وزارة التعليم العالي والبحث العلمي
جامعة الفرات الاوسط التقنية
المعهد التقني النجف

Introduction to Thermodynamics

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What's the thermodynamics

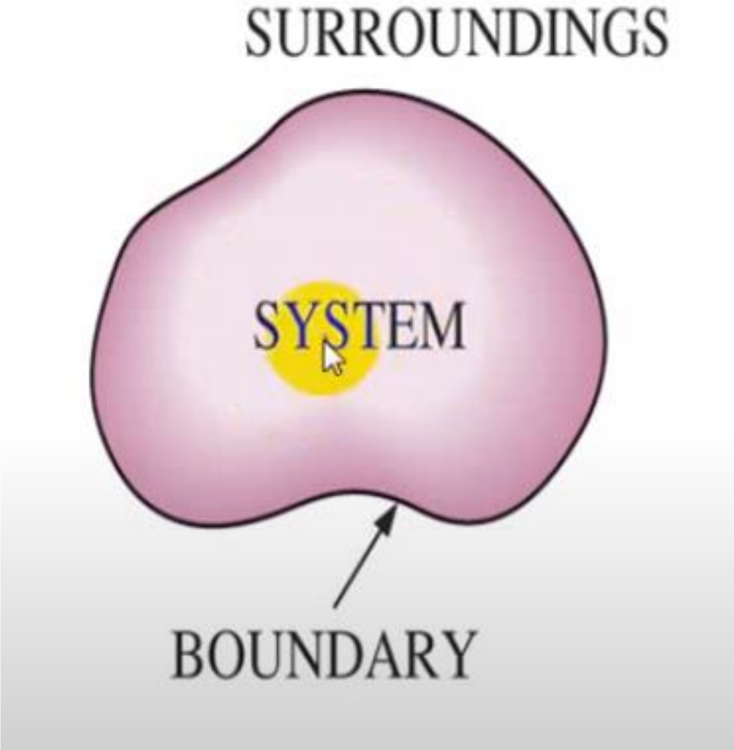
- The science of energy that concerned with the ways in which energy is stored within a body
- Energy transformation – mostly involve heat and work movement
- thermodynamics is the science that deals with interaction between energy and material systems

- The fundamental law is the conservation of energy principle: energy cannot be created or destroyed, but can only be transformed from one form to another

System, surroundings and boundary

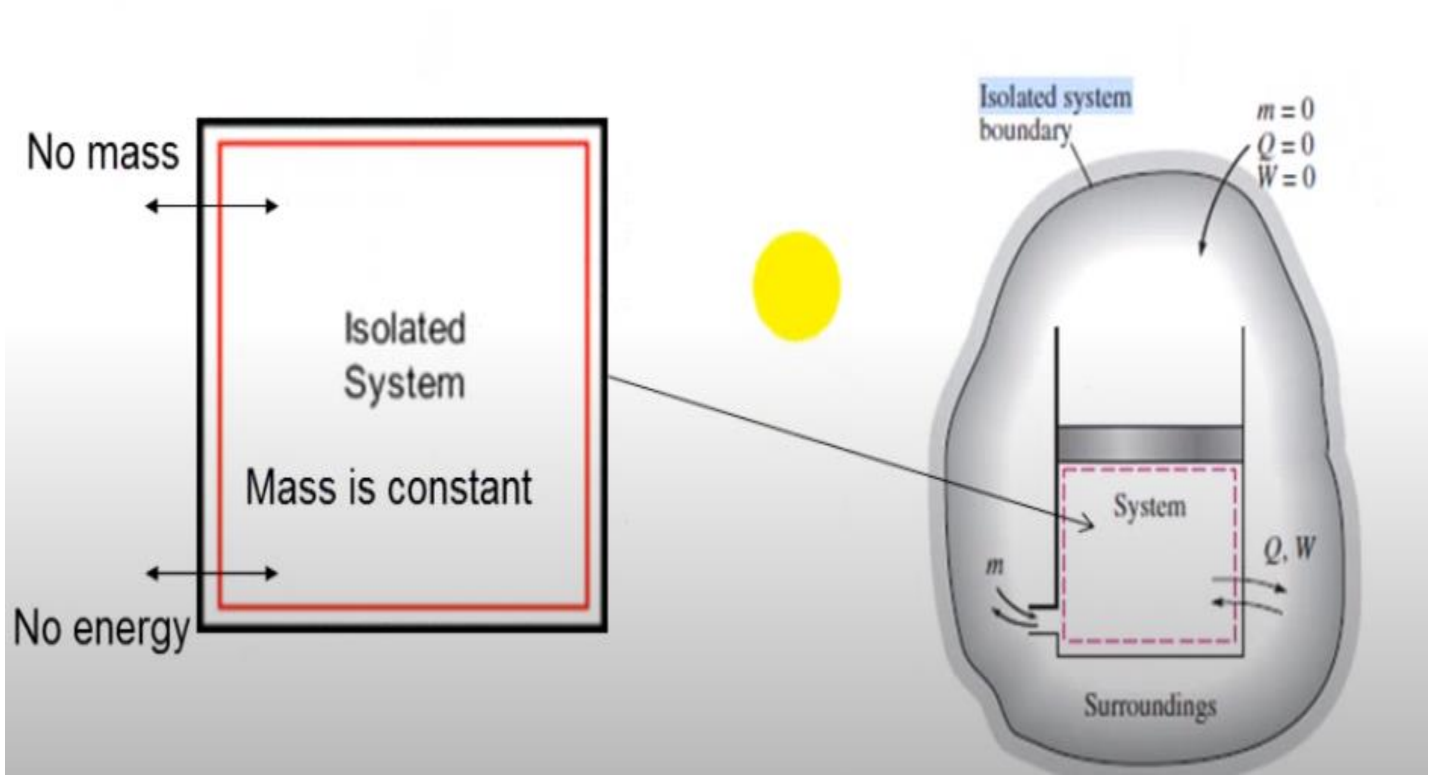
- System: a quantity of matter or a region in space chosen for a study
- surroundings: the mass or region outside the system
- Boundary: the real or imaginary surface that separates the system from its surroundings

System, surroundings and boundary

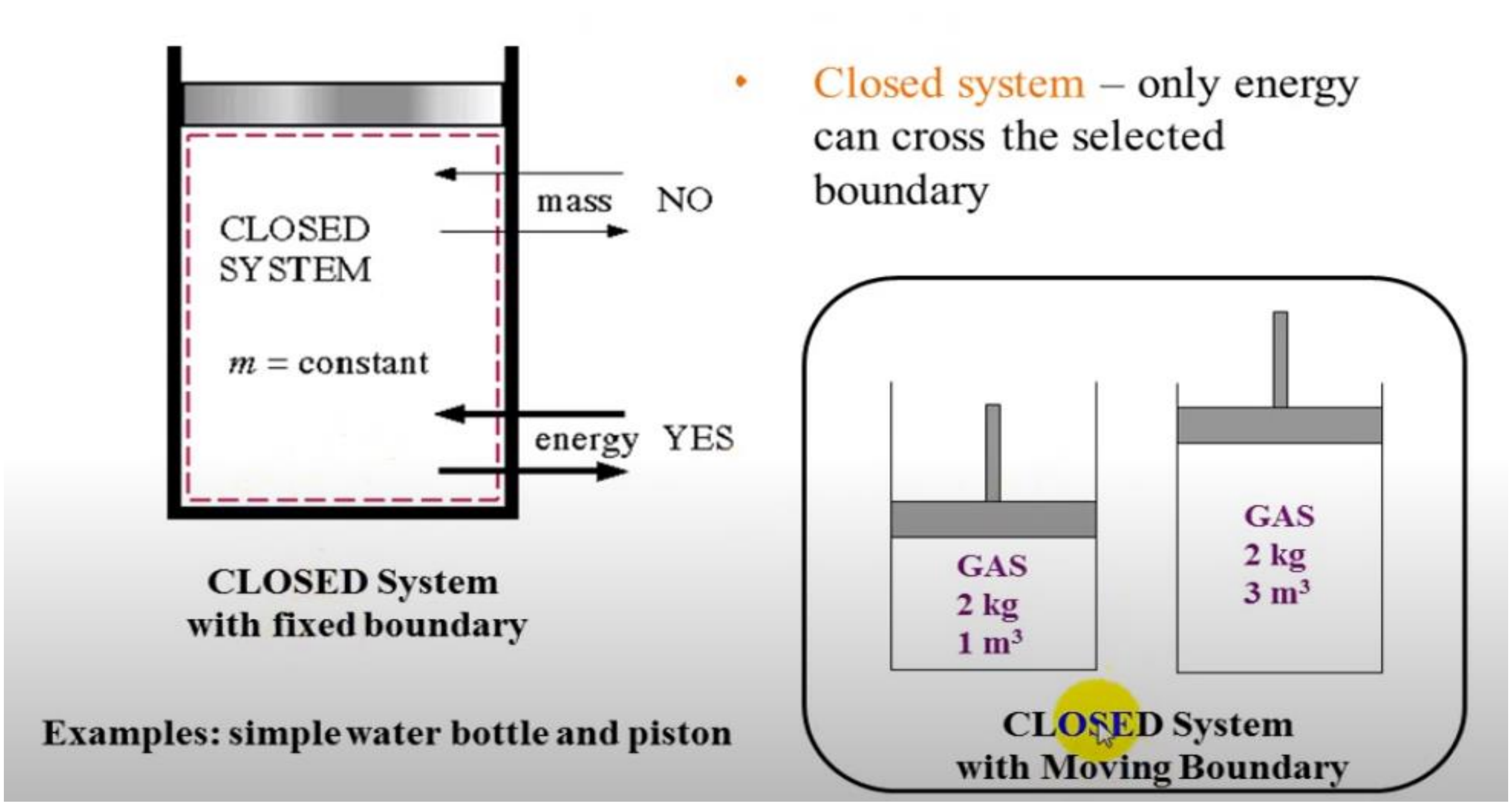


Types of systems

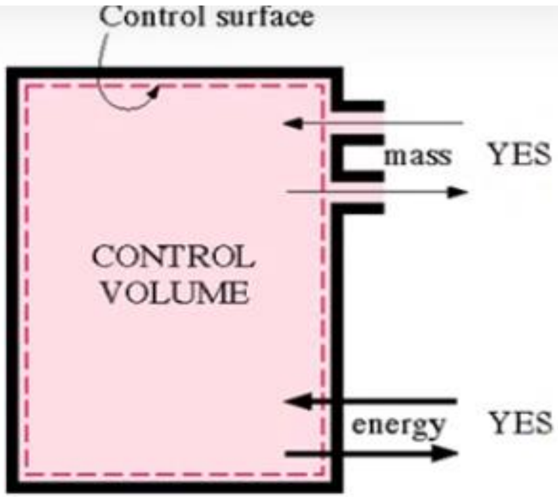
- Isolated system- neither mass nor energy can cross the selected boundary
- Example – coffee inside the bottle or container



- Closed system –only energy can cross the selected boundary



3- open system- both mass and energy can cross the selected boundary

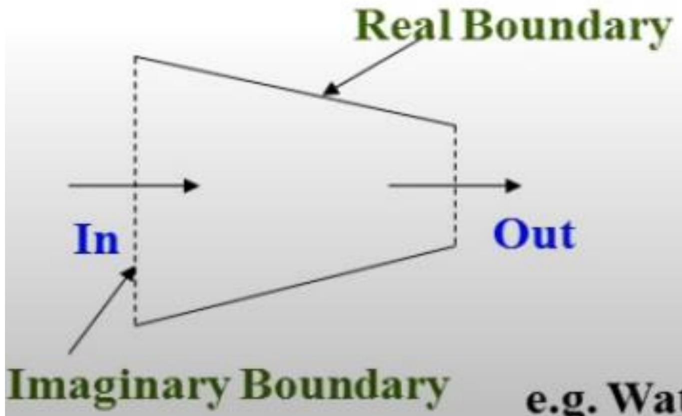


(3. Open system)

- Open system – both mass and energy can cross the selected boundary.

BOUNDARY of OPEN System is known as CONTROL SURFACE

Also known as CONTROL VOLUME



e.g. Water Heater, Car Radiator, Turbine, Compressor and nozzle.

Basic concepts

- 1.3.1 **Force (F):** The ability of accelerated a body of a given mass, the unit of the force is the Newton(N).
- 1.3.2 **Newton(N):** The force required to give a mass of I kg an acceleration of 1 m/s^2.
- 1.3.3 **pressure (P)** : Pressure is defined as the normal force per unit area. Where Pressure = F/A . The unit of pressure is N/m^2 and is called the Pascal (Pa).
- 1.3.4 **Heat :** is a form of energy which transferred from one body to another body at a lower temperature, by virtue of the temperature difference between the bodies. When the temperature of the bodies are equal no heat transfer takes place between them.
- 1.3.5 **Heat Engine :** Any type of engine or machine which derives heat energy from the combustion of fuel or any other source and converts this energy into mechanical work is termed as a heat engine.
- 1.3.6 **Work :** is usually defined as a force F acting through a displacement x, where the displacement is in the direction of the force.

Basic concept

- Already noted, work done by a system, such as that done by a gas expanding against a piston, is **positive**, and work done on a system, such as that done by a piston compressing a gas, is **negative**. In other form , positive work means that energy leaves the system, and negative work means that energy is added to the system .The product of unit force (one newton) acting through a unit distance (one meter). This unit for work in SI units is called the joule (J). 1 J = 1N.m

Some SI and English Units

In SI, the units of mass, length, and time are the kilogram (kg), meter (m), and second (s), respectively. The respective units in the English system are the pound-mass (lbm), foot (ft), and second (s).

Force = (Mass)(Acceleration)

$$F = ma$$

$$W = mg \quad (\mathrm{N})$$

$$1\ \mathrm{N} = 1\ \mathrm{kg \cdot m/s^2}$$

g is 9.807 $\mathrm{m/s^2}$

$$1\ \mathrm{J} = 1\ \mathrm{N \cdot m}$$

Density and Specific Volume:

Density ρ is defined as mass per unit volume.

$$\rho = \frac{m}{V} \qquad (\mathrm{kg/m^3})$$

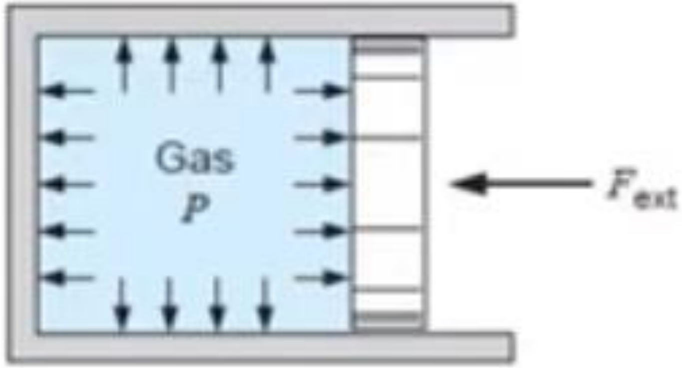
$$v = \frac{V}{m} = \frac{1}{\rho}$$

Specific volume v is defined as volume per unit mass.
V is the volume ($\mathrm{m^3}$) and m is the mass (kg).

Parameter	Units	Symbol
length, L	meters	m
mass, m	kilograms	kg
time, t	seconds	s
temperature, T	kelvin	K
velocity, $\mathcal{V}$	meter per second, $\equiv L/t$	m/s
acceleration, a	meter per second squared $\equiv L/t^2$	m/s^2
force, F	newton, $\equiv m \cdot L/t^2$	N
energy, E	joule $\equiv m \cdot L^2/t^2$	J

Pressure

Definition : the exerted force per unit area.



SI Units :

1 Pa = 1 N/m^2

1 kPa = 10^3 Pa

1 MPa = 10^6 Pa = 10^3 kPa

1 bar = 10^5 Pa = 0.1 MPa = 100 kPa

1 atm = 101325 Pa = 101.325 kPa = 1.01325 bar

English Units :

psi = Pound per square inch (lbf/in^2)

1 atm = 14.696 psi

Pressure types:

1. Absolute pressure (P_{abs}). 2. Gage pressure (P_{gage}). 3. Vacuum pressure (P

Pressure Types

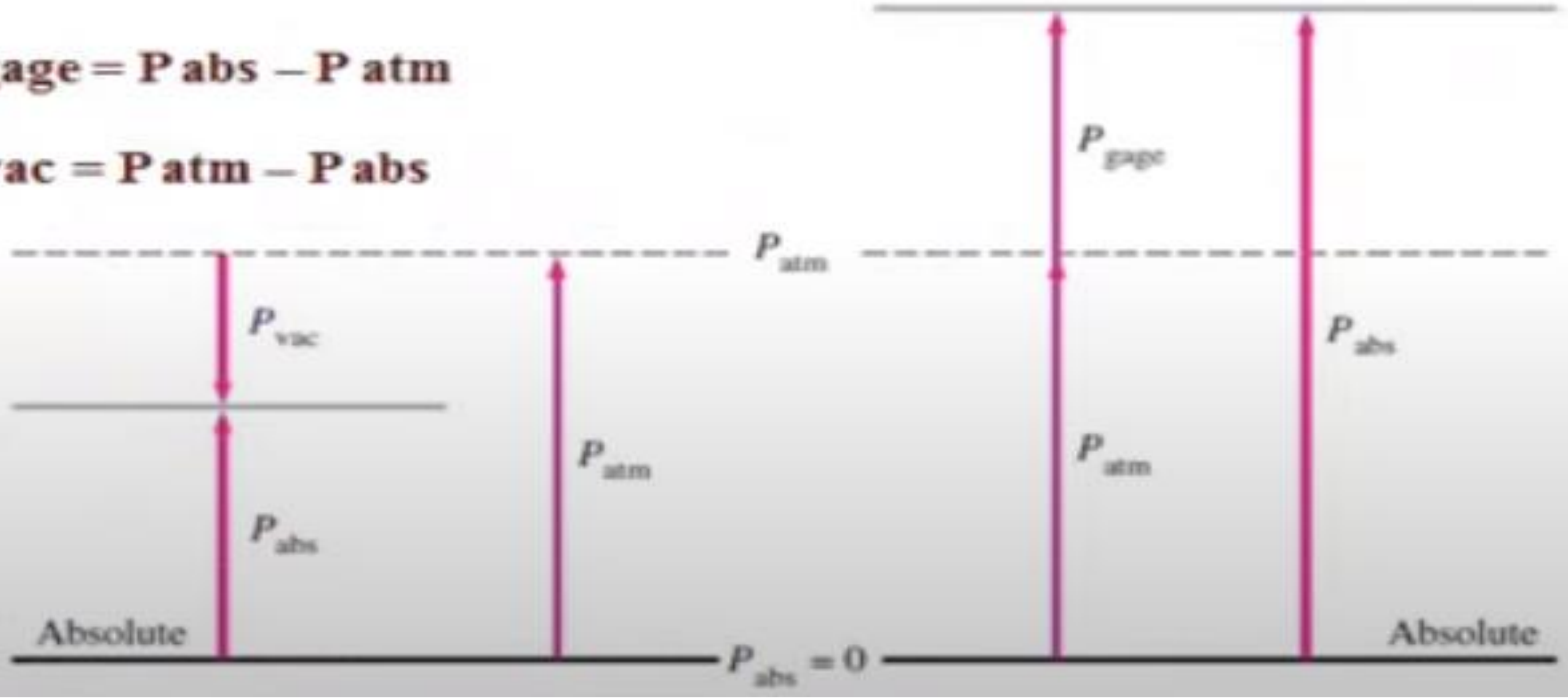
1. **Absolute Pressure** : Actual Pressure at a given position.

2. Pressure below than local atmospheric pressure is known as **Vacuum Pressure**

3. The difference between the absolute pressure and the local atmospheric pressure is called the **Gage Pressure**.

$$P_{gage} = P_{abs} - P_{atm}$$

$$P_{vac} = P_{atm} - P_{abs}$$



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Thermodynamics

State, Equilibrium and process

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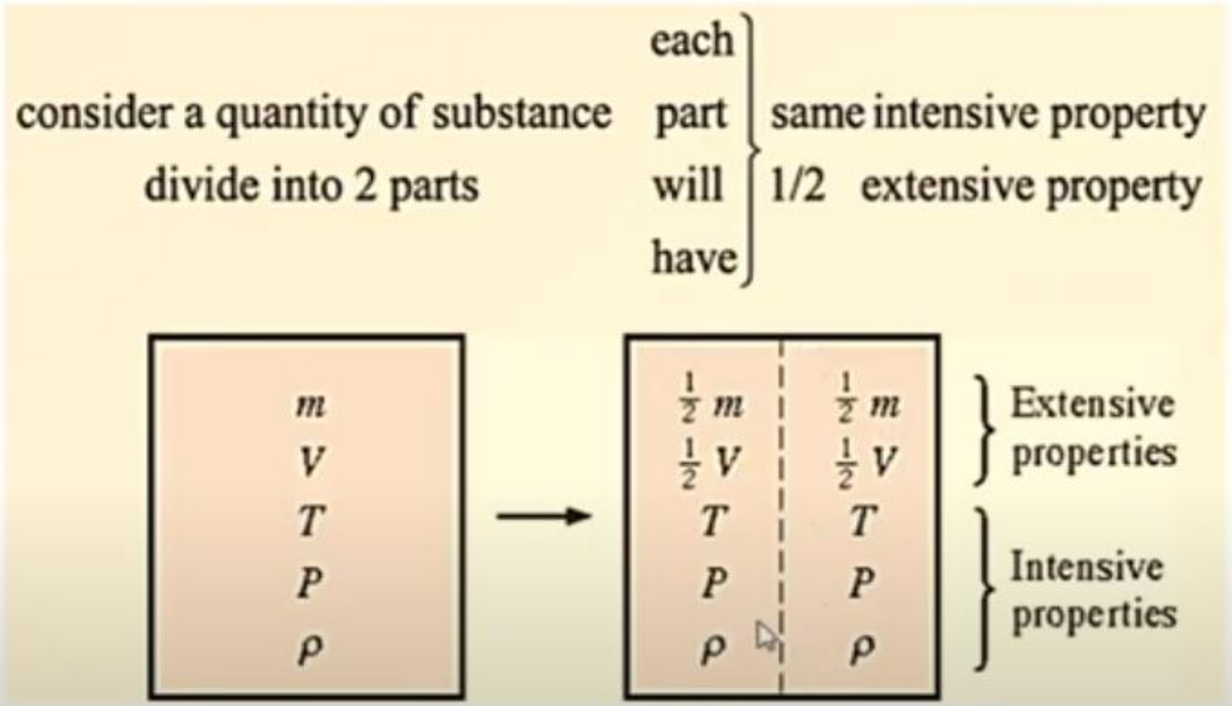
Properties of the system

Any characteristic of a system is called a **property.** Some familiar properties are pressure P, temperature T, volume V, and mass m. The list can be extended to include less familiar ones such as viscosity, thermal conductivity, modulus of elasticity, thermal expansion coefficient, electric resistivity, and even velocity and elevation. Properties are considered to be either intensive or extensive.

- 1.6.1 **Intensive properties:** are those that are **independent** of the mass of a system, such as temperature, pressure, and density.
- 1.6.2 **Extensive properties :** are those whose values **depend** on the size—or extent—of the system. Total mass, total volume, and total momentum are some examples of extensive properties. An easy way to determine whether a property is intensive or extensive is to divide the system into two equal parts with an imaginary partition, as shown in Fig. (1-7)

Properties of the system



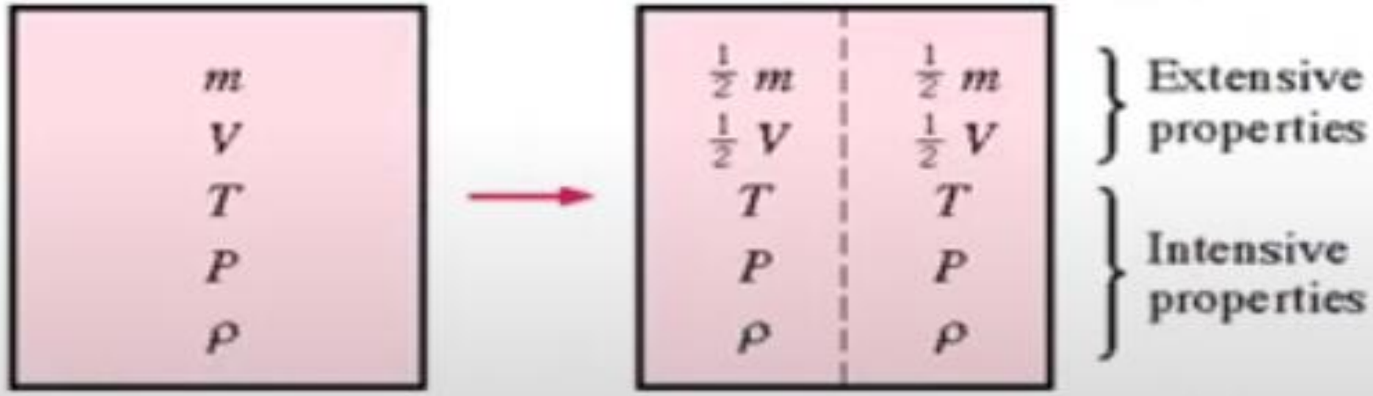
Extensive and Intensive properties

Properties of a system

Any characteristic of a System is known as its PROPERTY.

Properties may be intensive or extensive.

- **Intensive** – **Are independent on the amount of a mass:**
  e.g.: Velocity (v), Elevation (z), Temperature (T), Pressure (P), and Density (ρ),
- **Extensive** – **varies directly with the mass (dependent on a mass).**
  e.g.: mass (m), volume (V), energy (E), enthalpy (h).



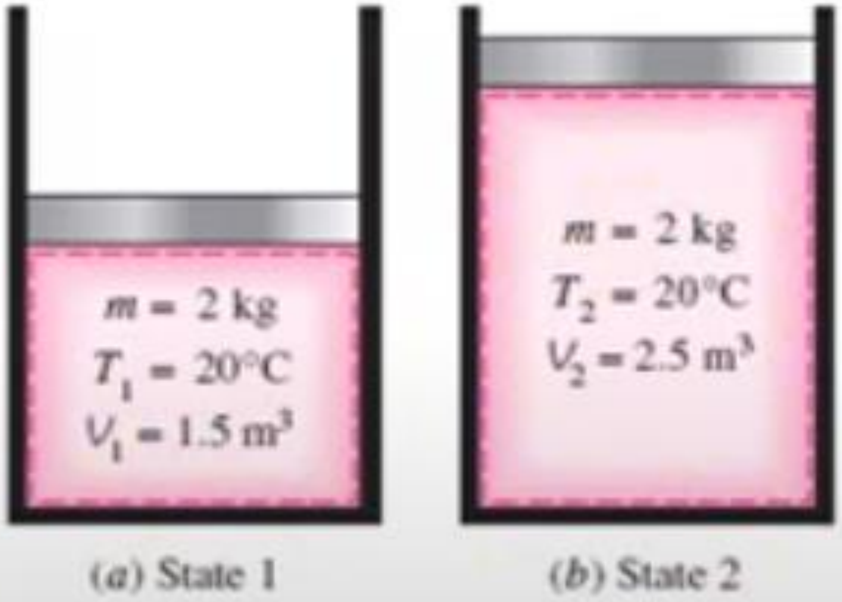
Fluid properties in a tank

The tank is divided into 2 parts

Factor	Prefix	Symbol
10^{-6}	micro	μ
10^{-3}	mili	m
10^{3}	kilo	k
10^{6}	mega	M

State, Equilibrium and Process

- **State** – a set of properties that describes the conditions of a system. e.g. Mass m, Temperature T, Pressure P, Volume V..
- **Equilibrium** – is a state of balance.
- **Thermodynamic equilibrium** – A system that maintains thermal, mechanical, phase and chemical equilibriums.



Thermal Equilibrium

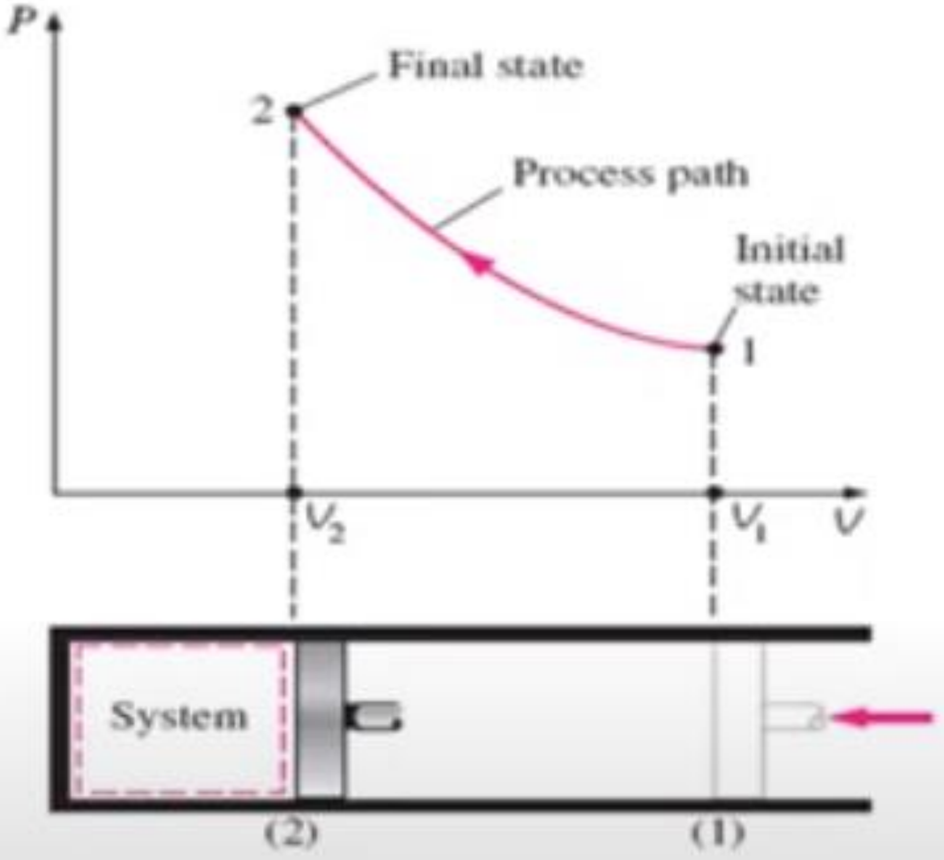
T = 20 °C

* **Mechanical equilibrium** is related to pressure, and a system is in mechanical equilibrium if there is no change in pressure at any point of the system with time.

Process: change from one equilibrium state to another.

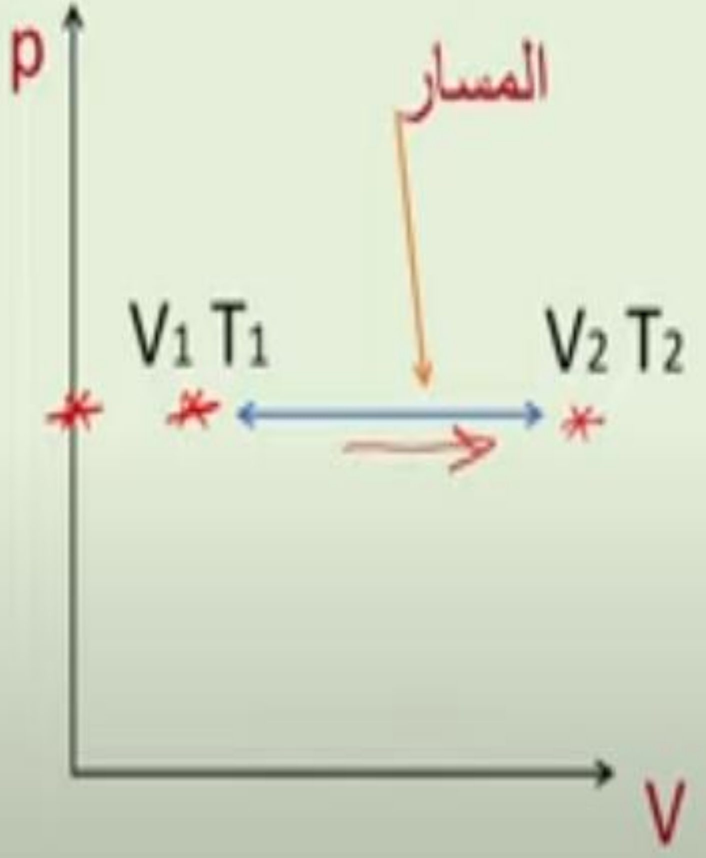
- Process – change from one equilibrium state to another.

Process	Property remains constant
isobaric	Pressure (P=c)
isothermal	Temperature (T=c)
isochoric (isometric)	Volume (v=c)
isentropic	Entropy (S=c)



Isobaric process: a process during which the pressure remains constant

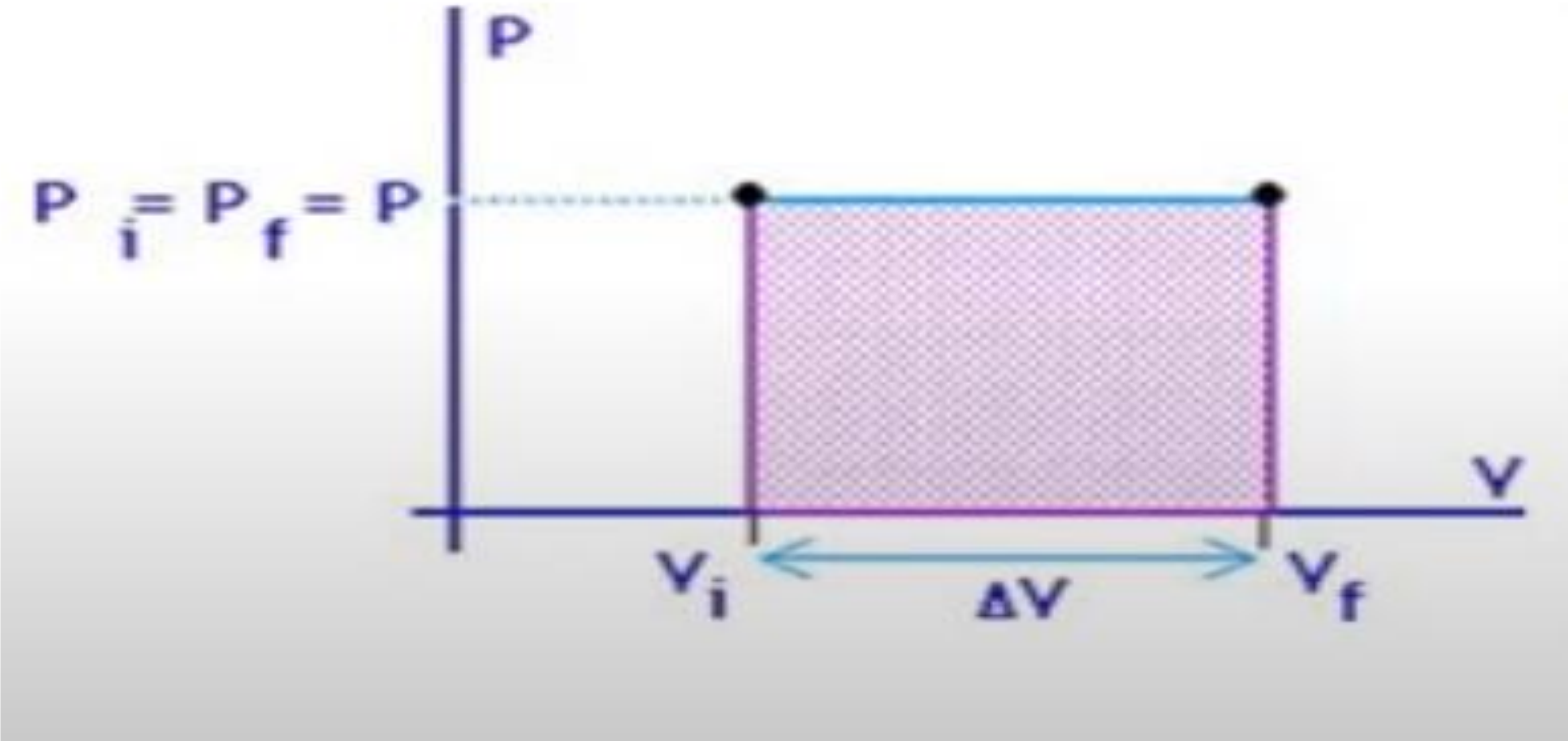
هي العملية التي يكون فيها التغير تحت ضغط ثابت



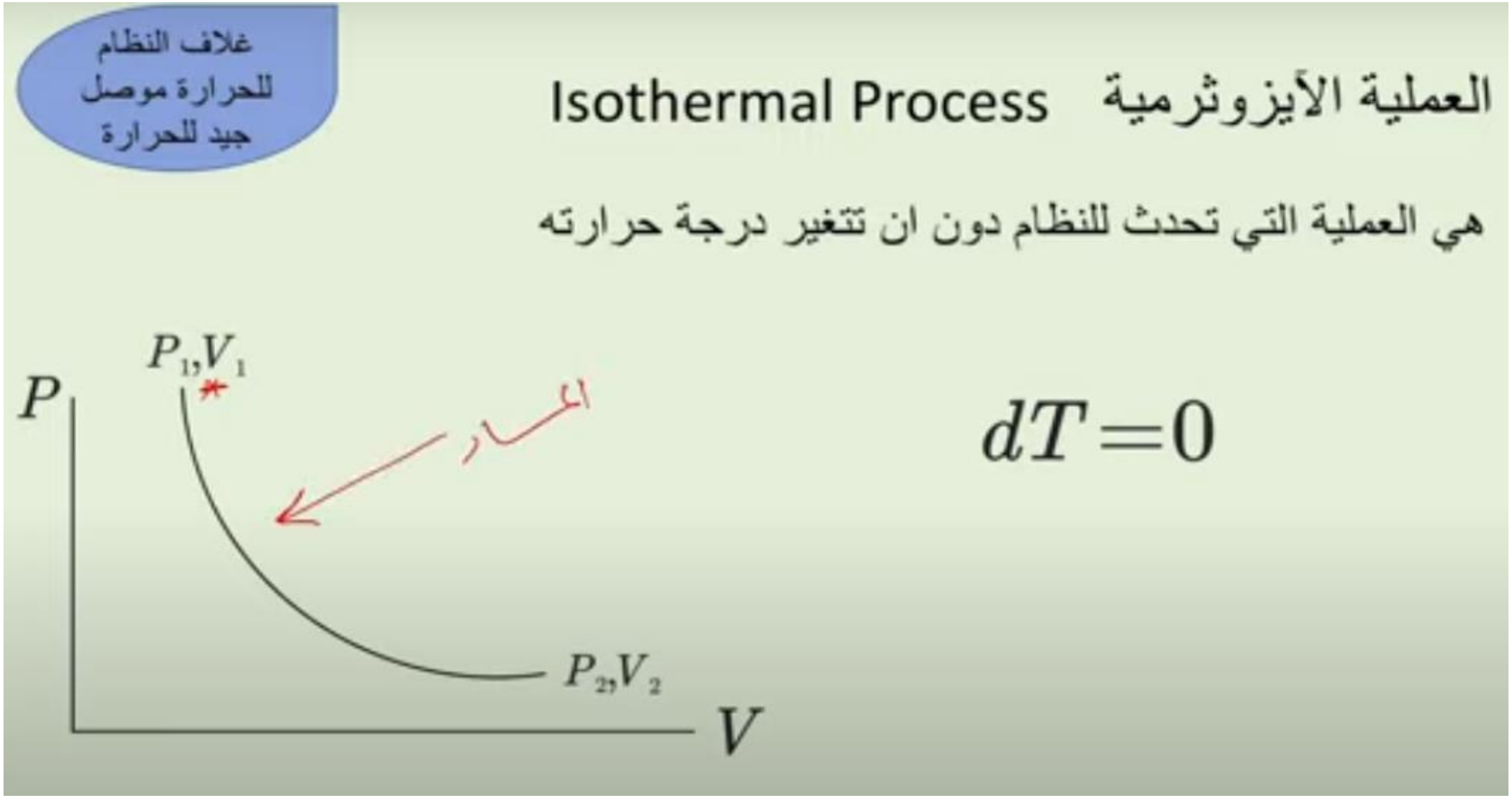
$$P_1 = P_2$$

$$dP = P_2 - P_1 = 0$$

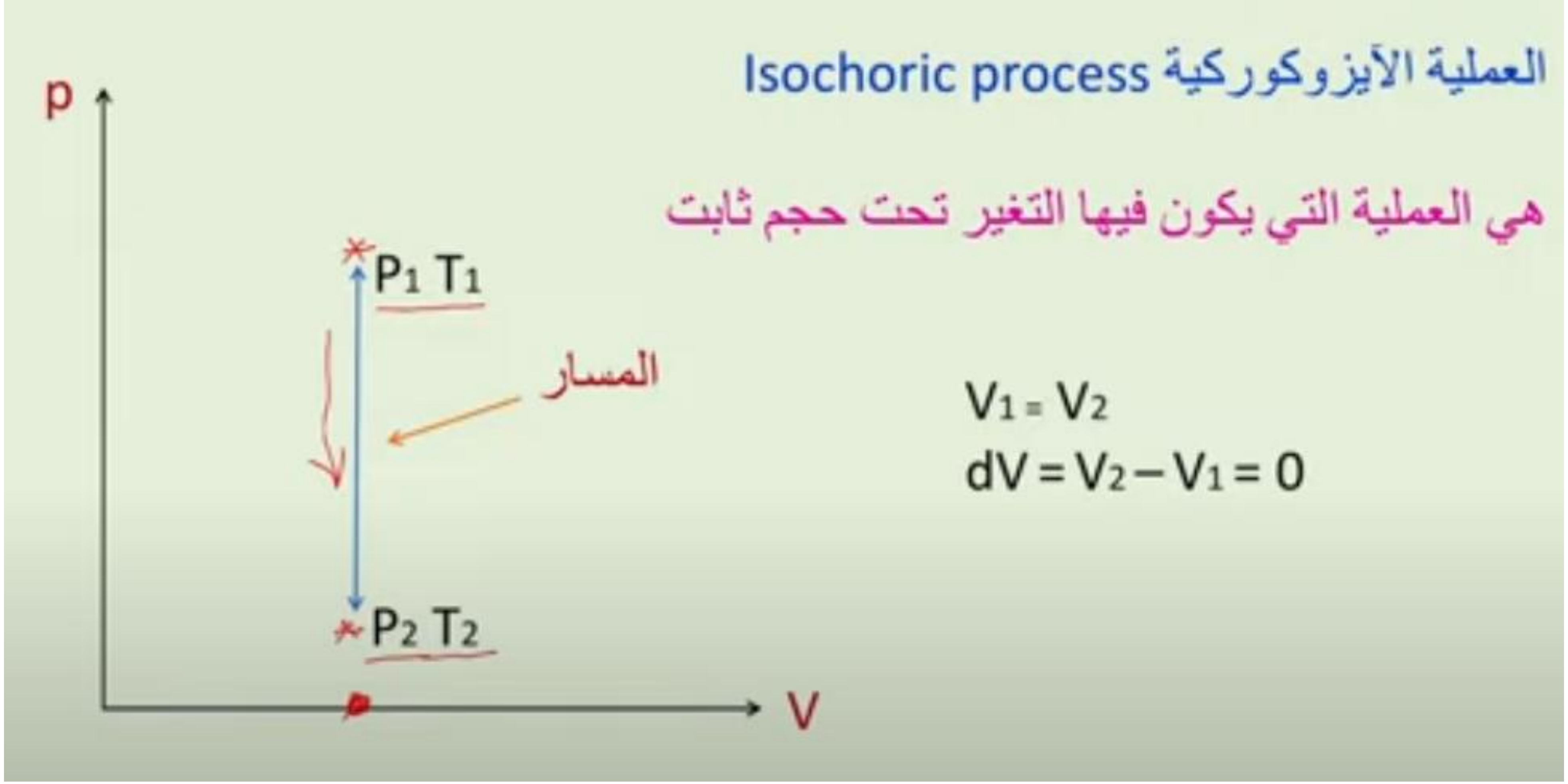
State, Equilibrium and Process



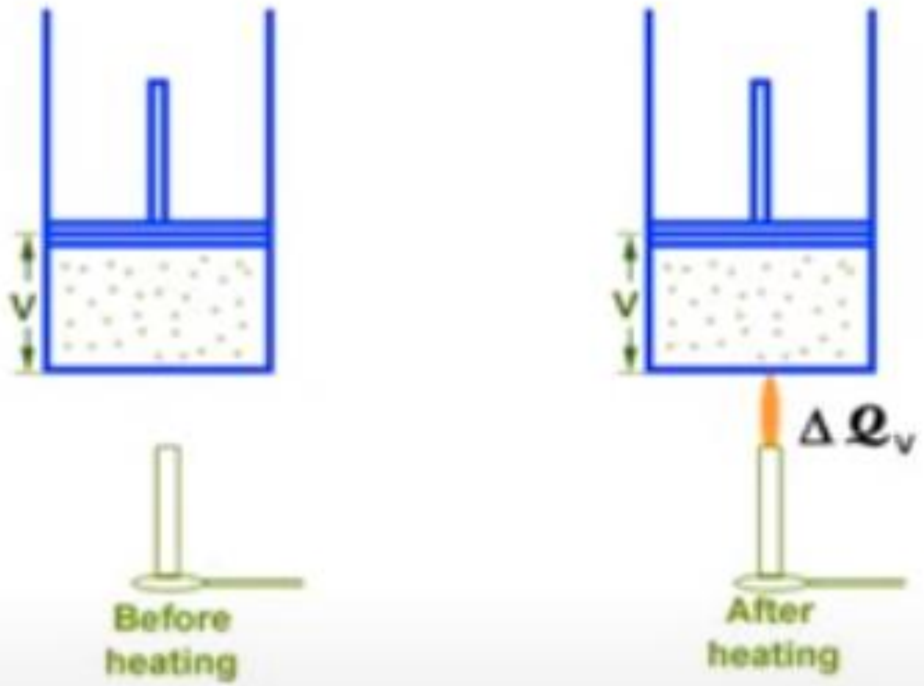
Isothermal process: a process which the temperature T remains constant



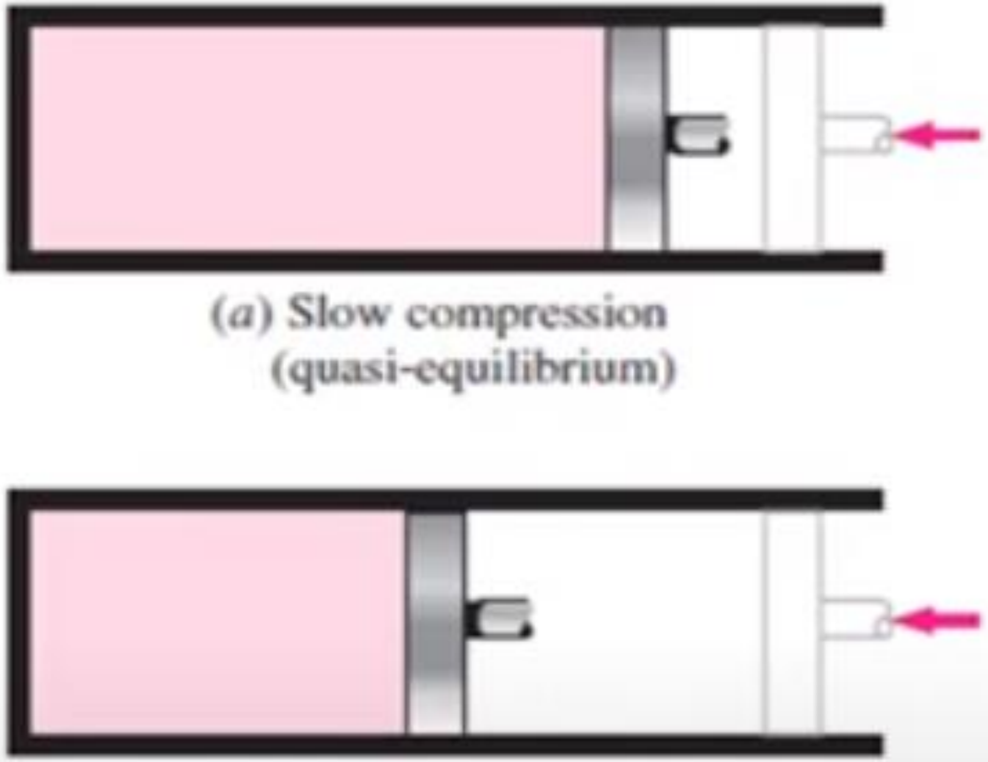
Isochoric or isometric process: a process during which the specific volume remains constant



Isochoric (or isometric) process: A process during which the specific volume v remains constant.



$T_2 > T_1$ and Q **is heat (kJ)** and $v_1 = v_2$.



(*a*) Slow compression (quasi-equilibrium)

(*b*) Very fast compression (nonquasi-equilibrium)

Isothermal process: A process during which the temperature **T** remains constant.

Temperature Pressure

Temperature: - It is may be defined the degree of heat or the level of heat intensity of a body.

Measurement of Temperature:-

The temperature of a body is measured by a thermometer. There are two scales for measuring the thermometer of a body.

1) Centigrade or Celsius Scale:-

This scale is most used by engineers. The freezing point of water = 0.

The boiling point of water = 100

We use symbol (ºC) to describe temperature.

2) Fahrenheit Scale:-

The freezing point of water = 32

The boiling point of water = 212

We use the symbol (ºF) to describe thermometer.

* The relation between centigrade scale and Fahrenheit scale is given by

$$F = 1.8\ ^{\circ}C + 32$$

Absolute Temperature:-

The absolute Celsius scale is called degree "Kelvin"

$$\mathbf{K = {}^{\circ}C + 273}$$

Absolute Fahrenheit scale is called degree "Rankine"

$$\mathbf{R = F + 460}$$

Pressure

Pressure: - is the force exerted by the system on unit area.

Absolute Pressure: - is the gauge pressure plus atmospheric pressure.

Gauge Pressure: - A gauge for measuring pressure records the pressure above atmospheric pressure.

Vacuum Pressure: - It is the pressure of the system below atmospheric pressure.

Equations

$P_{abs} = P_{atm} + P_{gauge}$

The positive gauge pressure

P_{abs} = Absolute Pressure

P_{atm} = Atmospheric Pressure

P_{gauge} = Gauge Pressure

$$P_{gauge} = P_{abs} - P_{atm}$$

The negative gauge pressure: - [Vacuum Pressure]

$$\text{Vacuum Pressure} = P_{atm} - P_{abs}$$

Manometer and Barometer

Manometer: - An instrument for measuring a pressure difference in terms of the height of a liquid.

$\Delta P = p_2 - p_1$

$$\Delta p = \rho \, g \, \Delta h$$

ρ = Density of Liquid

g = Ground Accelerate = 9.8

Δh = Height of the Liquid

Barometer: - An instrument for measuring the atmospheric pressure.

Units of Pressure:-

1 $p_{at\,m}$ = 76 cm. Hg = 760 mm. Hg

1 $p_{at\,m}$ = $10^5 \ \frac{N}{m^2} = 10^5 \ pa$

1 $p_{at\,m}$ = $10^2 \ \frac{KN}{m^2} = 10^2 \ Kpa$

1 $p_{at\,m}$ = 1.01325 bar

Example (1)
Change a pressure from 1500 mm Hg to bar.

Solution

760 mm Hg = 1.0132 bar

1500 mm Hg $\times \frac{1.0132}{760 \ mm\,Hg} = 1.999$ bar

Example (2)
A compound gauge reads (65 cm Hg) vacuum pressure. Compute absolute pressure.

Solution

76 cm Hg = 1.0132 bar

P_{vacc} = 65 cm Hg × $\frac{1.0132 \ bar}{76 \ cm \ Hg}$ = 0.867 bar

P_{vacc} = 0.867 bar

$P_{vacc} = P_{at\,m} - P_{abs}$

$0.867 = 1.0132 - P_{abs}$

$P_{abs} = 1.0132 - 0.867 = 0.147$ bar

Example (3)

A manometer is used to measure the pressure in a tank. The fluid is an oil with a specific gravity of (0.87) and the liquid height Δh = 45.2 *cm*. If the barometric pressure = 98.4 *kpa*, the density of water = 1000 $\frac{kg}{m^3}$ the gravity = 9.8 $\frac{m}{s^2}$, Determine the absolute pressure within the tank in kpa, 1 atm.

Solution

$$\text{Sp. Gr.} = \frac{\rho_{oil}}{\rho_{water}}$$

$$\rho_{oil} = 0.87 \times 1000 \, \frac{kg}{m^3} = 870 \, \frac{kg}{m^3}$$

$$p_1 = p_2 - \Delta p$$

$$p_1 = p_2 - \rho g \, \Delta h$$

$$\Delta p = \rho g \, \Delta h$$

$$= 870 \, \frac{kg}{m^3} \times 9.8 \, \frac{m}{s^2} \times 45.2/100$$

$$\Delta p = 3853.752 \, \frac{kg}{m.s^2} \times \frac{1N}{\frac{kgm}{s^2}}$$

$$= 3853.752 \, \frac{N}{m^2}$$

= 3853.75 pa

$$\Delta p = 3853.752/1000 = 3.853 kpa$$

P_1 = 98.4 *kpa* - 3.853 *kpa*

P_1 = 94.548 *kpa*

$$P_1 = 94.548 \; kpa \times \frac{1 \; atm}{10^2 \; kpa} = 0.94547 \; atm$$

<u>**Note:-**</u>

$$1 \; N = \frac{kg.m}{s^2}$$

$$1 \; kpa = 1000 \; pa$$

$$1 \; atm = 10^2 \; kpa$$

<u>Home work</u>

1**) Convert 20 ºC to Kelvin scale.**

2) Convert 400 ºK to Rankine scale.

3) Convert 170 ºF to Kelvin Scale.

4) Convert pressure 76 cm Hg to $\frac{KN}{m^2}$ **.**

5) Convert pressure 50 pa to mm Hg.

6) Convert 500 cm Hg to $\frac{KN}{m^2}$ **.**

7) Convert 2 kpa to mm Hg.

<u>Solution</u>

1) Convert 20 ºC to Kelvin Scale.

k = ºC + 273

k = 20 + 273

k = 293 ºF

2) Convert 400 ºK to Rankine Scale.

ºR =ºF + 460

ºk = ºC + 273

400 = ºC + 273

ºC = 400 – 273 =127 ºC

ºF =1.8ºC + 32

ºF = 1.8 (127 + 32)

ºF = 260 .6

ºR =260 .6 + 460 = 720.6

3) Convert 170 ºF to Kelvin Scale.

ºF =1.8ºC + 32

170 = 1.8ºC + 32

$$^{o}C = \frac{170 - 32}{1.8} = 76.666$$

k = ºC + 273

= 76.666 + 273

= 349.666 ºC

4) Convert pressure 76 cm Hg to $\frac{KN}{m^2}$.

76 cm Hg = $10^2\ \frac{KN}{m^2}$

5) Convert pressure 50 pa to mm Hg.

$\frac{760 mm.Hg}{10^5\ pa} \times 50$ pa

$= 38000 \times 10^{-5}$

= 0.38 mm .Hg

6) Convert 500 cm Hg to $\frac{KN}{m^2}$.

$\frac{10^2\ kN / m^2}{76\ cm\ .Hg} \times 500$ cm .H

= 657.894 kN / m^2

7) Convert 2 kpa to mm Hg.

$\frac{760 mm.Hg}{10^2\ pa}$ 2kpa

= 15.2 mm .Hg

Work

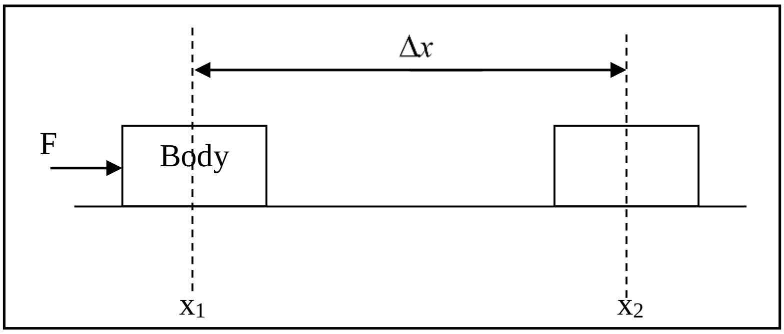
Work: - The product of a force with its corresponding displacement.

Work is one of energies types, that we can transform it to other types of energy such as (transform of mechanical work to electrical energy, kinetic energy, heat energy**)**.

Unit of Work (Joule) ($J = N.m$**)**

W = Force × Displacement

W = F × Δx

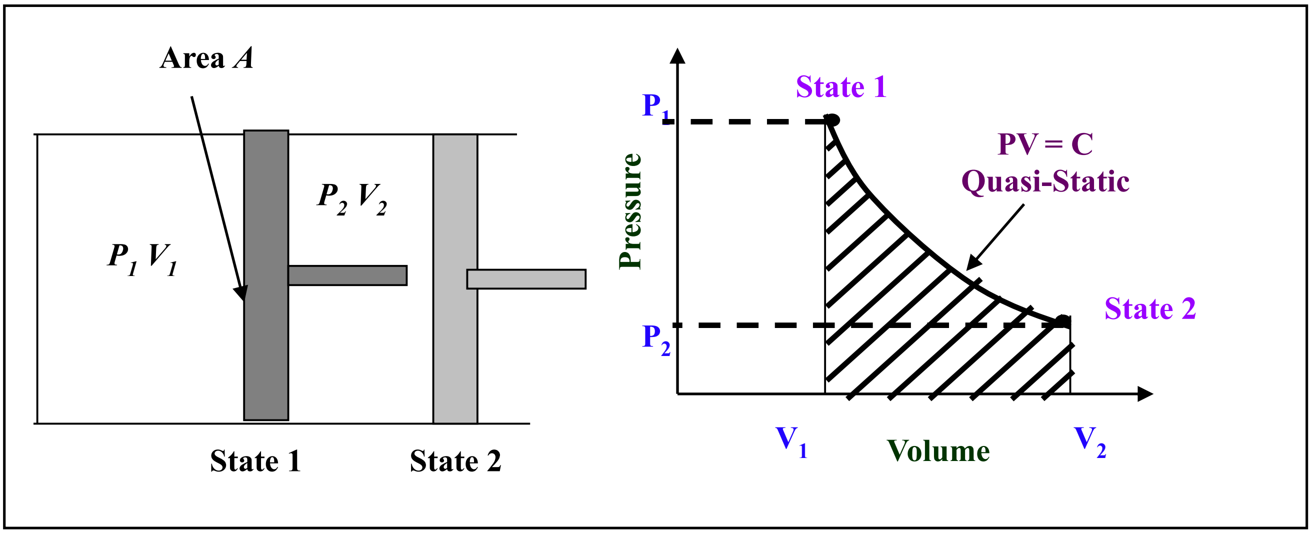


Notes:-

- If the work done by a thermodynamic system we say that is a positive work $+W$ or $W > 0$
- If the work done on a thermodynamic system we say that is a negative work $-W$ or $W < 0$

Let the Piston be moving from thermodynamic equilibrium from **state 1 *(P_1, V_1)*** to **state 2 (P_2, V_2).**

Let the values at any intermediate equilibrium state is given by P and V.



By taking a small element with length of p and width of dv

$$dw = p \, . \, dv$$

$$W = \int_1^2 P \; dV$$

$$dv = A \, . \, dL$$

$$W = \int_1^2 p \, . \; A \, dL$$

$$F = p \, . \, A$$

$$W = \int_1^2 F \; dL$$

$$W = F \, . \, L$$

F = Exerted Force.

P = Exerted Pressure.

L = Stork Length (m).

A = Area of Piston.

dL = Displacement Move by a Piston.

Flow Work

$W_F = F. L$

$F = p. A$

$W_F = P. A. L$

$$\boxed{W_F = P. V}$$

$$\Delta\ W_F = P_2\ V_2 - P_1\ V_1$$

$$\Delta\ W_F = W_{F2} - W_{F1}$$

The flow work (flow energy) per unit mass [specific flow work].

Unit of Flow Work (*J/kg*).

Types of Energies

1) Potential Energy (P.E):-

The energy that system possessed by virtue of its position relative to the surface of the earth.

P.E = *m. g .h*

m = Mass, *kg*

g = Ground Accelerate

h = Height, *m*

$$\Delta P.E = (P.E)_2 - (P.E)_1$$

$$\Delta P.E = (m.g.h)_2 - (m.g.h)_1$$

$$\Delta P.E = m.g\ (h_2 - h_1)$$

$$\Delta P.E = mg\,\Delta h$$

2) Kinetic Energy (K.E):-

The energy that a system possessed owing to its motion.

$$K.E = \frac{1}{2}\ mV^2$$

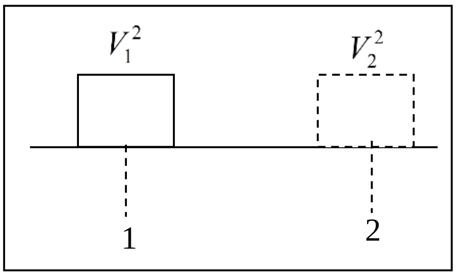
$$\Delta K.E = \frac{1}{2}\, m\,(V_2^2\ - V_1^2)$$

V = Velocity m/sec

V_2 = Final Velocity

V_1 = Initial Velocity

$$\Delta\ K.E = (K.E)_2\ -\ (K.\ E)_1$$



3) Internal Energy (I.E):-

The energy stored in the substance.

I.E = $m\ C_v\ T$

Example

A gas has a mass of (3 kg) and density ($21.6\ \frac{kg}{m^3}$) is transported by pipe of height (25 m) from earth, the temperature =123 ºC, the velocity flow (5 m /s) $C_v = 1.54 \frac{KJ}{kg.K}$.

Find: - 1) Potential energy.

2) Kinetic energy.

3) Internal energy.

Solution

1) P.E = m. $g.\ h$

P.E = 3 × 9.81 × 25 = 735.75 kJ

2) K.E = $\frac{1}{2}$ m v^2

K.E = $\frac{1}{2} \times 3 \times (5)^2$ = 37.5 kJ

3) I.E = $m.\ C_v\ .T$

I.E = 3 × 1.54 × (123 + 273) = 1829.52 kJ

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The First Law of Thermodynamics

The concept of energy and hypothesis is that it can be neither created or destroyed this is principle of the conservation of energy.

The first law of thermodynamics is merely one statement of this general principle with particular of this general principle with specific reference to heat energy and work.

The amount of heat absorbed by the system or lose it is the sum of the change in internal energy and that his work or make it.

$Q = \Delta u + W$

Q = The Heat.

Δu = Energy Change.

W = The Work.

Enthalpy

Enthalpy (H)

H = U + P . V (J, KJ)

Specific Enthalpy (h) (J/kg, kJ/kg)

$h = u + P \cdot V$

V = Specific Volume (m^3 / kg)

u = Specific Internal Energy (J/kg)

p = Pressure $(\frac{N}{m^2})$

Heat Energy (Q):-

It is the type of energy that transfers due to the different in temperature between the system and its surrounding.

Q: Heat Energy (J, kJ)

q: Specific Heat Energy (J/kg, kJ/kg)

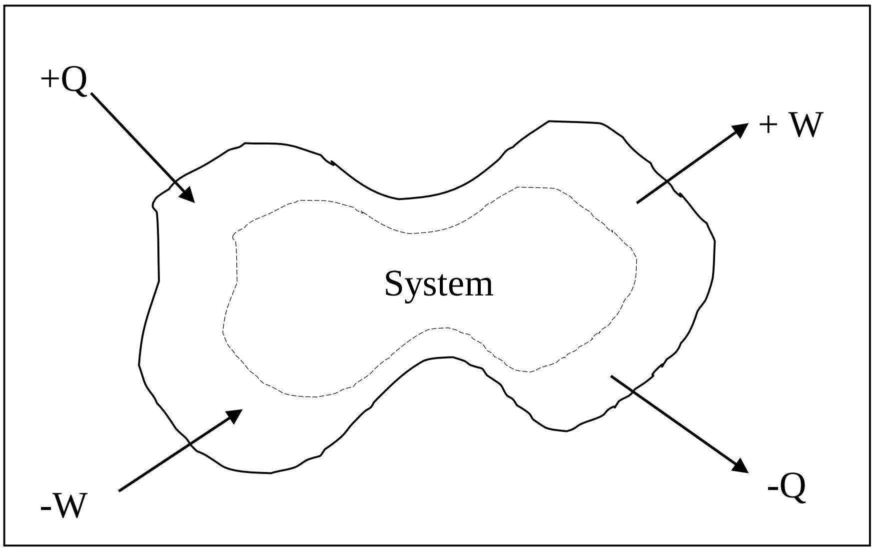
Heat Sign

1) Heat Added Input Use + Q

2) Heat Rejected or Output Use - Q

W_{net} = Net Work

Q_{net} = Net Heat



$W_{net} = W_{out} - W_{in}$

W_{out} = Output Work

W_{in} = Input Work

$Q_{net} = Q_{in} - Q_{out}$

Q_{in} = Input Heat

Q_{out} = Output Heat

Energy Equation

$(Q + U_1 + P_1V_1 + K.\ E_1 + P\ .E_1) = (W + U_2 + P_2V_2 + K\ .\ E_2 + P\ .E_2)$

$H = U + PV$

$(Q + H_1 + K.\ E_1 + P\ .E_1) = (W + H_2 + K\ .\ E_2 + P\ .E_2)$

$Q - W = \Delta H + \Delta K.E + \Delta P..E$

$\Delta K.E = \frac{1}{2} m\ (V_2^2 - V_1^2)$ Let $V = c$

$\Delta P.E = mg\ \Delta h$ Let $h = z$

We can written this equation

$$Q - W = (h_2 - h_1) + \frac{1}{2} m\ (C_2^2 - C_1^2) + mg\ (Z_2 - Z_1)$$

$$Q - W = \text{m}\ [(h_2 - h_1) + \frac{1}{2}\ (C_2^2 - C_1^2) + g\ (Z_2 - Z_1)]$$

Home Work

Question

A gas has a mass of (2 kg) and density ($21.6\ kg/m^3$) is transported by pipe of height (30.25 m) from earth, the temperature =138 ^oC, the velocity flow (6 m/s) $C_v = 0.674\ KJ/kg.K$ and the radius of the pipe (0.5 m). Find:

1) Flow work.
2) Potential energy.
3) Kinetic energy.
4) Internal energy.

Solution

m = 2kg

ρ = 21.6 kg / m^3

h = 30.25 m

T = 138 ºC

V = 6 m / sec

C_v = 0.674 $\frac{KJ}{kg.°K}$

r = 0.5 m

1) W_F = ?

2) K. E = ?

3) P. E = ?

4) I. E = ?

1) by monometer law

P = ρ . g . h

P = 21.6 × 9.81 × 30.25 = 6409.054 pas

V= $\pi\, r^2$h

V= 3.14 × (0.5)^2 × 30.25 = 5.93 m^3

W_F = p.v

W_F = 6409.854 × 5.93 = 38018.434 J

2) P.E = m . g . h

P.E = 2 × 9.81 × 30.25 = 593.5 KJ

3) K.E = $\frac{1}{2}$ m v^2

K.E = $\frac{1}{2}$ * 2 × (6)^2 = 36 KJ

4) I.E = m . C_v .T

I.E = 2 × 0.674 × (138 + 273) =554.028 KJ

Application the First Law of Thermodynamic on Closed Systems

Non – Flow Energy Equation (N. F. E. E):-

For closed system PV, K.E, P.E = 0

$$Q - W = \Delta U + \Delta PV + \Delta K.E + \Delta P.E$$

The energy equation become:-

$$\boxed{Q - W = \Delta U}$$

Example (1)

The change in the internal energy of closed system increase to (120 KJ) while (150 KJ) of work that go out of the system. Determine the amount of heat transfer a cross system boundaries?

Is the heat added or rejected?

Solution

From N. F. E.E

$$Q - W = \Delta U$$

$$Q - 150 = 120$$

$$Q = 270 \ KJ$$

The sign (+270) therefore the heat added to the system.

Note :-

If the change in the internal energy increase we use ($+\Delta u$).

If the change in the internal energy decrease we use ($-\Delta u$).

Example (2)

A tank contain a fluid is stirred by a paddle wheel the work input to the paddle wheel is (5090 KJ). The heat from the tank is (1500 KJ). Determine the change in the internal energy.

Solution

From N. F.E.E

$Q - W = \Delta u$

Q = - 1500 KJ (The heat out)

W = - 5090 KJ (The work input to the system)

- 1500 – (-5090) = ΔU

$\Delta U = -1500 + 5090$

$\Delta U = 3590 \ KJ$

Application the First Law of Thermodynamic on Opened Systems

Steady State Flow Energy Equation (S. F. E. E):-

For open system and steady state

$\dot{m}_{in} = \dot{m}_{out}$

The energy equation in steady state

$$\dot{Q} - \dot{W} = \dot{m}\,[(h_2 - h_1) + \frac{1}{2}(C_2^2 - C_1^2) + g\,(Z_2 - Z_1)]$$

$\dot{m}$ = Mass Flow Rate (kg/s)

$\dot{Q}$ = Rate of Heat Transfer $(J/s = W, kW)$

$\dot{W}$ = Rate of Heat Transfer (W, kW)

1) The Boiler

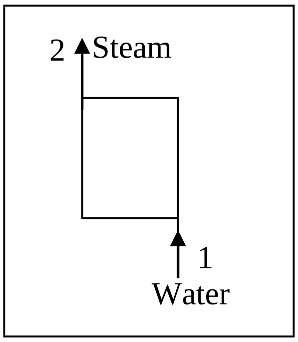
The boiler is a heat exchange which converts the liquid water to steam at constant pressure.

P = C

$$Q - W = m\,[(h_2 - h_1) + \frac{1}{2}(C_2^2 - C_1^2) + g(Z_2 - Z_1)]$$

$Q = m\,(h_2 - h_1)$

$h_2 > h_1 \Longrightarrow Q\,(+)$ Heat Added



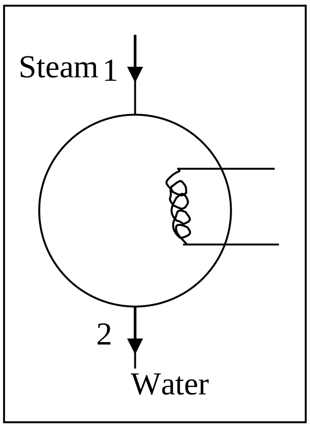
2) The Condenser

It is a heat exchanger work on condenser steam of water and converted it.

$$Q - W = m\,[(h_2 - h_1) + \frac{1}{2}(C_2^2 - C_1^2) + g(Z_2 - Z_1)]$$

$Q = m\,(h_2 - h_1)$

$h_1 > h_2 \Longrightarrow Q\,(-)$ Rejected (Heat Out)



3) The Turbine

It is a mechanical device used to convert the kinetic energy of fluid into mechanical work.

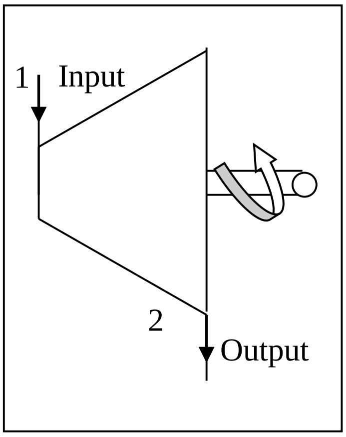
$T_1 > T_2$ $h_1 > h_2$ $P_1 > P_2$

$$Q - W = m\,[(h_2 - h_1) + \frac{1}{2}(C_2^2 - C_1^2) + g(Z_2 - Z_1)]$$

$- W = m\,(h_2 - h_1)$

$$\boxed{W = m\,(h_1 - h_2)}$$

$W = (+)$ Work Output



4) The Compressor

It is a mechanical device used to increase fluid pressure by using on external mechanical work.

$T_2 > T_1$ $h_2 > h_1$ $P_2 > P_1$

$$Q - W = m\,[(h_2 - h_1) + \frac{1}{2}(C_2^2 - C_1^2) + g(Z_2 - Z_1)]$$

$- W = m\,(h_2 - h_1)$

$$\boxed{W = m\,(h_1 - h_2)}$$

$W = (-)$ Work Input

Example (3)

A boiler is generating steam with rate of 8 kg the enthalpy of liquid water is 271 $\frac{KJ}{kg}$ and the enthalpy of steam is 3150 $\frac{KJ}{kg}$. For steady state conditions and by neglecting the change in K.E and P.E. Determine the rate of heat added to the steam in boiler.

Solution

$Q = m\,(h_2 - h_1)$

$h_1 = 271 \ \frac{KJ}{kg}$

$h_2 = 3150 \ \frac{KJ}{kg}$

m = 8 kg/s

$Q = m\,(h_2 - h_1)$

$= 8\,(3150 - 271) = 23032 \ \frac{KJ}{S} = 23032$ KW

Home Work

Question

Air enters a compressor at enthalpy (5000 J/kg) and leave with enthalpy (250 KJ / kg) the mass flow rate = 0.25 kg/s, Determine the work done.

<u>**Solution**</u>

h_1 = 5000 J / kg = $\frac{5000}{1000} = 5 \frac{KJ}{kg}$

h_2 = 250 $\frac{KJ}{kg}$

m = 0.25 kg / s

w =?

w = m (h_1 – h_2) = 0.25 (5 – 250)

w = 0.25 (-245)

w = - 61.25 KW

Specific Heat

Is the amount of heat required to raise the temperature of 1 kilogram of the mass of substance to one degree Celsius.

Types of Specific Heat

1) Specific Heat at Constant Pressure:-

$$C_p = \frac{\Delta h}{\Delta T}$$

C_p = Specific Heat at Constant Pressure

Unit [$\frac{KJ}{kg.k}$ *or* $\frac{J}{kg.k}$]

$\Delta h = h_2 - h_1$ = Change in Enthalpy

Unit [$\frac{KJ}{kg}$ *or* $\frac{J}{kg}$]

$\Delta T = T_2 - T_1$ = Change in Temperature

Unit [k]

$Q = \dot{m} \ \Delta h$

$\Delta h = C_p \ \Delta T$

$$Q = \dot{m} \ c_p \ \Delta T$$

m = Mass Flow Rate (kg)

T_2 = Final Temperature (k)

T_1 = Initial Temperature (k)

Q = Heat (KJ, J)

2) Specific Heat at Constant Volume:-

V = Constant ⟹ Closed system

$$C_v = \frac{\Delta u}{\Delta T}$$

C_v = Specific Heat at Constant Volume

Unit $[\frac{KJ}{kg.k} \quad or \quad \frac{J}{kg.k}]$

$\Delta u = u_2 - u_1$ = Change in Internal Energy

Unit $[\frac{KJ}{kg} \quad or \quad \frac{J}{kg}]$

ΔT = T_2 - T_1 = Change in Temperature

Unit [k]

$Q = \dot{m} \; \Delta u$

$\Delta u = C_V \; \Delta T$

$$Q = \dot{m} \; C_V \; \Delta T$$

The Relation Between (C_p & C_v)

$$\gamma = \frac{C_p}{C_v}$$

γ Without Units

γ Cama: - Is the adiabatic that represent the ratio between specific heat at constant pressure and specific heat at constant volume.

$\gamma > 1$ $C_p > C_v$

Example (1)

Determine the constant pressure of specific heat for steam if the change in enthalpy is (104.2 KJ/kg) and the change in temperature is (50 k).

Solution

$$C_p = \frac{\Delta h}{\Delta T} = \frac{104.2}{50} = 2.084 \quad \text{KJ/kg.k}$$

Example (2)

Determine the change of enthalpy as (1 kg) of a gas is heated from 300 k to 1500 ^{o}k $\gamma = 1.4$, $C_v = 0.718 \ \frac{KJ}{kg.{}^\circ k}$.

Solution

$$C_p = \frac{\Delta h}{\Delta T} \Rightarrow \quad \Delta h = C_p \ \Delta T$$

$$\gamma = \frac{C_p}{C_v} \ \Rightarrow C_p = \gamma \times C_v$$

$$C_p = 1.4 \times 0.718 = 1.005 \ \frac{KJ}{kg.k}$$

$$\Delta h = 1.005 \times [1500 - 300] = 1206.240 \ \frac{KJ}{kg}$$

The Relation Between (*R* & *C_p* & *C_v*)

$$h = u + pv$$

$$\boxed{\Delta h = \Delta u + p \Delta v} \quad \text{------------ (1)}$$

We know that the

$$\boxed{\Delta h = C_p \ \Delta T} \quad \text{------------ (2)}$$

$\Delta u = C_v \, \Delta T$ ------------ (3)

And for ideal gas $\Rightarrow$ p.v = m. R. T

For m = 1 kg

p.v = R. T

$p \, \Delta v = R \, \Delta T$ ------------ (4)

Sub. Equations (2), (3) and (4) in Equation (1)

$$C_p \ \Delta T = C_v \Delta T + R \Delta T$$

$$C_p = C_v + R$$

$$R = C_p - C_v$$

The Relation Retween R and (γ & C_p & C_v)

$R = C_p - C_v$ ------------ (1)

$\gamma = \frac{C_p}{C_v} \Rightarrow C_p = C_v \, . \, \gamma$ ----------- (2)

Sub. Equation (2) in Equation (1)

$$R = C_v \, . \, \gamma - C_v$$

$$R = C_v \ (\gamma - 1)$$

$C_v = \frac{R}{\gamma - 1}$ -------------- (3)

Sub. Equation (3) in Equation (2)

$$C_p = C_v \ . \ \gamma$$

$$C_p = \frac{R}{\gamma - 1} \cdot \gamma = \frac{\gamma \cdot R}{\gamma - 1}$$

$$\boxed{C_p = \frac{\gamma R}{\gamma - 1}}$$

Home work

Question

If it was $\gamma = 1.39$, $C_p = 1.0714 \frac{KJ}{kgk}$ the mass of gas = 2 kg, the initial temperature = 280 k and the final temperature = 1000 k

Determine:-

1) The amount of heat added.

2) Specific heat at constant volume.

3) Change in internal energy.

Solution

$\gamma = 1.39$

C_p = 1.074 KJ / kg. k

m = 2 kg

T_1 = 280 ºk

T_2 = 1000 ºk

1)Q = ?

2) C_V = ?

3) Δu = ?

1) $Q = \dot{m}\ C_p\ \Delta T$

$$Q = 2 \times 1.0714 \times (1000 - 280)$$

$$Q = 1542.816 KJ$$

2) $\gamma = \dfrac{C_p}{C_v}$ ⟹

$$C_v = \frac{C_p}{\gamma} = \frac{1.0714}{1.39} = 0.7708\ \frac{KJ}{kg.k}$$

3) $C_v = \dfrac{\Delta u}{\Delta T}$

$$\Delta u = C_v \times \Delta T = 0.7708 \times [1000 - 280]$$

$$\Delta u = 554.976\ \frac{KJ}{kg}$$

Gas Constant

The General Equation of Ideal Gas:-

$$\frac{P.V}{T} = C \qquad \div\ m$$

$$\frac{P.V}{m.T} = \frac{C}{m} \qquad \text{-----------------} \ (1)$$

Let $\frac{C}{m} = R$ ----------------- (2)

Sub. equation (2) in equation (1)

$$R = \frac{P.V}{m.T}$$

$$\boxed{P.V = m.R.T}$$ The general equation of ideal gas

Where:-

P = Absolute Pressure ($\frac{N}{m^2}$)

V = Volume (m^3)

T = Temperature (*k*)

C = Constant

m = Mass (kg)

R = Gas Constant ($\frac{KJ}{kg.k}$, $\frac{J}{kg.k}$)

$$\boxed{R_0 = R \times M}$$

R_0 = Universal Gas Constant

Universal Gas Constant: It is a physical constant used to study the properties of gases.

$$R_0 = 8.3144 \ \frac{J}{mol\ .\ k}$$

M = Molecular Weight (*mole*)

Example (1)

A tank has a volume of (0.5 in^3) and contains (10 kg) of an ideal gas having a molecular weight is 24 moles, the temperature = 25 ºC find the absolute pressure.

Solution

R_0 = R. M

$$R = \frac{R_0}{M} = \frac{8.3144}{24} = \frac{\frac{KJ}{k\,mole.k}}{\frac{kg}{k\ mole}} = 0.346\ \frac{KJ}{kg.k}$$

$$P.V = m.R.T$$

$$P \times 0.5 = 10 \times 0.346 \times (25 + 273)$$

$$P = \frac{10 \times 0.346 \times 298}{0.5} = 2066\ \ N/m^2$$

Example (2)

One kg of a perfect gas occupies a volume of ($0.85\ m^3$) at ($15\ ^oC$) and at a constant pressure of (1 bar). The gas is first heated at a constant volume and then at a constant pressure. If the $\gamma = 1.4$

Calculate: - 1) The specific heat at constant volume (C_v).

2) The specific heat at constant pressure (C_p).

Solution

1) $P_1\ V = m.\ R.\ T$

$$1\times10^5\ \frac{KN}{m^2}\times 0.85\ m^3 = 1\ (kg)\times R\times(15+273)k$$

$$R = \frac{1\times10^5\times 0.85}{1\times 288}$$

$$R = 0.295\ \frac{KJ}{kg.k}$$

$$C_v = \frac{R}{\gamma-1} = \frac{0.295}{1.4-1}$$

$$C_v = 0.788\ \frac{KJ}{kg.k}$$

2) $$\gamma = \frac{C_p}{C_v}$$

$$C_p = \gamma\ .\ C_v$$

$$C_p = 1.4\times 0.788$$

$$C_p = 1.033\ \frac{KJ}{kg.k}$$

Ideal Gas

The ideal gas is defined as the state of substance that follows well know Bolyle's and charle's laws .

Laws of Ideal Gas

The physical properties of a gas are controlled by the following variables:-

- Pressure (P) exerted by the gas.
- Volume (V) occupied by the gas.
- Temperature (T) of the gas.

The behavior of perfect gas is governed by the following laws:-

1) Bayle's Law:-

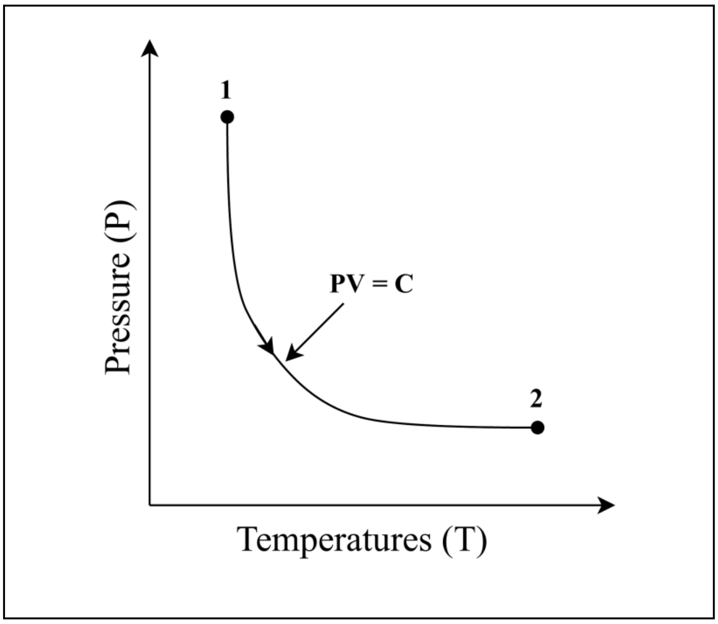
The absolute pressure of a given mass of ideal gas varies inversely of its volume when the temperatures remain constant.

$$P \, \alpha \, \frac{1}{V}$$

P V = C **T = C**

$$\boxed{P_1 V_1 = P_2 V_2 = C}$$

C = Constant



2) Charle's Law:-

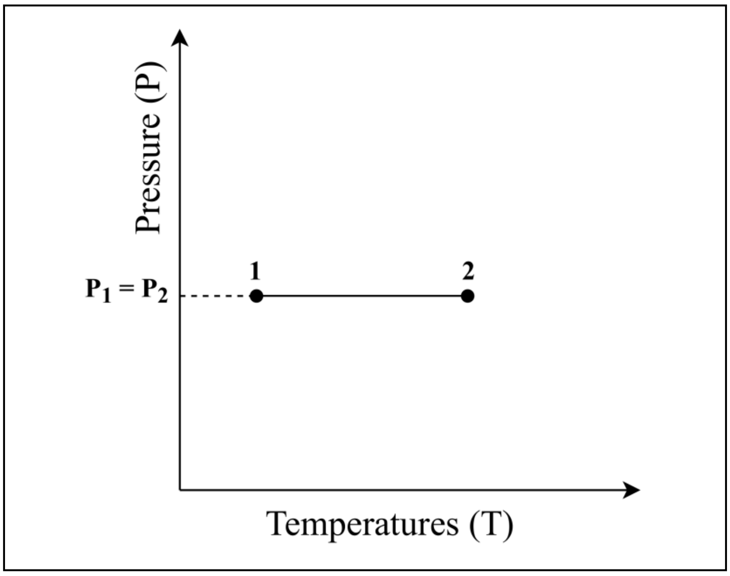
The volume of a given mass of ideal gas varies directly with the temperature when the absolute pressures remain constant.

$V \alpha T$

$\frac{V}{T} = C$ **P = C**

$$\boxed{\frac{V_1}{T_1} = \frac{V_2}{T_2} = C}$$

C = Constant



3) Gay Lussac Law:-

The absolute pressure of a given mass of ideal gas is proportional directly with the temperature at constant volume.

$P \alpha T$

$\frac{P}{T} = C$ **V = C**

$$\boxed{\frac{P_1}{T_1} = \frac{P_2}{T_2} = C}$$

C = Constant

General Process

It is transition of a substance from state one at have pressure, volume and temperature (P1, V1, T1) to state two at also have pressure, volume and temperature (P2, V2, T2) a cross a certain path.

$$\frac{P\,.V}{T} = C$$

$$\frac{P_1 V_1}{T_1} = \frac{P_2\, V_2}{T_2} = C$$

C = Constant

Where:-

P_1 = Initial Pressure (N/m^2)

P_2 = Final Pressure (N/m^2)

V_1 = Initial Volume (m^3)

V_2 = Final Pressure (m^3)

T_1 = Final Temperature (k)

T_2 = Final Temperature (k)

Example (3)

An air compressor is compress (2.8 m^3) of air from initial pressure of (1 bar) to final pressure of (14 bar) calculate the final volume of air if temperature is constant.

Solution

$P_1\, V_1 = P_2\, V_2$ T = C

1 bar × 2.8 m^3 = 14 bar × V_2

$$V_2 = \frac{1 \times 2.8}{14} = 0.2\ m^3$$

Example (4)

(0.2 m^3) of a gas at (50 ºC) the gas is heated at a constant pressure until its volume reached (0.4 m^3) determines the final temperature.

Solution

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} = C$$

$$\frac{0.2}{50 + 273} = \frac{0.4}{T_2}$$

$$0.2\ T_2 = 0.4\ (50 + 273)$$

$$T_2 = \frac{0.4\ (323)}{0.2} = 646\, k$$

Example (5)

(2 kg) of a gas at initial pressure of (1.4 bar) at temperature is 40 ºC and R = 188.34 $J/kg.k$, Determine:-

1) The initial volume of the gas

2) If the gas is heated at constant pressure to have a volume of (1.5 m^3). Find the final temperature.

Solution

1) $P_1\ V_1 = m\ R\ T_1$

$$1.4 \times 10^5\ \frac{N}{m^2} \times V_1 = 2\,kg \times 188.34\ \frac{J}{kg.k} \times (40 + 273)\ k$$

$$V_1 = \frac{2 \times 188.34}{1.4 \times 10^5}$$

$$V_1 = 0.842 \quad m^3$$

2) P = C

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

$$\frac{0.842}{40 + 273} = \frac{1.5}{T_2}$$

$T_2 = 557.6\ k$

Example (4)

The pressure of a gas =1.5 bar at 18 ºC temperature compute the volume of 1 kg, of the gas .If the gas is heated at constant pressure until the volume become $1m^3$.

Determine: - 1) The amount of added heat.

2) The work done.

C_p = 1.005 KJ/kg. *k* $C_v = 0.718\ \frac{KJ}{kg.k}$

Solution

1) $R = C_p - C_v$

$R = 1.005 - 0.718 = 0.278\ \frac{KJ}{kg.k}$

$P_1 V_1 = m R T_1$

$$V_1 = \frac{mRT_1}{P_1} = \frac{1\times\ 0.278\times(18+\ 273)}{10^2\times1.5}$$

$V_1 = 0.556\ m^3$

$Q = m\, C_p\, [T_2 - T_1]$

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

$$\frac{0.556}{291} = \frac{1}{T_2}$$

$T_2 = 526.2\ k$

$Q = 1 \times 1.005 \times [526.2 - 291] = 243.4$ KJ

2) $W = P\,[V_2 - V_1] = 1.5 \times 10^2\,[1- 0.556] = 66.48$ KJ

Home work

Questions

What is the mass of air contained a room (6m × 10m × 4m) If the pressure is (100 kpa) and the temperature is 25 ºC, Assume air to be an ideal gas $R = 0.287\ \frac{KJ}{kg.k}$.

Solution

$V = 6 \times 10 \times 4 = 240\ m^3$

$P = 100$ kpa

T = 25 ºC + 273 = 298 K

$R = 0.287\ \frac{KJ}{kg\,.k}$

m =?

$P.\ V$ = m. R. T

$$m = \frac{p\ .v}{R\ .T}$$

$$m = \frac{100 \times 240}{0.287 \times 298}$$

$$m = \frac{24000}{85.526}$$

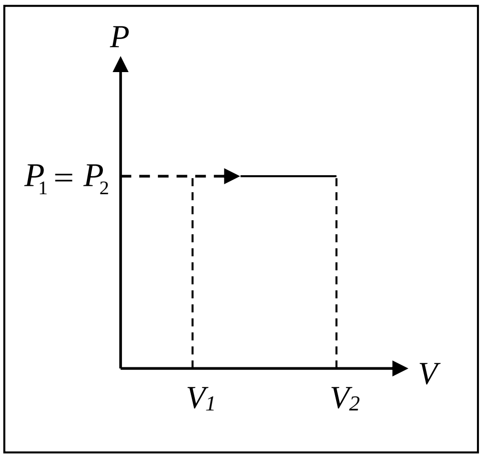
m = 280 .6 kg

<u>Thermodynamic Processes</u>

1) Constant Pressure Process

$$\frac{PV}{T} = C \implies \frac{V}{T} = C \implies$$

$$\boxed{\frac{V_1}{T_1} = \frac{V_2}{T_2}}$$



$Q = \Delta u + W$ (1)

$\Delta u = u_2 - u_1$ (2)

$W = p\,V_2 - p\,V_1$ (3)

Sub. Equations (2) & (3) in Equation (1)

$Q = u_2 - u_1 + p\,V_2 - p\,V_1$

$\because\ h = u + PV$

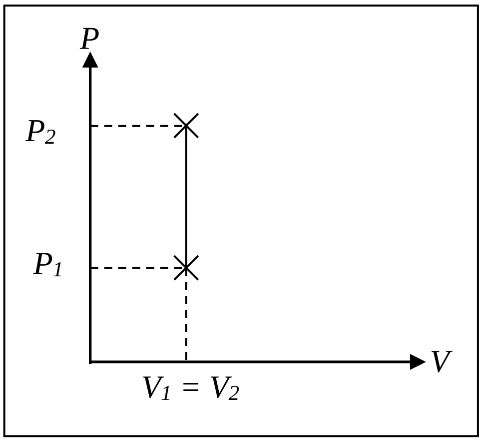
$\therefore\ Q = h_2 - h_1$

$$\boxed{Q = m\,C_p\,(T_2 - T_1)}$$

2) Constant Volume Process

$$\frac{PV}{T} = C \implies \frac{P}{T} = C \implies$$

$$\boxed{\frac{P_1}{T_1} = \frac{P_2}{T_2}}$$



$Q = \Delta u + W$

$W = p\,V_2 - p\,V_1$

$W = 0 \implies$

$Q = \Delta u$

$\Delta u = u_2 - u_1$

$$\boxed{Q = m\,C_v\,(T_2 - T_1)}$$

3) Constant Temperature Process

$\frac{PV}{T} = C \Longrightarrow PV = C \Longrightarrow$

$P_1 V_1 = P_2 V_2 \Longrightarrow$

$$\boxed{\frac{P_1}{P_2} = \frac{V_2}{V_1}}$$

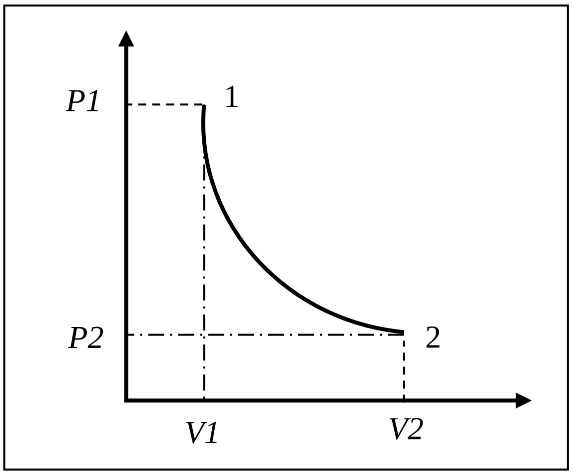
$Q = \Delta u + W$

$\Delta u = 0$

$Q = W$

$W = p_2 V_2 - p_1 V_1$

$d W = p\, d V$ for perfect gas



$$P = \frac{mRT}{V}$$

$$dW = \frac{mRT}{V} dV$$

$$dW = mRT \frac{dV}{V}$$

$$\int dW = \int mRT \frac{dV}{V}$$

$$W = \int_{V_1}^{V_2} mRT \frac{dV}{V}$$

$W = mRT\, [\, Ln\, V_2 - Ln\, V_1\,]$

$$W = mRT\, Ln \frac{V_2}{V_1}$$

$\because PV = mRT \Longrightarrow$

$$\boxed{W = P_1 V_1 Ln \frac{p_1}{p_2}} \quad \& \quad \boxed{W = P_1 V_1 Ln \frac{V_2}{V_1}}$$

4) Adiabatic Process (Isentropic)

$$PV^{\gamma} = C \implies P = \frac{C}{v^{\gamma}}$$

$$\gamma = \frac{C_p}{C_V}$$

$Q = \Delta u + W$

$Q = 0 \implies -W = \Delta u \implies W = \Delta u$

$d\,W = p\,d\,V$

$$dW = \frac{C}{v^{\gamma}}\,dV$$

$$dW = C\,v^{-\gamma}\,dV$$

$$\int dW = \int C v^{-\gamma}\,dV \implies \int dW = \int_{V_1}^{V_2} C v^{-\gamma}\,dV \implies$$

$$W = C\left[\frac{v_2^{1-\gamma}}{1-\gamma} - \frac{v_1^{1-\gamma}}{1-\gamma}\right] \implies W = C\left[\frac{v_2^{1-\gamma} - v_1^{1-\gamma}}{1-\gamma}\right] \implies$$

$$W = C\left[\frac{\frac{v_2}{v_2^{\gamma}} - \frac{v_1}{v_1^{\gamma}}}{1-\gamma}\right] \implies W = \left[\frac{v_2\frac{C}{v_2^{\gamma}} - v_1\frac{C}{v_1^{\gamma}}}{1-\gamma}\right] \implies$$

$$\boxed{W = \left[\frac{p_2 v_2 - p_1 v_1}{1-\gamma}\right]}$$

Example (1)

The pressure of a gas is 1.5 *bar* at 18 *ºC* temperature compute the volume of (1 *kg*) of the gas. If the gas is heated at constant pressure until the volume become ($1m^3$) Determine:-

1) The amount of added heat.

2) The work done.

C_p = 1.005 *KJ/kg.k* C_v = 0.718 *KJ/kg.k*

Solution

1) $R = C_p - C_v$

R = 1.005 – 0.718 = 0.287 *KJ/kg.k*

$P_1 V_1 = m R T_1$

$$V_1 = \frac{mRT_1}{P_1} = \frac{1\times 0.287\times(18+273)}{10^2\times 1.5}$$

$V_1 = 0.556\ m^3$

$$Q = m\ C_p\ (T_2 - T_1)$$

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

$$\frac{0.556}{291} = \frac{1}{T_2}$$

$T_2 = 526.2\ k$

$Q = 1 \times 1.005 \times [526.2 - 291] = 243.4\ KJ$

2) $W = P\ [V_2 - V_1] = 1.5 \times 10^2\ [1 - 0.556] = 66.48\ KJ$

Example (2)

Given [the pressure of air = 1.013 *bar*, the volume = 0.827 m^3 and the temperature = 25 *ºC*, the air is compressed with constant temperature until the pressure becomes = 13.78 *bar*. Determine the work done to compress the air.

Solution

$$W = P_1 V_1 \ln \frac{V_2}{V_1}$$

$P_1 V_1 = P_2 V_2$ $\quad\quad T = C$

$1.013 \times 0.827 = 13.78 \, V_2$

$$V_2 = \frac{1.013 \times 0.827}{13.78} = 0.060 \quad m^3$$

$$W = 1.013 \times 10^2 \times 0.827 \;\; \ln \frac{0.060}{0.827}$$

$$W = 83.775 \;\; \ln \;\; 0.073$$

$$W = 83.775 \times (-2.61)$$

$W = -218.653 \;\; KJ$ $\quad\quad$ the work input (–)

<u>Home work</u>

<u>Questions</u>

Given the volume of gas = 0.12 m^3, the temperature is 20 ºC and the pressure 1.013 *bar* is compressed adiabatically until the volume become 0.024 m^3, C_v = 0.718 *kJ/kg.k* and C_p = 1.005 *kJ/kg.k*.

Determine:-

1) The mass of the gas.

2) The final pressure and temperature.

3) The work done.

Solution

1) $R = C_p - C_v$

$R = 1.005 - 0.718 = 0.287 \quad kJ / kg.k$

$P_1 V_1 = m R T_1$

$1.013 \times 10^2 \times 0.12 = m \times 0.287 \times [20 + 273]$

$$m = \frac{1.013 \times 10^2 \times 0.12}{0.287 \times 293} = 0.145 \ kg$$

2) $$\gamma = \frac{C_p}{C_V} = \frac{1.005}{0.718} = 1.4$$

$$P_1 V_1^{\gamma} = P_2 V_2^{\gamma}$$

$1.013 (0.12)^{1.4} = P_2 (0.024)^{1.4}$

$$P_2 = 1.013 \left(\frac{0.12}{0.024}\right) = 9.64 \ bar$$

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

$$\frac{1.013 \times 0.12}{293} = \frac{9.64 \times 0.024}{T_2}$$

$$T_2 = \frac{293 \times 9.64 \times 0.024}{1.013 \times 0.12} = 557.7 \ k$$

3) $$W = \frac{P_1 V_1 - P_2 V_2}{\gamma - 1}$$

$$W = \frac{1.013 \times 10^2 \times 0.12 - 9.64 \times 10^2 \times 0.024}{1.4 - 1}$$

$W = -85.282 \ KJ$

The Second Law of Thermodynamic

The second law of thermodynamic is a natural law which indicates that although the net heat supplied in a system is equal to the net work done, the gross heat supplied must be greater than the net work done, some heat always rejected by the system, this law can be understood by considering the heat engine and heat pump.

Heat Engine

A heat engine is a system operating in a complete cycle and developing net work from supply heat.

The second law implies that a source of heat supply and sink for the rejection of heat are both necessary since some heat must be always be rejected by the system.

$\sum Q = \sum W$

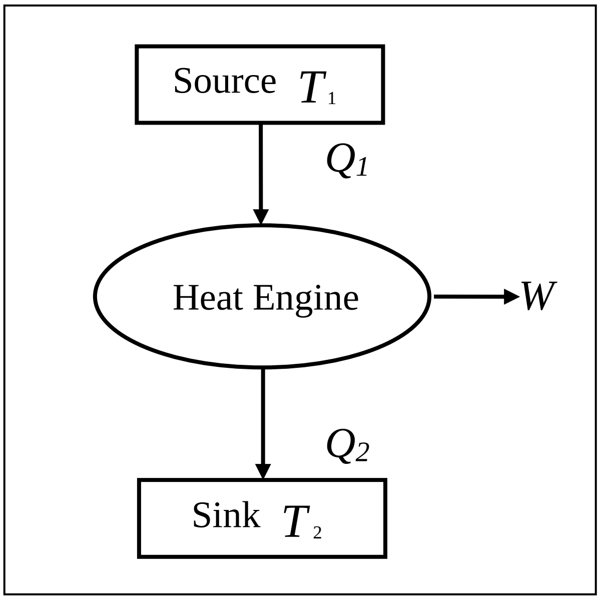
Net heat supplied = Net work done

The second law of thermodynamic

$W = Q_1 - Q_2$

$Q_1 > W$

$T_1 > T_2$ Source temperature > Sink temperature



Heat Engine

The Thermal Efficiency of Heat Engine

The ratio of net work done during the cycle to the gross heat supplied during the cycle.

$$\eta = \frac{W}{Q_1}$$

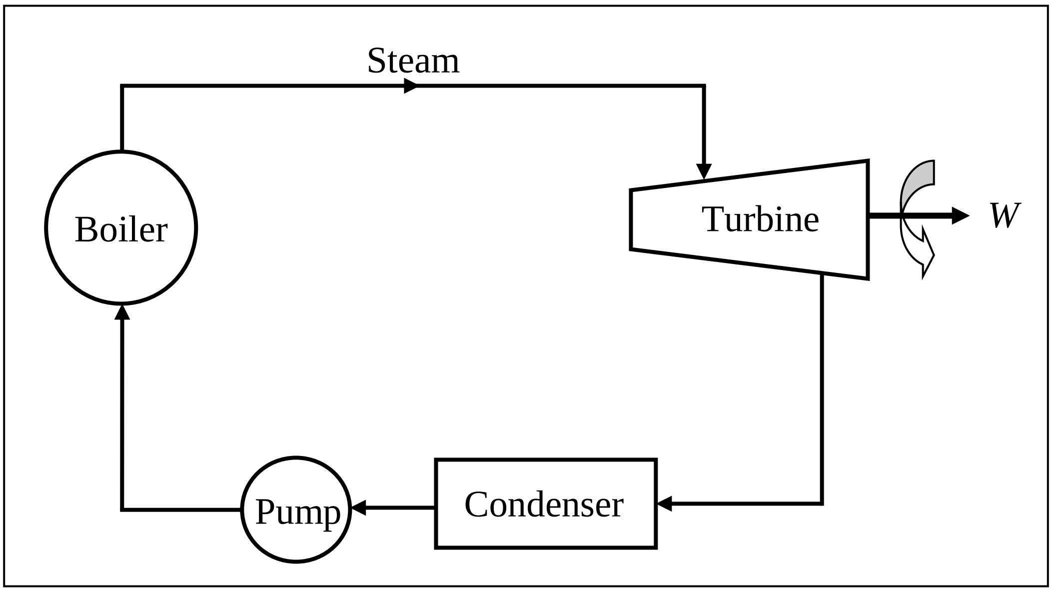
$$W = Q_1 - Q_2$$

$$\eta = \frac{Q_1 - Q_2}{Q_1} \Longrightarrow \eta = \frac{Q_1}{Q_1} - \frac{Q_2}{Q_1}$$

$$\boxed{\eta = 1 - \frac{Q_2}{Q_1}} \times 100\ \%$$

There for the thermal efficiency of a heat engine is always less than 100 %. One good example in practice of heat engine is a simple steam cycle in this cycle heat is supplied in boiler work is developed in turbine heat is rejected in a condenser and small amount of work is required for the pump.

There are many examples of the heat engine such as steam power plant shown the figure below.



Simple Steam Cycle

Boiler = Source, the heat called = Q_1

Condenser = Sink, the heat called = Q_2

Step1: Conversion the water into steam by boiler.

Step2: The steam spins the turbine we get the work **(**W**)**.

Step3: Because decrease of the pressure conversion the steam into water and goes to the condenser and pumped to the boiler by pump and get loss the work called (W').

$Q_1 - Q_2 = W - W'$

$$\eta = \frac{W - W'}{Q_1}$$

$$\eta = 1 - \frac{Q_2}{Q_1}$$

Example (1)

A power station contains a heat engine operating between two heat reservoirs, one consisting of steam at $100\ ^oC$ and the other consisting of water at $20\ ^oC$. Determine:-

1) The work done.   2) The thermal efficiency of heat engine.

Solution

1) $T_1 = 100\ ^oC$

$= 100 + 273 = 373\ K = Q_1$

$T_2 = 20\ ^oC$

$= 20 + 273 = 293\ K = Q_2$

$W = Q_1 - Q_2$

$W = 373 - 293 = 80\ J$

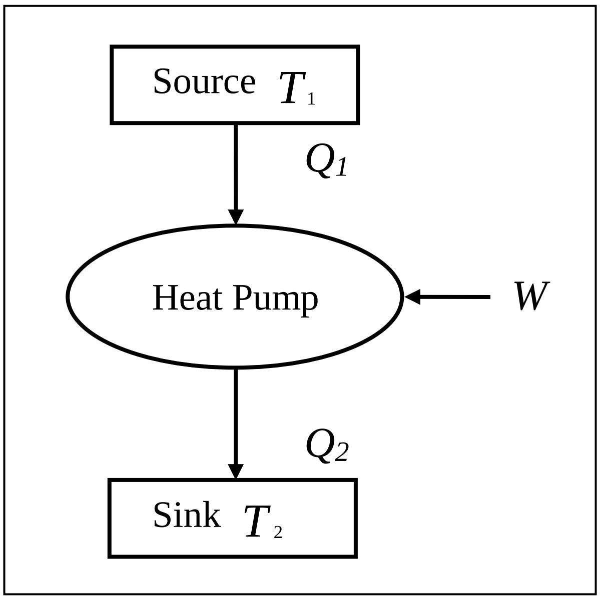
2) $\eta = 1 - \frac{Q_2}{Q_1}$

$$\eta = 1 - \frac{293}{373}$$

$\eta = 0.214 \times 100 = 21.4\%$

Heat Pump

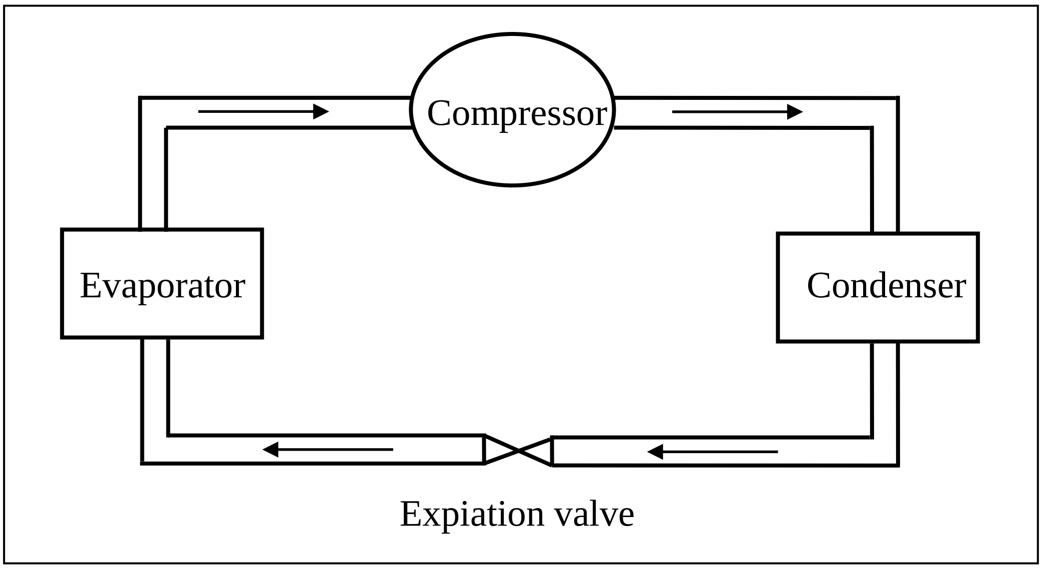
The heat pump is reversed heat engine in the heat pump cycle an amount of heat **(**Q_2**)** is supplied from the cold reservoir and an amount of heat **(**Q_1**)** is rejected to the hot reservoir and there must be a work done on the cycle **(**W**)**.



Heat pump

$$Q_1 = Q_2 + W$$

There for $W > 0$, the heat pump requires an input energy in order to transfer heat from the cold chamber and reject it at higher temperature.



Heat Pump Cycle

Example (2)

Calculate the thermal efficiency for an air-to-air heat pump used to maintain the temperature of a house at 70 ^oF when the outside temperature is 30 ^oF.

Solution

$T_1 = 70\ ^oF$

$T_2 = 30\ ^oF$

$^oF = 1.8\ ^oC + 32$

$70 = 1.8\ ^oC + 32 \Longrightarrow 1.8\ ^oC = 70 - 32 \Longrightarrow 1.8\ ^oC = 38 \Longrightarrow$

$^oC = 21.1 \Longrightarrow 21.1 + 273 = 294.1\ K = Q_1$

$30 = 1.8\ ^oC + 32 \Longrightarrow 1.8\ ^oC = 30 - 32 \Longrightarrow 1.8\ ^oC = -2 \Longrightarrow$

$^oC = -1.1 \Longrightarrow -1.1 + 273 = 271.9\ K = Q_2$

$$\eta = 1 - \frac{Q_2}{Q_1}$$

$$\eta = 1 - \frac{271.9}{294.1}$$

$$\eta = 7.5\ \%$$

Home work

Question

A power plant contains a heat engine operating between two heat tanks, the first tank contains the steam at (85^oF) and the heat engine another tank contains the water at (25^oF). Determine the thermal efficiency of heat engine.

Solution

$T_1 = 85\ ^oF$

$T_2 = 25\ ^oF$

$^oF = 1.8\ ^oC + 32$

$85 = 1.8\ ^oC + 32 \Rightarrow 1.8 = 85 - 32 \Rightarrow 1.8\ ^oC = 53 \Rightarrow$

$^oC = 29.44 \Rightarrow 29.44 + 273 = 302.4\ K = Q_1$

$25 = 1.8\ ^oC + 32 \Rightarrow 1.8\ ^oC = 25 - 32 \Rightarrow 1.8\ ^oC = -7 \Rightarrow$

$^oC = -3.88 \Rightarrow -3.88 + 273 = 269.12\ K = Q_2$

$$\eta = 1 - \frac{Q_2}{Q_1}$$

$$\eta = 1 - \frac{269.12}{302.44}$$

$\eta = 0.11 \times 100 = 11\%$

Entropy (S)

Entropy is defined as thermodynamic property that expresses the amount of storage energy in the system. Also it is a measure of system disorder and of the unavailability of energy to do work. Therefore, entropy is a way of expressing the second law of thermodynamics with regard to heat transfer from.

1) Temperature – Entropy Diagram

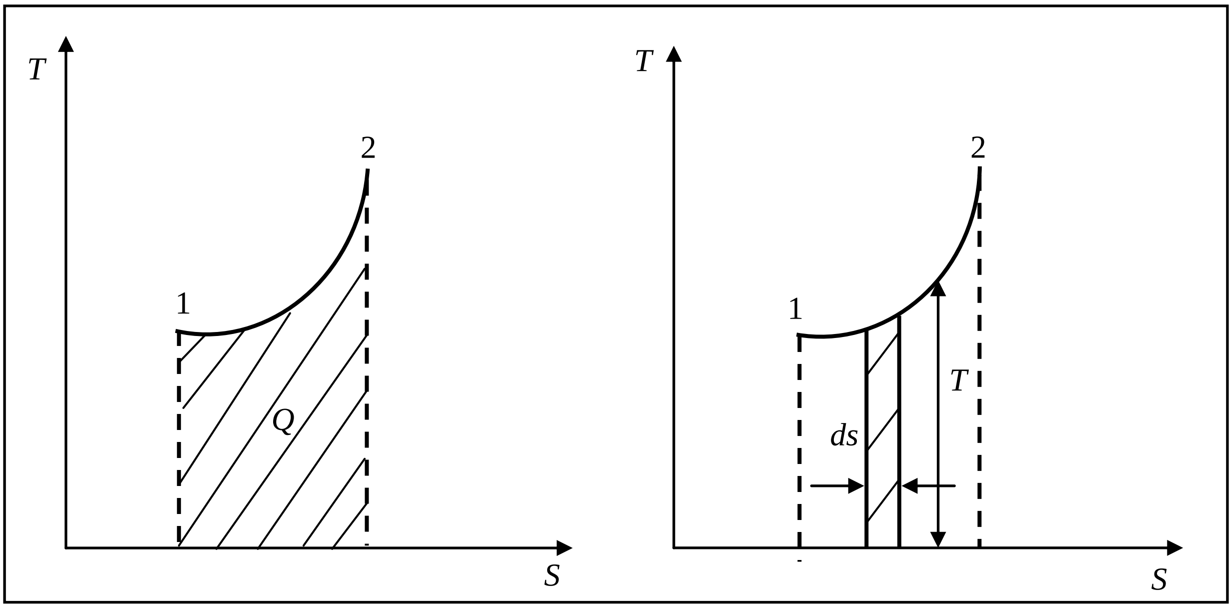


Diagram of temperatures vs. entropy

For the reversible process the area under (T-S) plane is equal the heat (1)

$dQ = Tds$ ……….. (1

$$\int Q = \int T \ ds$$

$$Q = \int_{s_1}^{s_2} T \ ds$$

From Equation (1)

$$\boxed{ds = \frac{dQ}{T}}$$

The unit of entropy is (J/k)

2) The Change of Entropy at Constant Pressure

$dQ = mdh$ ………… (1)

$C_P = \dfrac{dh}{dT} \Longrightarrow$

$dh = C_p dT$ ………… (2)

Sub. Equation (2) in Equation (1)

$dQ = mC_p dT \quad \div T$

$$\frac{dQ}{T} = m\ C_p \frac{dT}{T}$$

$$\because ds = \frac{dQ}{T}$$

$$ds = \int m\ C_p \frac{dT}{T}$$

$$ds = m\ C_p \int \frac{dT}{T}$$

$$\Delta S = m\ C_p\ Ln\ \frac{T_2}{T_1}$$

$\because \dfrac{T_2}{T_1} = \dfrac{V_2}{V_1}$ **at Constant Pressure**

$$\therefore \Delta S = m\ C_p\ Ln\ \frac{V_2}{V_1}$$

2) The Change of Entropy at Constant Volume

$dQ = mdu$ ………… (1)

$C_v = \dfrac{du}{dT} \Longrightarrow$

$du = C_v dT$ …………. (2)

Sub. Equation (2) in Equation (1)

$dQ = mC_v dT \quad \div T$

$$\frac{dQ}{T} = m\ C_v \frac{dT}{T}$$

$$\because ds = \frac{dQ}{T}$$

$$ds = \int m\ C_v \frac{dT}{T}$$

$$ds = m\ C_v \int \frac{dT}{T}$$

$$\Delta S = m\ C_v\ Ln\ \frac{T_2}{T_1}$$

$\because \dfrac{T_2}{T_1} = \dfrac{P_2}{P_1}$ **at Constant Volume**

$$\boxed{\therefore \Delta S = m\ C_v\ Ln\ \frac{P_2}{P_1}}$$

Notes

$\because C_p > C_v$

$\therefore \Delta s_{p=c} > \Delta s_{v=c}$

Example (1)

Determine the change of entropy for reversible process at constant pressure when the temperature vary from 120 *ºC* to 270 *ºC*, the mass of gas is 1 *kg* and $C_p = 2.1\ kJ / kg.k$.

Solution

$$\Delta s = m\, C_p\ Ln\, \frac{T_2}{T_1}$$

$$\Delta s = 1 \times 2.1\, Ln\ \frac{270 + 273}{120 + 273}$$

$$\Delta s = 2.1\ Ln\ 1.38$$

$$\Delta s = 2.1 \times 0.322 = 0.676\ kJ / k$$

Example (2)

The temperature vary from 150 *ºC* to 290 *ºC*, the mass of gas is 2 *kg* and the change of entropy is 1.083 *kJ/k*. Determine the specific heat at constant volume .

Solution

$$\Delta s = m\, C_v\ Ln\, \frac{T_2}{T_1}$$

$$1.083 = 2 \times C_v\ Ln\ \frac{290 + 273}{150 + 273}$$

$$1.083 = 2 \times C_v\ Ln\, 1.33$$

$$C_v = \frac{1.083}{2 \times Ln 1.33}$$

$$C_v = \frac{1.083}{2 \times 0.285} = 1.9\ kJ / kg.k$$

Home work

Question

Define the change of entropy for reversible process at constant volume for gas with a mass of 1 *kg*, the temperature vary from 130 ^oC to 250 ^oC and the specific heat at constant volume is 1.8 *kJ / kg.k*

Solution

$$\Delta s = m\, C_v\, Ln \frac{T_2}{T_1}$$

$$\Delta s = 1 \times 1.8\ Ln\ \frac{250 + 273}{130 + 273}$$

$$\Delta s = 1 \times 1.8\ Ln\ \frac{523}{403}$$

$$\Delta s = 1.8\ Ln\ 1.297$$

$$\Delta s = 1.8 \times 0.26 = 0.468\ kJ / kg.k$$

Carnot Cycle

The Carnot cycle was introduced as the most efficient heat engine that operate between two fixed temperatures ($T_H = T_{in}$ & $T_L = T_{out}$) . The Carnot gas cycle could also be achieved in a cylinder – piston apparatus (a reciprocating engine) as shown the figures below.

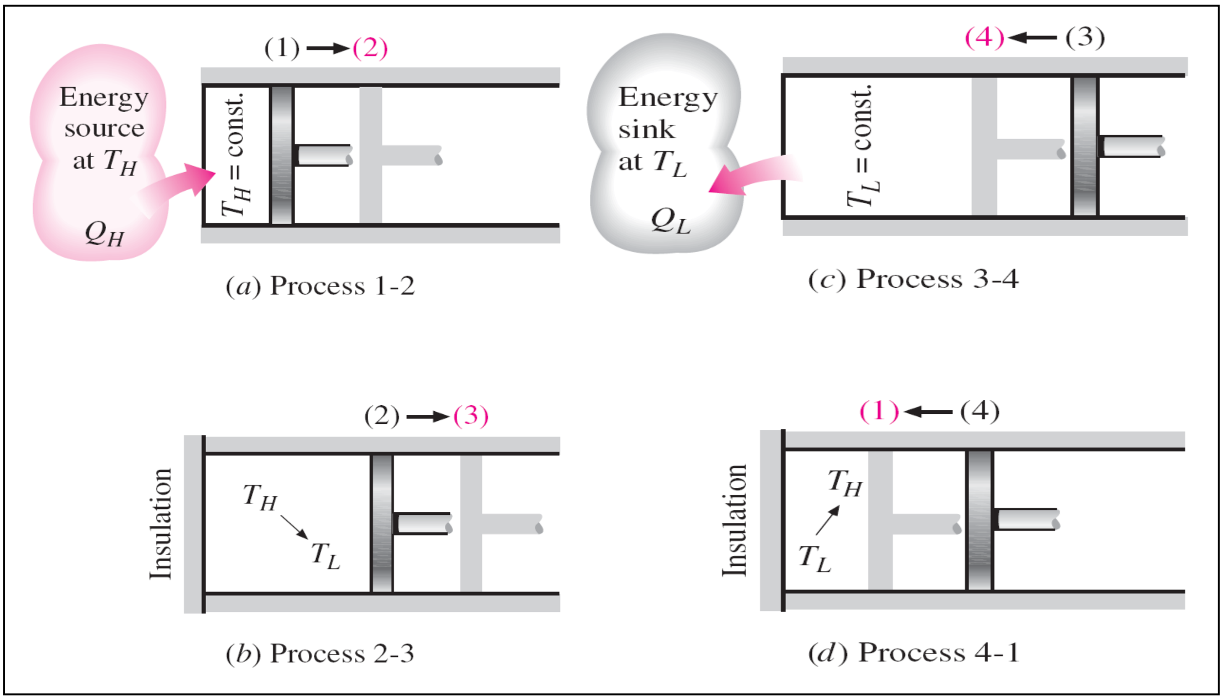


Figure 1. Execution of Carnot cycle in a piston cylinder device

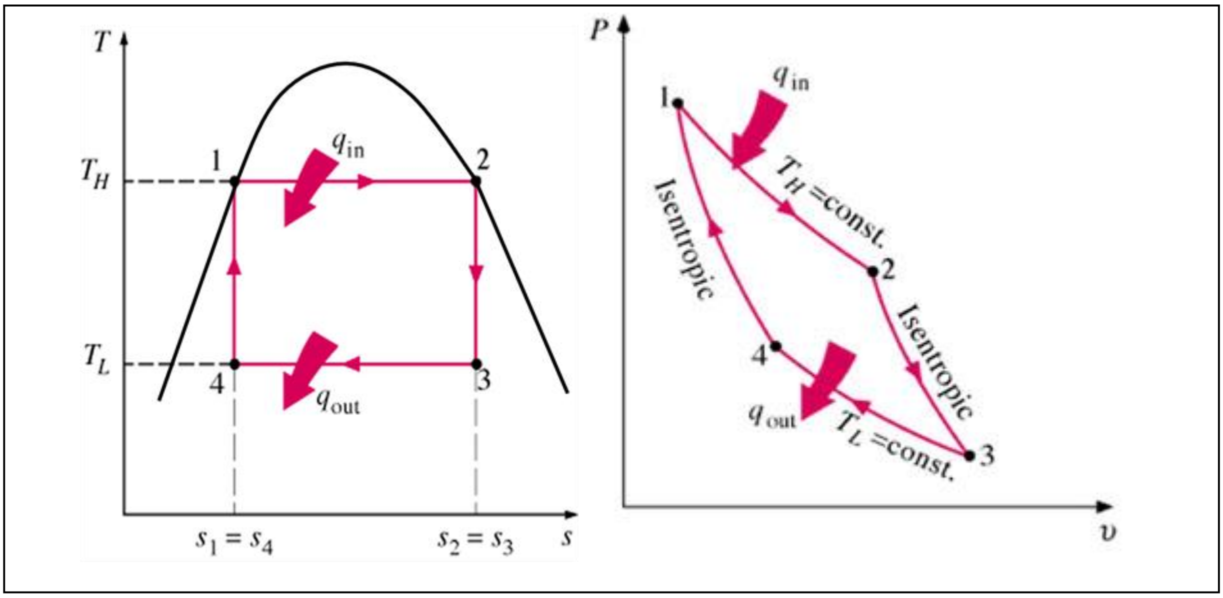


Figure 2. Carnot cycle on P-v and T-s diagrams

Description of work Carnot cycle:

From 1 to 2 -- isothermal heat addition at high temperature.

From 2 to 3 -- adiabatic expansion from high temperature to low temperature.

From 3 to 4 -- isothermal heat rejection at low temperature.

From 4 to 1 -- adiabatic compression from low to high temperature.

Carnot cycle analysis:

$T_H = T_{in}$ & $T_L = T_{out}$

The thermal efficiency of Carnot cycle is given by the expression:

$$\eta_{th} = 1 - \frac{T_{out}}{T_{in}}$$

$$\eta_{th} = 1 - \frac{T_4}{T_1}$$

$$\eta_{th} = 1 - \frac{T_3}{T_2}$$

Since the working fluid is an ideal gas with constant specific heats, we have for the isentropic process.

$$\frac{T_1}{T_4} = \left(\frac{V_4}{V_1}\right)^{\gamma-1} \quad \& \quad \frac{T_2}{T_3} = \left(\frac{V_3}{V_2}\right)^{\gamma-1}$$

Now, $T_1 = T_2$ & $T_4 = T_3$ therefore

$$\frac{V_4}{V_1} = \frac{V_3}{V_2} = r = \text{ Compression or expansion ratio}$$

The efficiency of Carnot cycle can be written as the follows:

$$\eta_{th} = 1 - \frac{1}{r^{\gamma-1}}$$

From the above equation, it can be observed that the thermal efficiency of Carnot cycle increases as "*r*" increases. This implies that the high thermal efficiency of a Carnot cycle is obtained at the expense of large piston displacement. Also, for isentropic processes we have.

$$\frac{T_1}{T_4} = \left(\frac{P_1}{P_4}\right)^{\frac{\gamma-1}{\gamma}} \quad \text{and} \quad \frac{T_2}{T_3} = \left(\frac{P_2}{P_3}\right)^{\frac{\gamma-1}{\gamma}}$$

Since, $T_1 = T_2$ and $T_4 = T_3$, we have

$$\frac{P_1}{P_4} = \frac{P_2}{P_3} = r_p = \text{Pressure ratio}$$

Therefore, the efficiency of Carnot cycle can be written as the follows:

$$\eta_{th} = 1 - \frac{1}{r_p^{\frac{\gamma-1}{\gamma}}}$$

From the above equation, it can be observed that, the thermal efficiency of Carnot cycle increase by increasing the pressure ratio. This means that Carnot cycle should be operated at high peak pressure to obtain large thermal efficiency.

Example

The highs theoretical efficiency of gasoline engine based on the Carnot cycle is 30 % of this engine expels its gases into atmosphere which has temperature of 300 *k***.** Calculate:

1) The temperature in the cylinder forthwith after combustion.

2) If the engine absorbs (837 *J*) of heat from the hot reservoir during each cycle how much work can it perform in each cycle.

Solution

1) $$\eta_{th} = 1 - \frac{T_{out}}{T_{in}}$$

$$T_{in} = \frac{T_{out}}{1-\eta_{th}} = \frac{300}{1-0.3} = 429\ k$$

2) $$\eta_{th} = \frac{W}{Q_{in}} \quad \Rightarrow \quad W = \eta_{th} \times Q_{in} \quad \Rightarrow$$

$$W = 0.3 \times 837 = 251\ J$$

Home work

Question

A Carnot engine is operated between two heat reservoirs at temperature of 450 k and 350 k , if the engine receive (1000 J) of heat in each cycle. Calculate:

1) The amount of heat rejects.

2) The efficiency of the engine.

3) The work done by the engine in each cycle.

Solution

$T_{in} = 450\ k$, $T_{out} = 350\ k$, $Q_{in} = 1000\ J$

1) $\frac{Q_{out}}{Q_{in}} = \frac{T_{out}}{T_{in}}$

$$Q_{out} = Q_{in}\frac{T_{out}}{T_{in}} = 1000 \times \frac{350}{450} = 777.7\ k$$

2) $\eta_{th} = 1 - \frac{T_{out}}{T_{in}}$

$$\eta_{th} = 1 - \frac{350}{450} = 0.22 = 22\%$$

3) The work done $= Q_{in} - Q_{out}$

$$= 1000 - 777.7 = 222.3\ J$$

Rankine cycle

Rankine Cycle is the basic building block in thermodynamics related to the steam engine. Shown the figures below the simple ideal Rankine cycle. It owes its name to the Scottish brand, "William Rankin".

Rankine cycle is to convert thermal energy to work. Fed heat from an external source to the closed loop, which usually uses water. This cycle generates about 80% of electric power around the world, including all power plants, solar thermal energy, biofuels energy, fossil fuels and nuclear power.

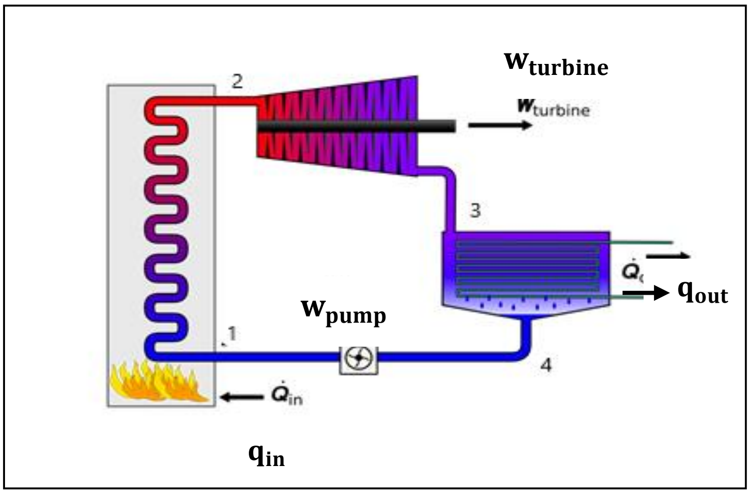


Figure 1: Working of Rankine engine

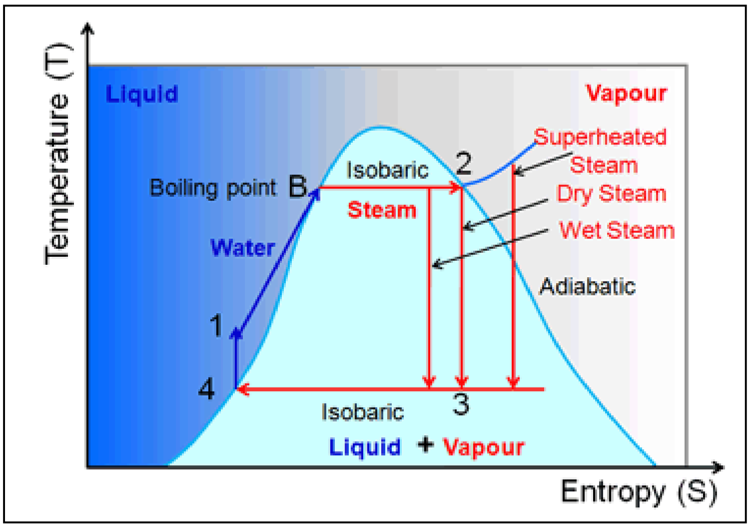


Figure 2: Rankine cycle on T-S diagram

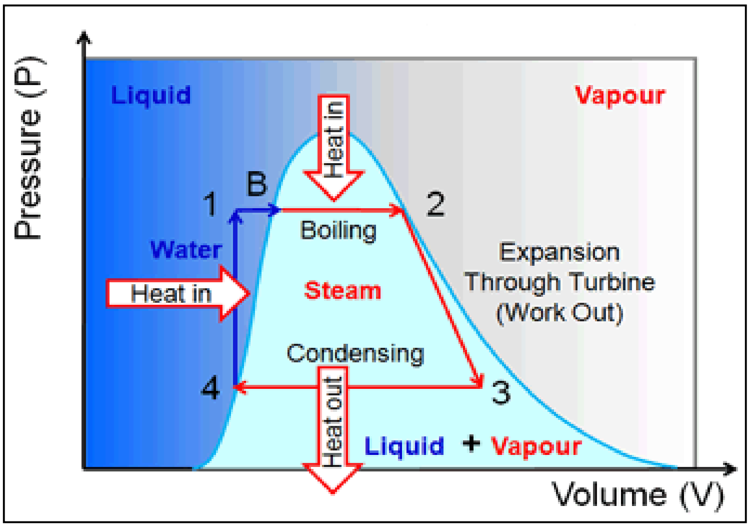


Figure 3: Rankine cycle on P-V diagram

Description of work of Rankine cycle

From 1 to 2 -- Constant pressure heat addition in a boiler.

From 2 to 3 -- Isentropic expansion in a turbine.

From 3 to 4 -- Constant pressure heat rejection in a condenser.

From 4 to 1 – Isentropic compression in a pump.

Rankine cycle analysis

In step 1 to 2 -- Constant pressure heat addition in a **boiler** ($W = 0$).

$$q_{in} = h_2 - h_1$$

In step 2 to 3 -- Isentropic expansion in a **turbine** ($q = 0$).

$$W_{turb} = h_2 - h_3$$

In step 3 to 4 -- Constant pressure heat rejection in a **condenser** ($W = 0$).

$$q_{out} = h_3 - h_4$$

In step 4 to 1 -- Isentropic compression in a **pump** ($q = 0$).

$$W_{pump} = h_1 - h_4$$

Net work $W_{net} = |W_{turb}| - |W_{pump}|$ ⇨

$$W_{net} = (h_2 - h_3) - (h_1 - h_4)$$

Thermal efficiency $\eta = \dfrac{w_{net}}{q_{in}} = \dfrac{(h_2 - h_3) - (h_1 - h_4)}{(h_2 - h_1)}$ ⇨

$$\eta = 1 - \frac{(h_3 - h_4)}{(h_2 - h_1)} \Rightarrow \boxed{\eta = 1 - \frac{q_{out}}{q_{in}}}$$

Example

If the ideal Rankine Cycle with superheat using water as the working fluid. Where $P_1 = 9.6$ *KP* , $P_2 = 3500$ *KP* , $V_1 = 0.0010\ m^3$, $h_1 = 188.42$ *kJ/kg*, $h_3 = 3337.2$ *kJ/kg*, $h_4 = 2214.2$ *kJ/kg* and mass flow is 7 *kg/s*. Calculate:

1) The thermal efficiency of this cycle.

2) The net power output in *KW*.

Solution

$P_1 = 9.6$ *KP*

$P_2 = 3500$ *KP*

$V_2 = 0.0010\ m^3$

$h_1 = 188.42$ *kJ/kg*

$h_3 = 3337.2$ *kj/kg*

$h_4 = 2214.2$ *kj/kg*

$m = 7$ *kg/s*

1) $W_{pump} = \int v dp \Longrightarrow W_{pump} = V(p_2 - p_1) \Longrightarrow$

$$W_{pump} = 0.00101(3500 - 9.6) = 3.525 KJ$$

$\because W_{pump} = h_2 - h_1 \Longrightarrow h_2 = W_{pump} + h_1 \Longrightarrow$

$$h_2 = 3.525 + 188.42 = 191.95 kj/kg$$

$$\eta = 1 - \frac{q_{out}}{q_{in}}$$

$q_{out} = h_4 - h_1 \Longrightarrow q_{out} = 2214.2 - 188.42 = 2025.78 kj/kg$

$q_{in} = h_3 - h_2 \Longrightarrow q_{in} = 3337.2 - 191.95 = 3145.25 kj/kg$

$\eta = 1 - \frac{2025.78}{3145.25} = 0.355 \Longrightarrow$

$$\eta = 0.355 \times 100 = 35.5\%$$

2) $W_{net} = |W_{turb}| - |W_{pump}|$

$W_{turb} = h_3 - h_4 \Longrightarrow W_{turb} = 3337.2 - 2214.2 = 1123 kj/kg$

$W_{pump} = h_2 - h_1 \Longrightarrow W_{pump} = 191.95 - 188.42 = 3.53 kj/kg$

$$W_{net} = 1123 - 3.53 = 1119.47 kj/kg$$

$$P_{net} = m \times w_{net}$$

$$P_{net} = 7 \times 1119.47 = 7836.29\ kw$$

<u>**Home work**</u>

Question

A supply of geothermal hot water is to be used as the energy source in an ideal Rankine cycle, where $h_1 = 256.54$ *kJ/kg*, $h_2 = 258.21$ *kJ/kg*, $h_3 = 458.1$ *kJ/kg* and $h_4 = 409.14$ *kJ/kg*. Calculate:

1) The thermal efficiency of this cycle.

2) Net work.

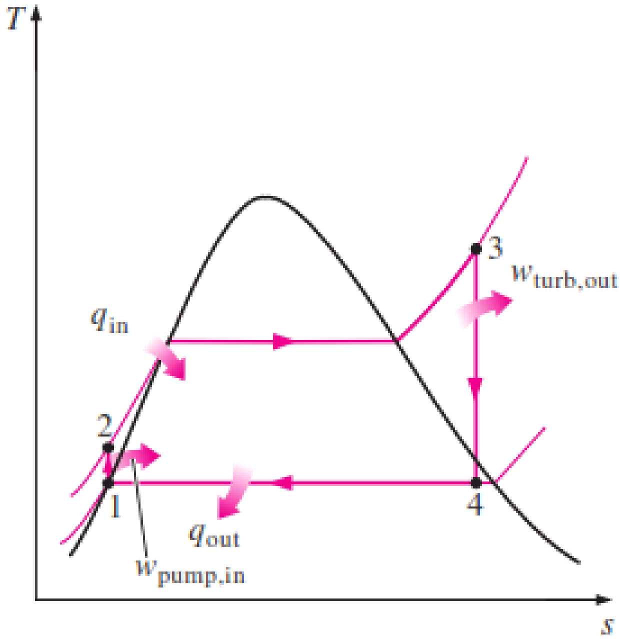
Solution

$h_1 = 256.54$ kj/kg

$h_2 = 258.21$ kj/kg

$h_3 = 458.1$ kj/kg

$h_4 = 409.14$ kj/kg



1) $$\eta = 1 - \frac{q_{out}}{q_{in}}$$

$$q_{out} = h_4 - h_1 \Longrightarrow q_{out} = 409.14 - 256.54 = 152.69 kj/kg$$

$$q_{in} = h_3 - h_2 \Longrightarrow q_{in} = 458.1 - 258.21 = 199.89 kj/kg$$

$$\eta = 1 - \frac{152.69}{199.89} = 0.23 \Longrightarrow \eta = 0.23 * 100 = 23\%$$

2) $$w_{net} = |w_{turb}| - |w_{pump}|$$

$$w_{turb} = h_3 - h_4 \Longrightarrow w_{turb} = 458.1 - 409.14 = 48.96 kj/kg$$

$$w_{pump} = h_2 - h_1 \Longrightarrow w_{pump} = 258.21 - 256.54 = 1.67 kj/kg$$

$$\therefore w_{net} = 48.96 - 1.67 = 47.29 kj/kg$$

تجربة رقم (1)

قانـــــون بـــويــــــل

Boyle's Law

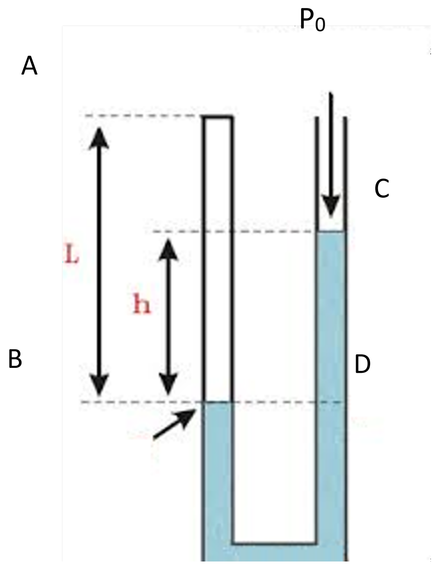
الهدف من التجربة *Aim of the Experiment*

إيجاد قيمة الضغط الجوي (p_0) باستخدام جهاز بويل وتحقيق قانون بويل للغازات .

الأجهزة المستخدمة *Apparatus*

1- محرار.

2- جهاز بويل: يتكون من انبوبة زجاجية (AB) منتظمة المقطع ومغلقة الطرف العلوي اما طرفها الثاني فيتصل بانبوبة مطاطية التي بدورها تتصل بأنبوبة زجاجية اخرى (CD) مشابهه للأولى ولكنها مفتوحة من نهايتها . يملأ معظم هذا الجهاز بالزئبق ثم يثبت بوضع شاقولي وعلى شكل حرف - U - حول مسطرة مترية كما هو مبين في الشكل (1):



شكل(1)

نظرية التجربة Theory

ينص قانون بويل على انه

" عند ثبوت درجة الحرارة يتناسب ضغط كتلة معينة من الغاز تناسبا عكسياً مع الحجم "
اي ان :

$$P \propto \frac{1}{V}$$

$$PV = constant \ldots\ldots(1)$$

فإذا كان (h cmHg)هو الفرق بين مستويي الزئبق في الأنبوبتين فالضغط المسلط على الغاز المحصور في الأنبوبة AB هو:

$$P = P_0 + h \ldots\ldots(2)$$

حيث (P_0) هو الضغط الجوي مقاساً بـــ (cm Hg).

بما ان الانبوبة ثابتة في مساحة مقطعها العرضي لذا فأن حجم الغاز المحصور ($V\ cm^3$) يتناسب طردياً مع طول الهواء المحصور(L cm) ، اي ان:

$$\therefore V = aL \ldots\ldots(3)$$

حيث (a) مساحة المقطع الداخلي للأنبوبة (AB) . لذلك فمن قانون بويل نحصل على:

$$(P_0 + h).La = C \ldots\ldots(4)$$

حيث (C) كمية ثابتة.

وبقسمة الطرفين على a ينتج :

$$(P_0 + h)L = K \ldots\ldots(5)$$

حيث K كمية ثابتة اخرى وتساوي $\frac{C}{a}$.

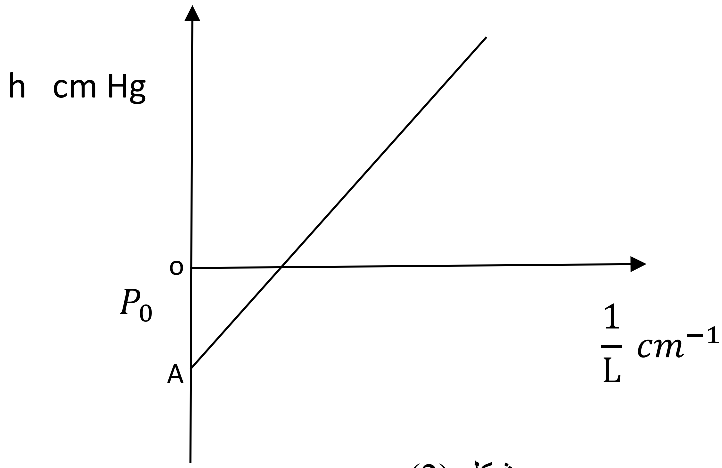
$$\therefore P_0 + h = \frac{K}{L} \ldots\ldots(6)$$

او

$$h = \frac{K}{L} - P_0 \ldots\ldots(7)$$

يتحقق قانون بويل فقط اذا كان الخط البياني بين h و $\frac{1}{L}$ خطا مستقيما .

فإذا رسمت علاقة بيانية بين قيم hعلى محور الصادات ومايقابلها من قيم $\frac{1}{L}$ على محور السينات نحصل على خط مستقيم يقطع المحور الصادي في نقطة (بالاتجاه السالب) تمثل قيمة الضغط الجوي (P_0) كما في شكل (2)



شكل (2)

$$|0A| = P_0 \ (\text{cm Hg})$$

طريقة العمل *Method*

1- سجل درجة حرارة المختبر قبل اجراء التجربة.

2- اخفض *الأنبوبة* AB إلى أقصى حد ممكن وارفع الانبوبة CD بحيث يكون مستويا الزئبق X ، Y في طرفي الجهاز مرئيين .

3- سجل قراءة المسطرة عند كل من (A،X،Y) ثم قس طول عمود الهواء المحصور في الأنبوبة (AX) وليكن L(cm) وكذلك جد الفرق بين مستويي الزئبق عند Y،X والذي يساوي قيمة h حسب العلاقات التالية :

h = Y – X

L = A - X

4- غير ضغط الهواء المحصور وذلك برفع الانبوبة المفتوحة (CD) الى اعلى قليلا في حدود (2cm) ثم انتظر دقيقتين تقريبا وبعدها سجل قراءة مستوي الزئبق في كلا الطرفين واحسب قيمة h(cmHg) ثم احسب قيمة L(cm) المقابلة لها.

5- كرر ماجاء بالخطوة (4) لعدد مناسب من المرات.

6-اخفض الانبوبة المفتوحة (CD) بحيث يصبح ضغط الهواء المحصور اقل من الضغط الجوي و احسب قيمة h(cmHg) وقيمة L(cm) المناظرة لها (h في هذه الحالة سالبة).

1- كرر ماجاء بالخطوة (6) لعدد مناسب من المرات.

Measurements and calculations القياسات والحسابات

1- سجل نتائجك كما في الجدول ادناه :

A(cm)	X(cm	*Y(cm)*	$h = Y - X(\mathrm{cm}Hg)$	L= A-X (cm)	$\frac{1}{L}\,(cm^{-1})$

2- ارسم علاقة بيانية بين قيم h(cmHg) على محور الصادات وما يقابلها من قيم لـ $\frac{1}{\mathrm{L}}\,(cm^{-1})$ على محور السينات تحصل على خط مستقيم يحقق قانون بويل (شكل 2).

3- احسب الضغط الجوي من القطع السالب لمحور الصادات

$$P_0 = |OA| \quad \mathrm{cm}Hg$$

Notes ملاحظات

1-تؤخذ قراءة التدريج في الانبوبتين الزجاجتين بمحاذاة سطح الزئبق المحدب.

2- بما ان التغيير الفجائي لضغط الهواء يؤدي الى تغير في درجة حرارته ، لذا يجب رفع وخفض مستوى الزئبق بصورة بطيئة ومن الافضل ان يترك الجهاز بعد تحريكه فترة من الزمن قبل اخذ القراءة .

3- يجب ان يكون وضع الانبوبتين بشكل شاقولي وبدون ميلان فيه.

Questions الاسئلة

1- لماذا يستخدم الزئبق لتحقيق قانون بويل ولا تستخدم غيره من السوائل؟

2- لماذا يجب الانتظار قليلا بعد تغيير حجم الغاز المحصور ثم اخذ القراءات ؟

3-ناقش العلاقة البيانية التي حصلت عليها ، وماذا تستنتج من الخط المستقيم؟

المحرار الغازي
Gas Thermometer

مقدمة

تعرف درجة الحرارة بانها تمثل مؤشراً لمدى سخونة او برودة الجسم . هذا التعريف يبدو غير محدد كون الاحساس بالبرودة او السخونة تعد مسألة نسبية تختلف من شخص الى آخر مما يستدعي وجود أساس دقيق لتحديد القيمة العددية لدرجة الحرارة كونها واحدة من خواص المادة القابلة للقياس .

الأداة التي تستخدم لتحقيق ذلك تسمى المحرار Thermometer والذي يستند في مبدأ عمله الى القانون الصفري لديناميك الحرارة والذي ينص على:

أذا كان جسمان في حالة اتزان حراري مع جسم ثالث فانهما سيكونان في حالة اتزان مع بعضهما.

فلو كان الجسم الثالث هو المحرار فعند ذاك سيكون الجسمان لهما نفس قراءة درجة الحرارة.

تستند طرق قياس درجة الحرارة الى تغير احدى خواص المادة بتغير درجة حرارتها ، مثالها تغير الحجم ، الضغط ، المقاومة الكهربائية ..الخ. من ذلك يمكن ربط تغير هذه الخاصية مع تغير درجة الحرارة عبر دالة رياضية محددة مما يمكن من بناء تدريج يناظر التغير بتلك الخاصية مع تغير معلوم بدرجة الحرارة.

الغرض من التجربة

تحقيق قانون غاي – لوساك وقياس درجة الحرارة باستخدام ضغط الغاز.

نظرية التجربة

قدم العالم والفيزياوي الفرنسي غاي- لوساك Gay-Lussac عام 1802م ملاحظاته حول تغير خواص الغاز المثالي بصيغة قانون عرف بأسمه وينص على :

لكتلة محددة من غاز مثالي فأن ضغط الغاز يتناسب طردياً مع درجة الحرارة بثبوت حجمه.

وبذلك يمكن التعبير رياضيا عن هذا التناسب بالشكل :

هذه الصيغة تقدم امكانية بناء محرار غازي يعمل تحت حجم ثابت بحيث يربط التغير بالضغط لغاز بتغير درجة حرارته واستنتاج تدريج مناسب لقياس درجات الحرارة بواسطته. هذا هو ما يعرف " المحرار الغازي ذي الحجم الثابت ". بتطبيق قانون غاي- لوساك على حالتين :

والان لو كانت احدى هاتين الحالتين تمثل الظروف القياسية بحيث :

حيث يمثل T_o درجة الحرارة المرجعية (الصفرية) ، بذلك سيكون:

لو عبرنا عن الثابت (1/273) بالرمز α فتصبح المعادلة:

حيث يمثل p_o ضغط الغاز عند درجة الحرارة المرجعية (0^oC) وهذا يعني انه عند حجم ثابت فان ضغط الغاز سيتغير بنسبة (1/273) عن قيمته عند الدرجة المرجعية. مرة اخرى بتطبيق قانون غاي – لوساك بين حالتين :

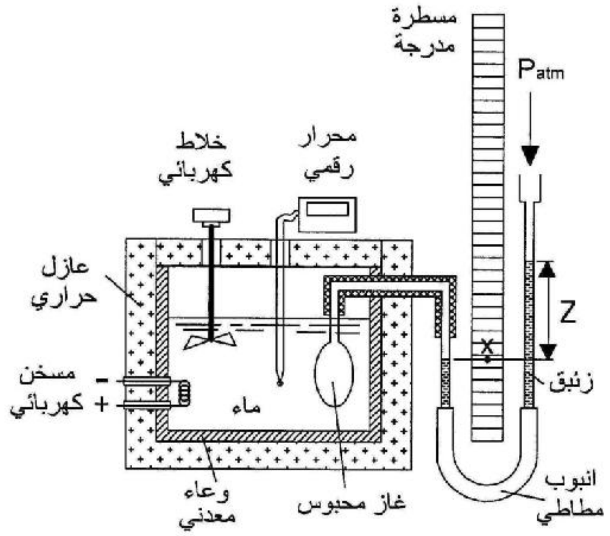
باعادة الترتيب والتبسيط تصبح المعادلة بالشكل:

وحيث ان ($\alpha = 1/273$) وان ($p = \rho g Z$) فعليه ستصبح:

وهي تمثل المعادلة المستخدمة لقياس معامل زيادة درجة الحرارة لهذا المحرار الغازي ذي الحجم الثابت.

الجهاز المستخدم

يتالف الجهاز المستخدم في التجربة من دورق زجاجي يتصل مباشرة بانبوبة زجاجية معزولة حراريا تحوي زئبق يحبس غازا في الدورق وقد ثبتت الانبوبة دون حركة. تربط انبوبة مطاطية مرنة الانبوبة المثبتة بانبوبة زجاجية اخرى مفتوحة الطرفين مثبتة على حامل له قابلية الحركة صعودا ونزولا مما يسمح بتغيير مستوى الزئبق في الانبوبتين. تم غمر الدورق في حوض من الماء مزود بمسخن كهربائي مسيطر عليه بواسطة ثرموستات للتحكم بدرجة حرارة الماء. يعمل الماء كوسط لتجانس درجة الحرارة حول الدورق والغاز المحبوس داخله ، كما وزود الحوض بخلاط كهربائي لتدوير الماء للمساعدة في تجانس درجات الحرارة في الحوض.



مخطط للمحرار الغازي

خطوات العمل

1. التاكد من وجدود ماء مقطر داخل الحوض الى ارتفاع بضعة سنتمترات من الحافة العليا للحوض ومن ثم تشغيل الخلاط الكهربائي.
2. تأشير موضع الزئبق في الانبوبة المثبتة لتحديد حجم الغاز المحبوس قبل بدء التجربة عندما يكون الماء بارد عند درجة حرارة الغرفة (الموضع x في الشكل اعلاه).
3. تجهيز المسخن بالطاقة الكهربائية لبدء تسخين الماء في الحوض وبالتالي تسخين الغاز المحبوس في الدورق المغمور في الماء.
4. تثبيت الزيادة في درجة الحرارة للماء بمقدار $4^{o}C$ بين كل قراءة وسابقتها وملاحظة تغير موضع مستوى الزئبق في الانبوبة المثبتة بسبب تمدد الغاز المحبوس.
5. يحرك الحامل للانبوبة المتحركة الى الاعلى لاعادة موضع مستوى الزئبق في الانبوبة المثبتة الى الاشارة الابتدائية (x) بهدف الحفاظ على حجم ثابت للغاز ومن ثم يقرأ الفرق في مستوى الزئبق بين الانبوبتين.
6. تكرر الخطوة (5) لعدة قراءات بما يتناسب والفرق المتاح في درجات الحرارة مع المحيط.