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

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Lecture 40

Basics of Refrigeration and Air Conditioning(Contd.)

So, good afternoon my dear friends and students. We are in the Refrigeration and Air Conditioning right. And we have already said that the two types of refrigerations are used, one is vapor compression refrigeration system, another is absorption refrigeration system, vapor absorption refrigeration system. Now, vapor absorption refrigeration system is not widely used, and that is why, only the cycle, we have shown, and the detail analysis, we said that, may not be so much useful for us. If someone wants to, typically, do some research work, and lot of work is also involved in that, still it is not commercialized, the reason being the requirements for that is not so well developed right. So, as a continuation of this, the basics of refrigeration and air conditioning, we are continuing in this class.

So, we come to the next that is called Evaporative Cooling. Now, evaporative cooling, I told you also in the previous some class, that the cooling tower, which, is used, is also an evaporative cooling right. So, the best example could have been, by the farmers, but, unfortunately in our country, again, when things do not come from outside, or abroad, they are not taken into serious consideration. This is off the cuff statement.

The reason being that, this system, could have been so well, so good for farmers, for giving, at least 7-10 days in good condition, before it goes to the market, or before it goes to the cold storages, it could have been well used. Besides, at home also you are using, those who are in hot areas, like Delhi, Rajasthan, in this eastern part, say Jamshedpur, part of Bihar etc., not in Bengal, because, Bengal, humidity is very high. And as I told you earlier also many times that, the dry and wet bulb, these two are very fundamental, right. More than dry, wet bulb is more fundamental, because you cannot cool below the wet bulb temperature, normally, with this kind of evaporative cooling.

And that is why, this type of cooling is not so good in eastern part of most of the places, like Bengal, as a whole, no, some part of Bengal, it could be, like, the like, the village, not villages, towns like Bankura, Birbhum, these areas also, they are dry. So, dry areas, it can be very well used. So, as you see from this pictorial view that, you have a perforated net kind of thing, which, can absorb, or which can hold some water, on the top, some sprinklers are there, and this is sprinkling some water, and you are blowing hot air, and when, it goes through this, the latent heat of vaporization of the water is taken out by the air, and air gets cooled, and it also carries some vapor with it. That is why, those, who are using this desert coolers, you have observed that, the doors and windows are kept open. Otherwise, the room will become, again, highly moist, and the purpose will be defeated.

So, in this case, air in contact with water to cool it, close to wet bulb temperature. It cannot be lower than the wet bulb temperature, close to wet bulb temperature. In dry areas, this wet bulb temperature, it is very low. So, it is very very effective there. Advantage is that, it is efficient cooling at low cost, but, as I told that, our Indian farmers, they are so rich, or so callous, or whatever you call.

Have you ever seen anywhere, any farmers whatever, whether farming fruits or vegetables or leafy vegetables, anything, are they using similar kind of cooling? No. At least, minimum 20 to 30 interactions, directly, one to one with them, in groups, I have told that this can be very easily constructed, as well as maintained, and this is good for you, with minimum, no cost, because, that air, which is coming, that is, by the nature, you do not have to use fan also, but it is not being used. There is a disadvantage, that is, air is rich in moisture, as I told that, when, from the left to the right, as in the picture, you are moving, then, the air is getting cold, but, it is also carrying some moisture. So, the humidity, that will go up, and again, the term discomfort, will start and that is why, the windows and doors are normally kept open. Now, if we analyze this, there are occasions, where, air conditioning, which are, which stipulates control of humidity, up to 50 percent, for human, control or comfort, or for process can be replaced by a much cheaper and less energy intensive evaporative cooling.

Evaporative cooling is an extremely efficient means of cooling at very low cost. The concept is very simple, and is the same as that of used in cooling tower. Air is brought in close contact with water to cool it to a temperature, close to the wet water temperature. The cool air can be used for comfort or process cooling. The disadvantage is that the air is rich in moisture.

The possibility of evaporative cooling is specially attractive to comfort cooling in dry regions. The principle is practiced in textile industries for certain processes. Then, assessment of refrigeration is like this, that, cooling effect in terms of tonnage of refrigeration, or tons of refrigeration. One ton of refrigeration is 3024 kilo calorie per hour, or roughly, 3.52 kilowatt heat equivalent, and TR is assessed, that is, tons of refrigeration, is assessed, as TR is equal to Q into C p into delta T, that is, T i minus T o, over 3024.

Assessment of Refrigeration:-

Cooling effect: Tons of Refrigeration
1 TR = 3024 kCal / h = 3.52 kW heat rejected
T_R is assessed as:
$T_R = Q \times C_p \times (T_i - T_o) / 3024$

Q = mass flow rate of coolant in kg/hr
C_p = is coolant specific heat in kCal /kg °C
T_i = inlet, temperature of coolant to evaporator (chiller) in °C
T_o = outlet temperature of coolant from evaporator (chiller) in °C
1 hp = 0.746 kW; 1 kCal = 4.2 kJ; 1 kCal/h = 1.1622 kW

This is one empirical relation, and in terms of obviously, 3024 is in kilo calorie. So, on that, Q is, the mass flow rate of the coolant, in kg per hour, C p is the coolant specific heat, in kilo calorie per kg, T i is the inlet or initial temperature of the coolant to the evaporator, rather, or chiller, in centigrade ,and T o is outlet temperature of the coolant, from evaporator, or chiller, in degree centigrade. Now, another relation is very useful. There is 1 hp is 0.746 kilowatt, and 1 kilo calorie is 4.2 kilo joules, and 1 kilo calorie per hour is 1.1622 kilowatt, right. So, these data are very much helpful, when, you are calculating. Specific power consumption, the moment we say, the specific, it is per unit mass. So, it is kilowatt per tonnage of refrigeration.

This is an indicator of refrigeration system's performance, and kilowatt per tonnage of refrigeration, of centralized chilled water system, is some of compressor, that is, kilowatt per tonnage of refrigeration, chilled water pump, that is, kilowatt per tonnage of refrigeration, condenser water pump, that is, kilowatt per tonnage of refrigeration, and cooling tower fan, that is, kilowatt per tonnage of refrigeration. All put together, gives the total kilowatt per tonnage of refrigeration. The specific power consumption, in kilowatt per tonnage of refrigeration, is a useful indicator of the performance of refrigeration system by measuring the refrigeration duty performed in tonnage of refrigeration, and the kilowatt, of course, inputs kilowatt per tonnage of refrigeration, is used as an energy performance indicator. In a centralized chilled water system, apart from the compressor unit, power is also consumed by the chilled water, that is, secondary coolant pump, the condenser water pump for the heat rejection to the cooling tower, and the fan in the cooling tower, these are used. Then, coefficient of performance, which we have seen earlier, very much, that COP Carnot, a standard measure of refrigeration efficiency.

$$COP_{Carnot} = T_e / (T_c - T_e)$$

$$COP = \frac{\text{Cooling effect (kW)}}{\text{Power input to compressor (kW)}}$$

It depends on evaporator temperature, T e and the condensing temperature T c. So, COP Carnot, that could be written as, T e over T c minus T e, and COP in industry, is calculated, for type of compressor, as COP is cooling effect, that is, kilowatt per power input to compressor, kilowatt, that we have also seen earlier. The theoretical, coefficient of performance, Carnot COP is a standard measure of refrigeration efficiency of an ideal refrigeration system, which, depends on two key systems, temperatures, evaporator temperature T e, and the condenser temperature T c, but COP Carnot is only a ratio of temperatures, and does not take into account, the type of compressor. Hence, the COP, normally used in industry is calculated using this above equation, that is cooling effect in kilowatt, over power input to the compressor, that is, also in kilowatt. If we look at COP, this we have also shown earlier, the effect of condenser temperature, and the effect of evaporator temperature, that, we have shown.

I hope, there is no difference, and we need to continue it again. Then, measure, air flow that is, Q in meter cube per second at fan coil units, that is, fcu of air handling unit, AHU. Anemometer is used. Air density, rho, that can be used by any density meter, right and specific gravity meter, rather, in kg per meter cube. Dry bulb and wet bulb temperatures can be used by the help of the thermometer, right.

$$TR = \frac{Q \times \rho \times \left(H_{in} - H_{out}\right)}{3.52}$$

So, tonnage of refrigeration, we can say is, Q into rho into h in minus h out over 3.52. that is another way of measuring the tonnage of refrigeration. Enthalpy, that is kilo calorie per kg per kelvin. So, of inlet air, that is, h in and outlet air, h out, can be used from the psychometric chart, right.

So, if we want to calculate, TR, as in case of air conditioning units, the air flow at the fan coil units, or the air handling units, can be measured with the help of anemometer. Dry and wet bulb temperatures are measured at the inlet and outlet of AHU, or bfcu and TR is calculated as tonnage of refrigeration, where, Q can be air flow, and rho is the density of air, h in is enthalpy of inlet air, and h out is enthalpy of outlet of air. Use of psychometric charts can be helpful to calculate the h in and h out from the dry and wet bulb temperature values, which, are measured during trials by a whirling psychrometer, right, which we have also shown. Power measurements, at compressor pumps, AHU fans, cooling tower fans, can be taken with a portable load analyzer, and the specimen power specific power consumption can be then calculated right. So, we can come to indicative TR load profile, that is, small office cabinets, can be, somewhere 0.1 tonnage of refrigeration per meter square. So 0.1 ton per meter square, in 1 meter square area, 0.1 ton, in 10 meter square area, it is 1 ton, right, meter square area, mind it.

So, it is something, 3.3 meter by 3.3 meter, so, roughly around 10 feet by 10 feet, right, cabinet, it is 1 tonnage of refrigeration, this is in a thumb rule. Medium size of office, where, 10 to 30 people are working with central AC rather, it is 0.06 tonnage of refrigeration per meter square. Large multi storied office, that complex with central AC, this can be 0.

04 tonnage of refrigeration per meter square, right. So, accuracy of measurement is the assessment consideration. Inlet, outlet temperature of chilled and condenser water flow, how accurately they are measured? It is also a part of the measurement. Integrated part load value, that is IPLV, there, it is kilowatt per tonnage of refrigeration for 100 percent load, but most equipment operate between 50 to 75 percent of the full load. It is not 100 percent full load, it is mostly around 50 to 75 percent.

So, IPLV can be calculated in terms of kilowatt per tonnage of refrigeration with partial loads, and 4 points are used in this case. 25, 50, 75 and 100, these are the 4 points, that can be used, right. So, accuracy of flow and temperature measurements are very important. So, we have already said in a field performance assessment, accurate instruments are required to measure the inlet and outlet temperatures of chilled water and condenser water, preferably, with a least count, it is called, of at least, 0.1 degree centigrade. Flow measurement of chilled water can be made with an ultrasonic flow meter, directly, or can be determined, based on pump duty parameters, right. And then, condenser water flow can also be measured with the help of non-contact flow meter, directly, or can be determined by using pump duty parameters. Then, integrated part load value, that is, IPLV, where, although the kilowatt per tonnage of refrigeration can serve as an initial reference, it should not be taken as an absolute guideline, since, this value is based on a 100 percent equipment capacity. But, most equipment are operated between 50 percent to 70 percent of the capacity. So, to overcome this, an average kilowatt per tonnage of refrigeration with partial loads has to be determined, which is called the integrated part load value, IPLV, right.

In this case, obviously, I would like to say that, this IPLV, this part, we are not so much concerned, because normally, we do not operate with IPLV, that is integrated part load, that, 25 percent of the full load, or 100 percent of the full load. This is not generally observed. We perform, around 70 75 percent by and large. So, may not be the part load is so much important to us at this moment. So, energy efficiency opportunities are, it is optimized process heat exchange, maintain heat exchanger surfaces, multi staging systems, matching capacity to system load capacity, control of compressors, multilevel refrigeration for plant needs, and chilled water storage system design features.

These are energy efficiency opportunities. Now, optimized process heat exchange is like this, proper sizing, heat transfer areas of heat exchangers, and evaporators are required. Heat transfer coefficient, on refrigerant side, normally, taken as 1400 to 2800 watt per meter square Kelvin, whereas, heat transfer area during the refrigerated side is generally, greater than 0.5 meter square per tonnage of refrigeration. Optimum driving force, that is, the difference between Te and Tc is 1 degree centigrade rise, in Te is equal to 3 percent power savings.

So, it is, how it is optimized, that if you can increase the evaporator temperature by 1 degree centigrade, then you are saving power by 3 percent, right. So, this we are skipping, and here we can see that evaporator temperature of 5.0, 0, minus 5, minus 10, minus 20, with refrigeration capacity in terms of tonnages, that 67.58, 56.07, 45.98, 37.20, 23.12, and specific power consumption of different numbers, 0.81, 0.94, 1.08 and 1.25, 1.67, these increase in kilowatt per tonnage of refrigeration. So, these are that based on compressor temperature of 40 degree centigrade and not only 40 degree centigrade, but at different evaporator temperatures of 5.0, minus 5, 0, minus 10, minus 20 and the refrigeration, it is in terms of tonnage of refrigeration 67.58, 56/07, 45.98, 37.2, 23.12, like that and the specific power consumption, comes to, 0.81 that is high evaporator temperature, low tonnage of kilowatt per tonnage of refrigeration, that is, specific power consumption, and minus 20, so low, is 1.67. So, increase in kilowatt per tonnage of refrigeration is around 106 percent. So high, if the evaporator temperature is lowered, right, which we have already said earlier also, right.

So, that was for evaporator temperature different, but condenser temperature fixed. The first table, there are two tables of course, yeah, this is one, and the other one was, this is also condenser temperature, this is also condenser temperature 40 degree centigrade, right. So, the first table shows that, the effect of evaporation temperature on the compressor power consumption at a constant condenser temperature of T c 40 degree centigrade, and lower evaporator temperature, reduce the refrigeration capacity, that is tonnage of refrigeration, and increase the power consumption. Second table, that is, what we have shown, is the effect of condensing temperature on the compressor power consumption at a constant evaporator temperature of T e of 10 degree centigrade increasing the condensing temperature leads to a reduction of the refrigeration capacity and an increase in the power consumptions. Then, the contribution can be drawn, is, that, if you try to keep the difference between T e and T c at an optimum level, to ensure the best tonnage of refrigeration, at the lowest power of consumption, right.

So, I hope, some of the information are very good, and it is corroborating whatever earlier we also had said, that the specific power consumption increase or decrease with the evaporator or condenser temperature, increase or decrease these relations with tabular form we have corroborated the earlier facts, which we have already said. I hope that, whatever we are saying, that is, corroborating whatever earlier cycles, and the analysis, we have done, these are the practical numbers, which are available commercially, right. So, with this, perhaps, we come to, or maybe another class will be required, to complete that air conditioning and refrigeration, because, some more things are also to be told. You must know that, cascading, many cases cascading are used, right.

So, those kind of things are still there. So, you may need, one more class, for this refrigeration and air conditioning. You are gradually heading towards completion of the cooling production, and then it will come to our utilization, maybe after few classes, we will start with that, right. So, no, there are some more, which may take a little time, that is, the individual component, that is, compressor, condenser, evaporator, expansion device. So, at least few classes, we have to spend on that.

So, let us see, how we can procee, ok. So, thank you all.