**Basic Principles and Calculations in Chemical Engineering**
Prof. S. K. Majumder
Chemical Engineering Department
Indian Institute of Technology – Guwahati

Module – 4: Basic Principles of Compressible System
Lecture – 4.1
State Equation of Ideal Gas and Calculation

Welcome to massive open online course on Basic Principles and Calculations in Chemical Engineering. Here we have discussed many things about that material balances based on nonreactive system, even with reactive systems in the previous module. So, in this module, we will try to discuss more about that the calculations here, but the calculations will be based on compressible system.

(Refer Slide Time: 00:53)
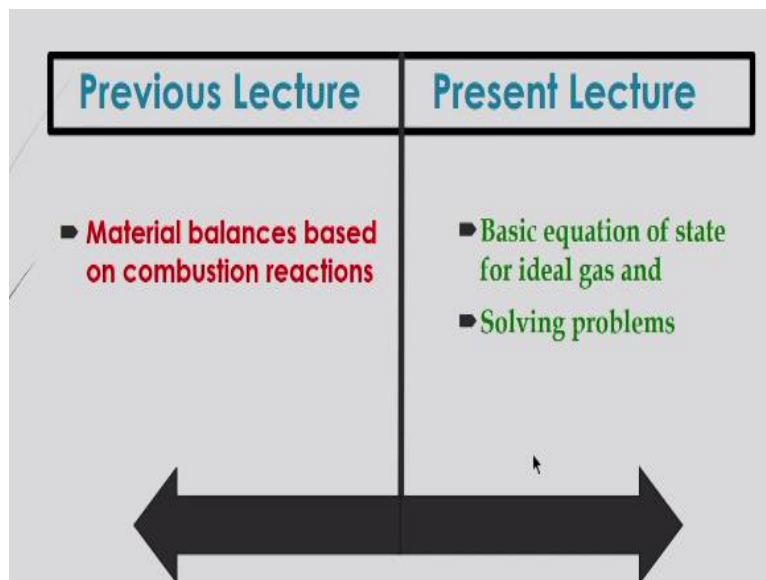
So, in this lecture, we will try to describe something about the state of equation of ideal gas and the calculation based on this ideal gas. So, present lecture will include the basic equation of the state for ideal gas and solving problems with that equation.

(Refer Slide Time: 01:17)

General Material Balance Equation (Recap)

$$\begin{bmatrix} \text{Accumulation} \\ \text{within the defined} \\ \text{system} \end{bmatrix} = \begin{bmatrix} \text{Input through} \\ \text{system} \\ \text{boundary} \end{bmatrix} - \begin{bmatrix} \text{Output through} \\ \text{system} \\ \text{boundary} \end{bmatrix} + \begin{bmatrix} \text{Generation} \\ \text{within the} \\ \text{system} \end{bmatrix} - \begin{bmatrix} \text{Consumption} \\ \text{within the} \\ \text{system} \end{bmatrix}$$

$$[\text{ACCUMULATION}] = [\text{INPUT}] - [\text{OUTPUT}] + [\text{GENERATION}] - [\text{CONSUMPTION}]$$

Positive contributions to the system: Input & Generation

Negative contributions to the system: Output & Consumption

Now, as we know that the general material balance equation that earlier these things you have to remember whenever you are going to calculate any unknown variables by this principles of general material balance equation there. So that equation is accumulation that will be equal to input minus output plus generation minus consumption. So, this will be your basic equation which will be useful for doing the material balance for a particular process system.

(Refer Slide Time: 01:45)

Ideal Gas Equation of State

- The ideal gas obeys the ideal gas law expressed as follows

$$PV = nRT$$

Where

P = the absolute pressure of the gas

V = the total volume occupied by the gas

n = the number of moles of the gas

R = the ideal gas constant in appropriate un

T = the absolute temperature of the gas

IDEAL GAS CONSTANT R

1.987 cal/(g mol)(K)
1.987 Btu/(lb mol)(°R)
10.73 (psia)(ft³)/(lb mol)(°R)
8.314 (kPa)(m³)/(kg mol)(K) = 8.314 J/(g mol)(K)
82.06 (cm³)(atm)/(g mol)(K)
0.08206 (L)(atm)/(g mol)(K)
21.9 (in Hg)(ft³)/(lb mol)(°R)
0.7302 (ft³)(atm)/(lb mol)(°R)

Now, if we talk about that in the process system, there are various types of that gas may be involved to process that process system for a particular operation. So, in that case, you have to know some extent of that behavior of that gas and how that gas will be changing its characteristics based on that process variables like pressure and temperature. What will be the basic equations if there is a change of pressure and what should be the volume how it will be changing with respect to temperature and pressure there, so we will be considering here.

So, in that case if I talk about that ideal gas, though there is no gas in the world that will be ideal in nature, but still we are considering that there will be hypothetical ideal gas and there will be certain equation to represent that ideal cash behavior. Now, those gases will and also follow these certain equation here, as given in the slide that PV is equal to nRT will be called as ideal gas. So, here in this case P is the absolute pressure of the gas and V the total volume occupied by the gas and also n here, n is the number of moles of that gas.

R is the ideal gas constant in appropriate unit and also this T is called that absolute temperature of the gas. So, whenever any gas will be flowing through the process unit you have to know what should be the pressure that is exerted by the gas or what should be the volume occupied by the gas and at that volume what should be the system pressure and also how the temperature will be used to change that volume accordingly. That is why, you have to calculate that pressure or volume based on that temperature change for that particular gases based on this equation.

So, this equation is called ideal gas equation, and based on this ideal gas equation, you have to calculate many things for its you know that how the density will be changing based on that temperature and pressure, even also volume, and also how that specific gravity will be changing and these parameters or you can say that variables or you can say that the characteristics of that flow of the gases to be required to calculate before are going to do that material balance in a particular system.

So, in this case, here you will see that one important constant that is called ideal gas constant that is required to know here because whenever you are actually going to perform any process for particular process synthesis, there you will see that you need to calculate that volume or pressure or you can say temperature at a particular condition, so in that case, by this equation of ideal gas, you have to calculate those unknown variables.

So, in that case here, this ideal gas constant is to be required to know because all the process unit sometimes will be mixed unit so in that case you have to convert that ideal gas constant into one unit system to the another unit system there. So, here in this table one conversion factor for that ideal gas constant is given there. So, if you are considering that calorie gram

mole K there, this R value will be is equal to 1.987, whereas in British system, this will be also this 1.987, in Btu this maybe it is thermal unit per unit pound mole and degree Rankine.

Similarly for psi system, they are also it will be in terms of psi means pound-force per inch square pressure. So, in that case, it will be 10.73. Similarly, for other units in SI system, this value is generally permitted as 8.314, whereas for SI system but the unit is in centimeter instead of meter and pressure is atmosphere and also there will be gram mol instead of kilomole and temperature is Kelvin, then it will be 82.06.

Also if you are representing that volume in terms of liter and temperature in Kelvin, but mole in terms of gram mole, but pressure is in atmosphere instead of Newton per meter square, then you have to use that gas constant at 0.08206. Similarly, for other unit system, it is given like 21.9 if you are using that gas in pressure unit as inch mercury and volume is feet cube and also mole as pound mole and temperature is in degree Rankine. So, in this way, you have to use ideal gas constant as per consistency of the unit whatever it will be used for your particular problem.

(Refer Slide Time: 07:23)

Sometimes, the ideal gas law is written as follows:

$$PV = nRT \implies P\nu = RT \qquad \nu = V/n$$

where v is the specific volume (volume per mole or mass) of a gas

Common Standard Conditions for the Ideal Gas

System	T	P	v
SI	273.15 K	101.325 kPa	22.415 m³/kmol
Universal scientific	0.0°C	760 mmHg	22.415 L/mol
Natural gas	60.0°F (15.0°C)	14.696 psia 101.325 kPa	379.4 ft³/lbmol
American engineering	32°F	1 atm	359.05 ft³/lbmol

After that, you have to consider that ideal gas law with other convenient way like this here the ideal gas law is sometimes written as per molar volume. In that case, you will see that PV will be is equal to nRT, that is you know that equation, but if I divide this V by n, that will be is equal to volume per unit mole. So, it will be called as a specific volume. So, if we represent that a specific volume as symbol here small v or you can see sometimes nu, then we can represent that v, nu is equal to RT, that is a small v, Pv is equal to RT.

So, this v will be is equal to specific volume, it will be is equal to V by n here. So in the other way also you can represent this v that will be sometimes it is represented by Vm sometimes or sometimes it is represented by V you know that hat like this. So, either way, any symbol that whatever conveniently you are using that you have to follow consistently. So, here this Vm or V that will be is equal to specific volume here. So, in terms of the specific volume that ideal gas equation will be is equal to Pv RT.

This gas equation to be used for your calculation of the different variables where that unknown variables will be there in specific problem. Now, at different systems, you will see that there will be some standard conditions for that ideal gas. In SI system, that standard conditions of the temperature is 273.15 Kelvin, whereas the pressure will be 101.325 kilopascal and this is specific volume that will be is equal to 22.415 meter cube per kilomole.

Universal scientific unit system their standard temperature is considered as 0 degree centigrade or Celsius whereas pressure is 760 millimeter mercury, whereas molar volume will be 22.415 liter per mole. In case of natural gas, you will see that that the standard conditions generally represented by 60 degree Fahrenheit or 15 degrees Celsius, whereas the pressure will be 14.7 psia or you can say that 101.325 kilopascal.

If you are considering that American engineering system, you have to consider that a standard condition of temperature will be 32 degree Fahrenheit and the pressure will be 1 atmosphere, whereas this specific volume will be is equal to 359.05 feet cube per pound mole. So, in this way, you have to consider that standard temperature and pressure for a particular process like okay.

(Refer Slide Time: 10:48)

Example

- **Problem:** Calculate the volume, occupied by 100 kg of an ideal gas (A) whose molecular weight is 16 at standard conditions. The standard temperature and pressure (STP) corresponds to a temperature of 273.15 K (0°C) and an absolute pressure of 100 kPa (1 bar). At STP, 1 mol of ideal gas occupies 22.4 L.

- **Solution:**

$$\frac{100 \text{ kg A}}{} \left| \frac{1 \text{ kmol A}}{16 \text{ kg A}} \right| \frac{22.42 \text{ m}^3 \text{ A}}{\text{kmol A}}$$

$$= 140.13 \text{ m}^3 \qquad \text{At standard condition}$$

Let us have some example to calculate that unknown quantity based on this ideal gas equation. It is supposed given to find out the volume that will be occupied by suppose 100 kg of an ideal gas whose molecular weight is 16 at standard conditions and the standard temperature and pressure corresponds to a temperature of 273.15 K that is 0 degrees Celsius and an absolute pressure of 100 kPa that will be 1 bar. So, at this standard temperature and pressure, 1 mole of ideal gas occupies 22.4 liter.

So, at this condition, you have to calculate what should be the volume that will be occupied by 100 kg of an ideal gas. So, if I considered that here that 100 kg you have to convert it that what should be that 100 kg of that gas will occupy what will be the volume of that container at which is it is kept at that particular operating condition. Now, you know that per mole of that ideal gas will have that is 22.42 meter cube of volume. So, in this case, this 100 kg of that ideal gas that is A here, it will be converted to its mole.

Since its molecular weight is 16, so it will be 1 by 16, this is mole into 100, then it will be converted into total mole of that A. Now per mole that volume will be 22.42 meter cube. So, out of this 100 divided by here 16 will come these moles will occupy how much volume that will be after calculation, it will be coming as simply that 140.13 meter cube in that particular standard condition.

(Refer Slide Time: 13:15)

Example

- **Problem:** A gas is available under the following conditions: a pressure of 0.95 bar and a temperature of 288 K. Calculate the volume occupied by 100 kg of the gas. Assume that the molecular weight of the gas is 44

- **Solution:**

$$PV = nRT \quad \text{and} \quad P_sV_s = nRT_s$$

Rearranging

$$\frac{PV}{P_sV_s} = \frac{nRT}{nRT_s} = \frac{T}{T_s}$$

S stands for standard condition

$$V = V_s \left(\frac{T}{T_s} \right) \left(\frac{P_s}{P} \right)$$

$$= \left(100 \text{ kg} \times \frac{1 \text{ kmol}}{44 \text{ kg}} \times \frac{22.415 \text{ m}^3}{1 \text{ kmol}} \right) \times \left(\frac{288 \text{ K}}{273.15 \text{ K}} \right) \left(\frac{1 \text{ bar}}{0.95 \text{ bar}} \right) = 56.57 \text{ m}^3$$

Here another example. Let us consider suppose a gas is available under the following conditions. In this case a pressure of 0.95 bar and a temperature of 288 Kelvin. In this condition, calculate the volume occupied by 100 kg of the gas. Assume that the molecular weight of the gas is 44. So, how to calculate? Here in this case, you have to calculate what should be the volume that will be occupied by 100 kg of the gas. Now, the pressure is given to you 0.95 bar and temperature is given to you 288 K.

Now, as per that ideal gas equation, that is PV is equal to nRT, so based on which you can say that at a particular operating condition of temperature, then you can write that PV is equal to nRT. Similarly, if we consider that other condition of the gas, so it will be regarded as suppose PsVs is equal to nRTs. So, s it stands for here standard condition. So, for the standard condition also, we can write this equation as per ideal gas law and for any temperature and pressure, then you can write this equation also this PV is equal to nRT.

Now, if we divide this ideal gas equation here by the ideal gas equation at its standard condition, then you can write here simply here PV by PsVs that will be is equal to here in this case nRT at certain temperature and also by nRTs at a standard condition. So, finally, if we have the same number of molecules and since the gas constant are same for all the gases here, so here in this case we can say that all conditions here, so we can say that this R and n will be cancelled out from this portion. So, simply it will be T by Ts here.

So, after rearranging of this equation, we can then express that to V at a particular temperature and pressure, it will be is equal to Vs into T by Ts into Ps by P. So, here at this

temperature and pressure upon that you know comparing on that standard temperature and pressure, you can calculate what should be the volume at a particular temperature and pressure. Now, substituting that value at standard condition and the given temperature and pressure, then you can finally calculate what should be the volume there.

Now let us substitute that value here, what should be the volume at a standard condition, it is simply that for 100 kg of the gas at a standard condition will occupy this here because 1 mole will occupy the 22.415 meter cube, so 100 kg you have to convert it to mole first by dividing its molecular weight here, let the molecular weight is 44. So, here it will be total mole of that gas that is 100 divided by 44 and then since 1 kilomole you know that will occupy 22.415 meter cube.

So, if you multiply this 100 divided by 44 into 22.415, then you will get what will be the total volume here. So, it will be your volume at a standard condition. Now, what is the temperature at your condition given as per problem, it is 288 K as per of your problem, whereas the standard temperature is your 273.15 Kelvin and also the Ps, Ps is you know that standard condition pressure is 1 bar, that is 1 atmospheric pressure you can say and the pressure is given at a particular condition is given as per your problem, it is 0.95 at which is the gas is intact in a system under that pressure.

So, it will be 0.95 bar here. So, you have to divide this Ps by P here like this. Now, if you are considering bar, so there you know that this should be 1 bar and this would be 0.9 bar, otherwise if you are having mixed unit of that pressure, suppose instead of bar it is given here some value of you know millimeter mercury, so you have to convert millimeter mercury to its bar, since it is given here what is that bar or whatever it is. So, anyway two pressure's units should be you know the same.

So, if it is given mercury, you know that millimeter mercury, then you have to convert it to bar and accordingly you know that standard pressure is 1 bar or otherwise you can convert it to standard pressure is 760 millimeter mercury, whereas here it is given certain value of mercury. So, simply here, it is not required to convert that pressure into other unit. So, there since both are the same, both units will be considered as the same unit, then simply you have to divide it here based on the same unit, otherwise you have to convert the unit there.

So, finally, after substitution of volume at a standard condition, temperature at standard condition, pressure at standard condition, and given temperature and pressure here from this equation you can finally get that what would be the volume occupied by that gas. So, to be simply you know that 56.57 meter cube. So, we can say that, that gas at that pressure of 0.95 bar and at a temperature of 288 K, the volume of the gas will be occupied as 56.57 meter cube.

(Refer Slide Time: 19:36)

Let us do another examples like this, you know that here in this problem it is given that to find out the density of 1 meter cube gas in SI units if the gas is available at a temperature of 300 K and a pressure of 1 bar. Now the molecular weight of that gas is you know 28. So, here you have to find out what should be the density of that gas. Now, you know that specific molar volume how it can be defined based on that standard temperature and condition and from your gas equation at a certain temperature and pressure.

So, here you can simply write this equation from those equation one is there like PV that will be is equal to RT at a given temperature and pressure and here Ps into Vs that will be is equal to RTs that is a standard condition. If you divide these two equation, you can simply represent it as v by vs that will be is equal to simply T by Ts into Ps by P here. So, this is your equation in terms of molar volume, so from which you can calculate what should be the v that will be equal to vs into T by Ts into Ps by P.

So, if again these are at a standard condition, what would be the molar volume if you know and if you substitute here, then you can easily calculate what should be the specific molar

volume at this particular temperature and pressure. So, if you substitute here vs will be equal to simply we can say that here 22.4 meter cube by 1 one kilomole. This is your actually at a standard condition the specific mala volume and here T by Ts, T is given temperature it is given as per your problem, it is 300 Kelvin.

It may be other temperature also according to your problem and standard condition temperature is 273.15 Kelvin and then here since pressure is kept at that 1 atmospheric pressure or 1 bar, so here that at a given pressure is 100 kPa and also you can say that the standard condition of the pressure will be same 100 kPa. So, it will be cancelled out. Finally, after calculation, you can get this specific molar volume at a particular temperature and the pressure of 1 bar is equal to 24.6 meter cube per kilomole.

Here simply we are getting that without changing the pressure only just by changing the temperature 273.15 to 300 K, see how that specific molar volume is changing, it is simply 24.6 meter cube, whereas at standard condition that volume is coming 24.4 meter cube. So, simply very small amount of volume is changing because of the small amount of temperature is changing there. Now, based on these specific molar volume at that particular temperature of 300 K, you can calculate the density from this specific molar volume, how to do that?

Simply you have to just inverse of this specific molar volume will give you that your density. So, this density can be calculated from the inverse of specific molar volume. So, specific molar volume that here given, v here that is kilomole that is 24.6 meter cube per kilomole. Then density can be calculated 1 by that v, so it will be coming as 1 by 24.6 meter cube per kilomole and it will be coming as in terms of kilomole per meter cube. Now, if you convert that kilomole into its mass by multiplying its molecular weight, then you can simply get that what should be the density of that gas in terms of kg per meter cube.

So, if here simply molecular weight is 28, if you multiply it by its molecular weight, from which you know inverse of specific molar volume, then you can get that volume that is 1.14 for here at this condition that is kg par meter cube. So, in this way we can solve the problem what should the density, what should be the specific volume of the gas at a certain temperature and pressure based on specific volume or a volume or pressure at its standard condition.

(Refer Slide Time: 25:22)

Example

- **Problem:** What is the specific gravity of 1 m³ of N₂ at 300 K and 1 bar compared with 1 m³ of air at 300 K and 1 bar?
- **Solution**

$$\frac{v}{v_s} = \frac{RT/P}{RT_s/P_s} = \left(\frac{T}{T_s}\right)\left(\frac{P_s}{P}\right)$$

- The molar volume related to standard conditions is

$$v = v_s\frac{RT/P}{RT_s/P_s} = v_s\left(\frac{T}{T_s}\right)\left(\frac{P_s}{P}\right) = \left(\frac{22.4\ m^3}{1\ kmol}\right)\left(\frac{300\ K}{273.15\ K}\right)\left(\frac{100\ KPa}{100\ KPa}\right) \approx 24.6\ m^3/kmol$$

- The density of N₂ is

$$\rho_{N_2} = \frac{Mw}{v} = \frac{Mw}{v_s\left(\frac{T}{T_s}\right)\left(\frac{P_s}{P}\right)} = 28/24.6 = 1.14\ kg/m^3$$

Let us do another example. Here what is the specific gravity of 1 meter cube of nitrogen at 300 K and at 1 bar, that is compared with 1 meter cube of air at 300 K and 1 bar. Here very interesting that you have to compare that to what should be the specific gravity here density of that nitrogen and also what should be the density of the air there at a particular temperature and pressure. Now, these components are different, nitrogen and air here.

So, if you consider that again that ideal gas equation, where we can write that v by vs that will be is equal to T by Ts into Ps by P based on that division of these 2 equations at a certain temperature and pressure and to the equation that is based on the standard temperature and pressure. Now, based on these equations, you can say that the molar volume related to the standard condition is calculated as like this v will be is equal to vs into T by Ts into Ps by P.

If you substitute that value that Ps will be is equal to what is that 22.4 per kilomole and temperature is given here 300 K and also the standard temperature is 273.15 and then pressure is here, the same pressure, it is considered the pressure that is atmospheric pressure. So, the ratio of this standard a pressure to its that you know again at a pressure of that equal to that atmospheric pressure, then it will be nullify here, to be canceled out here like this. So, we can say that finally we can get this specific molar volume of 24.6 meter cube at that particular 300 K.

What should be the density of that nitrogen at the particular 300 K. So, simply as per earlier what we have you know calculated that the density of the nitrogen, it will be simply inverse of that you know specific volume into its molecular weight, then you can calculate here by

this equation of this molecular weight by specific molar volume, and then finally you can have this value is equals to 1.14 kg per meter cube. So, this is your density of nitrogen.

(Refer Slide Time: 28:03)

- The density of air at 300 K and 1 bar is

$$\rho_{Air} = \frac{Mw}{v} = \frac{Mw}{v_s \left(\frac{T}{T_s}\right)\left(\frac{P_s}{P}\right)} = 29/24.6 = 1.18 \text{ kg/m}^3$$

Specific gravity of nitrogen is equal to its density divided by the density of air.

Therefore

Specific gravity = 1.14/1.18 = 0.97

Now, in the same way, you have to calculate what should be the density of air at that particular 300 Kelvin temperature and the pressure of 1 bar. Similarly, if you substitute that value, here the molecular weight of air is considered as 29. So, it will be 29 divided by what is that 24.6. So, it will come 1.18 kg per meter cube. So, specific gravity of nitrogen is equal to its density divided by the density of air okay. So, we can say that the specific gravity of the nitrogen it will be simply 1.14 divided by 1.18.

So, it will be coming as 0.97. So, what should be the specific gravity of this nitrogen, we can simply calculate based on this, but the definition of the specific gravity is actually the density of any gas at any temperature and pressure condition divided by the reference gas density. Here reference gas density is considered air density. So, here that is why we actually calculated the density of air at that particular temperature and pressure. So, finally, we are getting that density of air is like this, whereas density of nitrogen we have calculated earlier based on that temperature and pressure and from the ideal gas equation.

So, from that if we divide it, we can get this to 0.97 there. So, we have discussed that how to calculate that specific gravity of a gas just by calculating its density at a certain temperature and pressure and also what should be the density of that reference gas here like air at the particular temperature and pressure. So, dividing these densities of gas to its reference gas, then we can easily get that specific gravity, here as given in this example.

Now, another aspect of that ideal gas is that what should be the partial pressure of the particular gas mixer by its component gas will be exerted that also to be required for further calculation of the gas mixture in a particular processor unit. So, in that case, the partial pressure, that means individual component pressure in a particular mixture of gases, so, that can be actually exerted by that single component in a gaseous us mixer if it existed by itself in the same volume as occupied by the mixture and at the same temperature of the mixture.

So, according to that, you can say that if there are suppose n number of components in a gaseous mixture. So each component will actually exert the pressure individually on that particular system of same volume and the same temperature. So, in that case, what should be that individual component pressure, it will be called as partial pressure. Now, according to the Dalton's law, this the summation of partial pressure will be equal to the total pressure of the system and also for individual components for that particular pressure of that component that is called partial pressure of the component.

If you know the volume of that system, then you can also represent that ideal gas equation based on that partial pressure. So it can be actually retained as like this here if you know that partial pressure of component i and volume of the system, total volume of the system is Vt, then you can write here nRT, here n will be equal to mole of individual component and t will be here total temperature of the system. So, here we can write the same ideal gas equation for the partial pressure, but here in this case Pi is basically that partial pressure of the component i.

Now, again if we write that ideal gas equation for the whole system, then we can simply consider here that it will be P total into V total that will be equal to n total into T total into R, so in this way so if we divide this equation by this equation, that means here you see this equation here, then you can get your Pi will be is equal to Pt into ni by nt. From this simply, this divided by this, it will be simply Pi by Pt and then to here ni by nt and also R R will be cancelled out.

So, it will be T total and T total will be cancelled out, so simply it will be Pi will be equal to Pt into ni by nt, and this ni by nt basically what, this is basically a mole fraction of the gas okay. So, here it is your moles of component i divided by total moles of gaseous mixture. So, it will be regarded as mole fraction of the component i. So, Pi will be equal to here Pt into Yi, what is that, that means here partial pressure of component will be is equal to mole fraction into its total system pressure, here Yi is the mole fraction of the component i.

So, in this way you can calculate what will be the partial pressure of each component in a gaseous mixture at that particular volume of the mixture and its temperature. So, in an ideal gas mixture each component satisfies the ideal gas law that will provide the partial pressure and also pure component volumes that will be used for your calculation. So, in this way you can calculate. Now, according to that Dalton's law, if we calculate that individual component pressure that is individual partial pressure and if you sum it up all those partial pressure, then you will get the total pressure there.

(Refer Slide Time: 35:21)

Amagat's law also important there, here in this case instead of, calculating that partial pressure, Amagat told that that the partial volume of each component of the gas will give you the total volume. So, as per Amagat's law the summation of partial volumes will be equal to the total volume. Here simply that instead of partial pressure, we are just using what should be the volume occupied by individual component of the gas.

So, in that case if we write that ideal gas equation based on that partial volume and also total pressure and the system, then we can write P total into Vi that will be equal to ni into R into T total. So based these, we can say that this for the total temperature and pressure, we can also write here that P total into V total that will be is equal to n total into T total into R. So, if you divide this equation by this equation, then that means here you can get these and here R R will be cancelled out and T and T will be cancelled out, so also you can say that Pt and Pt will be canceled out.

So, here simply Vi that will be equal to Vt into ni by nt, here Vt is total pressure, Vi is the individual component volume, Vt is the total volume sorry and ni is the mole of individual component and nt is the total moles of total system. So, here we can say that again if we consider this ni by nt that will be mole fraction of that component i and then simply partial volume of that component i will be is equal to Vt into Yi. So, in this way, you can say that summation of all the components volume, individual volume then it will be contributing to the total volume of the system. Now, let us do some example for this.

(Refer Slide Time: 37:26)

Example

Problem: A gas is intake in a room of a volume 1000 m³ tightly. The room contains dry air at 20 °C and a total pressure of 1 atm.

(i) What is the partial volume of O_2 in the room?
(ii) What is the partial volume of N_2 in the room?
(iii) What is the partial pressure of O_2 in the room?
(iv) What is the partial pressure of N_2 in the room?

1000 m³, 1 atm, 0 °C, air

O_2 = ? m³ 1 atm, 20 °C, N_2 = ? m³ 1 atm, 20 °C

Solution

Basis is 1000 m³ of air at 20 °C and at 1 atm.

(i) V_{O2} = (1000)(0.21) = 210 m³ O_2 at 20 °C, 1 atm.

(ii) V_{N2} = (1000)(0.79) = 790 m³ N_2 at 20 °C, 1 atm.

Total Volume = (210 + 790) = 1000 m³ at 20 °C, 1 atm.

(iii) p_{O2} = (1 atm)(0.21) = 0.210 atm. when V = 1000 m³ at 20 °C

(iv) p_{N2} = (1 atm)(0.79) = 0.790 atm. when V = 1000 m³ at 20 °C

Total pressure = 0.210 + 0.790 = 1.000 atm. at 20 °C

It is given that the gas is intact in a room of volume 1000 meter cube tightly and the room contains a dry air at 20 degree Celsius and a total pressure of 1 atmosphere. You have to find out what is the partial volume of oxygen in the room, what is the partial volume of nitrogen in the room, what is the partial pressure of oxygen in the room, and also what is the partial pressure of nitrogen in the room? In this case, since gas is here simply dry air and dry air contains that oxygen and nitrogen only.

So, based on that some mole fraction or volume fraction or pressure percentage of that oxygen or nitrogen component will be in the air. So, if we consider that air that is composed of oxygen and nitrogen where this oxygen and nitrogen composition in the air will be mole fraction of the oxygen will 21% whereas nitrogen will be 79%. So, according to that if there are the volume is 1000 meter cube at 20 degrees Celsius and 1 atmosphere, we can say that oxygen volume that is V_{O_2} here it would be simply total volume into its mole fraction.

So, total volume is 1000 and mole fraction is 0.21 for oxygen. So, it will be coming as 210 meter cube at 20 degrees Celsius and on 1 atmosphere. So, only oxygen will occupy this 210 meter cube volume at that particular condition, whereas similarly for nitrogen, the volume of nitrogen will be in the system that would be total volume into its mole fraction. So, it will be 1000 into mole fraction is 0.79. So, it will be coming as 790 meter cube at that particular temperature and pressure.

So, we are getting here partial volume of that components oxygen and nitrogen. So, total volume, see what will be that here 210 + 790, it will be 1000 meter cube. So, according to this you know that Amagat's law, we can say that total volume will be contributed by this individual volume of this component, that is here partial volume, summation of partial volume will be equal to total volume at that particular operative condition. Similarly, you can find out the partial pressure.

So, partial pressure also actually is defined as that you know total pressure into its mole fraction that will be coming as 0.210 atmosphere when V is kept as 1000 meter cube as constant at 20 degree Celsius. Similarly, you know partial pressure of nitrogen you can calculate, that is total pressure into its mole fraction, then it will come here as per problem it will be 0.790 atmosphere, again the volume will be considered as 1000 meter cube at 20 degrees Celsius.

So, in this case, we are getting this atmosphere for oxygen and this atmosphere for nitrogen. Now, what will be the total pressure, simply that summation of this partial pressure that will be 0.10 + 0.90. So, it will be your 1 atmosphere. So, here also, we can say that this Daltons law of gas can be satisfied by this equation, and based on this example, we can simply calculate what should be the partial pressure, what should be the partial volume of each component and how that partial volumes or partial pressures will be contributing the total volume and total pressure respectively here.

(Refer Slide Time: 41:26)

Another example like an analysis of suppose 1 kg fuel gas that will results you 14.0% of carbon dioxide and 6% of oxygen and 80% of nitrogen at a temperature of 204 degrees Celsius and pressure at 1 atmosphere or 765 millimeter mercury. Now, in this case, calculate the partial pressure of each component. Simply the partial pressure of each component will be is equal to that means here Pi that will be is equal to Pt into its mole fraction, Pt is the total pressure.

So, if I consider that carbon dioxide, mole fraction here, y is given, Y of CO2 is given as you know that 0.14 and mole fraction of oxygen it is 0.06 and mole fraction of the nitrogen is simply 0.8. So, partial pressure of that individual component like PCO2 that it will be is equal to simply you know that 0.14 into total pressure is what is that 1 atmosphere, is 760 millimeter mercury. So, we can simply write that what should be the partial pressure of that carbon dioxide.

Similarly, partial pressure of oxygen, it will be is equal to what is that mole fraction given, total pressure is given 765 millimeter mercury into here what is that mole fraction is what 0.06. So, it will be coming as 45.9 millimeter mercury. Similarly, pressure of nitrogen that will be is equal to 765 into you know mole fraction is 0.8, then it will be coming as 612. So, if you add it all these partial pressure of all those components, and then you will see the total pressure will be equal to 765, but here then it is you know that will not be 760.

Here pressure is I think is 765 here, there is a mistake, that you please corrected it that 765 millimeter mercury, here it will be not that you know 1 atmospheric pressure, the pressure is 765 millimeter mercury. So accordingly here, we can say that here it will be 765, here 765, here 765. So, we can say that simply that here, anyway you have to calculate that partial pressure based on this, you know total pressure into mole fraction.

(Refer Slide Time: 44:26)

Now, let us do another example here like this methane gas containing 4% of oxygen that flows through a pipe. It is required to calculate that the volumetric flow rate of the gas that is flowing through the pipe. The condition are for the purpose of the 10 meter cube per minute of air at 27 degrees Celsius and 760 millimeter mercury are introduced into the pipe and several meters further down the pipe, a sample is drawn from here at a certain length of this pipe at the downstream and it is found to contain that 11% of oxygen and nitrogen mixer.

How many meter cube of that initial gas were flowing per minute at 27 degrees Celsius and 740 millimeter mercury through the pipe. So, this is your problem. That means here methane gas containing 4% of oxygen that will be flowing to the pipe, and in this case, you know that

the samples is taken out from this pipe at a certain distance downstream where the oxygen and nitrogen mixture will contain 11% there. Now, in this case how many meter cube of initial gas were flowing per minute at 27 degrees Celsius there.

(Refer Slide Time: 45:49)

Now in this case very interesting that let us assume that x meter cube per minute of methane oxygen mixture that flows through the pipe at 27 degrees Celsius and 760 millimeter mercury. Now to this 10 meter cube per minute of air is added at the same conditions. Now, total volume of the gas mixture that in this downstream will be is equal to 10 + x metre cube. Then oxygen in methane oxygen mixture will be is equal to 0.04 into x meter cube and oxygen in air to be is equal to 2.10 meter cube and nitrogen in air it will be you know that 7.90 meter cube accordingly.

So, here oxygen and nitrogen mixture is at the outlet that per the sample it is coming 11% in the downstream gas mixture. So, oxygen + nitrogen in the downstream will be is equal to what is that 0.04x, that means here this is plus here this 2.10 and then plus what is that nitrogen here this is 7.90. So, in this case, total amount of oxygen and nitrogen mixture is coming 10 + 0.04x there.

(Refer Slide Time: 47:10)

$$\therefore \quad \frac{10 + 0.04x}{10 + x} = \frac{11}{100}$$

$$\Rightarrow \quad x = 127.14 \ m^3/min$$

Let V = volume of initial gas mixture at $27°C$ and $740 \ mm \ Hg$

So, $\dfrac{V \times 740}{273 + 27} = \dfrac{127.14 \times 760}{273 + 27}$

$$\Rightarrow \quad V = 130.58 \ m^3/min$$

Or Gas flowing through the pipe at $27°C$ and $740 \ mm \ Hg = 130.58 \ m^3/min$

After that what will be the mole fraction of that? Here you know the total amount of oxygen and nitrogen mixture out of total volume is 10 + x there. So, we can say that here it will be close to you know that element by hundred as per you know given problem here because it is told that in the sample only containing 11% of nitrogen and oxygen there. So, finally after solving, you can get this x value is 127.14 meter cube per minute. So, let that volume of that initial gas mixture at 27 degrees Celsius and 740 millimeter mercury.

We can say that accordingly of that ideal gas equation if you substitute that value of V and also pressure at its temperature and also if you substitute that here for that particular temperature at that condition and pressure is there you know 760. So, after substituting or equating that ideal gas equation at this two conditions, we can get that volume will be is equal to 130.58 at a rate of meter cube per minute.

Now, this gas flowing through that pipe at 27 degrees Celsius and 740 millimeter mercury, we can then have this 130.58 meter cube per minute. So, this is your actually flow rate at the inlet of the pipe of the methane gas here.

(Refer Slide Time: 48:53)

Further reading......

Text Books:

- R. M. Felder, Ronald W. Rousseau, Lisa G. Bullard, Elementary Principles of Chemical Processes, 4th Ed., John Wiley & Sons, Asia, 2017.
- D. M. Himmelblau, J. B. Riggs, Basic Principles and Calculations in Chemical Engineering, 7/8th Ed., Prentice Hall of India, 2012.

Reference Books:

- N. Chopey, Handbook of Chemical Engineering Calculations, 4th Ed., Mc-Graw Hill, 2012.
- Olaf, K.M. Watson and R. A. R. Hougen, Chemical Process Principles, Part 1: Material and Energy Balances, 2nd Ed., John Wiley & Sons, 2004.

So, in this way we can calculate lot of things based on that ideal gas equation and there are several others also, you know important equations are there for non-ideal gas. There also we will consider non-ideal gas equation how to calculate that volumetric flow rate, even pressure and also mole fractions there in the different stream of the system, and we will discuss that non-ideal behavior of that gases and properties of that non-ideal gas in the next lecture.

So, there also we will discuss that what should be that state equation of that non-ideal gas and how to calculate based on that state equation there we will discuss. So, thank you for your attention.