Fluid Dynamics And Turbo Machines.
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Part C.
Module-2.
Lecture-7.
Pumping Systems.

Good afternoon, I welcome you all for today's discussion on pump systems. In the last lecture we have talked about the pump characteristic curves, how the head varies with volume flow rate for each of the blade angles, that is blade angle beta 2 less than 90 degree, equal to 90 degree and greater than 90 degrees. However we have also said that the other 2 blade angle that is beta 2 equal to 90 degree or beta 2 greater than 90 degree are not favoured and what is usually used is a backward facing vane or beta 2 less than 90 degree.

Today we have to talk about the system, when we say pumping system or pump systems, what we mean is that the pump is going to take water from one point to be another point. For example let us say the water has to be lifted or raised from the ground floor level to the top of your building. Or it can be taken from some lake and brought to the city. In whatever be the case, there is a transport of fluid, transport of water mostly if you think about and chemical industries, there would be transport of chemicals from one point to the another point.

Which means that just pump alone is not possible, we need the piping system. And the piping system automatically then brings to you the concept of the pipe losses, that means the energy has to be supplied. So in today's lecture what we will discuss is what are the pumping system requirements, what is called the system characteristic curve and how to get an operating point for a particular pump. So let us look at it.

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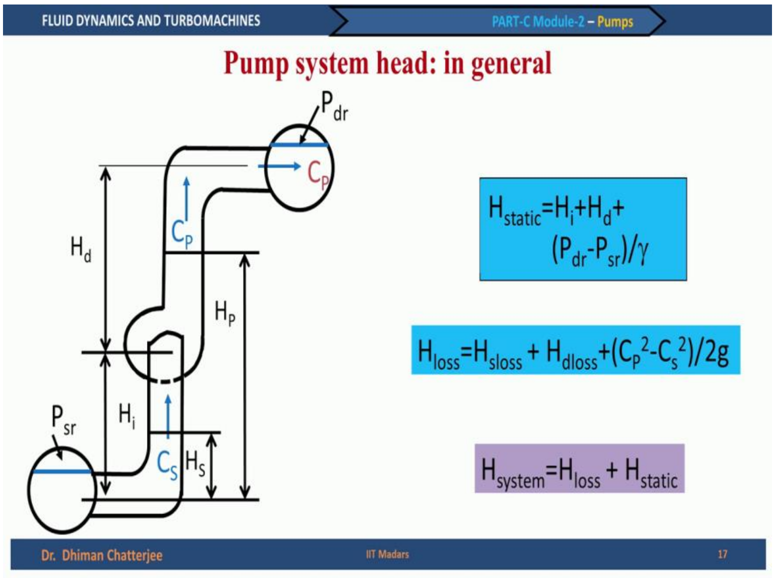

So we have talked about what is known as the pump characteristic curve. Now how does a pump work, it lifts water from the ground is some top reservoir, from a low-pressure to a high-pressure. So now it has to use some pipes, so let us see how the schematic works. So this is a pump, this is the schematic of a pump for me and this is a reservoir or sump which is at a pressure PSR and the water is lifted as shown in the arrow through pipes, this is the pipes connecting the one reservoir with the pump which is called the lower end reservoir and then the high-end, then we have a PDR which is a high-pressure maintained and we talk about the reservoir at the upstream.

So in the simplest case this will be the ground or earth which is opened to atmosphere and this can be the top of the reservoir in the top of your building. So we can say that even if there is no flow there will be **a** a energy because of the potential energy, the water has to be lifted from this tank to this tank, the total height being HI + HD. But not just that, it has to do actually overcome the pressure PDR which can be different from PSR. In the tank that we have in our houses, both the sump that is PSR and the upper top of the building reservoir can be at the atmospheric pressure and we may not get the term PDR - PSR by gamma here, gamma is rho G, we may not get it.

But there could be some chemicals being handled by the pump where it is taken from one tank to another tank and as it is transferred the entire system is pressurised. So in such a situation it is possible that let the PDR in principle can be different from better PSR. You have to apply this relationship carefully for the system that you are having in mind. And we can also say that there will be losses in the pipe, the some of the losses will take place in the suction side, suction pipe given by S, the subscript S refers to the suction pipe and subscript P refers to the pressure side pipe.

So CS refers to the pipes velocity of water in the suction pipe and CP refers to the velocity of water in the pressure side. So we can say that H loss is nothing but HS loss + HD loss. HS loss is the loss taking place in the suction side of the pipe, HD is the loss taking place in the discharge or the delivery side of the pipe and if there is any change in kinetic energy, that also has to be considered because that has to be supplied by the pump.

And hence we can write that H system, that is the system demands from the pump that is, let us say if the system could have talked, then the system would have said that if you have to transfer this much volume of water from the ground to the top reservoir, then I demand that I have to be supplied some energy. So that energy that is demanded by the system is H system or the head required by the system which needs to be overcome by the pump in order for the flow to be established from one reservoir to another reservoir.

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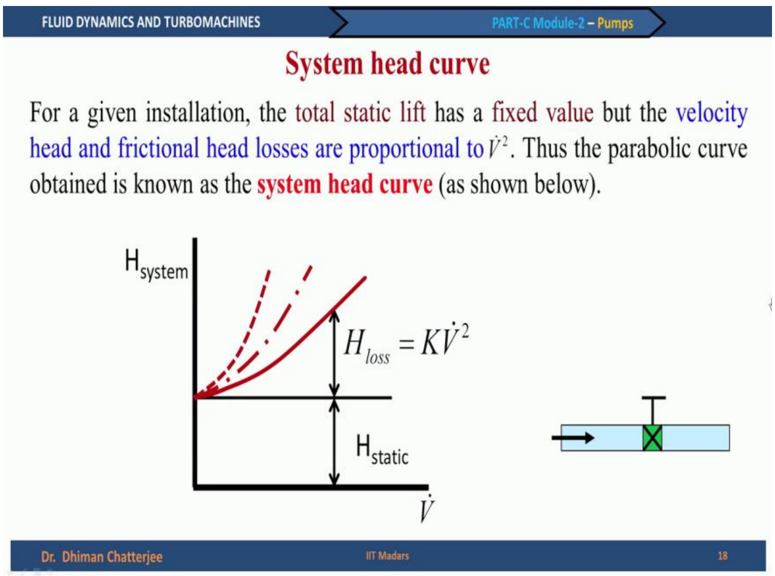

This comprises of one static component H Static which does not depend on the flow. And the other component which is loss which depends on the flow. And we said together that this is related with the total system requirements. So now we will introduce a 2nd notation called the system head curve. For a given installation the total static lift has a fixed value but velocity head and the frictional head, that is CP square of course goes with the volume square and frictional head loss you know from fluid dynamics studies, for example you have studied the Darcy-Weisbach relationship, you know that the frictional head loss also goes as V square.

And hence we can say that the total system curve has 2 components H Static which does not depend on the volume flow rate and hence constant and H loss which is some constant of proportionality K multiplied by V dot square, which is a parabola. You can imagine that there is a flow, you have a valve with the pipe. For the same pipe if you turn open the valve, it will be or close the valve further, this loss coefficient in the valve will change. And as it changes, this K value will also change and as a result the loss of head in the pipe will change.

Please note that when earlier we talked about the head developed by the pump we got the expressions for the blade specific work or the H BL infinity, W BL infinity, we said that we are interested only inside the pump. Now we say for the system head curve, I repeat for the system head curve we are considering only the pipings and not the pump. Alright, so we have to keep in mind 2 terms, the pump head or the pump characteristic curve which talks about the head developed by the pump blades which is related only inside the pump and the system curve is talking about the entire system from the one reservoir to be another reservoir just excluding the pump.

And when the flow has to be established you know that the demand of the head as demanded by the system has to be met by the supplier, in this case the pump. So the operating point of the pump will now come as an intersection of the system head curve and the pump characteristic curve, I will come to that soon. But before we go to that, let us take an example to make us familiarise with how the system at the calculations are done. I am not taking any numerical values, that we will limit for the tutorials but right now I will take just to show you how these calculations are done.

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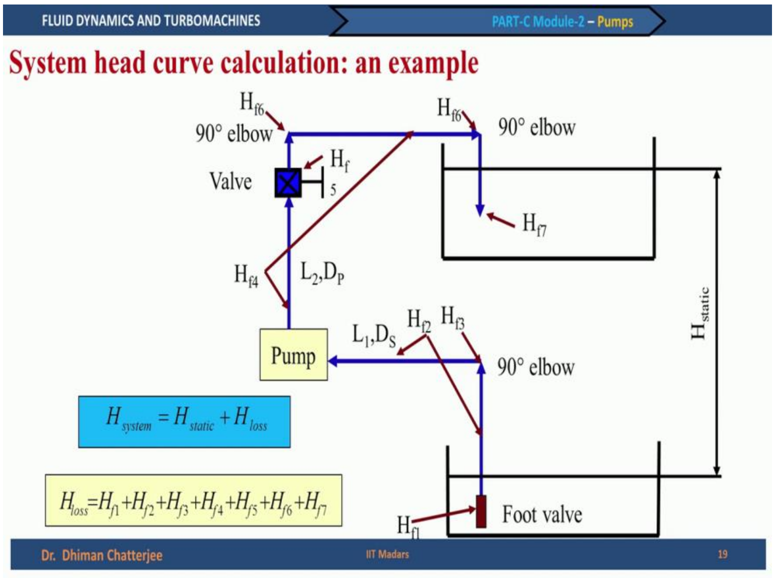

So let us say that I have a pump here which is connected with a sump, this is a sump which is open to atmosphere, could be pressurised also, there is a foot valve, the foot valves or any other nonreturn valves will allow the flow in one direction, that it will go from the sump to the pump and does not allow return flow and we have a valve at the downstream, we can have another valve or many more valves but I have just taken one representative valve which is used to control the flow rate perhaps and then there are bends and goes to the upper reservoir.

In doing the process, what happens is water is raised by a level H Static and then we say that the first loss takes place, example in the foot valve. The 2nd loss takes place in the pipes. H F talks about the head loss due to friction in the pipes, this HF is also talking about the friction but in the foot valve. The 3rd loss takes place in the 90 degree elbow, the 4th loss takes place in the pipes at the delivery side, then we have head loss due to the valves, we can have another head loss due to the 90 degree bend and another had loss again in the 90 degree bend, finally in the H F7.

So what I am trying to impress upon you is that you have to consider each and every element as is present in your system. So your system prefers to from this sump and the foot valve to the upper reservoir in this point, excluding the pump. If you see there is no loss talked about in the pump, the pump loss that we have talked about, it will relate with the pump characteristic curve. So we can say that H system is H Static + H loss. And we can also say that H loss has different opponents in this case I have just taken 7 numbers but you have to work it out for your system.

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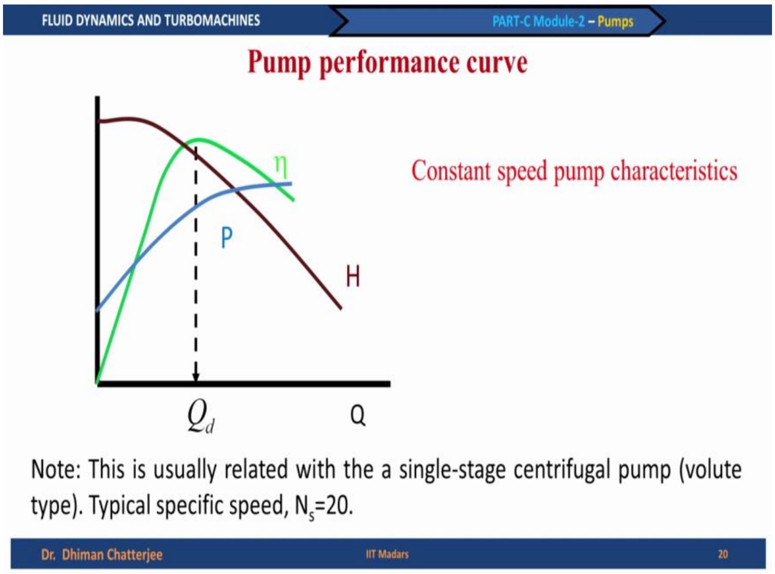

So now we talk about pump performance curve. So this is the pump characteristic curve which gives you, so if you buy a pump from a manufacture, most likely you will get a curve like this. First one the variation of head developed by the pump with volume flow rate, I have of course taken beta 2 less than 90 degree, then you will get an efficiency, so this is the design point, and you get the peak efficiency here, you will also get the power input that is given. So these are the things that collectively we can talk about pump performance curve but do not forget that these are constant speed characteristics.

Because this very curve head versus volume flow rate was derived as we have shown earlier for a constant speed N equal to constant. So this is usually related with the single stage centrifugal pump volute type, typical specific speed is about 20. These numbers for this course is not very important, for this lecture is not very important. But just to get you an idea what constitutes a pump performance curve. This is water supplied by the manufacturer.

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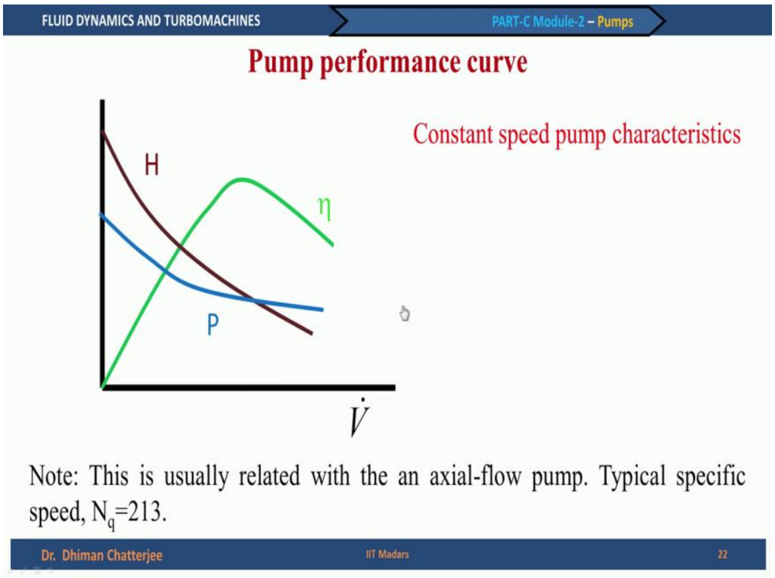

Now next comes is the operating point. If I want to have a steady flow of liquid as I just said, it is a question of demand meeting and supply. So what is the demand, the system is demanding the energy and who is providing it, it is a pump. So the intersection between the 2 give me the operating point. So this is the pump characteristic curve, this is H, you can write H pump but simply H is also good enough but the other one is the system characteristic curve, now let us look at this curve slightly with more attention.

So you see that the intersection of these 2 curves prefers to the V dot operation or operating point volume flow rate. You may also ask one thing that why do I have this, this is the levels that is not zero, that is because in the system that I have considered, there is a static lift and hence this refers to the static lift. So this one refers to the static lift, H Static. And you may also ask why does the pump start here, because remember the first term in the expression that we have got in the ideal case was A + - BV dot. So this A refers to the head developed in the absence of volume flow rate.

So what happens, you can imagine this way that you have filled the pump with water, you close the delivery valve completely and you start the pump for operation. Then what happens, you see there is no flow taking place but the energy is being supplied, the water is churned, so this head is called the shut-off head of a pump. So this is a shut-off head and normally we try to operate near the point with this the best efficiency point as I have shown in the other curve, the efficiency curves.

The attempt should be made to match the pump with the system in such a way that the point of operation is that or near the design or the best efficiency point. So we are talking about bringing one concept from the head, another concept from the head system and when these 2 intersects, we get the operating volume flow rate, operating head you can say and if your design pump system has been given and the efficiency curve is matching, that the peak of the efficiency curve is close to the V operating point, it is a happy situation.

So please note that if you are selecting a pump for your system, you have to keep in mind the pump performance characteristic is given by the manufacturer and your requirement. This is another pump performance curve for an axial flow type, I will not talk about these details but you shows the characteristics and again I repeat the peak is here, talking about the design point.

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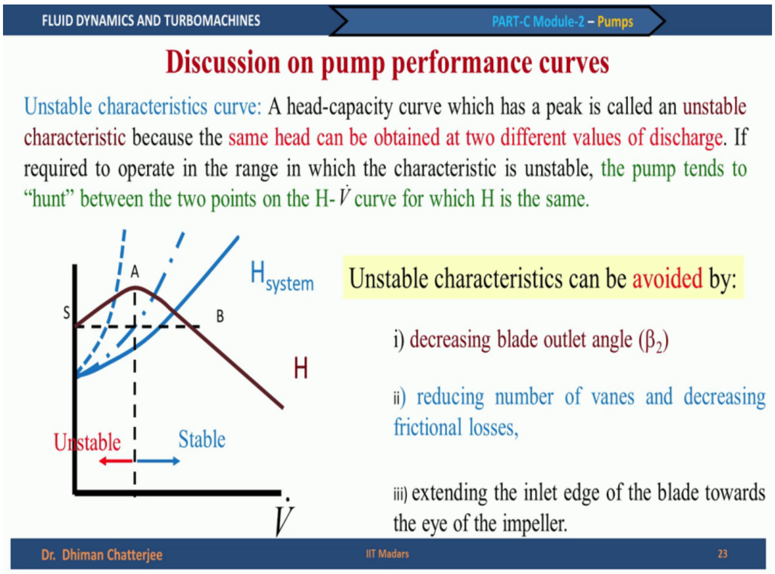

I talked about the unstable characteristic curve, I will come back to it. A head capacity, which has the peak is called an unstable characteristics because the same head can be obtained at 2 different values of discharge, let us look at it. Let us say that for a given pump I have the shirt shut-off head here HS and we have the curve like this. Many books, many textbooks will say, many persons will say that this entire curve is unstable characteristic curve. I would like to say in a slightly different way.

Had my operating point been here that is my system curve intersects the pump characteristics somewhere here and I never cross this point E, I never go to the left of the P, my volume flow rate never reaches less than this V dot A, then in the entire operation of the pump I will never face an unstable point. So there is nothing called unstable characteristic, you have to relate it with the operating point. So please keep in mind, the unstable operation of the pump or stable operation of the pump and not really unstable characteristic.

Those loosely speaking, people talk about it as unstable characteristic curve. How do I understand it, let us say this is my system curve and I am throttling a valve, so the resistance increases. Between this point and the next curve, what we see, as the volume flow rate reduces, the head developed by the pump increases. So what happens, as you have throttled the valve, the volume flow rate will reduce because you are throttled, the head requirement from the system increases and the pump is in a position to supply the extra head.

But imagine that you are crossing this point A, that is you are throttling this point further, you are using a valve and closing the valve rather. What happens, if the valve is closed further, the loss due to the valve is increasing, so the head of the system or the head demanded by the system increases. But however the pump beyond this point cannot produce such a high head. So it is like this, I am making a demand which is impossible for you to meet, then what will happen? You will not be able to meet the demand. So the pump says that I cannot have the flow if the pump would have talked.

So what will happen is the flow goes to 0. The moment flow goes to 0, there is no question of high head demanded by the system. So the flow will again resume at this flow rate, however my system demanded that somewhere near the energy requirement is. So the pump will again go back to S and the pump in this way will operate between S and B, it will hunt between these 2 points but it will not be able to give any steady output. This is undesirable and unstable characteristic. This unstable characteristic can be avoided by decreasing the blade outlet angle beta 2.

You know that if the blade outlet angle beta 2 is reduced, than the ideal curve would slow further round and hence you can avoid it. And this is another reason, yet one more reason for a pump not to have blade outlet angle greater than 90 degree. This has to be kept in mind. And you can reduce the number of vanes and decrees the frictional losses inside the vanes, I am talking inside the pump as a pump designer or a pump manufacturer will do. And you can extend the inlet into the blade towards the eye of the impeller.

So you see and I repeat before I change the discussion, this is a stable operation, so as long as you are between this point and point A, there is no problem, you will never encounter this unstable or hunting operation. The moment you are in the left side of A, this problem arises and this is called the unstable characteristics which is more predominantly seen with the larger blade outlet angle. Now it may so happen that one pump cannot raise water from the full height that is desired.

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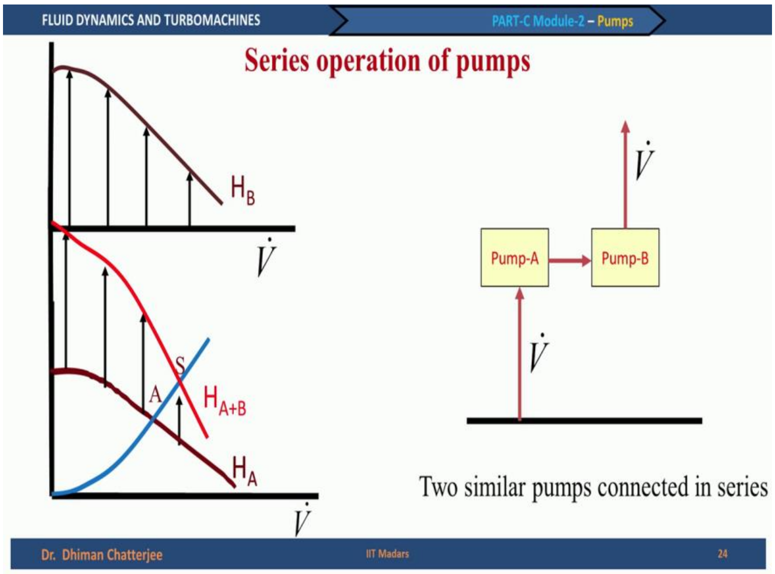

So what we can do, one option we have already discussed is multi-staging, the other option can be that we can connect 2 pumps in series. So we put the volume flow rate through one pump. Pump lifts it from the suction side, from the sump, then this flow is delivered to the 2nd pump and that pump in turn takes the flow to the higher level, this is called the series operation of a pump. Let us take that these 2 pumps are identical, it is not necessary but let us take that these 2 pumps are similar which are connected in series to make our discussion simpler.

So we know that this is my operating point and HA is the pump characteristic curve for this pump A, of course pump B has an identical curve. When these 2 pumps are added, the same volume flow rate flows through both the pumps. What is being done is the energy is being added by the respective pumps and the head increases and as a result what you see is the resultant curve becomes red. This is the H A + B is my way of saying that the head developed by both the pumps A and B together. And you can find out the operating characteristics.

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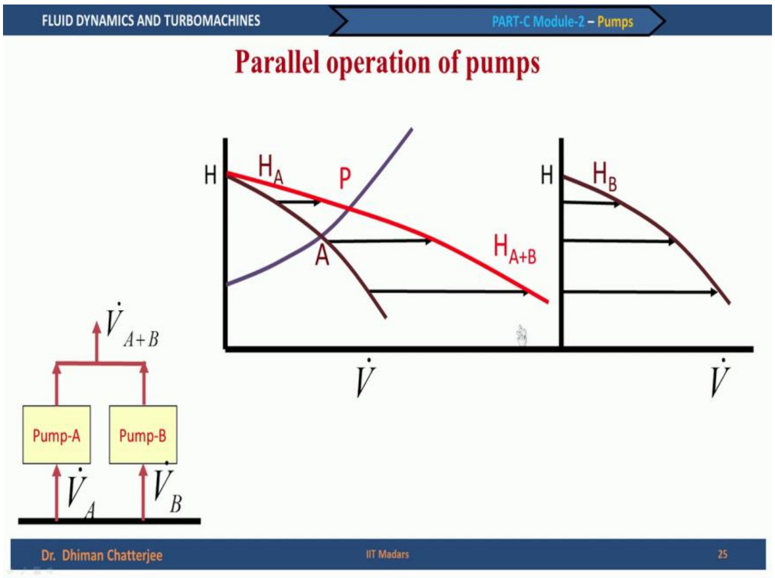

I will take up one problem and discuss it and then it will become clearer. Similarly we can talk about parallel operations when we want more will flow rate from the sump rather than the head, we have talked about in the last one, we can take V dot A from pump A and V dot B from B, so that the resultant volume flow rate is V dot A + B. And you see and here again were assuming that pumps A and B are identical. So this is my characteristic curve for the single pump, pump characteristic, this is for the another pump HB, here we are adding the volume for the given head. And hence the resultant curve V H A + B is given by the Red Line.

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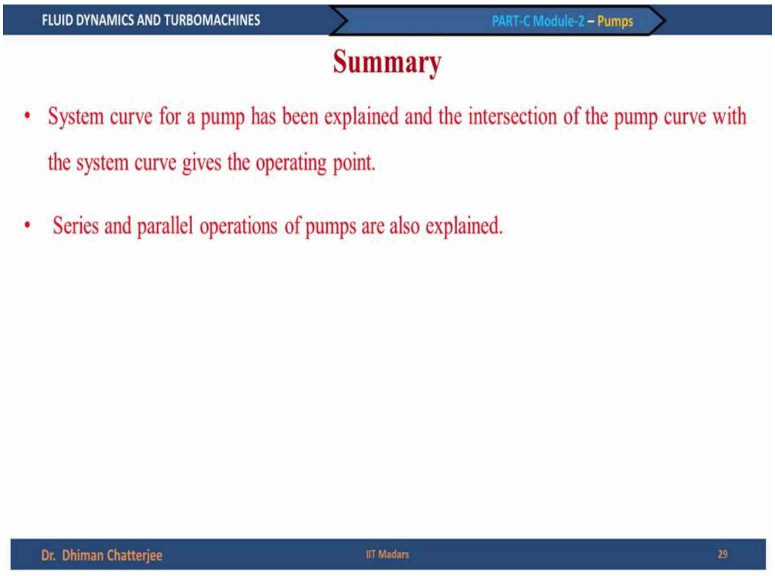

So we have discussed so far the requirement of the pump system or the piping head losses which we call the system characteristic curve. We have also discussed the series and parallel operations. So to summarise we can say that the system curve or the pump has been explained and the intersection of the pump curve with the system curve gives the operating point. It is desirable that the operating point should be as close to the best efficiency point or the design point and hence a careful selection of a pump for a given system is necessary. We cannot simply take a pump and use it for any system and expect the performance to be good.

So this is important, another point of also will come up, not today, in the lecture on cavitation that when we take a pump, it is not just the matching with the best efficiency point, we have to take into consideration that the pump does not cavitate, but that is a part of the another discussion. And we have also discussed how series and parallel operations of the pumps can be done, we will take up some problems in the tutorials in this week when we discuss how to solve the series and parallel operations of the pumps. In the next lecture we will discuss in detail that hydraulic turbines, how they work and their constructions and also their performance. Thank you.