

Cooling Technology: Why and How utilized in Food Processing and allied Industries

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Module No 03

Lecture 15

Basics of Thermodynamics Contd.

Good afternoon. In the previous class, we have said all the gas, all the all the thermodynamic laws and we have also discussed about the Carnot heat engine cycle, reversibility, and also the entropy right. So, in the basics of thermodynamics, this class, the topic which is of course, taking a little time, because this is the fundamental thing. Now, if we look at, if the gas to be a perfect gas right. If the gas to be a perfect gas, then from the equation of state, we can write pV is equal to RT or pv is equal to mRT or we can also write pv is equal to nR bar T . So, this we can write that p into small v is equal to capital T , where p is the absolute pressure in kilo Pascal, v is the specific volume, small v which is niu or small v you can write here, in meter cube per kg, capital V is the volume in meter cube and is v bar that is molal volume in meter cube per kg mole, v bar is meter cube per kg mole right.

$pV = RT$; or, $pv = mRT$; or, $pv = nRT$; or, $p = \frac{RT}{v}$. where, p is the absolute pressure in kPa, v is the specific volume in m^3 / kg , V is volume in m^3 and v is molal volume in m^3 per kg mole.

T is the temperature in K, \bar{R} is universal gas constant in $kJ / (kg \text{ mole } K)$, and R is gas constant for a particular gas in $kJ / (kg \text{ K})$. Hence, $\bar{R} = 8.314 \text{ kJ} / (\text{kg mole } K)$, and $R = \frac{\bar{R}}{M}$, M is the molecular weight of gas in $kg / kg \text{ mole}$.

T is the temperature in Kelvin, R is universal gas constant, So, we can write here that capital R is universal gas constant in kilo joules per kg mole per Kelvin right. Of course, it is it can be written as capital R bar which was here this capital R bar right is universal gas constant in kilo joules per kg mole per Kelvin and capital R is the gas constant for a particular gas in kilo joules per kg Kelvin right. So, R bar can be written as 8.314 kilo joules per kg mole per Kelvin and capital R right and capital R is capital R is R bar over m that is m is the molecular weight of the gas in kg per $kg \text{ mole}$. So, these relations are valid above critical temperature and low pressure where intermolecular

forces are negligible. So, there is no intermolecular forces. Now intermolecular forces, if you remember, that gas law, that, which we have also learnt in chemistry, that the gas law in the sense where there is no force of attraction, that was the fundamental of the gas law, right that kinetic theory of gases. There we have said that the molecules are free to move randomly all around right.

So, here we are saying that intermolecular forces are negligible if it is under perfect gas. For perfect gas we can also write, U is equal to, U is a function of T , right, U that is internal energy is a function of T , and h is equal to $U + p v$ that is again U as a function of T plus RT that means, h is also a function of T .

$$u = u(T), \text{ and } h = u + pv = u(T) + RT = h(T).$$

$$u_2 - u_1 = C_v (T_2 - T_1); \text{ and } h_2 - h_1 = C_p (T_2 - T_1).$$

Hence enthalpy of a perfect gas is also a function of temperature only. Hence, between two state points 1 and 2, if it is ideal gas mixture, then ideal gas mixture means a mixture of ideal gases, say if A and B are there, two gases, the molecular forces of attraction between the molecules of each constituent gas, that is A and B , is AA or BB and this AA or BB we can assume to be equal to 0. So, if these are ideal gases, then only this AA intermolecular forces between the same molecules and BB that is again another intermolecular forces between the same molecules are equal to 0, right, and if the mixture is to be a perfect gas then also the intermolecular forces between A and B , that is AB has to be 0, if it is to be a perfect gas.

So, let us consider a volume V of the gas, molecules of A and B at a pressure of p and temperature of T . So, each of the gases is assumed to follow the ideal gas relation, then if again, if we assume M_A and M_B be the masses of the constituent gases and M only M be the mass of the resultant mixture. Then from the conservation of mass we can write M is equal to M_A plus M_B . Therefore, we can also write p_A into V plus that p_B into V is equal to M_A into R_A into T and p_B is equal to M_B into R_B into T and also you can write pV is equal to MRT , where R is equal to $M_A R_A$ plus $M_B R_B$ over M . Then, if the gases are mixed adiabatically, without any change in kinetic and potential energy, and without any work output then according to the first law of thermodynamics, in steady state, the initial and final enthalpies are also same right.

So, this we keep in mind and the mixture can be said to have an enthalpy which can be written as h equal to $M_A h_A$ plus $M_B h_B$ over M . So, if we make it, in its differential form, we can write $M dh$ is equal to $M_A dh_A$ plus $M_B dh_B$. So, we can say that for a perfect gas dh is equal to $C_p dT$ therefore, the specific heat of the mixture can be written as C_p equal to $M_A C_{pA}$ plus $M_B C_{pB}$ over M . Similarly, the internal energy of the mixture also can be written as U is equal to $M_A U_A$ plus $M_B U_B$ over M and therefore,

C_v can be written as $M_A C_{pA}$ plus $M_B C_{pB}$ over M . Since the entropy of a mixture is not equal to the sum of the entropies of the individual components, the entropy of the mixing has to be included and this lets us to the process of irreversibility, because entropy of A and entropy of B, if we add them, then the resultant entropy should be addition of these two, but it is not.

$$s_2 - s_1 = C_v \ln (T_2 / T_1) + R \ln (v_2 / v_1)$$

and, $s_2 - s_1 = C_p \ln (T_2 / T_1) + R \ln (p_2 / p_1)$

In a constant volume heat transfer process, the work done $w_{1,2} = 0$, So, from first law, $q_{1,2} = u_2 - u_1 = C_v (T_2 - T_1)$. Similarly, for constant pressure process, $q_{1,2} = h_2 - h_1 = C_p (T_2 - T_1)$.

So, this means we are heading towards irreversibility and the irreversible process is that when we are mixing and this mixing is a irreversible process. Now, if it is to be a real gas and vapour then forces of attraction between molecules are not negligible, because if these are real gas, in kinetic theory also, you have seen. Earlier attempt to attempt to relate thermodynamic properties was known as Van der Waal equation and this is one of the earliest relationship where p plus a by v bar square into v bar minus b , that is equal to R bar into T , where of course, a by v bar square accounts for forces of attractions between molecules, B and A , right, between molecules, and b is the finite volume of B molecule.

$$\left(p + \frac{a}{v^2} \right) (v - b) = \bar{R}T$$

$$a = \left(\frac{27}{64} \right) \frac{\bar{R}^2 T_c^2}{p_c} \text{ and, } b = \frac{\bar{R}T_c}{8p_c}$$

The constants a and b , were found by looking at the isotherm passing through the critical point, which is supposed to have a point of inflection there. So, we can write a is equal to 27 by $64 R$ bar square T critical square over p critical and b is R bar T critical over $8 p$ critical.

Of course, T critical T_c and p_c are critical temperature and pressure respectively. Other equations are also known, but they are not so popular as that of the Van der Waals. Van der Waals was the very earliest for real gas and vapour, and is mostly, it is used, but some other relations are like that, that is dieterici equation, then $B T$ Bridgman equation, then Benedict Webb Rubin equation, It can be said, BWR equation, then Redlich-Nolm

equation, then Penn-Robinson equation etc. These are all the intermolecular forces, how much is there, they can be predicted, and the relation between PV with the intermolecular forces and volume of the molecule. In the real gas, the volume of the molecule is not neglected, neither the intermolecular forces are neglected.

So, they have a new relation that is $p + \frac{a}{v^2}$ into $v - b$ is equal to $R \cdot T$, instead of PV is equal to RT . So, this can be a new relation for real gases right. Now, if it is a dry air, right, we do not know what will be the condition. So, that is why everything we are covering that, if it is a dry air, then one of the aims of air conditioning is to control water vapour from a mixture of dry air and water vapour that is moist air. Standard air is considered to be consisted of 78.08 percent of nitrogen and 20.96 or 95 percent of oxygen on volume basis. The molecular weight and gas constant of air are 28.966 kg per kg mole and 0.2871 kilo joules per kg kelvin.

In most of the cases, air will be considered as perfect gas, and it has been precisely measured and concluded that at sufficiently low pressure, and temperature, well above the critical temperature and pressure or critical temperature, it has been found that within the temperature range of minus 75 to 100 degree centigrade dry air behaves like a perfect gas. For air conditioning, the range of temperature may be between 0 to 50 degree centigrade and the heat capacity values of air, that can be taken as C_p equal to 1.05 kilo joules per kg kelvin and C_v equal to 0.7179 kilo joules per kg kelvin. So, properties of pure substance, if we look at, then, it can be said who is the pure substance.

Now, pure substance we can say to that whose chemical composition does not change during thermodynamic processes for example, water refrigerants. So, they are pure substances because their properties does not change during the thermodynamic processes. Water exists in three states for example, water, water vapour and ice that is steam and hot water are used in heating buildings whereas chilled water is used for cooling buildings. So, what is refrigerant? Refrigerant is that substance those absorb heat from other substances or space. If a liquid which is a pure substance is heated at constant pressure the temperature at which it boils is called saturation temperature.

At this temperature the liquid and the associated vapour at the same temperature are in equilibrium and are called saturated liquid and saturated vapour of course, respectively. The saturation temperature is a function of pressure only and at atmospheric pressure the saturation temperature is called normal boiling point. And the temperature corresponding to the reverse phenomena is known as dew point temperature. Hence for a pure substance the dew point and boiling point are same at a constant pressure. The similar situation appears for a solid and a liquid and the phenomena which exists in this case are

melting and freezing and corresponding temperatures are melting point temperature and freezing point temperature.

Here also for a pure substance the melting point and freezing point temperatures are also same. So, the temperature at which all three phases of all pure substances exist in equilibrium is called triple point. The liquid vapour phase diagram can conveniently be shown in a pressure enthalpy or temperature entropy or any other convenient way such as three dimensional PVT diagram. Except dry ice manufacture we come across liquid and vapour phase only. So, in the figure we will show a typical P-H diagram of a pure substance and where this is the typical P-H diagram right.

And here you see you have critical point right, you have triple point and this is the phase diagram right. So, this is vapour and saturated vapour line. So, these are liquid lines, these are liquid and vapour in between right and this side it is pure solid and vapour right. So, this is a typical P-H diagram and from there we can come across all the property values which are required right. So, if we look at what we were looking at.

So, if we look at the temperature at which all the phases of all pure substance exist in equilibrium called triple point. The liquid vapour phase diagram can conveniently be shown as we have shown it. At critical point the states are denoted as T_c , P_c and V_c . The liquid below the pressure of P_c when heated first become a mixture of liquid and vapour and then becomes saturated vapour. At the critical point there is no distinction between the saturated vapour and liquid saturated liquid right.

So, liquid state F and saturated vapour state we call it to be G which merge together at the critical point. Now, for water the triple point is 273.16 Kelvin that is 0.01 degree centigrade and 611.

73 Pascal that is 0.0061173 bar. Critical point is 373.946 degree centigrade that is 647.096 Kelvin and 217.

7 atmosphere that is 22.06 kilo Pascal. For dry ice triple point is 216.55 Kelvin and 517 kilo Pascal and critical point is 31.04 degree centigrade that is 304.

19 Kelvin and 72.8 atmosphere or 7380 kilo Pascal. Why I have given these information to you? Because in many cases liquid carbon dioxide is used as one of the basic in unit for extraction right. So, that is why these information are also helpful ok. So, now, perhaps we have also shown you that PHE diagram, TS diagram we will come across subsequently and perhaps in the next class we will give you some more relations which

are very useful for heat and mass transfer as well some relation which are used in heat transfer for future in information ok. Thank you very much.