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 09

Lecture 43

Reciprocating Compressor

So, good afternoon my dear students and my friends. We are continuing with compressor and in the previous class we have dealt with how many types of compressors are there, their division, how they can be said hermetically sealed, then partially hermetically sealed or which is called semi hermetically sealed, then we also have touched upon reciprocating and screw and other types of compressors. So, today we will be doing Reciprocating Compressor, because in most of the cases, we come across with reciprocating type. I said in the other class also, it is not that other compressors will not be dealing with, but, as we said, we are running with the 9th week. So, our time is also limited, because, other classes are also there. So, it may not be possible to do everything, but I will try my best to give as much information as I can, ok.

So, for reciprocating type of compressors, this is the workhorse of the refrigeration and air conditioning industry. As I told you that this is also considered to be the heart of the refrigeration and air conditioning system, particularly, compressor. So, out of which reciprocating takes the major load, or major share. Now, it is most widely used compressor with cooling capacity ranging from a few watts to several hundreds of kilowatts, right.

So, modern, and I had said also earlier that, how much tonnage of refrigeration is related with the kilowatt, or watt, right. So, modern day, reciprocating compressors are, high speed, generally, around 3000 to 3600 rpm. So, you can imagine, 3000 to 3600 rpm, it is very high, right, and I will show you the diagram. So, no point of spending time, single acting, single or multiple cylinder, up to 16 cylinders are available, right. So, we will show you a figure, where it will show the schematic of a reciprocating compressor.

And reciprocating compressors consists of a piston, moving back and forth in a cylinder with suction and discharge valves attached to it to achieve suction and compression of the refrigerant vapour, right. So, its construction and working are somewhat similar to two-stroke engine as suction and compressor of the refrigeration vapour are completed in one revolution of the crank. The suction side of the compressor is connected to the exit of the evaporator, while the discharge side of the compressor is connected to the condenser inlet. This also we had said earlier, the suction inlet and the discharge outlet valves open and close due to the pressure differences between the cylinder and the inlet or outlet manifolds, respectively. The pressure in the inlet manifold is equal to or slightly less than the evaporator pressure.

Similarly, the pressure in the outlet manifold is equal to or slightly greater than the condenser pressure. Otherwise, from the inlet, if this is the valve, if this is the inlet, and if this is the valve, so, the valve seat has to open, because of the pressure of the inlet, then only it will go to the compressor, right. Similarly, the outlet one, there is a valve seat, the pressure of the cylinder has to be higher than the pressure of the condenser, otherwise, the seat will not open. The moment this pressure equalizes this come back, right.

So, this is the mechanism, how the inlet and outlet operates. The purpose of the manifolds, is to provide stable inlet and outlet pressures, for the smooth operation of the valves and also provide a space for mounting the valves. This is the typical schematic of or a reciprocating compressor, right. As you see, as you see from here, that, you have a suction valve, right, this is the cylinder, this is the cylinder, you have suction valve, you have a discharge valve, right, and clearance volume of the piston. So, with this crank and connecting rod mechanism this is called crank and connecting rod mechanism, right, by which, by which, the this rotates along with.

So, when it comes to this point, this goes there, when it goes to that point, this comes to this place, right. So, this way, it is, as the crank and connecting rod mechanism, what, it is also like that. So, you have the piston. This is the piston. I gave you example of that during your holi, you use similar kind of thing, right. So, like that, and this is that, where your suction and discharge, they are also controlled, right. So, there is a balancing weight, shaft crank pin connecting, piston rod etc. piston pin etc., this is the cylinder.

So, with this schematic diagram of the reciprocating type of compressor, now let us go into it. The valves used are reed or plate type, which are either floating or clamped, usually backstops are provided to limit the valve displacement and springs may be provided for smooth return after opening or closing. The piston speed is decided by, valve type to high speed, will give excessive vapour velocities, that will decrease the volumetric efficiency and the throttling loss will decrease the compression efficiency. Performance of a reciprocating compressor, that involves for a given evaporator, and condenser pressure, the important performance parameters of a reciprocating compressor or refrigerant, compressor are number 1. The mass flow rate number 1, the mass flow rate that is m or it can be said m dot, it is rather, I told also earlier, if it is flow rate, then it is generally, the nomenclature used is m dot of compressor for a given displacement rate.

Power consumption of the compressor, that is, W c, temperature of the refrigerant at the compressor exit, that is, T discharge, and performance under part load conditions. These are the parameters, which dictate the performance of the reciprocating type of compressor. Now, the mass flow rate decides the refrigeration capacity of the system and for a given compressor, inlet condition, it depends on the volumetric efficiency of the compressor. The volumetric efficiency, that is yeeta V, is defined as the ratio of the volumetric flow rate of the refrigerant to the maximum possible volumetric flow rate, which is equal to the compressor displacement rate, that is, yeeta volumetric, we can write to be equal to volumetric flow rate over compressor displacement rate, or we can say it to be, m dot into V e over V dot S W, right, where m dot are the mass flow rate, here we have written, m dot, but here, we could not, m dot are the mass flow rate of the refrigerant in kg per second, and V S W that is the compressor displacement rate in meter cube per second, this is there, and V e, is the specific volume, that is, meter cube per kg of the refrigerant at the compressor inlet, right. As you know that, specific volume is also a function of the pressure, or temperature. Now, if we go back a little, if we go back a little here, you see, here you see that, I was saying about specific volume, yes, that was the thing, that when the gas is or this piston position is here right. It has a evaporator pressure and that is P evaporator, right, and there, when it is going to the condenser, it is equivalent to the P condenser. Definitely, P condenser is much much higher than P evaporator, right.

$$\eta_V = \frac{Volumetric\ \ flow\ rate}{Compressor\ \ Displacement\ \ rate} = \frac{\dot{m}.v_e}{\dot{V}_{SW}} \quad \ldots (1)$$

So, likewise, when this pressure is getting up due to the compression, right, or it is the reverse, this way, as it is drawn. So, when it is compressed, the temperature also is going up. So, that is also saying that, the specific volume will be higher, right or rather, higher, or lower depending on the compressor, depending on the temperature, this will be, ok. For a given evaporator, and condenser temperatures, one can also use the volumetric refrigeration capacity, that is, kilowatt per meter cube to indicate the volumetric efficiency of the compressor. The actual volumetric efficiency, or volumetric capacity of the compressor, depends on the operating conditions, and the design of the compressor, right.

So, we can say, in earlier equation, we have shown it to be equation number 1. So, the power consumption, kilowatt in Kw, rather, or, alternatively, the power input per unit refrigeration capacity, that is kilowatt per kilowatt, that depends on the compressor efficiency, that is, yeeta compressor, efficiency of the mechanical drive, that is, yeeta mechanical, and the motor efficiency, that is, yeeta motor. All these three will dictate the resultant one. For a refrigerant compressor, the power input, W c, that can be obtained from the relation that, W c equal to W ideal over yeeta c into yeeta mechanical into yeeta motor right. So, where obviously, W ideal is the power input in ideal compressor, the temperature at the exit of the compressor, that is discharge compressor, is that, that depends on the type of refrigerant used and the type of compressor cooling, you are using, how you are using the compressor. I go back once more to show that compressor inlet or the diagram.

$$W_C = \frac{W_{ideal}}{\eta_C \eta_{mech} \eta_{motor}} \quad \text{---------} \ (2)$$

This diagram says that, this compressor, this compressor cylinder, when you are compressing it, this way, and you are relieving it, right. So, that time, because of the pressure difference, there will be temperature increase to keep the compressor at given operating temperature, some cooling facility are also provided with this. So, that the compressor is under cooling condition. Unnecessarily, there should not be rise in temperature, right. So, that is what we are saying here ok. Then ideal receding compressor, what it can be, because, if earlier also in cycles, we have shown, the earlier, sorry, the ideal cycle is the Carnot cycle.

So, if we know, what could be an ideal compressor, then, how your compressor actual is behaving, that can be compared. So, an ideal compressor, reciprocating compressor, is one, in which, the clearance volume is 0. Mind it again, we will go back because, this clearance volume, if it is not going back and forth, you remember, here we had two valves, one is suction and another is discharge, and there was that piston, which is reciprocating, this way or this way. Now, what we are saying that, there is no clearance volume for the ideal reciprocating type. So, this, if this would have been a clearance volume, that would have always remained there. So, that would have been, rather, eliminated, or could have been reduced from the volume of the refrigerant gas being under compression, right, but this is theoretical or ideal right.

So, we say that, the parameter, this we have already done, sorry, then, yeah, that clearance volume is 0, that is, at the end of the discharge process, the volume of refrigerant inside the cylinder is 0. No pressure drops during suction and compression. Again, another very very ideal. In reality, it may not be suction compression and discharge are reversible and adiabatic, right. So, Q is 0, and that we can confirm from the figure, which shows the schematic of an ideal compression process on pressure volume and pressure crank angle theta diagram, right. As it is shown in this figure, the cycle of the operation, that consists of process, ok. Let us first see that this is the ideal reciprocating compressor on a PV and P theta diagram.

Obviously, P theta, as you are saying that, this is the theta, right. So, because, depending on how it is rotating, what is the angle with, what is the position of the piston here, or here, that will depend on that theta. So, that is why, there is a graph for, there is a graph for P e P c, that is evaporator pressure, that is compressor pressure, right. So, this is P versus theta right and let us see into this, ok. So, that c and d, if you remember, there, what was the suction and another was the discharge, right.

So, P c is this way, that how it is progressing, this is the evaporator pressure. So, it is under compression, comes to a point 'a', this is the 'd', comes to a point 'a' and 'd' is the, and it, then, goes to the point 'b' right, where it attains the condenser pressure, P c, and then it comes to the point 'c' and then, comes back to again point 'd'. So, this is the cycle, right. So, what we need, we need to know that, in an ideal compressor, how it is varying with PV and P theta diagram, that we have shown, ok. So, if we go back, if we go back that process, 'DA', this is an isobaric suction process, during which, the piston moves from the inner dead centre, IDC to the outer dead centre ODC, right.

And the suction valve remains open, during this process, and refrigerant, at a constant pressure, P e, flows into the cylinder. Then, the process 'AB', that, this is an isentropic compression process. During this process, the piston moves from ODC towards IDC, right. Both, the suction and discharge valves remain closed, during this process, and the pressure of the refrigerant increases from a pressure P e to a pressure P c, right. So, this is what we have already discussed. Then process B to C, this is an isobaric discharge process. During this process, the suction valve remains closed and the discharge valve opens.

Refrigerant at a constant pressure P c is expelled from the compressor, as the piston moves to IDC. Since, the clearance volume is 0, for an ideal compressor, no gas is left in the compressor, at the end of this, ok. So, it comes back to ODC, and the volumetric flow rate of refrigerant at suction condition is equal to the compressor displacement rate. Hence, the volumetric efficiency of the ideal compressor is 100 percent. The mass flow rate of the refrigerant of an ideal compressor, that can be given by this m dot is equal to V s w over V e.

$$\dot{m} = \frac{\dot{V}_{SW}}{v_e} \quad \ldots (3)$$

For a given refrigeration capacity, the required size of the compressor will be minimum, if the compressor behaves as an ideal compressor. And the swept volume S w, the swept volume of the compressor is given by V s w equal to N into, capital N into pi d square by 4 into L right. Of course, N is the number of cylinders, cap, small n, capital N is the rotation speed of the compressor revolutions per second, D is the bore of the cylinder diameter and L is the stroke length, meter. Our time today is up. We will continue with this reciprocating compressor in the next class also. Thank you very much.

$$\dot{V}_{SW} = nN \frac{\pi D^2}{4} L \quad \dots (4)$$