Engineering Thermodynamics
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Lecture - 35
Applications. Problem Solving: Compressors, Fans & Blowers. Pumps

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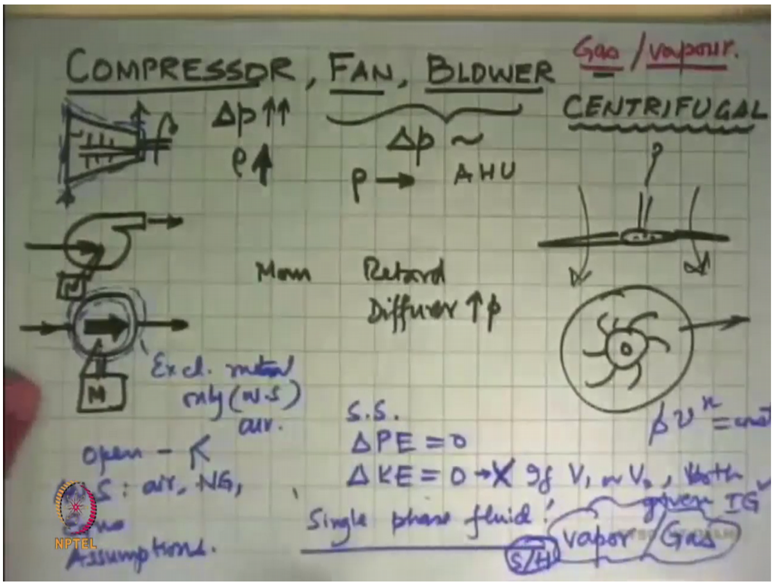

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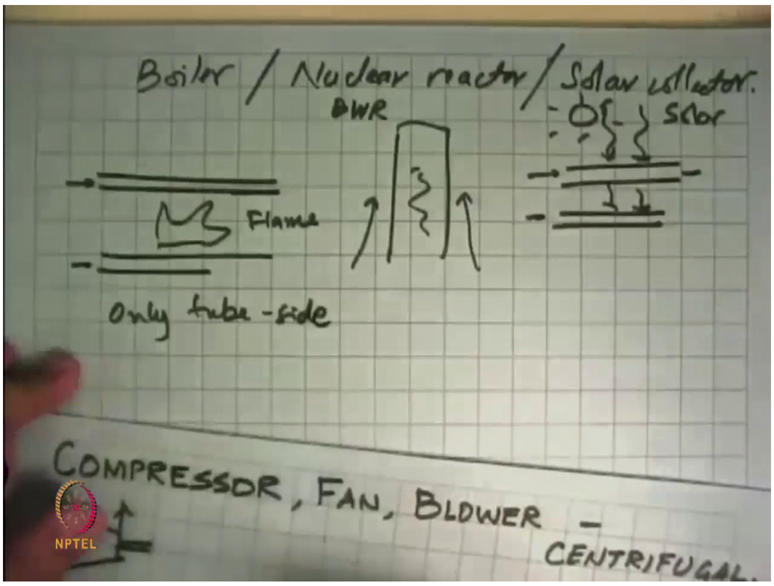

Well, one more type of a heat exchanger that we have not talked here, let us take a look it, when we needed. This is what is called a boiler, very common device that your main thing that produces high pressure, high temperature steam for generating electricity. For boiler, I can even put it this as a nuclear reactor or if this is given a solar collectors. What is happens here is that on the tube side, it is the same process that happens in the heat exchanger that we have seen.

So, we have tubes in which the fluid cold fluid enters, it gets heated up and comes out. But, what is happening outside the tubes is that in the case of a boiler, we have burning the fuel. So, there is a tube, there, a tube there into which we are putting the cold fluid, but outside here there is the flame or a fire or a combustion taking place. And this is transferring heat to the tube, this is not just by convection like we saw earlier, but both convection and radiation, it is heating up.

A nuclear reactor the heating takes place, because you have a fuel rod in which heat is being generated and outside this the coolant is going out. And this coolant gets hot and comes out. This could also result in phase change, if it is the boiling water reactor yet that would be using water here. And the solar collector, and you could have a bunch of tubes in which this fluid is flowing, and they are just getting heated from the outside by solar radiation. So, the outside is not strictly a heat transfer in the classical sense that we have seen, but at least on the tube side our analysis will be exactly the same on what we have talked a (Refer Time: 02:19). So, there is only a tube side's fluid, and its analysis can be done. So, behaviour group test ok.

Here the next set of equipment that I will use, I will put three names here a compressor, fan or blower. The slight difference between them you know, but all of them do is they call a gas typically air to flow. And in particular, they are looking at the fact that these are what are called centrifugal machines as different from or they displacement devices.

So, if this would the simplest example of a fan is your ceiling fan, so all you have this is a hub with blades on it, and there is a motor inside this. So, if you electricity to it, and it causes an airflow over there. So, the same thing with more blades, like this is exhaust fan of the kitchen or the bathroom that would be a fan or blow slightly different, you would have seen of blower in some of the desert coolers, where there is the circular device into which air goes in, and on this there is a wheel with these type of things, this is rotated and the air comes in from this side, it throws it out on one side that is one type of a blower here.

So, what fans and blowers do is that the pressure increase in these devices is very very small, and very modest. It is not very large millimeters of water, tonnes of millimeters of water is all you get that we do not really need much more than that. So, say a blower reduced in the air conditioning of a whole building will be one blower at one point, which is called a air handling unit A H U that takes in air part of the air from the room itself gets in some fresh air and blows it, and that is go over the evaporator coils, and that we are cool air inside the building (Refer Time: 04:33).

Compressors the difference is that delta p here is quite large and substantial. So, here this is compression taking place, so density increases. Here density is the almost constant. So, we can treat this as incompressible flows. So, we can treat that in the air density is not changing even though it is air, and small changes in pressure are there. But, here we cannot make that assumption. And the reason this is a density is constant, and because delta p is very small that is why, we can say the constant density or incompressible flows, this would be treated as a compressible flow within pressure changes.

In making schematic diagrams, we use these symbols over there. So, this is means that the gas or air goes in inside this there is a shaft on which there are blades, the air keeps flowing over this or the gas keeps flowing over this. There is a rotating part which will give momentum to the gas, and a stationary part which will reduce the kinetic energy, and increase the pressure without any work input or with input. Then the next stage we will do it little more, so like that we do the compression, you first we give momentum.

So, of the energy, and then we retard it. When you retard it, it is like a diffusion basically what we have and because of this the pressure goes down. And then we can again put it into the next set of blades to the same thing, and to the same thing here then again, so this would be called multi-stage compressor. And all practical compressors by enlarge or multi-state, the aircraft engine is the good example of that. In schematics, we can also use this symbol largely for sometimes for compressor, but largely for fans and blowers these symbols ok.

So, now we said how do I analyze these. And for that we accept that do this happen, there has to be a work input in this. So, we can show here by a symbol and write a motor that is a motor powering this or this has got a motor, this is powering this device. So, what it does is you have work input taking place, and the system it was defined in all of these which says that look, I will take all this this is my system or one say that. This is the system excluding all the metal, and only say the gas or the working substance which is their air or whatever. So, this system has one inflow, one outflow, and there is a power shaft power being input to this.

So, once you have drawn the system boundary, we know that these are the open systems. Even in this case, the story is the same. We can show the system boundary to be like that. These are open systems that means, we know that conservation of mass, conservation of energy, and interrupting equation which ones to put. And then we say that this could be air or it could be some other gas some that means there a methane is a natural gas N G.

And then we say ok, if these are the working substance now, what are the equations, we have to write, so that we do that. And the next step is what we assumptions, and that help us to get that big question into a simple thing. And the main assumptions we do here is firstly of course that being a flow system which says a steady state, I think you just a time.

Then we say that delta P E is equal to zero, because the potential the elevation difference between these devices, in some cases it is negligible, in some cases it may be a meter or two, and meter or two rho g h g is negligible compared to the other changes that take place here. So, delta P E equal to 0 is justified. Unless, otherwise given delta change in kinetic energy can be assume to be 0, if there is no mention about velocity in the problem.

However, if the velocity typically either the inlet or at the outlet or in both places is specified, then this is not to be assume, then the velocity term will remain in the first law equation. So, if V 1 or V 2 or both, they are given then this is not the case ok, so then this would be wrong. So, once we do that we get to the equations, and then we are in a position to solve.

Now, this type of device, and this is where engineering comes in, they always handle a single phase flow. Even the earlier device which are the positive displacement devices that I mentioned, they also are designed for handling single phase fluid. The practical engineering of this machines, if you had a wet substance going into this is extremely difficult, in last part because liquid will accumulate here or there by gravity or liquid droplets will go and hit the moving part and break it up.

And so we always make it a point that no matter what type of a work transfer device, it may be whether it is a positive displacement compressor, fan, blower, these always handle single fluids. So, these devices all that other earlier device, I said there will be a either handling in a vapour or a gas, I am not pulling the word liquid over here, because that we will see in the minute that machine that handles liquid is not called compressor fan or blower, but it is called the pump, so we look at pump separately ok. So, this is very very important.

Now, moment we say it is vapour or a gas, if it is the vapour state, it will be superheated vapour, it cannot be a wet state. And it could be possible to assume ideal gas behaviour, but if it is like nitrogen or oxygen in that case, ideal gas behaviour is ok. Otherwise, like in a refrigeration system, they will have to go to the property tables and get the data from there.

Nevertheless this process can be approximated by something like p v to the power n equal to constant. If it is p v to the power k equal to constant, we also know additionally like this is the reversible isentropic process, and I can use this equation in water. But, the important part is that compressors fans and blowers, they handle a gas or a vapour, and they never handle either a liquid. And of course, no machine with handle a wet substance. And we will see that in a minute on the what it means for the implication in designing cycles, but the wet state inside of over producing device or a over consuming device is a big big problem. So, all the engineers will do everything to avoid that.

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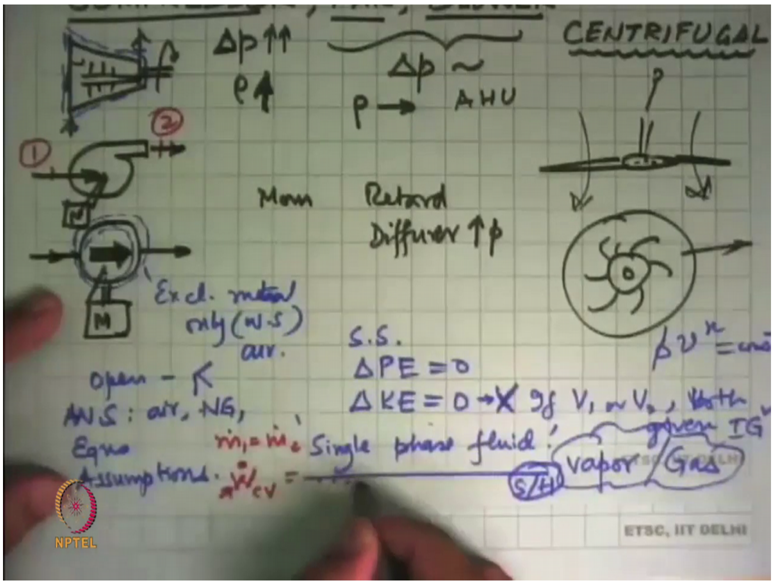

So, that was; so that the assumptions, these are the equation. Then we get the conservation equations that m dot 1 equal to m dot 2, they put the states 1 and 2 or inlet and outlet, and then get what will be the work transfer W dot c v in this case in terms of properties.

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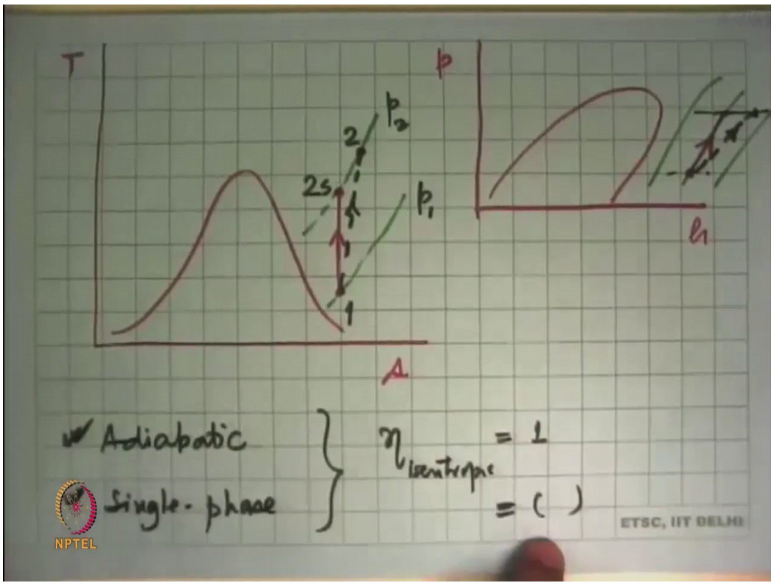

On the property diagrams, say we take the T s diagram. If it is a vapour, we will have to show the dome. And compression will be from say this state, to this state this is what happens in a air conditioner or you know refrigerator. So, we are well below the critical point, we have not very far away from the dome. So, we will show the dome that this is the compression process.

On the ph diagram away, we will show the dome. And we say that what are the constant entropy lines, then we assumed it be to isentropic. These are constantly entropy lines, say there only the constant entropy line, this this is the constant entropy line, where are my states its or inlet state is there, outlet state is there, this is the compression process.

And now we say what if the process is not isentropic ok, but being small devices and we do not want to make life too complicated is not only say that this is the state, we also say these are all adiabatic. So, the important things about work consuming work producing devices is firstly they are adiabatic. And from an engineering context, we necessarily have a single phase fluid.

Now, if it was not a reversible process, and we say it goes to the same final pressure. So, in this case the constant pressure lines are here and here. So, the inlet pressure is assumed to be constant, the discharge pressure is also the same. So, this was p 1, this was p 2, and then that anisotropic compressor would do that. So, this we will denote as 1 to 2 s means isentropic, and 1 to 2, this is the real lines a dotted line, because the process is irreversible.

So, you have to calculate the real work from the isentropic efficiency or you have to calculate isentropic efficiency, we need to know one of these things, either this change change or the working. And two of these are known, the third one can be calculated. On the p h diagram the discharge pressure is going to be the same, inlet pressure is the same, but entropy has to be increase. So, these are the lines of increasing entropy, so this we will go off on that side.

So, if nothing is said, we say that isentropic efficiency is equal to 1. If it if the value is given, then we know that we need to calculate one of these two points from the isentropic efficiency. So, those are the important things about fans compressors and blowers, let me take that these are adiabatic. They will handle a single phase substance. This is not that thermodynamically says, you cannot handle it. Thermodynamic said yes, you can put a wet thing through it, the science is not wrong. The engineering says that look it is too much of a nuisance, equipment becomes unreliable, we will not make equipment, and nobody makes equipment like that. And unless specified, we assume isentropic efficiency to be 1. If it is not 1, we have to take that into the problem, and then begin to solve it.

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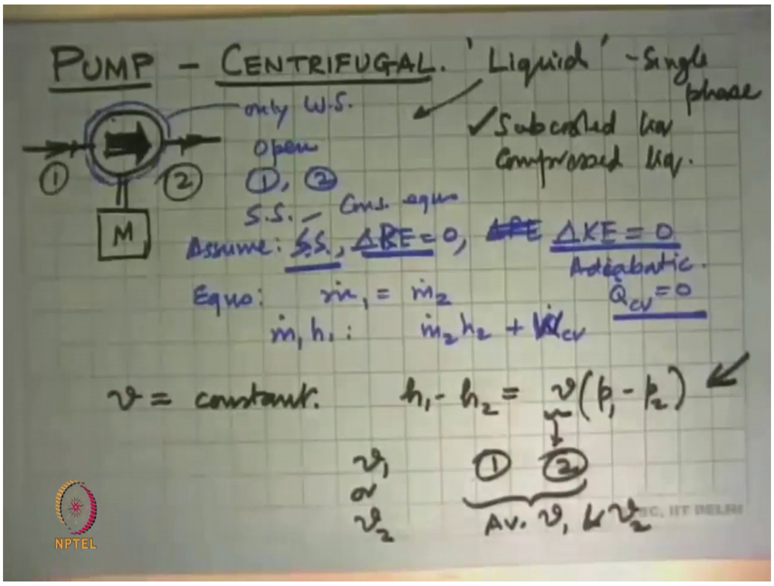

So, now we come to the counter part of the compressors and fans. And we say that they now look at a centrifugal pump. The word pump means that this handles a liquid, but what we know from thermodynamics is that what we call in common language is liquid is we can call it either a sub cooled liquid or compressed liquid.

And in all cases, we assume that from this is the symbol for that circle with an arrow, and we say that this is the inlet and this is the outlet, inlet state is 1, outlet state is 2 throughout the state the process, it remains a liquid. We do not want a situation whether either a inlet is wet, and then you make it into a compressed liquid that is not something you can do. But, like I said the earlier principal about engineering is that this will be single phase. But, there is one condition, where we do have a problem with a practical problem whose rules lie in thermodynamics, we will see that in the few minutes.

So, what does a centrifugal pump do? Firstly, it is a liquid thing, the moment we say this is the so let us go the systematic way that we would like to approach this having made the symbol. We say that this is our system boundary as (Refer Time: 18:09) well there is one inflow, one outflow, and to run the pump. We have an external prime mover, this could be a motor or the diesel engine that you seeing agricultural applications. So, there is work input to the pump, they have one inflow and one outflow.

And we say that our system if everything inside this, but that is only the working substance is there, no metal, oil, anything else is considered. This system we know is an open system, so there is one inflow, one outflow. And we know that this is a liquid, so that is a when how can we then begin the analysis. First thing we assume is the steady state. So, when I am writing this, we are actually should be saying that this is the assumed that there is steady state. And elevation references are very small delta K E equal to 0 is ok.

And pumps you know though they increase the pressure, they do not increase the velocity very significantly at all. So, it is perfectly fine to say that sorry the kinetic earlier case elevation was 0, so delta P E is equal to 0. Since, velocity changes in the machine are very small, you can say the kinetic energy changed from inlet to outlet of a pump is also 0. So, with that we do you know now that it is open system, what are the conservation equations we have to write.

Then under these assumptions, what will be the equations become. And in this case conservation of mass becomes m dot 1 is equal to m dot 2. And then we also say that this device does not lose heat, if it is a hot substance than ambient or it is not being heated. So, you said that this is a adiabatic device, which is the same thing about the reciprocating machines, we said the same thing about compressors, and blowers. Here often they say adiabatic means that Q dot c v is equal to 0. So, all we get is m dot 1 h 1 is somehow related to m dot 2 h 2, and plus Q dot c v. So, I get write that equation.

So, although we had a very long equation to begin with under these assumptions, the equation become very simple. And after some practice, you can directly jump to this. If you are certain that all the assumptions are there, and you are aware what the assumptions are, and you must write what these assumptions really are, so that that is what happens that the equation. And then we can sorry not W dot c, this is W dot c v, so here.

So, we can calculate the work. The difference between the treatment of pumps and the earlier type of machine is that here we have a liquid, we have altered some property considerations earlier that for a liquid v is a constant. We say that liquid and solid that encompass that is the thing that we are saying that v is constant in which case, we know that h 1 minus h 2 is v p 1 minus p 2. We assume v to be constant.

And the question which v to take, it should be v at state 1 or v at state 2 either value would be ok, because a difference between the two is very very small. But, if someone wants to be very very clear, and very say you can say that I will take v as the average of v 1 and v 2, but that really is not going to change the result very significantly, because the change in hardly 0.01 percent that type of a difference.

So, you can take either v 1 or v 2, but explicitly mention there in the solution that since the liquid is incompressible that taking specific volume of the liquid to be specific volume at state 2, whatever the pressure and temperature may be or at state 1, if you know the pressure and temperature over there. So, this is the thing we are making here, we are bringing here. In the case of fans and blowers also, then we said air is incompressible, there also approximately, we can put this. Otherwise, you can always go in gases as c p 0 T 2 minus T 1 and dot come from there that is fine the liquids, this is the important difference.

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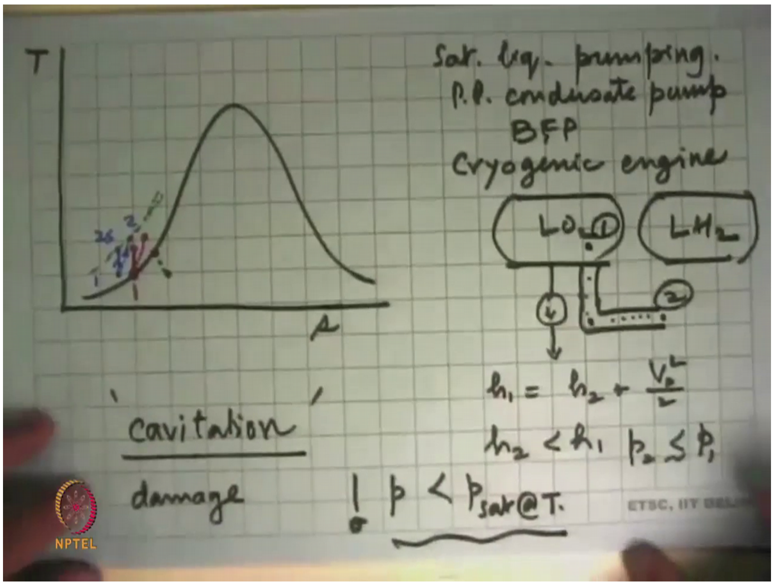

And now let us see, how do we show the process on property diagrams. Say this is T s, and one thing we need to know ok. We need to here of course, mentioned somewhere or check somewhere that this is valid in the given problem. Fortunately, what happens is when you compress, it becomes more of a compressed substance. So, as long as the inlet state is the compressed liquid or in some cases a saturated liquid. The moment you compress it, it will become a compressed it. So, if the inlet state is the compress state, then we are safe that throughout it will be a compressed liquid and our assumptions are fine that is something to check.

Now, let us look at T s diagram, I said pump your pumping and water ambient conditions. And we know that ambient water is slightly compressed liquid. And when we compress it, the pressure goes up. And in the ideal case is adiabatic, and if you do a reversible, it will go up over there, and this will be 1 to 2. I am exaggerating this, because I was showed the TS diagram the lines of 500 or 50 mega Pascal is pretty much very close to this. And say if I actually have to show this diagram, we cannot even show you simply because the effect of pressure on properties, so very very small.

But here we have done some exaggeration and showed it clarify that inlet state is compressed liquid, this is the isentropic compression in the ideal case it is gone from there to there. The real compression, we will go to the same pressure isobars are like that. So, the discharge when pressure isobar goes someone here, but it is extremely close to this manner is a very difficult to differentiate that. This is the isentropic case; this is the compress the real case.

If you are saying that we take saturated liquid and then we compress it and that is what happens in a power plant in where we have condensed the water it was saturated liquid and then we start pumping it. So, we can say that this initial state was here, and then we started pumping it, and it going there. So, it started 1 as a saturated liquid, went here and the ideal case it went slightly over there ok. So, that is the pumping of a saturated liquid. In the practical world, this is a very tricky operation.

So, pumping saturated liquid where do we encounter it? I have given the example of a every power plant condenser or condensate pump, also the main boiler feed pump when you are trying to compress a pump saturated liquid and cryogenic engines. ISRO is launching rockets very frequently these days. And they all have a cryogenic engine, when you have a tight containing saturated liquid oxygen. So, there we can say that here is the tank LO 2 or this is the another tank liquid hydrogen, both are saturated liquids at 1 bar pressure.

And you take a pipe, and you put it into a compressor that goes into the combustor. So, here is the problem that happens with saturated liquid that saturated liquid in the static case, but if I have this condition where it begins to move in a pipe, then because its velocity is increased and what we have learned from thermodynamics is that here and here if I apply the first law, here velocity is 0, here velocity is finite. So, this was state 1; this is state 2, all the assumption of steady states probably we take, then h 1 is equal to h 2 plus v 2 square by 2.

And even if v 2 is very, very small, it tells you that h 2 is less than h 1; and pressure p 2 is slightly less than p 1, that means, the moment you take this state and try to pump it, it will go there which means that some of the liquid became vapour and ended up with the two phase mixture and that is a problem. Therefore, earlier you see the specific volume is very large, suddenly the whole thing becomes crazy and the engineering becomes very, very difficult.

And so we have to ensure that you give at least minimum some static head, so that m this is saturated liquid, but as I just go down the gravity head rho g h adds on to it, so the pressure here under no flow will be more than the pressure here. So, will be slightly sub cooled liquid suddenly compressed liquid there you pump it to the pipe after the inlet of the pump, the pressure drop will take place. But at no place do we ensure that pressure is less than p sat at the given temperature. This is a very important consideration in designing all these type of devices.

So, even in a pump like this where it is taking compressed liquid and even impeller that is rotating very fast very close to surface of the impeller that velocity is very high in which case the locally the pressure at that point will be less than the saturation pressure at that point. And you could have a vapour bubble being formed. The moment is vapour bubble go moves out into a zone where the pressure is more it will compress where suddenly and gives out a shock wave and that is why you will see that some pumps sometimes make a hammering sound that this something it being hit inside it. There is nothing hitting it just that this device is happening that vapour is being pumped and this is called the issue of cavitation.

Even the propellers of ships especially in driven ships where the propeller is rotating in water the surface the in the velocity of the water adjacent to the surface of the propeller is high this pressure within the less, and if the pressure becomes less than the saturation pressure at the ambient temperature of the water, it will become a vapour bubble, it will move out collapse, leave or pressure wave, and that becomes a signature of that device and somebody else can detect your ship.

So, it is the big challenge that you want to control cavitation in that case for difference purposes, but in other cases here because when this bubbles form and break, they send out pressure waves and they do mechanical damage very badly; in no time at all the machine can get destroyed. So, we would like to take care of that, but this is why the thermodynamics tells you that an important thing that cavitation actually happens and what we need to do what engineering is all about ok. So, pumps will always start in the either in the saturated liquid state and go up or in the compressed liquid state and go up, but never in the wet region. Again we handled only a single phase ok. So, this is about pumps.