Principle of Hydraulic Machines and System Design
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Lecture – 09
NPSH: Caviation, effect of swirl on the cavitation

So, we will continue our discussion on Principles of Hydraulic Machines and System Design. Today, we will discuss about few important phenomena which are NPSH that is cavitation which is very undesirable phenomenon for the pumping operation and effect of swirl on the cavitation. So, to start with we will discuss what is cavitation, why it is occurring and if it occurs, then what would be the problem and how we can prevent cavitation from the pumping operation?

So, to do that I will just draw schematic of a where a radial flow form is installed to deliver a particular discharge at a given height.

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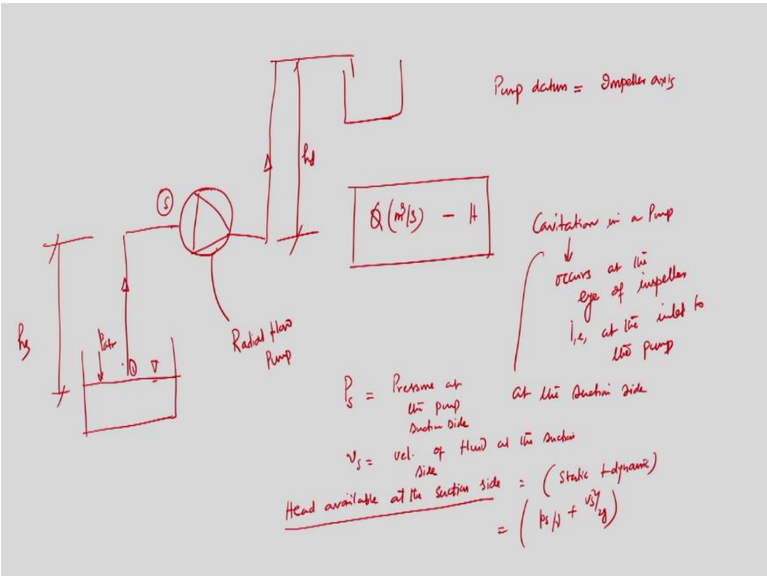

So, if I draw pumping station; so, suppose schematically I am drawing, this is a centrifugal pump and this pump is use to cater or pump is used to supply water in a certain height and it is drawing water from a sump which is placed certain height below the pump axis.

So, here pump axis is the impeller axis; pump datum is a impeller axis. Here, pump datum is the impeller axis and this radial flow pump is installed in a place, where the pump is use to supply pump is use to supply this radial flow pump, use to supply water may be Q m^3/sec against a head of H.

So, this pump is used to supply Q meter cube per second water against a head of H, in a reservoir while it is drawing water from a reservoir which is located say hs distance below the pump axis level. And it is also supplying water at which is supplying water to a reservoir which is again located hd distance above the pump axis level.

So, now question is whenever pump is running, then you know cavitation might occur. What is cavitation? Let me talk about of few words about this. Cavitation is a very common and it is not a desirable phenomenon at all. So, whenever pump is running, I will discuss 2 important thing; I mean normally we go for pump installation in a flooded suction mode not in a negative suction mode.

So, whenever pump is running, there is pump is I told you earlier that pump is a power machines which observes energy and here, mechanical energy is converted to the store energy of the fluid by and it is used to increase either by its special or velocity. So, we are talking about the pump is normally used to develop a head. So, develop a pressure.

So, whenever pump is running normally the cavitation occurs at the eye of the impeller; that is very important. This cavitation which is not an which is not a desirable phenomenon at all which occurs in a pump at the eye of the impeller; at the eye of the impeller that is at the entry to the pump. That means, that is at the inlet to the pump.

Now, if at the inlet of the pump pressure is something and if the pressure suppose I am telling that means, where it is happening the cavitation is most likely to occur at the suction side. So, from these I can say cavitation in a pump, cavitation in a pump which occurs at the eye of the impeller that is at the inlet of the impeller; that means, it occurs at the suction side.

Now, if I assume the pressure of the suction side is Ps and somehow, if that pressure falls below the vapor pressure at that temperature, then local boiling would express, and some vapor bubble will generate. Now, the vapor bubble will continue in you know will continue into generate and suddenly, it will collapse.

Whenever it collapses, there will be a you know cavity and the surrounding liquid will lasts towards to fill up that cavity and it will create some audible noise and it becomes very detrimental because it may erode some material from the impeller. So, it is very desirable, and it will create an audible noise and I said you from where pump of water can understand cavitation has started. So, he should take a preventive measure that he should immediately shop the pump.

So, what I said that if the suction side, if at the suction side pressure falls the falls below the vapor pressure at that temperature local wiring will take place, local wiring will starts as a result of which bubble will generate and bubble will be accumulated over there and there will be a situation when all the bubbles will be all the bubbles will collapse.

And then, there will be a cavity to fill up that cavity surrounding liquid will rough into the into there and there will be a audible noise and this phenomenon eventually erode some material from the pump impeller and this phenomenon is known as Cavitation. And this is not a desirable phenomenon as I told you. So, whenever operator will come to know that the cavitation has started by hearing and audible noise, he should stop the pump.

And not only that as a designing in your whenever he or she is designing or say a system a pumping system he or he or she should take care about this effect; I mean he should ensure he or she should ensure that there should not be cavitation at all because it is not use a detrimental to the pump operation.

So, now we had understood that cavitation; that means, as the suction side pressure should not fall the vapor pressure at the temperature. So, you have to ensure that whenever pump is withdrawing water; pump is drawing water from a sump at the suction side, we need to ensure that pressure should not fall the vapor pressure at the temperature. Otherwise cavitation may start.

So, how we can ensure that pressure should not fall on vapor pressure and to do that we need to know the expression of cavitation and we need to you need to know that what would be the head available at the pump suction side; it is a pressure head. So, you need to know the total head available at the pump suction side and if the total head falls below the you know that vapor pressure then probable cavitation will start.

So, this is the case that I have taken example, suppose hs is the distance; hs is the height below the pump datum level that is pump impeller axis level from an who's from where pump is withdrawing some water. And since, it is a open atmosphere; so, Ps atmospheric is acting on the sump. Now, what is a head available at the suction side that we need to know.

So, if I now apply Bernoulli equation or a steady flow energy equation between let us say this point 1 and 2 suction side, then if Ps is the suction side, pressure at the pump suction side at the pump suction side and Vs is the velocity of water at the suction side; velocity of fluid at the suction side. Then, what is a head available at the suction side? So, head available is total head that is static head plus dynamic head; that is static head plus dynamic head that is $\frac{P_s}{\gamma}+\frac{{V_s}^2}{2g}$. So, this is the total head available at the pump suction side you know that is a static head plus dynamic head.

Now, if this head falls below the vapor pressure at the temperature; that means, head available at the pump suction side static plus dynamic head and these head should not fall below the vapor pressure.

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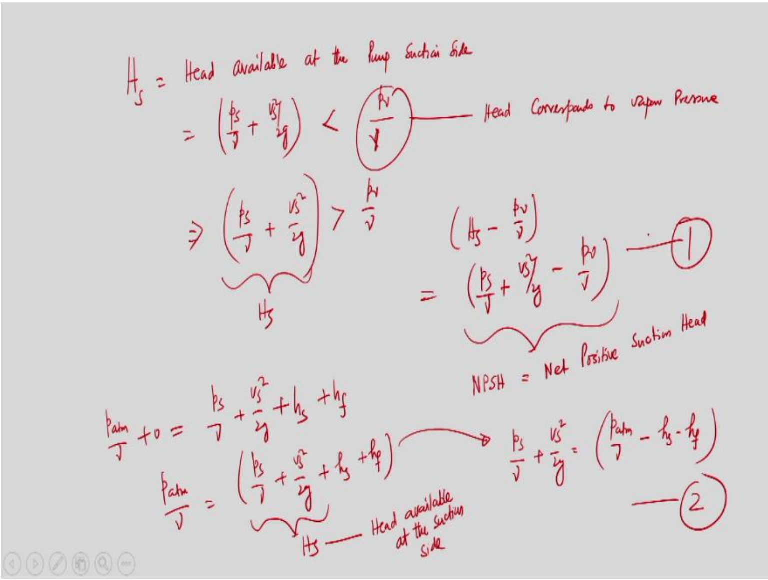

So, head available at the pump suction side Hs. So, this is Head available at the Pump Suction Side is equal to $\frac{P_s}{\gamma}+\frac{{V_s}^2}{2g}$. If this head is less than vapor pressure, the head corresponding to the vapor pressure p v by gamma. So, this is head corresponds to vapor pressure.

If $\frac{P_s}{\gamma} + \frac{{V_s}^2}{2g} > \frac{P_v}{\gamma}$

then, we can ensure that there should not be cavitation; that means, we know we need to know the that means, this quantity that is H s should be always greater than the head corresponds to vapor pressure at that temperature.

Then, we can ensure that the pump is in a safe condition that means cavitation should not start. So, we need to know the explicit magnitude of if Hs -$\frac{P_v}{\gamma}$ that is $\frac{P_s}{\gamma} + \frac{{V_s}^2}{2g}$ - $\frac{P_v}{\gamma}$ So, this is the expression well into know.

So, this quantity will give some for information. If it is negative, then there is a problem cavitation might start; if this quantity is positive; that means, H s is greater than $\frac{P_v}{\gamma}$ that is the net head available at the suction side is greater than the you know head corresponds to vapor pressure at that temperature, then pump is in a safe condition. So, cavitation should not start.

These quantities is known as net positive suction head or NPSH, very important quantity that you have I have written in the beginning of the in our lecture in the title. So, this is known as Net Positive Suction Head that is the suction head that amount of positive suction head, the total positive suction head available is the net positive suction head. There is a net positive suction head.

So, this quantity is an indicative measure of whether cavitation will start, or cavitation should not start in a pump operation. If this quantity is positive that is the net positive suction head, it will it I mean if this quantity is positive pump is in a safe condition cavitation should not start; but if this quantity is negative, then cavitation will start.

If I go back to my previous slide and if I apply Bernoulli equation between point 1 and these let us say this is point s at the suction side, this is s and this is 1; then, I can write I can write and if I take this is the datum level that is the pump level is a datum level. Then, I can write $\frac{P_{atm}}{\gamma}$ and also some cross sectional is much greater than the pipe cross sectional area. So, velocity can be node has compared to the velocity in the pipe.

$$\frac{P_{atm}}{\gamma} + 0 = \frac{P_s}{\gamma} + \frac{{V_s}^2}{2g} + hs + hf$$

if we just write the expression of this quantity which is again the head available at the suction side.

$$\frac{P_s}{\gamma} + \frac{{V_s}^2}{2g} = \frac{P_{atm}}{\gamma} - hs - hf$$

$$\text{NPSH} = \frac{P_s}{\gamma} + \frac{{V_s}^2}{2g} - \frac{P_v}{\gamma} = \frac{P_{atm}}{\gamma} - hs - hf - \frac{P_v}{\gamma}$$

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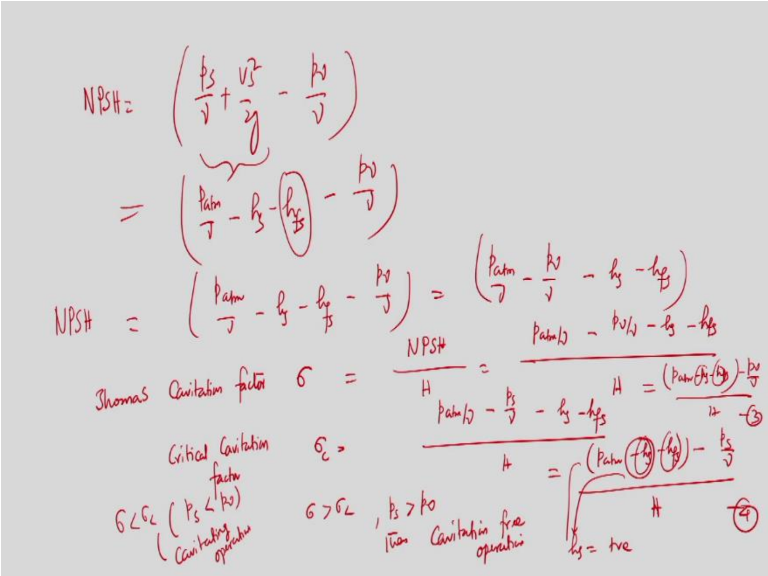

Note that we have taken the effect of losses into account in the suction side because I should tell you that whenever pump is installed in a particular station, it is always advisable that the whenever it is drawing water from a sump of from a reservoir at the end of the suction pipe which is located in the sump, we need to a we need to put a strainer.

And also there will be a valves at the suction side and because of the presence of and their might be some bends because of all these you know stuff that is strainers valves and bends, there will be a frictional losses and that losses will be taken into account where applying the study flow an execution between point 1 and s. And this quantity hfs, this quantity hfs takes into account all those loss I mean a losses due to all those stuff like valves you know strainer and bends.

Now, the very important pump is that one cavitation factor just like in the previous just like in the previous case, when we have defined slip, when you have quantified the amount of slip, we have you know defined 1 slip factor. That is the component of absolute velocity in presence of slip to the component of absolute velocity and tangential direction without slip that is $C_{\theta}'/ C_{\theta 2}$.

Similarly, we can define one you know cavitation factor which is known as Thomas Cavitation factor; Thomas Cavitation factor sigma which is defined that Net Positive Suction Head. So, this is all these terms in Net Positive Suction Head are the head represent a unit of head. So, this Net Positive Suction Head; so, when your defining a factor it should be a dimensionless. So, we have to define by again a head.

So, the each and every term in the expression of NPSH represents the unit of head and we would like to define one factor that is Thomas Cavitation factor. So, we should make the you know factor is a dimensionless. So, we should define by a quantity head. So, NPSH available, the net positive suction head available at the suction side divided by H; that is known as Thomas Cavitation factor or NPSH. So, this is very important quantity

Thomas Cavitation factor $\sigma = \frac{NPSH}{H} = \frac{\frac{P_{atm}}{\gamma} - hs - hf - \frac{P_v}{\gamma}}{H}$

So, these factors I will now discuss little bit about this factor. This factor will give an indication about that whether cavitation will start or not because fine, NPSH of course, will give you an indication these an indicative measure of cavitation that is cavitation will start or cavitation should not start that will be you know of that information you can obtain from the expression of net positive suction. But still, now we are defining another factor that is Thomas Cavitation factor and from where we can discuss about, we can tell that if what is cavitation zone and what is cavitation free zone.

So, that factor defined the net positive suction head to the head develop by the pump. Now if we you know write the expression of sigma and this is the Thomas Cavitation factor;

Critical cavitation factor $\sigma_c = \frac{\frac{P_{atm}}{\gamma} - hs - hf - \frac{P_s}{\gamma}}{H}$

So, from there we can again define a critical cavitation factor that is critical sigma; critical value of cavitation critical cavitation factor sigma c.

If $\sigma > \sigma_c$, Ps > Pv

I am telling of critical cavitation factor sigma c and when sigma this some are cavitation factor greater than the greater than a critical value which implying that ps should be greater than pv; then, you know this is known as Cavitation free operation. This is this is Cavitation free operation.

So, having a closer look at equation 3 and 4, equation 3 and 4 we can say that if sigma greater than sigma c; that means, which imply that p s should be greater than p v; then it is cavitation free operation. But if $\sigma < \sigma_c$ that is Ps < Pv, then this is known as Cavitating zone; Cavitating operation. So, whenever suction pressure the suction side falls below the vapor pressure, then sigma will be less than critical value. So, then cavitation might starts.

From where I can argue that see here another important quantity is hs and hfs, these are very important quantity and from where I will a discuss another important issue that if somehow I can make hs positive; that is if I make hs I mean minus hs if I can it is positive, then I can have a relatively you know safe operation of the pump.

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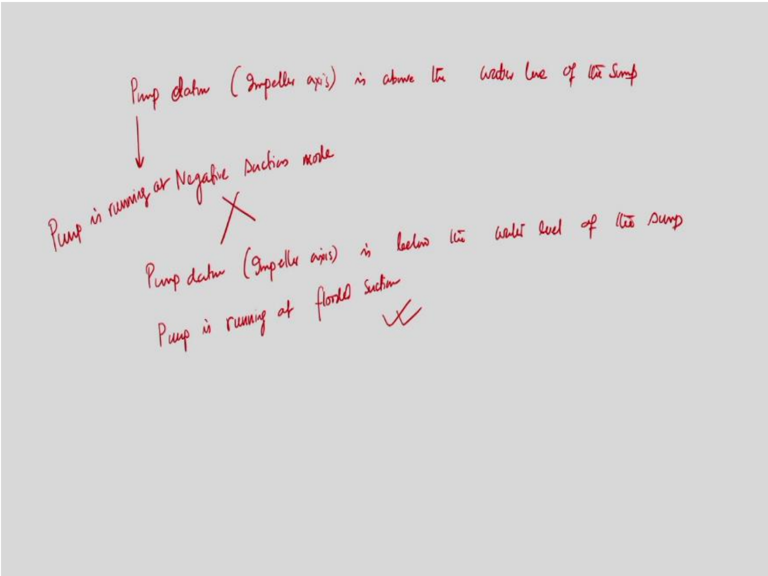

That means, whenever pump is drawing water rather whenever I will discuss now. So, from this expression I can tell that whenever pump axis level pump datum that is impeller axis is above the is above the water level of the sump; whenever pump datum the rather the impeller axis above the water level of the sump and if we operate the pump and then it is called the pump is called the Negative suction; is called Negative suction. Pump is operating pump is running at Negative suction; Negative suction mode. That means, whenever pump or impeller axis is above the water level of the sump that is a case we call it pump is running at a negative suction mode and that case it is very you know very important to ensure that cavitation should not occur and we need to take all the preventive measure.

So, this is not desirable for the pumping system design, if it is not possible at all to have if we need to go definitely that pump has to installed above the water level of the sump. Then of course, we have to go for this kind of operation mode that is negative suction of mode. Otherwise, it is in a desirable at all for the pumping system design. Rather when pump datum or impeller axis is below the water level of the sump, then pump is running at flooded suction mode. It is called at flooded suction, there is positive suction.

So that means pump axis or impeller axis is located below the water level at the sump; that means, where always having head available head by the static height. Atmospheric pressure is there, but whenever impeller axis is located let us say z distance or hs distance below the water level of the sump, then we always have that amount of a data level and this is known as flooded suction that is pump is running at flooded suction.

This is very important rather I should rather as a designing here everyone should prefer to design pumping system in that in this mode that a pump should operate in a flooded suction mode. If we design to operate rather if we design to run a pump in the flooded suction mode, then we can ensure that it is it is safe from this kind of phenomenon that is cavitation should not occur.

So, this is always desirable that you know impeller axis or pump datum should be always below the axis as a pump below the level of water level of the sump, level of water in the sump. If this is a case, then we can argue from the expression that we have derive in a in the last slide. In that case hs should be always positive. So, it will in that case this hs will be positive; if hs is positive I mean this entire quantity will be positive, this entire quantity will positive. So, this will add a head on the top of the head that is available because of the atmospheric pressure.

So, if we install a pump that is pump impeller axis or impeller pump datum is located below the water level of the sump, then apart from the atmospheric at a level we are having another head available that is equal to the static height that is there. So, in that case we are having a safe operation and we should go rather I should prefer rather I should suggest you that all the designers should design a pumping system in a flooded suction mode to avoid this kind of unreasonable phenomenon, I mean cavitation; cavitation should not occur ok.

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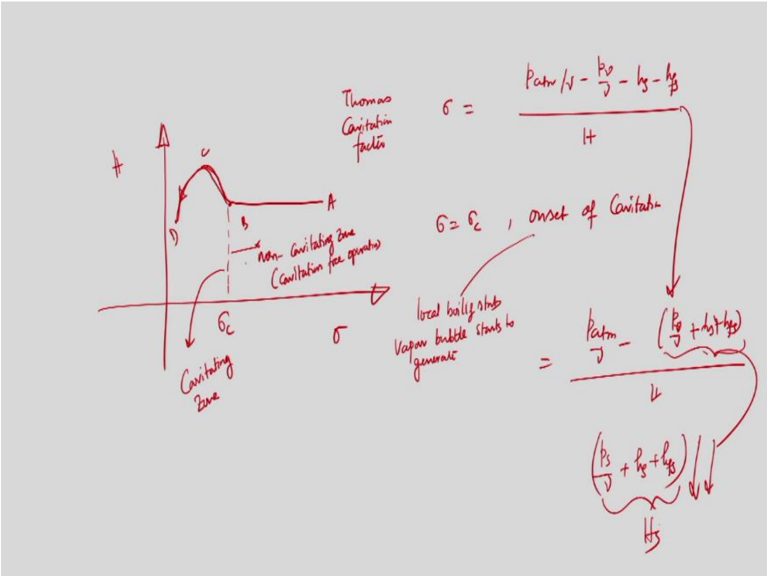

Now, I will discuss another important factor that I was said you Thomas Cavitation factor now Thomas Cavitation factor sigma is defined; this Thomas cavitation factor is defined $\sigma = \frac{NPSH}{H} = \frac{\frac{P_{atm}}{\gamma} - hs - hf - \frac{P_v}{\gamma}}{H}$ So, this is the Thomas Cavitation factor. Now, if I draw the H versus sigma with Thomas Cavitation factor. So, I will get a curve like this. I will explain why this is the curve look like this. So, this is sigma c, critical.

So, if I reduce the value of sigma and whenever sigma is sigma c. So, whenever sigma is equal to sigma c, then this is onset of cavitation; this is onset of cavitation. The curve look like this if I plot x versus sigma curve, then it look like this. So, if I reduce sigma by increasing that is by reducing this suction head, the suction pressure the head available the suction side. So, if I reduce the that means

So, now if I write, if I replace Pv in terms of Ps; so, this quantity if I replace Pv by Ps; hfs, then this is nothing but the suction head available the suction side. Now, if this quantity I mean if when ps is pv, then probably this is sigma c that is a onset of cavitation and onset of cavitation means you know local boiling starts that is vapor bubble starts generating; starts to generate.

So, when we reduce sigma value by changing this quantity, I mean by changing this static head., if I reduce sigma c sigma towards sigma c, then that is when this quantity reduces and when ps becomes pv, then that is onset of cavitation you know vapor bubble starts.

Now, we can see. So, this is A this is B this is C and this is D. Again, if you see that again is the further reduce sigma value, then probably you are having you know high head generation. Why it is happening? Because when sigma is equal to sigma c onset of cavitation vapor bubble starts generating and the vapor bubble will be accumulating, and it will make the surface very slippy. So, whenever liquid is flowing about the slippy surface, it does not feel the effect of solid surface and the frictional loss becomes less.

So, at the onset of cavitation vapor bubble will starts you know you know generating and vapor bubbles will be accumulating in a particular place and it will make the surface slippy and as if the water is flowing over a sleepy surface and it the water does not fill the presence of solid surface and frictional loss will be less. Since, the frictional loss is it become you know will be less, the head develop by the pump will be will increase and that is what is represent by the curve BC.

Now, see already cavitation started. So, the vapor bubble will continue the you know continue generation and there will be a situation when a huge number of vapor bubble will start blocking the passage and as a result of which it the water will flows a resistance and it that the head rise drastically false. So, then head falls drastically, and which is represented the by curve CD.

So, we have understood that at the onset of cavitation bubble will start generation. It will make the surface slippy because the vapor bubble will make the in a particular place very you know it will block and it will make the surface slippy and water and a fluid, one feel the presence of solid surface. It will eventually reduce the effect of frictional losses and the head develop will increase; that is that is represented by BC.

Now, since cavitation has already started. So, now, the vapor bubble will continue generation and there will be a situation when huge number of vapor bubble will block the liquid passage and it will eventually create a huge resistance and as a result of which head will drastically fall and that is represented by the curve CD.

So, this is the significance of the Thomas Cavitation factor that is if sigma becomes sigma c is a this is known as this is known as non-cavitating zone; this is known as non-cavitating zone; this is known as non-cavitating zone or cavitation free operation. While, when this zone is known as cavitation free operation, but when sigma c sigma is less than sigma c, this is known as Cavitating zone.

So, we need to take we should this you know very serious about this undesirable phenomenon. I mean whenever you are designing a pumping system. So, there are 2 suggestions; first one is that we should always go for started suction mode that is impeller axis should be always below the water level in the sump. So, that apart from the atmospheric head, we are having another head corresponds to static height. So, if we run pump in a flooded suction mode, we are always safe from this undesirable phenomenon and we always need to check that if sigma less than sigma c, then it is a cavitating zone.

Then we should we need to take into account that how we can reduce the frictional losses; how we can reduce the static height so that even if the pump is running in a negative suction mode, we need to ensure that frictional losses at the suction side as well as the static height the suction side should be reduced. So, that pump can be operation without having this kind of undesirable phenomenon.

I stop here today. We will continue our discussion in the next lecture.

Thank you.