College of Engineering
Mechanical Engineering Department

Second Stage

THERMODYNAMIC I

CHAPTER THREE – THE WORKING FLUID

LECTURE NO. 2 – THE PERFECT GAS

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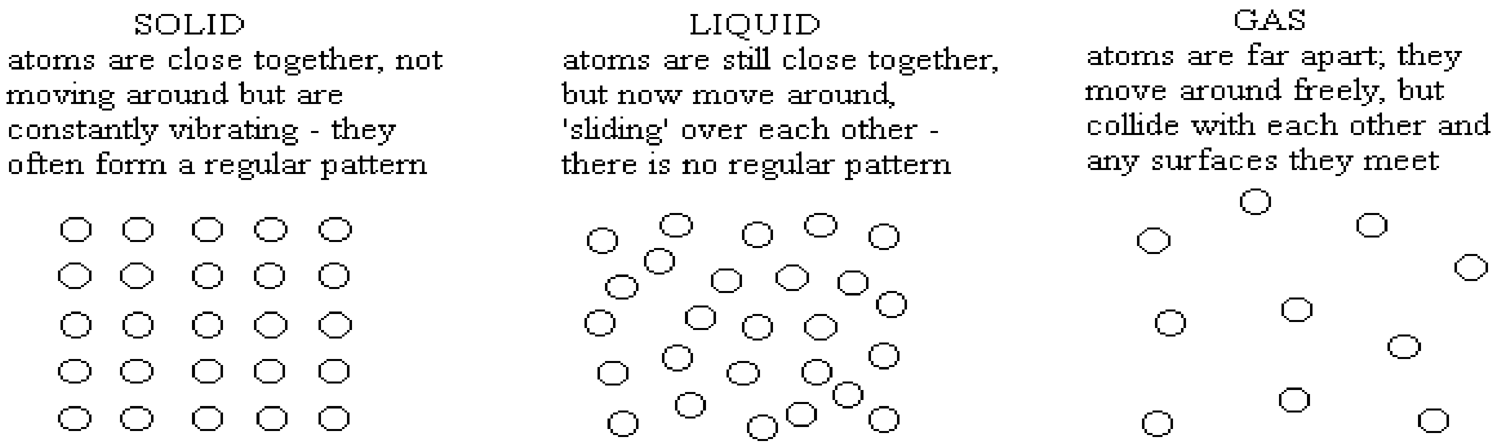
The Perfect Gas

THE PERFECT GAS :

It is a theoretical gas or imaginary gas composed of a set of randomly moving, non-interacting point like particles and they obeys the gas law always.

OR : An ideal gas is an imaginary gas that obeys gas law under all conditions



The Characteristic Equation of State

The Characteristic Equation of State :

At temperatures that are considerably in excess of critical temperature of a fluid, and also at very low pressure, the vapour of fluid tends to obey the equation:

$$\frac{pv}{T} = \text{constant} = R$$

NOTES :

- In practice, no gas obeys this law rigidly, but many gases tend towards it.
- Any gas which obeys this law is called a perfect gas,
- This equation is called the **characteristic equation of a state of a perfect gas.**

The Characteristic Equation of State ..Cont.

Usually, the characteristic equation is written as

$$pv = RT$$

or for *m* kg, occupying *V* m3

$$pV = mRT$$

Where :

The constant *R* is called the *gas constant (kJ/kg.k)*.

Each perfect gas has a different gas constant, See Table 2 Page 2 in Steam Table for value of R

T : Temperature in Kelvin (K)

p : Pressure in N/m2

v : specific volume (m3 /kg)

The Characteristic Equation of State ..Cont.

The characteristic equation in another form, can be derived by using kilogram-mole as a unit. As per definition of the kilogram-mole, for m kg of a gas, we have

m = nM

Where n = number of moles , M : The molecular weight of the gas (kg/mole)

$$pV = nMRT \quad \text{or} \quad MR = \frac{pV}{nT} \text{ , then } MR = R_o$$

As result

$pV = R_o nT$

Where :

R_o : *Universal gas constant (Fixed value for all gases*

$R_o = 8314.3$ Nm/mole K

The Characteristic Equation of State ..Examples

A vessel of volume 0.2 m^3 contains nitrogen at 1.013 bar and 15 °C. If 0.2 kg of nitrogen is now pumped into the vessel, calculate the new pressure when the vessel has returned to its initial temperature. The molar mass of nitrogen is 28 kg/kmol, and it may be assumed to be a perfect gas.

$$\text{Specific gas constant, } R = \frac{\tilde{R}}{\tilde{m}} = \frac{8314.5}{28} = 296.95 \text{ N m/kg K}$$

From equation (2.6), for the initial conditions

$$p_1 V_1 = m_1 R T_1$$

therefore

$$m_1 = \frac{p_1 V_1}{R T_1} = \frac{1.013 \times 10^5 \times 0.2}{296.95 \times 288} = 0.237 \text{ kg}$$

where $T_1 = 15 + 273 = 288$ K

The mass of nitrogen added is 0.2 kg, hence $m_2 = 0.2 + 0.237 = 0.437$ kg.

for the final conditions

$$p_2 V_2 = m_2 R T_2$$

but $V_2 = V_1$ and $T_2 = T_1$, therefore

$$p_2 = \frac{m_2 R T_2}{V_2} = \frac{0.437 \times 296.95 \times 288}{10^5 \times 0.2}$$

i.e. $p_2 = 1.87$ bar

Specific Heats

Specific Heats

The **specific heat** of a solid or liquid is usually defined as the heat required to raise unit mass through one degree temperature rise.

For small quantities, we have : $dQ = mcdT$

where

m = mass,

c = specific heat

dT = temperature rise.

Specific Heats..Cont.

We have two specific heats for gases are defined.

- *Specific heat at constant volume,* ***cv*** and,

- *Specific heat at constant pressure,* ***cp***

The heat flow between two temperature can defined as :

dQ = m cp dT **For a reversible non-flow process at *constant pressure***

and,

dQ = m cv dT **For a reversible non-flow process at *constant volume***

Specific Heats..Cont.

The values of c_p and c_v, for a perfect gas, are constant for any one gas at all pressures and temperatures , we have

Flow of heat in a reversible constant pressure process, Q = $mc_p(T_2 - T_1)$

Flow of heat in a reversible constant volume process, Q = $mc_v(T_2 - T_1)$

In case of real gases, c_p and c_v vary with temperature, but a suitable average value may be used for most practical purposes.

Joule's Law

Joule's Law

(Definition of Internal energy for perfect gas) :

The internal energy of a perfect gas is a function of the absolute temperature only. i.e., u = f (T)

Specific Internal energy, $u = c_v T$ for a perfect gas

or For mass *m*, of a perfect gas

Internal energy, $U = mc_v T$

For a perfect gas, in any process between states 1 and 2, we have

Gain in internal energy, $U_2 - U_1 = mc_v (T_2 - T_1)$

Relationship Between Two Specific Heats

Relationship Between Two Specific Heats

Consider a perfect gas being heated at constant pressure from T_1 to T_2. According to non-flow equation, Q = (U2 – U 1) + W

Also for a perfect gas, U2 – U1 = mc_v (T2 – T1) and Q = mc_v (T2 – T1) + W

In a constant pressure process, the work done by the fluid, W = p (V2 – V1) = mR (T2 – T1) , pV mRT ,

In this case On substituting

Q = mc_v (T2 – T1) + mR (T2 – T1) = m(c_v + R) (T2 – T1) But for a constant pressure process, Q = mc_p (T2 – T1) ,

By equating the two expressions, we have

$$m(c_v + R)(T2 - T1) = mc_p(T2 - T1)$$

∴ $c_v + R = c_p$ or $c_p - c_v = R$ Dividing both sides by c_v, we get $\frac{C_p}{C_v} - 1 = \frac{R}{C_v}$,

$$\Upsilon = \frac{C_p}{C_v}$$ **Ratio of Specific Heats**

The ratio of specific heat at constant pressure to the specific heat at constant volume is given the symbol γ (gamma). Then

$$Cv = \frac{R}{\Upsilon - 1} \quad \text{and } Cp = \frac{\Upsilon R}{\Upsilon - 1}$$

Enthalpy of Perfect Gas

Enthalpy

One of the fundamental quantities which occur invariably in thermodynamics is the sum of internal energy (u) and pressure volume product (pv). This sum is called **Enthalpy (h).**

i.e., h = u + pv

The total enthalpy of mass, m, of a fluid can be $H = U + pV$, where $H = mh$.

For a **perfect gas,** $h = u + pv = c_v T + RT$ Where $pv = RT$

$= (c_v + R)T = c_p T$ Where $c_p = c_v + R$

$h = c_p T$ and $H = mc_p T$