Air is thinner at higher elevations
- Less oxygen available for combustion
- Over-firing can occur if not de-rated
- Incomplete combustion risk

When Required:

- Check rating plate for maximum elevation
- Typically 2,000 feet (600 m) without de-rating
- Above this elevation, de-rate per manufacturer

De-rating Factors:

- Usually 4% reduction per 1,000 feet above rated elevation
- Manufacturer specifications vary
- Some appliances altitude-compensating (no de-rating needed)

Example:

- Furnace rated for 2,000 ft maximum without de-rating
- Installed at 4,000 ft elevation
- Excess elevation: 4,000 - 2,000 = 2,000 ft
- De-rating: 2,000 ÷ 1,000 × 4% = 8%
- Original input: 100,000 BTU/hr
- De-rated input: 100,000 × 0.92 = 92,000 BTU/hr

How to De-rate:

- Change orifices to smaller size
- Reduce manifold pressure
- Or combination
- Follow manufacturer instructions
- Document de-rating

Certification:

- De-rated appliances may need re-certification
- Check with authority having jurisdiction
- Maintain documentation

Propane Conversion De-rating

Why Sometimes Required:

- Propane has higher heating value (2,500 vs 1,000 BTU/ft³)
- Propane burns hotter
- Some appliances require de-rating when converted to propane

When Required:

- Check manufacturer conversion instructions
- Some appliances: same input both fuels
- Some appliances: must reduce input on propane
- Affects heat exchanger temperature

Example:

- Furnace: 100,000 BTU/hr on natural gas
- Conversion kit: de-rate to 85,000 BTU/hr on propane
- Smaller orifices AND lower manifold pressure
- Protects heat exchanger from overheating

Process:

- Follow conversion kit instructions exactly
- Change orifices
- Adjust manifold pressure
- May need different orifices than simple conversion would suggest
- Verify with combustion test

Load De-rating

Not Typically Required but Possible:

When Considered:

- Oversized equipment for load
- Cycling problems
- Comfort issues

Options:

- Reduce input by changing orifices
- Two-stage or modulating controls
- Proper sizing in first place (better)

Caution:

- May void warranty
- May violate certification
- Consult manufacturer
- Generally not recommended

9.6 Installation Fundamentals

Proper installation is critical for safety, efficiency, and appliance longevity.

Manufacturer's Instructions

Critical Requirement:

- Must follow manufacturer's installation instructions
- Part of appliance certification
- Code requires compliance
- Provided with appliance

Instructions Include:

- Clearances to combustibles
- Venting requirements
- Combustion air requirements
- Gas connection specifications
- Electrical connection
- Specific installation steps
- Commissioning procedures

If Instructions Lost:

- Download from manufacturer website
- Request from manufacturer
- Cannot install without instructions
- Required for inspection

Location Requirements

General Requirements:

Accessibility:

- Service access required
- Sufficient clearance for maintenance
- Door or panel access to controls

- Clearance for component removal

Protection:

- Protected from physical damage
- Not in traffic areas
- Protected from weather (if outdoor installation)
- Secure mounting

Ventilation:

- Adequate combustion air
- Room ventilation if required
- Not in sealed rooms (unless direct vent)
- Consider appliance requirements

CSA B149.1 Restrictions:

Not Permitted in:

- Bedrooms
- Bathrooms (with exceptions for direct vent)
- Closets (with exceptions)
- Storage rooms (with restrictions)
- Areas with corrosive atmosphere
- Locations subject to flooding

Permitted With Restrictions:

- Utility rooms (adequate combustion air)
- Basements (ventilation, protection from damage)
- Attics (accessibility, ventilation)
- Garages (elevated or protected from vehicle impact)
- Outdoors (weatherproof construction)

Support and Mounting

Floor-Standing:

- Level and stable
- Adequate floor support (structural capacity)
- Vibration isolation if needed
- Anchor if required by code or manufacturer

Wall-Mounted:

- Support adequate for weight
- Proper anchors for wall type
- Level installation
- No stress on gas connections

Suspended:

- Support from structure (not piping)
- Adequate hangers
- Seismic restraint (where required)
- Vibration isolation

9.7 Clearances to Combustibles

Clearances protect combustible materials from heat.

Why Clearances Required

Heat Transfer:

- Appliances generate heat
- Heat radiates and conducts
- Combustible materials can ignite
- Clearances provide safety margin

Combustible Materials:

- Wood framing
- Wood paneling
- Drywall (paper-faced)
- Plastic
- Insulation
- Carpet
- Most building materials

Non-Combustible:

- Concrete
- Masonry
- Steel
- Glass
- Ceramic tile

Clearance Requirements

Source of Requirements:

- Manufacturer specifications (primary)
- CSA B149.1 (code minimums)
- Most restrictive applies

Typical Clearances (Example Furnace):

- Front: 24-30" (service access)
- Sides: 3-6" to combustibles
- Rear: 1-3" to combustibles
- Top: 6-12" to combustibles
- Vent connector: 6" to combustibles (single-wall)

Zero-Clearance Appliances:

- Specifically designed and listed
- Can install against combustibles
- Follow manufacturer instructions exactly
- Common in fireplaces and inserts

Clearance Reduction Methods

When Clearances Cannot Be Met:

Option 1: Use Approved Protection

Manufacturer-Approved Shields:

- Metal shields with air space
- Typically 1" air space behind shield
- Reduces required clearance by 50-66%
- Must follow specific design

Example:

- Required clearance: 18"
- With approved shield: 9" or 6"
- Shield must be installed per specifications

CSA B149.1 Reduction Methods:

- Sheet metal with air space
- Specific construction details
- Certified reduction percentage
- Tables provided in code

Option 2: Relocate Appliance

- Better solution if practical
- Maintains full clearances
- No special protection needed

Option 3: Remove Combustibles

- Replace with non-combustible materials
- Concrete board
- Masonry
- Metal

Never:

- Assume clearances can be reduced without approval
- Install closer than specified without proper protection
- Use unapproved protection materials
- Rely on insulation alone

9.8 Combustion Air Requirements

Adequate air is essential for safe and efficient combustion.

Air Requirements

Two Types of Air:

Combustion Air:

- Air for burning fuel
- Oxygen for combustion
- Consumed by appliance
- Exits through vent

Dilution/Ventilation Air:

- Air for draft hood dilution (Category I)
- Room ventilation
- Not consumed
- Mixes with room air

Total Air Requirements:

- Must provide both
- Calculations based on appliance input
- Location (confined vs. unconfined space)
- Inside or outside air source

Confined vs. Unconfined Space

Confined Space (CSA B149.1 Definition):

- Space with less than 1.5 m^3 (50 ft^3) per 1,000 BTU/hr of total input
- Example: 100,000 BTU/hr appliance in room smaller than 150 m^3 (5,000 ft^3)
- Requires openings for combustion air

Unconfined Space:

- Space with 1.5 m^3 (50 ft^3) or more per 1,000 BTU/hr
- Example: 100,000 BTU/hr appliance in room larger than 150 m^3 (5,000 ft^3)
- Generally has adequate infiltration (older buildings)
- May still need openings (tight buildings)

Modern Consideration:

- Modern buildings are tight
- Even "unconfined" spaces may need openings
- Best practice: provide dedicated combustion air
- Direct vent appliances eliminate this concern

Calculating Combustion Air Openings

CSA B149.1 Methods:

Method 1: All Air from Inside Building

Two Permanent Openings Required:

- One near ceiling
- One near floor
- Each opening minimum size based on appliance input

Sizing:

- Minimum 100 cm^2 per 10 kW (220 in^2 per 100,000 BTU/hr)
- If using single combustion air opening: double the size
- Openings to adjacent unconfined space

Example:

- Furnace: 100,000 BTU/hr
- Water heater: 40,000 BTU/hr
- Total: 140,000 BTU/hr
- Each opening: $140 \times 220 \div 100 = 308$ in²
- Convert: $308 \div 144 = 2.1$ ft² = approximately 18" × 18"

Method 2: All Air from Outdoors (Direct)

Two Permanent Openings:

- One near ceiling connected to outdoors
- One near floor connected to outdoors
- Each opening to outdoors

Sizing:

- Minimum 50 cm² per 10 kW (110 in² per 100,000 BTU/hr) if vertical ducts
- Minimum 100 cm² per 10 kW (220 in² per 100,000 BTU/hr) if horizontal ducts
- Smaller than indoor method (more effective)

Example:

- Total input: 140,000 BTU/hr
- Vertical ducts: each opening $140 \times 110 \div 100 = 154$ in² = 1.07 ft²
- Approximately 12" × 12" each opening

Method 3: Mixed (One from Inside, One from Outside)

- Complex calculation
- Refer to CSA B149.1 tables
- Less common

Method 4: Mechanical Ventilation

- Powered ventilation
- Must provide adequate CFM
- Interlocked with appliances
- Requires engineering
- Special provisions per code

Combustion Air Duct Requirements

Material:

- Metal (galvanized steel typical)
- Minimum 26 gauge

- Sealed joints

Installation:

- Slope for drainage
- Screen at termination (1/4" mesh)
- No dampers or obstructions
- Protected from damage

Termination:

- Outdoors away from windows/doors
- Minimum 3 ft from forced air intakes
- Minimum 12" above grade (snow)
- Protected from wind (minimizes pressurization effects)

Maintenance Access:

- Cleanable
- Screens removable
- Periodic inspection required

Special Considerations

Direct Vent Appliances:

- Don't use room air
- No combustion air openings needed
- Sealed combustion
- Simplifies installation

Tight Buildings:

- Modern construction very tight
- Even unconfined spaces may need combustion air
- Exhaust fans create negative pressure
- Consider make-up air for exhaust systems

Depressurization:

- Exhaust fans (kitchen, bath, dryer)
- Central vacuum
- Fireplaces
- Can overcome natural draft
- Cause Category I spillage
- Direct vent or power vent eliminates this concern

Building Pressurization Test:

- Use manometer or draft gauge
- Measure pressure with exhaust equipment on
- -3 Pa (-0.01" W.C.) or more negative = concern
- May need make-up air or power-vented appliances

9.9 Appliance Inspection and Commissioning

Proper commissioning ensures safe and efficient operation.

Pre-Start Inspection

Visual Inspection:

Appliance:

- Physical damage during shipping or installation
- All covers and panels installed
- Access panels secure
- No loose parts

Gas Connection:

- Proper pipe size
- Shut-off valve accessible
- Drip leg installed (if required)
- All joints tight
- Leak tested

Electrical:

- Proper voltage supply
- Correct amperage circuit
- Ground wire connected
- No damaged wiring

Venting:

- Proper material for category
- Correct diameter
- Proper slope (condensing appliances)
- No gaps or leaks
- Proper termination

- Clearances maintained

Combustion Air:

- Openings adequate size
- Screens clean
- Ducts connected
- Not blocked

Clearances:

- Verified to combustibles
- No violations
- Proper protection if clearances reduced

Initial Start-Up Procedure

Step-by-Step:

1. Verify Gas Supply:

- Meter/tank has gas
- Service valve open
- Pressure adequate
- Appliance valve open

2. Set Thermostat/Control:

- Call for heat/operation
- Manual mode if available
- Bypass delays if testing

3. Observe Ignition:

- Pilot lights (if standing pilot)
- Igniter glows (if HSI)
- Spark visible (if DSI)
- Main burner ignites
- Time from call to ignition normal

4. Observe Flame:

- Proper flame characteristics
- Blue flame
- Stable
- No yellow tipping (or minimal)

- No lifting or flashback
- Even across burner

5. Verify Blower/Pump Operation:

- Blower starts (furnace)
- Circulator runs (boiler)
- Appropriate delay
- Proper rotation
- No unusual noise

6. Check Pressure:

- Manifold pressure at rating plate value
- Inlet pressure adequate
- Adjust if needed

7. Temperature Rise (Furnaces):

- Measure supply air temperature
- Measure return air temperature
- Calculate rise: Supply - Return
- Compare to rating plate range
- Typical: 40-70°F rise

8. Combustion Testing:

- Insert probe in flue
- Allow readings to stabilize
- Record: O_2, CO_2, CO, stack temperature
- Calculate efficiency
- Verify acceptable limits

9. Cycle Test:

- Allow appliance to complete full cycle
- Verify proper shut-down
- Restart and verify operation
- Multiple cycles

10. Safety Tests:

- Verify limits operate (test if possible)
- Verify pressure switches
- Check rollout switches
- Test flame sensor (simulate failure if possible)

Acceptance Criteria

Combustion:

- O_2: 5-9% typical
- CO: < 100 ppm air-free (CSA B149.1)
- CO_2: Natural gas 8-10%, Propane 10-12%
- Stack temperature: Per appliance type

Operation:

- Ignites reliably
- Burns steadily
- Proper flame appearance
- No unusual noise or vibration
- Controls function properly
- Safeties operate

Performance:

- Adequate heat output
- Temperature rise within range
- Pressure settings correct
- Efficiency acceptable

Safety:

- No gas leaks
- No spillage (Category I)
- No CO production in space
- All safeties function

Documentation

Record:

- Date and time of commissioning
- Manifold pressure
- Inlet pressure
- Combustion test results (all parameters)
- Temperature rise
- Any adjustments made
- Abnormalities noted
- Technician name and license
- Provide copy to customer

Customer Education:

Explain:

- How to operate appliance
- Thermostat/control use
- Filter changing (furnaces)
- Maintenance needs
- When to call for service
- Safety features
- Warranty information

Chapter Summary

Gas appliances convert fuel energy into useful heat through combustion. Major categories include heating equipment (furnaces, boilers, space heaters), water heaters (storage and tankless), cooking appliances, dryers, and specialty equipment (fireplaces, pool heaters, outdoor appliances). Each type has specific installation and performance characteristics.

Appliances are classified by venting category based on vent pressure and temperature. Category I (draft hood, non-condensing) requires Type B vent through roof. Category IV (positive pressure, condensing) uses PVC venting and achieves 90-98% efficiency by extracting latent heat from water vapor. Direct vent appliances use sealed combustion with outdoor air, eliminating spillage potential and combustion air requirements from living space.

All appliances must carry CSA, AGA/CGA, or ULC certification marks and rating plates showing input, gas type, electrical requirements, venting specifications, and clearances. Input ratings may require de-rating for high altitude (typically 4% per 1,000 feet above rated elevation) or propane conversion. Efficiency ratings include AFUE (annual average for furnaces and boilers), thermal efficiency (steady-state for water heaters), and combustion efficiency (field measurement).

Installation requires following manufacturer instructions for location, clearances to combustibles (reduced only with approved protection), and adequate combustion air. CSA B149.1 specifies calculation methods based on confined or unconfined space, with openings sized per total appliance input. Modern tight buildings often require dedicated combustion air even in apparently unconfined spaces.

Proper commissioning includes pre-start inspection, systematic start-up procedure, manifold pressure verification, combustion testing, and documentation. Acceptable combustion shows CO under 100 ppm air-free, proper O_2 and CO_2 levels, and efficient operation. Customer education on operation and maintenance completes the installation process.

Review Questions

Multiple Choice

1. A Category IV appliance is characterized by:
   - a) Natural draft and non-condensing
   - b) Positive vent pressure and condensing
   - c) Negative vent pressure and condensing
   - d) Positive vent pressure and non-condensing
2. AFUE stands for:
   - a) Actual Fuel Use Efficiency
   - b) Annual Fuel Utilization Efficiency
   - c) Approved Fuel Unit Efficiency
   - d) Average Furnace Use Efficiency
3. The typical de-rating factor for altitude is:
   - a) 2% per 1,000 feet
   - b) 4% per 1,000 feet
   - c) 6% per 1,000 feet
   - d) 10% per 1,000 feet
4. A confined space is defined as having less than:
   - a) 50 ft^3 per 1,000 BTU/hr
   - b) 100 ft^3 per 1,000 BTU/hr
   - c) 500 ft^3 per 1,000 BTU/hr
   - d) 1,000 ft^3 per 1,000 BTU/hr
5. Category I appliances use which type of vent?
   - a) PVC
   - b) Type B gas vent
   - c) Single-wall metal only
   - d) Flexible aluminum
6. The maximum acceptable CO reading in flue gas per CSA B149.1 is:
   - a) 50 ppm air-free
   - b) 100 ppm air-free
   - c) 200 ppm air-free
   - d) 400 ppm air-free
7. Direct vent appliances:
   - a) Use indoor air for combustion
   - b) Vent vertically through roof only
   - c) Use sealed combustion with outdoor air
   - d) Don't require venting
8. A furnace with 100,000 BTU/hr input and 80% AFUE has an output of:
   - a) 100,000 BTU/hr
   - b) 90,000 BTU/hr
   - c) 80,000 BTU/hr
   - d) 70,000 BTU/hr
9. Combustion air openings to outdoors are typically _____ the size of openings to indoors:
   - a) The same size as

- b) Half the size of
- c) Double the size of
- d) Four times the size of

10. The CSA certification mark indicates:
    - a) Appliance efficiency rating
    - b) Compliance with Canadian safety standards
    - c) Warranty period
    - d) Made in Canada

True or False

11. All gas appliances must have a recognized certification mark to be installed in Canada.
12. High-efficiency condensing appliances can vent with PVC pipe.
13. Clearances to combustibles can be reduced without manufacturer approval if protected with metal shielding.
14. Modern tight buildings may require combustion air openings even in unconfined spaces.
15. Input rating and output rating are the same for all appliances.

Short Answer

16. Explain the difference between AFUE and combustion efficiency. (4 marks)
17. List four pieces of information that must be shown on an appliance rating plate. (4 marks)
18. Why must some appliances be de-rated when converted from natural gas to propane? (3 marks)
19. What is the purpose of combustion air openings, and why are two openings required? (4 marks)
20. Describe the characteristics that distinguish a Category IV appliance from a Category I appliance. (5 marks)

Long Answer

21. A furnace rated 100,000 BTU/hr input is to be installed at 5,000 feet elevation. The rating plate indicates it's suitable for use up to 2,000 feet without de-rating, and requires 4% de-rating per 1,000 feet above that elevation.
    - Calculate the excess elevation
    - Calculate the required de-rating percentage
    - Calculate the de-rated input
    - Explain why de-rating is necessary at high altitude
    - Describe how de-rating would be accomplished (10 marks)
22. Describe the complete commissioning procedure for a new high-efficiency condensing furnace. Include:
    - Pre-start inspection items
    - Step-by-step start-up procedure
    - Measurements and tests to perform
    - Acceptance criteria for combustion
    - Safety tests required

- Documentation requirements
- Customer education topics (15 marks)

23. A utility room measures 8 ft × 10 ft × 8 ft high and contains a furnace (100,000 BTU/hr) and water heater (40,000 BTU/hr). Determine if this is a confined or unconfined space and calculate the required combustion air openings if combustion air is to be provided from outdoors through vertical ducts. Show all calculations and explain your work. (12 marks)

Practical Exercises

Exercise 1: Rating Plate Interpretation

Given various appliance rating plates:

1. Identify manufacturer and model
2. Determine gas type(s) permitted
3. Note input rating
4. Identify venting category
5. List clearance requirements
6. Determine electrical requirements
7. Check for altitude limitations
8. Identify efficiency rating

Exercise 2: Combustion Air Calculation

For given room and appliance loads:

1. Calculate room volume
2. Determine confined vs. unconfined
3. Calculate required opening sizes
4. Design combustion air system
5. Sketch installation
6. Specify materials and termination
7. Document calculations

Exercise 3: Appliance Commissioning

On training appliance or actual installation:

1. Complete pre-start checklist
2. Perform systematic start-up
3. Check manifold pressure
4. Adjust if needed

5. Perform combustion testing
6. Record all measurements
7. Verify temperature rise (furnace)
8. Test safeties
9. Complete documentation
10. Identify any issues

Exercise 4: Clearance Verification

In lab or using photos:

1. Identify appliance clearances required
2. Measure actual clearances
3. Determine if compliant
4. Identify violations if any
5. Recommend corrections
6. Calculate clearance reduction if appropriate
7. Sketch proper installation

Exercise 5: Efficiency Comparison

Compare various appliances:

1. Different AFUE ratings
2. Calculate annual fuel usage for each
3. Calculate operating costs
4. Determine payback period for higher efficiency
5. Consider installation cost differences
6. Make recommendations

Exercise 6: Venting Category Identification

For various appliances:

1. Identify venting category
2. Determine appropriate vent material
3. Identify termination requirements
4. Note special requirements
5. Compare different categories
6. Understand application of each

Case Studies

Case Study 1: Insufficient Combustion Air

Scenario: You're called to service a furnace that "keeps shutting down." The furnace is in a small utility room (6' × 8' × 7' high = 336 ft^3) with a tightly sealed door and no combustion air openings. Appliances: Furnace 100,000 BTU, Water heater 40,000 BTU (total 140,000 BTU). The furnace is Category I with draft hood. You observe spillage at the draft hood during operation.

Questions:

1. Is this a confined or unconfined space? (Show calculation)
2. What is causing the spillage?
3. Calculate required combustion air openings for indoor air source
4. Calculate required combustion air openings for outdoor air source
5. What immediate safety concerns exist?
6. Can the appliances operate safely without modification?
7. What are the correction options?
8. What do you tell the homeowner?

Case Study 2: Wrong Appliance for Application

Scenario: A homeowner had a handyman install a "really good deal" water heater he bought online. You're called because it won't stay lit. You find a U.S.-market water heater (40,000 BTU input, natural gas, 3.5" W.C. manifold pressure) installed in Canada on a propane system (11" W.C. supply pressure). The rating plate shows no CSA mark, only UL certification. The water heater has natural gas orifices and is connected to propane supply.

Questions:

1. What certification problems exist?
2. Why won't the water heater stay lit?
3. What pressure and orifice problems exist?
4. Is this installation legal in Canada?
5. Can this water heater be used in Canada?
6. What are the safety risks?
7. What is the proper correction?
8. What do you tell the homeowner?

Case Study 3: Clearance Violation

Scenario: During an inspection, you find a furnace installed with 1" side clearance. The rating plate specifies 6" minimum clearance to combustibles on sides. The wall is wood-framed with drywall. The homeowner says it's been like this for 5 years with no problems.

Questions:

1. Is this a code violation?
2. What is the safety risk?
3. Can the furnace remain in service?
4. What are the correction options?
5. Can clearances be reduced with protection?
6. How much would approved protection reduce clearances?
7. What if relocation is impossible?
8. What happens if homeowner refuses correction?

Case Study 4: Altitude Installation

Scenario: You're installing a furnace in a mountain town at 6,000 feet elevation. The rating plate states: "Suitable for use up to 2,000 ft without de-rating. De-rate 4% per 1,000 ft above 2,000 ft." The furnace is rated 80,000 BTU/hr input with natural gas orifice #43.

Questions:

1. Calculate the required de-rating
2. What should the de-rated input be?
3. How is de-rating accomplished?
4. What orifice size should be used?
5. What happens if not de-rated?
6. How do you verify proper de-rating?
7. What combustion testing would you perform?
8. What documentation is required?

Case Study 5: High Efficiency vs. Standard Efficiency

Scenario: A customer is replacing their furnace. Current furnace: 100,000 BTU, 80% AFUE, costing approximately $1,200/year in gas. Options:

- Option A: Standard efficiency 95,000 BTU, 80% AFUE, installed $3,500
- Option B: High efficiency 95,000 BTU, 96% AFUE, condensing, installed $5,800

Natural gas costs $0.80/therm (100,000 BTU). Heat load analysis shows 95,000 BTU output adequate.

Questions:

1. Calculate annual fuel cost for each option
2. Calculate annual savings with high efficiency
3. Calculate simple payback period
4. What other factors should customer consider?
5. What maintenance differences exist?
6. What installation differences?
7. What would you recommend and why?

8. How would propane prices change the analysis?

Case Study 6: Commissioning Failure

Scenario: You've installed a new high-efficiency furnace (Category IV, 96% AFUE, 100,000 BTU input). During commissioning, your combustion analyzer shows:

- O_2: 12%
- CO: 450 ppm air-free
- CO_2: 6%
- Stack temperature: 210°F The flame appears yellow with some soot.

Questions:

1. Are these readings acceptable?
2. What problem(s) do the readings indicate?
3. What is causing high CO?
4. What is causing low CO_2?
5. What should the readings be?
6. What would you check and adjust?
7. Can the furnace be left in service?
8. What if you can't correct the problem?

Key Terms

AFUE (Annual Fuel Utilization Efficiency): Seasonal average efficiency including all losses; expressed as percentage.

Category I Appliance: Draft hood equipped, natural draft, non-condensing, uses Type B vent.

Category IV Appliance: Positive vent pressure, condensing, high efficiency, uses PVC or other special vent.

Certification Mark: Symbol (CSA, AGA/CGA, ULC) indicating appliance meets safety standards.

Clearance: Minimum distance from appliance to combustible materials.

Combustion Air: Air provided for fuel combustion; oxygen source for burner.

Combustion Efficiency: Percentage of fuel energy extracted during combustion; field measurement.

Confined Space: Space with less than 50 ft^3 per 1,000 BTU/hr of appliance input.

De-rating: Reducing appliance input for altitude or fuel type change.

Direct Vent: Sealed combustion appliance using outdoor air; concentric vent common.

Input Rating: Rate at which appliance consumes fuel energy; measured in BTU/hr.

Output Rating: Useful heat delivered by appliance; always less than input due to losses.

Rating Plate: Metal tag on appliance showing specifications, certifications, and requirements.

Thermal Efficiency: Steady-state efficiency during continuous operation; used for water heaters.

Unconfined Space: Space with 50 ft^3 or more per 1,000 BTU/hr of appliance input.

End of Chapter 9

CHAPTER 10

Burners and Combustion Systems

Learning Objectives

Upon completion of this chapter, students will be able to:

1. Explain the operation of atmospheric and power burner systems
2. Identify different ignition system types and their operation
3. Understand flame sensing methods and troubleshoot sensor problems
4. Calculate and select proper burner orifice sizes
5. Adjust primary air for optimal combustion
6. Perform combustion analysis and interpret results
7. Calculate combustion air requirements per CSA B149.1
8. Identify and correct common combustion problems
9. Understand burner port loading and flame characteristics
10. Apply pressure and flow relationships to burner operation

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10.1 Atmospheric Burners

Atmospheric burners are the most common type in residential gas appliances, using natural draft and venturi principles.

Basic Operation Principles

Venturi Effect:

The core principle of atmospheric burners:

1. **Gas Flow:** Gas flows through orifice at pressure (typically 3.5" W.C. natural gas, 10" W.C. propane)
2. **Velocity:** High-velocity gas jet creates low-pressure area
3. **Air Entrainment:** Low pressure draws in primary air through air shutter
4. **Mixing:** Gas and primary air mix in venturi throat and mixing tube
5. **Delivery:** Mixed gas-air exits burner ports
6. **Secondary Air:** Additional air drawn from surrounding area during combustion

Components:

Gas Orifice (Spud):

- Precisely sized hole
- Controls gas flow rate
- Threads into manifold or burner
- Sized for gas type and input

Air Shutter:

- Adjustable opening
- Controls primary air entry
- Slide, rotating band, or fixed
- Sets air-fuel ratio

Venturi (Mixing Tube):

- Converging-diverging passage
- Creates low pressure for air entrainment
- Mixes gas and air
- Delivers mixture to burner

Burner Head:

- Port configuration
- Distributes flame
- Various designs (ribbon, inshot, slotted, etc.)
- Material: cast iron, steel, stainless steel

Primary and Secondary Air

Primary Air:

Definition:

- Air mixed with gas BEFORE combustion
- Drawn through air shutter
- Typically 40-60% of total air needed

Control:

- Air shutter adjustment
- Affects flame characteristics
- Critical for proper combustion

Too Little Primary Air:

- Yellow, lazy flame
- Incomplete combustion
- Soot and carbon monoxide production
- Lower efficiency
- Possible flame lifting

Too Much Primary Air:

- Short, sharp blue flame
- Hard, noisy combustion (roaring)
- Flame lifting or blowing off ports
- Flashback possible
- Heat loss through excess air

Correct Primary Air:

- Stable blue flame
- Soft, quiet combustion
- Inner cone distinct
- Slight yellow tips acceptable (minimal)
- No lifting or flashback

Secondary Air:

Definition:

- Air drawn into flame from surrounding area
- Completes combustion
- Approximately 40-60% of total air

Control:

- No direct control mechanism
- Must be available from room/combustion air supply
- Limited by combustion air provisions

Importance:

- Completes combustion
- Prevents CO formation
- Essential for safe operation
- Reason combustion air openings required

Burner Types and Designs

Understanding different burner configurations is essential for proper service and troubleshooting.

Atmospheric (In-Shot) Burners:

Description:

- Most common residential furnace burner
- Gas-air mixture "shoots" horizontally into heat exchanger
- Venturi throat at burner inlet
- Flame projects forward into heat exchanger tubes or clamshell

Construction:

- Cast iron or stamped steel
- Mixing tube with air shutter
- Burner head with port configuration
- Orifice threads into manifold

Operation:

- Gas jet creates venturi effect
- Primary air enters through shutter
- Mixed gas-air travels through mixing tube
- Exits ports and ignites
- Flame projects into heat exchanger

Port Configurations:

- Single row of ports
- Double row (ribbon style)
- Slotted ports
- Various patterns for flame distribution

Advantages:

- Simple and reliable
- Quiet operation
- Easy to service
- Good heat transfer
- Proven design

Applications:

- Residential forced-air furnaces (most common)
- Some commercial furnaces
- Standard efficiency equipment

Service Considerations:

- Air shutter adjustment critical
- Burner alignment important
- Must maintain proper spacing to heat exchanger
- Clean ports if clogged

Upshot (Vertical) Burners:

Description:

- Flame projects vertically upward
- Burner positioned below heat exchanger
- Gas-air mixture shoots upward into heat exchanger
- Common in older furnaces and some boilers

Construction:

- Similar to in-shot but vertical orientation
- Mixing tube vertical or angled
- Burner ports face upward
- Cast iron or steel construction

Operation:

- Venturi mixes gas and air
- Mixture travels up through burner
- Exits upward-facing ports
- Flame rises into heat exchanger above

Heat Exchanger Configuration:

- Clamshell heat exchanger typical
- Sectional cast iron (boilers)
- Heat exchanger surrounds flame

Advantages:

- Natural flame direction (upward)
- Good for gravity systems
- Simple design
- Effective heat transfer

Disadvantages:

- Larger footprint
- Less common in modern equipment
- More difficult to service (access)

Applications:

- Older residential furnaces
- Gravity furnaces (obsolete)
- Cast iron boilers
- Some commercial equipment

Ribbon Burners:

Description:

- Long, narrow burner
- Multiple ports in continuous row(s)
- Creates "ribbon" of flame
- Port arrangement provides wide flame pattern

Construction:

- Stamped steel body
- Hundreds of small drilled or stamped ports
- One or two rows of ports
- Length matches heat exchanger width

Port Configuration:

- Ports: 1/16" to 1/8" diameter typically
- Spacing: 1/4" to 1/2" center-to-center
- Single or double row
- Very uniform distribution

Operation:

- Gas-air mixture enters one end
- Distributes along length of burner
- Burns at many small ports
- Wide, even flame pattern
- Excellent heat distribution

Advantages:

- Very uniform heat distribution
- Efficient combustion
- Good flame stability
- Quiet operation
- Minimal flame impingement risk

Disadvantages:

- Port plugging possible (dust, debris)
- Requires proper manifold pressure
- Cleaning tedious (many small ports)

Applications:

- Modern high-efficiency furnaces
- Premix burners
- Commercial cooking equipment
- Industrial heaters

Service Considerations:

- Check all ports for plugging
- Clean with wire brush or compressed air
- Verify even flame across entire length
- Check for port erosion

Slotted Port Burners:

Description:

- Slots instead of round holes
- Common in water heaters
- Wide flame pattern from each slot
- Simple and economical

Construction:

- Stamped or cast metal
- Rectangular or elongated slots
- Typically 3-8 slots per burner
- Slots: 1/4" to 3/4" long

Operation:

- Gas-air mixture enters from below or side
- Exits through slots
- Each slot produces wide flame
- Flames overlap for coverage

Flame Characteristics:

- Wider, flatter flames than round ports

- Good stability
- Less prone to lifting
- Forgiving of slight adjustment errors

Advantages:

- Less prone to clogging than small ports
- Easy to clean
- Stable flames
- Forgiving design
- Lower cost

Disadvantages:

- Less uniform than many small ports
- Potential for flame impingement if misaligned
- Limited to lower input applications

Applications:

- Residential water heaters (very common)
- Small commercial water heaters
- Pool heaters
- Some space heaters

Service Considerations:

- Easy to clean
- Check for burner alignment
- Verify proper spacing to baffle/flame arrestor
- Look for flame impingement

Drilled Port Burners:

Description:

- Precision-drilled round holes
- Cast iron or heavy steel construction
- Very stable and durable
- Used in boilers and commercial equipment

Construction:

- Cast iron body (typical)
- Precision-drilled ports
- Port size: 1/8" to 1/4" typical

- Spacing designed for specific application
- Heavy, durable construction

Port Patterns:

- Linear rows
- Circular patterns
- Custom patterns for application
- Engineered for specific heat exchanger

Operation:

- Gas-air mixture supplied to burner
- Exits each drilled port
- Individual flame at each port
- Very stable combustion
- Predictable performance

Advantages:

- Very durable (cast iron)
- Long service life
- Precise flame control
- Excellent stability
- Resists warping

Disadvantages:

- Heavy
- Expensive
- Difficult to modify
- Requires proper support

Applications:

- Cast iron boilers (very common)
- Commercial boilers
- Industrial heaters
- High-quality residential boilers
- Long-life applications

Service Considerations:

- Check for cracks (cast iron)
- Clean ports with wire brush
- Verify proper seating/gasketing

- Check for port erosion
- Inspect for flame impingement

Multi-Port (Perforated) Burners:

Description:

- Many small holes (perforations)
- Often 100+ ports per burner
- Produces multiple small flames
- Very uniform heat distribution

Construction:

- Sheet metal with stamped or drilled holes
- Burner may be flat, cylindrical, or shaped
- Port size: 1/32" to 1/16" very small
- High port density

Applications:

- Infrared heaters
- High-efficiency appliances
- Radiant burners
- Commercial cooking (some)
- Specialized industrial applications

Characteristics:

- Many small flames or radiant surface
- Very uniform heating
- Excellent mixing
- Low emissions potential
- Quiet operation

Service:

- Prone to plugging (very small ports)
- Difficult to clean (many ports)
- May require replacement if damaged
- Critical to maintain proper pressure

Radiant Burners:

Description:

- Flame heats ceramic or metal surface
- Surface radiates infrared heat
- No visible flame (sometimes)
- Efficient radiant heating

Construction:

- Perforated burner or porous ceramic
- Gas-air mixture burns at or in surface
- Surface glows orange/red
- Reflector directs heat

Types:

Ceramic Radiant:

- Porous ceramic tile or panel
- Gas burns within ceramic matrix
- Surface glows bright orange
- Infrared radiation

Metal Mesh/Screen:

- Fine metal screen
- Flame stabilizes on screen surface
- Screen glows
- Radiant heat

Operation:

- Gas-air mixture supplied
- Combustion at surface
- Surface heats to 1500-1800°F
- Radiates infrared energy
- No convective heat transfer

Advantages:

- Efficient radiant heating
- Quiet operation
- No visible flame (safer perception)
- Targeted heating
- Good for outdoor/open areas

Disadvantages:

- Fragile (ceramic types)
- Expensive
- Requires precise control
- Can be damaged by impact

Applications:

- Outdoor patio heaters
- Industrial process heating
- Commercial space heating (high bay)
- Infrared comfort heating
- Paint drying, curing

Power Burners (Fan-Assisted):

Description:

- Uses fan to supply combustion air
- Positive or negative pressure
- More complex but higher performance
- Common in modern equipment

Types:

Forced Draft:

- Fan pushes air through burner
- Positive pressure in combustion chamber
- Fan upstream of burner

Induced Draft:

- Fan pulls air through burner
- Negative pressure in combustion chamber
- Fan downstream (after heat exchanger)

Premix:

- Gas and air completely mixed before burner
- Fan mixes and delivers to burner head
- Very efficient
- Lower emissions

Construction:

- Burner head with ports or mesh

- Fan (centrifugal or vane-axial)
- Gas valve with air mixing section
- Electronic controls
- Pressure switches

Advantages:

- Better combustion control
- Higher efficiency
- Can handle longer vents
- More compact
- Less sensitive to building pressure
- Can modulate

Disadvantages:

- More complex
- Higher cost
- Requires electricity
- Fan failure = no heat
- More maintenance

Applications:

- High-efficiency furnaces (90%+ AFUE)
- Condensing boilers
- Modulating equipment
- Commercial equipment
- Sealed combustion appliances

Sealed Combustion Burners:

Description:

- Combustion chamber sealed from room
- All combustion air from outdoors
- Often power burner design
- Direct vent configuration

Construction:

- Sealed combustion chamber
- Concentric vent (air in, flue out)
- Fan-powered typically
- Gaskets seal chamber

Operation:

- Fan draws outdoor air
- Mixes with gas
- Burns in sealed chamber
- Flue gases exhaust outside
- No room air involved

Advantages:

- No combustion air from conditioned space
- No spillage possibility
- Works in tight buildings
- Can install in confined spaces
- Improved efficiency (not heating outdoor air)

Disadvantages:

- More expensive
- Complex installation
- Requires specific venting
- Sensitive to wind effects

Applications:

- Modern high-efficiency equipment
- Tight building installations
- Bedroom closet installations (with restrictions)
- Commercial applications

Conversion Burners:

Description:

- Aftermarket burners
- Convert oil to gas (historical)
- Convert atmosphere to power (rare)
- Retrofit applications

Notes:

- Becoming obsolete
- Usually better to replace entire appliance
- Complex certification issues
- Limited applications today

Specialty Burners:

Bunsen Burner Style:

- Laboratory and process applications
- Adjustable air and gas
- Single flame
- Not common in HVAC

Surface Combustion:

- Industrial applications
- Combustion at or within porous material
- Process heating
- Specialized equipment

Duct Burners:

- Installed in ductwork
- Supplemental heating
- Commercial buildings
- Make-up air heating

Flame Characteristics

Proper Natural Gas Flame:

- Clear blue color
- Distinct inner cone (light blue)
- Outer mantle (darker blue/purple)
- Stable, not lifting or floating
- Soft, quiet combustion
- Minimal yellow tipping at outer edge

Proper Propane Flame:

- Blue flame with slight luminosity
- May show more yellow tipping than natural gas (acceptable if minimal)
- Stable and quiet
- Distinct inner cone

Flame Zones:

Inner Cone (Primary Combustion Zone):

- Light blue

- Hottest part: 1,980°C (3,600°F) for methane
- Primary air combustion
- Distinct boundary

Outer Mantle (Secondary Combustion Zone):

- Darker blue/purple
- Secondary air completes combustion
- Slightly cooler than inner cone
- May show slight yellow at tips

Problem Flames:

Yellow or Orange Flame:

- Insufficient air
- Incomplete combustion
- Soot formation
- CO production
- Requires adjustment

Lifting Flame:

- Flame lifts off ports
- Excessive primary air or gas velocity
- Can cause ignition failure
- Noisy operation
- Reduce primary air or check orifice size

Floating Flame:

- Flame hovers above burner
- Not stable on ports
- Usually too much primary air
- Dangerous - can extinguish

Flashback:

- Flame burns inside burner
- Too much primary air
- Gas velocity too low
- Very dangerous
- Shut down immediately
- Reduce primary air

Impingement:

- Flame contacts surfaces
- Heat exchanger too close
- Misaligned burner
- Causes incomplete combustion
- Yellow flame and CO

10.2 Power Burners

Power burners use fans to force combustion, providing better control and higher efficiency.

Power Burner Operation

Basic Principle:

- Fan forces air into combustion chamber
- Gas injected into air stream
- Premixed before combustion
- More precise air-fuel control

Advantages:

- Better mixing
- More complete combustion
- Higher efficiency
- More compact
- Independent of room conditions
- Can handle longer vent runs

Types:

Forced Draft:

- Fan blows air through burner
- Positive pressure in combustion chamber
- Fan before burner

Induced Draft:

- Fan draws air through burner
- Negative pressure in combustion chamber
- Fan after heat exchanger
- More common in residential

Premix:

- Gas and air fully mixed before combustion
- Very efficient
- Lower emissions
- Complex controls

Modulating Burners

Operation:

- Vary firing rate to match load
- Gas valve and fan modulate together
- Maintain optimal air-fuel ratio
- High efficiency

Advantages:

- Precise temperature control
- Fewer cycles
- Higher seasonal efficiency
- Better comfort

Control:

- Electronic controls monitor demand
- Adjust gas valve position
- Adjust fan speed
- Maintain proper ratio

Applications:

- High-efficiency furnaces
- Modulating boilers
- Premium residential equipment
- Commercial applications

Two-Stage Burners

Operation:

- Two firing rates: high and low
- Typically 65-70% low, 100% high
- Better than single-stage
- Simpler than modulating

Control:

- Thermostat or control board determines stage
- Cold call = high fire
- Moderate call = low fire
- Gas valve switches between outputs

Benefits:

- Reduced cycling
- Better efficiency
- Improved comfort
- Lower cost than modulating

10.3 Burner Orifices

Orifices control gas flow rate and are critical for proper appliance operation.

Orifice Function

Purpose:

- Meter gas flow
- Create specific input rate
- Match appliance requirements
- Convert pressure to flow

How Orifices Work:

- Gas under pressure enters orifice
- Small opening restricts flow
- Flow rate depends on:
    - Orifice size (diameter)
    - Gas pressure
    - Specific gravity of gas

Orifice Sizing

Factors Affecting Size:

Gas Type:

- Natural gas: larger orifices
- Propane: smaller orifices (60% of natural gas size typically)
- Different heating values require different flows

Pressure:

- Natural gas manifold: typically 3.5" W.C.
- Propane manifold: typically 10" W.C.
- Higher pressure = smaller orifice for same flow

Input Required:

- Higher input = larger orifice
- Flow in CFH needed
- Calculate from BTU input

Specific Gravity:

- Heavier gas = slower flow
- Lighter gas = faster flow
- Corrections needed if SG differs from standard

Drill Number Sizing

Drill Number System:

- Standardized drill sizes
- Numbered #1 through #80 (plus wire gauges)
- Higher number = smaller diameter
- Fractional sizes also used

Common Ranges:

- Natural gas: #35 to #50 typical residential
- Propane: #50 to #60 typical residential
- Varies by appliance and input

Example:

- #43 drill = 0.089" diameter
- #54 drill = 0.055" diameter

Measurement:

- Orifice drill size often stamped on orifice
- Can measure with drill bit gauge
- Precision critical (0.001" changes flow significantly)

Orifice Calculation

Basic Formula:

Flow (CFH) = $C \times d^2 \times \sqrt{P / SG}$

Where:

- C = constant (depends on units)
- d = orifice diameter (inches)
- P = pressure (inches W.C.)
- SG = specific gravity

Simplified Approach: Use manufacturer's tables or orifice capacity charts

Example Selection:

Furnace burner:

- Total input: 100,000 BTU/hr
- 5 burners
- Input per burner: 100,000 ÷ 5 = 20,000 BTU/hr
- Natural gas (1,000 BTU/ft^3)
- Flow per burner: 20,000 ÷ 1,000 = 20 CFH
- Manifold pressure: 3.5" W.C.
- From chart: #43 drill provides approximately 20 CFH at 3.5" W.C.

Verify:

- Check manufacturer specifications
- Use provided orifices when available
- Calculate only when needed

Altitude Compensation

At Higher Elevations:

- Less oxygen available
- Must reduce gas flow
- Smaller orifices required
- Or reduce pressure

Typical Adjustment:

- 4% reduction per 1,000 feet above rated elevation
- Accomplished by smaller orifices or lower pressure
- Follow manufacturer de-rating instructions

Example:

- Sea level orifice: #43
- 5,000 ft elevation
- May require #45 or #46 (smaller)
- Or reduce manifold pressure

Orifice Installation

Procedure:

1. Turn off gas supply
2. Release pressure downstream
3. Remove old orifice (wrench on hex)
4. Inspect threads
5. Install new orifice (hand tight then 1/4-1/2 turn)
6. Don't overtighten (brass threads)
7. Pressure test
8. Leak test with soap solution
9. Set manifold pressure
10. Verify input rate

Common Mistakes:

- Wrong orifice size
- Cross-threading
- Overtightening (cracks orifice or manifold)
- Not leak testing
- Forgetting pilot orifice

10.4 Ignition Systems

Modern appliances use various ignition methods to light burners safely and efficiently.

Standing Pilot

Operation:

- Small pilot flame burns continuously
- Ignites main burner when valve opens
- Thermocouple or thermopile proves flame
- Traditional system

Components:

Pilot Burner:

- Small orifice (typically #55-#60 drill)
- Pilot flame directed at thermocouple
- Must remain lit continuously

Thermocouple:

- Generates millivolts when heated
- Provides power to hold pilot safety valve open
- Typically 20-30 millivolts required
- See Chapter 10.5 for details

Pilot Safety Valve:

- Electromagnet holds valve open
- Thermocouple powers magnet
- If pilot out, magnet releases, valve closes
- Prevents gas flow without flame

Advantages:

- Simple and reliable
- No electricity required
- Proven technology
- Easy to relight

Disadvantages:

- Wastes gas (burns continuously)
- Heat loss
- Lower seasonal efficiency
- Not permitted on some high-efficiency equipment

Relighting Procedure:

1. Turn gas control to "OFF", wait 5 minutes
2. Turn to "PILOT"
3. Push and hold pilot button
4. Light pilot with igniter or match
5. Hold button 30-60 seconds
6. Release button - pilot should stay lit
7. Turn to "ON" position
8. Set desired temperature

Intermittent Pilot Ignition (IPI)

Operation:

- Pilot lights electronically only when needed
- Spark ignites pilot
- Pilot ignites main burner
- Pilot extinguishes when main burner off
- Saves gas vs. standing pilot

Components:

Ignition Control Module:

- Electronic controller
- Times ignition sequence
- Monitors flame
- Safety lockout if fails

Spark Generator:

- Creates high-voltage spark (10,000+ volts)
- Ignites pilot
- Similar to car spark plug

Spark Electrode:

- Positioned at pilot
- Gap to ground (typically 1/8")
- Creates arc to ignite pilot

Flame Sensor:

- Flame rod (rectification)
- Or thermocouple
- Proves pilot lit before opening main valve

Sequence:

1. Call for heat
2. Module energizes spark and gas valve (pilot)
3. Pilot ignites (typically 5-7 seconds)
4. Sensor proves pilot lit
5. Main valve opens
6. Main burner ignites from pilot
7. Spark stops
8. When satisfied, main valve closes
9. Pilot extinguishes

Advantages:

- Saves gas vs. standing pilot
- Automatic ignition
- No pilot outage problems
- Safer than standing pilot

Disadvantages:

- Requires electricity
- More complex than standing pilot
- Electronic components can fail
- More expensive

Direct Spark Ignition (DSI)

Operation:

- Spark directly ignites main burner
- No pilot flame
- Most efficient ignition
- Common in modern equipment

Components:

Ignition Control Module:

- Electronic controller
- Provides high-voltage spark
- Monitors flame
- Safety timing and lockout

Spark Electrode(s):

- At main burner
- Creates spark directly to burner ports
- Gap critical (typically 1/8" to 3/16")
- One or multiple electrodes

Flame Sensor:

- Flame rectification rod
- Separate from spark electrode (usually)
- Proves main burner lit
- Immediate sensing

Sequence:

1. Prepurge (induced draft fan runs)
2. Spark begins
3. Gas valve opens (pilot or main)
4. Flame ignites from spark
5. Flame sensor proves ignition
6. Spark stops
7. Normal operation
8. Safety lockout if no flame

Advantages:

- No pilot gas waste
- Fastest ignition
- Highest efficiency
- Fewer components than IPI

Disadvantages:

- Spark electrodes wear
- Gap maintenance required
- More sensitive to improper combustion
- Electronic failure potential

Hot Surface Ignition (HSI)

Operation:

- Silicon nitride or silicon carbide element heats electrically
- Glows bright orange (2,500°F)
- Ignites gas directly when valve opens
- No spark

Components:

Hot Surface Igniter:

- Ceramic element
- Glows bright orange when energized
- Very fragile
- Positioned in gas path

Ignition Control:

- Times warm-up period

- Opens valve when igniter hot
- Monitors flame
- Safety lockout

Flame Sensor:

- Often igniter itself (senses current change)
- Or separate flame rod
- Proves ignition

Sequence:

1. Prepurge (if applicable)
2. Igniter energized (30-90 seconds warm-up)
3. Control confirms igniter hot
4. Gas valve opens
5. Gas ignites instantly from hot igniter
6. Flame sensor confirms
7. Igniter remains energized (most systems) or de-energizes
8. Normal operation

Advantages:

- Very reliable ignition
- No pilot gas waste
- No spark maintenance
- Quiet (no spark noise)
- Long service life (if not damaged)

Disadvantages:

- Fragile (easily broken if touched)
- Warm-up time delay
- Requires replacement when failed
- Cannot be repaired
- Higher current draw than spark

Handling HSI:

- NEVER touch ceramic element with bare hands (oils cause failure)
- Handle by ceramic base only
- Use gloves if must touch
- Very fragile - breaks easily
- Replace if cracked

10.5 Flame Sensing

Flame sensing devices verify ignition and prove flame presence for safety.

Thermocouple Systems

Thermocouple Principle:

- Two dissimilar metals joined
- Heat at junction generates voltage
- Millivolt output (typically 20-30 mV for gas pilot)
- Powers pilot safety valve

Construction:

- Hot junction at tip (in pilot flame)
- Cold junction at base
- Insulated lead wire
- Various lengths

Operation:

1. Pilot flame heats tip
2. Generates 20-35 millivolts typically
3. Powers electromagnetic coil in valve
4. Magnet holds valve open
5. If flame out, voltage drops
6. Magnet releases, valve closes
7. Requires manual reset (relight pilot)

Testing:

- Measure millivolt output with meter
- Hot (in flame): 20-35 mV typically
- Cold (no flame): 0-2 mV
- Replace if output low (under 20 mV)

Problems:

- Weak output (replace)
- Loose connection
- Corroded or dirty tip
- Wrong position in flame
- Pilot flame too small

Thermopile:

- Multiple thermocouples in series
- Higher voltage output (500-750 mV typical)
- Powers gas valve directly (millivolt valve)
- Powers controls
- Common in standing pilot systems

Flame Rectification

Principle:

- Flame conducts electricity in one direction only
- AC current through flame becomes DC
- Control module senses DC current
- Modern standard for proving flame

How It Works:

1. Control applies AC voltage across flame rod and ground
2. Flame ionizes (conducts)
3. Flame acts as diode (conducts better one direction)
4. Resulting current is pulsing DC
5. Control detects DC current
6. DC = flame present
7. No DC = no flame, valve closes

Flame Rod:

- Stainless steel rod
- Positioned in flame
- Small gap to ground (burner)
- Insulated from burner
- Conducts through flame to ground

Signal:

- Microamps (μA) DC current
- Typically 0.5 to 6 μA for good flame
- Above 1 μA generally adequate
- Below 0.5 μA may not prove

Advantages:

- Very reliable
- Fast response (milliseconds)
- No mechanical parts
- Simple and inexpensive

- Standard in modern equipment

Disadvantages:

- Sensitive to grounding problems
- Carbon buildup affects sensing
- Proper positioning critical

Common Problems:

No or Low Flame Signal:

Causes:

- Flame rod positioned wrong (not in flame)
- Carbon buildup on rod
- Insulator cracked (grounding)
- Rod corroded
- Wrong gap to ground
- Poor ground connection at burner
- Weak flame (poor combustion)

Solutions:

- Reposition rod in proper flame zone
- Clean rod with fine steel wool
- Replace if insulator cracked
- Verify good ground path to control
- Check flame characteristics
- Verify proper combustion

Intermittent Flame Loss:

- Loose connections
- Intermittent ground
- Burner not grounded properly
- Control module failure

Testing Flame Rod:

1. Measure microamps with meter
2. Rod to ground with burner firing
3. Should read 1-6 μA typically
4. Below 0.5 μA problematic
5. Verify with manufacturer specifications

Flame Rod Position:

- In outer mantle of flame
- Not in hottest part (inner cone)
- About 1/2" to 1" into flame
- Proper gap to ground (1/8" typical)
- Follow manufacturer positioning

Optical Flame Sensors

Ultraviolet (UV) Sensors:

- Detect UV light from flame
- Fast response
- Commercial/industrial applications
- Not common in residential

Infrared (IR) Sensors:

- Detect IR radiation from flame
- Used in some high-end equipment
- Can distinguish flame from other heat sources

10.6 Combustion Air Requirements

Adequate combustion air is essential for complete, safe combustion.

Theoretical vs. Actual Air Requirements

Theoretical (Stoichiometric) Air:

For complete combustion of methane (natural gas):

- $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$
- Requires 2 molecules O_2 per molecule CH_4
- Air is 21% oxygen, 79% nitrogen
- Need approximately 9.5 ft^3 air per ft^3 natural gas
- This is MINIMUM for complete combustion

Actual Air Required:

Perfect mixing impossible, so excess air needed:

- **Atmospheric burners:** 40-60% excess air typical
- **Power burners:** 15-30% excess air typical
- Total air: theoretical × (1 + excess percentage)

Example:

- Theoretical air: 9.5 ft^3/ft^3 gas
- 50% excess air
- Actual air: $9.5 \times 1.5 = 14.25$ ft^3/ft^3 gas

For 100,000 BTU/hr appliance (natural gas):

- Gas flow: 100 CFH
- Air required: $100 \times 14.25 = 1{,}425$ CFH
- This air must come from somewhere!

CSA B149.1 Combustion Air Provisions

Review from Chapter 9:

Confined Space:

- Less than 50 ft^3 per 1,000 BTU/hr
- Requires combustion air openings

Unconfined Space:

- 50 ft^3 or more per 1,000 BTU/hr
- May have adequate infiltration (old buildings)
- Modern tight buildings may still need openings

Combustion Air Opening Sizing:

Method 1: All Air from Inside

- Two openings (top and bottom)
- Each: 220 in^2 per 100,000 BTU/hr total input
- To adjacent unconfined space or outdoors

Method 2: All Air from Outdoors

- Two openings to outdoors (top and bottom)
- Vertical ducts: 110 in^2 per 100,000 BTU/hr each
- Horizontal ducts: 220 in^2 per 100,000 BTU/hr each

Method 3: Mechanical Ventilation

- Powered ventilation
- 1 CFM per 2,400 BTU/hr minimum
- Special provisions and interlocks

Example Calculation:

System:

- Furnace: 100,000 BTU/hr
- Water heater: 40,000 BTU/hr
- Total: 140,000 BTU/hr

Combustion Air from Outdoors (Vertical):

- Each opening: $140{,}000 \div 100{,}000 \times 110 = 154$ in²
- Convert: $154 \div 144 = 1.07$ ft²
- Approximately 12" × 13" each opening

Make-Up Air Considerations

Building Depressurization:

Modern homes have powerful exhaust equipment:

- Kitchen exhaust fans
- Bathroom fans
- Dryer vents
- Central vacuums
- Fireplaces

Problem:

- Exhaust more air than enters
- Creates negative pressure
- Can overcome draft hood appliances
- Causes spillage
- Pulls CO into living space

Solution:

- Make-up air for powerful exhaust
- Interlock exhaust with make-up air supply
- Or use direct vent/power vent appliances
- Test for depressurization

Pressure Testing:

- Manometer or draft gauge
- Measure with exhaust equipment on
- -3 Pa (-0.01" W.C.) or more negative indicates problem
- Most building codes now address this

10.7 Combustion Analysis

Combustion analysis verifies proper combustion and safety.

Purpose of Combustion Testing

Verify:

- Complete combustion
- Safe CO levels
- Proper air-fuel mixture
- Equipment efficiency
- Vent operation

When Required:

- Initial installation
- Annual service
- After any combustion system repair
- After conversion
- Troubleshooting performance problems
- Code/manufacturer requirements

Combustion Analyzer Operation

Measurements:

Oxygen (O_2):

- Percentage in flue gas
- Indicates excess air
- Normal: 5-9%
- Too low (<5%): insufficient air, danger
- Too high (>10%): excess air, inefficiency

Carbon Dioxide (CO_2):

- Percentage in flue gas
- Indicates combustion completeness

- Natural gas: 8-10% ideal
- Propane: 10-12% ideal
- Lower values = more excess air

Carbon Monoxide (CO):

- Parts per million (ppm)
- Toxic gas measurement
- Air-free (corrected for O_2)
- Must be < 100 ppm air-free (CSA B149.1)
- Goal: < 50 ppm

Stack Temperature:

- Flue gas temperature
- °F or °C
- Indicates heat loss
- Used in efficiency calculation

Draft:

- Pressure in vent
- Negative for natural draft
- Positive for power vent
- Inches of water column

Taking Measurements

Procedure:

1. **Calibrate Analyzer:**
   - Fresh air calibration (bump test)
   - Zero sensors
   - Verify battery charged
2. **Warm Up Appliance:**
   - Run 10-15 minutes minimum
   - Reach steady state
   - Allows proper combustion to establish
3. **Insert Probe:**
   - Into flue per manufacturer instructions
   - 1-2 pipe diameters downstream of appliance
   - Through hole drilled or test port
   - Seal around probe
4. **Allow Stabilization:**
   - Wait 1-2 minutes
   - Readings stabilize

    - Note any fluctuations
5. **Record Readings:**
    - O_2, CO_2, CO (air-free), stack temperature
    - Ambient temperature
    - Draft (if measured)
    - Calculated efficiency
6. **Print or Document:**
    - Most analyzers can print
    - Keep record
    - Compare to previous tests

Interpreting Results

Acceptable Combustion (Natural Gas):

- O_2: 5-9%
- CO_2: 8-10%
- CO (air-free): < 100 ppm (preferably < 50 ppm)
- Stack temp: Varies by appliance type
- Efficiency: Close to rated AFUE

Problem Indicators:

High CO (>100 ppm):

- Insufficient combustion air
- Improper burner adjustment
- Flame impingement
- Heat exchanger problems
- Venting issues
- **Action required - don't leave in service**

Low O_2 (<5%):

- Insufficient air
- Dangerous condition
- High CO likely
- Incomplete combustion risk

High O_2 (>10%):

- Excess air
- Lower efficiency
- Wasted heat
- But safe combustion usually

Low CO_2 (<7%):

- Excess air
- Correlates with high O_2
- Lower efficiency

High Stack Temperature:

- Heat not extracted
- Dirty heat exchanger
- Poor efficiency
- Oversized or short-cycling equipment

Low Stack Temperature:

- Condensing in non-condensing appliance
- Vent sizing problem
- Backdrafting possible

Combustion Adjustments

To Improve Combustion:

High CO:

1. Check combustion air supply
2. Increase primary air (open air shutter)
3. Check for flame impingement
4. Clean burner
5. Verify proper orifice size
6. Check manifold pressure
7. Inspect heat exchanger

High O_2 (Low Efficiency):

1. Reduce primary air (close air shutter slightly)
2. Verify proper orifice size
3. Check manifold pressure
4. Don't reduce too much (watch CO)

General Adjustment:

1. Start with manufacturer settings
2. Adjust primary air for optimal flame
3. Check combustion readings
4. Fine-tune for best results

5. Balance efficiency vs. CO
6. Document final settings

Chapter Summary

Atmospheric burners use the venturi effect to entrain primary air (40-60% of total) with gas before combustion, with secondary air completing combustion at the flame. Proper primary air adjustment is critical: too little causes yellow flames and CO production, too much causes lifting, flashback, or noisy combustion. Correct adjustment produces stable blue flames with distinct inner cones and minimal yellow tipping.

Power burners use fans for forced or induced draft, providing better air-fuel control and higher efficiency. Modulating burners vary firing rate continuously to match load; two-stage burners provide high and low fire rates. Both improve comfort and efficiency compared to single-stage atmospheric burners.

Burner orifices meter gas flow based on size, pressure, and gas specific gravity. Natural gas requires larger orifices than propane (approximately 60% larger for same input). Orifice size is specified by drill number, with higher numbers indicating smaller diameters. Proper sizing is critical for correct input and safe operation.

Modern ignition systems include standing pilot (continuous flame, thermocouple safety), intermittent pilot (electronic spark ignites pilot on demand), direct spark ignition (spark directly ignites main burner), and hot surface ignition (glowing element ignites gas). Each system has specific safety controls and timing sequences per CSA B149.1.

Flame sensing methods include thermocouples (generate millivolts when heated), flame rectification (flame conducts AC current as pulsing DC), and optical sensors. Flame rectification is most common in modern equipment, requiring proper rod positioning in flame and good ground path for reliable operation.

Combustion analysis using electronic analyzers measures O_2, CO_2, CO (air-free), and stack temperature to verify safe and efficient operation. Acceptable natural gas combustion shows 5-9% O_2, 8-10% CO_2, and less than 100 ppm CO air-free (preferably under 50 ppm). High CO readings require immediate correction and indicate insufficient air, improper adjustment, or equipment problems.

Review Questions

Multiple Choice

1. Primary air in an atmospheric burner is typically what percentage of total air required?
   - a) 10-20%
   - b) 40-60%
   - c) 80-90%
   - d) 100%
2. A yellow, sooty flame indicates:
   - a) Perfect combustion
   - b) Too much air
   - c) Insufficient air
   - d) Correct primary air adjustment
3. Natural gas manifold pressure is typically:
   - a) 3.5" W.C.
   - b) 7" W.C.
   - c) 10" W.C.
   - d) 11" W.C.
4. The maximum acceptable CO reading in flue gas per CSA B149.1 is:
   - a) 35 ppm air-free
   - b) 50 ppm air-free
   - c) 100 ppm air-free
   - d) 400 ppm air-free
5. Hot surface igniters should:
   - a) Be touched only with gloves
   - b) Never be touched with bare hands
   - c) Be cleaned with sandpaper
   - d) Be tested by tapping with screwdriver
6. Flame rectification works by:
   - a) Generating voltage from heat
   - b) Measuring temperature
   - c) Detecting DC current through flame
   - d) Optical sensing of UV light
7. For atmospheric burners, theoretical air requirement is approximately:
   - a) 5 ft^3 air per ft^3 gas
   - b) 9.5 ft^3 air per ft^3 gas
   - c) 15 ft^3 air per ft^3 gas
   - d) 24 ft^3 air per ft^3 gas
8. Propane orifices compared to natural gas orifices for the same input are:
   - a) The same size
   - b) Larger
   - c) Smaller
   - d) Depends on pressure only
9. Acceptable O_2 reading in flue gas is typically:
   - a) 0-3%
   - b) 5-9%
   - c) 12-15%
   - d) 18-21%
10. A thermocouple generates approximately how many millivolts?

- a) 5-10 mV
- b) 20-30 mV
- c) 100-200 mV
- d) 500-750 mV

True or False

11. Secondary air is controlled by the air shutter adjustment.
12. Flame lifting indicates too much primary air.
13. Direct spark ignition is more efficient than standing pilot because it eliminates continuous pilot gas consumption.
14. A flame rod must be positioned in the hottest part of the inner cone for best sensing.
15. High CO readings always indicate the appliance must be shut down for safety.

Short Answer

16. Explain the difference between primary air and secondary air in atmospheric burners. (4 marks)
17. List four problems that can cause high CO production in gas burners. (4 marks)
18. Describe the proper characteristics of a correctly adjusted natural gas flame. (4 marks)
19. Why is a hot surface igniter very fragile and how should it be handled? (3 marks)
20. Explain how flame rectification works to prove flame presence. (5 marks)

Long Answer

21. An atmospheric burner produces a yellow, sooty flame with high CO readings (250 ppm air-free). Describe your systematic troubleshooting approach including:
    - What the flame characteristics indicate
    - Possible causes (list at least 5)
    - Step-by-step diagnostic procedure
    - How to correct each possible cause
    - How to verify correction was successful (15 marks)
22. Describe the complete procedure for performing combustion analysis on a natural gas furnace. Include:
    - Equipment preparation and calibration
    - Appliance preparation
    - Probe insertion and positioning
    - Measurements to record
    - Acceptable ranges for each measurement
    - What to do if readings are unacceptable
    - Documentation requirements (15 marks)
23. Compare standing pilot, intermittent pilot ignition (IPI), and hot surface ignition (HSI) systems. Include:
    - How each operates
    - Components in each system
    - Advantages and disadvantages

- Typical applications
- Common problems with each
- Why modern equipment uses electronic ignition instead of standing pilot (15 marks)

Key Terms

Air Shutter: Adjustable opening controlling primary air entry to atmospheric burner.

Atmospheric Burner: Burner using natural draft and venturi effect; no fan.

Burner Port: Opening in burner where gas-air mixture exits and burns.

Combustion Efficiency: Percentage of fuel energy extracted during combustion; measured with analyzer.

Direct Spark Ignition (DSI): Ignition system using spark directly at main burner; no pilot.

Flame Impingement: Flame contacting surfaces, causing incomplete combustion.

Flame Rectification: Flame sensing method using flame's ability to conduct AC as DC current.

Flashback: Flame burning inside burner instead of at ports; dangerous condition.

Hot Surface Ignition (HSI): Ignition using electrically heated ceramic element.

Intermittent Pilot (IPI): Electronically ignited pilot that lights only when needed.

Lifting (Flame): Flame lifting off burner ports; indicates too much air or gas velocity.

Orifice (Spud): Precisely sized opening metering gas flow to burner.

Port Loading: BTU input per inch of burner port; affects flame characteristics.

Power Burner: Burner using fan to force or induce combustion air.

Primary Air: Air mixed with gas before combustion (40-60% of total).

Secondary Air: Air drawn into flame during combustion to complete reaction.

Standing Pilot: Continuously burning pilot flame; traditional ignition method.

Thermocouple: Device generating millivolts from heat; proves pilot flame.

Venturi: Converging-diverging passage creating low pressure for air entrainment.

End of Chapter 10

CHAPTER 11

Gas Valves and Safety Controls

Learning Objectives

Upon completion of this chapter, students will be able to:

1. Identify different types of manual and automatic gas valves
2. Explain the operation of combination gas valves
3. Understand redundant valve systems and 100% shut-off requirements
4. Describe various safety control devices and their functions
5. Test and troubleshoot limit controls and pressure switches
6. Understand flame safeguard control sequences per CSA B149.1
7. Explain ignition trial timing and lockout requirements
8. Wire and test safety control circuits
9. Diagnose common valve and control failures
10. Apply proper sequence of operations for different appliance types

---

11.1 Manual Gas Valves

Manual valves allow human control of gas flow and are required at specific locations per code.

Ball Valves

Most Common Manual Valve Type

Construction:

- Ball with hole through center
- Quarter-turn operation (90°)
- Lever handle
- Full port or standard port
- Brass or steel body

Operation:

- Handle parallel to pipe = OPEN
- Handle perpendicular to pipe = CLOSED

- Quick positive shut-off
- Visual indication of position

Advantages:

- Fast operation
- Clear on/off indication
- Full flow when open (full port)
- Reliable
- Long service life
- Minimal pressure drop

Disadvantages:

- Not repairable (replace if fails)
- Can be accidentally turned
- Must be fully open or closed (not throttling)

Applications:

- Appliance shut-off valves (most common)
- Equipment isolation
- Service valves
- Main building shut-offs

Sizes:

- 1/4" through 2" common for residential
- Larger for commercial

Code Requirements:

- Required within 6 feet of each appliance
- Accessible location
- Same room or adjacent space
- Lever handle type
- Listed for gas service

Plug Valves

Traditional Design

Construction:

- Tapered or cylindrical plug
- Quarter-turn operation

- T-handle or lever handle
- Plug seats in valve body
- Lubricated or non-lubricated

Operation:

- Rotate plug to align hole with flow path
- Quarter-turn from open to closed
- Positive sealing

Types:

Lubricated:

- Grease lubricates plug
- Can be re-lubricated
- Smooth operation
- Common in older systems

Non-Lubricated:

- Teflon or other coating
- No maintenance
- Modern standard

Advantages:

- Durable
- Can be serviced (lubricated types)
- Long life
- Positive shut-off

Disadvantages:

- Requires more torque than ball valve
- Can stick if not operated regularly
- Lubricated types need maintenance

Applications:

- Main building shut-offs
- Meter valves
- Older installations
- Gas distribution systems

Gate Valves

Rarely Used in Modern Gas Work

Construction:

- Wedge or gate slides across flow path
- Multiple turns to open/close
- Rising or non-rising stem

Characteristics:

- Slow operation (many turns)
- Full flow when open
- No position indication when non-rising stem
- Can partially open (throttling possible)

Use in Gas:

- Generally not recommended for gas service
- Can collect debris when partially open
- Difficult to determine position
- May leak through seats over time

Where Seen:

- Very old installations
- Some industrial applications
- Generally being replaced

Stop-and-Waste Valves

Combination Function

Features:

- Shut-off function
- Drain port when closed
- Drains line downstream
- Prevents freeze-up

Applications:

- Outdoor gas lines (seasonal use)
- Freeze protection
- Lines that need draining
- BBQ gas lines (some installations)

Valve Installation Requirements

Per CSA B149.1:

Appliance Shut-Off Valve:

- Within 1.8 m (6 ft) of appliance
- Readily accessible
- Same room or adjacent space accessible without tools
- Not behind appliance (must be reachable)
- Lever handle type (clear indication)
- Listed for gas service

Main Building Shut-Off:

- At meter or gas entry point
- Accessible location
- Clearly identified
- Protected from damage

Branch Line Valves:

- At each branch serving multiple appliances
- Accessible for service
- Proper support

Proper Installation:

- Support valve independently (not pipe support)
- Don't over-torque
- Install with handle clear (not against wall)
- Install in accessible location
- Identify purpose (labels helpful)
- Test for leaks after installation

Common Mistakes:

- Valve behind appliance (inaccessible)
- Installed upside-down (handle hits wall)
- Over-tightened (cracks valve body)
- Wrong type for gas (water valve used)
- No support (stress on piping)

11.2 Automatic Gas Valves

Automatic valves control gas flow electrically or mechanically in response to control signals.

Solenoid Valves

Electromagnetically Operated

Construction:

- Coil (electromagnet)
- Plunger (valve stem)
- Spring (holds closed)
- Valve seat
- Electrical terminals

Operation:

De-energized (Normal Position):

- Spring holds plunger closed
- Valve seat sealed
- No gas flow
- Fail-safe design

Energized:

- Coil creates magnetic field
- Magnetic field lifts plunger
- Valve opens
- Gas flows

When Power Lost:

- Spring closes valve
- Automatic shut-off
- Safety feature

Characteristics:

- Fast acting (milliseconds)
- Positive shut-off
- Simple operation
- On/off only (no modulation)

Types:

Normally Closed (NC):

- Most common for gas
- Closed when de-energized
- Opens when powered
- Safety shut-off

Normally Open (NO):

- Rare in gas applications
- Opens when de-energized
- Not used for main gas valves

Direct Acting:

- Solenoid directly operates valve
- Small valves
- Low pressure differential

Pilot Operated:

- Small solenoid controls pilot valve
- Pilot valve controls main valve
- Larger capacities
- Uses system pressure to help open

Voltages:

- 24VAC most common (control voltage)
- 115VAC (line voltage)
- Millivolt (500-750mV for standing pilot systems)

Applications:

- Safety shut-off valves
- Redundant valves
- Main gas valves in combination controls
- Zone valves

Testing:

- Measure voltage at coil (should match rating)
- Measure coil resistance (typically 10-100 ohms)
- Listen/feel for click when energized
- Verify gas flow when energized
- Check for leakage when de-energized

Common Problems:

- Coil burnout (open circuit)
- Stuck plunger (debris, corrosion)
- Weak spring (won't close)
- Dirt on valve seat (leaks)
- Wrong voltage applied

Diaphragm Valves

Pressure-Operated with Electric Control

Construction:

- Flexible diaphragm
- Valve disc attached to diaphragm
- Pressure chamber
- Solenoid pilot valve or bleed port
- Spring

Operation:

To Open:

1. Pilot solenoid opens bleed port
2. Pressure above diaphragm bleeds off
3. Gas pressure below lifts diaphragm
4. Valve opens
5. Uses gas pressure to assist opening

To Close:

1. Pilot solenoid closes bleed port
2. Pressure builds above diaphragm
3. Pressure and spring push diaphragm down
4. Valve closes

Characteristics:

- Slower than pure solenoid (seconds vs milliseconds)
- Can handle higher flow rates
- Smooth opening/closing
- Less electrical power required
- Self-actuated by gas pressure

Types:

Single Diaphragm:

- One pressure chamber
- One valve seat
- Simple design

Double Diaphragm:

- Two pressure chambers
- Redundant sealing
- Higher safety

Advantages:

- Large capacity possible
- Lower power consumption
- Smooth operation
- Reliable

Disadvantages:

- Slower response than solenoid
- More complex
- Diaphragm can fail
- Bleed port can clog

Applications:

- Main gas valves in furnaces
- Boiler valves
- Large capacity applications
- Commercial equipment

11.3 Combination Gas Valves

Modern appliances use integrated combination valves combining multiple functions.

Components in Combination Valve

Typical Functions:

1. **Manual On/Off:**
    - External knob or switch
    - On - Off - Pilot positions
    - Manual safety shut-off
2. **Pressure Regulator:**

- Reduces inlet pressure to manifold pressure
- Maintains constant manifold pressure
- Adjustable (some models)
- Natural gas: 3.5" W.C. typical
- Propane: 10" W.C. typical

3. **Main Gas Valve:**
    - Solenoid or diaphragm operated
    - On/off or modulating
    - Controlled by system
4. **Pilot Valve (if standing pilot):**
    - Supplies gas to pilot
    - Safety shut-off if pilot out
    - Separate from main valve
5. **Safety Shut-Off:**
    - Pilot safety (thermocouple/thermopile)
    - Or electronic flame safeguard
    - Prevents gas flow without flame
6. **Electrical Terminals:**
    - Connections for controls
    - Thermostat
    - Limit switches
    - Ignition control

Common Valve Models:

Honeywell:

- VR8000 series (standing pilot)
- SV9500 series (electronic ignition)
- VR8300 series (combination)

White-Rodgers:

- 36C series (standing pilot)
- 36E series (electronic)
- 36J series (combination)

Robertshaw:

- 7000 series (unitized)
- Various models for specific applications

Valve Operation Modes

Standard On/Off:

- Valve fully open or fully closed
- Controlled by thermostat
- Simple operation
- Most common

Two-Stage:

- Two levels of opening
- Low fire and high fire
- Better comfort and efficiency
- Two solenoids or modulating motor

Modulating:

- Continuously variable opening
- Motor-driven valve actuator
- Matches load precisely
- Highest efficiency
- Most complex and expensive

Testing Combination Valves

Voltage Tests:

1. Measure voltage at valve terminals (24VAC typical)
2. Check during call for heat
3. Verify proper voltage present

Pressure Tests:

1. Measure inlet pressure (before valve)
2. Measure manifold pressure (after valve)
3. Verify manifold pressure matches rating plate
4. Check during operation

Gas Flow Test:

1. Clock the meter (time per revolution)
2. Calculate input rate
3. Compare to rating plate
4. Verify proper input

Leak Test:

1. Valve closed (no call for heat)
2. Downstream pressure should hold

3. Soap test at valve
4. No leakage acceptable

Common Problems:

- Coil failure (no opening)
- Stuck valve (debris)
- Regulator drift (wrong manifold pressure)
- Pilot safety lockout (thermocouple weak)
- Electrical connection problems

11.4 Redundant Valve Systems

Safety requirements often mandate redundant (backup) gas shut-off.

100% Shut-Off Requirement

CSA B149.1 Requirements:

When required:

- Some commercial applications
- Some jurisdictions
- When specified by engineer
- High-hazard locations

Definition:

- Two valves in series
- Both must be closed to stop flow
- Redundancy prevents single-point failure
- One valve can fail, other still protects

Valve Arrangements

Two Solenoid Valves:

- Both must open for gas flow
- Both must receive power
- If either fails closed = safe
- If either fails open, other still protects

Combination Valve with Redundant Valve:

- Main combination valve
- Separate redundant solenoid valve
- Often integrated in modern valves
- Both must open for gas flow

Proving Systems:

- Verify both valves operate
- Check for leakage through closed valve
- Pressure switches between valves
- Test before each cycle (some systems)

Safety Shut-Off Valves

Manual Reset Required:

- After lockout or safety condition
- Cannot restart automatically
- Person must determine cause
- CSA B149.1 requirement for some applications

Automatic Reset:

- Restarts automatically after resolution
- Common in residential
- Allowed for most applications
- Check local requirements

11.5 Limit Controls

Limit controls prevent unsafe operating conditions by stopping the burner.

Temperature Limits

High Limit (Furnace):

Purpose:

- Prevents overheating of heat exchanger
- Opens if temperature exceeds setpoint
- Safety device

Operation:

- Bimetal switch or electronic sensor
- Mounted on heat exchanger or plenum
- Opens circuit when temperature high
- Closes circuit when temperature drops

Typical Settings:

- 160°F to 200°F (71-93°C)
- Depends on appliance design
- Set above normal operating temperature
- Below danger point

Types:

Manual Reset:

- Must be manually reset after trip
- Button on switch
- Indicates serious problem
- Not common in modern residential

Automatic Reset:

- Resets automatically when cools
- Most common type
- Fixed differential (10-25°F typical)

Adjustable vs. Fixed:

- Adjustable: can set trip point
- Fixed: preset at factory
- Fixed more common in residential

Testing:

1. Block airflow (filter or duct)
2. Allow temperature to rise
3. Limit should open circuit
4. Burner shuts off
5. Restore airflow
6. Limit should close
7. System should restart

Common Problems:

- Sticking closed (won't open when hot)

- Sticking open (no safety protection)
- Wrong location (doesn't sense true temperature)
- Loose mounting (doesn't sense properly)
- Wrong setting

Fan Control vs. Limit:

Fan Control:

- Turns fan on when warm
- Turns fan off when cool
- Comfort control
- Not safety device

Combined Fan/Limit:

- Single control both functions
- Common in older furnaces
- Separate settings for fan on, fan off, and limit

Rollout Switch:

Purpose:

- Detects flame rollout (flame outside combustion chamber)
- Emergency safety shut-off
- Indicates serious problem

Location:

- Outside combustion chamber
- Near burner area
- Where rollout would occur

Operation:

- Bimetal switch
- Opens if heated by flame outside chamber
- Usually manual reset
- Should not trip in normal operation

Causes of Rollout:

- Blocked vent
- Insufficient combustion air
- Cracked heat exchanger

- Burner misalignment
- Overfiring

Response:

- **DO NOT simply reset**
- Determine cause
- Serious safety hazard
- May indicate heat exchanger failure
- Complete inspection required

Spill Switch:

Purpose:

- Detects spillage from draft hood
- Indicates backdrafting or vent blockage
- Safety shut-off

Location:

- At or near draft hood
- In spillage path

Operation:

- Bimetal switch heated by spillage
- Opens circuit
- Usually automatic reset (some manual)

Causes:

- Blocked vent
- Insufficient draft
- Building depressurization
- Vent sizing problem
- Wind conditions

Boiler Limit Controls:

High Limit:

- Prevents boiler overtemperature
- Typically 200-240°F setpoint
- Opens circuit to shut down
- Manual reset usually

Low Water Cutoff (LWCO):

- Prevents boiler operation without water
- Float or probe type
- Critical safety device
- Prevents heat exchanger damage/explosion

11.6 Pressure and Airflow Switches

These switches verify proper operation of fans and venting.

Pressure Switches

Purpose:

- Prove adequate airflow before ignition
- Verify inducer/blower operation
- Safety interlock

Construction:

- Diaphragm with switch contacts
- Two pressure ports (+ and - or single port)
- Adjustment screw (some models)
- Electrical terminals

Operation:

Differential Pressure:

- Measures pressure difference
- One port to pressure source
- One port to reference (atmosphere or suction)
- Switch closes when differential adequate

Vacuum Switch:

- Single port to negative pressure
- Other port to atmosphere
- Closes on adequate vacuum

Settings:

- Typically 0.2" to 1.5" W.C. differential

- Factory preset or field adjustable
- Must not be adjusted without reason

Applications:

Inducer Fan Proving:

- Hose from inducer to switch
- Verifies inducer creating draft
- Must prove before ignition permitted
- CSA B149.1 requirement

Vent Blockage Detection:

- Verifies adequate vent draft
- Opens if vent blocked
- Prevents operation with inadequate venting

Combustion Air Proving:

- Verifies combustion air fan operation
- Required on some systems

Testing:

Functional Test:

1. Start system
2. Inducer starts
3. Pressure switch should close within seconds
4. Verify electrical closure with meter
5. If doesn't close, no ignition

Manual Test:

1. Disconnect hose
2. Apply suction or pressure
3. Listen for click
4. Measure continuity

Adjustment:

- Should not be needed
- If drift occurs, investigate cause
- Adjust only per manufacturer instructions
- Verify with manometer

Common Problems:

- Stuck diaphragm (won't close)
- Hose disconnected or cracked
- Port plugged (condensate, debris)
- Wrong adjustment
- Failed contacts
- Hose connected to wrong port

Troubleshooting:

1. Verify inducer runs
2. Check hose connections
3. Measure actual pressure differential
4. Compare to switch rating
5. Listen for click when pressure applied
6. Check electrical continuity when closed

Air Flow Switches (Sail Switch)

Construction:

- Hinged "sail" in airflow
- Microswitch
- Mounts in duct

Operation:

- Airflow pushes sail
- Sail closes switch contacts
- Verifies air movement

Applications:

- Blower proving
- Duct heaters (must have airflow)
- Commercial systems
- Interlock for heating (prevents overheating)

Less Common:

- Mostly commercial
- Residential uses pressure switches instead

11.7 Flame Safeguard Controls

Flame safeguard systems ensure gas flows only when flame present and provide timed safety shut-off.

Sequence of Operations

Pre-Purge (if required):

- Some systems purge combustion chamber before ignition
- Inducer runs alone
- Typically 15-30 seconds
- Clears any residual gas

Ignition Trial:

- Period during which ignition attempted
- Spark or hot surface igniter active
- Gas valve opens
- Flame must establish

Trial for Ignition (TFI):

- CSA B149.1 specifies maximum time
- **4 seconds maximum** for direct ignition
- **45 seconds maximum** with pilot (total including pilot establishment)
- If flame not proven within TFI, lockout occurs

Flame Proving:

- Flame sensor must detect flame
- Must occur within TFI
- Continuous monitoring during operation

Main Flame:

- Normal operation
- Flame monitored continuously
- If flame lost, immediate shut-off

Post-Purge (if required):

- After flame out
- Continues inducer to clear products
- 15-30 seconds typical

Lockout

Definition:

- Safety shut-off after ignition failure
- Requires manual intervention
- Indicates problem exists

Causes:

- No flame within trial for ignition
- Flame loss during operation (multiple times)
- Safety switch opening
- Control malfunction

Types:

Hard Lockout:

- Cannot restart automatically
- Power must be interrupted
- Requires reset
- Most safe

Soft Lockout:

- Attempts restart after delay
- May try several times
- Then hard lockout

Recycle:

- Tries again automatically
- May be limited number of attempts

CSA B149.1 Requirements:

- Trial for ignition limits
- Lockout required after failed attempts
- Specific timing requirements
- Safety standards must be met

Ignition Control Modules

Functions:

- Time pre-purge
- Control ignition sequence
- Monitor flame
- Provide lockout
- Control post-purge

Types:

Standing Pilot Systems:

- Simpler controls
- Pilot safety circuit (thermocouple/thermopile)
- Thermostat completes circuit to main valve

Intermittent Pilot Ignition (IPI):

- Module controls spark generator
- Times pilot ignition
- Proves pilot
- Opens main valve
- Shuts off spark

Direct Spark Ignition (DSI):

- Module controls spark
- Opens gas valve
- Proves main flame
- Simultaneous spark and gas
- Lockout if no flame

Hot Surface Ignition (HSI):

- Module powers igniter
- Waits for igniter to heat
- Opens gas valve
- Proves flame
- Times all sequences

Advanced Controls:

- Integrated furnace control (IFC)
- Controls all functions
- Communication capability
- Self-diagnostic
- Modulation control

Flame Sensor Circuits

Thermocouple Circuit:

- Millivolt DC (20-30 mV)
- Powers electromagnet directly
- Open circuit = valve closes
- Simple and reliable
- No external power needed

Flame Rectification Circuit:

- AC voltage applied across flame
- Flame conducts as DC
- Microamps measured
- Requires good ground path
- Standard in modern equipment

Optical Sensors:

- UV or IR detection
- Electronic signal
- Commercial/industrial
- Very reliable but expensive

Testing Controls

Verify Sequence:

1. Call for heat
2. Observe pre-purge (if equipped)
3. Note ignition sequence
4. Verify flame establishment
5. Time trial for ignition
6. Verify lock-out if flame fails

Flame Sensor Test:

1. Measure flame signal (μA for flame rod)
2. Simulate flame loss (disconnect sensor)
3. Verify immediate shut-off
4. Verify lockout after retries

Timing Tests:

1. Use stopwatch

2. Time each sequence phase
3. Compare to manufacturer specifications
4. Verify compliance with CSA B149.1

11.8 Safety Circuit Wiring

Understanding safety circuits is essential for troubleshooting.

Series Safety Circuits

Concept:

- All safety devices in series
- All must be closed for operation
- Any one opens = system stops
- Fail-safe design

Typical Series Circuit:

```
Power → Fuse → Transformer → Limit → Pressure Switch →
Rollout → Flame Sensor → Control Board → Valve → Return
```

All devices must be closed (conducting) for voltage to reach gas valve.

Common 24VAC Control Circuit:

- Transformer provides 24VAC
- R terminal (hot from transformer)
- C terminal (common/neutral)
- W terminal (heat call from thermostat)
- Safety switches in series between R and valve

Parallel Circuits

Operating Controls:

- Parallel to allow independent operation
- Example: Fan relay parallel to valve
- Each can operate independently

Not Used for Safety:

- Safety always series
- Ensures all must be satisfied

Troubleshooting Control Circuits

Systematic Approach:

1. Verify Power:

- Check voltage at transformer (115VAC)
- Check transformer output (24VAC)
- No power = check breaker, fuse

2. Trace Circuit:

- Start at transformer R terminal
- Check voltage at each point in series
- Voltage present before open switch
- No voltage after open switch

3. Identify Open Device:

- Find where voltage disappears
- Device immediately before = problem
- Could be open switch, bad connection, or faulty device

4. Test Device:

- Check continuity across device (power off)
- Verify proper operation
- Check mounting and connections

5. Repair or Replace:

- Fix wiring if problem
- Replace faulty device
- Verify proper operation after repair

Example Troubleshooting:

Symptom: Furnace won't start

Testing:

1. Check 24VAC at transformer: OK (24.5V)
2. Check at limit switch: OK (24.5V)
3. Check at pressure switch: OK (24.5V)
4. Check at rollout switch: 0V
5. Conclusion: Rollout switch open

Further Investigation:

- Why rollout open?
- Check for recent rollout event
- Inspect venting
- Check heat exchanger
- Determine root cause before resetting

11.9 Troubleshooting Common Problems

No Gas Flow (Valve Won't Open)

Possible Causes:

1. **No Power to Valve:**
   - Check voltage at valve
   - Trace back through circuit
   - Find open safety switch
2. **Manual Valve Closed:**
   - Check all manual valves
   - Appliance shut-off
   - Building main
3. **Failed Gas Valve:**
   - Coil burned out
   - Stuck closed
   - Internal failure
   - Replace valve
4. **Safety Lockout:**
   - Control locked out
   - Reset and determine cause
   - Check flame sensor
5. **Low Gas Pressure:**
   - Check upstream
   - Meter/regulator issue
   - Empty propane tank

Gas Leakage When Valve Closed

Possible Causes:

1. **Dirt on Valve Seat:**
   - Debris prevents sealing
   - Clean or replace valve
2. **Worn Valve:**

    - Age/use wears seat
    - Replace valve
3. **Wrong Valve:**
    - Not rated for gas
    - Replace with proper valve
4. **Damaged Valve:**
    - Physical damage
    - Frozen valve cracked
    - Replace

Testing:

- Valve closed, downstream pressure should hold
- Soap test at valve
- No leakage acceptable

Valve Cycles On and Off

Possible Causes:

1. **Limit Cycling:**
    - Limit opens, cools, closes, repeats
    - Airflow problem
    - Wrong limit setting
2. **Flame Sensor Problem:**
    - Intermittent signal
    - Dirty sensor
    - Loose connection
    - Clean or replace
3. **Control Problem:**
    - Faulty control board
    - Temperature sensor failure
    - Replace control
4. **Short Cycling (Thermostat):**
    - Rapid on/off cycles
    - Different problem (not valve)

Chapter Summary

Manual gas valves provide human control of gas flow, with ball valves being most common due to clear position indication and reliable operation. CSA B149.1 requires an accessible shut-off valve within 6 feet of each appliance with lever handle for clear on/off indication.

Automatic gas valves use solenoids or diaphragm operators to control gas flow electrically. Combination gas valves integrate manual control, pressure regulation, main valve, and safety shut-off in one unit. Modern valves operate in on/off, two-stage, or modulating modes for varying efficiency and comfort levels.

Limit controls prevent unsafe operating conditions by monitoring temperature. High limits prevent overheating, rollout switches detect flame outside combustion chamber, and spill switches detect draft hood spillage. These devices open control circuits to stop burner operation when unsafe conditions occur.

Pressure switches prove adequate airflow before permitting ignition, typically monitoring inducer fan operation. These switches close when pressure differential reaches setpoint, completing control circuit. Failed pressure switches prevent ignition and require troubleshooting of airflow, hose connections, and switch operation.

Flame safeguard controls enforce safe ignition sequences per CSA B149.1, including maximum 4-second trial for ignition for direct ignition systems and 45 seconds with pilot. Lockout occurs if flame not proven within trial time, requiring manual intervention. Control modules time all sequences, monitor flame continuously, and provide safety lockout.

Safety control circuits wire all safety devices in series, ensuring all must be closed for operation. Any open device prevents gas valve operation. Troubleshooting traces voltage through circuit to identify which device is open and causing problem.

Review Questions

Multiple Choice

1. The most common type of manual gas valve is:
    - a) Gate valve
    - b) Globe valve
    - c) Ball valve
    - d) Butterfly valve
2. An appliance shut-off valve must be located:
    - a) Within 3 feet of appliance
    - b) Within 6 feet of appliance
    - c) Within 10 feet of appliance
    - d) Anywhere in same room
3. A solenoid valve in the de-energized position is:
    - a) Always open
    - b) Always closed (for normally closed valve)
    - c) Partially open
    - d) Depends on gas pressure
4. The maximum trial for ignition time for direct ignition per CSA B149.1 is:

- a) 2 seconds
- b) 4 seconds
- c) 10 seconds
- d) 45 seconds

5. A high limit switch on a furnace:
   - a) Turns the fan on
   - b) Turns the fan off
   - c) Opens to stop burner when too hot
   - d) Opens to start burner
6. A pressure switch on an induced draft furnace:
   - a) Proves adequate inducer operation
   - b) Measures gas pressure
   - c) Controls modulation
   - d) Adjusts fan speed
7. Safety control devices are wired in:
   - a) Series (all must be closed)
   - b) Parallel (any can complete circuit)
   - c) Series-parallel combination
   - d) Separately with individual circuits
8. A rollout switch that trips indicates:
   - a) Normal operation
   - b) Fan needs adjustment
   - c) Serious safety problem requiring investigation
   - d) Time for routine maintenance
9. Combination gas valves typically include:
   - a) Manual shut-off only
   - b) Pressure regulator only
   - c) Main valve only
   - d) Manual shut-off, regulator, and main valve
10. When a pressure switch fails to close:
    - a) Ignition will proceed normally
    - b) Ignition will not occur
    - c) Only affects fan operation
    - d) Causes immediate lockout

True or False

11. Ball valve handles should be parallel to the pipe when the valve is open.
12. All safety controls can be automatically reset without manual intervention.
13. A rollout switch should be reset immediately without investigation when it trips.
14. Flame safeguard controls must provide lockout after failed ignition attempts.
15. Manual gas valves can be used as throttling devices to reduce gas flow.

Short Answer

16. Explain why safety switches are wired in series rather than parallel. (3 marks)

17. List four possible causes of a pressure switch not closing. (4 marks)
18. What is the difference between a high limit and a rollout switch? (4 marks)
19. Describe the basic operation of a solenoid valve. (4 marks)
20. What is meant by "100% shut-off" and when is it required? (4 marks)

Long Answer

21. A furnace attempts to ignite but immediately shuts down. The sequence is: inducer starts, pressure switch closes, spark begins, gas valve opens, flame ignites, burner runs for 3-4 seconds, then shuts down and locks out. Describe your systematic troubleshooting approach including:
    - What this sequence indicates
    - Most likely cause
    - How to diagnose the problem
    - Tests to perform
    - Expected findings
    - Proper correction (12 marks)
22. Describe the complete sequence of operation for a modern induced draft furnace with hot surface ignition from thermostat call through main burner operation. Include:
    - All control components involved
    - Timing of each step
    - Safety interlocks
    - What happens if any step fails
    - CSA B149.1 timing requirements (15 marks)
23. Explain combination gas valves including:
    - Components typically included
    - Functions of each component
    - Advantages over separate components
    - How to test proper operation
    - Common problems and diagnosis
    - When replacement is necessary versus adjustment (15 marks)

Key Terms

Ball Valve: Quarter-turn valve with ball containing hole; most common manual gas valve.

Combination Gas Valve: Integrated valve containing manual shut-off, regulator, main valve, and safety functions.

Diaphragm Valve: Gas valve using flexible diaphragm and gas pressure to operate valve.

Flame Safeguard: Control system ensuring gas flows only when flame present; enforces safety timing.

Hard Lockout: Safety lockout requiring manual reset; cannot restart automatically.

High Limit: Temperature switch opening to prevent overheating; safety device.

Lockout: Safety shut-down after ignition failure requiring manual intervention.

Normally Closed (NC): Valve closed when de-energized; opens when powered (standard for gas safety).

Pressure Switch: Switch operated by pressure differential; proves fan operation or draft.

Redundant Valve: Backup valve providing 100% shut-off if primary fails.

Rollout Switch: Safety switch detecting flame outside combustion chamber; indicates serious problem.

Series Circuit: Circuit where devices are connected end-to-end; all must be closed for current flow.

Solenoid Valve: Valve operated by electromagnetic coil; fast-acting on/off control.

Spill Switch: Safety switch detecting spillage from draft hood; indicates backdrafting.

Trial for Ignition (TFI): Maximum time allowed to establish flame; 4 seconds direct, 45 seconds with pilot.

End of Chapter 11

CHAPTER 12: Venting Systems

Learning Objectives

After completing this chapter, you will be able to:

- Explain the principles of natural draft and mechanical draft venting
- Identify appropriate venting materials for different appliance categories
- Size vent systems using CSA B149.1 tables
- Install Type B vents according to code requirements
- Design and install direct vent and power vent systems
- Manage condensate from high-efficiency appliances
- Diagnose and correct common venting problems
- Conduct proper spillage testing

Introduction

The venting system is one of the most critical safety components of any gas appliance installation. A properly designed and installed vent system safely removes products of combustion from the building while preventing spillage of harmful gases into occupied spaces. This chapter covers venting principles, materials, design, installation, and troubleshooting according to CSA B149.1-25 requirements.

12.1 Venting Principles

Natural Draft Operation

Natural draft venting relies on the buoyancy of hot combustion gases to create flow up through the vent system. This fundamental principle has been used for centuries and remains common in many atmospheric appliances.

How Natural Draft Works:

When fuel burns in an appliance, the combustion process produces hot gases containing carbon dioxide, water vapor, and other products of combustion. These hot gases are less dense than the surrounding air, creating buoyancy that causes them to rise naturally through the vent system and exit at the termination point.

The driving force for natural draft is the temperature difference between the hot flue gases and the cooler outside air. The greater this temperature difference, the stronger the draft. This is why natural draft systems work better in cold weather than in warm weather.

Stack Effect

Stack effect is the air movement within a building caused by temperature differences between inside and outside air. In winter, warm indoor air rises and escapes through upper openings, while cooler outside air enters through lower openings. This creates a pressure difference that can affect appliance venting.

Positive Stack Effect (Winter):

- Lower building levels experience negative pressure
- Upper building levels experience positive pressure
- Can help natural draft venting in basements
- Can hinder venting in upper floors

Negative Stack Effect (Summer):

- Upper building levels experience negative pressure
- Lower building levels experience positive pressure
- Less common but can occur with heavy air conditioning use

Impact on Venting:

Stack effect can either assist or oppose natural draft venting depending on the appliance location and season. In tall buildings, strong stack effect can create significant pressure differences that must be considered in vent system design.

Available Draft

Available draft is the pressure difference that causes combustion gases to flow through the vent system. It is measured in Pascals (Pa) or inches of water column (in. W.C.).

Factors Creating Draft:

- **Temperature Difference** - Primary driver of natural draft

Vent Height - Taller vents create more draft

Vent Diameter - Affects flow resistance

Outdoor Temperature - Colder weather increases draft

Required vs. Available Draft:

Every appliance requires a minimum draft to operate safely. This required draft overcomes:

- Resistance through the heat exchanger
- Friction losses in the vent connector
- Friction losses in the vent pipe
- Exit losses at the vent termination

Available draft must exceed required draft for safe operation. The difference provides a safety margin for variations in weather, wind, and building conditions.

Measuring Draft:

Draft is measured using a draft gauge or manometer at the draft hood relief opening (for draft hood-equipped appliances) or at the test port in the vent connector. Typical measurements:

- **Natural draft appliances:** -0.02 to -0.04 in. W.C. (-5 to -10 Pa)
- **Stronger draft:** -0.05 to -0.10 in. W.C. (-12 to -25 Pa)
- **Positive pressure:** Indicates spillage condition

Factors Affecting Draft

1. Vent Height:

Taller vents create more draft due to the greater column of hot, buoyant gases. Each metre of vent height adds approximately 1 Pa of draft at typical temperature differences. CSA B149.1 specifies minimum vent heights above the roof surface to ensure adequate draft and prevent downdrafts from roof effects.

2. Vent Diameter:

Oversized vents cool the flue gases excessively, reducing buoyancy and draft. Undersized vents create excessive friction losses, restricting flow. Proper sizing using CSA B149.1 tables ensures optimal performance.

3. Number of Elbows:

Each elbow (90° turn) adds friction loss equivalent to approximately 1.5 to 3 metres of straight pipe, depending on elbow radius. CSA B149.1 limits the number of elbows and total offset distances to maintain adequate draft.

4. Vent Material:

Smooth interior surfaces reduce friction losses. Type B double-wall vents have lower friction than single-wall pipe. The material's thermal properties affect how quickly gases cool in the vent.

5. Outdoor Temperature:

Colder outdoor temperatures increase the density difference between flue gases and outdoor air, creating stronger draft. Hot summer weather reduces draft significantly, which is why some appliances are more prone to spillage in warm weather.

6. Wind Effects:

Wind blowing across a vent termination can create either positive or negative pressure at the vent outlet:

- **Downward flow** into the vent (downdraft) opposes natural draft
- **Suction effect** can enhance draft
- Proper termination height and location minimize adverse wind effects

7. Building Depressurization:

Operation of exhaust fans, clothes dryers, kitchen range hoods, and even forced-air furnaces can depressurize a building, creating negative pressure that opposes natural draft. CSA B149.1 requires consideration of these effects, especially in tightly constructed modern buildings.

Spillage and Backdrafting

Spillage occurs when products of combustion escape from the draft hood, barometric damper, or other vent opening instead of flowing up the vent. **Backdrafting** is spillage that continues after the normal start-up period.

Causes of Spillage:

- **Insufficient draft** - Vent too short, oversized, or blocked
- **Building depressurization** - Exhaust fans overpowering natural draft

Vent blockage - Bird nests, debris, ice, or condensation

Improper installation - Incorrect sizing, negative slope, too many elbows

Damaged vent - Holes, disconnections, or corrosion

Extreme weather - Very warm outdoor temperatures, downdrafts

Spillage Testing:

CSA B149.1 requires spillage testing on all naturally vented appliances after installation and after any vent system modifications. The standard procedure:

Close all doors and windows

Turn on all exhaust fans at maximum speed

Turn on clothes dryer if present

Start furnace and water heater simultaneously

Wait one minute after burner ignition

Use smoke or match at draft hood relief opening

Observe smoke movement for at least one minute

Acceptable Results:

Smoke drawn steadily into draft hood - PASS

Brief spillage (less than 30 seconds) at start - ACCEPTABLE

Continuing spillage after one minute - FAIL

Corrective Actions for Spillage:

Verify vent sizing using CSA B149.1 tables

Check for blockages and clear if present

Verify proper vent slope and support

Check for damaged or disconnected sections

Consider powered venting if building conditions prevent natural draft

Install makeup air for exhaust appliances if needed

Never seal draft hoods or block relief openings

12.2 Venting Materials

CSA B149.1 categorizes appliances and venting materials based on pressure and condensation characteristics. Understanding these categories is essential for selecting appropriate venting materials.

Appliance Categories

Category I (Positive Pressure, Non-Condensing):

Operates with negative vent pressure

Vent gas temperature above 60°C (140°F)

Natural draft or induced draft

No condensation in vent under normal conditions

Examples: Most atmospheric furnaces, water heaters, boilers

Category II (Negative Pressure, Condensing):

Rare configuration in modern equipment

Operates with negative vent pressure

Vent gas temperature may drop below 60°C

Potential for condensation

Category III (Positive Pressure, Non-Condensing):

Operates with positive vent pressure (forced draft)

Vent gas temperature above 60°C

Requires sealed vent system

Examples: Some power-vented water heaters, non-condensing power-vented boilers

Category IV (Positive Pressure, Condensing):

- Operates with positive vent pressure
- Vent gas temperature below 60°C
- Condensation designed into operation
- Requires corrosion-resistant materials
- Examples: Condensing furnaces, condensing boilers, condensing tankless water heaters

Type B Gas Vent

Type B gas vent is specifically designed for venting Category I appliances with draft hoods. It consists of double-wall construction with an air space between inner and outer walls that provides insulation to maintain flue gas temperature and prevent excessive heat transfer to combustibles.

Construction:

- **Inner wall:** Aluminum, typically 0.018 inches (0.46 mm) thick
- **Air space:** Approximately 1/4 inch (6 mm)
- **Outer wall:** Aluminum or galvanized steel, typically 0.016 inches (0.41 mm) thick
- **Listed to ULC S636:** All Type B vent must be listed and labeled

Features:

- Maintains higher flue gas temperature than single-wall pipe
- Reduced clearances to combustibles (typically 1 to 2 inches / 25 to 50 mm)
- Prevents condensation better than single-wall
- Twist-lock or snap-lock connections
- Available in diameters from 3 to 24 inches (76 to 610 mm)

When to Use Type B:

- Category I appliances with draft hoods
- Single appliance venting through unconfined spaces

- Common venting of multiple Category I appliances
- When passing through combustible walls, floors, or ceilings
- For vertical vent runs in residential and light commercial

Limitations:

- NOT for use with Category III or IV appliances
- NOT for positive pressure applications (except in tested systems)
- NOT for condensing appliances
- Must not be used as vent connector (unless specifically listed for that use)

Type BW (Water Heater Vent)

Type BW vent is similar to Type B but specifically designed and listed for residential gas water heaters. It typically has a smaller air space and is available in smaller diameters.

Specifications:

- Diameters typically 3 to 6 inches (76 to 152 mm)
- Listed to ULC S636
- Lower cost than Type B
- Similar clearances to combustibles

Applications:

- Residential water heaters only
- Single water heater installations
- Some manufacturers allow common venting of water heaters

Not Permitted For:

- Furnaces or boilers
- Commercial water heaters
- Combined venting with other appliance types (unless specifically listed)

Category II, III, IV Venting Materials

Category II Systems (Rare):

If encountered, require special corrosion-resistant materials capable of handling condensate. Follow manufacturer's specifications exactly.

Category III Materials:

Category III appliances operate with positive pressure but temperatures high enough to prevent condensation. Acceptable materials:

- **Type B vent in tested systems** - Some manufacturers have listed systems
- **Single-wall steel pipe** - Must be mechanically fastened and sealed
- **Stainless steel** - AL29-4C or equivalent
- **Manufacturer-specific materials** - Always follow listing requirements

All joints must be sealed to contain positive pressure gases. Regular screws and sheet metal connections are insufficient; special fasteners and high-temperature sealants are required.

Category IV Materials:

Category IV appliances produce condensate, requiring corrosion-resistant materials:

- **PVC (Polyvinyl Chloride) Schedule 40:**
  - Most common material for condensing appliances
  - Maximum temperature rating: 140°F (60°C)
  - Excellent corrosion resistance to condensate
  - Low cost and easy to work with
  - Must be properly supported (every 4 feet / 1.2 m horizontally)
  - Requires primer and cement for joints
  - Cannot be used if flue gas temperature exceeds 140°F (60°C)
- **CPVC (Chlorinated Polyvinyl Chloride):**
  - Higher temperature rating than PVC: up to 200°F (93°C)

Used when manufacturer specifies

More expensive than PVC

Installation methods similar to PVC

Polypropylene (PP):

Higher temperature tolerance than PVC

Excellent chemical resistance

Some manufacturers specify for certain appliances

Requires special fittings and joining methods

Stainless Steel AL29-4C:

Highest corrosion resistance

Suitable for all Category IV applications

Required for temperatures above PVC limits

Much more expensive than plastic venting

Useful for short exposed sections or high-temperature applications

ABS (Acrylonitrile Butadiene Styrene):

Some manufacturers permit for specific applications

Temperature and chemical resistance between PVC and CPVC

Less common than PVC

PVC/CPVC for Condensing Appliances

PVC has become the standard venting material for condensing furnaces and boilers due to its corrosion resistance, low cost, and ease of installation.

Installation Requirements:

1. Material Selection:

Use Schedule 40 PVC (white or grey) or CPVC (beige/cream)

Verify manufacturer's specifications for approved materials

Never mix PVC and ABS in the same vent system

Use cellular core PVC or solid PVC as specified

2. Proper Support:

Horizontal runs: support every 1.2 m (4 feet)

Vertical runs: support every 3 m (10 feet)

Use hangers that allow for thermal expansion

Do not compress pipe with tight clamps

Provide clearance at wall and ceiling penetrations for expansion

3. Joining Methods:

Clean pipe ends and fittings thoroughly

Apply PVC primer to both surfaces

Apply PVC cement evenly

Insert pipe into fitting with slight twist

Hold for 30 seconds

Allow proper cure time before pressure testing (typically 15 minutes minimum)

4. Slope Requirements:

Slope horizontal runs toward condensate trap: minimum 6 mm per metre (1/4 inch per foot)

Prevents condensate from pooling in vent

Eliminates gurgling noises

Check slope with level during installation

5. Clearances:

PVC vent may contact combustible materials

- Maintain clearance from heat sources
- Protect from physical damage
- Paint if desired (water-based paint only)

6. Termination:

- Follow manufacturer's specifications exactly
- Maintain clearances from windows, doors, air intakes, property lines
- Typical: 600 mm from windows, 300 mm from corners
- Use proper terminal fittings designed for application
- Secure against wind and vibration

Common Errors with PVC Venting:

- Insufficient support causing sagging
- Improper slope trapping condensate
- Using wrong cement (ABS cement on PVC)
- Inadequate cure time before operation
- Missing primer step
- Pipe cut at angle instead of square
- Improper clearances at termination

Stainless Steel Systems

Stainless steel venting provides the ultimate in corrosion resistance and temperature tolerance. AL29-4C stainless (containing 29% chromium and 4% molybdenum) is the standard for condensing applications.

When Stainless Steel is Required:

- Flue gas temperatures above PVC limits
- Exposed outdoor installations in cold climates

- Long vent runs where temperature may vary
- High-altitude installations
- Extreme condensate conditions
- Manufacturer specifications

Types of Stainless Systems:

- **Single-wall AL29-4C:**
  - For positive-pressure condensing appliances
  - Requires listed fittings and installation per manufacturer
  - All joints must be sealed
- **Double-wall insulated stainless:**
  - Better temperature maintenance
  - May allow reduced clearances
  - Higher cost but better performance in cold climates
- **Flexible stainless liner:**
  - For relining existing masonry chimneys
  - Allows adaptation to condensing appliances
  - Must be properly sized and insulated

Installation Considerations:

- Use only listed materials and fittings
- Seal all joints with high-temperature sealant
- Support according to manufacturer requirements
- Protect from physical damage
- Maintain specified clearances

- Use proper flashing and termination components

Material Selection Per Appliance Category

Appliance Category	Acceptable Vent Materials	Notes
Category I (Draft hood)	Type B, Type BW, Masonry chimney with listed liner	Natural draft only
Category I (Fan-assisted)	Type B (listed systems), Stainless steel	Check manufacturer specifications
Category III	Type B (tested systems), Stainless steel, Listed materials	Positive pressure, sealed joints required
Category IV	PVC, CPVC, Polypropylene, Stainless steel AL29-4C	Follow manufacturer specifications exactly

Key Principle: Always consult the appliance manufacturer's installation instructions. The appliance listing and labeling specify approved venting materials, and these requirements supersede general guidelines.

12.3 Venting System Design

Proper vent system design ensures safe and reliable operation throughout the life of the appliance. CSA B149.1 provides detailed requirements for sizing and installing vent systems.

Sizing Vents Per CSA B149.1 Tables

CSA B149.1 includes comprehensive tables for sizing Type B vents based on:

- Appliance input rating (kW or MBH)
- Vent height
- Type of vent connector (single-wall or Type B)
- Lateral length of connector
- Combined vs. single appliance venting

Table Selection Process:

Step 1: Determine appliance category and draft hood presence

Draft hood appliances → Use Category I tables

Fan-assisted Category I → Use appropriate fan tables

Category III/IV → Follow manufacturer requirements

Step 2: Identify total vent height

Measure from draft hood outlet to vent termination

Include all vertical sections

Height ranges typically from 2m to 15m

Step 3: Determine lateral length

Measure horizontal vent connector from appliance to vertical vent

Include equivalent length for elbows

Maximum lateral depends on height and capacity

Step 4: Read table for minimum vent diameter

Find intersection of input rating and height

Verify lateral length is acceptable

Check that combination meets requirements

Common Sizing Scenarios:

Example 1: Single Furnace

Input: 100,000 BTU/h (29.3 kW)

Vent height: 4.5 m (15 feet)

Lateral: 1.5 m (5 feet) single-wall

Table result: 127 mm (5 inch) minimum vent diameter

Example 2: Water Heater

Input: 40,000 BTU/h (11.7 kW)

- Vent height: 6 m (20 feet)
- Lateral: 1.2 m (4 feet)
- Table result: 76 mm (3 inch) minimum vent diameter

Critical Sizing Rules:

- **Never undersize** - Undersized vents cause spillage and carbon monoxide production
- **Avoid significant oversizing** - Oversized vents cool gases excessively, reducing draft
- **Use tables conservatively** - When between sizes, choose larger size
- **Consider all appliances** - Common vents must accommodate total input of all connected appliances

Single Appliance Venting

Single appliance venting is the simplest and most reliable configuration. One appliance connects to one dedicated vent system.

Design Advantages:

- Simpler sizing calculations
- More reliable operation
- Easier troubleshooting
- No interaction between appliances
- Greater flexibility in equipment replacement

Installation Requirements:

- **Vent Connector:**
    - Minimum size equals appliance outlet size
    - Maximum length per CSA B149.1 tables
    - Minimum slope: 6 mm per metre rise toward vent
    - Single-wall or Type B (affects sizing)

Vertical Vent:

Size per CSA B149.1 tables based on:

Appliance input

Total height

Connector length and type

Must be properly supported

Maintain required clearances

Termination:

Proper height above roof

Clearance from vertical walls

Appropriate termination cap

Consider local wind patterns

Special Considerations:

Offset vents: Each 90° elbow reduces available draft; limit offsets and account for in design

Vents through unconditioned spaces: Maintain temperature or use insulated vent

Multi-story vents: Additional height helps draft but increases cooling

Common Venting Requirements

Common venting connects two or more Category I appliances to a single vent system. This is more complex and requires careful sizing to ensure all appliances vent safely under all operating conditions.

When Common Venting is Permitted:

CSA B149.1 allows common venting of:

Multiple Category I appliances with draft hoods

Appliances in same category and pressure classification

Where properly sized using code tables

When all appliances are located in the same room or space

When Common Venting is NOT Permitted:

Mixing appliances from different categories (e.g., Category I with Category IV)

Fan-assisted appliances with natural draft (unless specifically listed for common venting)

Appliances in different fire compartments

Where manufacturer prohibits it

Sizing Common Vents:

Common vents must handle several operating scenarios:

All appliances operating simultaneously

Only one appliance operating (oversizing concerns)

Various combinations of appliances operating

Sizing Process:

Step 1: Calculate total input

Add input ratings of all appliances

Use maximum input for modulating equipment

Step 2: Size common vertical vent

Use total input of all appliances

Measure from lowest connector to termination

Size using appropriate CSA B149.1 table

Step 3: Size individual connectors

Each connector sized for its appliance

Lateral length from appliance to common vent

Must rise continuously toward common vent

Step 4: Size manifold (lower section of common vent)

From lowest connector to next connector

Must handle largest single appliance plus any below it

Special sizing may be required

Critical Common Venting Rules:

Connector Entry:

Must enter common vent from side, never from top

Must enter at angle (horizontal or upward, not downward)

Use swept tee fittings, never plain tees

Connector Separation:

Vertical separation: minimum 300 mm between connector centerlines

Allows proper mixing and prevents spillage

Size Transitions:

Common vent may not decrease in size going upward

Each connected appliance may require size increase

Never reduce size above a connector entrance

Height Limitations:

CSA B149.1 tables have maximum and minimum heights

Too short causes inadequate draft

Very tall vents may overcool small appliances

Example Common Vent Scenario:

Furnace: 100,000 BTU/h, connector 1.5 m lateral

Water heater: 40,000 BTU/h, connector 1.2 m lateral

Water heater connector enters common vent below furnace connector

Total input: 140,000 BTU/h

Total height: 5 m

Sizing:

Common vent above furnace: Use 140,000 BTU/h input

Manifold (between connectors): Use 100,000 BTU/h minimum

Furnace connector: Size for 100,000 BTU/h

Water heater connector: Size for 40,000 BTU/h

Maximum Vent Length

CSA B149.1 limits vent lengths to ensure adequate draft and prevent excessive cooling of flue gases.

Horizontal Limitations:

Single-wall connector: Maximum length varies by appliance size and vent height, typically 1.5 m to 3 m

Type B connector: May allow longer runs due to better temperature retention

Consult CSA B149.1 tables for specific limits

Total System Length:

While focused on lateral (horizontal) limitations, consider total vent length:

Very long vents cool gases excessively

May cause condensation even in non-condensing systems

Friction losses reduce available draft

Consider mechanical venting for extreme situations

Calculating Equivalent Length:

- Each 90° elbow adds approximately 0.6 m (2 feet) equivalent length
- Each 45° elbow adds approximately 0.3 m (1 foot)
- Use actual lateral length plus elbow equivalent lengths
- Compare total to table limits

Offsets and Elbows

Offsets in vent systems add friction losses and reduce draft. While sometimes necessary for building structure, they should be minimized.

Types of Offsets:

- **Horizontal offsets:** Moving vent to the side before continuing upward
- **Angular offsets:** Using 45° or 30° elbows to change direction gradually
- **Combination offsets:** Multiple direction changes

Limitations on Offsets:

- **Natural draft systems:** Minimize offsets; each 90° turn is significant
- **Two 90° offsets maximum** in most residential systems
- **Use 45° elbows** when possible to reduce friction
- **Long-radius elbows** preferred over short-radius

Installation Requirements:

- **Support all horizontal sections**
  - Prevent sagging
  - Maintain slight upward slope
  - Support every 1 m for single-wall, 2 m for Type B
- **Secure connections**
  - All joints must be fastened (3 screws minimum)
  - Apply mastic or high-temperature sealant

Ensure alignment to prevent gas leakage

Accessibility

Provide access for inspection and cleaning

Consider future maintenance needs

Measurement and Documentation:

Measure and record all offset dimensions

Calculate equivalent length

Verify against CSA B149.1 table limits

Document for inspection and future reference

Termination Requirements

Vent termination is the point where combustion products exit the vent system and disperse into the atmosphere. Proper termination ensures safe dispersal and prevents recirculation or backdrafting.

Termination Height Above Roof:

CSA B149.1 specifies minimum termination heights based on roof slope:

Flat to 6/12 pitch:

Minimum 300 mm above highest point where vent passes through roof

Minimum 600 mm above roof surface measured at the vent

Steeper than 6/12 pitch:

Minimum 1.2 m above highest point where vent passes through roof

Within 3 m horizontally from vertical wall or parapet:

Extend 600 mm above the wall or parapet

Purpose of Height Requirements:

Prevents downdrafts from roof effects

- Keeps termination above snow accumulation
- Ensures adequate dispersion
- Prevents recirculation into air intakes

Clearance from Vertical Surfaces:

When vent terminates near a vertical wall:

- Maintain 300 mm minimum from wall surface
- Prevents downdrafts from wall effects
- Reduces staining of building surfaces

Horizontal Terminations (Direct Vent, Power Vent):

Different requirements apply to horizontal terminations of sealed combustion or power-vented appliances:

- Specific clearances from doors, windows, air intakes
- Minimum heights above grade or expected snow level
- Clearances from property lines
- Follow manufacturer's requirements exactly

Termination Cap Requirements:

- **Natural draft (Type B):**
  - Must use listed cap designed for Type B vent
  - Must not restrict draft
  - Should resist wind-induced downdrafts
  - Screen to prevent entry of birds and debris
- **Powered vents:**
  - Use manufacturer-supplied terminal
  - Must handle positive pressure

Design prevents rain and snow entry

Consider condensate freezing in cold climates

Prohibited Termination Locations:

Under building overhangs less than 600 mm

Within 600 mm of door or window that opens (for powered vents)

Less than 300 mm above forced air inlet

Where combustion products could enter building

Into enclosed spaces (attics, crawl spaces, garages)

Through walls less than 300 mm above grade

Clearances to Air Intakes

Preventing combustion products from entering air intakes is critical for safety. Carbon monoxide and other combustion gases must not be drawn into the building ventilation system or combustion air intakes.

Clearance Requirements (Typical - Verify Local Codes):

From mechanical draft terminations:

300 mm above forced air inlet

1.2 m from adjacent building openings (horizontally)

600 mm from openable windows and doors

600 mm from property lines (unless adjacent property is owned by same owner)

From natural draft terminations:

Less restrictive than mechanical draft

Adequate height above roof prevents most issues

Consider prevailing winds and air circulation patterns

Special Considerations:

Building Depressurization:

- Air intakes for makeup air or combustion air must not conflict with vent terminations
- Coordinate all intake and exhaust locations

Snow Accumulation:

- Consider maximum expected snow depth
- Terminate high enough to remain clear
- Provide snow guards or platforms if needed

Adjacent Buildings:

- Consider effects on neighboring properties
- Maintain code-required clearances
- Be a good neighbor - avoid nuisance conditions

Design Best Practices:

- Sketch building elevation showing all openings, intakes, and exhausts
- Identify potential conflict areas
- Locate vents to maximize clearances
- Consider winter wind patterns
- Document clearances for inspection

[Continuing with sections 12.4 through 12.8 in next response due to length...]

12.4 Type B Vent Installation

Assembly Requirements

Type B vent uses a male-female connection system where the male end always points downward to prevent condensate leakage.

Assembly Process:

Inspect components:

- Check for damage, dents, or defects
- Ensure all components are Type B listed
- Verify diameter matches system design

Insert male into female end:

- Male end has slightly smaller diameter
- Slides into female end
- Creates overlapping joint

Engage locking mechanism:

- Twist-lock: Rotate until tabs engage
- Snap-lock: Push until locks click
- Verify secure engagement around entire circumference

Fasten with screws:

- Install minimum 3 sheet metal screws per joint
- Screws penetrate both inner and outer walls
- Space screws evenly around circumference
- Use appropriate screw length (typically 9 mm or 3/8 inch)

Apply sealant (if required):

- High-temperature mastic or sealant
- Apply to male end before insertion
- Creates gas-tight seal
- Required for positive-pressure applications

Common Assembly Errors:

- Installing male end upward (causes leakage)
- Insufficient overlap (reduces draft)
- Missing screws (allows separation)
- Damaged components (creates leaks)
- Misaligned sections (causes restriction)

Support Spacing

Proper support prevents sagging, maintains alignment, and ensures safe operation throughout the life of the vent system.

Support Requirements:

Vertical Type B Vents:

- Support at intervals not exceeding 3 m (10 feet)
- Support at each floor or ceiling penetration
- Support at offsets and directional changes
- Bottom support carries weight of entire vent

Horizontal Type B Sections:

- Support every 2 m (6 feet) maximum
- Additional support near elbows and offsets
- Straps or hangers that don't compress vent
- Maintain slope toward vertical section

Support Methods:

- **Wall straps:**
  - Secure to structural members
  - Allow for thermal expansion
  - Don't compress vent walls

Minimum 22-gauge galvanized steel

Ceiling support boxes:

Listed for Type B vent

Provide firestopping at penetration

Maintain required clearances

Support vent weight

Roof jacks and flashings:

Listed for Type B application

Weatherproof seal at roof penetration

Support vent at roof line

Maintain clearances to roof deck

Adjustable supports:

Allow for settling and thermal expansion

Spring-loaded or sliding connections

Prevent binding of vent sections

Installation Tips:

Install support at firm, level base

Check plumb with level during installation

Tighten supports securely but not excessively

Recheck after initial appliance operation

Clearances to Combustibles

Type B vent requires less clearance to combustibles than single-wall pipe due to its double-wall insulated construction.

Standard Clearances:

Most Type B vents: 25 mm (1 inch) to combustibles

Some high-efficiency Type B: 50 mm (2 inches)

Through combustible walls/ceilings: Use listed thimbles or ceiling boxes

From metal chimneys: Per manufacturer specifications

Maintaining Clearances:

Wall Penetrations:

Use listed Type B wall thimble

Center vent in thimble

Seal opening with non-combustible material

Do not fill air space between vent and thimble

Ceiling Penetrations:

Use listed ceiling support box

Provides proper clearance automatically

Firestop rated for floor/ceiling assembly

Support weight of vent above

Attic and Concealed Spaces:

Maintain minimum clearances throughout

Protect from damage (insulation, storage)

Shield from contact with insulation

Provide access for inspection

Proximity to Other Equipment:

Electrical wiring: 150 mm minimum

Plumbing: Consider thermal expansion and condensation

- HVAC ducts: Coordinate installations

Reduced Clearance Systems:

Some Type B vent systems are listed for reduced clearances with specific shields or protection methods. Always verify with manufacturer's instructions and label on the vent.

Slope Requirements

Proper slope prevents condensate accumulation and ensures smooth gas flow.

Required Slopes:

- **Vent Connectors (horizontal sections):**
  - Minimum 6 mm per metre rise toward vertical vent (1/4 inch per foot)
  - Ensures any condensate drains back to appliance
  - Prevents gas pockets and restrictions
- **Horizontal Vent Sections:**
  - Not recommended in Type B natural draft systems
  - If unavoidable, slope upward in direction of gas flow
  - Support adequately to maintain slope
- **Offsets:**
  - Maintain minimum slope throughout
  - Support to prevent sagging
  - Avoid level or negative slope sections

Checking Slope:

- Use carpenter's level
- Verify during installation and after appliance operation
- Check for sagging at midpoints between supports
- Document slope measurements

Correcting Slope Problems:

- Adjust support locations
- Add intermediate supports
- Replace sagging sections
- Verify system sizing is appropriate

Connector Sizing and Length

The vent connector is the horizontal or near-horizontal section between the appliance and the vertical vent.

Sizing Connectors:

- **Minimum size:**
  - Never smaller than appliance outlet
  - Size using CSA B149.1 tables based on:
    - Appliance input
    - Vent height
    - Connector length
    - Connector material (single-wall or Type B)
- **Single-wall vs. Type B connectors:**
  - Single-wall: Less expensive, cools gases more rapidly
  - Type B: Maintains temperature better, allows longer runs
  - Tables give different lengths for each type
- **Oversizing concerns:**
  - Excessive oversizing cools gases too much
  - Follow table recommendations
  - One size larger than minimum is acceptable

More than one size larger requires engineering evaluation

Maximum Connector Length:

CSA B149.1 tables specify maximum lateral connector length based on:

- Appliance input rating
- Total vent height
- Connector material type

Typical Maximums:

- Small appliances, short vents: 5 feet (1.5 m)
- Larger appliances, tall vents: 10 feet (3 m) or more
- Always verify using appropriate table

Equivalent Length Adjustments:

- Add 2 feet (0.6 m) for each 90° elbow
- Add 1 foot (0.3 m) for each 45° elbow
- Compare total equivalent length to table limit

Termination Height and Location

Termination height ensures adequate draft and prevents downdrafts or recirculation of combustion products.

Height Above Roof:

Flat roofs to 6/12 pitch:

- Minimum 300 mm above point where vent passes through roof
- Minimum 600 mm above roof surface within 3 m horizontally

Steep roofs (greater than 6/12):

- Minimum 1.2 m above point where vent passes through roof

Near walls or parapets:

- Minimum 600 mm above wall within 3 m horizontally
- Prevents downdrafts from vertical surfaces

Multiple Vent Spacing:

When multiple vents terminate near each other:

- Minimum 1.2 m separation (some jurisdictions)
- Prevents interaction and re-entrainment
- Taller vent may need to be even higher

Location Selection:

- **Avoid roof valleys:**
  - Snow and ice accumulation
  - Difficult maintenance access
  - Potential leakage issues
- **Consider maintenance:**
  - Accessible for inspection and cleaning
  - Safe working conditions
  - Protection from damage
- **Aesthetic considerations:**
  - Minimize visual impact
  - Coordinate with architectural features
  - Paint to match (high-temperature paint only)

Cap Requirements

The termination cap completes the vent system and must allow free exhaust of combustion products while preventing entry of rain, snow, and debris.

Cap Features:

Rain protection:

Umbrella or cone design

Large enough to prevent water entry

Does not restrict gas flow

Bird/rodent screen:

Minimum 13 mm (1/2 inch) mesh

Maximum 19 mm (3/4 inch) openings

Stainless steel or equivalent corrosion resistance

Secure mounting:

Fastened to vent with screws or twist-lock

Weather-resistant fasteners

Withstands wind loads

Listed for application:

ULC listed for Type B vent

Proper diameter for vent size

Compatible with vent system

Installation:

Install per manufacturer's instructions

Ensure proper orientation (typically arrow or marking indicates front)

Fasten securely to prevent wind displacement

Verify clearances maintained to roof and walls

Check stability after installation

Inspection and Maintenance:

- Annually inspect for nests, debris, corrosion
- Clean screen if present
- Verify secure attachment
- Replace if damaged or deteriorated

12.5 Direct Vent Systems

Direct vent systems are sealed combustion systems that draw combustion air directly from outdoors and exhaust combustion products directly to outdoors through a dedicated vent system. They do not use indoor air for combustion.

Concentric Vent Design

The concentric (coaxial) vent uses a pipe-within-a-pipe configuration where the outer pipe brings in combustion air while the inner pipe exhausts combustion products.

Design Benefits:

- **Single penetration:**
  - One opening through wall or roof
  - Simplified installation
  - Reduced cost
  - Better aesthetics
- **Balanced air flow:**
  - Equal flow rates in and out
  - Minimal effect on building pressure
  - Better for tightly constructed buildings
- **Preheated combustion air:**
  - Exhaust gases warm incoming air
  - Improved efficiency

Better cold-weather operation

Reduced clearances:

Cooler outer surface

Safer near combustibles

More flexible installation

Construction:

Inner pipe: Stainless steel or AL29-4C for exhaust

Outer pipe: Aluminum or stainless for intake

Spacers: Maintain concentric relationship

Terminal: Sealed unit combining intake and exhaust openings

Applications:

Gas fireplaces

Direct vent water heaters

Some condensing furnaces

Wall-hung condensing boilers

Horizontal Terminations

Horizontal terminations are common with direct vent systems, offering installation flexibility not available with natural draft venting.

Installation Requirements:

1. Termination Location:

Minimum 300 mm above grade or expected snow level

Minimum 300 mm from doors and windows that open

Minimum 1.2 m below or beside doors and windows that open

Minimum 1.2 m from property lines

Minimum 600 mm from inside corners (prevents recirculation)

Minimum 1.2 m from outside corners

2. Support and Slope:

Support pipe adequately to prevent sagging

Slope exhaust toward appliance or condensate trap

Minimum 6 mm per metre slope (1/4 inch per foot)

Prevents rain and condensate from pooling

3. Termination Fitting:

Use manufacturer-supplied terminal

Verify proper orientation (marked on fitting)

Secure against wind displacement

Consider condensate freezing in cold climates

4. Maximum Lengths:

Follow manufacturer's specifications exactly

Varies widely by appliance model

May be limited to 1.5 m to 15 m or more

Reduce maximum for each elbow used

Special Considerations for Horizontal Terminations:

Wind Effects:

Strong winds can affect draft even in power-vented systems

Locate away from areas of high wind turbulence

Consider prevailing wind direction

Some installations benefit from wind deflectors

Condensate Drainage:

- Ensure proper slope prevents freezing at terminal
- Consider drain pan or extension beyond building
- Protect surfaces below terminal from condensate discharge

Landscaping and Maintenance:

- Keep clear of shrubbery and plantings
- Allow access for inspection and snow removal
- Protect from lawn mower and trimmer damage
- Consider underground conduit for vent near grade

Vertical Terminations

While less common with direct vent appliances, vertical terminations may be necessary or preferred in some installations.

Design Configurations:

- **Concentric vertical:**
  - Same pipe-within-pipe design
  - Terminates through roof
  - Requires proper flashing and weatherproofing
- **Separate intake and exhaust:**
  - Two pipes terminate near each other
  - Allows flexibility in routing
  - May be required for longer runs

Installation Requirements:

1. Roof Penetration:

- Use proper flashing for pipe size

- Seal weathertight
- Support vent at roof penetration
- Maintain clearances to roof deck

2. Termination Height:

- Follow manufacturer specifications
- Typically 300 to 600 mm above roof surface
- Consider snow accumulation
- Ensure separation between intake and exhaust

3. Intake Protection:

- Screen or cover prevents debris entry
- Consider wildlife and insects
- Avoid restriction of air flow
- Maintain access for inspection

When Vertical Termination is Preferred:

- Long horizontal run would exceed limits
- Horizontal termination clearances cannot be met
- Cold climate with heavy snow concerns
- Better draft performance needed
- Aesthetic preference for cleaner walls

Clearance Requirements

Direct vent clearances differ from natural draft venting due to sealed combustion and often cooler outer surface temperatures.

Clearances to Combustibles:

- **Vent pipe:** Typically 25 mm to 50 mm (verify with manufacturer)

Termination: Varies by design; some terminals contact siding directly

Through combustibles: Use listed thimbles or follow manufacturer's details

Clearances Between Intake and Exhaust (Separate Pipes):

Minimum vertical separation: 300 mm

Minimum horizontal separation: 150 mm at terminal

Prevents recirculation of exhaust into intake

Follow manufacturer specifications exactly

Clearances from Building Features:

These are critical safety requirements:

Feature	Minimum Clearance
Doors/windows that open	300 mm (above, below, or beside)
Forced air inlets	300 mm
Grade level	300 mm
Inside corners	600 mm
Outside corners	300 mm
Property lines	1.2 m (unless both properties same owner)
Adjacent public walkways	2.1 m above walkway

Special Clearances:

From other vent terminations: 1.2 m minimum

From air conditioning equipment: 1 m minimum

From gas meters and regulators: 1 m minimum

Manufacturer Specifications

CRITICAL: Direct vent systems must be installed exactly according to manufacturer's installation instructions. The appliance is tested and listed as a complete system including specific vent components.

What Manufacturer's Instructions Include:

Approved vent materials:

- Specific pipe material and thickness
- Listed fittings and components
- Terminal design and model numbers

Maximum vent lengths:

- Total length limitations
- Reductions for elbows (each elbow equivalent length)
- Minimum length requirements

Support requirements:

- Support spacing
- Methods of support
- Allowance for thermal expansion

Clearance specifications:

- To combustibles
- From building features
- Terminal location requirements

Assembly details:

- How components connect
- Sealing requirements
- Proper orientation

Substitutions NOT Permitted:

Cannot substitute pipe or fittings from different manufacturer

Cannot use "equivalent" materials not specifically listed

Cannot exceed maximum lengths

- Cannot reduce clearances below specified minimums

Documentation:

- Keep installation instructions with appliance
- Provide copy to homeowner
- Include with permit application
- Essential for future service

Installation in Cold Climates

Cold climates present unique challenges for direct vent systems, particularly regarding condensate freezing and draft performance.

Freezing Prevention:

1. Termination Design:

- Use terminals designed for cold climates
- Some have built-in heat trace or anti-freeze features
- Extended terminals project beyond wall to drain clear of building
- Upward-angled exhausts reduce freezing potential

2. Condensate Management:

- Ensure continuous slope prevents water accumulation
- Consider heat trace on horizontal vent sections
- Insulate vent in extremely cold locations
- Verify condensate trap has freeze protection

3. Intake Air Considerations:

- Very cold intake air can affect combustion efficiency
- Some systems have intake air dampers or pre-heaters
- Longer intake pipes warm air slightly before reaching burner

Balance energy savings against freeze protection needs

Snow and Ice:

Terminate high enough to remain above expected snow accumulation

Install snow guards or platforms if needed

Clear snow regularly around termination

Ensure homeowner understands maintenance requirements

Wind Chill Effects:

Extreme wind chill can cool vent excessively

Can cause icing at termination

May require insulated vent pipe

Consider wind deflectors or alternate location

Temperature Extremes:

At -40°C:

PVC venting becomes brittle

Thermal expansion/contraction is significant

Condensate freezing is major concern

Some installations may require stainless steel venting

Best Practices for Cold Climates:

Minimize horizontal vent lengths

Maintain maximum slope for drainage

Use terminals specifically designed for cold weather

Consider stainless steel over PVC in extreme climates

Insulate exposed vent sections

- Educate homeowner on winter inspection needs
- Include maintenance reminders for snow clearing

12.6 Power Venting

Power venting uses a fan to move combustion products through the vent system, allowing installations where natural draft is inadequate or where horizontal venting is desired.

Induced Draft Systems

Induced draft systems place the fan downstream of the heat exchanger, pulling combustion products through the appliance and pushing them out the vent.

How Induced Draft Works:

- Inducer fan starts before main burner
- Fan establishes negative pressure through heat exchanger
- Pressure switch verifies adequate draft
- Control allows main burner to ignite
- Fan continues through combustion cycle
- Fan runs post-purge after burner shuts off

Advantages:

- Heat exchanger under negative pressure (any leaks draw in, not out)
- Well-established technology
- Compatible with many older furnace designs
- Can overcome draft problems in existing installations

Components:

- **Inducer Motor:**
  - PSC (permanent split capacitor) or ECM (electronically commutated motor)

Typically 1/25 to 1/10 HP

Runs continuously during appliance operation

Blower Wheel:

Must handle hot, corrosive combustion gases

Steel or special coatings for longevity

Balanced for smooth, quiet operation

Pressure Switch:

Proves adequate draft before burner ignition

Safety interlock prevents operation without draft

Tubing must be clear and properly routed

Housing:

Connects to heat exchanger outlet

Withstands high temperatures

Sealed to prevent leakage

Venting Considerations:

Vent system under negative pressure before inducer, positive after

Uses Category I or Category III materials depending on design

Follow manufacturer's venting requirements exactly

Maximum vent lengths typically longer than natural draft

Forced Draft Systems

Forced draft systems place the fan upstream of the heat exchanger, blowing air through the burner and pushing combustion products through the appliance and vent system.

How Forced Draft Works:

Fan starts and builds pressure

Pressure switch verifies adequate airflow

Control allows ignition

Air/gas mixture forced through burner

Combustion products pushed through heat exchanger

Entire system under positive pressure

Advantages:

Better air/gas mixing for more complete combustion

Can overcome very long vent runs

Allows low-profile wall-hung boilers

Enables sealed combustion designs

Disadvantages:

Entire system under positive pressure (leaks release combustion products)

Requires sealed, pressure-tight heat exchanger

More complex controls

Higher initial cost

Applications:

Wall-hung condensing boilers

High-efficiency water heaters

Commercial heating equipment

Where space or building constraints prevent natural draft

Vent Materials and Sizing

Power-vented appliances have specific venting requirements based on whether they are condensing or non-condensing.

Non-Condensing Power Vent (Category III):

Materials:

Type B in tested, listed systems (manufacturer-specified)

Single-wall steel pipe (properly sealed)

Stainless steel

Follow manufacturer requirements exactly

Sizing:

Use manufacturer's tables or instructions

Generally more forgiving than natural draft (fan overcomes friction)

Still must size properly to prevent excessive backpressure

Monitor for restriction or blockage

Condensing Power Vent (Category IV):

Materials:

PVC Schedule 40 (most common)

CPVC (if specified)

Polypropylene (some manufacturers)

Stainless steel AL29-4C

Must resist condensate corrosion

Sizing:

Follow manufacturer's specifications exactly

Tables account for pressure drop through pipe and fittings

Maximum length varies widely (1.5 m to 30 m depending on model)

Each elbow reduces maximum length

Sealing Requirements:

Power vent systems are under positive pressure, requiring:

All joints sealed:

High-temperature silicone (non-condensing)

PVC cement (condensing PVC systems)

No leaks permitted

Mechanical fastening:

Screws at all joints (minimum 3 per joint)

PVC systems: cement provides primary seal, screws prevent separation

Metal systems: screws plus sealant

Pressure testing:

Some installations require pre-commissioning pressure test

Verify no leaks at rated operating pressure

Document test results

Electrical Interlocks

Power-vented appliances have electrical interlocks that prevent operation if venting is inadequate. Understanding these systems is essential for safe installation and troubleshooting.

Pressure Switch Operation:

The pressure switch is the primary safety device:

Normally open switch:

Contacts open when no pressure

Close when adequate pressure/vacuum sensed

Sensing Tubing:

Small diameter (typically 6 mm)

One side to inducer housing or vent

Other side to atmosphere or reference point

Must be clear, properly routed, secured

Switch Setpoint:

Calibrated to close at specific pressure

Typically -0.5 to -1.5 in. W.C. for induced draft

+0.1 to +0.5 in. W.C. for forced draft

Should not be adjusted in the field

Sequence of Operation:

Typical induced draft sequence:

Thermostat calls for heat

Inducer motor starts

Pressure switch must close within time limit (typically 30-60 seconds)

If pressure switch closes, control proceeds to ignition

If pressure switch does not close, control locks out with error code

After burner lights, pressure switch must remain closed

If pressure switch opens during operation, burner shuts down immediately

Troubleshooting Interlocks:

Inducer runs but pressure switch won't close:

Blocked vent or intake

Plugged pressure switch tubing

Failed pressure switch

Exhaust restriction in appliance

Inadequate inducer speed (motor problem)

Pressure switch closes then opens:

- Partial vent blockage
- Ice at termination
- Wind effects
- Pressure switch tubing partially blocked
- Weak pressure switch (marginal operation)

Electrical Wiring:

- Pressure switch in series with ignition control
- Break in circuit prevents burner operation
- 24V circuit typical in residential applications
- Some commercial applications use 115V interlocks

Condensate Handling

Many power-vented appliances, especially condensing types, produce significant condensate that must be managed properly.

Condensate Production:

- Condensing appliances produce 2-8 litres per hour depending on size and efficiency
- Condensate is acidic (pH 3-5) due to dissolved CO_2 and NO_x
- Temperature at condensate drain typically 40-60°C
- Continuous production whenever appliance operates

Drain Requirements:

1. Condensate Trap:

- Required on all condensing appliances
- Typically 75-150 mm deep trap
- Prevents flue gas escape through drain

Must be filled with water before operation

2. Drain Line Sizing:

Minimum 19 mm (3/4 inch) for single appliance

Larger for multiple appliances

PVC, CPVC, or ABS pipe acceptable

Must be properly supported

3. Slope:

Minimum 2% slope toward drain

Prevents standing water

Ensures continuous flow

Check during installation

4. Drain Termination:

Indirect drain to laundry sink, floor drain, or sump

Air gap required (50-75 mm minimum)

Never connect directly to sewer (gas backflow potential)

Never terminate outdoors (freezing in winter)

Neutralization:

Some jurisdictions require condensate neutralization before discharge to drain:

When Required:

Local plumbing codes vary

Generally required for commercial installations

May be required for residential in some areas

Check with local authority having jurisdiction

Neutralization Methods:

Limestone chips in neutralizer cartridge

Raises pH from 3-5 to 6-7

Filter prevents sediment in drain

Must be serviced periodically (annually typical)

Installation:

Install after condensate trap

Size per manufacturer and condensate production rate

Provide access for service

Replacement indicator (some models)

Safety Controls

Power-vented appliances incorporate multiple safety controls to ensure safe operation.

Primary Safety Controls:

1. Pressure/Vacuum Switch:

Proves adequate draft

Must close for burner operation

Opens immediately on draft loss

Adjustable setpoint (factory set)

2. High Limit Switch:

Prevents overheating

Mounted on heat exchanger

Shuts off burner if exceeded

Manual or automatic reset

3. Flame Sensor:

Proves flame presence

Flame rod or thermopile

Must sense flame within trial for ignition (typically 4-7 seconds)

Loss of flame signal shuts off gas immediately

4. Blocked Vent Switch (some models):

Redundant safety for vent blockage

Senses over-temperature or pressure

Locks out on activation

Manual reset required

Secondary Safety Controls:

1. Combustion Air Proving:

Some models verify combustion air intake open

Differential pressure switch sensing

Prevents operation if intake blocked

2. Condensate Switch:

Detects high water level in condensate trap

Prevents operation if drain blocked

Automatic reset when condition clears

3. Control Lockouts:

After repeated ignition failures

After pressure switch failures

After flame sensor failures

- Requires manual reset or power cycle

Testing Safety Controls:

After Installation:

- Block vent temporarily and verify appliance won't start or shuts down
- Verify pressure switch operation with manometer
- Test flame sensor by observing flame response
- Verify high limit operation (if feasible)
- Document all tests

Periodic Testing:

- Annual check of pressure switch operation
- Verify interlocks functional
- Clean flame sensor
- Check condensate trap and drain
- Test blocked vent response

12.7 Condensate Management

Condensing gas appliances extract additional heat by condensing water vapor from the combustion products. This creates significant condensate that must be managed properly.

Condensate Production

Quantity of Condensate:

A condensing appliance produces approximately:

- 4 litres per hour per 100,000 BTU/h input (typical)
- A 100,000 BTU/h (29 kW) furnace: 4 litres/hour
- A 200,000 BTU/h (58 kW) boiler: 8 litres/hour

Varies with efficiency and return water temperature

Condensate Characteristics:

Chemical Properties:

Acidic: pH typically 3.0 to 5.0

Contains dissolved CO_2 (carbonic acid)

May contain nitric acid (from NO_x)

Corrosive to some metals

Can affect some drain materials

Physical Properties:

Clear, colorless liquid

Temperature: 40-60°C (104-140°F)

Constant production during appliance operation

Volume varies with outdoor temperature and heating load

Environmental Considerations:

May require neutralization before discharge

Can affect septic systems if not neutralized

Should not be discharged to soil

Municipal sewer systems typically tolerate condensate

Drain Requirements

Proper drainage prevents water backup, appliance shutdown, and damage to building components.

Condensate Trap:

Every condensing appliance requires a condensate trap to prevent flue gas escape through the drain line.

Trap Depth:

Minimum 75 mm (3 inches) for negative pressure systems

Minimum 150 mm (6 inches) for positive pressure systems

Depth based on maximum system pressure

Manufacturer specifies required depth

Trap Location:

Immediately at appliance condensate outlet

Before any horizontal drain runs

Accessible for inspection and cleaning

Protected from freezing

Priming the Trap:

Fill with water before initial operation

Essential to prevent gas escape

Check water level during commissioning

Inform homeowner of this requirement

Drain Line Installation:

1. Material Selection:

PVC Schedule 40 (most common)

ABS pipe (acceptable in most jurisdictions)

CPVC (if required by temperature)

Never use metal pipe (corrosion)

2. Sizing:

Minimum 19 mm (3/4 inch) for residential

25 mm (1 inch) preferred for longer runs

32 mm (1-1/4 inch) for commercial or multiple appliances

Size per manufacturer requirements

3. Support:

Support every 600 mm (2 feet) minimum

Prevent sagging

Maintain continuous slope

Secure to building structure

4. Slope:

Minimum 2% slope (20 mm per metre, or 1/4 inch per foot)

Greater slope acceptable and preferred

Check with level during installation

Ensure no low spots or reverse slopes

5. Air Gap at Termination:

Minimum 50 mm (2 inches) above drain

Prevents backflow into appliance

Required by plumbing codes

Indirect drain to funnel, sink, or floor drain

Termination Options:

1. Floor Drain:

Direct to drain with air gap

Use funnel or drain pan

Protect from freezing if in unheated space

Must remain accessible

2. Laundry Sink:

Common in residential installations

Convenient for inspection

Air gap easily maintained

Keep drain line below rim

3. Sump Pump:

When gravity drain not available

Condensate lift pump may be required

High water safety switch essential

Battery backup recommended for critical applications

4. Condensate Pump:

For basement installations below drain level

Automatic float operation

High water switch for safety

Discharge to appropriate drain with air gap

Never Acceptable:

Direct connection to sewer (no air gap)

Termination outdoors (freezing concern)

Connection to soil or foundation drain

Drainage to landscaping or garden

Neutralization (Where Required)

Condensate neutralization raises pH from acidic (3-5) to neutral (6-7) before discharge to drain.

When Neutralization is Required:

Check Local Codes:

Requirements vary by jurisdiction

Some require for all installations

Some only for commercial

Many residential applications exempt

Septic Systems:

Often required when discharging to septic

Acidic condensate can harm septic bacteria

Check local health department requirements

Environmental Protection:

Some areas have strict pH discharge limits

Industrial and commercial applications more regulated

Residential may be exempt

Neutralization Methods:

1. Limestone Chip Neutralizers:

Most common method:

Container filled with calcium carbonate (limestone chips)

Condensate flows through limestone bed

Acid reacts with limestone, raising pH

Produces calcium bicarbonate and CO_2

Sizing:

Based on BTU input of appliance

Typical sizing: 3-4 kg limestone per 100,000 BTU/h

Larger capacity extends service interval

Manufacturer provides sizing charts

Installation:

Install after condensate trap

Provide adequate clearance for service

Support weight of unit and water

Install on drain pan (protection against overflow)

Maintenance:

Replace limestone annually or per manufacturer schedule

More frequent in high-use applications

Limestone dissolves gradually

Sediment filter (if present) may need cleaning

2. Liquid Neutralization:

Less common for residential:

Liquid neutralizing solution metered into drain

More consistent pH control

Higher cost and complexity

Used in large commercial applications

3. Dilution:

Not a true neutralization:

Large volume of water dilutes acidic condensate

May be acceptable in some jurisdictions

Not reliable or recommended

Cannot be used in many applications

Monitoring Neutralization:

pH Testing:

Test condensate pH at commissioning

Periodic testing during maintenance

Litmus paper or pH meter

Document results

Visual Inspection:

Check limestone level

Look for unusual sediment or color

Verify flow through unit

Check for leaks or overflow

Freeze Protection

Condensate drain lines passing through unheated spaces require freeze protection.

Freeze Risk Locations:

Attics and crawl spaces

Exterior walls

Unheated garages or mechanical rooms

Long outdoor runs (not recommended)

Near air conditioning refrigerant lines

Prevention Methods:

1. Insulation:

Pipe insulation minimum 13 mm (1/2 inch) thickness

More in extreme climates

Seal all joints

Protect from damage

2. Heat Trace:

Electric heating cable wrapped around pipe

Thermostatically controlled

Must be GFCI protected

Cover with insulation

3. Routing:

Keep drain lines within heated space when possible

Minimize exposure to cold

Increase slope in cold areas (faster drainage)

Avoid long horizontal runs in unheated spaces

4. Drain Line Heaters:

Self-regulating heat cable inside pipe

Maintains minimum temperature

More reliable than external heat trace

Higher cost but better protection

Emergency Measures:

If freeze occurs:

Shut down appliance immediately

Thaw drain line carefully (warm water, heat gun on low)

- Never use open flame
- Inspect for cracks after thawing
- Add permanent freeze protection before restarting

Trap Requirements

The condensate trap is critical for safe operation of condensing appliances. Understanding proper trap design and installation prevents dangerous situations.

Purpose of Trap:

- **Prevents flue gas escape** through condensate drain
- **Maintains pressure seal** in negative pressure systems
- **Overcomes positive pressure** in forced-draft systems
- **Ensures proper drainage** without airflow interference

Trap Design Principles:

Negative Pressure Systems (Induced Draft):

- Vent under negative pressure (vacuum)
- Trap prevents air being drawn in through drain
- Relatively shallow trap adequate (75 mm typical)
- Water seal must be maintained

Positive Pressure Systems (Forced Draft):

- Vent under positive pressure
- Trap must overcome system pressure
- Deeper trap required (150 mm typical)
- Pressure in Pa × 10 = trap depth in mm (approximately)

Trap Configuration:

P-Trap Style:

Most common configuration

Easy to fabricate with standard fittings

U-bend followed by return up

Cleanout access recommended

Running Trap:

Two 90° elbows create trap

Used in limited space

Less ideal for cleaning

Adequate if properly sized

Factory-Supplied Traps:

Many appliances include integral trap

Pre-sized for system pressure

Typically clear plastic for visual inspection

Follow manufacturer installation exactly

Installation Considerations:

Location:

As close to appliance as practical

Before any horizontal runs

Accessible for inspection

Protected from freezing

Cleanout Access:

Provide removable section or cleanout

Allows trap cleaning

Prevents sediment buildup

Facilitates troubleshooting

Venting the Drain:

Drain line should not be trapped twice

Building drain trap adequate

Air gap at termination prevents siphoning

No need for separate vent pipe

Initial Fill:

Fill with water before startup

Prevents gas escape during first operation

Use clean water

May need refilling after long shutdown periods

Common Trap Problems:

Dry trap: Evaporation after long shutdown (fill before restart)

Insufficient depth: Pressure overcomes trap seal (redesign trap)

Sediment buildup: Reduces effective depth (clean trap)

Freezing: Destroys trap seal (add freeze protection)

Siphoning: Improper drain routing (add air gap)

Testing Condensate Systems

Proper testing ensures the condensate system functions reliably and safely.

Pre-Commissioning Tests:

1. Visual Inspection:

Verify all joints made up properly

Check support and slope

Confirm trap depth adequate

Ensure termination has air gap

Look for damage or defects

2. Water Flow Test:

Pour water into condensate collection pan

Observe flow through trap and drain

Verify continuous drainage

Check for leaks at all connections

Confirm slope prevents standing water

3. Trap Seal Test:

Fill trap with water

Start appliance

Verify no gas escape at trap

Check for bubbling in trap (indicates air leak)

Monitor during initial operation

4. High Water Safety Test (if equipped):

Temporarily block drain line

Verify high water switch prevents appliance operation

Safety switch must shut down appliance

Clear blockage and verify normal operation resumes

Operational Testing:

1. Monitor Initial Operation:

Observe condensate production

Verify continuous drainage

Check trap maintains seal

Listen for gurgling or unusual sounds

Document any issues

2. Measure Condensate pH (if neutralizer installed):

Test pH before neutralizer

Test pH after neutralizer

Verify pH raised to 6-7

Document results

3. Flow Rate Check:

Measure condensate production

Compare to expected rate

Significant deviation indicates problem

Normal variation with load is expected

Maintenance Testing:

Annual Inspection Should Include:

Visual inspection of all components

Trap water level check

Drain line inspection for leaks or damage

Flow test to verify no restrictions

High water switch test

Neutralizer service (if present)

pH test if required

Documentation of findings

Troubleshooting Condensate Problems:

Condensate Overflow:

Check for drain blockage

Verify trap not frozen

Ensure proper slope

Check for sediment buildup

Verify pump operation (if present)

No Condensate Production:

Appliance may not be condensing

Return water temperature too high (boilers)

Check for vent system leaks

Verify heat exchanger condition

Intermittent High Water Switch Trips:

Partial drain blockage

Inadequate slope causing slow drainage

Undersized drain line

Trap seal problem

12.8 Troubleshooting Venting Problems

Systematic troubleshooting of venting problems protects occupants from carbon monoxide exposure and ensures reliable appliance operation.

Spillage Detection and Correction

Spillage is the escape of combustion products at the draft hood or vent opening. It represents a serious safety hazard requiring immediate correction.

Spillage Testing Procedure:

CSA B149.1 requires spillage testing after:

- New installation
- Vent system modifications
- Appliance replacement
- Service work affecting venting
- Investigation of carbon monoxide incidents

Standard Test Method:

- **Prepare Building:**
  - Close all doors and windows
  - Turn on all exhaust fans at maximum
  - Turn on clothes dryer (if present)
  - Turn on any central vacuum system
  - Activate kitchen range hood at highest setting
- **Start Appliances:**
  - Light all naturally vented appliances
  - Start furnace and water heater simultaneously
  - Allow both to operate
- **Wait for Stabilization:**
  - Wait minimum 1 minute after ignition
  - Allows vent to heat and establish draft
  - Brief initial spillage is normal

Conduct Smoke Test:

Hold smoke source near draft hood relief opening

Observe smoke movement for minimum 60 seconds

Smoke should be drawn steadily into draft hood

Document Results:

Pass: Smoke steadily drawn in

Marginal: Brief spillage but corrects within 30 seconds

Fail: Continued spillage after 1 minute

Corrective Actions for Spillage:

Immediate Actions:

Shut down spilling appliance

Open windows for ventilation

Do not restart until corrected

Warn occupants of danger

Investigation Steps:

1. Check for Blockage:

Inspect vent termination

Look for bird nests, debris, ice

Check for collapsed vent sections

Verify dampers open properly

2. Verify Vent Sizing:

Measure vent diameter

Calculate vent height

Measure lateral lengths

Compare to CSA B149.1 tables

Check for incorrect sizing

3. Assess Draft:

Measure draft at draft hood with manometer

Normal: -0.02 to -0.04 in. W.C.

Weak draft: -0.01 in. W.C. or less

Positive pressure indicates severe problem

4. Evaluate Building Conditions:

Check for excessive exhaust fan capacity

Assess building tightness

Look for competing appliances

Consider stack effect (tall building)

5. Inspect Vent System:

Look for disconnected sections

Check for holes or corrosion

Verify proper slope

Ensure adequate support

Look for crushed or damaged pipe

Common Causes and Solutions:

Cause	Symptoms	Solution
Blocked vent	Strong spillage, possible odors	Clear blockage, add bird screen
Undersized vent	Spillage on cold, calm days	Resize vent per code tables
Oversized vent	Spillage on warm days	May require induced draft
Building depressurization	Spillage only with exhaust fans	Add makeup air, reduce exhaust

Cause	Symptoms	Solution
Damaged vent	Intermittent spillage	Repair or replace damaged sections
Common vent problems	One appliance spills	Re-evaluate common venting design

When to Install Powered Vent:

If natural draft cannot be achieved:

Building conditions prevent adequate draft

Vent routing requires excessive length or offsets

Common venting of incompatible appliances

Replacement appliance conflicts with existing vent

Draft Measurement

Measuring draft quantifies vent system performance and aids troubleshooting.

Measurement Tools:

1. Draft Gauge (Inclined Manometer):

Most accurate for small pressures

Reads in inches water column

Range typically 0 to -0.25 in. W.C.

Clear oil or red gauge fluid

2. Magnehelic Gauge:

Easier to read

Range 0 to -0.50 in. W.C. typical

More durable than liquid manometer

Good for field use

3. Digital Manometer:

Highest accuracy and resolution

Multiple pressure ranges

Can measure positive or negative

More expensive but versatile

Measurement Procedure:

1. Preparation:

Ensure appliance at normal operating temperature

All burners firing

Building conditions representative

Allow 5-10 minutes stabilization

2. Measurement Location:

Draft hood-equipped appliances: at draft hood relief opening

Fan-assisted: at designated test port

Insert probe carefully

Avoid turbulent areas

3. Reading:

Allow gauge to stabilize (30-60 seconds)

Record measurement

Note appliance firing rate

Document building conditions

4. Interpretation:

Natural Draft Appliances:

Normal: -0.02 to -0.04 in. W.C. (-5 to -10 Pa)

Strong draft: -0.05 to -0.10 in. W.C. (-12 to -25 Pa)

Weak draft: -0.01 in. W.C. (-2 Pa) or less

Positive pressure: Spillage condition (0 or positive reading)

Induced Draft Appliances:

Varies by model: typically -0.10 to -0.50 in. W.C.

Consult manufacturer specifications

Pressure switch setpoint is minimum acceptable

Significantly lower reading indicates problem

Factors Affecting Draft:

Outdoor temperature: Colder increases draft

Wind: Variable effects depending on direction

Building pressure: Exhaust fans reduce draft

Vent temperature: Hotter gases create more draft

Vent height: Taller vents create more draft

Diagnostic Value:

Draft too weak:

Undersized vent

Blockage or restriction

Insufficient vent height

Excessive lateral length

Oversized vent (gases cool too much)

Draft too strong:

Can indicate over-firing

May cause burner problems

Usually not a safety concern

Could indicate vent fire or unusual conditions

Condensation Issues

Condensation in venting systems not designed for condensing operation indicates problems requiring correction.

Causes of Condensation:

1. Oversized Vent:

Large diameter allows excessive cooling

Flue gas temperature drops below dew point

Most common cause in natural draft systems

Size reduction may be required

2. Excessive Vent Length:

Long horizontal runs cool gases

Extended vertical runs in cold spaces

Heat loss through vent walls

Inadequate insulation

3. Uninsulated Vent in Cold Space:

Vent passing through attic, crawlspace, exterior wall

Cold surrounding temperature

Metal vent conducts heat away

Single-wall pipe in cold locations

4. Low Flue Gas Temperature:

Oversized appliance cycling short periods

High-efficiency appliance approaching condensing

Insufficient appliance firing rate

Heat exchanger problems

5. External Cooling:

Wind blowing on exposed vent

Contact with cold surfaces

Proximity to air conditioning

Inadequate clearances

Symptoms of Condensation:

Water stains on ceiling or walls near vent

Dripping from vent connector joints

Rust and corrosion of vent components

Water in appliance base

Deterioration of masonry chimney

White mineral deposits (efflorescence)

Health and Safety Concerns:

Corrosion weakens vent system

Potential for carbon monoxide leaks

Structural damage to building

Mold growth from moisture

Accelerated equipment deterioration

Corrective Actions:

1. Resize Vent System:

Reduce diameter per CSA B149.1 tables

Verify all aspects of sizing

May require new vent installation

Most effective permanent solution

2. Insulate Vent:

Wrap single-wall with insulation

Replace with Type B double-wall

Insulate entire length in cold spaces

Maintain required clearances

3. Reduce Horizontal Length:

Minimize lateral runs

Move appliance closer to vertical vent

Eliminate unnecessary offsets

Consider alternate vent routing

4. Liner Installation:

Install liner in oversized masonry chimney

Properly sized liner maintains temperature

Insulated liner in very cold climates

Must be continuous and sealed

5. Convert to Power Vent:

Eliminates condensation in vent connector

Maintains higher vent temperatures

Allows more flexible routing

Higher cost but reliable solution

6. Replace with Condensing Appliance:

Designed for condensate production

Proper materials for condensate

Most energy efficient

May be most cost-effective long-term

Blockage Identification

Vent blockages prevent safe appliance operation and must be identified and cleared promptly.

Types of Blockages:

1. Bird Nests and Animal Entry:

Most common cause of complete blockage

Occurs during off-season (summer)

Twigs, grass, leaves, debris

Prevention: proper termination cap with screen

2. Ice and Frost:

Forms at termination in cold weather

Condensate freezing

Water vapor from flue gases

More common in marginal draft situations

3. Debris Accumulation:

Leaves, paper, plastic bags blown into vent

Roof debris during construction

Inadequate termination cap

Poor maintenance

4. Structural Failure:

Collapsed vent sections

Crushed or damaged pipe

Separated joints

Deteriorated masonry

5. Corrosion Buildup:

Rust scale narrows vent passage

Gradual accumulation over years

More common in older systems

Indicates end of vent life

6. Condensate Freezing:

Water trapped in vent freezes

Blocks passage in horizontal sections

Forms at termination

Results from improper slope or oversizing

Detection Methods:

1. Visual Inspection:

Inspect termination from outside

Look for visible obstruction

Check for ice buildup

Note any damage or deterioration

2. Draft Measurement:

Very weak or zero draft indicates blockage

Compare to previous measurements

Test at multiple firing rates

3. Spillage Testing:

Immediate spillage on appliance start

No improvement after warm-up period

Smoke test shows complete blockage

4. Camera Inspection:

Inspection camera through cleanout

Identifies location of blockage

Assesses internal condition

Documents problems

5. Appliance Symptoms:

Frequent limit switch trips

Carbon monoxide alarm activation

Soot production

Yellow or lazy flame

Noisy combustion

Clearing Blockages:

1. Safety First:

Shut down appliance

Ventilate area

Use personal protective equipment

Have assistance available

2. Access the Blockage:

From termination (safest)

Through cleanout

May require vent disassembly

Protect surrounding areas

3. Removal Methods:

Mechanical: brushes, rods, vacuum

Manual: remove nest material carefully

Air pressure: only if safely directed

Never use excessive force

4. Verify Clearance:

Visual confirmation

Draft test after clearing

Spillage test

Camera inspection if available

5. Prevent Recurrence:

Install proper termination cap

Add bird screen (13 mm mesh)

Improve drainage

Schedule regular inspections

Address root cause (condensation, etc.)

When to Replace vs. Clear:

Replace if:

Extensive corrosion throughout

Structural damage

Repeated blockages

Does not meet current codes

More cost-effective than repair

Carbon Monoxide Production

Carbon monoxide (CO) production from venting problems represents an immediate life safety hazard.

How Venting Problems Cause CO:

1. Incomplete Combustion:

Insufficient combustion air

Improper air/fuel ratio

Flame impingement

Dirty burner

Results in CO formation at burner

2. Spillage:

Venting problem causes flue gas spillage

CO enters building rather than exiting

Even properly-combusting appliances dangerous if spilling

Rapid CO accumulation possible

3. Recirculation:

Exhaust gases re-enter combustion air intake

Dilutes oxygen available for combustion

Causes incomplete combustion

- Progressive worsening

Warning Signs:

Appliance Indicators:

- Yellow-tipped flames (should be blue)
- Sooty deposits
- Spillage at draft hood
- Condensation on cool surfaces
- Unusual odors

Building Indicators:

- CO alarms activating
- Occupant symptoms (headache, nausea, dizziness)
- Multiple people feel ill simultaneously
- Symptoms improve when leaving building

Immediate Actions if CO Suspected:

- **Evacuate Building:**
  - Get all occupants to fresh air immediately
  - Do not attempt repairs before evacuation
  - Account for all people
- **Call Emergency Services:**
  - Fire department can measure CO levels
  - Emergency medical services for symptomatic people
  - Do not re-enter until cleared by authorities
- **Shut Off Gas (if safe):**

Turn off at meter or appliance

Only if can be done without risk

Do not delay evacuation to shut gas

Ventilate:

Open doors and windows

Turn off appliances

Allow building to air out completely

Do Not Restart:

Qualified technician must inspect and test

Identify and correct cause

Test CO levels before reoccupation

Document findings and repairs

Investigation After CO Incident:

1. Combustion Testing:

Measure CO in flue gases

Should be less than 100 ppm air-free

Higher levels indicate incomplete combustion

Also measure CO_2, O_2, efficiency

2. Appliance Inspection:

Check burner condition and adjustment

Inspect heat exchanger for cracks

Verify proper orifice sizing

Check gas pressure and manifold pressure

3. Venting Assessment:

Complete spillage testing

Draft measurement

Visual inspection

Check for blockages

Verify proper sizing

4. Building Evaluation:

Test for depressurization

Check exhaust fan capacities

Assess makeup air provisions

Evaluate combustion air

5. CO Alarm Verification:

Ensure alarms present and working

Correct locations (per code)

Recent testing and maintenance

Consider additional alarms

Prevention:

Regular appliance maintenance

Annual combustion testing

Proper venting system design

CO alarms in all required locations

Homeowner education

Prompt response to warning signs

Corrective Actions

After identifying venting problems, appropriate corrective actions ensure safe and reliable operation.

Prioritizing Corrections:

1. Immediate Safety Hazards:

- CO production or spillage
- Blocked vents
- Damaged/disconnected vents
- Positive pressure at draft hood

Actions: Red-tag appliance, do not operate until corrected

2. Code Violations:

- Improper clearances
- Missing termination components
- Inadequate support
- Non-compliant materials

Actions: Correct to bring into compliance, document

3. Performance Issues:

- Marginal draft
- Condensation in non-condensing vents
- Excessive cycling
- Noise or odors

Actions: Address to prevent future problems, improve reliability

Correction Methods by Problem Type:

Spillage Problems:

Clear blockages

Resize vent per tables

Add induced draft

Provide makeup air

Repair damaged sections

Draft Problems:

Increase vent height

Reduce lateral length

Eliminate unnecessary offsets

Replace oversized vent

Install power vent

Condensation Problems:

Downsize vent diameter

Insulate vent in cold spaces

Install liner in chimney

Convert to condensing appliance

Improve drainage

Blockage Problems:

Clear obstruction

Install proper cap and screen

Correct condensation issues

Replace deteriorated sections

Schedule regular inspection

Material Problems:

- Replace non-compliant materials
- Use correct materials for category
- Seal positive-pressure systems
- Update to current standards

Installation Problems:

- Correct slope
- Add proper supports
- Achieve required clearances
- Install missing components
- Secure all connections

Documentation:

After corrections:

- Photograph work
- Document measurements
- Record test results
- Provide written summary to customer
- Keep records per requirements
- Notify authority having jurisdiction if required

Follow-Up:

- Retest after corrections
- Verify no spillage
- Measure draft

Combustion analysis

Customer instruction on proper use and maintenance

Schedule follow-up if needed

Chapter 12 Summary

Venting systems are critical safety components that remove combustion products from buildings while maintaining proper appliance operation. Key principles include:

Venting Fundamentals:

Natural draft relies on buoyancy of hot gases

Available draft must exceed required draft

Stack effect and building pressure affect operation

Spillage testing required after installation and modifications

Materials Selection:

Appliance category determines appropriate materials

Type B for Category I draft hood appliances

PVC/CPVC for Category IV condensing appliances

Stainless steel for high-temperature or corrosive conditions

Design Principles:

Size vents using CSA B149.1 tables

Consider total height, lateral length, and number of elbows

Common venting requires careful sizing for all operating scenarios

Termination location critical for safety

Installation Requirements:

Proper assembly with male end down

Adequate support prevents sagging

Maintain clearances to combustibles

Correct slope ensures drainage

Secure all connections

Special Systems:

Direct vent provides sealed combustion

Power venting overcomes draft limitations

Condensate management essential for condensing appliances

Electrical interlocks provide safety protection

Troubleshooting:

Systematic spillage testing identifies problems

Draft measurement quantifies performance

Address condensation in non-condensing systems

Clear blockages promptly

Recognize CO production warning signs

Proper venting system design, installation, and maintenance protects occupants from carbon monoxide exposure and ensures reliable, efficient appliance operation for the life of the equipment.

Chapter 12 Review Questions

Multiple Choice

What is the primary driving force for natural draft venting? a) Wind pressure b) Temperature difference between flue gases and outdoor air c) Building stack effect d) Appliance gas pressure

Type B vent is appropriate for: a) Category I appliances with draft hoods b) Category IV condensing appliances c) All gas appliances d) Outdoor applications only

The male end of Type B vent sections must point: a) Upward b) Downward c) Horizontal d) Direction doesn't matter

What is the minimum slope for vent connectors? a) 2 mm per metre b) 6 mm per metre c) 10 mm per metre d) No slope required

Category IV appliances produce flue gases with temperatures: a) Above 200°C b) Above 100°C c) Above 60°C d) Below 60°C

PVC venting is acceptable for: a) All gas appliances b) Natural draft appliances c) Category IV condensing appliances per manufacturer specs d) Category III positive pressure non-condensing only

During spillage testing, continued spillage after ____ minute(s) indicates a failed test: a) 0.5 b) 1 c) 2 d) 5

Standard clearance for Type B vent to combustibles is typically: a) 0 mm (can touch) b) 25 mm c) 150 mm d) 300 mm

In a common venting system, connectors must enter the common vent: a) From the top b) From the side or at upward angle c) From below d) Entry angle doesn't matter

What pH range is typical for condensate from condensing appliances? a) 7-9 (alkaline) b) 6-7 (neutral) c) 3-5 (acidic) d) 1-2 (highly acidic)

The pressure switch in an induced draft system: a) Controls gas pressure to the burner b) Proves adequate draft before burner ignition c) Limits maximum vent pressure d) Adjusts fan speed

Direct vent terminations must maintain minimum clearance from windows that open of: a) 150 mm b) 300 mm c) 600 mm d) 1200 mm

A condensate trap is required: a) Only on Category IV appliances b) On all gas appliances c) On natural draft appliances only d) Only when local codes require

Normal draft reading at a draft hood should be: a) 0 in. W.C. b) -0.02 to -0.04 in. W.C. c) -0.10 to -0.15 in. W.C. d) +0.05 in. W.C.

The most common cause of complete vent blockage is: a) Ice buildup b) Corrosion c) Bird nests d) Condensate

True/False

Oversized vents can cause spillage due to excessive cooling of flue gases. ____

Type B vent can be used for all categories of gas appliances. ____

Condensate from condensing appliances can be discharged directly outdoors. ____

Each 90° elbow in a vent system adds approximately 0.6 m equivalent length. ____

The minimum vent height above a flat roof is 300 mm. ____

Short Answer

Explain the difference between spillage and backdrafting.

List three factors that can reduce available draft in a natural draft system.

Why must condensate drain lines terminate with an air gap rather than connecting directly to a sewer?

Describe the proper procedure for conducting a spillage test per CSA B149.1.

What corrective actions should be taken if spillage continues after 1 minute during testing?

Calculations and Applications

A furnace with 100,000 BTU/h input has a vent height of 6 m and a lateral connector length of 2 m using single-wall pipe. Using CSA B149.1 tables, what minimum vent diameter is required? (Use provided table excerpt)

Calculate the equivalent length of a vent connector that includes 1.5 m of horizontal pipe and two 90° elbows.

A 29 kW condensing furnace operates for 8 hours. Approximately how many litres of condensate will be produced?

A common vent serves a 100,000 BTU/h furnace and a 40,000 BTU/h water heater. The water heater connector enters the common vent 1 m below the furnace connector. The total vent height is 7 m. What minimum common vent size is required above the furnace connector?

A direct vent water heater has a horizontal vent length of 3 m with one 90° elbow. The manufacturer specifies maximum equivalent length of 4 m, with each elbow counting as 1 m. Is this installation acceptable?

Practical Scenarios

Scenario 1: You arrive at a home where the carbon monoxide alarm activated overnight. The atmospheric furnace and water heater are both venting into a common Type B vent system. What are your immediate actions and investigation steps?

Scenario 2: During a service call, you observe water stains on the ceiling around the vent pipe for a natural draft water heater. The vent appears properly sized per tables. What are the possible causes and corrective actions?

Scenario 3: A new high-efficiency furnace installation requires a horizontal termination. The only suitable wall has a window 1.5 m above the desired termination location and an air conditioning unit 0.8 m to the side. Evaluate if this location is acceptable and explain your reasoning.

Scenario 4: You are installing a new water heater in a basement. The existing vent system is a 127 mm (5 inch) Type B common vent that also serves the furnace. The old water heater was 40,000 BTU/h, and the new one is 50,000 BTU/h. The furnace is 80,000 BTU/h. What must you verify before connecting the new water heater?

Scenario 5: A condensing boiler keeps shutting down on high water switch. The condensate drain line slopes properly to a floor drain 4 m away. What troubleshooting steps would you take?

Answer Key

Multiple Choice:

b 2. a 3. b 4. b 5. d 6. c 7. b 8. b 9. b 10. c 11. b 12. b 13. a 14. b 15. c

True/False: 16. True 17. False (only Category I with draft hoods) 18. False (must drain indoors with air gap) 19. True 20. True

Short Answer: 21. Spillage is the escape of combustion products at the draft hood or vent opening. Backdrafting is spillage that continues after the normal start-up period (beyond 30-60 seconds).

- Any three of: low vent height, oversized vent diameter, excessive lateral length, too many elbows/offsets, blockage/restriction, cold outdoor temperatures reducing temperature differential, building depressurization from exhaust fans, damaged or leaking vent.

- Air gap prevents backflow of sewer gases into the appliance and prevents the condensate drain from being siphoned dry, which would allow flue gases to escape through the drain. Direct connection to sewer also violates plumbing codes.

- Close all windows and doors, turn on all exhaust fans at maximum, start clothes dryer if present, light all naturally vented appliances simultaneously, wait 1 minute after burner ignition, use smoke source at draft hood relief opening, observe for minimum 60 seconds. Smoke should be drawn steadily into draft hood.

Shut down the spilling appliance immediately, ventilate the space, red-tag the appliance as unsafe to operate, investigate cause (check for blockages, verify sizing, measure draft, assess building conditions), correct the problem, retest before returning to service.

Calculations: 26. Answer depends on specific table values provided, typically 127 mm (5 inch) or 152 mm (6 inch).

Equivalent length = 1.5 m + (2 × 0.6 m) = 2.7 m

Approximately 4 litres/hour × 8 hours = 32 litres (using typical rate of 4 L/hr per 29 kW)

Total input = 140,000 BTU/h. Answer depends on table values, typically 152 mm (6 inch) or 178 mm (7 inch).

Equivalent length = 3 m + (1 × 1 m) = 4 m. This equals the maximum, so it is acceptable but at the limit. No additional length or elbows could be added.

Practical Scenarios: (Answers should include key points listed below)

Scenario 1:

Evacuate building immediately

Call emergency services

Shut off gas if safe to do so

Do not restart until investigated and corrected

After clearance: perform combustion analysis, spillage testing, draft measurement, inspect vent for blockages, check for proper sizing, evaluate building depressurization, inspect heat exchangers for cracks, verify CO alarms properly located

Scenario 2:

Probable cause: condensation due to oversized vent

Measure vent diameter and verify against sizing tables

Check vent height and lateral length

Look for uninsulated vent in cold space

Solutions: reduce vent diameter, insulate vent, install liner in chimney, verify proper slope, consider replacement with power-vented or condensing unit

Scenario 3:

Window 1.5 m above: requires 300 mm minimum clearance from windows that open; 1.5 m exceeds this - ACCEPTABLE

A/C unit 0.8 m to side: requires 1 m minimum clearance; 0.8 m is insufficient - NOT ACCEPTABLE

Must relocate termination or relocate A/C unit to achieve proper clearances

Scenario 4:

Verify new total input (130,000 BTU/h) is acceptable for existing 127 mm common vent

Check tables for common venting with this total input and system configuration

Verify existing vent height and connector lengths

Size manifold section (between connectors) for furnace input minimum

Verify individual connector sizes appropriate

May need to upsize common vent to 152 mm (6 inch)

Scenario 5:

Check for drain line blockage (flush with water)

Verify condensate pump working if present

Inspect trap for proper depth and water seal

Look for improper slope or low spots

Check for freezing if line passes through cold space

Test high water switch operation

Verify drain line not restricted at termination

Check for excessive condensate production indicating other problems

CHAPTER 13: Heating Systems

Learning Objectives

After completing this chapter, you will be able to:

- Identify components and operation of forced air furnaces
- Explain differences between condensing and non-condensing systems
- Install furnaces according to CSA B149.1 requirements
- Understand control sequences and safety interlocks
- Install and commission hydronic heating systems
- Work with radiant heating applications
- Perform proper start-up and commissioning procedures
- Diagnose common heating system problems systematically

Introduction

Heating systems represent the primary application of natural gas and propane in Canadian buildings. Understanding heating system design, installation, operation, and troubleshooting is fundamental to gas technician competency. This chapter covers forced air furnaces, hydronic boilers, radiant heating, and related components according to CSA B149.1-25 requirements and current industry best practices.

13.1 Forced Air Furnaces

Forced air furnaces are the most common residential heating appliances in Canada. They heat air in a heat exchanger and distribute it throughout the building using a blower and duct system.

System Components

A complete forced air heating system consists of the furnace itself plus the air distribution system. Understanding each component's function is essential for proper installation and service.

Primary Furnace Components:

1. Heat Exchanger:

The heat exchanger is the barrier between combustion gases and circulating air. It must transfer heat efficiently while preventing any mixing of flue gases with building air.

- **Primary heat exchanger:** Where main combustion heat transfer occurs
- **Secondary heat exchanger (condensing furnaces):** Extracts additional heat by condensing water vapor
- **Materials:** Aluminized steel, stainless steel, or specialized alloys
- **Critical safety component:** Any cracks or holes create carbon monoxide hazard

2. Burner Assembly:

The burner assembly mixes gas and air for efficient, clean combustion.

- **Burner type:** In-shot, ribbon, slotted port, or mesh
- **Gas manifold:** Distributes gas to individual burners
- **Primary air adjustment:** Some models allow adjustment, others factory-set
- **Burner tube orientation:** Typically fires horizontally into heat exchanger

3. Gas Valve:

The gas valve controls gas flow to the burners under direction of the control system.

- **Valve types:**
  - Single-stage (on/off)
  - Two-stage (low fire/high fire)
  - Modulating (infinite adjustment)
- **Safety shutoff:** Closes immediately if flame lost
- **Manual shutoff:** External handle for service
- **Pressure regulator:** Maintains manifold pressure (typically 3.5 in. W.C. / 0.87 kPa)

4. Ignition System:

Modern furnaces use electronic ignition, eliminating standing pilots.

- **Hot surface igniter (HSI):** Silicon nitride or silicon carbide element heats to 2500°F (1371°C)
- **Direct spark ignition (DSI):** Creates spark to ignite gas
- **Intermittent pilot:** Electronic pilot that lights only on call for heat
- **Ignition control module:** Manages ignition sequence and safety timing

5. Flame Sensor:

The flame sensor proves flame presence to the control, ensuring safe operation.

- **Flame rod:** Detects flame through flame rectification
- **Thermopile:** Generates voltage from flame heat
- **UV sensor:** Detects ultraviolet light from flame
- **Must prove flame within trial for ignition:** Typically 4-7 seconds
- **Continuous monitoring:** Loss of signal shuts gas valve immediately

6. Blower Assembly:

The blower circulates air through the heat exchanger and duct system.

- **Blower wheel:** Forward-curved centrifugal fan
- **Motor types:**
    - PSC (Permanent Split Capacitor): Single or multi-speed
    - ECM (Electronically Commutated Motor): Variable speed, high efficiency
    - X13: ECM with enhanced controls
- **Blower housing:** Sheet metal enclosure directing airflow
- **Mounting:** Resilient isolation reduces vibration transmission

7. Air Filter:

The filter protects equipment and improves indoor air quality.

Location: Upstream of blower (negative pressure side)

Types: Flat disposable, pleated, electronic, HEPA

Size: Must match system capacity

MERV rating: Indicates filtration efficiency (higher = better filtration)

Maintenance critical: Restricted filter reduces airflow and efficiency

8. Control Board:

The integrated control board manages all furnace operations.

Microprocessor-based: Complex logic and safety algorithms

Inputs: Thermostat, pressure switch, limit switch, flame sensor

Outputs: Gas valve, igniter, blower motor, inducer motor

Diagnostics: LED codes indicate system status and faults

Communication: Some models have advanced communication protocols

9. Limit Switch:

The high limit switch prevents overheating by shutting down the burner.

Temperature setpoint: Typically 160-200°F (71-93°C)

Location: Mounted in supply plenum or on heat exchanger

Function: Opens on excessive temperature, breaking circuit to gas valve

Reset: Automatic when temperature drops

Repeated trips: Indicate airflow problems requiring investigation

10. Pressure Switch (Induced/Forced Draft):

Required on all induced draft and forced draft furnaces.

Proves adequate draft/airflow: Must close before ignition permitted

Sensing tubing: Connects to inducer housing or vent

Prevents operation with blocked vent: Critical safety function

Calibrated setpoint: Typically -0.50 to -1.50 in. W.C. (-124 to -373 Pa)

11. Inducer Motor (Induced Draft Furnaces):

The inducer motor establishes draft before and during burner operation.

Timing: Starts before ignition, proves pressure switch closure

Motor type: PSC or ECM

Power: 1/25 to 1/10 HP typical

Shaft seal: Prevents flue gas leakage

Condensate protection: Sealed against corrosive environment

Duct System Components:

1. Supply Plenum:

Connects directly to furnace outlet

Distributes heated air to supply branches

Houses high limit switch

Must be sealed airtight

2. Return Air System:

Returns air from building to furnace

Sizing critical for proper airflow

Filter location typically in return

Multiple returns may be needed in larger homes

3. Supply Registers and Return Grilles:

Control air distribution to rooms

Adjustable for balancing

- Size affects noise and comfort
- Location affects comfort and efficiency

4. Ductwork:

- Sheet metal, flex duct, or duct board
- Sizing based on CFM requirements
- Insulation reduces heat loss
- Sealing prevents air leakage (significant energy loss)

Airflow Principles

Proper airflow is essential for furnace efficiency, comfort, and longevity. Understanding airflow principles allows proper system design and troubleshooting.

Airflow Requirements:

Residential furnaces typically require:

- **Heating mode:** 400-600 CFM per 100,000 BTU/h input
- **Condensing furnaces:** Often toward lower end (400-450 CFM)
- **Non-condensing furnaces:** Often toward higher end (500-600 CFM)
- **With air conditioning:** May need 450-500 CFM per ton of cooling

Factors Affecting Airflow:

1. Static Pressure:

Static pressure is the resistance to airflow through the duct system.

- **External static pressure:** Total resistance from return through supply
- **Measured in inches W.C. (or Pa)**
- **Typical residential:** 0.5 to 0.8 in. W.C. (124 to 199 Pa)
- **Maximum depends on blower capacity:** Typically 0.8 to 1.0 in. W.C. (199 to 249 Pa)

Components of Static Pressure:

Filter: 0.1 to 0.5 in. W.C. (25 to 124 Pa) when clean

Supply ductwork: Varies with length, size, fittings

Return ductwork: Generally lower than supply

Registers and grilles: Each adds resistance

Coils (if A/C present): 0.15 to 0.30 in. W.C. (37 to 75 Pa)

2. Temperature Rise:

Temperature rise is the difference between supply and return air temperature.

Calculation:

Temperature Rise = Supply Air Temperature - Return Air Temperature

Acceptable Range:

Listed on furnace data plate

Typically 40-70°F (22-39°C) for standard furnaces

Narrower range for high-efficiency: 35-65°F (19-36°C)

Significance:

Too high: Insufficient airflow (high limit may trip)

Too low: Excess airflow (reduced comfort, condensing may not condense)

Within range: Proper operation

Checking Temperature Rise:

Measure return air temperature (in return duct near furnace)

Measure supply air temperature (in supply plenum, 2-3 feet / 0.6-0.9 m from furnace)

Calculate difference

Compare to data plate acceptable range

Adjust blower speed if needed and permitted

3. Duct Sizing:

Proper duct sizing ensures adequate airflow with acceptable static pressure and noise levels.

Sizing Methods:

- **Velocity method:** Limits air velocity to acceptable levels (typically 600-900 FPM / 3-4.6 m/s in mains, 400-600 FPM / 2-3 m/s in branches)
- **Equal friction method:** Maintains constant friction rate throughout system
- **Static regain method:** Used in complex commercial systems

Common Sizing Errors:

- Undersized returns (most common residential issue)
- Oversized supply mains (reduces velocity, increases noise)
- Flex duct runs too long or with tight bends
- Insufficient return air paths between rooms

4. Air Balance:

Balanced systems deliver proper airflow to each room and return adequate air to the furnace.

Balancing Process:

- Measure airflow at each supply register
- Compare to design requirements
- Adjust dampers to achieve balance
- Verify total return airflow adequate
- Check temperature rise remains in range
- Document final settings

Heat Exchanger Types

Heat exchangers have evolved significantly, improving efficiency and reliability while reducing size and weight.

Tubular Heat Exchangers (Non-Condensing):

Traditional heat exchanger design in standard efficiency furnaces (80% AFUE).

Construction:

- Steel tubes (typically 16-18 gauge aluminized steel)
- Tubes arranged vertically or slant-mounted
- Burners fire upward into tubes
- Hot gases travel through tubes, heating surrounding air

Characteristics:

- **Flue gas temperature:** 300-500°F (149-260°C)
- **Heat transfer:** Primarily convective
- **Durability:** 15-25 year life expectancy typical
- **Maintenance:** Relatively simple to inspect
- **Failure mode:** Cracks develop from thermal cycling and corrosion

Serpentine Heat Exchangers (Non-Condensing):

More compact design allowing shorter furnace height.

Construction:

- Continuous formed steel path (clam-shell design)
- Gas travels through serpentine path
- Larger heat transfer surface area
- More compact than tubular

Characteristics:

- **Efficiency:** Similar to tubular (80% AFUE)
- **Advantages:** Shorter cabinet, easier installation in low basements

Disadvantages: More difficult to inspect internally

Common in: Mid-efficiency furnaces from 1980s-2000s

Primary/Secondary Heat Exchangers (Condensing):

High-efficiency condensing furnaces use two-stage heat exchange.

Primary Heat Exchanger:

Similar to non-condensing furnaces

Extracts sensible heat from combustion gases

Typically stainless steel or aluminized steel

Temperature drops from ~3000°F to ~300°F (1649°C to 149°C)

Secondary Heat Exchanger:

Extracts latent heat by condensing water vapor

Must resist corrosion from acidic condensate

Materials: Stainless steel (AL29-4C), ceramic-coated steel

Temperature drops from ~300°F to ~100-140°F (149°C to 38-60°C)

Design Features:

Multiple small tubes or cells: Maximize surface area

Turbulators: Create turbulence for better heat transfer

Condensate collection: Directs water to drain

Insulated cabinet: Reduces heat loss, lowers surface temperature

Advantages:

90-98% AFUE efficiency

Lower operating costs

Reduced greenhouse gas emissions

Smaller vent pipe (PVC)

Challenges:

More complex, higher initial cost

Requires condensate drainage

More sensitive to poor combustion or airflow

Shorter life expectancy than traditional (15-20 years)

Inspection Considerations by Type:

Tubular Heat Exchangers:

Visible cracks often detectable with flashlight

Mirror and camera inspection through burner ports

Pressure testing possible

Rust and scale indicate moisture problems

Serpentine Heat Exchangers:

External inspection limited

Camera inspection through burner opening

Pressure or combustion analysis may be needed

Look for signs of overheating (distortion, discoloration)

Condensing Heat Exchangers:

Visual inspection of primary section

Secondary section inspection difficult (very compact)

Combustion analysis critical for detecting problems

Condensate condition indicates heat exchanger health (rusty = deterioration)

Condensing vs. Non-Condensing

Understanding the differences between condensing and non-condensing furnaces is essential for proper application, installation, and service.

Non-Condensing Furnaces (80-83% AFUE):

Operation:

Flue gas temperature above dew point (~135°F / 57°C)

Water vapor remains in gaseous state

Exhausts through Type B vent or masonry chimney

Natural draft or induced draft operation

Characteristics:

Lower initial cost: Simpler design and components

Simpler installation: No condensate drain required

Traditional venting: Uses proven technology

Higher operating cost: More fuel consumed for same heat output

Longer proven life: Many units operate 25-30 years

Applications:

Replacement in existing installations with masonry chimneys

Budget-constrained installations

Where condensate drainage problematic

Preference for simplicity and longevity

Non-Condensing Installation Considerations:

Draft hood or induced draft venting

Proper vent sizing per CSA B149.1 tables

Common venting often possible

Combustion air from building or outdoors

Condensing Furnaces (90-98% AFUE):

Operation:

- Cools flue gases below dew point
- Extracts latent heat from water vapor condensation
- Produces acidic condensate requiring drainage
- Forced or induced draft with sealed combustion
- PVC or stainless steel venting

Characteristics:

- **Higher efficiency:** 10-15% fuel savings vs. non-condensing
- **Lower flue gas temperature:** 100-140°F (38-60°C)
- **Complex heat exchanger:** Primary and secondary sections
- **Requires condensate management:** Drain, trap, possibly neutralization
- **Higher initial cost:** More complex design and installation
- **Shorter life expectancy:** Typically 15-20 years (vs. 20-30 for non-condensing)

Applications:

- New construction (code requirements often mandate high efficiency)
- Energy-conscious consumers
- Situations with high heating costs
- Where utility rebates offset higher initial cost
- Installations without existing chimneys

Condensing Furnace Installation Requirements:

- **Venting:**
    - PVC Schedule 40 or manufacturer-specified material

Proper slope toward appliance (1/4 inch per foot / 6 mm per metre)

Support every 4 feet (1.2 m) horizontally

Sealed joints to contain positive pressure

Termination per manufacturer specifications

Condensate Drain:

Trap required (typically 3-6 inches / 75-150 mm deep)

Drain line minimum 3/4 inch (19 mm)

Slope minimum 2% toward drain

Indirect termination with air gap

Protection from freezing in cold spaces

Combustion Air:

Sealed combustion from outdoors typical

Two-pipe system: dedicated intake and exhaust

Intake pipe sized per manufacturer specifications

Screen at intake to prevent debris entry

Clearances between intake and exhaust

Electrical:

115V power supply

Condensate pump if gravity drain unavailable

GFCI protection may be required

Comparison Table:

Feature	Non-Condensing (80-83%)	Condensing (90-98%)
Efficiency	80-83% AFUE	90-98% AFUE
Vent Temperature	300-500°F (149-260°C)	100-140°F (38-60°C)

Feature	Non-Condensing (80-83%)	Condensing (90-98%)
Venting	Type B / Masonry	PVC / SS
Condensate	None	1-2 gal/hr (4-8 L/hr)
Combustion Air	Building or outdoors	Sealed from outdoors
Initial Cost	Lower	Higher (20-40% more)
Operating Cost	Higher	Lower (10-15% savings)
Complexity	Simpler	More complex
Life Expectancy	20-30 years	15-20 years
Maintenance	Less frequent	More frequent

Decision Factors:

Choose Non-Condensing When:

- Existing chimney available and suitable
- Budget constraints significant
- Condensate drainage difficult or expensive
- Simplicity and longevity prioritized
- Replacement unit in older system

Choose Condensing When:

- Energy savings important
- New construction or major renovation
- No existing chimney
- Utility rebates available
- Long-term ownership expected
- Environmental considerations priority

Efficiency Ratings

Understanding efficiency ratings helps select appropriate equipment and set realistic customer expectations.

AFUE (Annual Fuel Utilization Efficiency):

AFUE measures the percentage of fuel energy converted to useful heat over an entire heating season.

Calculation:

AFUE = (Heat Output / Fuel Input) × 100

Accounts for cycling losses, pilot light consumption (if present), jacket losses

Does not account for duct losses (can be 15-30% in typical installations)

AFUE Categories:

Standard Efficiency:

80-83% AFUE: Non-condensing furnaces

Natural or induced draft

Atmospheric or power burner

Chimney or Type B venting

Mid-Efficiency (Obsolete Category):

85-89% AFUE: Rarely produced anymore

Not quite condensing (marginal condensation)

Problematic in many installations

Most manufacturers discontinued this range

High Efficiency:

90-95% AFUE: Condensing furnaces, economical models

Full condensing operation

PVC venting

Sealed combustion

Premium Efficiency:

96-98% AFUE: Top-tier condensing furnaces

Two-stage or modulating burners

Variable-speed blowers

Advanced controls

Optimal comfort and efficiency

Factors Affecting Real-World Efficiency:

Even high-AFUE furnaces may not achieve rated efficiency due to:

Duct Losses:

Leakage at connections (10-30% loss typical)

Uninsulated ducts in unconditioned spaces

Poor duct design or installation

Oversizing:

Short cycling reduces efficiency

Less time at steady-state operation

Increased standby losses

Inadequate Maintenance:

Dirty filters reduce airflow

Dirty burners reduce combustion efficiency

Heat exchanger deposits reduce heat transfer

Poor Installation:

Incorrect gas pressure or manifold pressure

Improper airflow (temperature rise out of range)

Combustion air restrictions

Thermostat Programming:

Large night setback/morning pickup increases fuel use

Frequent temperature changes prevent steady-state

Energy Star Certification:

In Canada, Energy Star requirements for furnaces:

Minimum 95% AFUE in most regions

Variable-speed blower motor (ECM)

Two-stage or modulating gas valve

Third-party testing and certification

EnerGuide Rating:

Canadian energy labeling system:

Shows AFUE percentage

Estimates annual energy cost

Allows comparison between models

Required on all furnaces sold in Canada

Heat Output Ratings:

Beyond efficiency, output capacity is critical:

Input Rating:

BTU/h or kW fuel consumed

Listed on data plate

Used for gas line sizing and venting

Output Rating:

BTU/h or kW heat delivered to space

Output = Input × Efficiency

Used for heat loss calculations

Example: 100,000 BTU/h input × 0.95 AFUE = 95,000 BTU/h output

Deration for Altitude:

At higher altitudes, burners must be derated:

4% reduction per 1000 feet (305 m) above sea level

Orifices may need to be changed

Follow manufacturer deration tables

Affects both input and output ratings

Multi-Stage and Modulating Systems

Advanced furnaces use staged or modulating burners to improve comfort and efficiency.

Single-Stage Operation:

Traditional furnaces operate at full capacity or off.

Characteristics:

On/off (100% or 0%) operation

Simple controls

Lower equipment cost

More temperature swing

Higher cycling losses

Applications:

Smaller homes with low heat loss

Budget installations

Replacement of existing single-stage

Adequate for many applications

Two-Stage Operation:

Two-stage furnaces operate at low fire (typically 65-70%) or high fire (100%).

How It Works:

- Thermostat calls for heat
- Furnace starts at low fire
- If temperature target not met within set time (typically 10 minutes)
- Switches to high fire for additional capacity
- Returns to low fire when approaching setpoint

Advantages:

- **Longer run cycles:** Reduces cycling losses
- **Better comfort:** Smaller temperature swings
- **Lower sound levels:** Quieter operation at low fire
- **Improved efficiency:** Less short-cycling
- **Better air circulation:** More even temperatures

Components:

- **Two-stage gas valve:** Low fire and high fire solenoids
- **Two-stage thermostat:** Communicates staging to furnace
- **Control logic:** Manages stage transitions
- **Dual-speed or variable-speed blower:** Matches airflow to firing rate

Typical Staging Sequence:

- 1st stage fires: 65% capacity, 65% airflow
- 2nd stage fires: 100% capacity, 100% airflow

Applications:

- Homes with moderate to high heat loss
- Improved comfort priority
- Open floor plans
- Combined with two-stage cooling

Modulating Furnaces:

Modulating furnaces continuously adjust capacity from minimum (typically 40-50%) to maximum (100%).

Operation:

- Continuously varies gas flow and airflow
- Maintains very tight temperature control
- Runs longer cycles at lower capacities
- Optimal comfort and efficiency

Control Methods:

- **Temperature-based:** Adjusts capacity based on temperature error
- **Outdoor reset:** Adjusts capacity based on outdoor temperature
- **Communicating systems:** Thermostat and furnace exchange detailed information

Advantages:

- **Maximum comfort:** Minimal temperature variation (±0.5°F / 0.3°C)
- **Highest efficiency:** Extended run times at optimal firing rates
- **Quietest operation:** Usually runs at low capacity
- **Even temperatures:** Eliminates hot and cold spots
- **Better humidity control:** Continuous air circulation

Disadvantages:

- **Higher cost:** Significantly more expensive than single-stage

Complex controls: More difficult to troubleshoot

Proprietary systems: Limited service options

May require specific thermostats: Communicating systems especially

Components:

Modulating gas valve: Continuously variable from 40-100%

Variable-speed blower: ECM motor with wide speed range

Advanced control board: Sophisticated algorithms

Multiple sensors: Supply and return temperature, pressure, outdoor

Communicating thermostat: Required for full functionality

Applications:

Premium installations

Large homes with zoning

High comfort expectations

Geothermal or solar integration

Optimal efficiency priority

Comparison:

Feature	Single-Stage	Two-Stage	Modulating
Capacity Control	On/Off	65% / 100%	40-100% continuous
Temperature Swing	±3-4°F (1.7-2.2°C)	±1-2°F (0.6-1.1°C)	±0.5°F (0.3°C)
Run Cycles	Short, frequent	Longer, less frequent	Very long, continuous
Efficiency	Good	Better	Best
Comfort	Acceptable	Good	Excellent
Cost	Lowest	Moderate	Highest
Complexity	Simple	Moderate	Complex

13.2 Furnace Installation

Proper furnace installation according to CSA B149.1 ensures safety, efficiency, and reliable operation.

Location Requirements

CSA B149.1 specifies location requirements to prevent hazards and ensure proper operation.

General Requirements:

1. Accessibility:

- Service access required on at least one side
- Minimum 24 inches (600 mm) clearance for service
- Controls and data plate accessible
- Filter accessible for replacement
- Space for future removal and replacement

2. Ventilation:

- Mechanical room must have adequate ventilation
- Combustion air provisions per CSA B149.1
- Relief of heat buildup from equipment

3. Protection from Damage:

- Not subject to mechanical damage
- Protected from vehicle impact if in garage
- Elevated if subject to flooding
- Secure mounting prevents tipping

4. Proximity to Gas Meter:

- Reasonable piping length
- Avoid unnecessary complexity
- Consider future service access

Prohibited Locations:

CSA B149.1 prohibits installation in certain locations:

1. Sleeping Rooms (Bedrooms):

Not permitted except direct vent sealed combustion

Includes rooms used for sleeping even if not designated bedroom

2. Bathrooms:

Not permitted in most cases

Moisture and lack of combustion air

3. Storage of Flammable Materials:

Separate from flammables by firewall

Adequate clearance from stored materials

Consider ignition source hazards

4. Confined Spaces Without Adequate Combustion Air:

Must provide combustion air openings per code

Calculate volume and openings based on input ratings

Specific Location Considerations:

Basement Installations:

Advantages:

Central location for duct distribution

Protected from weather

Easy service access

Away from living spaces (noise)

Considerations:

Adequate ceiling height for service

Floor drain for condensate desirable

Combustion air provisions

Floodproofing if in flood-prone area

Protection from storage and household activities

Utility Room / Mechanical Room:

Advantages:

Dedicated space

Controlled access

Good for combustion air

Other mechanical equipment nearby

Considerations:

Size room for all equipment and service access

Sound transmission to adjacent spaces

Adequate ventilation

Door for security and sound control

Garage Installations:

Special Requirements:

Elevation: Burner/ignition source minimum 18 inches (450 mm) above floor

Protection: Bollards or barriers prevent vehicle impact

Clearances: Per manufacturer and code

Venting: Special attention to combustion products

Reasoning:

- Gasoline vapors heavier than air
- Accumulate at floor level
- Ignition sources must be elevated above vapor layer

Attic Installations:

Allowed but challenging:

- Must have permanent access (stairs or walkway)
- Platform for service
- Adequate clearances for combustion air and service
- Proper drainage for condensate
- Insulation and air sealing considerations
- Typically commercial applications

Alcove / Closet Installations:

Possible with proper provisions:

- Louvered doors or combustion air openings
- Adequate volume or air openings per calculations
- Access for service and filter replacement
- Return air must not come from closet unless provisions made
- Adequate clearances to walls and shelves

Outdoor Installations:

Requires specialized equipment:

- Outdoor-rated furnace cabinet and controls
- Weather protection
- Freeze protection for water lines (if coil present)

- Protected from wind and rain at intakes/exhausts
- Foundation to prevent settling
- Less common in cold Canadian climates

Clearances Per Code

Clearances protect combustible materials from heat and allow safe servicing.

Clearances to Combustibles:

Manufacturer's instructions specify minimum clearances, typically:

Front (Service Side):

- **Minimum:** 24 inches (600 mm) or per manufacturer
- **Recommended:** 36 inches (900 mm) for better service access
- Space for pulling blower and accessing controls

Sides:

- **Minimum:** 0-6 inches (0-150 mm) depending on model
- High-efficiency models often allow zero clearance
- Must allow air circulation and panel removal

Rear:

- **Minimum:** 0-2 inches (0-50 mm) typical
- Must accommodate vent and gas piping connections
- Some models require several inches for combustion air

Top:

- **Minimum:** 0-12 inches (0-300 mm) typical
- Must accommodate supply plenum
- Adequate clearance for vent or flue pipe connections

Vent Connector Clearances:

Single-Wall Vent Connector:

- **Minimum 6 inches (150 mm)** to combustibles
- 9 inches (230 mm) preferred in some jurisdictions
- Cannot pass through combustible walls or ceilings without protection

Type B Vent Connector:

- **1 inch (25 mm) ** to combustibles typically
- Must use listed Type B components
- Can pass through combustibles with proper thimbles

Category III/IV Venting:

- Depends on material and temperature
- PVC may contact combustibles
- Follow manufacturer specifications exactly

Plenum Clearances:

Supply Plenum:

- Must maintain clearances unless insulated
- Typically 1-6 inches (25-150 mm) to combustibles depending on temperature
- Higher temperatures require greater clearances

Return Plenum:

- Minimal clearances required (cool air)
- Must be sealed to prevent air leakage

Floor Clearances:

- Furnaces typically installed on non-combustible base

Concrete floor: no clearance required

Wood floor: typically requires 18-gauge sheet metal or equivalent

Some models designed for direct installation on combustible flooring

Clearance Reduction Methods:

When space limited, clearances may be reduced using:

1. Manufactured Shields:

Listed specifically for clearance reduction

Follow instructions exactly

Typically reduces clearance by 50-66%

2. Sheet Metal Shields:

24-gauge (or heavier) sheet metal

1 inch (25 mm) air space behind shield

Reduces clearance by 66% typically

3. Insulation Board:

Non-combustible board (millboard, cement board)

Often combined with sheet metal

Verify acceptability with authority having jurisdiction

Important Notes:

Never reduce clearances below manufacturer minimums without approval

Clearance reduction must not obstruct combustion air

Document any clearance reduction methods

Some jurisdictions prohibit clearance reduction

Return Air Considerations

Adequate return air is critical for furnace operation, efficiency, and safety.

Return Air Requirements:

Sizing Guidelines:

- Return air must accommodate full system CFM
- Often uses lower velocity than supply (lower pressure drop)
- Typical residential: 500-700 FPM (2.5-3.6 m/s) face velocity at return grilles

Calculation:

- Required CFM based on furnace capacity (typically 400-600 CFM per 100,000 BTU/h)
- Determine acceptable velocity
- Calculate required free area: **Area (sq ft) = CFM / Velocity (FPM)**
- Add 25-50% for grille restriction

Multiple Returns:

Benefits:

- Better air distribution
- Reduced pressure drop
- More even temperatures throughout building
- Easier to achieve adequate free area

Locations:

- Central return in main living area (minimum)
- Additional returns in bedrooms ideal
- Consider returns on each floor of multi-level home

Return Air Pathways:

Closed doors can block return air, creating pressure imbalances.

Solutions:

- Dedicated return in each bedroom
- **Transfer grilles:** Through walls between rooms and hallway
- **Door undercut:** 1-2 inches (25-50 mm) clearance under door
- **Jump ducts:** Over-door duct connection between room and return area

Prohibited Return Air Sources:

CSA B149.1 prohibits return air from:

- **Mechanical room containing atmospherically vented appliance:**
  - Creates negative pressure affecting draft
  - May cause backdrafting
- **Garage:**
  - Carbon monoxide from vehicles
  - Fuel vapors
  - Chemical storage
- **Within 10 feet (3 m) of draft hood or draft control device**
- **Bathroom** (typically)
- **Kitchen** (typically, unless special provisions)
- **Crawl space or attic** (without proper sealing)

Combustion Air vs. Return Air:

Critical Distinction:

- **Return air:** For building heating/cooling, circulates through living space
- **Combustion air:** For burner operation, separate requirement

Sealed Combustion Systems:

- Combustion air completely separate from building air
- Return air comes from building only
- No interaction between systems

Open Combustion Systems:

- Combustion air may come from same space as return air
- Must calculate both requirements
- Building depressurization concerns

Return Air System Installation:

1. Ducting:

- Sized to carry full CFM with acceptable velocity
- Sealed to prevent air leakage
- Insulated if in unconditioned space
- Supported adequately

2. Filter Location:

- Typically at return air entry to furnace
- Must be easily accessible
- Filter rack or slot provided
- Size marked for homeowner

3. Sealing:

- All return duct joints sealed (mastic or tape)
- Especially critical in unconditioned spaces
- Leaks pull in dusty, humid, or contaminated air

4. Balancing:

Adjust dampers for proper distribution

Verify each return contributing appropriately

Maintain overall system balance

Common Return Air Problems:

Undersized Return:

High static pressure

Reduced airflow

Noisy operation

Increased energy use

Solution: Increase return free area

Too Few Return Locations:

Uneven temperatures

Pressure imbalances

Solution: Add returns or transfer grilles

Return Air Leaks:

Pull in unconditioned air

Moisture and pollutants enter system

Energy waste

Solution: Seal all duct joints

Blocked Returns:

Furniture against grilles

Dirty filters

Solution: Customer education, maintenance

Filter Access

Easy filter access encourages regular replacement, critical for system performance.

Filter Location:

Standard Locations:

- Slot in return duct near furnace
- Filter rack in return air plenum
- Built-in filter rack in furnace cabinet
- Return air grille with filter slot

Accessibility Requirements:

- Homeowner can reach without tools
- Clear path, no obstacles
- Adequate light or add light
- Instructions nearby

Filter Types and Sizing:

Disposable Flat Filters:

- Fiberglass, 1 inch (25 mm) thick
- MERV 1-4 rating
- Low cost, low filtration efficiency
- Monthly replacement typical
- Standard sizes: 16×20, 16×25, 20×20, 20×25 inches

Pleated Filters:

- Polyester or cotton, 1-4 inches (25-100 mm) thick
- MERV 6-12 rating typical

Better filtration, higher cost

3-month replacement typical

Available in most sizes

High-Efficiency Filters:

MERV 13-16

Hospital-grade filtration

Requires lower static pressure or high-capacity blower

May need modification to existing systems

6-12 month replacement

Electronic Air Cleaners:

Separate device in ductwork

MERV 8-12 equivalent

Washable collector cells

Requires 115V power

Periodic cleaning required

Filter Sizing:

Face Velocity:

Recommended 300-500 FPM (1.5-2.5 m/s) for standard filters

Higher efficiency filters may require larger size (lower velocity)

Calculation:

System CFM / Desired Face Velocity = Required Filter Area

Example: 1600 CFM / 400 FPM = 4 sq ft needed

Could use: One 20×24" (3.3 sq ft) - undersized

- Better: Two 16×25" (5.6 sq ft total) - proper size

Installation Details:

Filter Rack:

- Secure and rigid
- Proper seal around edges
- Arrow indicating airflow direction
- Size marked clearly

Filter Orientation:

- Arrow on filter points toward blower (direction of airflow)
- Pleated filters have supporting grid on downstream side
- Filter must fit snugly, no bypass gaps

Access Panel:

- Hinged or removable
- Easy to open without tools (or one screw maximum)
- Large enough to slide filter in and out
- May require lighting

Customer Education:

Topics to Cover:

- **Importance of regular replacement**
  - System efficiency and longevity
  - Indoor air quality
  - Energy costs
- **Replacement frequency**

Monthly for basic filters during heating season

3 months for pleated filters

More often with pets or construction

How to check and replace

Demonstrate during installation

Show proper orientation

Where to buy filters

What size to buy

Write size on filter rack

Provide sizes in installation manual

Explain actual vs. nominal sizing

Warning signs of problems

High limit tripping

Reduced airflow at registers

Increased energy bills

Dust accumulation

Common Filter Problems:

Wrong Size:

Gaps allow bypass

Solution: Measure and order correct size

Backward Installation:

Higher pressure drop

Reduced filter life

Solution: Check arrow direction

No Filter:

Extremely dangerous for equipment

Dirt accumulates on blower and heat exchanger

Solution: Install filter immediately, clean equipment if needed

Extremely Dirty Filter:

High static pressure

Possible heat exchanger cracking (overheating)

Solution: Replace and educate customer

Gas Piping Connections

Gas piping connections to furnace must follow CSA B149.1 requirements.

Connection Methods:

Threaded Connections:

Standard for rigid iron or steel pipe

Use approved pipe thread sealant

Minimum two threads engagement, maximum three threads exposed

Wrench on fitting, not on appliance connection

CSST (Corrugated Stainless Steel Tubing):

Requires listed fittings

Follow manufacturer instructions exactly

Bonding per electrical code requirements

Support per manufacturer specifications

Flexible Connectors:

Listed appliance connectors allowed in most jurisdictions

Maximum length typically 6 feet (1.8 m)

Size for appliance input rating

Must be accessible for inspection

Never concealed in walls or floors

Flare Fittings:

Common for copper or aluminum (propane)

Double flare preferred

Verify compliance with local requirements

Gas Piping Installation:

1. Sizing:

Calculate based on input rating and length

Use CSA B149.1 sizing tables

Account for all appliances on same line

Consider future appliances

2. Support:

Adequate support prevents sagging

Intervals per code (typically every 6 feet / 1.8 m horizontal)

Secure but allow thermal expansion

Protect from physical damage

3. Protection:

In exposed locations: guard against physical damage

Sleeves through walls and floors

Corrosion protection where needed

UV protection for some materials (CSST)

4. Testing:

Pressure test at 1.5 times working pressure (minimum 3 psi / 20 kPa)

Soap bubble test all joints

Document test results

Comply with inspection requirements

Furnace Gas Connection:

1. Manual Shutoff Valve:

Required within 6 feet (1.8 m) of appliance

Accessible location

In same room as appliance

Lever or handle for easy operation

2. Sediment Trap (Drip Leg):

Required on appliance inlet

Minimum 3 inches (75 mm) deep nipple and cap

Tee with cap extending below inlet

Catches debris and condensate

3. Union or Flange:

Allows appliance disconnection for service

Located between shutoff and appliance

Ground joint union typical

Must be accessible

4. Gas Valve Connection:

May be threaded directly to gas valve

Some furnaces have flexible connection to gas valve

Follow manufacturer requirements

Use only approved sealants (never on flare fittings)

Typical Furnace Gas Connection (from meter):

Pipe → Shutoff Valve → Tee (sediment trap down) → Union → Flexible Connector → Furnace Gas Valve

Gas Pressure:

Inlet Pressure:

Natural gas: 4-10 inches W.C. (1.0-2.5 kPa) typical (7 inches / 1.7 kPa standard)

Propane: 11 inches W.C. (2.7 kPa) typical

Verify at furnace inlet with manometer

Must be within manufacturer specifications

Manifold Pressure:

Natural gas: 3.5 inches W.C. (0.87 kPa) typical

Propane: 10 inches W.C. (2.5 kPa) typical

Adjusted at gas valve

Critical for proper burner operation

Check during commissioning

Common Gas Piping Errors:

Undersized piping:

Low gas pressure at appliance

Poor combustion

Nuisance shutdowns

Solution: Upsize piping per tables

No sediment trap:

Code violation

Debris can enter gas valve

Solution: Install proper drip leg

Improper sealant:

Using PTFE tape on flare fittings

Wrong type of pipe dope

Solution: Use appropriate sealant for fitting type

Inaccessible shutoff:

Code violation

Difficult emergency shutoff

Solution: Relocate to accessible location

Leak at connections:

Improper thread engagement

Insufficient sealant

Crossed threads

Solution: Remake connection properly, leak test

Electrical Connections

Furnaces require proper electrical installation for safety and code compliance.

Power Requirements:

115V Single Phase:

- Standard for residential furnaces
- 15A circuit typical
- Dedicated circuit required (no other loads)
- Circuit breaker in panel
- Disconnect switch at furnace

Power Consumption:

Typical amperage:

- **Single-stage, PSC blower:** 8-12 amps
- **Two-stage, PSC blower:** 10-14 amps
- **Modulating, ECM blower:** 6-10 amps (more efficient)

Electrical Installation:

1. Dedicated Circuit:

- 115V, 15A minimum
- No other appliances on circuit
- Home run to main panel
- Labeled in panel

2. Wiring Method:

- NMD90 (Romex) in residential typical
- AC90 (BX) or EMT conduit in commercial
- Sized for load plus 25% (typically 14 AWG minimum)
- Proper cable support and protection

3. Disconnect Switch:

- Required within sight of furnace

Lockable-off type

Rating equal to or greater than furnace draw

Red faceplate typical

Labeled "FURNACE"

4. Furnace Connection:

Junction box on furnace or nearby

Strain relief at entry

Connections per wiring diagram

Proper grounding

5. Grounding:

Equipment grounding required

Green or bare ground wire

Bonded to furnace cabinet

Continuous to panel ground

Control Wiring (Thermostat):

Low Voltage (24V):

Class 2 circuit per CEC

18 AWG minimum (22 AWG acceptable short runs)

May be run without conduit

Not required to be in separate raceway from power

Typical Connections:

R: 24V power from transformer

C: Common (return to transformer)

W: Heat call

G: Fan (blower) call

Y: Cooling call (if A/C present)

Advanced Controls:

Communicating systems use 2-4 wires

Proprietary communication protocols

Follow manufacturer wiring diagrams exactly

Thermostat Wiring Best Practices:

Use proper size (18 AWG preferred)

Label wires at both ends

Neat routing, secured adequately

Test before final connections

Document wiring (photo)

CSST Bonding Requirements:

If CSST used for gas piping:

Must be electrically bonded per CEC

Bonding conductor from CSST to service equipment ground

Size per code requirements (typically 6 AWG minimum)

Clamp on CSST and electrical ground

Critical for lightning protection

Safety Considerations:

Lockout/Tagout:

Turn off power at disconnect before service

Lock switch in off position

Tag switch indicating work in progress

Verify zero energy before touching

Testing:

Verify proper voltage at disconnect (115V ±10%)

Check voltage at furnace terminals

Measure current draw during operation

Compare to nameplate ratings

Common Electrical Problems:

No power to furnace:

Tripped breaker

Blown fuse

Disconnect switch off

Solution: Restore power, investigate cause

Low voltage:

Undersized wire

Poor connections

Voltage drop under load

Solution: Check connections, verify wire size

Transformer failure:

Shorted thermostat wiring

Control board failure

Lightning damage

Solution: Identify and correct short, replace transformer

Ground faults:

Damaged wire insulation

Water intrusion

Loose connections

Solution: Locate and repair fault

Combustion Air Provisions

Adequate combustion air is critical for safe operation and code compliance.

Combustion Air Requirements:

All fuel-burning appliances require air for:

Combustion: Oxygen for burning fuel

Draft control (atmospheric appliances): Dilution air at draft hood

Ventilation: Cool equipment room

Calculating Combustion Air:

CSA B149.1 Methods:

Method 1 - Indoor Air (Known Infiltration):

Building must have adequate infiltration

50 cubic feet per 1000 BTU/h total input (all appliances)

Example: 100,000 BTU/h furnace needs 5,000 cu ft space minimum

Rarely used in modern construction (too tight)

Method 2 - Indoor Air (Unconfined Space):

Appliances in large, open areas

50 cubic feet per 1000 BTU/h total input

- Room must not be confined
- Adequate infiltration assumed

Method 3 - Indoor Air (Confined Space with Openings):

When room volume insufficient:

Two Openings Required:

- One within 12 inches (300 mm) of ceiling
- One within 12 inches (300 mm) of floor
- Each opening minimum **1 square inch per 1000 BTU/h** (220 mm²/kW)
- Openings communicate with unconfined space or outdoors
- May use ducts (increase size to 1 sq in per 2000 BTU/h if horizontal duct)

Example:

- 80,000 BTU/h furnace + 40,000 BTU/h water heater = 120,000 BTU/h total
- Each opening: 120 square inches minimum (120 sq in / 144 = 0.83 sq ft)
- Could use: Two 6-inch diameter ducts (28 sq in each) - undersized
- Proper: Two 8-inch diameter ducts (50 sq in each) - acceptable
- Better: Two 10-inch diameter ducts (78 sq in each) - good margin

Method 4 - Outdoor Air (Direct):

All Combustion Air from Outdoors:

- Two permanent openings directly to outdoors
- Openings start within 12 inches (300 mm) of floor and ceiling
- Minimum size if both vertical or both horizontal:
  - **1 square inch per 4000 BTU/h** (55 mm²/kW)
- Minimum size if one horizontal and one vertical:

Vertical: 1 sq in per 4000 BTU/h

Horizontal: 1 sq in per 2000 BTU/h

Method 5 - Outdoor Air (Ductwork):

Similar to Method 4 but using ducts instead of direct openings:

Two ducts to outdoors

Terminate outside with screens or louvers

Size as Method 4

Support ducts adequately

Protect terminations from weather

Method 6 - Mechanical Combustion Air:

Fan provides combustion air

Requires interlock with appliance operation

Engineered system

Less common in residential

Sealed Combustion Systems:

High-efficiency furnaces typically use sealed combustion:

No combustion air from building

Direct-piped intake from outdoors

Intake pipe sized per manufacturer specifications

Two-pipe system: separate intake and exhaust

Concentric system: intake surrounds exhaust

Intake Piping:

Size per manufacturer (typically same or one size larger than exhaust)

Slope toward outdoors (drainage)

Screen at termination (prevent debris entry)

Clearances from exhaust and building openings

Combustion Air Installation:

1. Louvers and Grilles:

Free area often 50-75% of opening size (account for restriction)

Specify actual required free area

Weather-resistant materials

Bird screen if outdoors

2. Duct Installation:

Rigid duct preferred (sheet metal)

Flexible duct acceptable for short runs

Support every 4 feet (1.2 m)

Seal all joints

Insulate if in very cold spaces

3. Termination Protection:

Screen or louver prevents debris entry

Protect from wind-driven rain/snow

Location avoids blockage (snow, landscaping)

Adequate height above grade

4. Makeup Air:

Large exhaust fans may require makeup air

Calculate total exhaust capacity

If exceeds 10 CFM per 100 sq ft, provide makeup air

Mechanical or passive makeup air systems

Common Combustion Air Problems:

Inadequate openings:

Undersized per calculation

Blocked by storage, furniture

Grilles restrict more than accounted for

Solution: Enlarge openings, clear blockages

No makeup air for exhaust:

Building depressurization

Backdrafting of atmospherically vented appliances

Solution: Provide makeup air, reduce exhaust, or convert to sealed combustion

Sealed combustion intake blocked:

Snow, ice, leaves, bird nest

Pressure switch won't close

Solution: Clear blockage, prevent recurrence

Intake too close to exhaust:

Recirculation of combustion products

Reduced oxygen, increased CO

Solution: Relocate intake or exhaust per clearances

Venting Installation

Venting installation covered in detail in Chapter 12. Key points for furnace installations:

Non-Condensing Furnaces:

Natural Draft:

Type B vent or listed chimney liner

Size per CSA B149.1 tables

Draft hood provided on furnace

Common venting possible with water heater

Minimum height requirements

Proper slope and support

Induced Draft:

Type B in listed systems or Category III materials

Size per manufacturer specifications

Pressure switch proves adequate draft

More flexible routing than natural draft

All joints must be sealed for positive pressure

Condensing Furnaces:

Category IV Venting:

PVC Schedule 40 most common

Size per manufacturer tables

Slope toward appliance (1/4 inch per foot / 6 mm per metre)

Support every 4 feet (1.2 m) horizontally

Sealed joints (PVC primer and cement)

Termination clearances critical

Common Venting Errors:

Improper slope:

Condensate pools in vent

Restriction or blockage

Solution: Re-pitch vent properly

Inadequate support:

Sagging creates low spots

Accelerates problems

Solution: Add supports every 4 feet (1.2 m)

Wrong materials:

Using ABS instead of PVC

Single-wall on positive pressure

Solution: Replace with correct materials

Clearance violations:

Intake too close to exhaust

Termination near windows, doors

Solution: Relocate to meet clearances

13.3 Furnace Controls and Sequences

Understanding control sequences is essential for troubleshooting and ensuring safe operation.

Thermostat Operation

The thermostat is the primary user interface and system controller.

Basic Thermostat Functions:

Temperature Sensing:

Measures room temperature

Compares to setpoint

Initiates heating or cooling call

System Control:

Sends signals to furnace control board

Manages staging (if multi-stage system)

Controls fan operation

User Interface:

Temperature adjustment

System mode selection (Heat, Cool, Auto, Off)

Fan mode (Auto, On)

Programming (if programmable)

Thermostat Types:

Mechanical Thermostats:

Bimetal coil or liquid-filled bellows senses temperature

Mercury switch or mechanical switch

Simple, reliable

Less accurate (±2-3°F / 1-1.5°C)

No longer permitted (mercury hazard)

Electronic Non-Programmable:

Thermistor or other electronic sensor

Solid-state switching

More accurate (±1°F / 0.5°C)

Digital display

Inexpensive

Programmable Thermostats:

Multiple daily temperature settings

7-day or 5+2 programming typical

Energy savings through setback

More complex for users

Smart/WiFi Thermostats:

Internet connectivity

Remote access via smartphone

Learning algorithms adjust to patterns

Energy usage reporting

Integration with home automation

Higher cost, more features

Communicating Thermostats:

Proprietary communication with compatible equipment

Advanced staging and modulation control

Detailed system information

Enhanced comfort features

Required for full functionality of some furnaces

Thermostat Wiring:

Standard Wiring (Non-Communicating):

R (Red): 24V hot from transformer

C (Common/Blue): 24V return to transformer

W (White): Heat call

Y (Yellow): Cool call (if A/C)

G (Green): Fan call

O/B (Orange/Blue): Changeover for heat pumps

Additional Wires:

W2: Second stage heat

Y2: Second stage cool

X/AUX: Emergency heat or auxiliary

L: Service indicator light

Communicating Systems:

Typically 2-4 wires only

Proprietary protocols (cannot mix brands)

Carry power and communication

Thermostat Placement:

Proper Location:

Interior wall, away from exterior walls

4-5 feet (1.2-1.5 m) above floor

Away from heat sources (sunlight, appliances, lamps)

Away from drafts (doors, windows, supply registers)

In representative location (not isolated rooms)

Away from corners or dead air spaces

Poor Locations:

Above supply registers

- Near exterior doors
- In direct sunlight
- Near heat-producing devices
- In rooms that are closed off

Thermostat Installation:

- **Mount securely** to wall (studs or drywall anchors)
- **Level** the base (important for mercury and some electronic types)
- **Wire carefully** per diagram, secure connections
- **Configure** system type and settings
- **Test** operation (heating, cooling, fan)
- **Program** if applicable
- **Instruct user** on operation

Anticipation:

Some thermostats use anticipation to reduce temperature overshoot.

Heat Anticipator (Mechanical):

- Small adjustable resistor in thermostat
- Heats bimetal element slightly during burner operation
- Causes thermostat to shut off before reaching setpoint
- Settings based on current draw of heat circuit
- Requires adjustment for each installation

Electronic Anticipation:

- Programmed into digital thermostats
- Learns system characteristics

Adapts to prevent overshoot

No user adjustment required

Blower Control Sequences

Blower operation must be coordinated with burner operation for comfort and safety.

Heating Mode Blower Sequences:

Fan-On Delay:

After burner ignites, blower delay prevents cold air discharge.

Typical sequence:

Thermostat calls for heat

Inducer starts (if present), ignition sequence

Burner lights

Delay 30-90 seconds (allow heat exchanger to warm)

Blower starts at programmed speed

System operates until thermostat satisfied

Fan-Off Delay:

After burner shuts off, blower continues to extract remaining heat.

Typical sequence:

Thermostat satisfied, burner shuts off

Blower continues running

Delay 90-180 seconds (extract residual heat)

Blower stops

Inducer stops (if separate post-purge timer)

Time Delays:

- **Fan-on delay:** Typically 30-90 seconds
    - Longer in colder climates (prevent initial cold air)
    - Adjustable on some controls
- **Fan-off delay:** Typically 90-180 seconds
    - Extracts maximum heat
    - Reduces cycling
    - Some systems use temperature-based shutdown (air temp drops to setpoint)

Blower Speed Control:

PSC Motors:

- Discrete speeds (low, med-low, med-high, high)
- Taps on motor winding
- Control board energizes selected tap
- Typical heating: Medium or Medium-High speed
- Typical cooling: High speed (more CFM needed)

ECM/Variable-Speed Motors:

- Continuous speed adjustment
- Control board sends signal (PWM or 0-10V)
- Motor adjusts to maintain programmed CFM or torque
- Compensates for filter loading and duct restrictions
- More efficient, better comfort

Multi-Stage Blower Control:

Two-Stage Furnaces:

- Low fire: Lower blower speed (65-70% CFM)

High fire: Higher blower speed (100% CFM)

Matches airflow to burner capacity

Improves comfort, efficiency, and quietness

Modulating Furnaces:

Blower speed continuously adjusted with burner capacity

Maintains proper temperature rise

Can run very low speeds for extended periods

Complex algorithms balance comfort, efficiency, and noise

Continuous Fan Mode:

When thermostat set to "Fan On":

Blower runs continuously

Low speed typically used

Improves air circulation and filtration

Increases electrical cost

Some systems use very low ECM speed (50-200 CFM) for air circulation

Fan Proving:

Some commercial systems prove blower operation:

Airflow switch or current sensor

Must prove blower running before allowing ignition

Safety feature prevents firing without airflow

Limit Switch Operation

Limit switches protect against overheating and are critical safety devices.

Types of Limit Switches:

Fixed Limit:

- Opens at specific temperature
- Common setpoint: 160-200°F (71-93°C)
- Automatic reset when cools
- Simple, reliable

Adjustable Limit:

- Setpoint can be adjusted
- Commercial applications
- Allows customization for specific applications

Combination Fan/Limit Control:

- Controls both fan operation and high limit
- Fan-on setpoint (typically 90-120°F / 32-49°C)
- Fan-off setpoint (typically 80-110°F / 27-43°C)
- Limit setpoint (typically 160-200°F / 71-93°C)
- Less common in modern furnaces

Limit Switch Operation:

Normal Operation:

- Burner fires, heat exchanger heats
- Temperature rises
- Blower starts, circulates air
- Heat exchanger temperature stabilizes below limit setpoint
- Limit switch remains closed

Limit Trips (Overheat):

Heat exchanger temperature exceeds setpoint

Limit switch opens

Breaks circuit to gas valve

Burner shuts off immediately

Blower continues (extract heat)

Temperature decreases

Limit switch closes (auto reset)

Control may restart or require manual reset depending on design

Causes of Limit Tripping:

1. Restricted Airflow:

Dirty filter (most common)

Blocked return or supply ducts

Closed supply registers

Undersized ductwork

Blower failure

2. Blower Problems:

Motor failure

Capacitor failure (PSC motors)

Blower wheel dirty or loose

Belt broken or slipping (belt-drive blowers)

Wrong speed tap selected

3. Overfiring:

Gas pressure too high

Wrong orifices installed

Gas valve problem

4. Duct Problems:

Disconnected supply duct

Severe duct leakage

Crushed or blocked ducts

5. Control Problems:

Blower delay set too long

Blower speed too low

Fan-on delay stuck

Control board failure

Safety Considerations:

Never bypass limit switch: Critical safety device

Never increase setpoint above design: May allow heat exchanger damage

Multiple trips require investigation: Identify and correct root cause

Manual reset limits: Require technician intervention (serious problem)

Limit Switch Location:

Mounted in supply plenum near heat exchanger outlet

Sensing element in airstream

Must be upstream of any duct splits

Secured to prevent vibration or movement

Must be accessible for testing

Testing Limit Switch:

Visual Inspection:

- Check mounting security
- Look for signs of overheating (discoloration)
- Verify sensing element properly positioned

Electrical Test:

- Check continuity when cool (should be closed)
- Measure voltage drop when operating (should be near zero)
- Force trip by blocking airflow briefly (not recommended except for troubleshooting)

Functional Test:

- Restrict airflow gradually (partially block filter)
- Monitor supply air temperature
- Verify limit opens near setpoint temperature
- Restore airflow immediately after trip

Ignition Control Modules

Modern furnaces use sophisticated ignition control modules to manage safe, reliable ignition.

Ignition Control Functions:

- **Sequence Management:**
  - Pre-purge timing
  - Igniter warm-up
  - Gas valve opening
  - Trial for ignition timing
  - Post-purge
- **Safety Monitoring:**

Flame sensing

Pressure switch status

Limit switch status

Rollout switch status

Lockout on repeated failures

Diagnostic Functions:

LED fault codes

Fault history storage

System status indication

Communication with thermostat (advanced systems)

Equipment Protection:

Prevents short cycling

Manages restart delays

Protects igniter from excessive cycles

Monitors system health

Ignition Types:

Hot Surface Ignition (HSI):

Most common in modern furnaces.

Operation:

Thermostat calls for heat

Inducer motor starts

Pressure switch proves draft (typically 15-45 seconds)

Igniter energized: Heats to 2500°F (1371°C) over 15-30 seconds

- **Gas valve opens:** Main burner or pilot
- Gas ignites from hot surface igniter
- Flame established within trial for ignition (4-7 seconds typical)
- Flame sensor proves flame
- Igniter de-energized after flame proven
- Normal operation continues

HSI Components:

- **Silicon nitride or silicon carbide element:** Glows bright orange when hot
- **Ceramic holder:** Insulates and protects
- **Mounting bracket:** Positions igniter properly
- **Electrical connections:** Handle carefully (brittle when hot)

HSI Advantages:

- No standing pilot (energy savings)
- Reliable ignition
- Long life (3-7 years typical)
- Simple design

HSI Disadvantages:

- Fragile (handle carefully, avoid touching element)
- Shortened life if exposed to flame (sulfur contamination)
- Requires warm-up time (15-30 seconds)
- Expensive to replace

HSI Failure Modes:

- Element cracked or broken (no glow)

High resistance (insufficient heat)

Contaminated (inefficient heating)

Age-related failure

Direct Spark Ignition (DSI):

Uses spark to ignite gas, similar to gas stove.

Operation:

Thermostat calls for heat

Inducer and pressure switch sequence

Spark electrode energized: Creates spark across gap

Gas valve opens (pilot or main burner)

Spark ignites gas

Flame sensor or flame rod proves flame

Spark stops after ignition confirmed

DSI Components:

Spark electrode: Creates spark

Ground electrode or grounded burner: Completes spark path

Spark module/transformer: Generates high voltage (typically 10,000-20,000V)

Sensing electrode: May be same as spark electrode or separate flame rod

DSI Advantages:

Instant ignition (no warm-up)

No igniter to wear out

Lower power consumption than HSI

Can retry immediately if needed

DSI Disadvantages:

- More complex electronics
- Requires proper spark gap (typically 1/8 inch / 3 mm)
- Sensitive to electrode condition and position
- Spark module can fail

Intermittent Pilot Ignition:

Electronic pilot that lights only when needed.

Operation:

- Thermostat calls for heat
- Inducer and pressure switch sequence
- Pilot gas valve opens
- Spark or HSI ignites pilot
- Pilot flame established and proven
- Main gas valve opens
- Main burner lights from pilot
- Pilot may stay lit through cycle or extinguish after main burner established

Advantages:

- Proven pilot flame before main burner
- More reliable than direct main burner ignition in some applications
- Can use standing pilot in power outage (if manual pilot light available)

Disadvantages:

- More complex valve assembly
- Two ignition stages (pilot, then main)

Slower than direct ignition

Ignition Sequence Timing:

Typical hot surface ignition timing:

Pre-purge: 0-30 seconds (clears any residual gas)

Inducer start: 0 seconds (begins immediately)

Pressure switch prove: Within 45 seconds

Igniter warm-up: 15-30 seconds

Gas valve opens: After igniter hot

Trial for ignition: 4-7 seconds (flame must be proven)

Flame proving: Continuous during operation

Igniter off: After flame proven (typically 3-10 seconds)

Post-purge: 0-30 seconds after burner off

Safety Timing:

Trial for Ignition:

Limited time for flame to establish

Typically 4-7 seconds after gas valve opens

If no flame detected: gas valve closes immediately

Prevents gas accumulation

Retry Attempts:

1-3 retry attempts typical

Brief delay between attempts (typically 30-90 seconds)

After maximum retries: lockout

Lockout:

- System shuts down after repeated ignition failures
- Requires manual reset or power cycle
- Protects against repeated ignition attempts
- Indicates problem requiring service

Ignition Control Diagnostics:

LED Fault Codes:

Most controls use flashing LED to indicate status:

Normal Operation:

- Steady on or slow flash
- Indicates system ready or operating normally

Fault Codes:

- Specific flash patterns indicate problems
- Count flashes: 1 flash = code 1, 2 flashes = code 2, etc.
- Pause between code repeats
- Refer to furnace wiring diagram or tech manual for code meanings

Common Fault Codes:

- **Pressure switch stuck closed:** Induced draft issue
- **Pressure switch won't close:** Draft/venting problem
- **Limit switch open:** Overheating/airflow problem
- **No flame sensed:** Ignition failure
- **Flame sensed with gas valve off:** False flame signal or valve leak
- **Auxiliary limit open:** Rollout switch or secondary limit
- **Lockout:** Multiple failed ignition attempts

Troubleshooting Ignition Problems:

No Igniter Glow:

Check power to control board

Verify igniter connections

Test igniter resistance (typically 50-100 ohms when cold)

Check control board output

Replace igniter if cracked or high resistance

Igniter Glows But No Ignition:

Verify gas supply (valve open, adequate pressure)

Check gas valve operation (control signal present)

Test gas valve coil continuity

Verify gas pressure at manifold

Check for blocked orifices or burners

Ignites Then Shuts Off:

Flame sensor dirty (most common)

Poor flame sensor position

Ground connection problems

Control board failure

Weak flame (gas pressure, air/fuel ratio)

Weak or No Spark (DSI):

Check spark gap (should be 1/8 inch / 3 mm)

Clean electrodes

Verify electrode not cracked

Check spark module output

Verify ground connection

Integrated Furnace Controls:

Modern furnaces use sophisticated integrated controls.

Microprocessor-Based Controls:

Features:

Multiple inputs monitored continuously

Complex safety and operational algorithms

Self-diagnostics with fault code memory

Precise timing control

Programmable parameters

Inputs:

Thermostat calls (W1, W2, G, Y1, Y2)

Pressure switch status

Limit switch status

Rollout switch status

Flame sensor signal

Supply air temperature (some models)

Outputs:

Inducer motor

Hot surface igniter

Gas valve (single-stage, two-stage, or modulating)

Blower motor (speed control)

Indicator lights

Communication signals

Advanced Features:

Adaptive Learning:

Monitors system performance

Adjusts delays and timing

Compensates for aging components

Optimizes comfort and efficiency

Fault History:

Stores recent fault codes

Aids troubleshooting

Shows patterns or recurring issues

Accessed through diagnostic mode

Self-Test Modes:

Component testing (blower, igniter, valves)

Allows testing without thermostat call

Diagnostic sequences

Accessed through jumper settings or button presses

Communication Protocols:

High-end systems use proprietary communication:

Thermostat and furnace exchange detailed information

Control of staging, modulation, fan speed

Status reporting, fault codes

- Cannot mix brands (incompatible protocols)

13.4 Hydronic Heating Systems

Hydronic systems use hot water to distribute heat throughout the building. They are efficient, comfortable, and increasingly popular in Canadian installations.

Hot Water Boilers

Hot water boilers heat water and circulate it through piping to radiators, baseboard heaters, or in-floor radiant systems.

Boiler Types:

Cast Iron Sectional Boilers:

Traditional design, still common in many installations.

Construction:

- Multiple cast iron sections bolted together
- Nipples and gaskets seal between sections
- Combustion chamber within sections
- Water surrounds combustion area

Characteristics:

- **Heavy:** Difficult to install, requires structural support
- **Durable:** 25-40 year life expectancy
- **High water content:** Slower to heat, more stable temperature
- **Repairable:** Sections can be replaced
- **Efficiency:** 80-85% AFUE typical

Applications:

- Replacement in existing systems

Large commercial installations

Where longevity is priority

Outdoor reset control compatibility

Steel Fire-Tube Boilers:

More compact than cast iron.

Construction:

Welded steel tank

Fire tubes pass through water

Combustion gases travel through tubes

Heat transfers to surrounding water

Characteristics:

Lighter: Easier installation

Compact: Smaller footprint

Lower water content: Faster response

Not repairable: Tank failure requires replacement

Efficiency: 80-85% AFUE typical

Condensing Boilers:

High-efficiency design extracts maximum heat.

Construction:

Primary and secondary heat exchangers

Stainless steel or aluminum construction

Compact modular design

Wall-hung common (space saving)

Characteristics:

- **High efficiency:** 90-98% AFUE
- **Low water content:** Fast response
- **Modulating burners:** Match load precisely
- **Condensate production:** Requires drainage
- **PVC or stainless venting:** Category IV
- **Sealed combustion:** Outdoor air for combustion

Operation:

- Returns water temperature below 130°F (54°C) for full condensing
- Extracts latent heat from water vapor
- Produces acidic condensate (pH 3-5)
- Requires proper water treatment

Applications:

- New construction
- High-efficiency retrofits
- Radiant floor heating (low temperature)
- Where space limited (wall-hung)
- Energy-conscious installations

Combination Boilers (Combi):

Provides both space heating and domestic hot water.

Operation:

- **Priority domestic hot water:** DHW call takes precedence
- **Space heating:** When no DHW demand

Modulating burner: Adjusts to load

Plate heat exchanger: For domestic hot water

No storage tank: Tankless DHW

Advantages:

Space savings (no separate water heater or storage)

High efficiency

Endless hot water (if properly sized)

Reduced standby losses

Disadvantages:

Limited DHW flow rate (typically 2-4 GPM)

Not suitable for large homes with high simultaneous DHW demand

More complex controls

Higher initial cost

Applications:

Small to medium homes

Radiant floor heating with modest DHW needs

Condominiums and townhouses

European market more common than North American

Boiler Sizing:

Unlike furnaces, boilers should NOT be significantly oversized.

Heat Loss Calculation:

Accurate heat loss calculation essential

Room-by-room calculation preferred

Account for insulation, windows, infiltration

Design day temperature for location

Sizing Guidelines:

Pick-up factor: 1.15-1.20× calculated heat loss

Accounts for warming up cold mass (cast iron radiators, etc.)

Avoid excessive oversizing (short cycling, inefficiency)

Indirect Water Heater Sizing:

If using indirect water heater for DHW

Add DHW load to space heating load

Or select boiler with priority DHW and adequate recovery

Example:

Heat loss: 80,000 BTU/h

Indirect water heater: 40,000 BTU/h

Pick-up factor: 1.20

Boiler size: 80,000 × 1.20 = 96,000 BTU/h minimum

Consider DHW priority: May need 100,000-120,000 BTU/h for good DHW recovery

System Components

Hydronic systems require several key components beyond the boiler itself.

Circulator Pumps:

Move hot water through the system.

Types:

Wet Rotor Circulators:

Most common in residential

Water circulates through motor for cooling

Quiet operation

Maintenance-free (no seals or bearings to service)

Typical residential: 1/25 to 1/8 HP

Inline Circulators:

Installed directly in pipe

Compact design

Bronze or stainless body

Permanent lubrication

Base-Mounted Circulators:

Mounted on separate base

Easier to service

More common in commercial

Higher flow rates available

Variable-Speed Circulators:

ECM motor technology

Adjusts speed to maintain setpoint (delta-T or pressure)

Energy savings (50-80% vs. standard)

Quieter operation

Higher initial cost

Circulator Sizing:

Based on two factors:

1. Flow Rate (GPM):

Formula: GPM = BTU/h ÷ (500 × ΔT)

ΔT = Design temperature drop (typically 20°F / 11°C)

Example: 100,000 BTU/h ÷ (500 × 20) = 10 GPM

2. Head Pressure (Feet of Head):

Resistance through piping, fittings, boiler, radiation

Calculate or estimate based on system size

Typical residential: 5-15 feet of head

Larger systems: 15-25 feet

Selection:

Use manufacturer pump curves

Plot flow rate vs. head pressure

Select pump that operates in middle of curve

Avoid operating at extreme ends

Circulator Installation:

Pump toward boiler (return side) for best air elimination

Horizontal shaft preferred (some models)

Isolation flanges or valves for service

Electrical connection per code

Check rotation direction

Expansion Tanks:

Accommodate water expansion and contraction with temperature changes.

Purpose:

Water expands approximately 4% when heated from 40°F to 200°F (4°C to 93°C)

Closed system requires space for expansion

Prevents pressure relief valve discharge

Maintains system pressure

Types:

Compression Tank (Old Style):

Steel tank partially filled with air

Air compresses as water expands

Requires air separator to maintain air cushion

Large and heavy

Rarely used in new installations

Diaphragm Tank (Bladder Tank):

Air and water separated by rubber diaphragm

Pre-charged with air (typically 12-15 psi / 83-103 kPa)

No air mixing with water

Compact, lightweight

Standard in modern systems

Sizing Expansion Tank:

Based on:

System water volume (gallons)

Temperature range

Fill pressure and maximum pressure

Simplified Sizing:

1-2 gallon tank: Small systems (under 30 gallons water content)

2-5 gallon tank: Medium residential (30-75 gallons)

5-15 gallon tank: Large residential or small commercial

Use manufacturer sizing tables or software for accuracy

Installation:

Connect to cold (return) side of system

Before circulator

Support tank weight (especially when full)

Accessible for inspection and replacement

Check pre-charge pressure (should equal system fill pressure)

Air Elimination Devices:

Remove air from system water.

Air Separator:

Centrifugal or tangential flow design

Separates air bubbles from water

Automatic air vent at top releases air

Install before circulator on return line

Critical for system performance

Automatic Air Vents:

Float mechanism opens to release air

Installed at high points in system

On air separator

At manifolds in radiant systems

Must be vertical, removable for service

Manual Air Vents (Bleeders):

- On radiators and baseboard
- Require manual operation
- Used during filling and purging
- Homeowner may need education

Air Problems:

- Noise in system
- Pump cavitation
- Reduced heat transfer
- Radiators don't heat fully
- Short circulator life

Backflow Preventer:

Prevents contaminated system water from entering potable supply.

Requirements:

- Required by plumbing code
- Typically reduced pressure zone (RPZ) or double-check valve
- Must be tested annually
- Install on makeup water line

System Fill Valve and Pressure Reducing Valve:

Functions:

- Automatically fills system to proper pressure
- Reduces city water pressure (typically 60-80 psi / 414-552 kPa) to system pressure (12-20 psi / 83-138 kPa)
- Fast fill bypass for initial filling

Adjustment:

- Set to maintain system pressure when cold
- Typically 12-15 psi (83-103 kPa) cold
- Should not activate during normal operation
- If activating frequently: leak in system

Pressure Relief Valve:

Required safety device.

Specifications:

- Temperature and pressure relief valve (T&P)
- Typical settings: 30 psi / 250°F (207 kPa / 121°C)
- Sized for boiler input
- ASME certified

Installation:

- Directly on boiler (no valves between)
- Vertical discharge pipe
- Terminate safely (drain or outside)
- Support discharge pipe
- Annual testing recommended

Zone Valves:

Control flow to individual zones.

Operation:

- Thermostat calls for heat
- Valve motor opens valve

End switch closes when fully open

Circulator starts (if wired through end switches)

Zone receives heat

Types:

Normally Closed:

Most common

Valve closed when de-energized

Opens when zone calls for heat

24V or 115V models

Floating Action:

Can modulate between open and closed

Allows outdoor reset control

More complex and expensive

Installation:

Arrow indicates flow direction

Horizontal piping preferred

Accessible for service

Transformer or control provides 24V power

Zone Valve vs. Zone Circulator:

Zone Valves:

Single circulator serves all zones

Zone valves direct flow

More compact, less piping

Single electrical connection for circulator

Zone Circulators:

Dedicated circulator for each zone

No zone valves needed

Better for very different zone sizes

More piping and electrical connections

Low Water Cutoff:

Shuts off boiler if water level drops.

Purpose:

Prevents boiler damage from low water

Required on steam boilers (always)

Recommended on some hot water boilers

Operation:

Float switch monitors water level

Opens circuit if level drops

Prevents boiler firing without water

Manual reset typical

Mixing Valves (3-Way or 4-Way):

Blend supply and return water to achieve desired temperature.

Applications:

Radiant floor heating (requires lower temperature)

Outdoor reset control

Protection of non-condensing boiler from low return temperature

Types:

3-Way Mixing:

- Hot supply, mixed supply, return
- Blends to achieve setpoint
- Motorized or thermostatic

4-Way Mixing:

- Separate supply and return connections
- Better control in some applications

Controls:

- Thermostat or outdoor sensor
- Motorized actuator adjusts valve
- Supply temperature sensor provides feedback

Piping Configurations

Proper piping design ensures even heat distribution and efficient operation.

Series Loop (One-Pipe):

Simplest but least flexible.

Design:

- Single pipe loop from boiler through all heat emitters and back
- Water temperature drops at each emitter
- Last radiator receives coolest water

Advantages:

- Simple, low cost
- Minimal piping

Disadvantages:

Uneven temperatures

Last radiator often undersized

No individual room control

Not zoned

Entire system on or off together

Applications:

Small, simple systems

Slab heating (in-floor)

Rarely used in modern installations

One-Pipe Diverter System:

Improved version of series loop.

Design:

Main loop with diverter tees at each radiator

Portion of flow diverted through radiator

Main loop continues with less temperature drop

Advantages:

Better temperature distribution than straight series

Simple valving

Disadvantages:

Still uneven (first radiator hottest)

Limited control

Special diverter fittings required

Two-Pipe Direct Return:

Most common residential system.

Design:

- Supply main from boiler to all radiators
- Each radiator supplied from main
- Return from each radiator to return main
- Return main back to boiler

Advantages:

- Even temperature distribution
- Individual balancing possible
- Can add zone valves for control
- Standard components

Disadvantages:

- More piping than series
- First radiator has shortest circuit (highest flow)
- Last radiator has longest circuit (lowest flow)
- Balancing required

Balancing:

- Adjust valve at each radiator
- Throttle closest radiators slightly
- Ensure adequate flow to farthest radiators
- Measure temperature drop at each radiator

Two-Pipe Reverse Return:

Best for even distribution.

Design:

Supply main similar to direct return

Return main connects to radiators in reverse order

First radiator supplied = last returned

Last radiator supplied = first returned

All circuits approximately equal length

Advantages:

Self-balancing (equal pipe lengths)

Even flow distribution

Minimal balancing needed

Excellent performance

Disadvantages:

More piping (longest total length)

More complex layout

Higher installation cost

Applications:

Large systems with many radiators

Commercial installations

Where even distribution critical

Primary-Secondary Piping:

Allows multiple circuits at different flow rates and temperatures.

Design:

Primary loop: Boiler and circulator

Secondary loops: Each with own circulator

Closely-spaced tees connect primary and secondary

Hydraulic separation between circuits

Advantages:

Multiple zones with different temperatures

Each zone independent flow rate

Boiler operates at optimal conditions

Can mix radiant and baseboard

Disadvantages:

More complex design

Additional circulators and controls

Higher cost

Applications:

Combination systems (radiant + baseboard)

Multiple temperature requirements

Indirect water heater + space heating

Modern high-performance systems

Near-Boiler Piping:

Proper piping at boiler critical for performance.

Key Principles:

Air Elimination:

Air separator on return before circulator

Automatic vent at air separator

Purge valves at boiler

Expansion Tank:

Before circulator (cold side)

Connected to air separator location

System Fill and Pressure:

Fill valve maintains system pressure

Pressure gauge visible

Pressure relief valve on boiler

Purge Connections:

Drain valves for system draining

Hose bibb connections for flushing

Isolation valves for boiler service

Flow Direction:

Pump away from expansion tank

Supply from boiler flows to zones

Return to boiler through air separator

Pipe Sizing:

Sizing Methods:

Residential: Rule of thumb

3/4 inch (19 mm): Up to 50,000 BTU/h

1 inch (25 mm): Up to 100,000 BTU/h

1-1/4 inch (32 mm): Up to 200,000 BTU/h

1-1/2 inch (38 mm): Up to 350,000 BTU/h

Better Method:

Calculate flow rate (GPM)

Limit velocity to 4 fps (1.2 m/s) in residential

Use pipe sizing charts based on GPM and head loss

Branch Sizing:

Size for specific radiator or zone load

Typically smaller than mains

Adequate flow with acceptable pressure drop

Temperature Controls

Hydronic systems require sophisticated temperature control for comfort and efficiency.

Aquastat Control:

Controls boiler water temperature.

Functions:

Maintains boiler water at setpoint

High limit prevents overheating

Circulator control (in some systems)

Settings:

Operating Range:

Low limit (burner on): Typically 140-160°F (60-71°C)

High limit (burner off): Typically 180-200°F (82-93°C)

Differential: 10-20°F (5-11°C)

Condensing Boilers:

Target return temperature below 130°F (54°C)

Supply temperature varies with outdoor temperature

Modulating burner maintains setpoint

Advanced Controls:

Outdoor Reset Control:

Adjusts supply water temperature based on outdoor temperature.

Principle:

Colder outdoor = hotter water needed

Warmer outdoor = cooler water acceptable

Maintains comfort while improving efficiency

Settings:

Reset ratio: Temperature change per degree outdoor change

Typical: 1.5 ratio (supply drops 1.5°F per 1°F rise outdoors)

Design temperature: Coldest expected (-20°F / -29°C typical)

Warm weather shutdown: Temperature above which heat not needed

Benefits:

Improved comfort (less overheating)

Energy savings (5-15%)

Extended equipment life (less cycling)

Better for radiant floors

Implementation:

Outdoor sensor mounted on north wall

Protected from sun and wind

Control adjusts mixing valve or modulates burner

Some systems use injection mixing

Multiple Zone Control:

Typical Configuration:

Zone thermostats call for heat

Zone valves open (or zone circulators start)

End switches or flow switches prove zone open

Boiler fires

Main circulator runs (if zone valve system)

Heat delivered to calling zones

Boiler Control:

Boiler fires when any zone calls

Maintains temperature for fastest response

May have warm weather shutdown

Priority Zones:

Domestic hot water (indirect) takes priority

DHW zone opens, others close

Ensures adequate DHW recovery

Setback Strategies:

Night Setback:

Lower temperature at night

Energy savings 5-15%

Longer recovery time than forced air (thermal mass)

Recommendations:

- Moderate setback (5-8°F / 3-4°C)
- Start recovery 2-3 hours before wake time
- Outdoor reset reduces need for deep setback

Multiple Boiler Systems:

Large installations may use multiple boilers.

Lead-Lag Control:

- Primary boiler handles normal load
- Second boiler stages on for additional capacity
- Improves efficiency (boilers run at higher load percentage)
- Redundancy if one boiler fails

Rotation:

- Alternate which boiler is lead
- Equalizes run time and wear

Boiler Installation Requirements

Proper installation per CSA B149.1 ensures safe, reliable operation.

Location:

Accessibility:

- Service clearances on at least two sides
- Access to controls, flue, and connections
- Adequate lighting
- Floor drain nearby desirable

Clearances to Combustibles:

Per manufacturer specifications

Typically 1-6 inches (25-150 mm) sides and rear

18-36 inches (450-900 mm) front for service

Floor:

Adequate structural support (cast iron boilers heavy)

Level surface (within 1/4 inch per 10 feet / 6 mm per 3 m)

Non-combustible base if required

Venting:

Non-Condensing Boilers:

Type B vent or masonry chimney with liner

Size per CSA B149.1 tables

Adequate height for draft

Common venting possible with water heater (if Category I)

Condensing Boilers:

PVC or stainless steel Category IV venting

Size per manufacturer specifications

Horizontal or vertical termination

Clearances from openings per code

Combustion Air:

Sealed Combustion (Condensing):

Intake piped directly from outdoors

Size per manufacturer specifications

Clearances between intake and exhaust

Protection from blockage

Atmospheric or Open Combustion:

Combustion air per CSA B149.1

Calculate based on input rating

Adequate openings or dedicated ducts

Consider building depressurization

Piping Connections:

Supply and Return:

Sized for system flow rate

Unions or flanges for service

Isolation valves for boiler removal

Piping support prevents stress on boiler

Boiler Drain:

Drain valve at low point

Hose connection for flushing

Terminate to safe location (floor drain or outside)

Pressure Relief Valve:

Install directly on boiler

No shutoff valve between PRV and boiler

Discharge piping to safe location

Size per boiler rating

Gas Piping:

Installation:

Size per CSA B149.1 and boiler input

Manual shutoff within 6 feet (1.8 m)

Sediment trap (drip leg) at boiler

Union for service disconnect

Pressure test and leak check

Pressure:

Natural gas: Verify 7 inches W.C. (1.7 kPa) nominal at inlet

Adjust manifold pressure per manufacturer (typically 3.5 inches W.C. / 0.87 kPa)

Propane: 11 inches W.C. (2.7 kPa) inlet, 10 inches W.C. (2.5 kPa) manifold typical

Electrical:

Power:

115V dedicated circuit

Disconnect switch within sight of boiler

Wiring per CEC

Proper grounding

Controls:

Low voltage (24V) for thermostats and zone valves

Transformer typically built into boiler

Wiring per diagram

Neat routing, proper support

Water Quality:

Critical for Boiler Life:

Proper water treatment prevents:

Scale buildup (reduces efficiency, causes overheating)

Corrosion (leaks, component failure)

Fouling (reduces heat transfer)

Water Treatment:

Closed System:

Treat once during fill

Minimal makeup water

Inhibitor prevents corrosion

pH buffer maintains neutral pH

Treatment Products:

Inhibitor/passivator

pH adjuster

Scale inhibitor if hard water

Procedure:

Fill system with treated water (or add treatment after filling)

Circulate throughout system

Purge air

Check pH and adjust if needed

Annual testing recommended

Condensing Boilers:

Some manufacturers provide built-in feedwater treatment

May require specific water quality (hardness, pH)

Flush heat exchanger periodically

Monitor condensate pH

Initial Fill and Purge:

Procedure:

Close all drain and purge valves

Open supply and return valves at boiler

Slowly open system fill valve

Monitor pressure gauge (fill to 12-15 psi / 83-103 kPa)

Open purge valves at high points to remove air

Start circulator and purge at radiators/baseboards

Continue until water flows without air

Recheck pressure and top up if needed

Verify expansion tank pre-charge (should equal fill pressure)

CSA B149.1 Specific Requirements:

Clearances:

Maintain manufacturer minimums

Never reduce below listed clearances

Document any variations

Venting:

Size per code tables or manufacturer (whichever more restrictive)

Proper materials for boiler category

Testing required

Piping:

Pressure test per code requirements

Leak check all joints

Proper sizing for input rating

Controls:

Aquastat or limit control required

Circulator protection

Low water cutoff on steam and some water boilers

Inspection:

Rough-in inspection before concealing

Final inspection after completion

Provide documentation to inspector

13.5 Radiant Heating

Radiant heating provides comfortable, efficient heat by warming surfaces rather than air.

In-Floor Heating Systems

In-floor radiant heating is increasingly popular for new construction and renovations.

System Types:

Hydronic (Water-Based):

Most common and efficient for whole-house heating.

Components:

Tubing embedded in floor

Boiler or water heater provides heat

Circulator pumps water through tubing

Manifold distributes flow to zones

Controls manage temperature

Tubing Types:

PEX (Cross-Linked Polyethylene):

- Most popular choice
- Flexible, easy to install
- Resistant to corrosion and scale
- Long life expectancy (50+ years)
- Available in oxygen barrier and non-barrier types
  - **Oxygen barrier PEX required** for closed loops (prevents corrosion of ferrous components)

PEX-AL-PEX:

- PEX with aluminum layer
- Better dimensional stability
- Holds bends without support
- More expensive than standard PEX

PERT (Polyethylene of Raised Temperature):

- Similar to PEX
- Less expensive
- Good flexibility and durability

Tubing Sizing:

- Residential: 1/2 inch (13 mm) most common
- Commercial: 5/8 or 3/4 inch (16 or 19 mm)
- Smaller tubes: Closer spacing, better heat distribution, lower water content

Installation Methods:

1. Concrete Slab (Below Grade or On Grade):

Procedure:

Insulation below slab (critical for efficiency)

Minimum R-10 (RSI 1.8) under heated slab

Vapor barrier below insulation

Tubing secured to wire mesh or rebar

Concrete poured over tubing (minimum 1.5 inches / 38 mm cover)

Advantages:

Excellent thermal mass (even heat, slow response)

Durable, permanent installation

Good for commercial or high-traffic areas

Disadvantages:

Slow response time (hours to change temperature)

Difficult to access if problems develop

Heavy (structural considerations)

2. Above-Floor (Thin Slab):

Procedure:

Subfloor prepared (plywood or concrete)

Insulation below if over unconditioned space

Tubing attached to surface

Lightweight concrete or gypsum overlay (3/4 to 1.5 inches / 19 to 38 mm)

Floor covering over overlay

Advantages:

Faster installation than full slab

Less weight than full slab

Can be done in renovation

Disadvantages:

Raises floor level (doorways, transitions)

Less thermal mass than full slab

Requires compatible floor covering

3. Below-Floor (Joist Bay):

Procedure:

Tubing installed between floor joists

Aluminum heat transfer plates distribute heat

Tubing snaps into plates

Insulation below tubing (R-19+ / RSI 3.3+)

Subfloor and finish floor above

Advantages:

No floor height increase

Existing structure (retrofit possible)

Accessible from below if needed

Disadvantages:

Less efficient (heat must travel through subfloor)

Higher water temperatures required

More challenging installation

4. Above-Floor (Sleeper System):

Procedure:

Sleepers (wood strips) on subfloor

Tubing run between sleepers

Aluminum plates improve distribution

Subfloor or finish floor over top

Advantages:

Minimal floor height increase

Accessible

Good for retrofit

Disadvantages:

Less thermal mass

Some floor unevenness possible

Requires careful carpentry

Design Considerations:

Heat Output:

15-30 BTU/h per square foot (47-95 W/m^2) typical residential

Depends on floor covering, insulation, water temperature

Must match room heat loss

Tubing Spacing:

6-12 inches (150-300 mm) on center typical

Closer spacing in cold climates or high heat loss areas

Perimeter zones may need closer spacing

Calculate based on heat output requirements

Water Temperature:

80-120°F (27-49°C) typical (much lower than radiators or baseboard)

Depends on floor covering, tubing depth, heat output

Maximum: 85°F (29°C) for hardwood floors (prevents damage)

Higher for tile, lower for carpet

Loop Length:

Maximum 300-400 feet (90-120 m) per loop (1/2 inch tubing)

Longer loops increase pressure drop

Divide large areas into multiple loops

Balance loop lengths for even flow

Zoning:

Each room or area can be separate zone

Manifold with actuators controls zone valves

Thermostats in each zone

Mix open zones to maintain boiler flow

Floor Covering Compatibility:

Best:

Ceramic tile: Excellent heat transfer, durable

Stone: Very good heat transfer, thermal mass

Engineered hardwood: Good (more stable than solid)

Acceptable:

Laminate: Acceptable (check temperature limits)

Vinyl/LVT: Good (follow manufacturer guidelines)

Challenging:

Carpet: Insulates floor (reduces output 20-50%)

Solid hardwood: Risk of warping or cracking (limit temperature)

Use low pad density if carpet required

Controls:

Basic:

Zone thermostats

Manifold with zone valves or actuators

Mixing valve maintains supply temperature

Single or variable-speed circulator

Advanced:

Outdoor reset control (optimal efficiency)

Individual room temperature sensors

Web-based or app control

Integration with home automation

Manifold:

Central distribution point for all loops.

Components:

Supply manifold with flow meters

Return manifold with actuators or valves

Air vents at high points

Drain/purge valves

Thermometer or temperature sensors

Pressure gauge

Location:

Central to zones (minimizes piping)

Accessible for service

Protected from freezing

Manifold cabinet for appearance

Electric Radiant Heating:

Alternative to hydronic for smaller areas.

Types:

Radiant Cable:

Resistance wire embedded in floor

Typically in thin-set mortar under tile

120V or 240V

Controlled by thermostat with floor sensor

Radiant Mats:

Pre-spaced wire on mesh

Easier installation than cable

Cut and fit to room shape

Under tile or LVT

Advantages:

Simpler installation (no boiler or plumbing)

Low cost for small areas

Responsive (heats quickly)

No maintenance

Disadvantages:

High operating cost (electric resistance)

Expensive for whole-house heating

Less even heat than hydronic

Cannot provide DHW or other uses

Applications:

Bathroom floors

Kitchen floors

Small tile areas

Supplemental heat only (usually)

Panel Radiators

European-style panel radiators provide efficient, attractive heat.

Design:

Construction:

Stamped steel panels

Welded water passages

Convection fins behind panels (some models)

Factory painted finish

Configurations:

Single panel, no fins (Type 11)

Single panel with fins (Type 21)

Double panel with fins (Type 22)

Triple panel with fins (Type 33)

More panels/fins = higher output in same size

Heat Output:

Rated in BTU/h at specific water temperatures

Derated for lower water temperatures

Ideal for low-temperature systems (condensing boilers)

Manufacturer provides output tables

Sizing:

Calculate room heat loss

Select radiator from manufacturer tables

Account for water temperature and flow rate

Multiple smaller radiators better than single large (more even heat distribution)

Installation:

Mounting:

Wall brackets (most common)

Floor stands (if wall mounting not possible)

Must be level for proper air venting

Support weight when filled with water

Connections:

Bottom connections most common (cleaner appearance)

Side connections available

Thermostatic radiator valves (TRVs) for individual control

Balancing valve on return

Advantages:

Attractive, modern appearance

Efficient heat distribution (convection + radiation)

Responsive (low water content)

Individual room control possible

Compatible with low-temperature systems

Disadvantages:

Higher cost than baseboard

Requires wall space

May not fit all room layouts

Thermostatic Radiator Valves (TRVs):

Allow individual radiator control.

Operation:

Wax element expands/contracts with temperature

Modulates valve to maintain room temperature

No electrical connection required

Numbered settings (typically 1-5)

Installation:

On supply side of radiator

Sensing element must sense room air (not trapped behind curtains, furniture)

Not on radiator in same room as system thermostat (conflicts)

Benefits:

Room-by-room comfort

Energy savings (unoccupied rooms cooler)

Prevents overheating

Unit Heaters

Gas-fired unit heaters provide heat in garages, workshops, and commercial spaces.

Types:

Separated Combustion:

Sealed combustion chamber

Direct vent or power vent

Combustion air from outdoors

Required in most residential applications

Conventional (Atmospheric):

Open combustion chamber

Natural draft or power vent

Combustion air from space

Commercial applications typically

Design:

Components:

Gas burner and heat exchanger

Fan blows air across heat exchanger

Cabinet and mounting brackets

Thermostat or control

Venting components

Capacity:

30,000 to 400,000 BTU/h typical

Select based on space heat loss

Consider ceiling height and air changes

Mounting:

Ceiling-Mounted:

Most common

Brackets hang from ceiling or roof structure

Adequate clearance to combustibles

Consider service access

Wall-Mounted:

For lower mounting heights

Horizontal discharge

Keep discharge away from occupied areas

Clearances:

To combustibles per manufacturer (typically 12-36 inches / 300-900 mm)

Discharge must not blow on people or combustibles directly

Consider snow and ice if outdoors

Installation:

Venting:

Separated combustion: Direct vent through wall or roof

Atmospheric: Type B vent or power vent per code

Size per manufacturer specifications

Adequate height and termination

Gas Piping:

Size for input rating

Manual shutoff accessible

Sediment trap

Pressure test and leak check

Electrical:

115V for fan and controls

Thermostat wiring (typically 24V)

Proper grounding

Controls:

Thermostat:

Remote wall thermostat typical

Located in heated space (not near unit)

Away from drafts and heat sources

Safety Controls:

High limit prevents overheating

Flame sensor proves combustion

Pressure switch (if power vented)

Blocked vent safety (if applicable)

Applications:

Residential:

Garages (must be sealed combustion, elevated per code)

Workshops

- Attached buildings

Commercial:

- Warehouses
- Shops
- Loading docks
- Aircraft hangars

Advantages:

- Fast heat (fan-forced)
- No ductwork required
- Can heat large open spaces
- Economical for intermittent use

Disadvantages:

- Noisy (fan operation)
- Uneven heat (warm near unit)
- Air movement may be uncomfortable
- Not suitable for residential living spaces

Installation Considerations

Radiant Systems:

Design Expertise:

- Complex heat loss calculations
- Tubing layout design
- System pressure drop calculations
- Consider professional design for large systems

Installation Quality:

Proper insulation critical (80%+ of heat should go up)

Pressure test tubing before embedding (100 psi / 690 kPa for 24 hours)

Protect tubing during construction

Document tubing locations (photos, drawings)

Startup:

Gradual temperature increase (especially concrete systems)

Purge air completely

Balance flows at manifold

Verify controls operate correctly

Panel Radiators:

Piping:

Size for system flow requirements

Pitch piping for proper air venting

Isolation valves for service

Balancing valves for proper distribution

Air Purging:

Critical for proper operation

Automatic air vents at high points

Purge during fill and startup

Recheck after first heating season

Unit Heaters:

Location:

Adequate clearances per code

Consider discharge pattern and reach

Access for service

Electrical and gas connections nearby

Sizing:

Account for air infiltration (garage doors opening)

Higher heat loss in poorly insulated spaces

Consider ventilation requirements

Control Strategies

Radiant Floor:

Outdoor Reset:

Ideal control method

Supply temperature varies with outdoor temperature

Maximizes comfort and efficiency

Prevents overheating in mild weather

Setback Strategies:

Moderate setback (3-5°F / 1.5-3°C) due to thermal mass

Start recovery several hours early

Some systems maintain constant temperature (optimal comfort)

Zoning:

Each room or area controlled independently

Sleeping areas cooler than living areas

Unoccupied spaces set lower

Significant energy savings possible

Panel Radiators:

TRVs provide best control:

Each room independent

Responds to internal heat gains

User-adjustable

No wiring required

Central Control:

System thermostat + TRVs

Weather compensation

Time programming

Unit Heaters:

Thermostat control:

On/off control typical

Set temperature for comfort during occupied periods

Lower during unoccupied (energy savings)

Two-Stage:

Low fire for mild weather

High fire for cold weather

Better comfort, lower cost

13.6 Heat Pump Systems (Dual Fuel)

Heat pumps can be integrated with gas furnaces for optimal efficiency across all temperatures.

Integration with Gas Furnaces

Dual-fuel systems combine electric heat pump with gas furnace backup.

System Configuration:

Heat Pump:

- Provides heating and cooling
- Most efficient in mild weather
- Capacity and efficiency drop as outdoor temperature falls
- Economical down to balance point

Gas Furnace:

- Backup heat source
- Takes over when heat pump capacity insufficient
- Or when gas is more economical than electricity

Why Dual Fuel:

Economic Optimization:

- Use most economical fuel at any outdoor temperature
- Heat pump efficient in mild weather (COP 2-4)
- Gas economical in very cold weather
- Switches automatically at programmed changeover point

Performance:

- Heat pump capacity drops below 32°F (0°C)
- May struggle to maintain comfort below 15-20°F (-9 to -7°C)
- Gas furnace provides reliable capacity in extreme cold

Equipment:

Compatible Systems:

- Furnace must be compatible with heat pump coil
- Multi-speed or variable-speed blower ideal
- Control board must handle dual fuel logic
- Some manufacturers offer matched systems

Coil:

- Indoor coil for air conditioning and heat pump
- Sized for both heating and cooling loads
- Proper airflow critical (heat pump requires higher CFM than A/C)

Changeover Controls

Sophisticated controls manage the transition between heat pump and gas furnace.

Changeover Methods:

1. Outdoor Temperature:

Most common method.

Operation:

- Outdoor sensor monitors temperature
- Heat pump operates above changeover temperature
- Furnace operates below changeover temperature
- Typical changeover: 25-35°F (-4 to 2°C)

Setting Changeover Point:

- Based on local utility rates (gas vs. electric)
- Heat pump efficiency at various temperatures
- Calculate operating cost at each temperature

- Set changeover where costs cross over

Example:

- Gas: $0.70 per therm
- Electric: $0.12 per kWh
- Heat pump COP at 32°F: 2.2
- Furnace efficiency: 95% AFUE
- Calculation shows heat pump economical above 30°F (-1°C)
- Set changeover at 30°F

2. Time of Day (Demand Rates):

For utilities with time-of-day pricing.

Operation:

- Heat pump during off-peak hours (lower rates)
- Furnace during peak hours
- Or combination of temperature and time

3. Manual:

User selects heat source.

Operation:

- Switch or thermostat setting
- "Heat Pump" or "Furnace"
- May override automatic changeover
- Least efficient (relies on user)

Control Strategies:

Staged Heating:

Stage 1: Heat pump only

Mild weather

Moderate heating demand

Most economical

Stage 2: Heat pump + furnace

Colder weather or high demand

Both systems operate

Furnace supplements heat pump

Some systems skip this stage

Stage 3: Furnace only

Very cold weather

Below changeover point

Heat pump off

Furnace provides all heat

Defrost Supplemental Heat:

During heat pump defrost cycles:

Heat pump reverses to cool mode briefly

Melts frost from outdoor coil

Furnace may activate to maintain comfort

Prevents cold air discharge

Emergency Heat:

Backup mode if heat pump fails.

Operation:

- User activates or control detects heat pump fault
- Furnace provides all heating
- Heat pump disabled
- Service light illuminates

Control Wiring:

Typical Connections:

- W1: First stage heat (heat pump)
- W2: Second stage heat (furnace)
- O/B: Heat pump reversing valve
- C: Common (24V return)
- R: 24V hot
- G: Fan
- Y1/Y2: Cooling stages

Thermostat Requirements:

Must support dual fuel:

- Separate control of heat pump and furnace
- Changeover logic
- Emergency heat setting
- Outdoor sensor input (if temperature-based changeover)

Lockouts:

Prevent simultaneous operation when not desired:

- Furnace locked out above changeover point
- Heat pump locked out below changeover point (except defrost supplemental heat)

- Time delay between mode changes

Efficiency Considerations

Dual fuel systems optimize efficiency and operating cost.

Seasonal Analysis:

Heating Season Profile:

- Mild weather (above 40°F / 4°C): 40-60% of season
- Moderate (25-40°F / -4 to 4°C): 25-35% of season
- Cold (below 25°F / -4°C): 15-25% of season

Fuel Usage:

- Heat pump handles majority of hours
- Furnace handles coldest weather (high heating load hours)
- Overall system efficiency very high

Efficiency Metrics:

HSPF (Heating Seasonal Performance Factor):

- Heat pump efficiency rating
- Higher is better (typical: 8-13 HSPF)
- Modern high-efficiency: 10-12 HSPF

AFUE:

- Furnace efficiency
- 90-98% typical for condensing furnaces
- Dual fuel system should use high-efficiency furnace (95%+ recommended)

Combined Efficiency:

- Weighted average based on hours at each mode

Can exceed either system alone

Typical combined efficiency equivalent to 125-150% AFUE

Economic Analysis:

Factors:

Local fuel costs ($/therm gas, $/kWh electric)

Equipment efficiencies

Local climate (heating hours distribution)

Utility rate structures (demand, time-of-day)

Payback:

Dual fuel costs more than heat pump alone or furnace alone

Savings in operating cost justify premium

Typical payback: 3-7 years in cold climates

Marginal in mild climates

Optimal Changeover:

Calculate hourly operating cost for each mode

Plot against outdoor temperature

Changeover where curves intersect

Adjustable based on rate changes

Best Applications:

Ideal Conditions:

Cold climate with significant heating demand

Low natural gas cost relative to electricity

High heat pump efficiency (modern equipment)

Long heating season

Less Suitable:

Mild climates (heat pump adequate alone)

High gas cost relative to electricity

Short heating seasons

Where simplicity prioritized over efficiency

Installation Best Practices:

Equipment Selection:

Right-size both heat pump and furnace

Don't oversize (reduces efficiency, comfort)

Match equipment (same manufacturer often best)

High-efficiency both systems

Control Setup:

Proper changeover point setting

Test all modes operation

Verify staging works correctly

Customer education on thermostat

Performance:

Commission properly (refrigerant charge, airflow)

Verify defrost operation

Test emergency heat mode

Document settings

13.7 Commissioning Heating Systems

Proper commissioning ensures safe, efficient, code-compliant operation.

Start-Up Procedures

Systematic start-up prevents problems and ensures optimal performance.

Pre-Start Checklist:

1. Visual Inspection:

- All panels secured
- No tools or materials left in equipment
- Filter installed correctly
- Electrical connections tight
- Gas connections completed and tight
- Venting properly supported and sealed
- Clearances to combustibles maintained
- Data plate visible and installation manual provided

2. Verify Installations:

- Gas piping sized correctly, properly supported
- Electrical properly sized and protected
- Combustion air provided per code
- Condensate drain (if applicable) properly installed and trapped
- Thermostat located and wired correctly
- Return air adequate

3. System Preparation:

- Gas pressure test passed

Leak test passed (soap bubble all joints)

Filters in place (new, clean)

Ductwork sealed and complete

Access panels replaceable

Safety devices (disconnects, shutoffs) accessible

Initial Startup Sequence:

Forced Air Furnace:

Verify Utilities:

Gas main valve open

Gas meter supplying gas

Electrical disconnect on

Circuit breaker on

Set Controls:

Thermostat to lowest setting ("Off" position if possible)

Ensure call for heat not active

Purge Gas Line:

Crack union or test port at gas valve

Bleed air from line until gas flows

Tighten connection immediately

Verify no leaks with soap bubble

Energize Furnace:

Turn on electrical disconnect

Control board should power up

LED indicates status (steady or slow flash typically normal)

Initial Run:

Set thermostat to call for heat

Observe sequence:

Inducer starts (if present)

Igniter glows or spark begins

Gas valve opens

Burner ignites

Blower starts after delay

Allow to run 10-15 minutes

Shut Down:

Return thermostat to lower temperature

Burner should shut off

Blower continues (fan-off delay)

Blower stops

Inducer stops (if separate post-purge)

Hydronic System:

Fill and Purge:

Fill system slowly to proper pressure (12-15 psi / 83-103 kPa)

Purge air at all high points

Open purge valves at radiators

Run circulators to move air to vents

Refill as needed during purging

Verify Expansion Tank:

Check pre-charge pressure with system drained or isolated

Should equal system fill pressure

Add air if needed

Start Boiler:

Verify gas supply and electrical power

Set aquastat to normal operating temperature

Start boiler per manufacturer instructions

Verify ignition and operation

Check Circulation:

Start zone circulators

Verify flow (watch flow meters if present)

Check for leaks at all connections

Verify heat delivery to zones

Verify Controls:

Test each zone thermostat

Verify zone valves or circulators activate

Check temperature control

Test high limit and safeties

First-Run Observations:

Smooth ignition (no delay, banging, or rollout)

Steady flame (no yellow tips, lifting, or rolling)

No unusual odors or smoke

- No vibration or noise
- Controls operating in proper sequence
- No leaks (gas, water, or combustion products)

Temperature Rise Checks

Temperature rise verification ensures proper airflow and furnace operation.

Purpose:

- Confirms adequate airflow through heat exchanger
- Verifies system operating within design parameters
- Prevents overheating or underheating
- Required for warranty and code compliance

Procedure:

1. Preparation:

- Install accurate thermometers or use calibrated digital thermometer
- Allow furnace to reach normal operating temperature (15-20 minutes)
- Close all doors and windows
- Open all supply registers

2. Measurement Locations:

- **Return air:** In return duct within 6 feet (1.8 m) of furnace, before any branches
- **Supply air:** In supply plenum 2-3 feet (0.6-0.9 m) from furnace, before any branches

3. Temperature Measurement:

- Insert thermometer probes into ductwork (through service port or small hole)
- Place in center of airstream (not touching duct walls)
- Allow to stabilize (1-2 minutes)

Record both temperatures simultaneously

4. Calculate Temperature Rise:

Temperature Rise = Supply Air Temp - Return Air Temp

Example:

Supply air: 135°F (57°C)

Return air: 70°F (21°C)

Temperature rise: 135 - 70 = **65°F (36°C)**

5. Compare to Data Plate:

Furnace data plate lists acceptable temperature rise range

Typical: 40-70°F (22-39°C) for standard furnaces

High-efficiency: 35-65°F (19-36°C) typical

Temperature rise must fall within this range

Interpreting Results:

Temperature Rise Too High:

Indicates insufficient airflow.

Possible Causes:

Dirty or restricted filter

Undersized or blocked ductwork

Closed supply registers

Blower speed set too low

Blower wheel dirty

Belt slipping (belt-drive blowers)

Undersized return air

Corrective Actions:

- Replace filter
- Verify all registers open
- Increase blower speed (if adjustable)
- Clean blower wheel
- Check duct sizing
- Investigate air restrictions

Temperature Rise Too Low:

Indicates excessive airflow or low heat output.

Possible Causes:

- Blower speed set too high
- Oversized ductwork
- Gas pressure too low (underfiring)
- Blocked burners or heat exchanger
- Too much return air

Corrective Actions:

- Decrease blower speed (if adjustable)
- Check and adjust gas pressure
- Inspect burners and clean if needed
- Verify proper temperature rise at high fire (two-stage furnaces)

Special Considerations:

Two-Stage Furnaces:

- Check temperature rise at both low fire and high fire

Both must be within acceptable range

Low fire typically 10-15°F (5-8°C) higher rise than high fire (less airflow)

Modulating Furnaces:

Check at minimum, maximum, and mid-range firing

All should fall within acceptable range

Control adjusts blower to maintain target temperature rise

ECM Blowers:

Some maintain constant CFM regardless of static pressure

Temperature rise should be consistent

Verify blower running at correct RPM or CFM setting

Altitude:

Furnaces derated at altitude

Temperature rise may be different than sea level rating

Consult manufacturer altitude deration tables

Documentation:

Record supply and return temperatures

Calculate and record temperature rise

Note blower speed setting

Compare to data plate range

Include in commissioning report

Combustion Testing Requirements

Combustion testing ensures safe, efficient operation and code compliance.

When Required:

CSA B149.1 and manufacturers require combustion testing:

- New installations
- After service affecting combustion (gas valve, burner, heat exchanger, venting)
- Annual maintenance
- Investigation of problems
- Verification of repairs

Equipment Required:

Combustion Analyzer:

Measures critical combustion parameters.

Measurements:

- Oxygen (O_2): Indicates excess air
- Carbon monoxide (CO): Indicates combustion quality
- Stack temperature: Flue gas temperature
- Draft/pressure: For draft measurement
- Efficiency calculation: Based on above measurements

Types:

- **Flue gas analyzer:** Measures O_2, CO, CO_2, temperature
- **Electronic combustion analyzer:** Calculates efficiency, stores readings
- **Must be calibrated regularly** (annually minimum)

Other Tools:

- Manometer for gas pressure measurement
- Draft gauge
- Thermometers for temperature rise

Gas leak detector

Test Points:

Furnaces:

In flue: Sample port in vent connector within 6-12 inches (150-300 mm) of furnace

Create sample port if not present (3/8 inch / 10 mm hole with removable plug)

Or use built-in test port if provided

Boilers:

Sample port in vent connector or flue outlet

Follow manufacturer test port location

Combustion Testing Procedure:

1. Preparation:

Furnace at normal operating temperature (15+ minutes)

All panels in place (normal operating configuration)

Door interlocks engaged

Access only through test ports

2. Insert Probe:

Insert combustion analyzer probe into sample port

Position in center of flue gas stream

Seal around probe (prevents air dilution)

Allow analyzer to stabilize (30-60 seconds)

3. Record Measurements:

Oxygen (O_2):

Indicates excess air in combustion

Lower O_2 = less excess air (more efficient but potentially incomplete combustion)

Typical range: 5-9% O_2

Below 5%: May indicate incomplete combustion, check CO

Above 10%: Excess air, reduced efficiency

Carbon Monoxide (CO):

Indicates combustion quality

Should be very low in properly-adjusted appliance

Acceptable: Less than 100 ppm air-free (undiluted)

Target: Less than 50 ppm air-free

High CO indicates problem requiring correction

Carbon Dioxide (CO_2):

Inverse of O_2 (more CO_2 = less excess air)

Natural gas: 8-10% CO_2 typical

Propane: 10-12% CO_2 typical

Stack Temperature:

Flue gas temperature

Indicates heat exchanger efficiency

Non-condensing: 300-500°F (149-260°C) typical

Condensing: 100-140°F (38-60°C) typical

Excessive: May indicate blocked heat exchanger or overfiring

Draft:

Measured at draft hood (natural draft) or test port

Natural draft: -0.02 to -0.04 in. W.C. (-5 to -10 Pa)

Induced draft: -0.10 to -0.50 in. W.C. (-25 to -124 Pa) typical

Verify manufacturer specifications

Efficiency:

Combustion analyzer calculates based on O_2, CO_2, and stack temperature

Should be close to AFUE rating

Lower indicates problem or normal seasonal variation

Gas Pressure:

Inlet Pressure:

At furnace gas valve inlet

**Natural gas: 4-10 inches W.C. (1.0-2.5 kPa