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# First Law of Thermodynamics:

Change in energy = Heat - Work

For cycles that start and end at same point, = 0

For a steam engine, we want heat in and work out, thus those are the positive values.

in: from surrounding to system out: from system to surrounding

|  | Metric | English |
| --- | --- | --- |
| Work | kJ | Btu |
|  |  |  |

Audiobatic:

# Polytropic Processes:

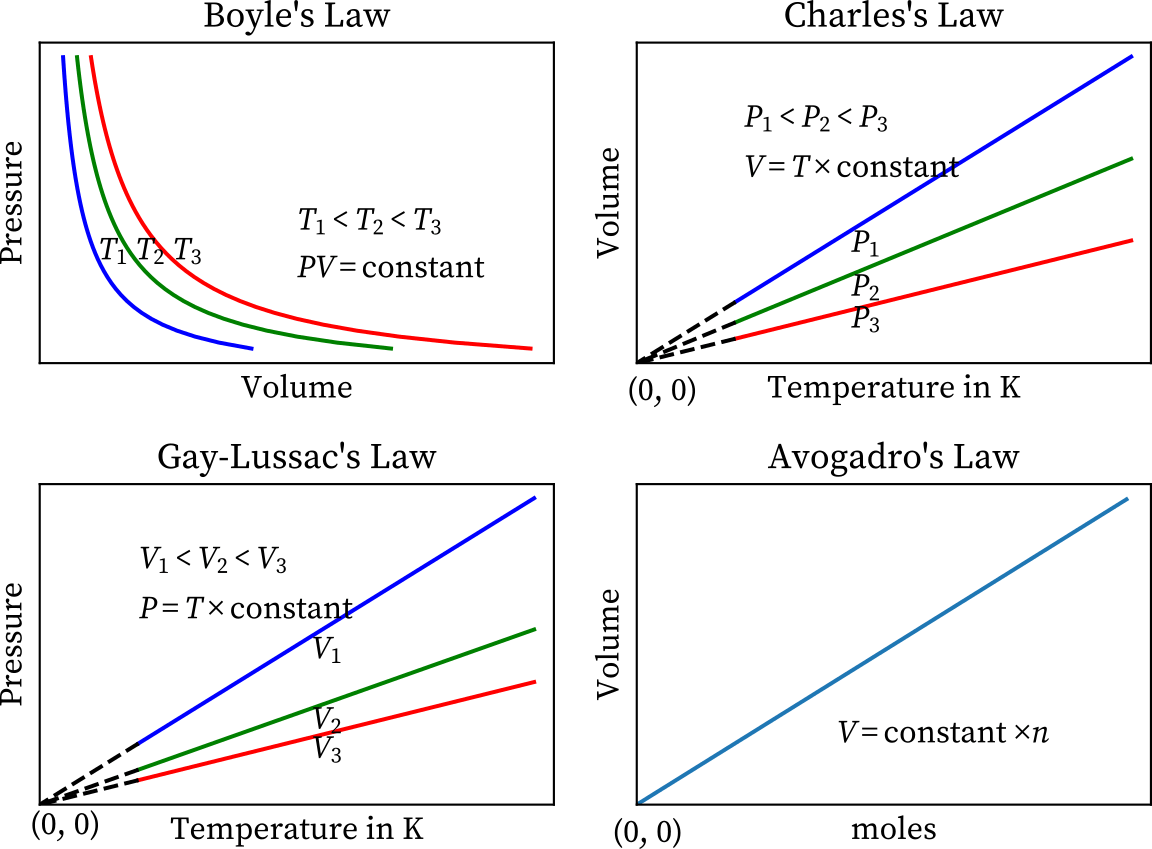
| Always |  |
| --- | --- |
|  |  |
|  |  |

# Polytropic Ideal Gasses:

| Isothermal: |  |  |
| --- | --- | --- |
|  |  |  |

# Ideal Gases:

Ideal gases are far from the vapor dome



, and all other properties are only defined by T

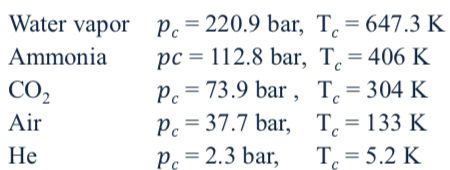
If and are constant-ish: Not large change in and

# Approximating Ideal Gases:

Compressibility factor: If , then you can assume Ideal

Reduced Values, look at compressibility chart:

“c” values by substance can be found in a table



Specific heat, general:

When volume is constant:

When pressure is constant:

# Thermodynamic Cycles:

Note: we are taking the absolute values of andfor these below:

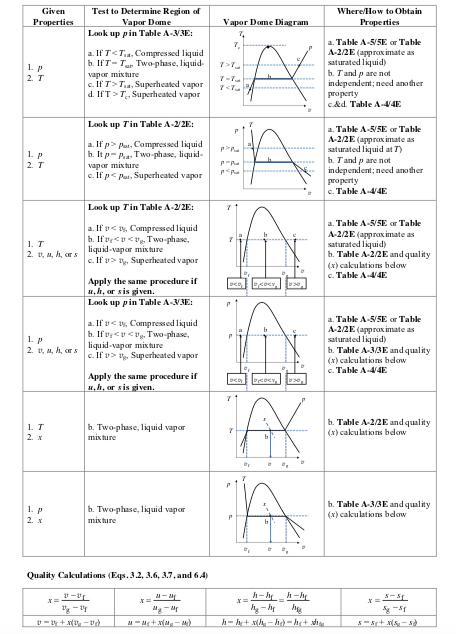
| Power Cycle |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Refrigeration Cycles |  |  |  |  |  |
| Heat Pump |  |  |  |  |  |

Power Cycle: Tradition cycle, take heat and give out work

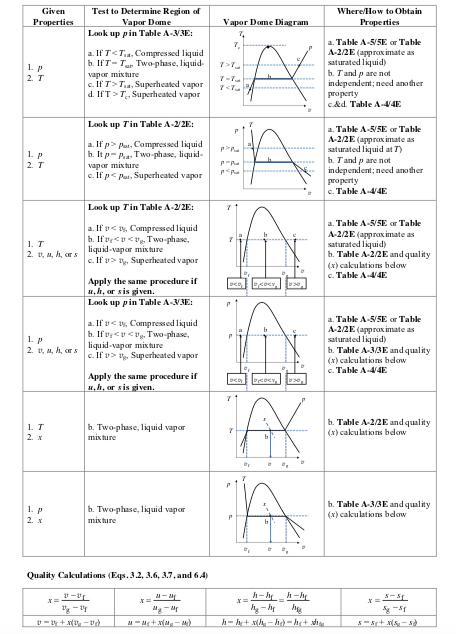
Refrigeration cycle: Use work to take heat out of something cold, making it colder

Heat Pump: Use work to heat up from something cold/neutral to make something hot

# Vapor Dome:

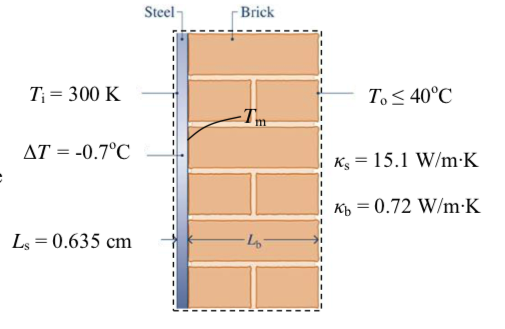


## Interpolation (Linearization):



# Heat Transfer:

Conduction:



is the same for the whole material:

Convection:

Radiation:

based of surface

# 

# Types of Power:

# Open Systems:

Flow of energy:

Enthalpy

## At steady state:

If one inlet and outlet: conservation of mass

Integrate over time

# Engineering Devices:

at steady state

## Nozzle/Diffuser (if Q = 0)

## Turbine/Compressors/Pumps/Fans (if Q = 0)

## Throttling devices: decrease the pressure (if Q = 0)

## Heat exchanger:

When heat is exchanged within the system:

Heat is from surrounding:

# Second Law of Thermodynamics:

Kelvin Planck Statement:

Heat must flow from one reservoir to another

If you have **one reservoir**, you can’t get more work out

work can only go in and go to heat

no irreversibilities

some irreversibilities

Carnot corollaries:

1. The thermal efficiency of an irreversible power cycle is always less than the thermal efficiency of a reversible power cycle when each operates between the same two thermal reservoirs.
2. All reversible power cycles operating between the same two thermal reservoirs have the same thermal efficiency.

# Entropy:

None reversible:

Entropy Rate Balance:

## Incompressible Liquid:

Constant density/specific volume/pressure

## Ideal Gases:

Assumingandis relatively constant:

Air only:

only:

Assumingandis relatively constant and only:

# Efficiency/Coefficient of Performances:

Ratio:

| Power Cycle |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Refrigeration Cycles |  |  |  |  |  |  |
| Heat Pump |  |  |  |  |  |  |

Open System Entropy:

At steady State:

One inlet, one outlet:

# Carnot Cycle:

| Adiabatic Compression From to  Isothermal expansion at  Adiabatic Expansion from to  Isothermal compression at |  |
| --- | --- |

# Rankine Cycle:

A subsystem of a power plant

## Ideal Rankine Cycle:

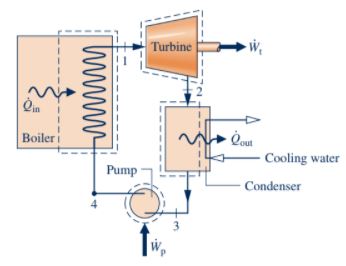


1-2: Isentropic Expansion from saturated vapor to condenser pressure

2-3: Isobaric condensation to a saturated liquid

3-4: Isentropic compression to subcooled liquid

4-1: Isobaric evaporation to saturated vapor





## Superheated Rankine Cycle:

Same as Ideal except state 1

1-2: Isentropic expansion from superheated vapor to condenser pressure

2-3: Isobaric condensation to a saturated liquid

3-4: Isentropic compression to subcooled liquid

4-1: Isobaric evaporation to superheated vapor

## Reheat Rankine Cycle:



Often used when combustion used to heat stage 5-6 produces extra energy

1-2: Isentropic expansion from superheated vapor to

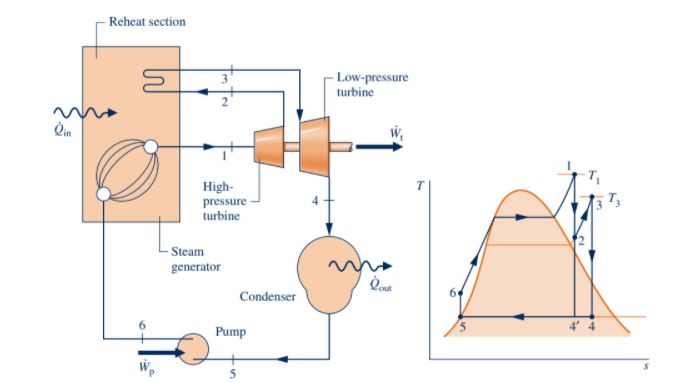
2-3: Isobaric heating using extra energy from an excess combustion

3-4: Isentropic expansion to

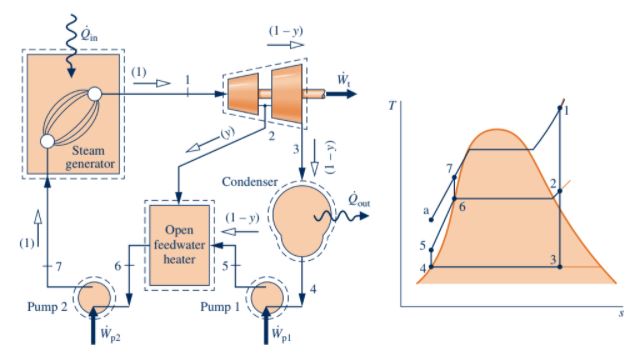
4-5: Isobaric condensation to a saturated liquid

5-6: Isentropic compression to subcooled liquid

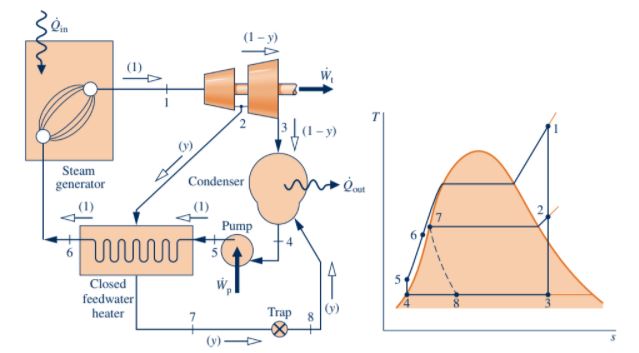
6-1: Isobaric evaporation to superheated vapor



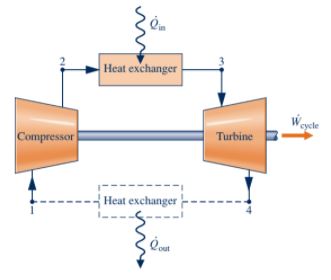
Regenerative Open Feedwater Heater:



Closed Feedwater Heater:



# Brayton Cycle:



1-2 Adiabatic compression

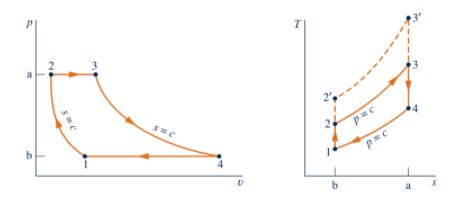
2-3 Isobaric heating

3-4 Adiabatic expansion

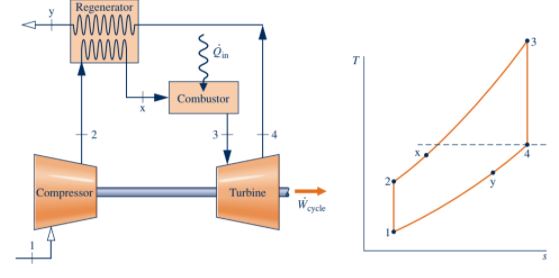
4-1 Either lose to atmosphere modeled as isobaric heating

Cold Air Approx: contact spec heats at 300K

Second part is only with cold air approx

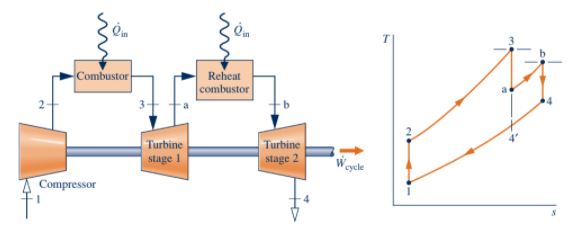


## Regenerative Gas Turbine:



If then:

## Reheat gas turbines:



Ideally

## 

## 

## 

## Intercooled gas:

Idea is that isothermal is less work input for the same pressure raise.

Look at the shaded area that we avoided.

Adding intercooler approximates isothermal more

### Pressure ratio:

For turbines you want :

## 

## Ericsson Cycle:

Infinite intercooling and reheating

# Reciprocating engine equations:

Volume ratio:

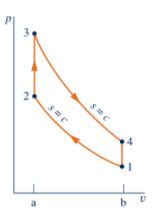
## Break Power Output

Power at crankshaft: 4-stroke: 2-stroke:

is the number of cylinders, is rev/sec

## Mean Effective Pressure:

# Otto Cycle:

Volume ratio: Efficiency: 

1-2: Isentropic compression of air in the piston(Compression stroke)

2-3: Isochoric heat addition. This is because fuel lighting combustion happens so fast, it is like the volume doesn’t change (start of power stroke)

3-4: Isentropic expansion of piston (finish of power)

4-1:Isochoric heat rejection (exhaust and intake)

Using yields:

## Cold Air Otto:

# Diesel cycle:

Cut off ratio:

1-2: Isentropic compression

2-3: Isobaric heat addition. Compression is needed to ignite injected fuel

3-4: Isentropic expansion

4-1: Isochoric heat rejection

because constant pressure

Use ideal gas law to find states:

## Cold Air Diesel:

# Dual Cycle:

Combined otto and diesel assumptions

# Ideal Stirling cycle:

1-2: Isothermal heat addition

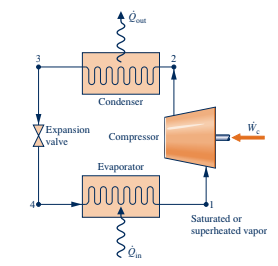
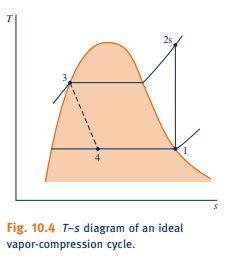
2-3: Isochoric regeneration (storing heat somewhere else)

3-4: Isothermal heat removal

4-1: Isochoric regeneration (take heat from the stored heat)

# Refrigeration cycles:

## Vapor-Compression refrigeration:



1-2: Isentropic/Adiabatic compression

2-3: Isobaric heat rejection

3-4: Isenthalpic/Adiabatic expansion

4-1: Isobaric heat addition

The “refrigerator” would be known as the cold reservoir. In order to ensure heat flow, the fluid at 4 must be colder than the cold reservoir and hotter than the hot reservoir at 3

Heat flows from fluid to hot reservoir

Heat flows from cold reservoir to fluid

and

# *Moist* Air

Dalton Model:

For water vapor (v) and air (a)

## Partial pressure

Arbitrary component (i):

## Properties

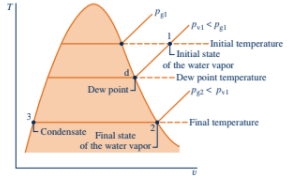
Arbitrary properties (B):

Mass fraction and mole fraction:

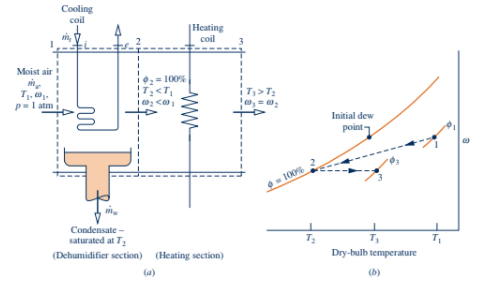
## Humidity ratio

## Relative humidity

## Dew point temperature



Dehumidifier



# Psychrometric chart:

Given a point:

Vertically down to axis: Dry-Bulb temp

Horizontally right to axis: Humidity ratio

Horizontally let to: Dew Point temp

Diagonally up/left to: Wet-Bulb temp