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

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Lecture 31
Practical Difficulties with Carnot Cycle

Good afternoon, my friends and students. If you remember, in the previous class, we had shown the COP of Carnot, and today we shall discuss with the practical difficulties with Carnot cycle, right. It is true that, Carnot refrigeration cycle is one of the best, right. Then, why it is not used? If Carnot is the best, obviously, you will always try to use the best one. So, then, why it is not commercially used, that comes the question? So, you are the best boy, and if you are not given opportunity to work, then what is the fun of you being the best boy? This is a definitely automatic question, which comes to everybody's mind, that Carnot cycle is the best cycle but cannot be used.

It is taken as the highest, for comparison, or best, for comparison, then, in spite of that, why we are not using Carnot? COP is very high, rather the highest COP you can obtain, then, even, we are not using it, why? This, why reply comes from the difficulties of using Carnot cycles. Yes, there is no ambiguity that, the Carnot refrigeration cycle is the best cycle, which, we can think of, and which, we can target, that, we should be able to reach this, our COP will be maximum, and power consumption also accordingly will be low. Then, for commercial application, this could be the best, but unfortunately, it could not be, because of the difficulties, or practical difficulties, associated with the Carnot cycle, right.

If you remember the cycle, which we had shown you earlier, if you remember that, in a TS diagram, if this was the T, and if this was the, S and if this was the vapour dome, right then, our point started from here, went up, went left, came down, and this was our point 1, point 2, point 3, and point 4, right. So, in this cycle, you see that, this was the compressor work, right. So, compressor is getting liquid, as the input, right. This point is the inlet to the compressor. I, sorry, compressor, and this point is the outlet from the compressor, right, and then, it goes to the condenser, gets liquefied, then it comes back, after expansion through throttling, lowering down the temperature, as you require, accordingly, you are throttling and then, it is giving your whatever work you have done corresponding to that you are getting the refrigeration effect. So, if these be true, then what is the problem? Problem lies, here is that, it is difficult to build and operate a Carnot refrigeration system due to the reasons, which are very difficult practically. The reason number 1, we can say that, during the process 1 to 2, this process, which I will be referring to, during the process 1 to 2, a mixture consisting of liquid and vapour have to be compressed isentropically, this is S.

So, this is entropy, constant. So, isentropically, it has to be compressed in the compressor. Such a compressor is known as wet compressor, this compression 1 to 2 is known as wet compression, and this is why wet compression, because there is a presence of liquid in it, because, it is a mixture of vapour and liquid. So, in practice, wet compression is very difficult, especially with reciprocating type of compressors, when we will come to compressor, typically, that time you will see that, reciprocating type of compressors are commonly used commercially in most of the cases, right. So, reciprocating type of compressors is very difficult, if it is handling liquid refrigerant in the compressor, right. So, I say again, for your benefit that, in the T-S diagram, which we have seen, the dome or dome was like this, right and we started from here, there, there, there.

So, this was point 1, this was point 2, and this is under compression condition, right. So, when, the this is the inlet to the compressor, and this is the outlet from the compressor, right, this is showing that the compressor has to handle, this is a mixture of vapour liquid, so, some liquid, compressor is bound to work, or is supposed to work with vapour, no problem, but if there is liquid, then that becomes very difficult for the compressor, which is working with reciprocating type, right. Obviously, reciprocating type, I had given you one example, that you use during the holy, that one, plunger kind of thing right.

So, you are taking some colour water and forcing it. So, there, you are compressing and when, you are withdrawing liquid then you are sucking, right. That is what it is happening. Suction is here, and discharge is here, right. So, if in the suction period, we have vapour and liquid mixture, then compressor is not able to handle. Such kind of compressors are very difficult to develop. So, this is the first negative point of the Carnot cycle, Carnot system, right. Now, next one is that, this problem is practically severe, in case of high speed reciprocating compressor.

The one, which, I gave you, just example, that, you are playing, during the holi with coloured, or colourful water, or some liquid, right, but that time you are making both the compression, as well as suction slowly. A similar one, suppose, like in fast forward mode, you see, any picture, then, your, how it will look like, your, this coming, and going, it will be very very very fast right. Even, much faster, is the actual reciprocating type. So, where, the speed of the compressor is very high, right, where, the speed of the compressor is very, very high. So, this get damaged due to the presence of liquid droplets in the vapour.

Even though, some types of compressors, can tolerate the presence of liquid in vapour, even though, this is very very difficult. Since, reciprocating compressors are most widely used in refrigeration, some part, which, some part of the compressors, which, can take care of this problem, that does not come into solution. Because, reciprocating type of compressors are very widely, or commonly used, which, having very high speed, is not possible to handle this liquid mixture in the inlet of the compressor. Traditionally, dry compression, that is compression of vapour only, is preferred, over wet compression, right. So, I am regularly showing you the Carnot cycle in T-S diagram right.

So, you should not forget, because, it is very difficult to ask you question, the pattern, which are given to us for making their such type of building, or rather not building such type of photo or figure is difficult to give. So, that is why, so that, it is in your mind. I am repeatedly showing you that, in the T-S diagram this was the dome, and we started with 0.1, then 0.2, then 0.3 and then 0.4 right. So, we are giving inlet to the compressor, vapour liquid mixture. So, that, this, as we said, the reciprocating compressors cannot handle, right, though there are few compressors, or some compressors, which can handle liquid, but they are not commercially, so widely used. So, obviously, the one, which you are using commercially, you will look for its best solution, right. So, it is preferred that, over wet compression, dry compression is always preferred, dry compression, means, where, only vapour is there.

Then, for which, you, what you need to do? You need to again, let us draw that T-S, and the dome right, earlier, it was like this. Now, you need to transfer this 0.1 from here to there, and then, you can do the compression, like this, right. So, this could be one such solution, will come, will come in detail afterwards. Let us first finish, the other difficulties, associated with the Carnot refrigeration system.

The second difficulty is that, the second difficulty is that, with Carnot cycle, it is using a turbine, and extracting work from the system, during the isentropic expansion, right, of liquid refrigerant, and this is not economically feasible, right. Similarly, in case of small captive system, this could be very very ineffective, or rather, ineffective, or economically not feasible. So, what we are saying? We are saying that, we have, sorry, we are saying that, we have this T-S, this is T, this is S. That part 1, we have already taken care of, said, it will, if it is transferred to there, but this part, that is, the expansion, right, this was the expansion part and using turbine and liquid, with here, also it is liquid, liquid with turbine, and that is also, a compressor, that is very, and using isentropic process, it is a very much expensive. It is very much expensive, and it is not economical. So, second point also, we have looked into right, why Carnot being so highly impressive cycle, and which one is taken as the best cycle, in spite of that, it is not used commercially. So, we have said, two difficulties, let us look into others.

Third one is, before that, we have said, isentropically, it is expanded, with the turbine. So, what it says, this is due to the fact that, why it is not economical, due to the fact that the specific work output, specific work, the moment, it is we said, per kg right. So, specific work output, that is per kilogram of the refrigerant, from that turbine, can be given as W 3 to 4 is integral of V dp, within the domain of Pe to Pc right. So, within the domain of Pe to Pc. So, there was a negative for which it is supposed to be from Pc to Pe actually. It is supposed to be from Pc to Pe, right because, that is what you are doing, you are compressing from, repeat, Ts right.

This is due to the fact that the specific work output (per kilogram of refrigerant) from the turbine is given by:

$$w_{3-4} = \int_{Pe}^{Pc} v.dP \quad \ldots(6)$$

So, you are, this is the point 3, and this is the point 4, right. So, from point 3, you are doing that turbine, and it is doing from point 3 to point 4, expansion, right. So, it is Pc to Pe, that is to be, but there it is minus V dp, right, because dp is decreasing, Pc is high, and Pe is low. So, it is minus V dp, and to take care of this minus, we have made it plus, and change the limit from Pe to Pc, V dp, right. So, what is that? dp is becoming, or pressure is becoming very very low, at the output of the turbine, from high pressure to a very low pressure, for which, the liquid is expanded, and the temperature is reduced, right.

So, this is why it is very difficult for the turbine, right, and as you know that this volume for the gas is high, but volume for the liquid is very low. So, that V dp, which you are integrating. So, there the value becomes very low, and it is very difficult to use economically, the turbine as the expansion device right. Then since the specific volume of liquid is much smaller, compared to the specific volume of gases, or vapours, right. So, the work output from the turbine, in case of the liquid, will be very small, right, this I just told.

Then, the net output will be further reduced, because, that V dp is, for the liquid, is very very very low. As a result, using a turbine for extracting the work from the high pressure liquid is not economically justified, and this is true for most of the cases, right. However, currently, some efforts are being done, so that this difficulty can be improved by the system efficiency right. So, we have done 3 such difficulties. So, one way of achieving this is dry compression, in control refrigeration, rather, in Carnot refrigeration, is to have 2 compressors, one isentropic, and one isothermal.

So, this is also shown, subsequently we will show you. So, this is the T-S diagram, we said that one isentropic and one isothermal. So, we have shifted, if you remember, we have shifted the point here. So, this point, this is isentropic compression. So, from there, if it is done isothermally, and then isothermal, this was there, right and subsequently, it will come here, and there may be, this is one such improvement, which we are talking about.

But, in reality, when in future, you will see that, there are also some difficulties, for this kind of system right. So, we say that, though, we are in 2 stages, right, or 2 compressors, one isentropic, and one isothermal, can handle the dry compression, instead of wet, fine, that, we are taking it, right. So, this will come back again. Another, thing which, I would like to say, perhaps, yeah this also should have been said here. What is that? That, we are saying that, we are saying that, during this compression, that liquid is coming to the compressor valves, right.

There is a piston, and this is one end, and that is another end, ok. There is a valve here, there is also a valve here, in the inlet and in the outlet. So, this goes on reciprocating, right. So, when, it is done, that time, what is happening, the liquid droplets, they are at a very high speed, and they go and hit. This is, these are, the compressors, these are the compressor inlet and outlet path.

The material, by which it is made of, so, there, this liquid droplets, hits, like a bullet. So, a continuous impact of such bullets will make the wear and tear of the compressor very high. So, every now and then, you may need to change the compressor, and make the repair for the next operation. This is again, another drawback, because of the wet compression, right. That it is hitting the valve of the compressor very high, at a very high speed, and the liquid hits it like a bullet. So, that is damaging the compressor sheet, and is not justifiable, otherwise, your, wear and tear will be very very high, right.

So, we have said that, what are the difficulties of Carnot system using commercially, right. Our time is over today. Thank you for listening very good.,