Principles and Practices of Process Equipment and Plant Design
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Module - 04
Lecture - 57
Plant Hydraulics (End)

Hello, good day to you all. Today is basically the 4th lecture on Plant Hydraulics and what we intend to discuss today is basically the remaining part of it which is compressible flow and the compressors and the blowers. We had started the topic in the last class.

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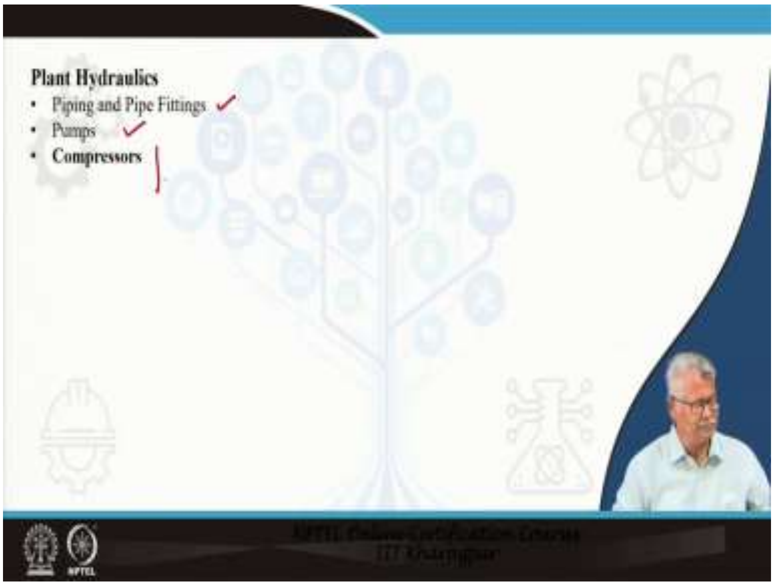

And in the plant hydraulics, so far what we have covered are the pipe and the pipe fittings the pumps and we started on compressors.

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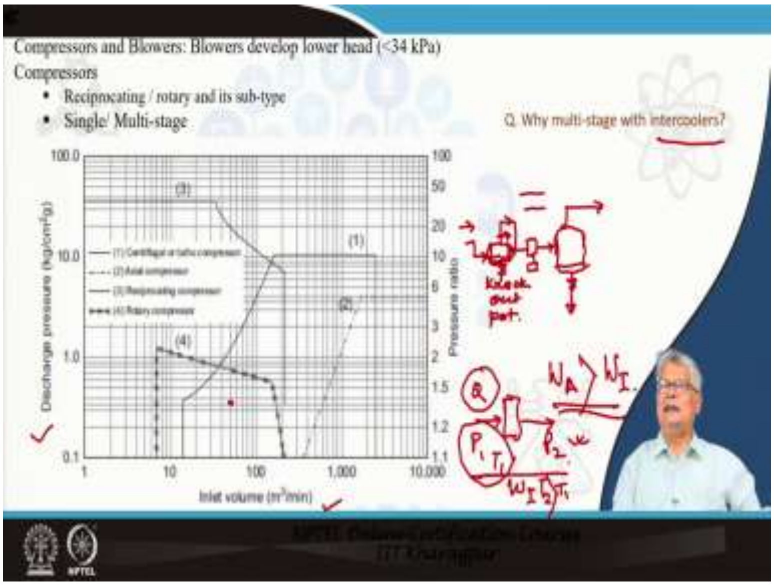

In compressors what we have seen that there is a basic difference between the blowers and compressor, the blowers are for high capacity low delta H or delta P. The delta P in blowers is normally limited to about one-third atmospheres which is about 34 kPa approximately. Well it is just a suggestion I mean it is a convention rather. Now, if you talk about a compressor, the compressors could be the reciprocating type or rotary type and there are several sub types of the rotary compressors.

Both type can be a single stage compressor or a multi-stage compressor. Now, here we have here a diagram which may help us in selecting what type of compressor we may go for. Incidentally, you definitely must be knowing and here well aware of this factor also earlier even that pumps and compressors are basically bought out the items. No one goes for designing it, but what you do is, you need to have a detailed specification drawn out depending on your process application.

In your process application, the inlet volume flow rate which basically is a capacity of a compressor or a blower is one of the major parameters and you have a discharge capacity limit which is there in the Y axis left side. And you also have a pressure ratio limit which is there on the right side. You will notice that this is a log log graph.

Well, there will be some boundary between two distant distinct type of compressors, but in some cases you can have a choice of choosing either of these two as well it depends on where exactly on your graph the point lies. An example of this could be at this particular point. Now, if I look at compressors particularly you will see that most of the compressors that we use today are multi-stage.

The simplest and the most common compressor you must have seen is in a motorcycle repair shop or in a cycle repair shop which compressors air. What does it have? Let us just have a look at components of it, there it is a reciprocating compressor. So, there is a piston which is sliding inside a cylinder with valves, the suction is from the ambient air and the discharge goes to a vessel which is called a receiver.

Few features I would like to mention here in this particular case say if I draw the schematic of this, if I draw the schematic of this, this way which normally is a typical symbol for a reciprocating compressor. From here it will be entering a vessel, it will be entering a vessel and here you have the vessel. Here from the top the discharge goes out and here normally what you have is a drain. This is something very important for you to know that often the moisture which is getting compressed along with the air will be condensing inside.

And you have to periodically drain such compressors which are taking suction from the ambient air. That means the air if it is wet, the condensation will be there in this particular vessel and you have to drain it periodically. Now, in many of the compressors you will also find that there is one more drum here and the suction is not from here exactly. The suction is basically from the top. This is not there, but the entry will be from here.

So, this is used as a knock out pot, this is called a knockout drum or a knockout pot upstream of the compressor circuit to remove any particle or liquid droplet that may be accompanying the inflow through the suction. The knockout pot similarly will also have an arrangement to drain it because you cannot have an accumulation of liquid beyond a particular level. In all type of compressors whether it is a reciprocating or rotary, you do not want liquid to go in. It damages the compressor beyond repair in many cases.

Particularly with centrifugal compressors as well as in reciprocating simple reciprocating compressors liquid is a big no. Now, we come to the question that we have here why multi-stage? I know the purpose of a compressor is to have a fluid at a pressure P1 and finally, deliver it at a pressure P2. The mass flow would remain constant and since the pressure changes from P1 to P2, the Q if it is the volumetric rate would come down at the discharge.

And we also have iterated many times that for compressors is this Q at the suction condition is definitely your capacity as per the convention in industry. Now, what is there is in it? If I have a part of compression which is isothermal, if I have a path of taking the Q volume from P1 and T1 and increase the pressure to P2 keeping the same temperature as T1, I have a work done which is isothermal work.

Now, isothermal work is one option that we can have. What is the other option? The other option is we rapidly compress it and this happens in most of the compressors. So, what happens is you have adiabatic compression and the corresponding work is accompanied by a temperature T2 which is higher than T1. So, there is a rise in temperature also.

And the corresponding work is W adiabatic, you will find that always W adiabatic is greater than W isothermal. This is from the basic thermodynamics you can prove it yourself. Now my point is the increase in temperature creates two types of difficulties. If I have multi-stage compression, the increase in temperature is definitely going to increase the suction volume to the next stage.

So, I will have the requirement for a bigger cylinder lower than the first one of course in the second stage. So, if I can somehow reduce the temperature using an intercooler mostly cool either by air or by water flow, in that case the temperature would come down.

It helps us two ways in two ways. Number one, it reduces this reduction in temperature to the next stage, reduces the volume that has to be received in the next stage, number one. What is the other one? If you have a process which is closer to isothermal, your work done requirement will be less.

So, if you have adiabatic compression followed by cooling, followed by a second stage of adiabatic compression, this is closer to what you have in an isothermal. It is not an isothermal definitely, but ideally what is isothermal? Isothermal means I increase the pressure by a very small differential amount, cool it down to the earlier temperature. I decompress it, increase the temperature and this I repeat infinite number of times in order to reach from a pressure P1 to final pressure P2. Instead of having in finite numbers if I have such intercooling and adiabatic compression over finite inter stage compression ratios that is closer to what you have in isothermal compression.

So, use of intercoolers not only reduces the size of the downstream cylinders and piston, it also reduces the power requirement and the compression in increasing the pressure from a pressure P1 to P2. So, we have an idea that multi stage compressors why these are so common. Lowering of temperature before the second stage has got another advantage which should also be included particularly when you have a very high compression ratio. It helps in reducing the temperature to the second stage, so that you can go for an inferior or a cheaper metallurgy.

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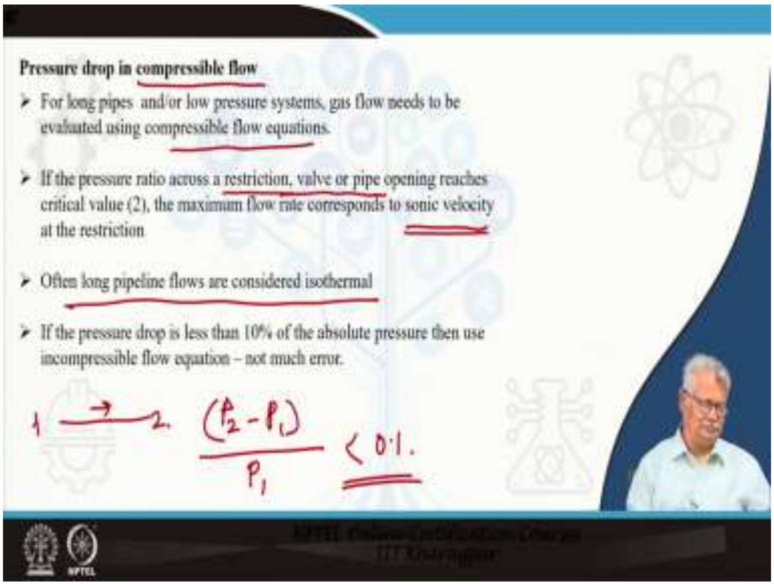

Now, we have talked about the compressors. We will know about it more in more details after these compressors are basically to overcome the pressure drop which is going to happen when I have a, when I have a compressible fluid circuit which could be an air circuit, it could be a vapour or a gas circuit. And there is naturally a pressure drop associated with it and this pressure drop has to be overcome and for that we use compressors.

Now, there are few interesting things and we know the calculations in case of compressible flow are more complicated and you already have done in case of your pumps incompressible flow calculations which involves finding out friction factor and so on. Normally for long pipes and low pressure gases, the flow needs to be evaluated using compressible flow equations. This is something very important.

Why? Because there is a large pressure ratio. If the pressure ratio across a restriction if which could be a valve or even a pipe opening or an orifice reaches a critical value, the maximum flow rate that can happen through that particular restriction is limited to the sonic velocity at the restriction. That means, you will normally try to operate in a zone which is away from this particular maximum limit and how do you achieve it? You do not go for such a high pressure ratio.

That means, in a single stage if the pressure ratio changes and it comes close to the critical value, you get limited in your flow limit. Often the long gas pipeline flows are considered isothermal the reason is very simple the long pipeline will have a large surface area through which there is it is possible there will be heat losses or heat gain. And more or less there will be an averaging out of temperature in many such cases a simple isothermal calculation suffices.

Now, comes the last criteria if the pressure drop; that means, the P 2 minus P 1 is less than 10 percent of the absolute pressure P 1 and P 2 being the absolute pressure. That means, P 2 minus P 1, P 2 is the discharge pressure, P 1 is a suction pressure divided by I mean these are the pressure at the end of a pipeline the pipeline flow is from 1 to 2.

And P 2 minus P 1 is a pressure drop, this with respect to the absolute pressure if it is below 0.1. Normally, if we use an incompressible flow equation as we have done in case of pumps that suffices it does not introduce much of error. So, this is a practical thing which we often cache and if you really feel that there is a large pressure drop you can split it up into different sections of the pipeline where the P 2 by P 2 delta P upon P 1 is less than 0.1 then at the pressures totally later on.

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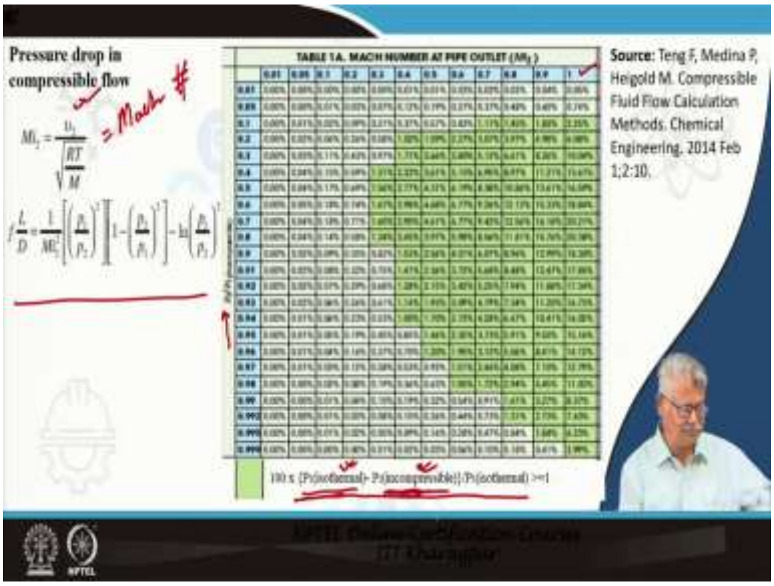

This is regarding compressible flow the compressible flow. In fact, the source that I have referred to here gives you an engineering accuracy quick way of evaluating pressure drop. Here this is equal to Mach number, this is the Mach number, the Mach number. What is the Mach number? It is a velocity of the gas divided by the velocity the sonic velocity in the gas.

The sonic velocity is given by root over R T upon M M being the molecular weight. Now, 2 refers to the downstream of your pipeline. So, if I know the downstream condition; that means, if I decide that at the downstream I am going to have this much of volumetric flow rate in a particular size D my v 2 is known. So, quite naturally I know my M i 2 also; that means, the Mach number at the discharge point.

Now, under this condition the basic relationship is this the relationship between P 1 and P 2 the Mach number and the frictional drop they are related by this particular relationship. Now f times L by D f is a friction factor here now what was done by the authors of this particular paper is very very interesting. If you look at this particular chart what they did is the y axis of the vertical column is the P 2 upon P 1 the left vertical column in this particular table.

The right side what you have? The right side you have here is the Mach number the Mach number naturally the maximum limit is 1; obviously, because you cannot have v 2 exceeding the sonic limit and it starts from 0.1, so 1 percent of the Mach velocity. Now corresponding to this what he did is basically he found out this expression, what it shows? It shows that at low Mach number and lower P 2 by P 1, lower P 2 by P 1 means the pressure difference between P 2 and P 1 is small. There is hardly any difference between whether you consider isothermal flow or incompressible flow.

And its only the green zone where the deviation is beyond 1 percent. So, this is a very quick chart to find out considering isothermal compression or rather isothermal flow of your fluid find out the pressure drop and estimate from there what exactly it is. In fact, I made a mistake by saying while speaking I should not have said this, I should have said that by comparing the isothermal pressure drop and the incompressible flow pressure drop.

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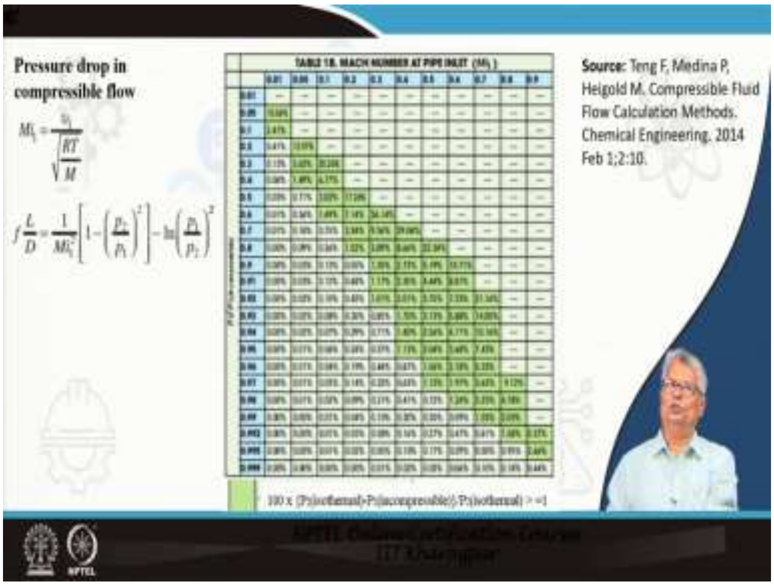

The previous chart which is shown to you was a condition when the discharge condition was known. In this case what you have? In this case you have the suction Mach number is known; that means, where the gas or the vapour enters the particular pipeline thats known now. And the relationship is slightly different because it involves the other Mach number now. But rest of the chart is the same and it uses exactly the same thing and here also the green sections show that the deviation is more than 1 percent.

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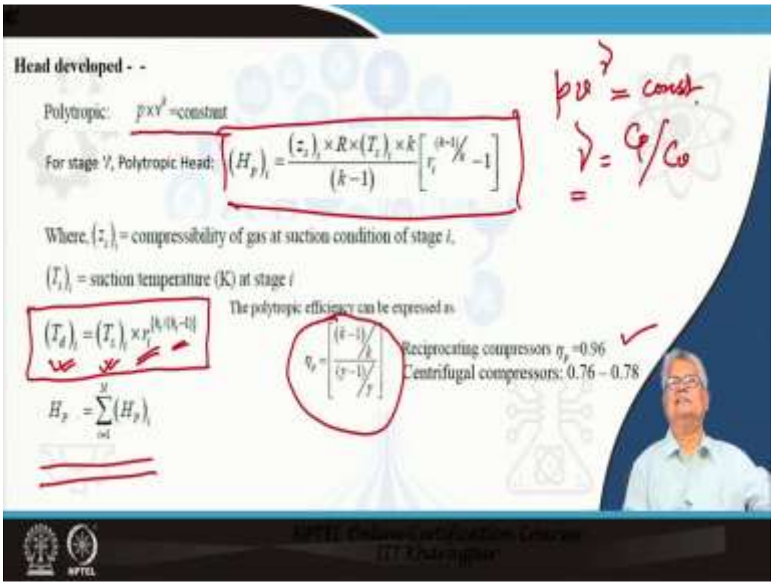

In reality when you have compressors it is neither fully adiabatic and it is definitely not isothermal. If it is adiabatic the relationship between the p and the v would be p v to the power gamma is equal to constant, what is gamma? Gamma is the ratio of the specific heat at constant pressure and the specific heat at constant volume. In reality what you have you have a polytropic thing; that means, your k is not equal to this particular gamma which is the ratio of the C P and C v for your gas.

Now you will notice one thing there is something which is called polytropic efficiency, the definition of polytrophic efficiency is given here. For reciprocating compressors the polytropic efficiency is close to 0.96; that means, if you know the gamma for your gas or vapour which is getting pumped which is getting compressed its possible for you to estimate the value of k. In case of centrifugal compressors it is 0.76 to 0.78, normally, in commercial compressors.

So, in this case also if you know your gamma it is possible for you to estimate your k. Now, comes the question in case of reciprocating compressor why it is close to 1. You will notice polytropic efficiency equal to 1 means adiabatic compression; that means, k is very close to gamma. In reciprocating compressor the piston moves very fast which leads to practically no loss of heat from the gas to the surface of the cylinder. So, in case of reciprocating compressor the polytropic efficiency will always be higher and close to 0.96 in most commercial installations.

You will notice a few other things also you will notice here for a particular stage i if you know the suction temperature of the stage in kelvin. And you know the pressure ratio r i or the compression ratio r i which is nothing but the ratio of the volumes of the ratio of the pressures in this particular stage i. And if you have found out the value of k in this particular case already its possible for you to estimate the corresponding discharge temperature from this.

This is very important because depending on this rise in temperature you may have to handle you may have to cool the gas. So, this calculation is also important the polytropic head is given by this expression. And it is obvious that if I know the polytropic head for the stage i and some all such heads if I have 2, 3 or 4 number of stages in that case its possible for me to find out the total head to be delivered by my multi stage compressor. In case you are using a single stage compressor the matter is much more simple.

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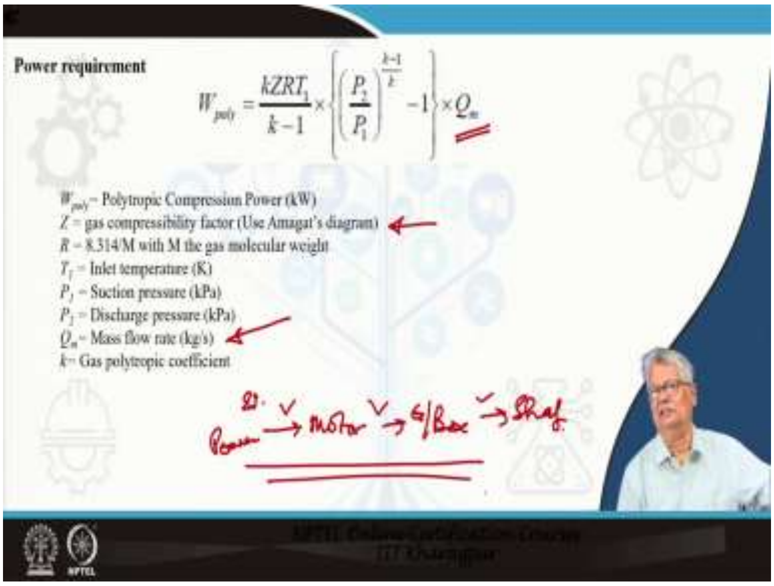

The power requirement is again given by a direct formula and here note one thing your Q m here is a mass flow rate. And we have provided you exactly this formula which may be directly used and the only thing that you have to be careful is knowing this particular gas compressibility factor. And how do you find out the gas compressibility factor gas? Compressibility there is a generalized Amagat's plot which relates the compressible compressibility factor to the temperature and pressure of the gas with respect to the critical condition.

That means, if you know the gas you know its critical temperature and critical pressure you know the temperature and pressure of the gas. So naturally, you can find out the reduced temperature as well as a reduced pressure of the gas. And look at the Amagat's plot and find out and use the Z which is the compressibility factor for your operating conditions.

The rest of the things are very simple the units are also provided here. So, this is a very direct way of estimating the power required in your compressor. But remember one thing this is the power which is to be delivered to the fluid; that means, your shaft work will be more and the shaft will be driven most fully by a gearbox. So, the power input to your gearbox also will be more by considering an efficiency of the gearbox. Now another thing is also there the gearbox power possibly will be coming from a motor.

So, the electrical power which, so the power which goes as electrical power goes to the motor goes to the gearbox goes to the shaft. In each of these step you have an efficiency factor and all these will be covered when we talk about the utilities. Typically, what are the efficiency factors you normally use for these. I do not think I will go any more and I will stop here today. And in the next class what I plan to cover is the other part of it which involves the process vessels.

Thank you.