Advanced Hydraulics
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Module - 6
Turbines
Lecture - 2
Pumps-1

Good morning everyone. Welcome back to our lecture series on advanced hydraulics. As you know, we are in the 6th module. Today is the second lecture of this particular module on turbines.

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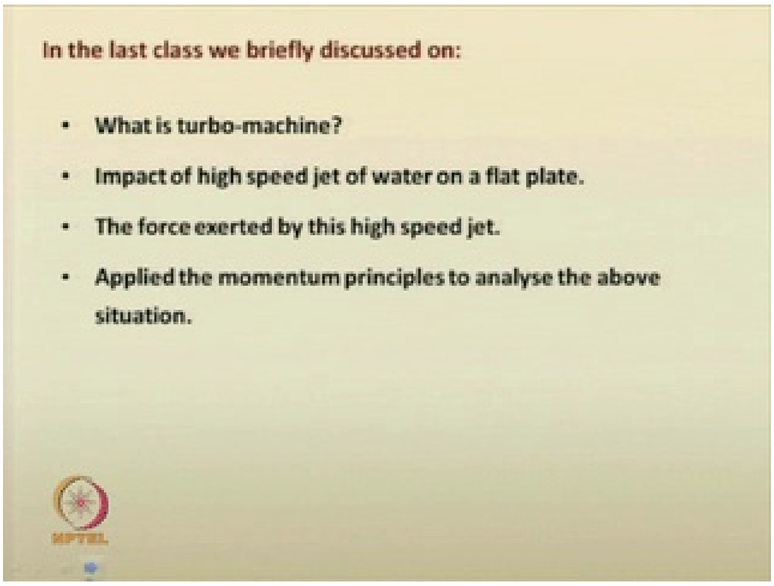

Today, we will be going to take a portion related to pumps. For example, in the last class, if you recall them; we have briefly discussed on what is meant by turbo-machine. You have remembered that, turbo-machine involves pumps and turbines and some other instruments as well. How the impact of high speed jet of water occurs on a flat... What is that impact due to high speed jet of water hitting a flat plate? You have analysed that, what is the force exerted. These things also we have seen it in the last class. We have applied the momentum principles to analyse the above situation both in flat plate and curve plates and all.

Today, one of the turbo-machine, which we are interested to analyse, is pumps, because as I said in the previous lecture; if you go to the site, you may be required to investigate about the pump facilities there; or, even as an engineer, when you have to go there and visit the things. Even in irrigation sector, not only in hydropower sector; in the pumps facilities, whether the pump designed is sufficient for the extraction of water and all. So, some basic knowledge on pumps – that will be covered in this particular topic.

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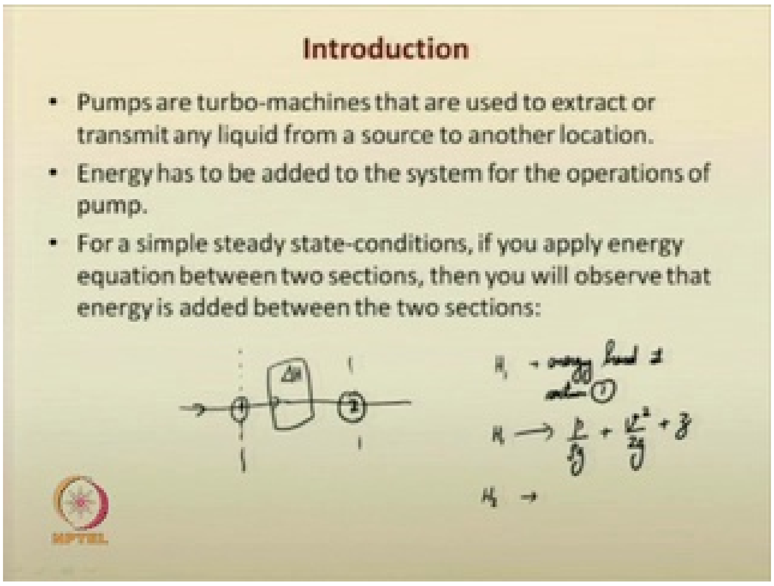

Let me introduce about the pumps. Pumps are the turbo-machines that are used to extract or transmit any liquid from a source to another location. To provide this thing; that is, if you want to transmit water, what is the thing required? You need to supply certain quantity of energy; you need to provide energy. And that energy will be utilised for transmitting water. For a simple steady state-condition, if you apply energy equation between two sections, if you see that then you will observe that the energy is added between. For example, I am just drawing a line diagram in such a way that you recall the steady state mostly in the open channel hydraulics and all. We were able to apply Bernoulli's equation; that is or the energy equation also, if you recall that, you were able to apply that.

The Bernoulli's equation – what it was stating if you remember them? If you take two sections, then the total hydraulic head or total energy head in both the sections – they will be same; or, if there are losses, then that quantity also you need to take into account.

In this particular situation, if I take say a line diagram, where say this is the section 1 at a particular location; you can envisage it as some maybe channel or maybe some water resource body and all. And, another section is there – 2. So, water – you need to extract; you need to (( )) so, there will be some energy, energy head at section 1. And, that energy is not sufficient; means that is the natural energy. How do you write the energy head equation, if you recall them? That is, we used to write it pressure head plus velocity head plus datum head. Like this we used to write the total energy head at any section. This energy at this particular portion – if it is given; similarly, at section 2 also, you can write appropriately the energy head. There will be... If the flow is occurring from left to right; there could be some natural energy losses. If you take that also into account, that is fine.

Now, this energy is not sufficient to draw water from a particular location. Suppose if you want to draw more water to some other location; what we have to do? In addition to this energy, you have to provide some external energy. And, that some external energy del H will be provided between these two sections. So an additional del H will be provided between these two sections. And you will get a modified energy at section 2. That is how energy is added into the system using a pump and you are able to draw water. The reverse process occurs in turbines.

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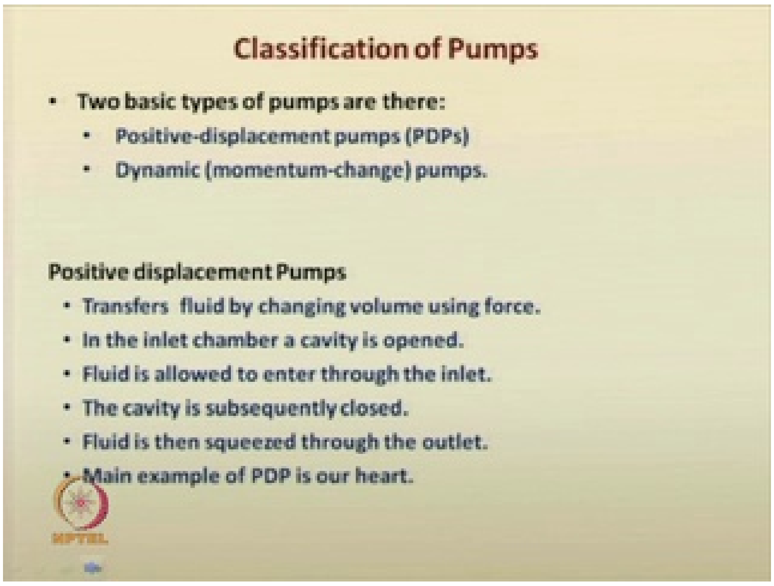

Let me give classifications of the pumps – a brief classification. There are mainly two basic types of pumps; they are the positive-displacement pumps, or in short, they are called PDPs. In many of the references, you can see them – (( )) PDP's and all. It is called positive displacement pumps. And the second type is dynamic or momentum-change pumps. So, what do you mean by positive-displacement pumps? That is, positive-displacement pumps – what they do is that, they extract water by a particular principle; that is, you use or you change volume of a liquid at a certain location by a force. Using some force, they change the volume of the liquid and then subsequently transmit the water. This particular principle is being suggested in positive-displacement pumps.

For example, if there is an inlet chamber or if you have a cavity at the inlet location; that cavity if... Let us consider that cavity in a cavity form; it is an enclosed cavity. If that cavity is now open to certain water location, wherever water is available; then, fluid is allowed to enter into the inlet to the cavity. Once the water enters, the cavity gets closed. Now, inside that cavity, water starts getting rotated through some other mechanisms. You can provide some appropriate instruments like rotor mechanisms and all. And also, it gets squeezed. The outlet of the cavity now opens and the water gushes out through that outlet. When it gushes out, it will be having more speed, more velocity. This is the principle behind the positive-displacement pump. A very simple example and one of the highly quoted example, is heart of any animal or any human being.

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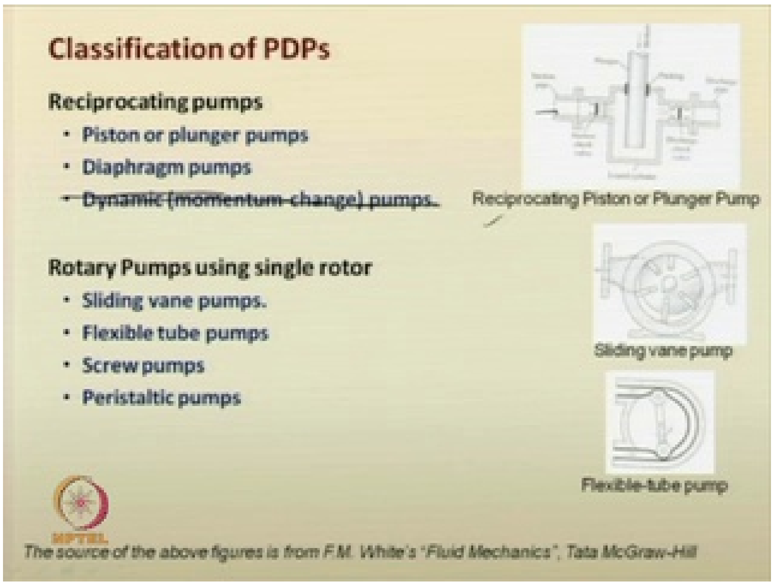

We can just give some classification of the positive-displacement pumps. How the positive-displacement pumps are classified? One of the first classification is reciprocating pumps. The reciprocating pumps consist of piston or plunger pumps as the... Let me again reiterate here. Our objective is not to go at a higher level in the turbo-machinery or subjects and all. You can read any of the reference topics related to turbo-machinery; or, there are many handbooks related to turbo-machinery as well. You can read them and you can gain more knowledge. It would be appropriate. We will be here just briefly suggesting the terminologies that will be useful whenever you go to site or whenever you try to design certain aspects on hydropower sector or irrigation sector. So, the piston reciprocating pumps consist of piston or plunger pumps. It consists of... It can be a diaphragm pump; then, it can be... Here it is wrongly typed; this particular – it is not dynamic. Reciprocating pumps consist of piston or plunger pumps and diaphragm pumps.

Then, you can have another classification for positive-displacement pump; that they are rotary pumps or single rotor pumps. In rotary pumps, you may see examples like sliding vane pumps, flexible tube pumps, screw pumps, peristaltic pumps. Just see the figures. We have quoted this figure from the Tata McGraw-Hill published book – Fluid Mechanics authored by F. M. White. So, from the figures, we can see the reciprocating pump. Just the portion of the reciprocating sectional views of the... It consists of liquid chambers, suction check valves; you can see here inlet means... So, the cavity portion is there. Then, it opens; then, it rotates; then, it gives the discharge at this location. Similarly, in the rotary pumps, you can see sliding vane pumps. So, the vane slides. And, due to the sliding, it opens at one portion and closes at another portion. Like that principles are there. Flexible tube pumps are there in single rotor rotary pumps and all like... So, such figures are taken.

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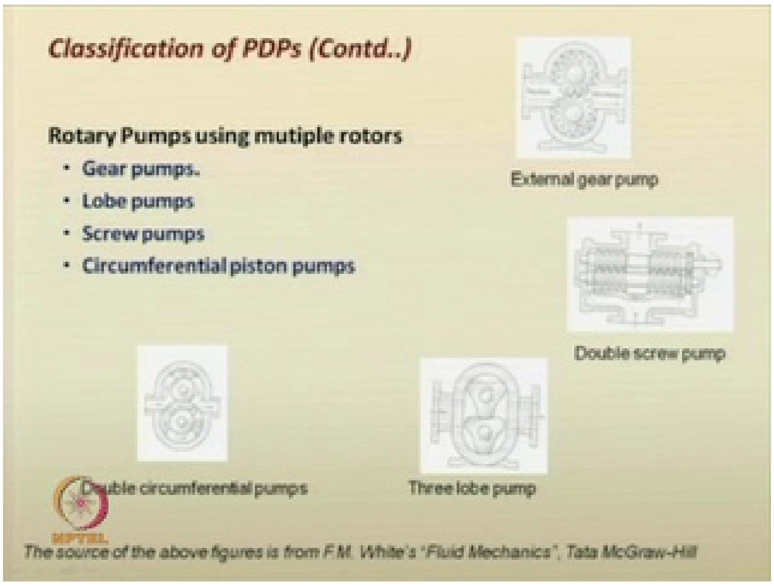

Now, rotary pumps can also include multiple rotors. Some of the figures are given here. External gear pumps; then we have given another example of lobe pumps, screw pumps, circumferential piston pumps. Like this classifications are given. You can just note it down. So, as per the, you have double rotors here. You can see the two rotors here in this also. Multiple rotors are there; double screw, double circumferential, three lobe pumps and all.

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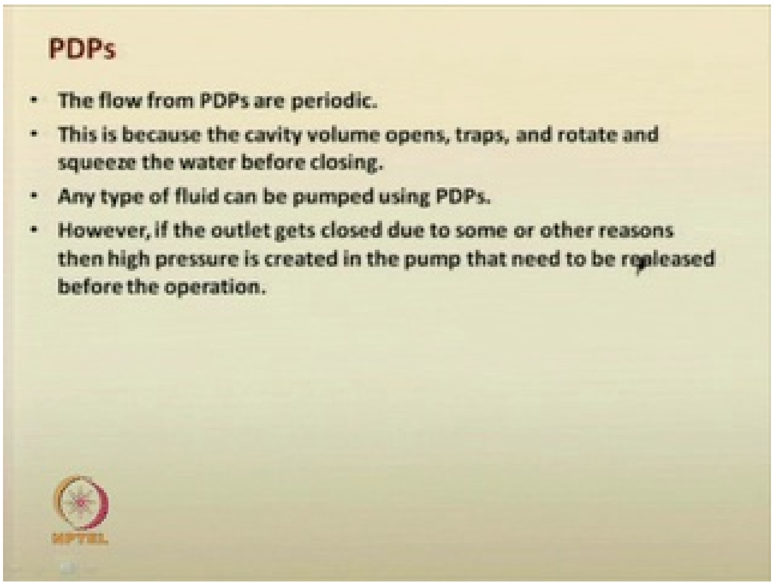

We are not going to discuss on the design aspects of these machines. PDPs – as we suggested, in the positive-displacement pump, the cavity opens and it allows water inside; then, the cavity is closed; water gets rotated and squeezed; and, the cavity door is opened and water gushes out through that. That is the mechanism going on. So, in this case, the inlet and the outlet of the pump – it is not operating simultaneously. Having that, it is some sort of a periodic state. One – an inlet will be open; it allows water; then, it closes; then, outlet opens. So, it involves some periodic mechanism. The flows from positive-displacement pumps are usually periodic. This is because, as we suggested, the cavity volume opens, traps, and rotate and squeeze the water before closing. In this mechanism, any type of fluid can be used for pumping. Whether it is a low viscosity liquid or whether it is high viscosity or even sludges in environmental, you can use the positive-displacement pump for pumping those materials.

But you need to take care. You cannot operate in every conditions the positive-displacement pump. If the outlet of the pump gets closed due to some or other reasons, then definitely you need to take care, because if the outlet gets closed, a huge pressure starts building up inside the motor. And this pressure it can burst the entire machine and all; and, you cannot directly operate them. So, you need certain types of valves to reduce the pressure or to release those pressures from appropriate places. So, that mechanism is required. So, you take those things into picture.

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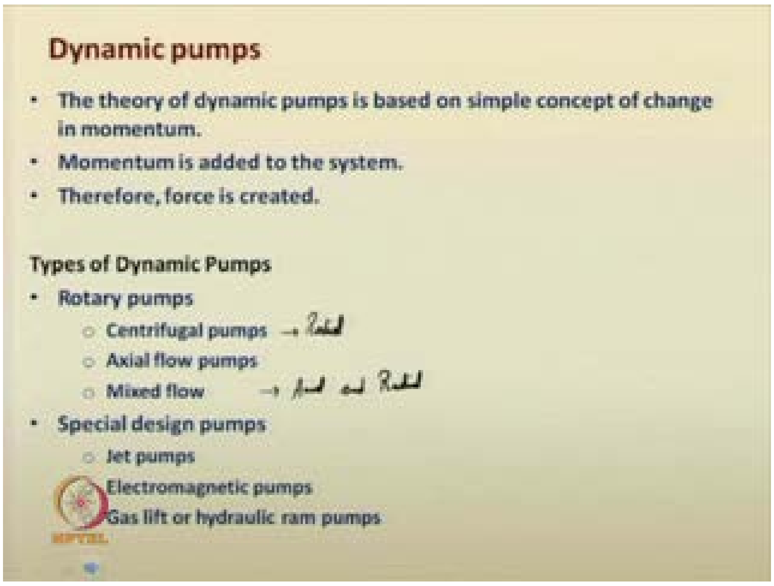

Let us go into the next type of pumps. We suggested that, there are two main classification of pumps: positive-displacement pumps and dynamic pumps. We will be discussing here on both the aspects. Now, briefly let me tell, what dynamic pump is. The theory of this dynamic pump is based on the very simple concept of change in momentum. Even in the last class, you have studied for the vanes. If a high speed jet impacts a jet, there involves change in momentum that will create force. That simple principle is being used. But here what we are going to do? We are now going to add momentum to the system. If you add further momentum to the system; definitely, you are getting more force to those situation. So, more force is being created. So, that is the principle behind dynamic pumps.

What are the types of dynamic pumps? It involves rotary pumps. Some of the rotary pumps are centrifugal pumps, axial flow pumps. Please note as a centrifugal, you will be seeing that, the centrifugal mechanisms are involved there. Axial flow – as the name suggests, there could be some long axis involved somewhere. An axis flow pump means... So, direct straight... You can have mixed centrifugal or it is also called radial flow. It can be a radial flow. Here you can have mixed axial and radial flow combined. Such pumps are also available. Then, the next type of dynamic pumps are specially designed pumps. These are most of the general things. Specially designed pumps like jet pumps are involved. We will briefly discuss them anyhow. Electromagnetic pumps – the simple principles of the electromagnetism is being involved there. You can use gas lift or hydraulic ram. And, pumps are working on that hydraulic principles also. Such pumps are also available.

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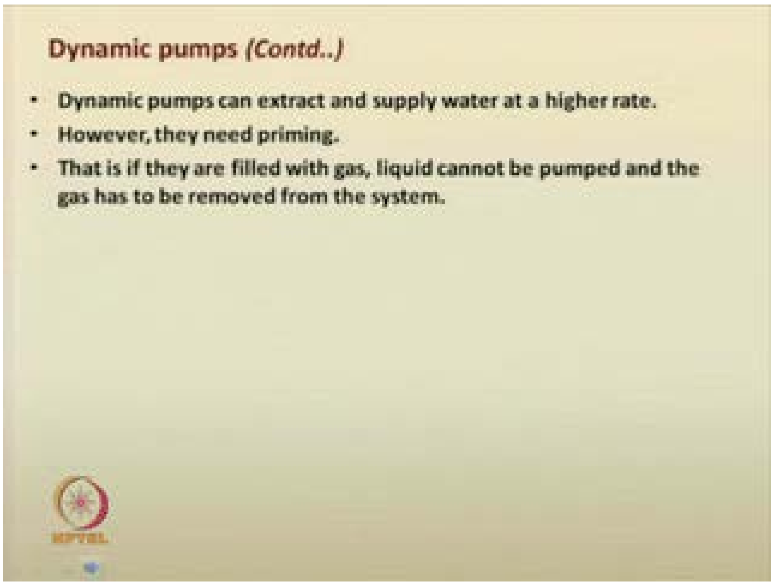

Dynamic pumps – they can extract and supply water at a higher rate. Compared to the positive-displacement pump, dynamic pumps can extract... means it can supply water at a faster rate. It has been recorded that through many analysis and all. It has been observed that. But, the thing is that, dynamic pumps require a mechanism called priming. What is that? That is, if the... Gas is... If you have a pump set for extracting water from a location. And, if gas is being filled in some of the chambers; if gas happens to enter into those chambers and all. Then, you cannot directly use the dynamic pump for extracting fluid or water from the source. So, that way, you need to remove that gas from the system before starting the operation of the pump. So, that mechanism is called priming. One of the most importantly used dynamic pumps is centrifugal pump. So, we will first deal with the centrifugal pumps.

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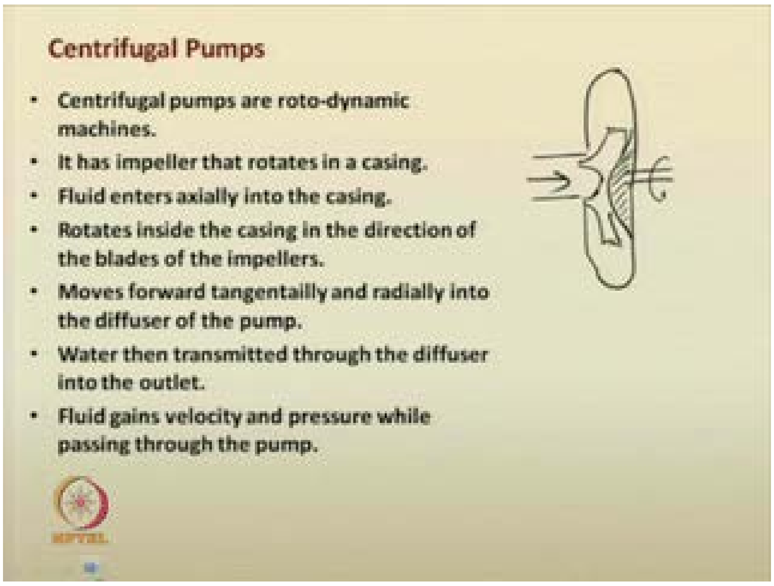

What is meant by a centrifugal pump and all? We will just have a brief discussion today on those aspects. The centrifugal pumps – they are a type of roto-dynamic machines. It has an impeller that rotates in a casing. Then, fluid enters axially into the casing. The fluid rotates inside the casing in the direction of the blades of that impellers. And, it moves forward tangentially and radially into the diffuser of the pump. Then, water is then transmitted through a diffuser into the outlet. Usually, the fluid gains velocity and pressure while passing through the pump. So, I can just give a brief sectional view of the centrifugal pump and all. As we mentioned, it is a type of roto-dynamic machine. So, you can have the sectional view. Say a casing is given here. It is connected with an inlet.

And, let us assume this as a casing. And, it consists of impeller blades and all. Let us assume this shaded region, where water cannot enter or it is connected to a shaft; it rotates. So, the impeller has some sort of blades like these blades and all. I will just show another sketch of how the actual impeller and its blade look like that. Here just let us assume that. This is the inlet portion; water will come inside like this in this; it will come in this particular direction. Then, along this, it will heat the impeller blade; it is rotated through some source. Through some other energy sources, you are rotating the impeller blades. So, water also gets rotated along with it. Then, it gets transmitted. It goes further and into the diffuser portion of the pump. Then, from the diffuser portion, it is transmitted to the outlet. Like that the water is getting pumped. So, usually, what happens is the fluid gains velocity and pressure while passing through the pump. So, we have suggested that, in pumps, you are adding energy to the system. Whereas, in turbines, the energy is taken from the system. So, here through external sources; that is energy is added and there will be an added... There will be an increase in velocity and pressure of water. Thereby, the purpose of pump is being suggested.

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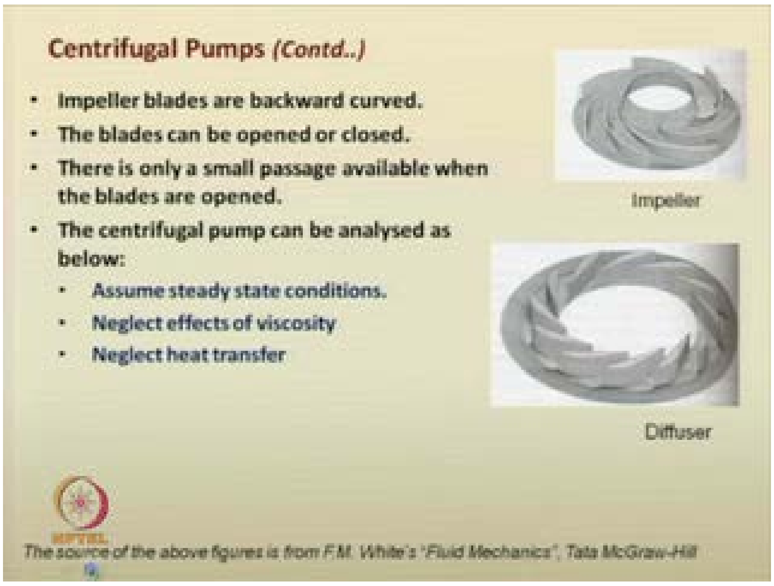

Here we have just given sketch taken from F. M. White’s Fluid Mechanics published by Tata McGraw-Hill. You can see a part portion of impeller. This is how the impeller. So, in the inlet of the pump, wherever we have suggested this particular portion; it consists of such an impeller disk having impeller blades as shown here. Say there are various radii; you can see curved impeller blades on that impeller disk. So, this is connected at the inlet. So, water comes and goes in into the system like this. So, it will rotate. So, if the impeller blade is rotated, water starts rotating. Then, it goes tangentially as well as radially further into the other cavities and all. Then, from there it is connected to a diffuser. From the diffuser, the water is coming out like this. From the impeller portion, it is coming. Then, it goes into the diffuser. It diffuses into the outlet chamber. So, this is how the impeller and diffuser portion looks in a pump.

You can see the blades. As we have already studied the vanes and all, you can clearly imagine. When the water strikes these blades and all, you can use the same principles of vanes; means high speed jet hitting a vane and all. So, the same principles are applied here. So, the impeller blades – they are backward curve as shown here. The blades can be opened or closed. You can open or close appropriately. So, there is only a small passage available when the blades are opened. If you look into the previous figure, slide and all, there will be only a small passage from the inlet. So, you can suggest now the centrifugal pump. Usually, we analyze it with the following assumptions. We are first trying to suggest steady state conditions. The entire system is now in the steady state condition. Then, we neglect the effects of viscosity; we neglect the heat transfer mechanism.

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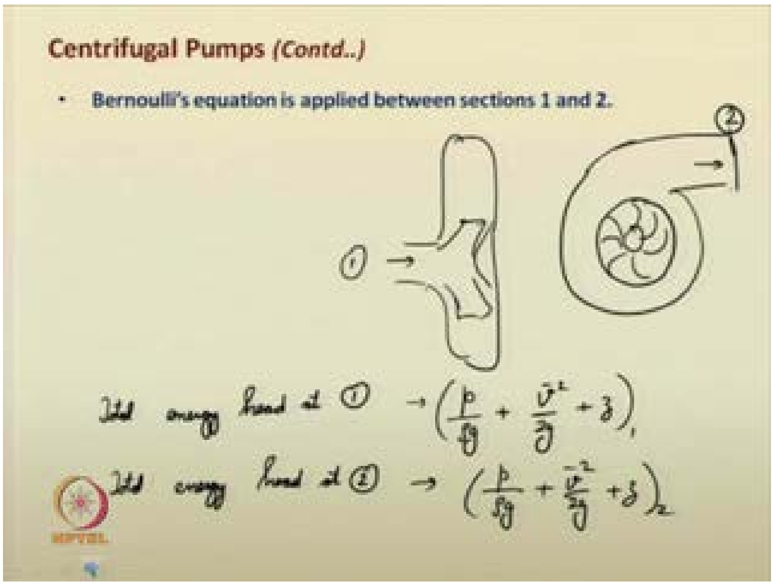

Then, we are now going to apply Bernoulli's equation between sections 1 and 2. Again, I am just redrawing the portion. You have inlet here. So, for a better clarification, I can just give... Say let us consider this as section 1. And, the section 2 will look more like this. You can have a circular disk having the impeller blades. You have already seen the picture of impeller; like this. So, it is mounted; this impeller blade is mounted in a casing. And, the entire casing is then further extended. It will be connected to the diffuser portion. And, from there, it is being suggested to the outlet. So, this is the section 2. Like this let us assume the situation now. Here I can assume this as section 2, section 1. In the inlet, the impeller blade is there; in the outlet, after passing through the diffuser blade at the outlet, you can assume it as a section 2. It could be pipe or it could be any other water carrying source and all.

We can apply the same Bernoulli's equation between sections 1 and 2. It is the famous, because we have already considering the conditions as steady state. You know that, Bernoulli equation can be applied only in steady state conditions. So, the Bernoulli's equations will now be applied; equation will be applied. That total energy equation will be applied between sections 1 and 2. So, the total energy head at section 1 – this can be given as say the pressure head plus velocity head plus datum head at section 1. Like this, we can write it. Total energy head at section 2 – this can be given as p by rho g plus the velocity head plus datum head at section 2. So, use these equations.

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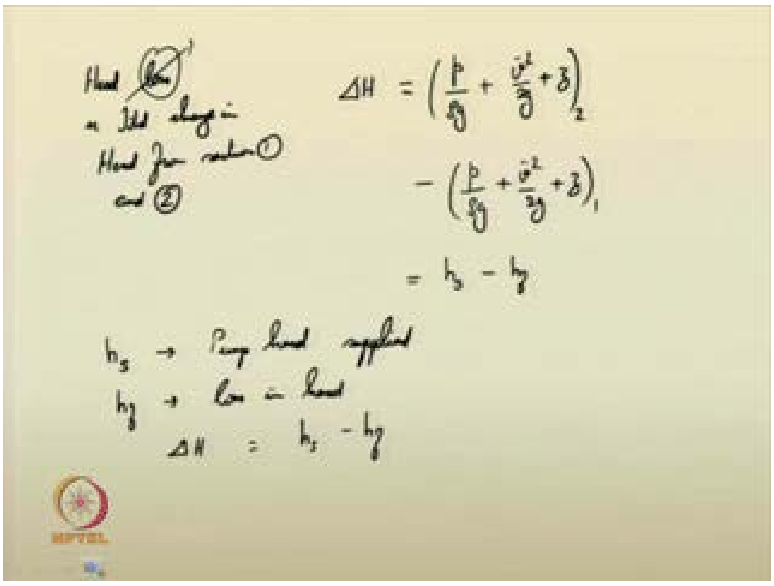

Head loss or total change in head from section 1 and 2; why I am writing it additionally like this there? You cannot claim it as head loss; in the pump, you are supplying additional energy. So, you are gaining some energy. So, we can write it as total change in head from section 1 and section 2; that is, del H – I can write it del H. This is nothing but equal to the quantities – total head at section 2 minus total head at section 1. And, this is nothing but equal to h s minus h f; where, h f is called the pump head – additional pump head supplied.

This is the additional energy head you are going to supply through the pump. It is not h f; it is h s. h f is the loss in head; the head can get lost. Say in various chambers, this is the casing volume, is there; or, it can get lost in some other means and all. So, you can easily suggest now. So, h f is the loss in head that can come into picture. So, we will be writing the total change in energy head as h s minus h f. So, if you look into this side sectional view of this particular casing of pump, you will see that, the datum – it can be taken;

means there will be very much less difference in the heights between two sections. So, it can be almost considered as negligible. If it is more or less, less than 1 meter and all, it can be considered negligible. Then, what happens? The velocity – we are assuming steady state conditions. And, moreover, the velocity at section 1 and section 2 – they may also be assumed same.

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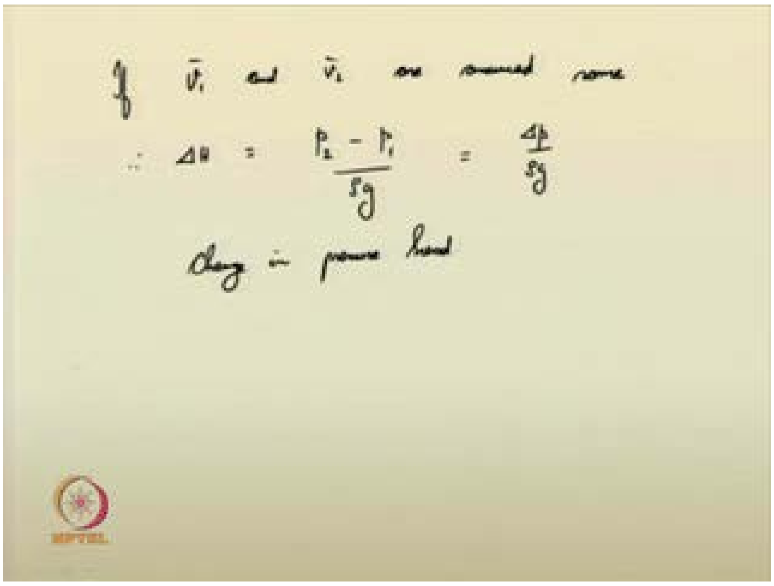

If v 1 and v 2 are assumed same; then, what happens? You are having steady discharge in the conditions. Therefore, the change in head – this is nothing but equal to p 2 minus p 1 by rho g. That is equal to change in pressure head. Or, we can suggest, whatever additional head you are providing – that is nothing but the change in pressure head. So, in that way, it is now easily understandable; in the sense that, the entire energy head – even though you supply energy head; although the total energy consist of pressure head, velocity head and datum head; the contributions or change in velocity head and datum head are negligible. And, we consider the entire change in the energy head is reflected in the change in the pressure head of the system.

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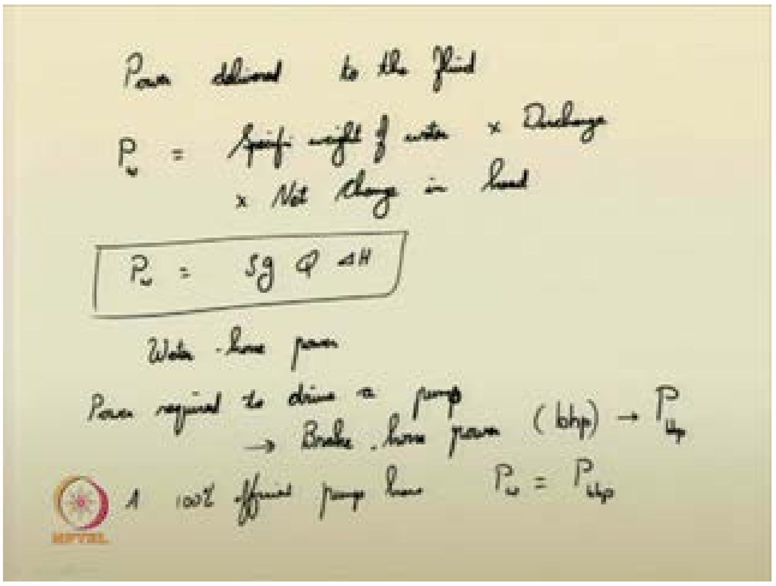

What is the power? Means we can now go for power. Power delivered to the fluid. What is the power delivered to the fluid by the pump now? This can be given as P w. P w is nothing but the products of specific weight of water or any fluid. The discharge... We have suggested that, this is for a certain discharge. So, discharge into the net change in head. You just go to the previous (Refer Slide Time: 34:14) portion; change in head is del H. So, that same thing will be taken here. So, specific weight into discharge into del H. So, this is the power intended to be delivered to the fluid by the pump. This power is called water horsepower. So, that is... This is the power that is required or that is supposed to be delivered by the pump to the fluid, so that the fluid can gain so and so energy. So, that is the objective here.

Now, what do you think so? Whether if the pump through some other source – if they use only this much of power and if it is delivered; means whether the pump will be able to deliver this much amount of power to the fluid? Is it possible? The power required to drive a pump – it is called brake horsepower. In certain books, it is written bhp also. I will be using it as P bhp; that is, this much amount of power you have to supply to the pump. Then only, the pump will be able to supply a power P w to the fluid. So, what does that mean? Theoretically, pump requires more power. And, some of the energy is lost due to various losses and all – water losses and all. Subsequently, the amount of power transmitted to the fluid is P w. A 100 percent efficient pump, which is not practically possible have a 100 percent efficient pump; have P w is same as the power required to drive a pump. So, P bhp.

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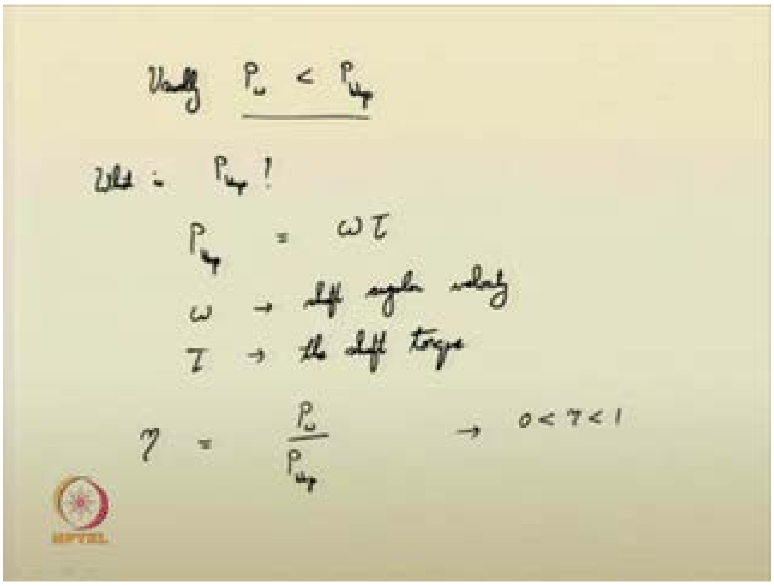

But, you know due to various losses, you can easily suggest that, usually, P w is less than P bhp. What is P bhp? How will you evaluate it? P bhp is usually given as the angular momentum into the torque of the shaft. The angular momentum into torque of the shaft – that is given as the power required to drive a pump. So, I can suggest it as shaft angular velocity; tau can be given as the shaft torque. In our earlier lectures, some of the modules and all, we have used tau for shear stress. So, please do not confuse with the symbol here. Here the tau symbol is used to denote the torque of the shaft. As we mentioned, power delivered to the fluid is less than the power used to drive the pump. Therefore, we can devise an efficiency factor eta. Let us consider the efficiency factor. This is nothing but equal to P w by P bhp; where, eta ranges from 0 less than eta less than 1.

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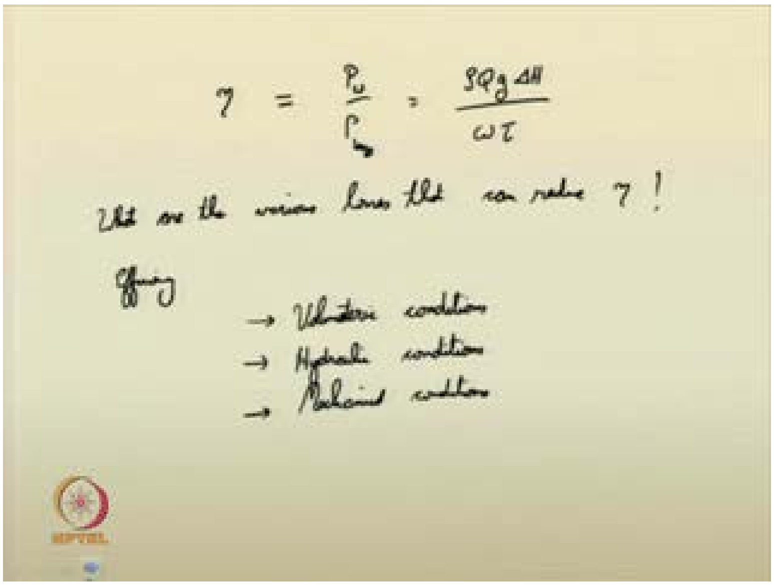

Eta is equal to P w by P bhp means this is rho Q g delta H by this is – P bhp is omega tau. What should be a pump designer’s aim? A pump designer’s aim should be – he should like to design a pump that is having a high value of eta. What are the various losses that can reduce the value of eta? What are the various losses that can reduce eta? You can think of the efficiency condition; that is, eta – you know it is efficiency factor. So, efficiency can be correlated with the volumetric continuation of the system. Volumetric conditions – it can be interpreted with the hydraulic conditions; it means it happens that, particular pump design is not hydraulically efficient. So, there may be considerable loss due to bad hydraulic design. So, that may also reduce the efficiency; the volumetric condition – another feature; then, the mechanical conditions.

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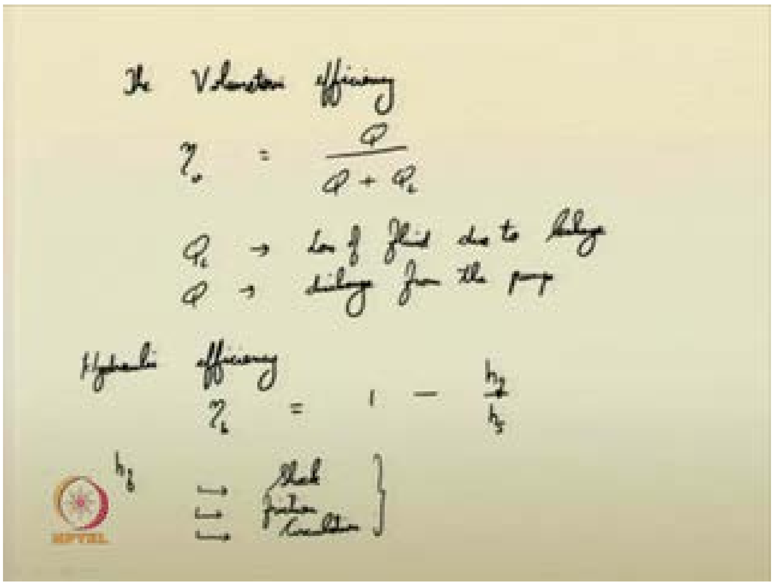

The volumetric efficiency – we can discuss it with the following terminology. Say we can give it as eta v now – subscript v. This is the discharge intended or the discharge from the pump. It is not intended means that is the design value. So, we are taking discharge Q by Q plus Q L; where, Q L is the loss of fluid. You might have seen several pump sets and all, where some minor leaks are there; leakages or water is coming out from certain locations and all. So, they are all various types of leakages. So, there could be loss of fluid due to leakage. Q is the discharge – steady discharge from the pump. So, this is the volumetric efficiency relationship.

Hydraulic efficiency – we can now correlate hydraulic efficiency say by a factor eta h. This is nothing but 1 minus h f by h s. Can you recall these terms? h f is suggested that loss in the total energy head due to various (( )) like friction and all; h s is the energy supply to the system. So, if the water system (( )) energy... h s is the energy head supplied to the system. So, there could be... h f can be of... h f – that is, the losses can be of various nature. It can be due to shock if some shock waves are generated or else some shock is created; means abrupt interruption of water or some type of this thing. That can create some loss. So, that is shock loss due to friction. There can be some loss in head. And, due to circulation of water, there will be some loss in the energy head. So, these factors create loss in head. That is correlated with the hydraulic efficiency of the system.

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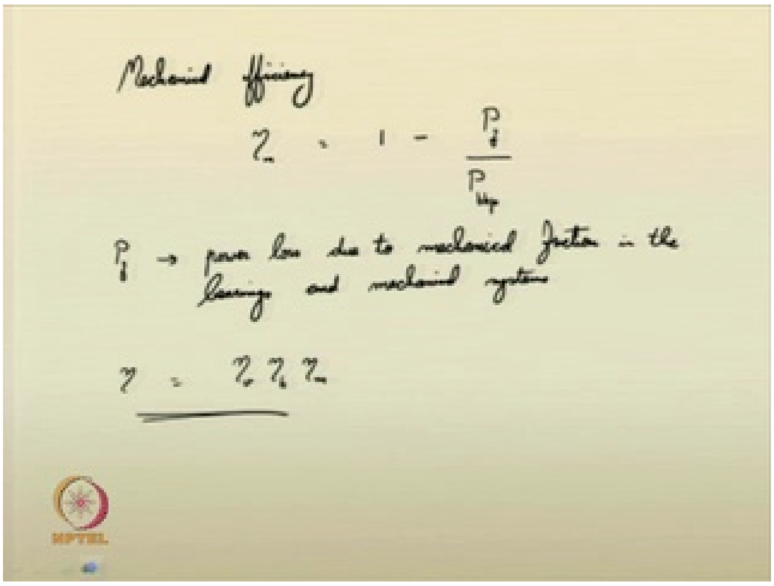

Mechanical efficiency – you can suggest now mechanical efficiency as say eta m. This is nothing but equal to 1 minus power called P f by P bhp; where, we are now suggesting the P f is the power loss due to mechanical frictions in the bearings and mechanical systems. So, this is... Say how it is getting differentiated now? You have seen the figure of an impeller, diffuser and all. So, these are all mechanical devices. So, those mechanical equipments – when they are connected to the shaft and all; for rotating if you require some ball bearing connections and all; due to those connections, there could be friction loss. So, those friction losses will cause the loss in power; means whatever power we were interested to transmit to the water – some of them get reduced due to the connections of various mechanical equipments. So, that loss is now termed as mechanical loss or the corresponding efficiency is termed as mechanical efficiency. So, you know that P bhp is the brake horsepower of the pump. So, the total efficiency – usually, it is given as the product of these three quantities eta v, eta hydraulic efficiency and eta mechanical efficiency.

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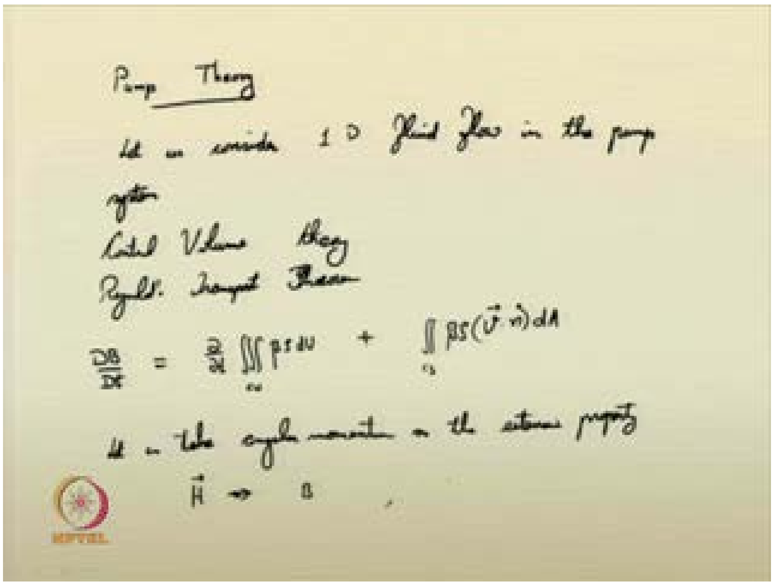

Now, what can you say now? We can just briefly go through the pump theory. Let us consider a one-dimensional fluid flow in the pumps system. Now, if you recall the Reynolds transport theorem and all; if you are considering this entire pump portion as a system now, we can use the control volume theory. So, the entire pump is a control volume. Reynolds transport theorem – we can utilise them. So, in the Reynolds transport theorem... Just for your benefit, I am again writing it. We have suggested, the Reynolds transport theorem for any arbitrary property p, which is an extensive property related to mass of the system. So, the material derivative of that quantity is nothing but the net amount of that extensive property generated within the system plus v dot n d; that is, this quantity is the net outflow of that extensive property through the control surfaces of the control volume. So, like this, we have repeatedly... We have seen for various cases this particular... The same thing you can now utilise here for these pumps also. Here let us take angular momentum as extensive property. So, let us take angular momentum as the extensive property. So, angular momentum – it is a vector. You can now suggest H as the angular momentum. So, H is the quantity B in the above equation.

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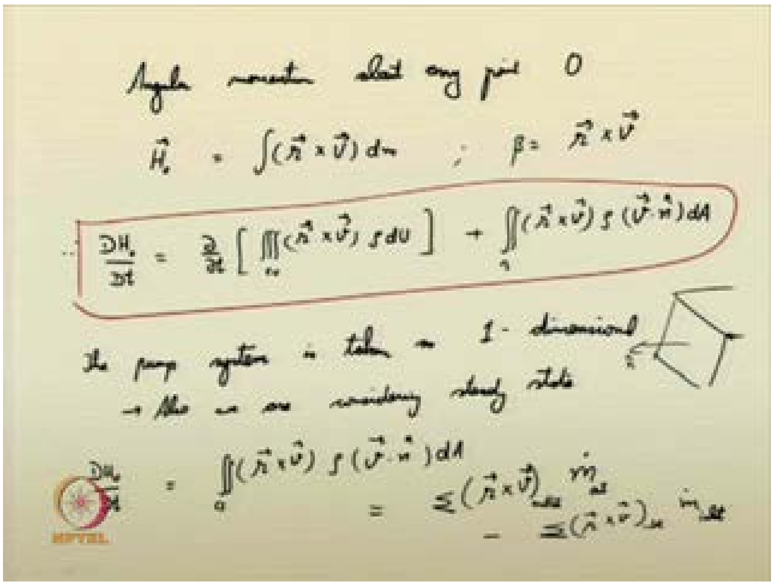

And, say angular momentum about any point O in the control volume. You can now suggest this as H O. This can be written as r cross v d m; that is, we are suggesting it as an extensive property related to mass. You know that, the quantity r cross v gives the angular momentum per unit mass. So, this quantity – if it is integrated with respect to the entire mass in that volume; that will give you the angular momentum in that control volume. This is just to denote it as an extensive property. From this, you will get the intensive property beta is nothing but equal to r cross v. Therefore, the Reynolds transport theorem D H O by D t is nothing but equal to dou by dou t the control integral volume r cross v rho du; that is, du is the elemental volume of the control volume; that is, for the integration plus the controls of... You are having aerial integral r cross v rho v dot n dA. Just go to the previous slide– the same equation as specified here. For the angular momentum, we have suggested it now appropriately.

As we suggested the pump system, the pump system is taken as one-dimensional. We suggested that, the pump system is taken as one-dimensional. So, you have a definite radius means inlet condition and definite outlet condition. All other directional control surfaces – they are not transmitting any flux. Also, we are considering steady state conditions. We can have D H over D t now is equal to r cross v rho v dot n... See here the velocity is given in the vectorial form. We have not averaged it to any sections and all. That is averaged only after integrating the thing. Or, we can take the average velocity into area appropriately and suggest the quantities. So, this is nothing but if the momentum or the aerial correction factors – if they are negligible, you can just take these quantities now. This is nothing but r cross v at the outlet into... What is rho v dot n dA at any particular section? Say if I am taking an arbitrary; say if this is the inlet portion; this is the area. So, this particular area you are integrating. So, rho v dot n dA – you can now write the same quantity as n is outward vector – unit outward vector from this surface. So, v... So, v dot n will give you the magnitude or the velocity appropriate to that plane. So, v dot n will give you... So, v dot n into dA will give you the discharge quantity through that inlet. So, discharge into rho – what is that quantity? It will be the rate of mass coming in or going out. So, I can suggest now this quantity as m dot, that is, rate of mass going out – m dot out minus sigma r cross v inlet at the inlet. So, like this, I can now write for the one-dimensional case.

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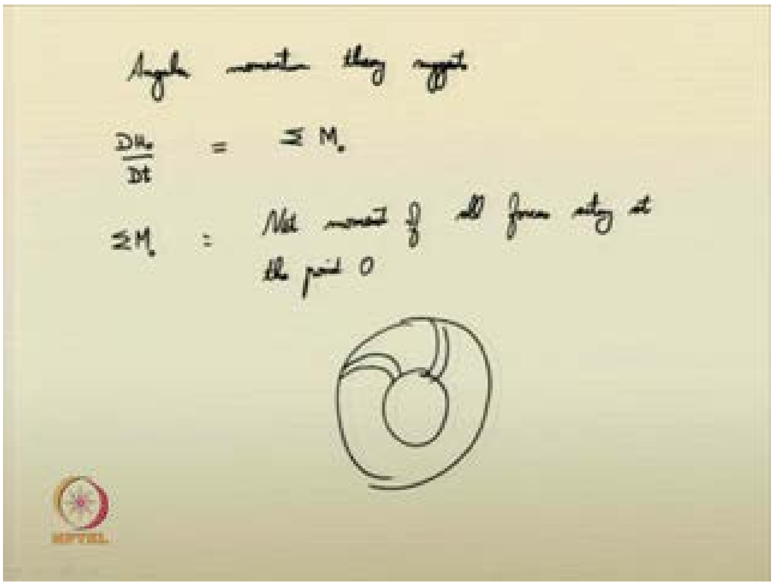

What is this angular momentum theory suggest? Angular momentum theory suggests the material derivative of angular momentum, is nothing but the sum of moments of all forces acting at the arbitrary point O in the control volume. This is the theory behind the angular momentum. That theory we will be incorporating it here; that is, the sigma M O is the net moment of all forces at point O. We can suggest net moment of all forces acting at the point O. Incorporate the same phenomenon now. We will be applying this same angular momentum theory for the blade impellers as well as the diffusers in the pumps.

In the next class, we will demonstrate or we will go through how... Say if you can devise a... Say this is the... You have already seen the impeller disc. The impeller – I can just redraw the thing. Say it consists of inner radius and outer radius. The impeller blade can be in the curved form like this. Water – when it hits here, then it gets transmitted like this; then, it goes out from here. It can go out; it goes like this. This is how the impellers work. So, the same thing we will now discuss on the... We will discuss how to apply the angular momentum theory on that and we will work out on that theories and efficiencies related to pump.

Thank you.