1. Properties and safe handling of fuel gases

Overview

Purpose

A gas technician/fitter must know the physical properties and combustive elements of the most common fuel gases. If their physical properties are understood, the technician/fitter can troubleshoot and adjust equipment appropriately.

Objectives

At the end of this Chapter, you will be able to:

- describe the common fuel gases;
- identify the properties and characteristics of natural gas and propane; and
- identify combustion data.

Terminology

Term	Abbreviation (symbol)	Definition
Boiling point		Temperature at which the vapour pressure of the liquid equals the pressure surrounding the liquid and the liquid changes into a vapour
Boyle's Law		$p_1V_1 = p_2V_2$ Absolute pressure that a given mass of an ideal gas exerts is inversely proportional to the volume it occupies if the temperature and amount of gas remain unchanged within a closed system
British Thermal Units	Btu	Amount of energy needed to cool or heat one pound of water by 1°F
Calorific value		Energy released during combustion of a given volume of fuel
Gas: Dry gas		Natural gas with all the heavier hydrocarbons removed
Gas: Natural gas		Naturally occurring mixture of hydrogen (H) and carbon (C) and other gases Usually represented by the chemical formula for methane (CH_4)

CSA GROUP

CSA Group Gas Trade Training Materials – Red Seal Alignment

Red Seal		CSA Gas Trade Unit	1	2	3	4	4A	5	6	7	8	9
2014 Red Seal Block	2014 Red Seal Task	Title	Safety	Fasteners, Tools and Testing Instruments	Properties, Characteristics, and Safe Handling of Fuel Gases	Utilization Codes, Acts and Regulations	Utilization Codes, Acts, and Regulations – Ontario Supplement	Introduction to Electricity	Technical Manuals, Specifications, Drawings and Graphs	Customer Relations	Introduction to Piping and Tubing Systems	Introduction to Gas Appliances
A - Common Occupational Skills	Task 1	Performs safety-related functions.	✓									
	Task 2	Maintains and uses tools and equipment.	✓	✓	✓							
	Task 3	Plans and prepares for installation, service and maintenance.	✓			✓	✓	✓	✓			
B - Gas Piping Preparation and Assembly	Task 4	Fits tube and tubing for gas piping systems.									✓	
	Task 5	Fits plastic pipe for gas piping systems.									✓	
	Task 6	Fits steel pipe for gas piping systems.									✓	
C - Venting and Air Supply Systems	Task 7	Installs venting.									✓	✓
	Task 8	Installs air supply system.										
	Task 9	Installs draft control systems.										
D - Controls and Electrical Systems	Task 10	Selects and installs electronic components.						✓				
	Task 11	Selects and installs electrical components.										
	Task 12	Installs automation and instrumentation control systems.										
E - Installation of Systems and Equipment	Task 13	Installs gas-fired system piping and equipment.									✓	✓
	Task 14	Installs gas-fired system components.										
	Task 15	Installs propane storage and handling systems.										
F - Testing & Commissioning of Gas-fired Systems	Task 16	Tests gas-fired systems.										
	Task 17	Commissions gas-fired systems.	✓	✓	✓	✓	✓	✓			✓	✓
G - Servicing Gas-fired Systems	Task 18	Maintains gas-fired systems.										
	Task 19	Repairs gas-fired systems.										✓
	Task 20	Decommissions gas-fired systems.	✓	✓	✓	✓	✓	✓			✓	✓

Term	Abbreviation (symbol)	Definition
Gas: Liquid petroleum gases – LP gases		Hydrocarbons that have undergone refining, storage, and transport as a liquid under pressure (C3H8)
Heat content		Same as calorific value
Kilopascal	kPa	Unit of pressure measurement
Mega joules per cubic meter	MJ/m^3	Measurement for calorific value
Mercaptan		Odorant added to natural gas and propane for safety
Pounds per square inch gauge	psig	Pressure measurement relative to atmospheric pressure
Relative density		Same as specific gravity
Specific gravity		Comparison between the weight of the volume of a vapour or liquid and the weight of an equal volume of air or water
Upper explosive limit	UEL	Highest concentration (percentage) of a gas or vapour in the air capable of producing a flash of fire in the presence of an ignition source (arch, flame, and heat)
Vapour pressure		Pressure that a vapour exerts in equilibrium with its solid or liquid phases

Common fuel gases

When animal and vegetable matter decays in the absence of air, the tiny organisms that function only in an oxygen-free environment form gases. The most common gas formed is methane, which is the major ingredient in fuel gas. You can observe methane production at landfills, which isolates garbage and excludes air. In swamps and tidal flats, you can see bubbles of methane gas rising through the mud. These are the beginnings of a millions-of-years-old process: the creation of fossil fuels, or petroleum gases.

The petroleum gases that the gas industry most commonly use are natural gas and its two processed derivatives, propane and butane. In this course, you will deal with natural gas and propane. They come from a group of gases composed of hydrogen and carbon, the hydrocarbons.

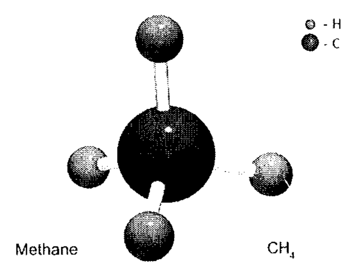
Natural gas

Natural gas is a naturally occurring mixture of hydrogen (H) and carbon (C) and other gases. A typical breakdown of the components of natural gas is as follows:

Percentage	Gas	Formula
87.40%	Methane	CH_4
6.80%	Ethane	C_2H_6
3.20%	Nitrogen	N
1.55%	Propane	C_3H_8
0.81%	Butane	C_4H_{10}
0.14%	Carbon dioxide	CO_2
0.10%	Oxygen	O

Since 85%-95% of its content is methane, for convenience, the chemical formula for methane (CH_4), as shown in Figure 1-1, usually represents natural gas. Methane is also called "the gaseous phase of petroleum" because it is usually present wherever petroleum oil is in formation. It is the most stable of hydrocarbons, existing unchanged at temperatures of up to 1022°F (550 ° C).

Figure 1-1
The chemical structure of methane (CH_4)



Coal generates methane as it matures, and often, large quantities of natural gas can be found locked into coal seams.

Different types of gas

A gas technician/fitter should be familiar with the terms that distinguish the different types of natural gas.

Term	Description
Wet gas	Wet gas is natural gas containing the heavier hydrocarbons: propane, butane, pentane, hexane, and heptanes. They are normally extracted immediately after the gas is brought to the surface. The gas industry uses the extracted propane and butane as liquefied petroleum gases (LP-gases). Wet gas extracts are also valuable to the petrochemical industry.
Dry gas (or processed natural gas)	Dry gas is natural gas with all the heavier hydrocarbons removed. It is stored in underground storage tanks for use as a fuel gas.

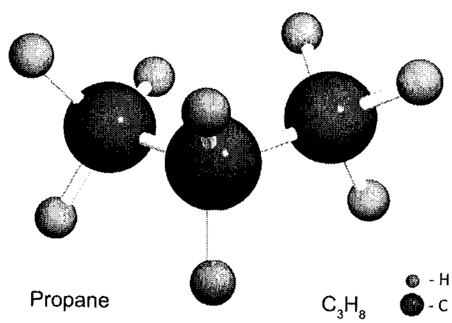
Term	Description
Sour gas	Sour gas contains a high percentage of hydrogen sulphide. It produces carbon black, a common ingredient used in rubber products.
Sweet gas	Sweet gas is natural gas with little or no hydrogen sulphide content.

Propane

LP-gases (of which propane is the most common) are hydrocarbons extracted from both oil and natural gas that have undergone refinement, storage, and transportation as a liquid under pressure, followed by vapourization into a fuel gas when released for use in a gas burning appliance.

Figure 1-2 illustrates the chemical formula C_3H_8, which represents propane.

Figure 1-2
The chemical structure of propane (C_3H_8)



Composition of LP-gas

Both propane and butane are extracted from petroleum oil and natural gas. After their separation into a liquefied state from wet natural gas, fractionation (chemical separation) into their final processed forms occurs.

- Processed propane is normally 100% pure.
- Butane, when processed, is 93% pure, with 7% propane added.

Under normal atmospheric temperature and pressure, propane and butane are gases. At cooler temperatures and at higher pressures, both easily changes into liquid form.

Properties and characteristics of natural gas and propane

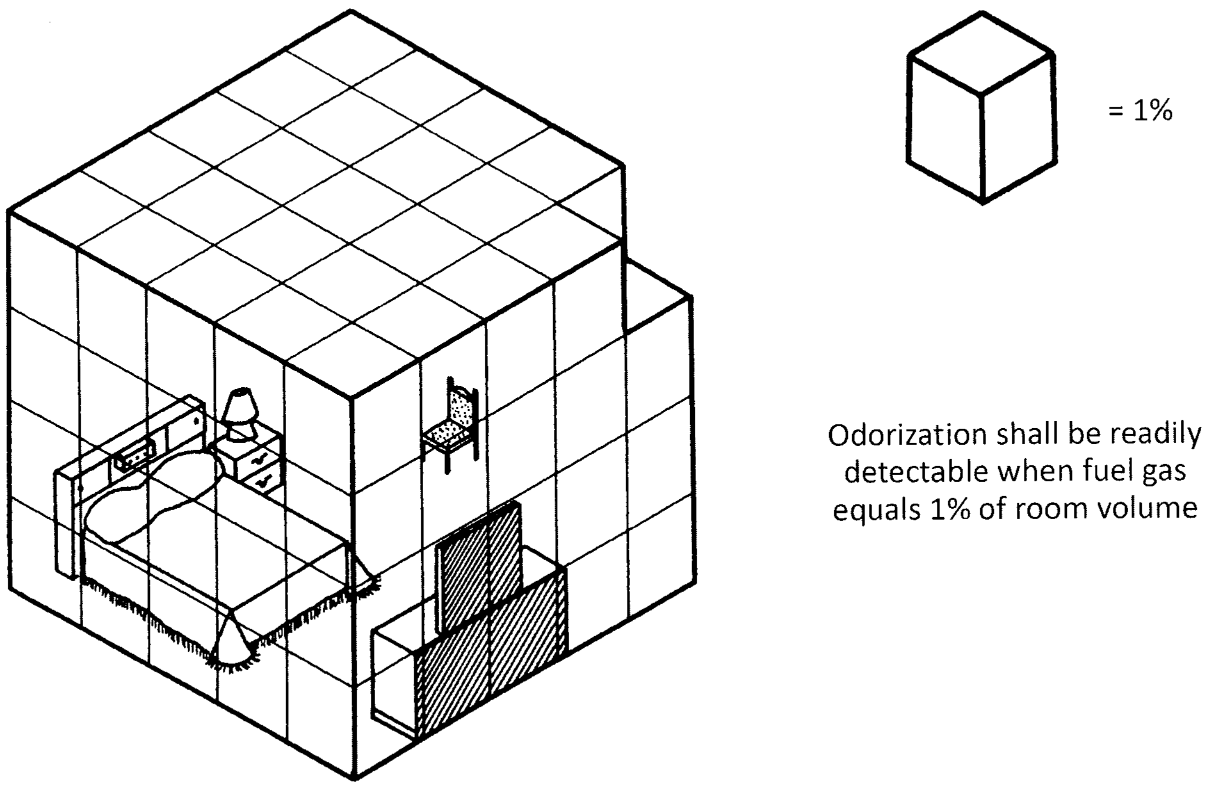
Several physical properties are common to natural gas and propane. It is important for a gas technician/fitter to be thoroughly familiar with these when working in different aspects of fuel delivery and utilization.

Common properties

Natural gas and propane are nontoxic, tasteless, colorless, invisible, and odorless.

Since your sense of smell cannot detect the gases, safety requires the addition of an odorant known as mercaptan to natural gas and propane. The chemical formula for ethyl mercaptan typically used in natural gas is C_2H_6S. Mercaptan alerts the user of a gas escape and the possible danger of explosion or fire. To detect a gas leak below its lower flammable limit, every one million cubic feet of gas should have approximately one pound of mercaptan.

Figure 1-3
Insight to the suggested concentration of Odorization for effective detection of fuel gases



Other properties

A gas technician/fitter should be familiar with a number of the physical properties of fuel gas. These include:

- specific gravity;
- expansion factors;
- boiling point;
- temperature and pressure relationships; and
- calorific value (heat content).

Specific gravity

Specific gravity, or relative density, is the comparison between the weight of the volume of a vapour or liquid and the weight of an equal volume of air or water. You must know the specific gravity of a gas when you are:

- checking for gas leaks;
- calculating flows through gas piping systems; and
- sizing orifices.

Specific gravity of vapour gases and air

When comparing the specific gravity of air and gas, ensure that both are at the same pressure and temperature.

Air has a specific gravity of 1.0. With a specific gravity of 0.55, natural gas is lighter than air and will rise to the ceiling of a room. Both propane and butane are heavier than air, so if a leak develops in a gas line or appliance, LP-gas is likely to settle in low areas. This is an important consideration when trying to find the source of a leak or working where a leak has occurred. Figure 1-4 demonstrates the specific gravity of the three common fuel gases and air.

Figure 1-4
Specific gravity of common fuel gases (vapour)

	Sg
Methane CH_4	0.6
Air	1.0
Propane C_3H_8	1.52 or 1.53
Butane C_4H_{10}	1.95 or 2

Specific gravity of LP-gases

The specific gravity of LP-gas is normally compared to water, which has a specific gravity of 1.0. Understanding liquid specific gravity can be useful in the following cases:

- During delivery of propane to a plant, the liquid specific gravity marked on a bill of lading helps you check the type and amount of LP-gas delivered.
- During filling, you may use the liquid specific gravity to determine the proper filling limit to prevent overfilling of the tank.

Figure 1-5 compares the specific gravity of water with that of propane and butane.

Figure 1-5
Specific gravity of liquefied gases

	Sg
Propane C_3H_8	0.509 or 0.51
Butane C_4H_{10}	0.58
Water H_2O	1.0

Expansion factors

It is important to understand the behaviour of propane inside a container and the effect of heat on its liquid state. When the temperature of a liquid is increased, the liquid expands with a resulting increase in its volume. This is stated in Boyle's Law, which concerns the relationship between pressure and volume in gases, i.e., $p_1V_1 = p_2V_2$.

Allowing an expansion space between the level of liquid and the top of the container requires filling LP-gas containers to a maximum of 80%. Vapour forms above the liquid to fill the space left for expansion. The molecular movement of LP-gas vapours results to vapour pressure. Withdrawing LP-gas vapour from a container lowers the vapour pressure. This causes the remaining liquid gas to boil and replace the vapour, stabilizing the reduced pressure in the tank.

When a fuel changes from liquid to gas, a tremendous expansion takes place. At atmospheric pressure, the expansion ratio of liquid to gases is:

Gas	Ratio
Natural gas	1: 600
Propane	1: 270

This information can be useful when calculating the volume of vapour available from a volume of liquid fuel.

Boiling point

Because LP-gas is subject to temperature changes, the temperature of the liquid determines the pressure in the container. At atmospheric pressure:

- Natural gas has a boiling temperature of −260°F (−162.2 °C).
- Propane has a boiling temperature of −44°F (−42.2 °C).

A gas technician/fitter almost always handles natural gas in the gaseous state. (The utility company may, however, store liquefied natural gas for use during high demand periods.)

Temperature and pressure relationships

Vapour pressure is directly related to the temperature of the liquid in an enclosed container. If the temperature of a fuel gas lower than its boiling point, it will not vapourize, and no vapour pressure will develop. As the LP-gas temperature increases, so does the pressure increase in the storage tank.

Liquefication of natural gas is only possible at very low temperatures and/or very high pressures so the gas technician/fitter always finds it in a gaseous state. However, in enclosed cylinders, propane is commonly in its liquid state. You can maintain this liquid state at temperatures above −44°F, if you increase the pressure above atmospheric. Refer to Table 1-1.

The temperature-pressure relationship is such that as the pressure is increased, the boiling temperature (saturation point) becomes progressively higher. When vapour exhausts from the cylinder, the pressure drop causes the boiling temperature to drop and the liquid starts to vapourize to maintain the temperature-pressure relationship. The boiling stops when the vapour pressure is high enough to suppress the boiling of the liquid at that temperature.

The pressure always varies with the temperature, not with the liquid content of the cylinder. For example, the pressure in a cylinder that is 30% full is the same as the pressure when it is 60% full.

Note that butane has similar characteristics to propane. The biggest factor in the nonuse of butane in Canada is that its boiling temperature is 32°F (0 °C). At that same temperature, butane has a vapour pressure of zero.

Table 1-1
Temperature/pressure relationship of propane

Temperature		Vapour pressure		Temperature		Vapour pressure	
°F	°C	psig	kPa	°F	°C	psig	kPa
−45	−43	0.0	0.0	50	10	77.1	531.3
−40	−40	1.5	10.3	55	13	84.6	583.0
−35	−37	3.4	23.4	60	16	92.4	645.1
−30	−34	5.6	38.5	65	18	100.7	694.0
−25	−32	8.0	55.1	70	21	109.3	753.3
−20	−28	10.7	73.7	75	24	118.5	816.7
−15	−26	13.6	93.7	80	27	128.1	882.8
−10	−23	16.7	115.1	85	29	138.4	953.8
−5	−21	20.0	137.8	90	32	149.0	1 026.9
0	−17.8	23.5	161.9	95	35	160.0	1 102.7
5	−15	27.2	187.4	100	38	172.0	1 185.4
10	−12	31.3	215.7	105	40	185.0	1 275.0

(Continued)

Table 1-1 (Concluded)

Temperature		Vapour pressure		Temperature		Vapour pressure	
°F	°C	psig	kPa	°F	°C	psig	kPa
15	−10	35.9	247.4	110	43	197.0	1 357.7
20	−7	40.8	281.2	115	46	211.0	1 454.2
25	−4	46.2	318.4	120	49	225.0	1 550.7
30	−1	51.6	355.6	125	52	239.0	1 647.2
35	2	57.3	394.9	130	54	257.3	1 773.3
40	4	63.3	436.2	135	57	273.3	1 883.5
45	7	69.9	441.7	140	60	290.3	2 000.7

Calorific value (heat content)

The calorific value (heat content) of a fuel usually refers to the energy released during combustion of a given volume of fuel. Generally, the Units of measurement used are British Thermal Units per cubic foot (Btu/ft^3) or mega joules per cubic meter (MJ/m^3).

A Btu is the amount of heat required to raise the temperature of 1 lb of water 1°F.

The calorific value of natural gas varies from gas well to gas well because of the different components of natural gas. You need to understand the calorific value of gases when calculating input rates to appliances.

- The gas industry usually accepts the following **calorific values** for natural gas and propane.
- For convenience when working with appliance input rates in kilowatts, you can express the **metric calorific values** in kW/m^3, as provided.

Gas	Calorific value	Metric calorific value
Natural gas	1,000 Btu/ft^3 or 0.030 MJ/m^3	10.35 kW/m^3
Propane	2520 Btu/ft^3 or 0.075 MJ/m^3	26 kW/m^3

Table 1-2 summarizes the properties of natural gas and propane discussed in this section.

Table 1-2
Properties of natural and propane (values approximate)

Properties	Natural gas	Propane
Formula designation	CH_4	C_3H_8
Toxicity	Nontoxic	
Physical properties	Colourless, tasteless, and odourless	

(Continued)

Table 1-2 (Concluded)

Properties	Natural gas	Propane
Odorant	Mercaptan	
Specific gravity-vapour	0.55	1.52
Specific gravity-liquid	—	0.51
Weight-liquid propane	—	5.1 lb/imp gal
Vapour expansion–ft^3 (vapour from ft^3 liquid)	600 ft^3 (17 m^3)	270 ft^3 (7.6 m^3)
Boiling point	−260°F (−162 °C)	-44°F (−42 °C)
Calorific value–Btu/ft^3 (vapourized)	1 000 Btu/ft^3 (0.030 MJ/m^3) (10.35 kW/m^3)	2 520 Btu/ft^3 (0.075 MJ/m^3) (26 kW/m^3)
Calorific value–Btu/lb (vapourized)	23 875	21 622

Combustion data

In this section, you identify combustion data related to the physical properties of natural gas and propane.

Property	Description
Limits of flammability	Limits of flammability are the upper and lower ranges of gas in the air-gas mixture that supports combustion. You must know these limits in order to supply the correct amount of air to gas burners or troubleshoot burner problems. Also, knowing the limits of flammability is key to responding to a gas leakage call. The lower flammable limit is the weakest air-gas mixture that burns. The upper limit is the strongest air-gas mix that produces and sustains combustion. Too low an amount of fuel makes the mixture "lean." Too high an amount of fuel renders the mix too "rich."
Ignition temperature	Ignition temperature is the temperature at which an air-gas mixture initiates and supports combustion. It varies according to the fuel gas used.

Property	Description
Flame temperature	You can only reach maximum flame temperature at perfect combustion, which is the theoretical point at which combustion may occur. In practice, the gas technician/fitter provides excess air to provide enough oxygen to ensure the complete combustion of the fuel. Each fuel gas has its own maximum flame temperature.
Flame speed	Flame speed is the speed at which the flame front moves towards the air-gas mixture issuing from the burner port (Figure 1-6). Flame speed depends on the quantity of air in the air–gas mixture and the type of gas you are using.

Figure 1-6
Flame front moving towards air-gas mixture

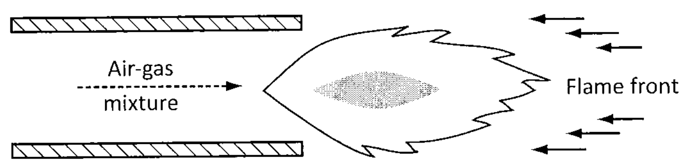


Table 1-3 summarizes the combustion data.

Table 1-3
Combustion data (values approximate)

Item	Natural gas	Propane
Limits of flammability	4–15%	2.4–9.5%
Ignition temperature	1 300°F (700 °C)	920°F (495 °C)
Maximum flame temperature	3 600°F (1980 °C)	3 600°F (1980 °C)
Flame speed* *Approximate flame speed based on Bunsen-type burner test method.	12 in/s (305 mm/s)	11 in/s (280 mm/s)

Chapter 2. *Combustion* explains the principles of combustion.

Assignment Questions – Chapter 1

1) What is the main component of natural gas?
   a) Butane
   b) Methane
   c) Propane
   d) Carbon