Introduction to Fluid Machines, and Compressible Flow
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Lecture - 17
Diffuser, and Cavitation

Good morning, welcome you to this session. Today we will be discussing first the diffuser of a centrifugal pump, and subsequently the cavitation in a centrifugal pump well as you know the purpose of diffuser in a centrifugal pump is to convert the kinetic energy of the fluid at the impeller outlet to the pressured energy at the pump outlet this is, because at the pump outlet we want fluid at high pressure instead of high velocity. So, therefore, the prime function of the diffuser is to convert the high velocity to high pressure in diffuser.

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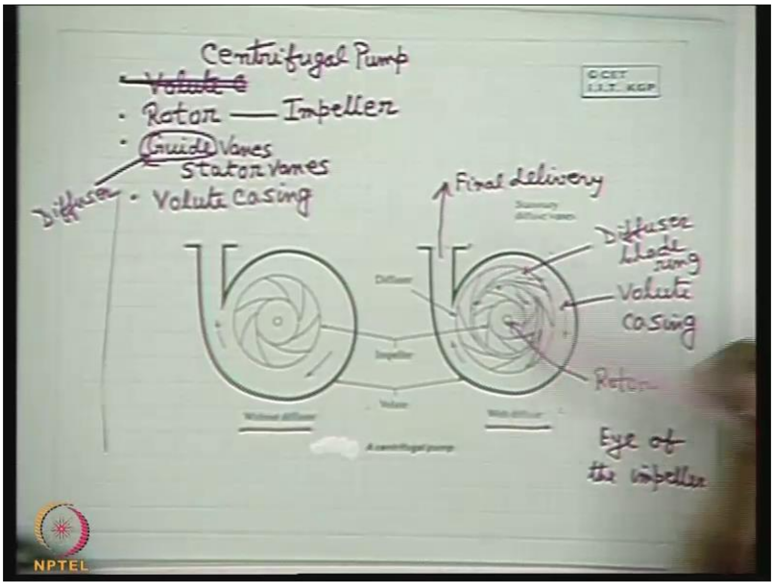

Now, if you see the different components of a pump as we have already studied here you see that the pump this is the pump impeller after the impeller; there are two types of diffusers one at one is the vane diffuser where in number of static vanes are there which form a diverging passage while the fluid flow through this passage its pressure is increased while the velocity is decreased, then at after this vane diffuser; that means, that the outlet of the vane diffuser the fluid comes out, and then enters in another casing; that means, there is another casing which is known as volute casing or spiral or scroll casing which in which when the fluid flows the cross sectional area increases in the direction of the fluid.

So, therefore, an additional pressure rise or the conversion from velocity to pressure there is a typical conversion process from kinetic energy to pressure energy takes place in this volute casing in some cases there is no static vanes or the diffuser vanes where fluid from the pump impeller; that means, at the outlet of the pumpeller impeller directly it comes into the diffuser of scroll casing; that means, in that case the diffuser a volute casing itself is the diffuser while in this case both the static vanes, and the volute case act as the diffuser. So, that is why these are known as vane diffusers, and this diffuser is usually known as this volute casing is known as volute diffuser.

Now, let us first think of this diffuser volute casing. So, when the fluid comes out from the impeller e if you neglect the frictional effect no additional torque or force is acted on the fluid. So, therefore, in this passage either in the volute chamber or in the diffuser vanes the fluid angular momentum of the fluid remains constant.

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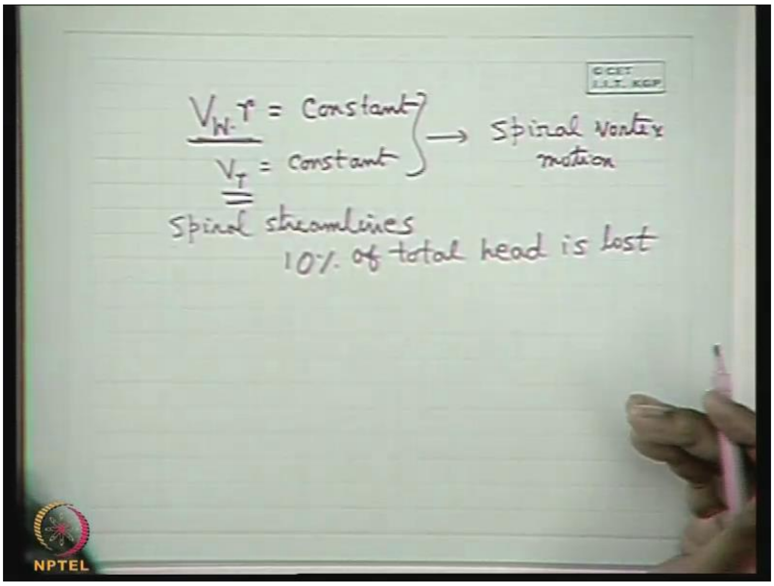

That means we can write that the tangential velocity times the radius radius means the radius from the axis of rotation is constant, which means that the fluid shows us free vortex motion; that means, a free vortex type motion exists if we disregard the frictional effect, because no additional torque or force is exerted on the fluid.

Moreover if we consider the fluid to be ideal; that means, the frictional effects if we disregard, then the flow velocities with which the liquid is coming out from the impeller is also uniform; that means, the variation in radial velocity we can neglect as you know for a an ideal fluid he variation across at a section across the flow is uniform; that means, in that case we can consider the radial velocity is also constant. So, a combination of a uniform radial velocity, and a free vortex motion gives rise to a spiral spiral vortex motion a spiral vortex motion for which the streamlines are spiral in shape; that means, this gives rise to a pattern of spiral streamlines this combinations of free vortex motion, and the constant radial velocity gives rise to a spiral pattern of spiral streamlines.

And the most important fact is that r most important consideration is that the shape of the volute has to be made in matching with the streamlines pattern; that means, that have to be may made spiral in matching with the pattern of the streamline this is one of the most important considerations in designing a diffuser usually at maximum efficiency ten percent of the total head is lost in the diffuser, because frictional effect we cannot neglect of total head is lost; that means, in diffuser frictional effect cartels ten percent of the total head in converting its kinetic energy into pressure energy. So, this is almost all in short about the volute casing as the diffuser.

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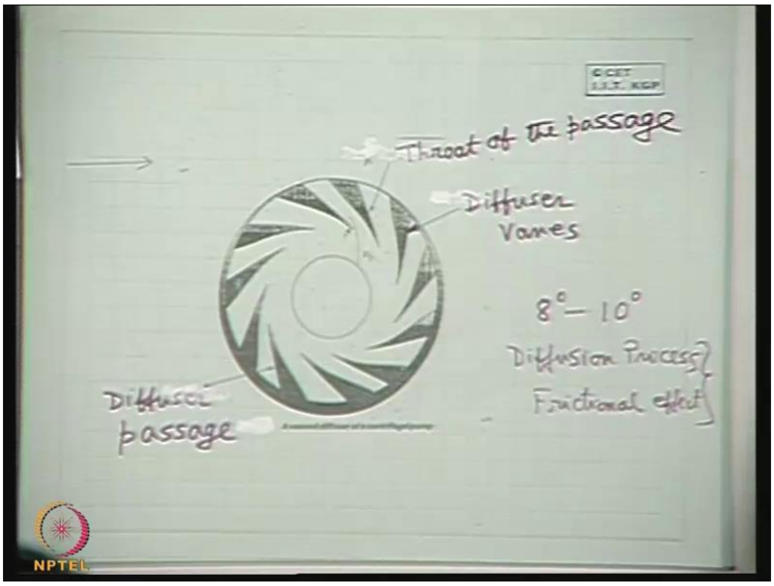

Then we come to the vane diffuser you see that how does a vane diffuser look like well a vane diffuser looks like this now as we have seen that in many circumstances there is a set of static vanes act as vane diffuser these are provided when a shorter length of a pump is required to give a required pressure; that means, when the rising pressure from the impeller outlet is required in a shorter length; that means, when the size of the pump is important there is an advantage of having static vanes as the diffuser vanes well; that means, when the size of the pump is reduced. So, the diffuser vanes act in addition to the volute casing in changing the kinetic energy into pressured energy, so that we can get higher pressure at the pump outlet.

So, what is that you see that a ream of static vanes surrounds the impeller outlet this is the impeller this is the impeller, so these at the static vanes. So, this creates the diverging passage this is the diffuser passage, and here the process of diffusion that is conversion from kinetic to pressure energy takes place in a very efficient way within a shorter length the design criteria is that this angle of divergence should be limited to limited between eight degree to ten degree to avoid boundaryless separation.

Another criteria is that that the number of vanes should be compromise between two phenomena one is that if you increase the number of vanes the process of diffusion will be better process of diffusion means the conversion from kinetic to pressured energy will be better, but; however, if we increase the on the other hand if we increase the number of vanes the frictional losses will be more. So, therefore, he diffusion process, and the frictional effect diffusion process, and the frictional effect this two counteracting phenomena decides the number of vanes; that means, if we have more number of diffuser vanes the process of diffusion that is the conversion from kinetic to pressured energy will be better whereas, the frictional losses will be more.

But if we have less number of vanes the frictional losses will be less, but the conversion will not be better; that means, though the total energy at the outlet will remain same, but one of the major aims; that means, purpose to increase the pressure energy will not be much. So, that the compromise between; these two decides the number of vanes in this diffuser usually the number of another criteria is that the number of vanes should not have any common factor with the number of vanes in the impeller to avoid resonant vibration. So, these are the important criteria for vane diffusers.

So, this is almost all in short the principle of diffusers in a centrifugal pump that to convert the kinetic energy into pressured energy will provide vane diffusers, and also a volute chamber vaneless diffuser known as volute chamber, and scroll casing. So, now, I will come to the cavitation phenomena of cavitation in a centrifugal pump I think you all what is the cavitation we have already studied it in case of turbine. So, here we will see that how the cavitation phenomena limits the operational or made may puts the constant on the operational conditions that the height above which a pump has to be set from the sump that is the reservoir level from which the liquid has to be pumped.

Now, look, and the question of cavitation comes in any hydraulic circuit as you know when there is a chance of having a pressure lower than the atmospheric pressure in this hydraulic circuit now in a pump as you see that the liquid is usually taken from the sump which is at atmospheric pressure therefore, in a sectional line the pressure is below the atmosphere; obviously, otherwise it cannot draw the liquid from atmospheric pressure to a higher height. So, therefore, while it is flowing through the section pipe no energy is added from outside. So, fluid has to flow, because of the pressure differences; that means, the atmospheric pressure should be higher than that in the section pipe. So, therefore, in the section pipe pressure is below the atmosphere, and this pressure is minimum at the end of the section pipe obviously; that means, at the impeller inlet.

So, therefore, we see there should be a check for this pressure. So, that this pressure should not fall below the vapour pressure of the liquid, and the working temperature this is the restriction for the cavitation. So, let us now see how we can develop the expression for this simply by writing the bernoulli’s equation. Now if we write the bernoulli’s equation between the two points one at impeller inlet another at the sump.

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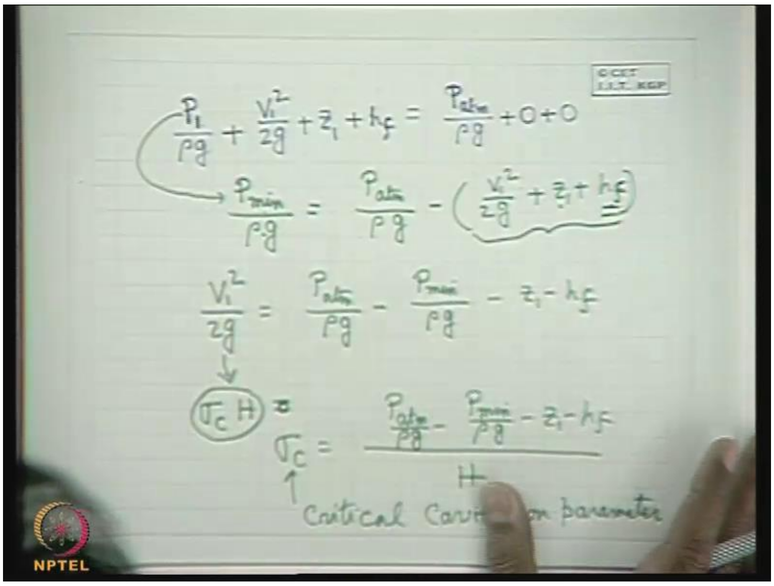

We can write this that at the impeller inlet if we describe the quantities with a suffix one the p one by rho g plus v one square by two g well plus z one plus head loss h f this head loss is head loss in the section pipe is equal to the pressure at the sump at the liquid free surface of the liquid at the lower reservoir, this will be atmospheric pressure p atmosphere rho g there is no velocity well there is well the datamate is zero, because if we measure this elevation z one from the level of the free surface at the sump, then the velocity is also zero.

So, therefore, we see that this p one that is the minimum pressure let us now write the p one as the p minimum p one as the p minimum that is the minimum pressure which is at the impeller inlet it will be p atmosphere by rho g minus all these quantities v one square by two g plus z one plus h f, and it is obvious from the physical concept that if liquid has to be drawn to a height z one overcoming a frictional resistance h f, and generating a velocity v one from an atmospheric pressure under static condition the pressure at the outlet end of the pipe has to be less than p atmospheric by this amount, because this difference creates this velocity of the fluid it is elevated to a distance z one, and overcomes a frictional resistance loss loss due to frictional resistance h f. So, straight from the Bernoulli's equation, we get this here one interesting thing is that in case of a turbine we have seen that in a draft tube h f made a favorable effect in this p minimum; that means, if the loss was more, then the pressure at the runner outlet or at the draft tube inlet was higher, but here it is just the reverse if the frictional losses are more. So, pressure at the impeller inlet is lower. So, therefore, friction loss has to be made as minimum as possible this is the reason for which we try to avoid any additional restriction in the section tube usually there is a very interesting thing we sometime ask that if a pump you see the two sides the pipes are of different diameters definitely you will install the pump with the it is obvious, because if we cannot see the thing from outside everything is under the casing it is very difficult to know which one is the inlet, and which one is the outlet.

So, it is from this sense you can guess that a pump of pipe of higher diameter is the section side, because section side losses has to be kept as small as possible, because pipe with higher diameter keep lower hydraulic losses similarly we avoid any extra bins or any extra valves if it is not needed in the section like, because we cannot help without giving strainer in the section life, because in section line we will have to get rid of the impurity in the liquid to be pumped otherwise it will cause bad effect or damage to the impeller blades.

Similarly, there is a valve known as non return valve in the section line this there this is, because the liquid should not go back to the sump again while in operation. So, these are the essential accessories or attachment to the section line. So, we avoid any additional bins additional valves or preferably a relatively higher diameter in the section line this is, because to keep the hydraulic losses or losses due to friction minimum. So, that the cavitation is avoided. So, that the minimum pressure which takes place at the inlet to the impeller at the outlet of the section pipe should be kept as high as possible. So, this is one of the important considerations in section designing the section pipeline.

Now, in a similar fashion if we define a cavitation parameter how did we define in case of turbine that if I write this velocity head, then the velocity head will be p atmosphere by rho g simply algebraic manipulation minus p minimum now I write p one as the p minimum a same thing; that means, I take it here p minimum by rho g minus z one minus h f. So, this is v one square by two g, and in the similar fashion as I did as we did in case of turbine if this is expressed in terms of sigma c into h where sigma c is known as critical cavitation parameter or simple cavitation parameter sigma c into h, then we can write this same quantity; that means, the if this write this is expressed as sigma c into h the straight way we can write sigma c is equal to p, because I want to reduce another line by rho g minus p minimum by rho g minus z one minus h f by h.

So, this is the value of the this is known as the critical cavitation parameter cavitation parameter parameter which is definitely a operating parameter or a design parameter for selecting the pump for its operational conditions in a similar way as it was done in case of turbine.

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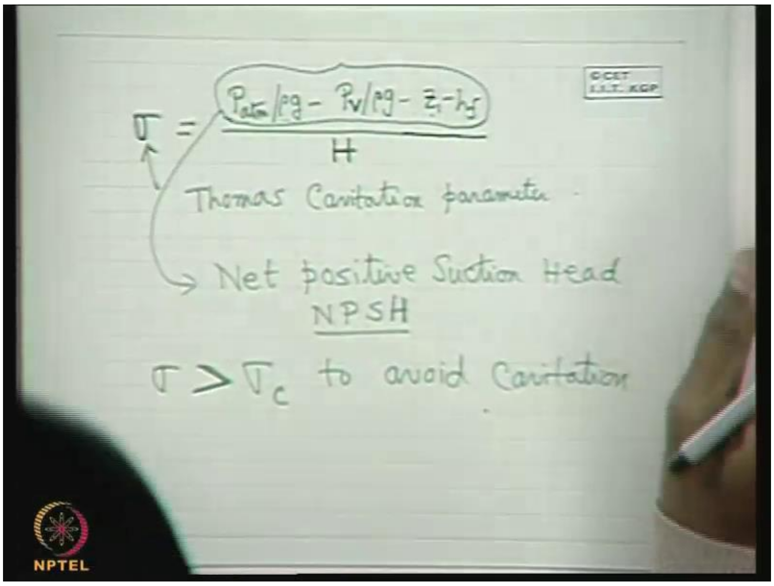

We can define another cavitation parameter sigma known as thomas cavitation parameter where you see the minimum pressure will be the vapour pressure of the liquid at the working temperature; that means, if we just express or substitute this minimum pressure as the vapour pressure which should be the minimum limit minimum pressure this minimum means this is the minimum pressure compared to the pressure in the entire hydraulic circuit of the pump. So, this minimum pressure should fall to a minimum value of the vapour pressure for the working of the pump to avoid cavitation.

Now, if I substitute this you know in the similar fashion as we did in case of turbine this is known as thomas cavitation parameter thomas cavitation thomas cavitation parameter the numerator of this is very important in testing a pump or designing a pump the numerator of this quantity which is known as net positive you write it, it is very important net positive suction head in short we write n p s h net positive suction head this quantity this p atmospheric by rho g minus p v by rho g minus z one minus h f this is the net positive suction head p v that p minimum should not fall below p v.

So, therefore, we see for cavitation to avoid. So, the pressure at the impeller inlet should always be higher than this; that means, sigma should be greater than sigma c to avoid cavitation. So, this is the fixed design parameter this thomas cavitation parameter as you know earlier in case of turbine, and sigma c is determined from the operating condition from the operating condition of the pump its specific speed, and the operating condition . Now, therefore, sigma c should always be less than sigma or sigma should be greater than sigma c to avoid cavitation; that means, for a pump the design should be such that it should give a high value of the thomas cavitation parameter to do that or to maintain that this z one has to be as low as possible.

So, depending upon the vapour pressure of the liquid at the working temperature, and the head under which the pump is operating. So, therefore, sometimes we will see to make this sigma high to avoid cavitation z one has to be kept very low sometimes negative for which the pump may have to be set below the level of the sump you know sometimes from your common experience if you have a deep well if you have to pump liquid from that well. So, if you place the pump at the top floor of the well, then you can expect the cavitations you can calculate it that simply the height of the water column could correspond to a pressure which is lower than the vapour pressure at the outlet end of the pipe.

So, therefore, pump has to be set at a level below that fluid level, because if you give a very. So, there's builds a very much restriction you must know that for a centrifugal pump you should not allow a vertical height of the suction pipe to a level where it simply for the height itself without velocity head without considering the velocity head, and losses gives a pressure which is very equal or very near to the vapour pressure of the liquid into water for example, at the working temperature. So, sometimes we will see in practice the pumps are set at a level very low the pumps are not set at the top floor of the deep well ok.

Now, therefore, we see sometimes we may have to go for a negative z; that means, sometimes below the sump level pump has to be set to increase sigma to avoid cavitation. So, I feel at this juncture to understand cavitation better we should solve a problem immediately.

Excuse me sir.

Yes please.

Sir if we.

Yes.

Ah decrease z yeah also sigma c is also affected.

No here the problem is that if we decrease z you are correct sigma c is affected, but this affect cannot be seen altogether, because z, and p minimum are not independent, because if you decrease z. So, p minimum will also change the minimum pressure at the inlet to the impeller or at the outlet of the pump. So, here you cannot say a solely the effect of z on sigma c yes if you decrease z, then p minimum will also increase. So, therefore, this value may not be increased. So, therefore, here you cannot see the effect solely that is why it is the sigma where z one is the only operational parameter well.

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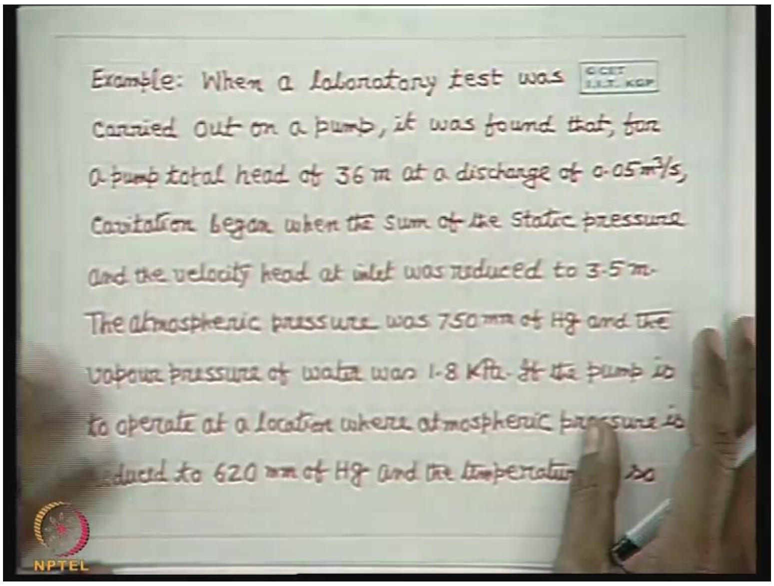

Let us solve a problem good let us solve a problem. So, that we can immediately apply this concept, how it is done just take one problem example when you can write it when a laboratory test was carried out when a laboratory test was carried out on a pump well it was found that for a pump total head of thirty six meter at a discharge of zero point zero five meter cube per second cavitation began when the sum of the static pressure, and the velocity head at inlet was reduced to three point five meter; that means, the cavitation began the total head of the pump is thirty six meter the discharge point zero five meter cube per second these are the two important operational parameters operating conditions of a pump head, and cavitation began when the sum of the static pressure, and the velocity head at inlet inlet means inlet to the pump which means inlet to the impeller, because impeller is the first component which is reached by the fluid was reduced to three point five meter the atmospheric pressure well the atmospheric pressure was seven fifty millimeter of mercury this is the atmospheric pressure seven fifty millimeter of mercury, and the important data is that.

And the vapour pressure water was one point eight kilopascals; that means, this is the vapour pressure of water which means this is the saturation pressure corresponding to the working temperature to the water at this pressure water boils out at the working temperature well if the pump is to operate at a location where atmospheric pressure is reduced to six twenty millimeter of mercury; that means, it is referred to another working condition where the atmospheric pressure is reduced to 620 millimeter of mercury; that means, the reduced pressure you operate the pump at a higher altitude, but the pressure is reduced.

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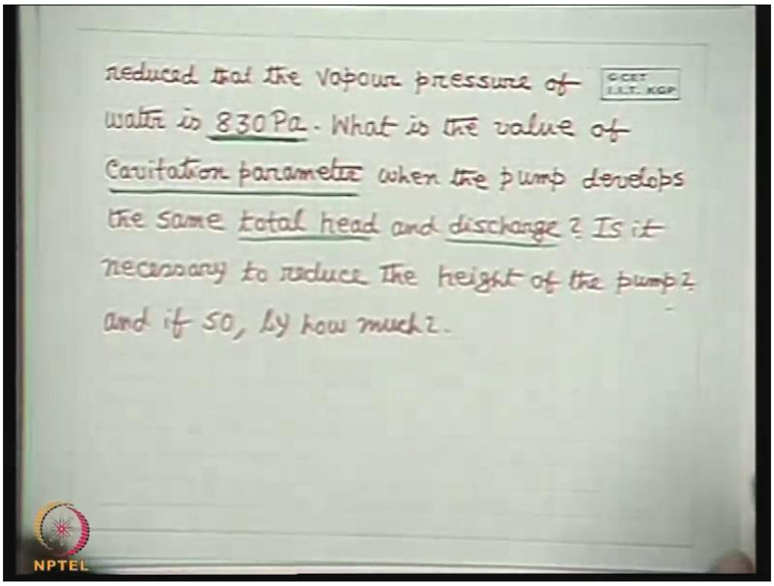

And the temperature is. So, reduced, and the temperature is. So, reduced that the vapour pressure of water is eight thirty pascal's; that means, you go to a region where the pressure atmospheric pressure is reduced to six twenty millimeter of mercury, and also the temperature is reduced such that the saturation pressure of water at that working temperature is eight thirty pascal the temperature is. So, reduced that the vapour pressure of water is eight thirty pascal what is the value of cavitation parameter when the pump develops the same total head, and discharge; that means, in the second case the pump head, and discharge remains the same well this is the clue to the problem the total head, and discharge remains the same, and we have to find out what is the cavitation parameter; that means, this is sigma c is it necessary to reduce the height of the pump now in the second case is it necessary to reduce the height of the pump, and if. So, by how much it is clear now let us well let us solve the problem, well.

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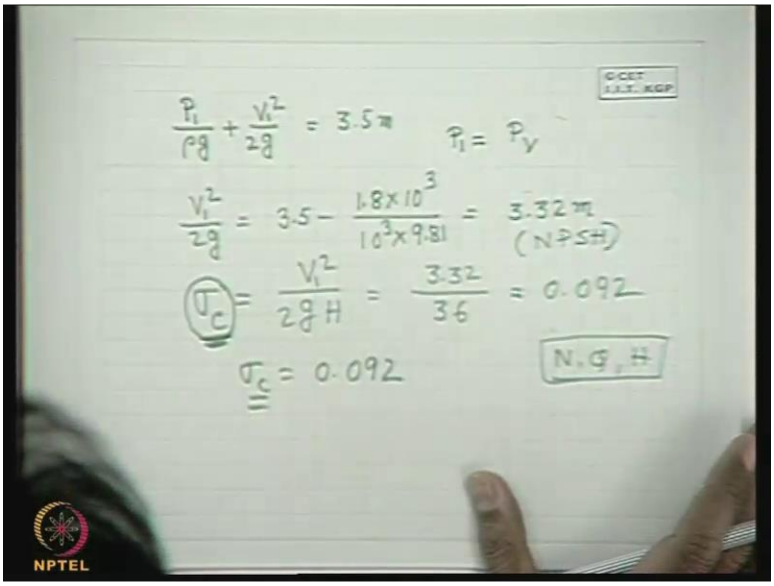

Now, let us solve the problem let us solve the problem now you see initially the pressure head p one first case by rho g plus v one square by two g it is given as how much.

Three point.

Three point five meter now at this condition what happen the cavitation began well the cavitation began at this condition; that means, the p one is p v. So, at when the cavitation begins that p one is p v. So, therefore, what is p v p v is 1.8 kilopascals. So, we can find out v one square by two g is equal to three point five minus p one is one point eight kilopascals ten to the power three pascal’s, and rho nine point eight one. So, this gives well three point three two meter.

So, if you recall this is the net positive suction head this is the net positive suction head, let us recall this what is net positive suction head this is net positive suction head, and this is nothing but v one square by two g you know this is nothing but v one square by two g. That we have already seen earlier that this is the v one square by two g. So, therefore, this is three point three two net positive suction head v one square by two g.

So, sigma the cavitation parameter sigma c is v one square by two g h. So, this will be three point three two divided by what is the head that is thirty six meter that becomes zero point zero nine two now here one thing you will have to understand that this thomas sorry critical cavitation parameter is a dimensionless quantity, and it depends upon the pump speed pump discharge, and the head when the discharge head speed are constant. So, the this value of sigma c representing a dimensionless parameter representing the similarity criteria remains same for the second case also; that means, this value will not change until, and unless the specific speed is change understand the specific speed is changed, because this dimensionless value is a function of specific speed. So, so long n q, and h remains same; that means, the pump is operating at the same specific speed well pump is operating at the same specific speed. So, this sigma c value will be unchanged this also I discussed while discussing the turbines.

So, therefore, sigma c in the second case as it is given in the problem in this way; that means, you calculated in the first case, and tell that this is same for the second case too. Now let us find out really the whether the height restriction; that means, whether the height has to be decreased or not if decreased by how much?

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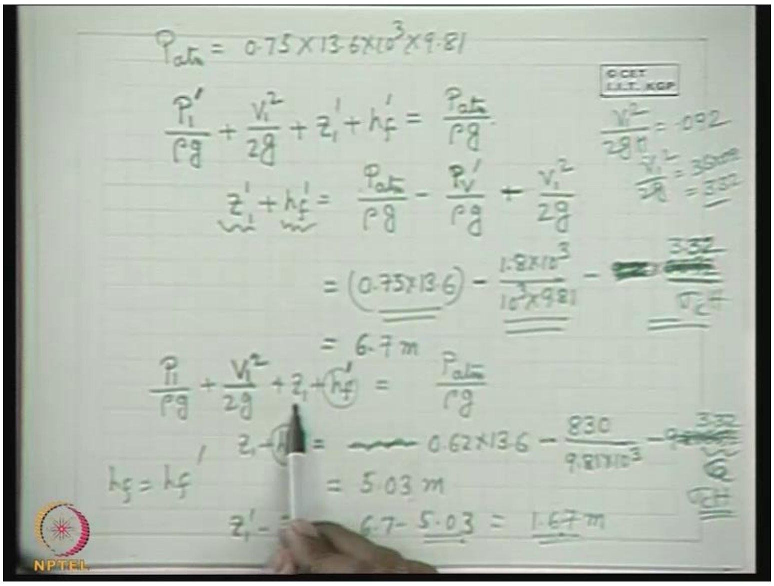

So, let us find out from the bernoulli's equation in the first condition p one by rho g the write the bernoulli's equation between the pump impeller inlet, and the sump inlet sump free surface at the pump, let us define by this prime at the superscript in the first case that v one square by two g well plus z one dash plus h f one h f dash is p atmosphere by rho g well.

So, therefore, we can write z one dash plus h f dash is p atmosphere by rho g minus p one dash by rho g; that means, the minimum pressure which is the vapour pressure in the first case rho g well vapour pressure n the first case.

Second case.

Second case I told that superscript for the second case or first case.

First.

First case. So, this is the first case well p atmospheric minus v one square. So, velocity is same for both the cases, because the critical cavitation parameter remains the same. So, in the first case what is the atmospheric pressure atmospheric pressure is seven fifty millimeter of mercury. So, it will be point seven five into thirteen point six. So, I rho is ten to the power three in case of water. So, 0.75 into 13.6 into 10 to the power three nine point eight one nine point eight will cancel what is p v dash p v dash in the second cases one point eight into ten to the power three pascal's ten to the power three into nine point eight one, and v one square by two g we have calculated v one square by two g that is point zero nine two into nine point eight one, because point zero nine two is v one square by two g h that is the sigma c into g.

So, with consistent unit this is z one dash plus h f dash yes any problem p atmosphere why all right atmospheric pressure is point seven five meter of mercury times its density thirteen point six ten to the power three times the g that is in pascal's. So, this divided by rho g of the water, because this is all in head of the working liquid that is water. So, this becomes this this is p v dash by rho g this is v one square by two g this comes out to be if you calculate six point seven meter; that means, the sum of the elevation head elevation head or elevation from the sump to the pump impeller inlet, and the frictional losses comes out to be six point seven meter well all right.

If I calculate it in the second case which I define without suffix p one by rho g v one remains same plus z one plus h f is equal to p atmosphere by rho g, then what is the value of z one plus h f now you can find out only the application of bernoulli's equation at the pump inlet that is impeller inlet, and the free surface at the sump. So, this will be p atmosphere by rho g now I write the expressions what is the atmospheric pressure please tell me n that case.

Point (( )).

Six twenty millimeter; that means, we can straight write point six two into thirteen point six rho g rho g will cancel minus what is the vapour pressure of water at that condition the vapour pressure of water.

Point eight (( )).

Eight thirty very good eight thirty pascal's. So, it is already in pascal's nine point eight one into ten to the power three this is p one by rho g minus v one square by two g this remains the same, because this is again nine point eight one into zero point zero nine two that is sigma c.

Thirteen point (( )) twenty six.

Twenty six.

Which one?

Thirty six (( )).

That was three point three.

That is three point three two.

Which one?

V one (( )).

V square by two g is (( )).

V one square by two g is three point.

Three two.

Three two o. So, why I am writing this v one square by two g h o sorry very good three point three two. So, this is not sigma c this is sigma c into h v one square by two g this is sigma c I am just putting the value of sigma c very good it will be three point three two into nine point eight one.

No sir (( ))…

O it will be simply 3.32, because it is rho g v one square by two g yes it is simply three point you are correct. So, this value will be six point seven as I am writing from this figure which is worked out problem. So, it will be six point seven taking three point three two I am sorry three point three two yes, because v one square by two g h is this point zero nine two you have calculated. So, v one square by two g is equal to thirty six into point zero nine two your correct, because we already calculated v one square by two g is three point three two, then divided by the head we got this fine this is the head in terms of meter two g is already divided. So, three point three two very good.

So, here also three point three two I think it is no.

Yes sir.

If you calculate it, it will be giving a value of five point zero now here one assumption is there one assumption is there which is very important this is the very silly thing actually I just made a silly mistake the most important assumption is that we consider the h f to be constant here we have written that h f dash here has got h f dash; that means, h f is equal to h f dash here one important assumption comes the next step before going to next step is that if we consider the frictional losses in why this is justified that if we discharge the same, and the velocity at the impeller inlet is same we can consider that the hydraulic losses that the losses due to friction also remains same.

So, if we do that, then we can tell that z one dash minus z one, because h f will cancel will be six point; that means, this is the amount by which. So, if we consider that h f in the two cases are same therefore, by comparing the value we can tell that yes it has to be reduced, and by what amount by this amount six point seven minus five point zero three it becomes one point six; that means, in the second case we have to reduce by this amount the height of the pump from the sump; that means, it has to be kept at this value otherwise he cavitation will occur simply, because if you make this z one more than five point zero three this pressure will be lower than this vapour pressure eight thirty pascal's corresponding to this atmospheric pressure.

So, you see how we use the cavitation parameter sigma c, and by making use of the bernoulli's theorem or Bernoulli's equation between the pump inlet impeller inlet, and the inlet or the free surface of the sump we can determine the height above which from the sump free surface of the sump the pump has to be placed. So, this way you get a clear idea how the cavitation parameter is used in determining the height of the pump where it has to be set above the sump to avoid the cavitation; that means, the minimum pressure that is the pressure at the inlet to the impeller should be more than the vapour pressure of the working fluid at the working temperature well thank you any question very simple I think very simple.

Thank you.