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

Prof. Tridib Kumar Goswami
Department of Agriculture Engineering
Indian Institute of Technology, Kharagpur

Module No 10

Lecture 50
Evaporator and Expansion Device

Good morning, my dear boys and girls and my dear friends. We are in the last phase of completion of the individual components. We have already done compressors, we have done condensers, and some extra. We have also incorporated, because, as I told you earlier also, the moment a new thing comes, which, may or may not be, a part of it, but, I would like to highlight on that, because, it helps, because, otherwise, you have to go back to somewhere, and then find out what is that. So, that is how, I have given you. In some cases, I had to really go forward a little fast, because, time, because of the time constraint, right. So, now, we are in the last class of the individual components. So, let us now look into the other two remaining parts that is expansion device, and the evaporator.

Since, we have just completed condenser, and I told you also earlier that, condenser and evaporator, both are basically heat exchangers. So, whatever is applicable, more or less in condenser, evaporators are also similar, except the application, as heat exchanger, they are similar, but the application could be a little different, that is why condenser is a condenser, and evaporator is an evaporator. So, let us look into evaporator and expansion device. So, we go from there.

So, evaporators, what is that? Evaporators are basically a heat exchanger, as I said earlier, many times, the refrigerant boils or evaporates in the evaporator and absorbs heat from the substance being cooled, which is the main purpose of the refrigeration system. Yes, exactly the same, why, what is the function of the refrigerator system? Evaporator of a system or refrigeration system functions as extracting heat, right and who is doing that? Evaporator is doing that right. So, the heat exchanger is called evaporator, because, the evaporation process occurs in the evaporator, whose evaporation obviously, you know, but still, this is the evaporation of the refrigerant, right, giving away the latent heat. It is the refrigerant getting evaporated. It can be classified depending upon the heat transfer process or refrigerant flow or condition of the heat transfer surface, evaporates, from the heat transfer surface, right. So, evaporators can be classified as natural and forced convection type, where, in the natural convection, the fluid being cooled, and it flows due to natural convection currents arising out of density differences caused by the temperature difference.

This is true. You know, how, if you have air conditioner, and you have seen that, air conditioner is mounted on the top, if it is split type, then that is the evaporator, and in that room, if there is no fan, that is forced circulation. So, how room is getting cooled, because hot air is flowing from top to bottom, rather, the river, sorry, the cold air is flowing from top to bottom, and the bottom hot air is going up again. So, this way, there is a natural circulation, and that is what, in most of the cases, not, mean, most, in all the cases where there is no fan. The refrigerant boils inside tubes and is located at the top right. Now, the temperature of the fluid which is cooled by the refrigerant decreases and its density increases.

The cool fluid moves downward, due to the, due to its higher density, and the warm fluid rises up to replace it. Refrigerant flow inside or outside tubes, depending on that, another division of evaporators. The heat transfer phenomena, during boiling inside and outside tubes is different. Again for detail of the flow, you can again look into from NPTEL, I have a course in that, where, fluid flow, we have covered, as well as the heat transfer. So, accordingly, in classification of evaporators, these are classified as evaporators with refrigerant flow inside the tubes, and those with refrigerant flow outside the tubes.

Evaporators of natural convection type, the evaporators is confined and boils inside the tubes, while the fluid being chilled, flows over the tubes. An example of forced convection type of evaporator, where the refrigerant is confined inside the tube is, the direct expansion, called type of evaporators. Where, obviously air is directly cooled in contact with the tubes, cooled by refrigerant, boiling inside. In many forced convection types of evaporators, the refrigerant is kept in a shell and tube, and rather, shell and tube type heat exchanger, where, refrigerant is in the shell side and the fluid being chilled is carried out in tubes, which are immersed in the refrigerant, as kept in shell. And the fluid being chilled is carried in tubes, which are immersed in the refrigerant shell rather, refrigerant.

So shell and tube brine, or shell and tube brine chillers, and water chillers, are mainly of the evaporators, of this type. If the liquid refrigerant covers, the entire heat transfer surface area, then, the heat exchanger is said to be flooded type of evaporator, right. You will see, when we will go to ice cream manufacturing, there, the ice cream freezer, it has a flooded type of evaporator, which uses a float type of expansion valve. When a portion of the heat exchanger is used, for super heating the refrigerant vapour, after its evaporation, it is called dry type of evaporator, which uses, of course, thermostatic expansion valve. Now, natural convection coils are mainly used in cold storages, where, or fin types of long lengths are mounted near the ceiling or along the high side walls of the cold store.

This will also come across, show you the figures also, real, during our cold store classes. From the expansion valve, the refrigerant is fed to these tubes, inside of which, the refrigerant evaporates and cools the air, whose density increases. Cooled air of high density flows downwards, through the product, kept for cooling, by the time air reaches the floor it becomes warm, which rises up through the free area, like a passage, provided in the cold store. However, the same free area for, or the passage, is used for loading and unloading the product, stored in the cold room. And this is, there is again, this is also called, dry type of evaporator, which uses thermostatic valve.

Now, these coils are very useful, when low air velocities, and minimum de-medication of the product is required. Household refrigerators display cabinets, walk-in coolers reach in refrigerators, and large cold storage, are some of the use of this type of natural convection coils. Sufficient gaps should be provided between the evaporator and the ceiling to permit air circulation over top of the, over top of the coil. Some baffles are also provided to separate the warm air and the cold air, and single ceiling mounted evaporators are used for rooms of width less than 2.5 meter. Now, in the flooded evaporator type, for large ammonia systems, these types of evaporators are used. The refrigerant enters a surge drum through a float type expansion valve. The flash vapour formed during expansion is drawn directly by the compressor. The vapour does not take part in cooling the product. Hence, its removal makes the evaporator more compact and pressure drop due to this is also avoided. From the bottom of the surge drum, liquid refrigerant enters the evaporator, as heat is absorbed by the refrigerant, it boils inside the tubes. The mixture of liquid and vapour bubbles rises up along the evaporator tubes. As the vapour enters the surge drum, it is separated, and the remaining evaporated liquid is re-circulated in the tubes along with the constant supply of liquid refrigerant from the expansion valve.

If m dot is the mass flow rate through the expansion valve to the compressor, the mass flow rate in the evaporator tube is also a function of m dot, where 'f' is called re-circulation factor. Now, let x expansion is the quality of mixture, after the expansion valve, and x b is the quality of mixture after boiling in the evaporator. The mass flow rate from the expansion valve at steady state is same as the mass flow rate to the compressor. Hence, from the conservation of mass, we can write, x evaporated dot times m dot plus x b f m dot f m correction factor is equal to m dot right. If x expansion and x b equals to 0.2, the circulation factor is 4. This means, the mass flow rate through the evaporator is 4 times that through the compressor.

Therefore f is 1 minus x expansion over x b. The liquid refrigerant is always in contact with whole of the evaporator surface, which, makes the evaporator more effective. A pump may increase the heat transfer coefficient, since the lubricating oil may tend to accumulate in the flooded evaporator and oil separator is normally be used immediately after the compressor. Its application is in most of the cold rooms with a ceiling fan over the tubes to circulate the air. To increase the heat transfer coefficient, the tubes may also be fitted with fins. Another type is the shell and tube sealers obviously, there will be some shell and tube in the sense, I have shown you earlier in the in the condenser, right. There was, whether it is series or parallel, or rather it is parallel, or parallel, or counter current flow, depending on that, I had shown you, right.

Since, our time is limited, so, I am skipping it. For small and medium tonnage of refrigeration capacity, dry expansion type of evaporators is used, ranging from 2 to 350 tonnage of refrigeration. The flooded type is available in larger capacities, ranging from 10 to several thousands of tonnage of refrigeration. So, there, we use shell and coil sealer, double pipe sealer, direct expansion coil and plate surface evaporators. Now, after evaporator, of course, it should have been before evaporator, as our, as our, this circuit is concerned, expansion valve is before evaporator. However, as I said that both evaporator and the condenser are the heat exchangers.

So, I covered from condenser expansion evaporator. Now, we come to the expansion valve. This is very much useful, and its usefulness is like this, to reduce the pressure from the condenser to the evaporator pressure, and to control the mass flow rate, according to some predetermined criteria. Its importance is like this, mass flow rate in the system should be proportional to the cooling load on the plant under ideal conditions. If the product to be cooled is required to be maintained at a constant evaporator temperature, or if the liquid refrigerant should not enter the compressor, the mass flow rate has to be controlled in such a way, in such a manner, that only the superheated vapour leaves the evaporator. Now, if you remember our, this circuit, that 1 2 3 4, this was 1 2 3 4, right. This 4 to 1 is the evaporator, this 2 to 3 is the condenser, and 1 to 2 is the compressor, and this is the expansion device, right.

This is the hot liquid coming, right, ok. Let me go to some other place, otherwise, this part is being used. So, let me go to this part, that, we have this expansion device, here. So, there, it is liquid, here at high temperature and high pressure, which is reduced to low temperature and low pressure, right and after this, it is going to the evaporator. Now, this evaporator when it is going to the compressor after the evaporator, when it is going to the compressor, that time, it should be, like this, before it is entering to the compressor, it must be superheated, otherwise, you have the compressor with wet compression.

So, to avoid that, it has to be superheated, that is what is the function of the expansion device, so that, the mass flow rate is controlled in such a way that, after extracting the evaporator heat, it is getting superheated before it enters into the compressor, right. So, an ideal refrigerant, and ideal refrigerant system should have the facility control the mass flow rate in such a way, the energy requirement is minimum, and both the required circulator, circulation of the temperature and cooling load are satisfied. Some additional control, to control the capacity of the compressor and the space temperature may be required, as well as, or rather, as well, so as to minimize the energy consumption. Two basic types of controls on the compressor are there, for example, on off control and the proportional control, right.

Obviously, on off control means, you are switching on or off. This is on off control. Proportional control means, acquiring two requirements. It is proportional, right. Of course, the expansion valve used in refrigeration system has to be compatible with the overall control systems. Now, the types of expansion valves are, there are five types, and these are capillary tube, then, automatic expansion valve, this maintains a constant temperature in the evaporator, load type of expansion valve, where it can be high pressure side float valve which maintains a constant level of refrigerant in the evaporator, or low pressure side float valve that maintains a constant level of refrigerant in the evaporator, right. Automatic expansion valve, that also is there, so these are the types of expansion valve.

Now, in capillary type, it is a constant diameter narrow tube, or bed, tube serves the purpose of reducing the pressure in a refrigerant system. I said in one of the classes, that, from high pressure, when it is flowing through a narrow space, then, it throttles, the temperature drops, right, and that is exactly here, which is happening. So, from the high pressure condenser, when it is passing through narrow, very narrow capillary tubes, then the pressure drops so much, and there is a reduction in temperature significantly. The refrigerant has to overcome the frictional resistance offered by the capillary tube or tube walls leading to some pressure drop. The liquid refrigerant flashes, that is, vaporizes into mixture of liquid and vapor, at the pressure, as the pressure reduces, rather.

$$\dot{m} = \rho v A$$

The density of vapor is less than that of the liquid. In the evaporator, the average density of the refrigerant decreases, as it flows in the capillary tube, the mass flow rate, and the capillary tube diameter. Hence, the area being constant, the velocity of the refrigerant increases, this is because, m dot is equal to rho into v into A, this increases in velocity, this increase in velocity, or acceleration of the refrigerant also requires a pressure drop. Though in capillary, surface in capillary, rather, surface tension is an important property, but, in this case, it is not required. Generally, the tube diameter range from 0.4 millimeter to 2 millimeter and the length ranges from 0.6 to 6 meter. Once, the capillary tube of required dimension is selected, for a refrigeration system, the mass flow rate of the refrigerant, through it will vary in such way that the local pressure drop, or rather, total pressure drop through it, matches the pressure differences between the condenser and the evaporator. For a given bore and length of a capillary tube, I hope, bore you understand, now, we have already said earlier also, that this is the bore, right this is the bore, or diameter, that is the bore, which we have also said in the compressor, if you remember correctly, right, sorry, if you remember correctly. Now, the mass flow rate through it, a bore, and length of the capillary, ok, for a given bore and length of a capillary tube, the mass flow rate through it is totally dependent upon the pressure difference across the capillary tube. This means the mass flow rate cannot adjust itself in response to variation in load, right. So, this is how we have covered the expansion valve and evaporator and by this we have completed the individual parts of the refrigeration system.

We have completed compressors, we have completed condensers, we have completed together evaporator, and the expansion device right. So, our production of cool is over, method of production, why we want to produce these are all over, we are left with the application of the production of the cold, what do we do by producing that, also you should know that also, should be a part of it, right. We have already said that why we need, we said how we produce and what are the requirements, all these we have all said, now, we are left with the application of this produced cold, right and this will follow in subsequent classes. Thank you very much.