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

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Module No 10

Lecture 48

Condenser

Good afternoon my dear students, and good afternoon to all of you. My friends, who are attending the course, we have completed compressors. Now, we go to another very useful and very much required, may not be the heart of the refrigeration system, but this is also, may be equivalent to lung, right. Because, compressor, if it be heart, then, condenser, and evaporator, could be equal to lung. Because, condenser and evaporator, both are heat exchangers basically. Compressor is different, because, it is compressing, expanding by that process, it is making the vapour at high temperature high pressure, but it is not so in case of condenser or evaporator.

So, we will proceed to condenser, and then, expansion device, and then, evaporator, as the cycle following, right. We have completed, compressors, now condensers, then, expansion device, and then, the evaporators, right, we have very limited time, ok, sorry. So, in this lecture, we are coming to condenser. So, what is condenser? So, it is a heat exchanger, where, the refrigerant is first dissipated, and then, saturated vapor, condenses, into liquid state.

If you remember that cycle, where, NTS diagram, where, we had compressed, it, whether, it is isentropic, or any other way, then, it comes to the superheated condition, and then, it gets into the condenser, and from there, the expansion device, and back to evaporator. So, this was our cycle. So, here it gets superheated. So, first the condenser does it, dissipated, the vapour, or gas, which, is available there, right. So, the liquid may be sub cooled in some condensers, unless, the step is there, the refrigerant cannot be recycled, which step, that is, super cooling.

Because, unless, super cooling is done, then, you will not be able to extract the heat from the evaporator, right. So, though, heat transfer, the heat absorbed by the evaporator, at low temperature, and the work of compression are rejected to the surroundings, the heat is rejected, either to air directly, or to water, which, in turn, rejects, it to the surroundings in a cooling tower. The heat transfer coefficient, h c is small in vapour phase, but the temperature difference between the refrigerant, and the coolant, that is delta T, is large. In some of the cases, this delta T, you have written with small t, but it is capital T, right, while, during the condensation, the heat transfer coefficient is large, but the temperature difference is small. As a result the product of h c into delta T is approximately same in both the regions.

Now, hence, we can tell that, while, designing, it can be assumed that, the condenser, or condensation, occurs through, throughout the condenser itself, whether, it is superheated portion or sub cooled portion, that we have shown that, the heat transfer coefficient times the delta T, more or less equal to same remaining. So, another term, which, is, heat rejection ratio, right, heat rejection ratio, that we must know, that, it is the ratio of heat rejected to the heat absorbed ratio of heat rejected to the heat absorbed. So, heat rejection ratio R, can be said equal to Q c to Q e, Q c is the heat rejection and Q e is the heat absorption. So this Q c is Q e plus W c, earlier we have also seen, over Q e. So, it is 1 plus 1 by COP, because COP, we have seen to be equal to Q e over W c, how much, we have given, how much we have obtained, that is the COP, right.

$$R = \frac{Q_c}{Q_e} = \frac{Q_e + W_c}{Q_e} = 1 + \frac{1}{COP}$$

So, heat rejection ratio is, 1 plus 1 by COP, right, for a fixed evaporator temperature, as the condenser temperature increases, the COP decreases, and the heat rejection ratio also increases, because, if COP is decreasing, that means, this part is low. So, 1 by this part is high. So 1 plus this part is high, right, it is high, that way. So, R is increasing right. Then for a fixed condenser temperature, as the evaporator temperature decreases, the COP decreases, and the heat rejection ratio also increases, the same, which, we earlier had said, but, here, only a new term, that is, heat rejection ratio, R, we have introduced, and said the effect of condenser and evaporator temperature effect.

Types of condenser: there are 3 types, one is air cooled, there are 3 types, one is air cooled condensers, another is water cooled condenser, and third one is evaporative condensers, right. So, depending on the geometry and the type of heat transfer, the condensers are further classified as, rather, it is further classified, and that, we can say to be, that the temperature difference, if it is Tc minus T coolant, that is T condenser minus T evaporator. If it is air cooled, then, the temperature is around 50 to 20 degree centigrade, whether, if it is water cooled, then it is 6 to 12 degree centigrade. Volumetric flow rate of the coolant per unit tonnage of refrigeration, air cooled, it is 12 to 20 cubic millimeter, whereas, for water cooled, it is 7 to 20 liters per minute. Heat transfer area per tonnage of refrigeration for air cooled, required is, 10 to 15 meter square, whereas, for water cooled it is only 0.5 to 1meter square. Gas velocity, that is, 2 to 5 meter per second, in terms of air cooled, and in terms of water cooled, it is 2 to 3 meter per second, and then, power consumption per tonnage of refrigeration, if it is air cooled, blower is 0.1

to 0.2 hp, whereas, pump, for power pump, for water cooled, is negligible, right. So, air cooled vis-a-vis air cooled condenser, that is only air, advantage of air cooled condensers is like that, simple in construction, disposal of warm air is not a problem, and available in plenty, air is plenty available.

Cleaning of condenser is also small, maintenance is also of very low cost. Disadvantage of air cooled condensers are, in this regard, let me also tell you, once more, that our household refrigerator, which, are old type, which is having on the back, that net type condenser, that is air cooled, right and no maintenance, there is no such deposition of anything on the condensers, other than some dust and other things, which, you can just blow or take out. Since, air has one-fourth specific heat, and one-hundredth of density, than, those of water, the volume flow rates required are very large. Since, thermal conductivity of air is also very small, the heat transfer coefficient is also very small, and available air is at dry bulb temperature, whereas, water is available at low temperature, that is 2 to 3 degree centigrade above the wet bulb temperature. The rise in temperature is much higher than that of the water, and hence the condenser temperature becomes very large.

Therefore, COP reduces, its use is normally restricted to 10 tonnage of refrigeration, although, blower power goes up beyond 5 ton of refrigeration. In middle east countries, where, there is scarcely, or scarcity of water, or fresh water, air cooled condensers are used up to even hundred tons of refrigeration, or more. Its cost is 2 to 3 times more than that of water cooled condenser, but they have no water, so what they can do? So, they are buying air only. So, water cooled condensers, requires cooling tower to recycle the water and minimize the loss of water.

Unfortunately, the installation, and maintenance, installation and maintenance cost, they are high of cooling tower, offset the cost of advantage of water cooled condensers, because, the maintenance, and installation of the cooling towers, are also high. But, running cost for the condensers are also small, and also you can beautify your place with the cooling tower. Fowling, on the heat exchanger surface is a big problem in use of water cooled condensers, right. If you remember, by mistake, I now realize that, by mistake, we had said, here, air cooled vis a vis air cooled, no, that is air cooled versus this one, air cooled vis a vis water cooled, ok. So, when we come to this that water cooled vis a vis evaporative condensers, this comparison, then evaporative condensers, that is cooling tower, combine the features of cooling tower, and a water cooled condensers in a single unit.

Water is spread from the top, on a bank of tubes, carrying the refrigerant, and air is induced upwards. This, I will show you afterwards, when we come to storage, that time, because, every time showing is very difficult. Now, a thin water film around the condenser tubes, evaporates, cooling, evaporates, cooling the refrigerant in the condenser, this is called evaporative cooling, and the huge latent heat of evaporation is utilized to cool the refrigerant. The heat transfer coefficient is very large, the water flow counter currently to the air flow, and acts as a cooling tower. In the evaporative condenser, the condenser is located close to the compressor, requiring more pipe line, right, is located close to the compressor, requiring more pipe length, ok.

Then, these pipes feed the refrigerant and run through the evaporative condenser, the compressor power is little higher, but the water pump power is less, since water lines are short. Whereas, the water cooled condenser is located next to the compressor, requiring less compressor power, but water pump power is large, because, the cooling tower is located outside. Two types of air cooled condensers are there, natural and forced convection, or forced convective type. Natural convection types are used for small capacity refrigeration system, such as the household refrigerators, and the freezers. The condensers are either plate surface type, or finned tube type, air velocity typically, varies between 2 to 3.5 meter per second, with air flow rates of 12 to 20 centimeter cubic, right, per tonnage of refrigeration. Specific heat of air is 1.005 kilo joules per kg kelvin, and the density is 1.2 kilo joule, rather, kg per meter cube. So, for one tonnage of refrigeration, the temperature rise, that is, delta T a, is equal to say 3.5 into 167 over 1.2 into 1.005 into 16 over 60, that is, 10.9 degree centigrade, for average air flow rate of 16 cubic meter, or rather, not, cubic meter, C m m, that is, cubic millimeter. Since, the air temperature rises by 10 to 15 degree centigrade, compared to 3 to 6 degree centigrade for water. The rise of, or, the area of the condensers, seen from outside, in the direction of air flow is called the face velocity, right.

So, this earlier also, we termed, so the face velocity, we can say is the condenser, seen from outside in the direction of air flow, and that is called the face velocity, which is obtained as the volume flow rate divided by the face area. The face velocity is restricted to 2 to 3.5 meter per second to minimize the pressure drop due to frictional resistance. The coils of the tubes in the direction of flow is called rows. There are 2 to 8 rows of the tubes that can be there, carrying the refrigerant.

Two types of finned tubes are there, that is, spiral fins and continuous flat plate fins. Generally, the fins are made of aluminum and the tubes are made of copper and the fitting is done through bulleting. If the refrigerant is ammonia, the tubes and fins are made, of course, of mild steel. The reason being that, copper or aluminum, they are reacting to the ammonia, right. So, which are either cooled or galvanized, of course, either welded or galvanized.

Finned coils are very compact. The secondary surface area is 10 to 30 times the bare pipe area. Heat transfer is rather, in finned type coils are very complicated, and air cooled condensers are cross flow type, with flow reversal, on the refrigerant side. Now, if we see in this, there is a term called LMTD, that is log mean temperature difference. Generally, it is defined as delta Tm and that is, delta T2 minus delta T1 over ln of delta T2 by delta T1, right. And what are those delta Ts? Because, heat exchangers come in so many shapes, sizes, makes, and models, they are categorized, according to common characteristics.

$$LMTD = \Delta T_m = \frac{\Delta T_2 - \Delta T_1}{\ln\left(\Delta T_2 / \Delta T_1\right)}$$

Once, one common characteristic, that can be used to categorize them is, the direction of flow. That two of fluids have directions, relative to each other, right. The three categories are parallel flow, counter flow, and cross flow, right. Now, parallel flow is illustrated as in the figure 1. What is that? This is the parallel flow, right.

So, you see here, this is coming and this is also going, right, which are all parallel. So, that is why, it is called parallel flow, and inlet to outlet, the temperature distribution of the two, that is, inlet and outlet, are like this. This is the typical nature of the parallel flow right. Whereas, the counter current, ok, first let us complete it that, in this case the two fluids entered the heat exchanger from the same end, with a large temperature difference. As the fluids transfer heat as the fluids transfer heat, rather hotter to cooler, the temperatures of the two fluids, approach each other.

Note, particularly, that the hottest cold fluid temperature is always less than that of the coldest hot fluid temperature, right. Then, counter flow, this is illustrated in the next one, here, you see that, one fluid is going like this, another fluid is coming like this. So, these are counter flow, and if we have the inlet to outlet temperature versus that, you see, inlet to outlet of one, and inlet to outlet of the other fluid, they are in the reverse direction, right. So, we can say that, for counter flow type, for counter flow type, it exists when the two fluids flow in opposite directions. Each of the fluids enters the heat exchanger at opposite ends because, the cooler the fluid exists the counter flow heat exchanger at the end, where the hot fluid enters the heat exchanger, the cooler fluid will approach the inlet temperature of the hot fluid.

Counter flow heat exchangers are the most efficient of the three types and in contrast to the parallel flow heat exchanger, the counter flow heat exchanger can have the hottest cold fluid temperature, greater than that of the coldest cold fluid temperature, right.

Now, another one is the cross flow, as you see, from here, this is flowing like this, and there is a perpendicular to this another fluid, right. So, this is called cross flow and it exists when one fluid flows perpendicular to the second fluid, that is, one fluid flows through tubes and the second fluid passes around the tubes at 90 degree angle. Cross flow heat exchangers are usually finned or usually found, rather, in applications, where on the fluids charges or rather fluids changes state that is, two phase flow is occurring and an example is a stream is, a steam systems, rather condensers, in which the steam exit, exiting the turbine enters the condenser shell side, and the cool water cooling in the tubes, cool water flowing in the tubes, absorbs the heat from the steam condensing it into water. Large volumes of vapour may be condensed using this type of heat exchanger, or the flow of heat exchanger right.

Now, this is a typical problem, if you have, T 1, 90 degree centigrade, T 2, 80 degree centigrade, for hot fluid, and t 1, 30 degree centigrade, and t 2, 70 degree centigrade for whole cold fluid. So, LMTD, that can be for counter flow, it is 32.74, for parallel flow, it is 27.9 degree centigrade, right, whereas, for cross flow there is a correction factor, in cross flow and according to that, once you have the correction factor, then, you can use that correction factor, and get the difference around, if it is 0.933, that is, close to the counter flow. Now, another thing, which, we have shown, is the mean temperature difference, and that is 30.54, whatever, you check, and we have given you, the relation. So, you find out how you are going to use log mean temperature difference right. So, with this, perhaps, there is no time now, we stop this class, but we will continue with the condenser and try to finish in the next class. Thank you so much.

Given, T_1 = 90 ^oC, and T_2 = 80 ^oC for hot fluid, and t_1 = 30 ^oC and t_2 = 70 ^oC for the moist air.

$$LMTD = \Delta t_{m,cf} = \frac{\Delta t_2 - \Delta t_1}{\ln\left(\Delta t_2 / \Delta t_1\right)} = \frac{(T_2 - T_1) - (T_1 - t_2)}{\ln\left(\frac{T_2 - t_1}{T_1 - t_2}\right)}$$

$$= \frac{(80-30)-(90-70)}{\ln\left(\frac{80-30}{90-70}\right)} = 32.74^oC$$

$$LMTD = \Delta t_{m,pf} = \frac{\Delta t_1 - \Delta t_2}{\ln\left(\Delta t_1 / \Delta t_2\right)} = \frac{\left(T_1 - T_1\right) - \left(T_2 - t_2\right)}{\ln\left(\dfrac{T_1 - t_1}{T_2 - t_2}\right)}$$

$$= \frac{\left(90 - 30\right) - \left(80 - 70\right)}{\ln\left(\dfrac{90 - 30}{80 - 70}\right)} = 27.9\,^{o}C$$