

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

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Lecture 16
Basics of Thermodynamics Contd.

Good afternoon my dear students. Basically, you have come across the basic thermodynamics, because we are in the last part of the basics of thermodynamics, and it is a continued one since 4, 5 classes, because as you see that lot many things, we have learnt from here. Certain more things are also there which we need to learn. So, if you remember that in the previous class we have shown you p h diagram right and lot of things we have introduced like entropy, definition of entropy, relations of entropy with many other, internal energy, enthalpy. So, all these, we have already talked about, but still there are certain relations which we need to know like work, also we have shown that it is $p dv$, integral $p dv$ right. So, these things we need to nurture regularly so that we come across the actual relations as and when required, right.

So, we now go back to that p h diagram as you see from here that p h diagram, it tells many things right, but one thing you see that the constant entropy lines, these are the constant entropy lines, right, but these constant entropy lines are not straight, right it is not straight. So, that is the thing that entropy is changing, that we have to keep in mind whereas, you see saturated liquid line, saturated vapour line, pressures, they are more or less, it can be said that they are straight, but entropy is not there. So, this tells the critical point, triple point everything from p h diagram we will show afterwards T-S diagram, whenever it is coming right, but you see the

characteristics of this p-h diagram is that the dome is a little inclined right. I have to incline this way, dome is little inclined and this inclination as it is evident, this is the dome right.

I hope you can see the cursor, as it is moving. So, this is called the dome and that is vapour liquid saturation line right. So, this saturation line is the vapour liquid saturation line and in p-h diagram this is a little inclined may not be so in T-S diagram, right we will come in T-S diagram, do not worry about it. So, pressure versus enthalpy, that is h there is kilojoules per kg and pressure is in Pascal or kilo Pascal. So, this gives, someday, I will also show, there are, nowadays, softwares available from where you can make this saturation line and many other properties available.

These are nowadays available because as you know with time, progress of time, lot of research are going on including the development of the basic thing like that P-h diagram, T-S diagram, P-V diagram, all these are nowadays available in software right. So, software companies have developed them, will use them. Now, this one is a typical p-h diagram, and the pressure P₁ and pressure P₂ are there which are as it is here, P₁, it is P₁ and this is P₂. I can use this, that is not here, next time we will do that. So, pressure, this is P₁, this is P₂, right are there where P₁ is obviously, as it is seen P₁ is greater than P₂.

The constant pressure line that is 1, 2, 3, 4; where is 1, this is 1, this is 2, this is 3, and this is 4 so, this line is constant pressure line. So, for pressure P₁ it is constant pressure line portions of 1 to 2 is the sub cooled region, this is the saturated line right. So, anything beyond that this side will be sub cooled right. Similarly between 2 to 3 this one is the wet region because here this is a mixture of vapour liquid right, this is a mixture of vapour liquid. So, 2 to 3 is the wet region,

meaning there is a mixture of liquid and vapour.

So, between 3 to 4 it is again, this side, it was sub cooled, this side, it is super heated right this side, it is sub cooled this side it is super heated region right. So, 1 to 2 is sub cooled region, 2 to 3 is saturated region, 3 to 4 is super heated region, right. So, it is a frequent problem in refrigeration cycle, calculation to find the properties of sub cooled liquid, at point A, as we can see from the previous figure that there is a sub cooled point, a, right. It is very difficult to find out the property values at this point, right. So, the liquid is at a pressure of p_1 , and the temperature is T_a and it is sub cooled.

So, the liquid at point a prime, where is that point a prime? You see, this is a and if we come perpendicular to this, it comes to the saturated line, and this is a new point 'a'. Obviously, this pressure, which was p_1 , there the pressure is not p_1 , right because it is p h diagram. So, p is constant all along 1, 2, 3, 4, but this when we are going from 'a' to 'a' prime the pressure is not constant ok. The liquid at the point a prime is saturated liquid at lower pressure that is p_a , but at the same time at the same temperature T_a also right. Again, go back at the same temperature T_a temperature did not change pressure has come down.

it has come to p_a right or p_a prime whereas, temperature remained as T_a right that could have been seen from T S diagram or if we have the bigger p h diagram including the temperatures then we could show that this is so right. So, if we say that then we can write for this $T dS$ is equal to dU plus $p dv$. If the liquid can be assumed to be incompressible then obviously, dv is 0 right, because incompressible, we have said earlier also, that the density becomes 0. So, dv is also 0 therefore, $T dS$ can be written as dU . So, it is valid to assume that for liquids the internal energy may be function of temperature alone.

$$T ds = du + p dv; dv = 0. \therefore T ds = du.$$

So, we can write U_a is equal to $U_{a'}$, therefore, we also can write S_a is equal to $S_{a'}$. Since the temperatures T_a are same as $T_{a'}$ or rather is same as $T_{a'}$. Hence, the states a and a' are coincident, right they are coinciding. We can also see, from the relation $T ds = dh - v dp$ and there the specific volume is small for liquid, and hence, $v dp$ can be neglected, because v is very small, specific volume for liquids are very small, density of liquids are high, density of gases are low, but its specific volume is high, right this information keep in mind. The specific volume is small for liquids, hence, $v dp$ can be neglected.

So, we can write that h_a is also equal to $h_{a'}$ right because that $v dp$ is out. So, $T ds = dh$ right. So, we can write that h_a is equal to $h_{a'}$. This means that the enthalpy of the sub cooled liquid is equal to the enthalpy of the saturated liquid, at liquid temperature right. Then we also can say that for all practical purposes, the constant pressure line are assumed to be coincident with the saturated liquid line in the sub cooled liquid region.

So, in the sub cooled region, we can also say that the pressures are also becoming coincident. This concept is very useful and as we have seen from the other figure that is figure A let us go into that. So, as we can see that this $p-h$ diagram, the constant pressure lines, where they are the constant pressure lines, entropy, vapour, saturated liquid, vapour saturated, line solid vapour and constant temperature lines, and this is saturated liquid lines and these are the constant pressure lines right. So, from there, we can say that the saturated liquid line in the sub cooled region is also pressure becomes coincident right. So, we can write that $T-s$ diagram and this if we show in $T-s$ diagram, and that gives a lot of information about the refrigeration cycle.

It is observed from the relation given below that for a reversible process the heat transfer is governed by the change in energy that is dQ_{rev} equal to Tds or we can write between 3 to 4. Now, between 3 to 4 means we go back to where again here that 3 to 4 this portion that is superheated right. So, between 3 to 4 we can integrate it with the boundary being 3 to 4 and the integral part is dQ_{rev} and this is equal to Q_{3-4} right. Therefore, we can write this is also equal to $T ds$ integral between 3 to 4 right. The integral on the right hand side represents the area under the line 3 to 4 on a $T-s$ coordinate by definition of integral right.

$$\int_3^4 dQ_{rev} = Q_{3-4} = \int_3^4 T ds$$

Therefore, according to this equation the heat transfer for a process is equal to the area under the line on $T-s$ diagram. We also know that $T ds$ is equal to $dh - v dp$. So, for a constant pressure process $T ds$ is also equal to dh . For an isobaric process now isobaric means constant pressure right. For an isobaric process the area under the curve is equal to change in enthalpy on $T-s$ diagram.

$$\int_3^4 T ds = h_4 - h_3$$

Along the constant pressure line that is 3 to 4 isentropic lines are vertical lines on $T-s$ diagram isentropic that means, entropy is constant. So, if we draw then we will see that this s is constant and it is coming vertical lines right. Hence, line with 5 to 6 let us look into that 5 to 6 whether it is here or not yeah it is not here it is some other picture. So, there we see that this is an isentropic line that is constant entropy and along this lines S_5 is equal to S_6 right. So, there integral of 3 to 4 is equal to $h_6 - h_5$ that is equal to specific work and the line 5 to 7 is a real non isentropic compression process in the $T-s$ diagram.

$$\int_3^4 v dp = h_6 - h_5 = \text{Specific work}$$

So, from the pressure enthalpy diagram it is observed that the constant entropy lines are not parallel to each other which I said that they are a little away right they are not straight rather they are divergent right it is really like this it is going out and it is divergent. The advantage of this divergence is of great importance in reheat process for steam turbines and the results in saving of compressor work in multi stage compression processes. The pressure scale in this diagram may be linear or logarithmic if it is logarithmic then the dome becomes very flat to the critical point right. So, this we again look at because we have the p h diagram here. So, the this dome that means, when it is saying that this critical point it comes down right and the dome becomes more flat unlike this is having a shape proper shape, but there it will be going down that critical pressure or critical temperature critical point that will come down and the nature of the curve will be like this.

So, it will be much compressed right. So, if we go back to that we can say that if the pressure scale is logarithmic then the dome becomes very much flat or it becomes flattened right. So, the critical point also goes down a lot because of the flattening of the p h curve right when if it is plotted in logarithmic scale it can be plotted in normal or logarithmic that is linear or logarithmic, but linear you have no problem, but if it is logarithmic then the entire dome is squeezed and the critical temperature or point that goes down this we have to keep in mind right. Now I would like to share some of the relations and its definition which are very very useful in anywhere any heat transfer, any mass transfer, any moment momentum transfer this is very very helpful right. For example, we know very well, Reynolds number that is $d v \rho$ by μ and how it is expressed? It is said to be a ratio of internal forces to the viscous forces right.

So, ratio of internal forces to the viscous forces is the Reynolds number and most of you use it many many times right. Prandtl number another one which is used in heat transfer very much and that is $C_p \mu$ by k right. I hope we know that d is diameter, v is velocity, ρ is density, μ is viscosity and here C_p is specific heat under constant pressure, $C_p \mu$ we have already said k is thermal conductivity right. So, this is also expressed as ratio of momentum diffusivity that is kinetic viscosity to thermal diffusivity right. The third one is Nusselt number that is Nu and it is expressed as $h d$ by k , h is the heat transfer coefficient, d is the diameter, k is the conductivity of the material.

So, it is also expressed in terms of ratio of convective to conductive heat transfer across or normal to the boundary that is the Nusselt number. It is also used very much in heat transfer. Schmidt number Sc it is ν by D , ν we have already said it is kinematic viscosity and D is the diameter, then it is expressed as ratio of momentum diffusivity where viscosity is present and mass diffusivity right. No, this capital D is not diameter, this capital D is diffusivity, mass diffusivity right. And in many cases, of course, you may give the particular nomenclature may be d , mass or D diffusivity this kind of nomenclatures are also used.

However, others are like Grashof number is $g \beta \Delta T L^3$ over ν^2 or ν square rather. This is ratio of the buoyancy to viscous forces acting on a fluid. And for today the last one is say Sherwood number, this is also used very much in mass transfer that Sherwood number is $\rho_a h D$ into L over D . Here obviously, h is the heat transfer coefficient that is ratio of convective to diffusive mass transfer right. So, h for diffusion, L is the length of course, ρ_a is the density and this D is the diffusivity ok.

Some useful Non Dimensional numbers:-

Reynolds Number	$Re = \frac{Dv\rho}{\mu}$	Ratio of inertial forces to viscous forces
Prandtl number	$Pr = \frac{C_p \mu}{k}$	Ratio of momentum diffusivity (kinematic viscosity) to thermal diffusivity
Nusselt Number	$Nu = \frac{hD}{k}$	Ratio of convective to conductive heat transfer across (normal to) the boundary
Schmidt Number	$Sc = \frac{\nu}{D}$	Ratio of momentum diffusivity (viscosity) and mass diffusivity
Grashof Number	$Gr = \frac{g\beta\Delta T L^3}{\nu^2}$	Ratio of the buoyancy to viscous force acting on a fluid
Sherwood number	$Sh = \frac{\rho_a h_D L}{D}$	Ratio of convective to diffusive mass transport

So, subsequently, in subsequent classes we will give some more relations which are very very helpful. Thank you.