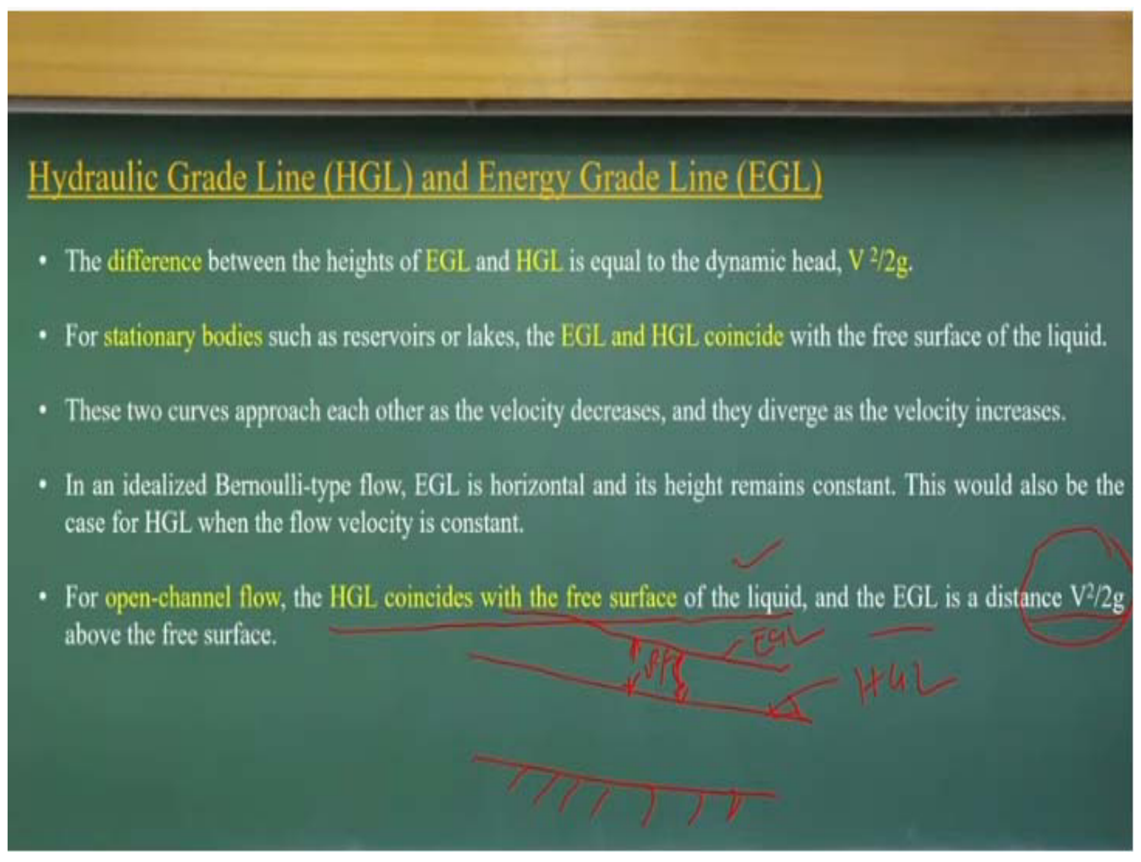

And okay, we are not discussing about open channel flow heads, but in case of open channel flow, the hydraulic gradient lines coincides with the free surface of the liquid okay. Because there is no pressure head. So, whatever the water surface free surface, that what will be hydraulic gradient line and the energy gradient lines will have a included the velocity head above the free surface. That means, if you consider a open channel flow, this is the free surface.

This free surface will be representing us hydraulic gradient line and $V^2/2g$ of this, adding this velocity head, will get energy gradient line, okay, in case of open channel flow because there is no pressure head. But in case of the pipes, we can have a piezometer to measure it, what could be the hydraulic gradient lines. Energy gradient line to measure it we need to have a pitot tube to compute what will be these things.

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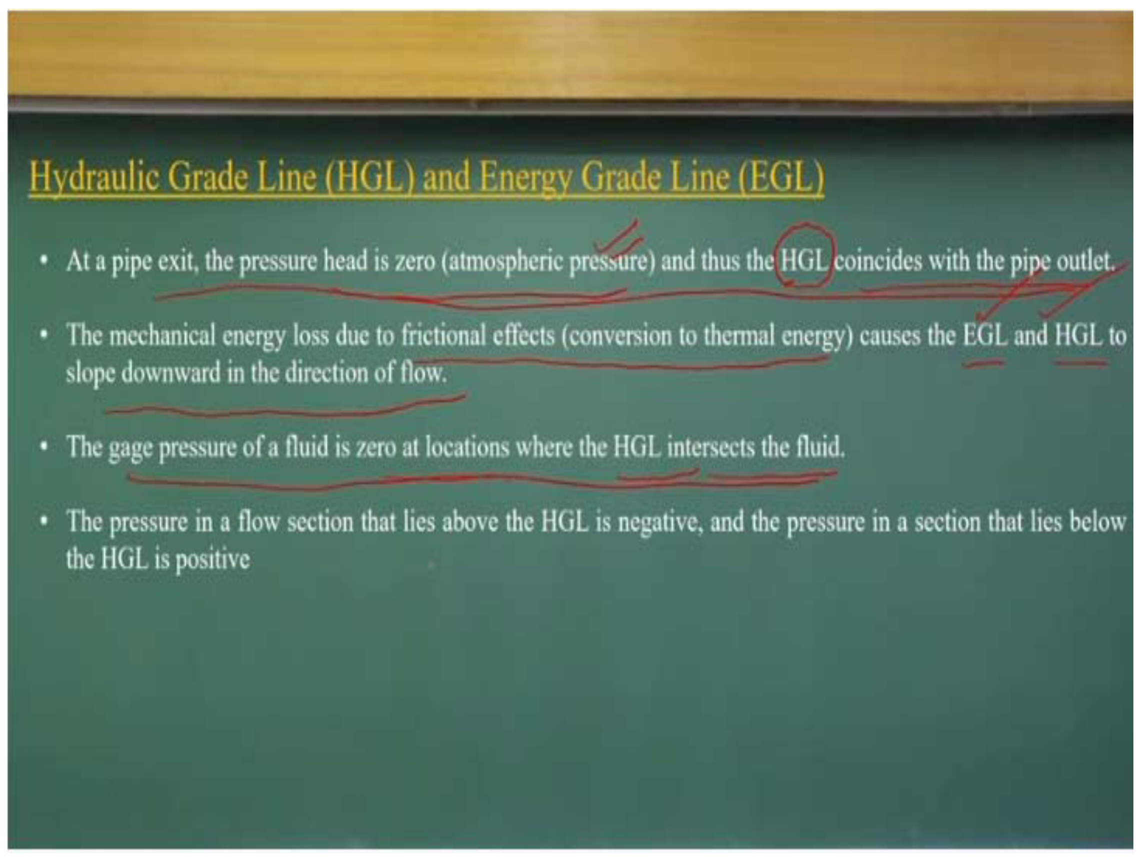

Now very basic things we should understand it, whenever a pipe exit, that means flow is going out. The pressure head becomes atmospheric pressure, no doubt about that. And that is the reason, the hydraulic gradient lines coincidence with the pipe outlet. So, when the pressure head becomes zero, that is what we said it, in case of open channel flow, when there is no pressure, is pressure is atmospheric pressure, that the surface becomes hydraulic gradient line.

Exactly same way, when you exiting, a pipe is exiting the flow to the atmosphere, that means your hydraulic gradient line should coincidence with the pipe outlet. Mechanical energy losses due to the frictional effects, which is converting from thermal energy, the causes the energy gradient line, hydraulic gradient line, to a slope downwards in the directions of the flow, that is what I try to explaining to you. That there will be energy losses whenever you have the flow systems, okay.

So, there will be a slow downward in the direction of flow of energy gradient line and also the hydraulic gradient lines. But energy gradient lines should have this, but sometimes maybe hydraulic gradient may not have the slope downward in direction of the flow. The gauge pressure of the is zero at the locations when the hydraulic gradient line intersect the fluids. The same things I think we are repeating it whatever we have said it in the first point.

This is the same point what we are talking about here, that it happens it, if there is a gauge pressure, okay. Pressures in a flow sections lies above the hydraulic gradient line is negative. Pressure in a section when the lies below the hydraulic gradient line is positive and the negative that is the difference what we get it. Pressure in a flow section that lies above the hydraulic gradient line is negative and pressure in a section that lies below the hydraulic gradient line will be the positive value.

So whenever will solve the pipe flow problems, will show it how the pressure it changes negative to positive directions in respect to the hydraulic gradient line.

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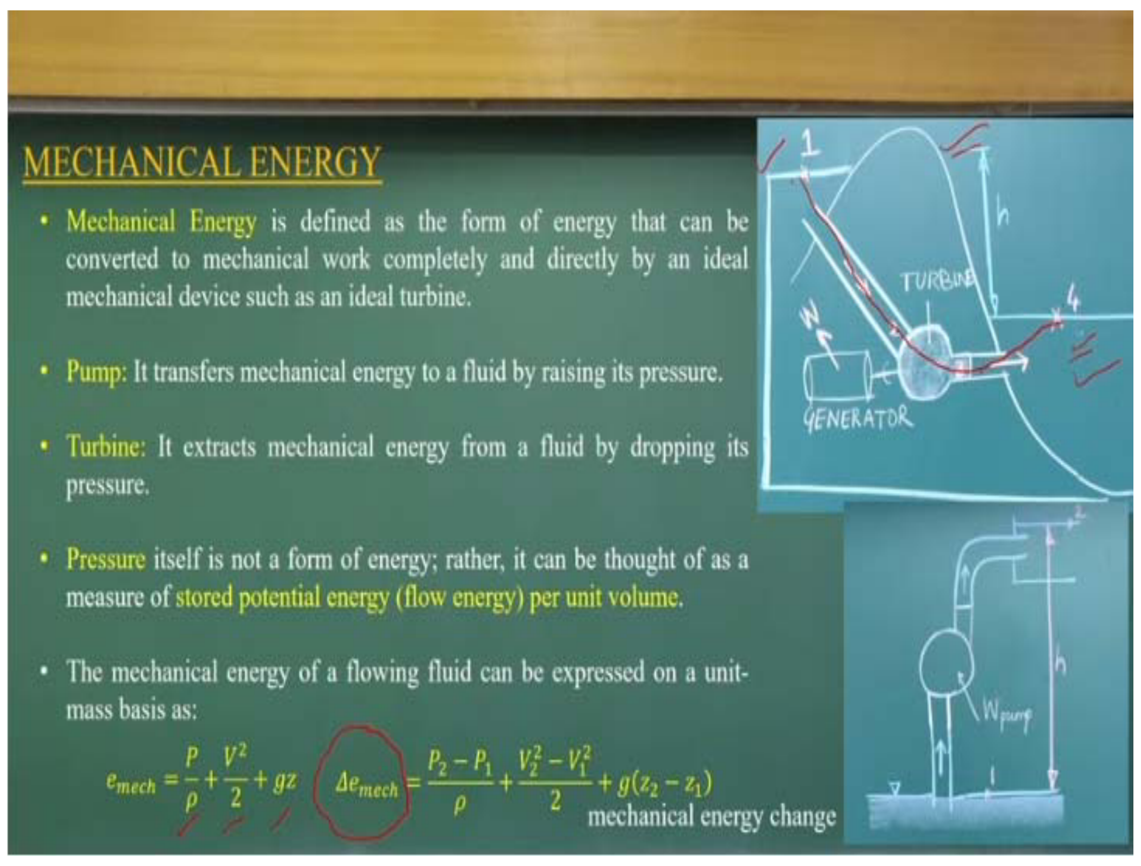

Now, let us consider is the problems when we generally use as a engineer having a pump and turbine systems. As you know it, the pump is transfer from mechanical energy to fluid by rising pressures, okay. Transfer the mechanical energy to a fluid. So, fluid gains the energy because of the pumping systems by rising its pressures, that is the. Similar way, the turbine does opposite things, that it takes out or extract the mechanical energy from the fluid by dropping it pressure.

So, this is what the **(()) (38:27)** turbine. So, when you have a flow systems and a pipe network of your campus, you can see there is a series of pumps are there to increase the energy in the flow systems, the mechanical energy in the flow systems. And the turbines are there wherever you have a hydropower projects. So you need to have a turbine, they extract the energy from the flow systems by dropping its pressures. So increasing the pressure and dropping the pressure.

Pressure itself is not a form of energy as we all say that, it is just a flow energy or storage potential energy per unit volume that is the pressures. So, if I look it this, again coming back to the Bernoulli equations, I have the three terms which will be define us as an energy term, okay. And if I have a two points, I am differentiating between these two energy, the difference part will show me the net energy difference will come it. That means, for example, I have a these systems.

There is a dam, the reservoir, water is going through a turbine and generators, coming out at the three, then it is related to the tail end reservoir. So, we have upstream reservoir, I have a tail end reservoir, there is a connections between the pipes and in between, I have the turbines and the generators. If you look it, if I take a flow streamlines, assuming the flow is comes like this and coming to this point, okay. So, I can find out what is the mechanical energy difference between these two part, just differentiating this energy at the one end flow level locations.

$$e_{mech} = \frac{P}{\rho} + \frac{V^2}{2} + gz$$

$$\Delta e_{mech} = \frac{P_2 - P_1}{\rho} + \frac{V_2^2 - V_1^2}{2} + g(z_2 - z_1)$$

Similar way, two and three locations we can find out. And this is a very simple pumping arrangement you can know it that we use a pumping to enhance the mechanical energy in the fluid flow systems by rising its pressures and because of that we have a lifting the waters in a water head tank as you know it.

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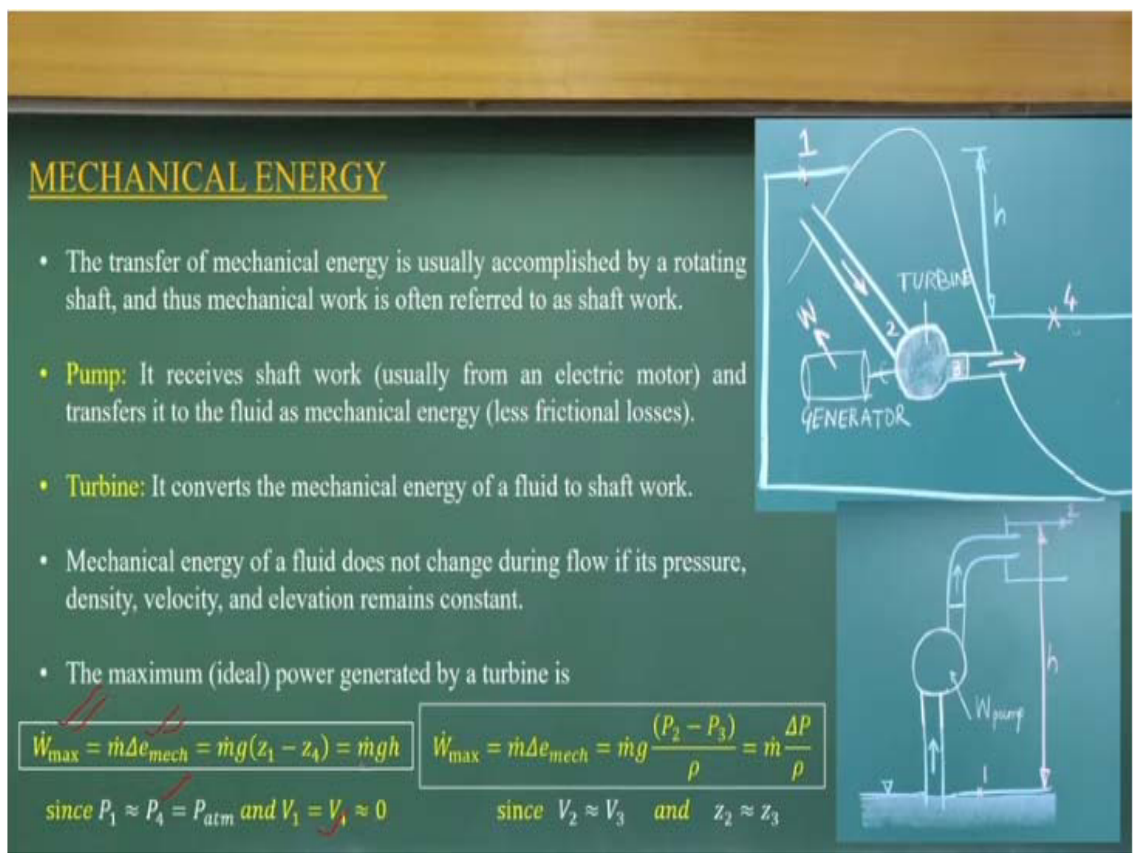

This mechanical energy what we get it and if I multiply with a mass rate, I will get the work done part, okay. How much of work done we are getting it or how much power we are getting it, maximum ideal power generated by turbines will be m dash and the energy part, mass flux part which we will be talk about work per unit time is the power. So, basically, we are looking for the power part, which will be, since this energy per unit mass, so we have multiplied with the mass rate to find out what will be the power will be there.

For example, if I take it the same problems, I need to know it what is the maximum ideal power generated by this turbine. Assuming it that all are 100% efficient systems that maximum power generated from these one and two four points. As you know it, the pressure at these two points will be atmospheric pressures and both are the same. The velocity at one and four, the velocity becomes zero, only this elevations difference, the potential difference what will be get it, that what is maximum ideal power generate by the turbine, okay.

$$\dot{W}_{\max} = \dot{m}\Delta e_{mech} = \dot{m}g(z_1 - z_4) = \dot{m}gh$$
$$since\ P_1 \approx P_4 = P_{atm}\ and\ V_1 = V_4 \approx 0$$

$$\dot{W}_{\max} = \dot{m}\Delta e_{mech} = \dot{m}g\frac{(P_2 - P_3)}{\rho} = \dot{m}\frac{\Delta P}{\rho}$$
$$\text{since}\quad V_2 \approx V_3 \quad and \quad z_2 \approx z_3$$

But if I consider the two and three, this before turbine and after turbine. At that locations, I have a $V_2 \approx V_3 \quad and \quad z_2 \approx z_3$. Substitute this value, I will get it the power generated by the turbine will have a mass flux and ΔP, the pressure difference between P_2 and P_3 by the ρ value. So, these are very simple calculations, you can do it.

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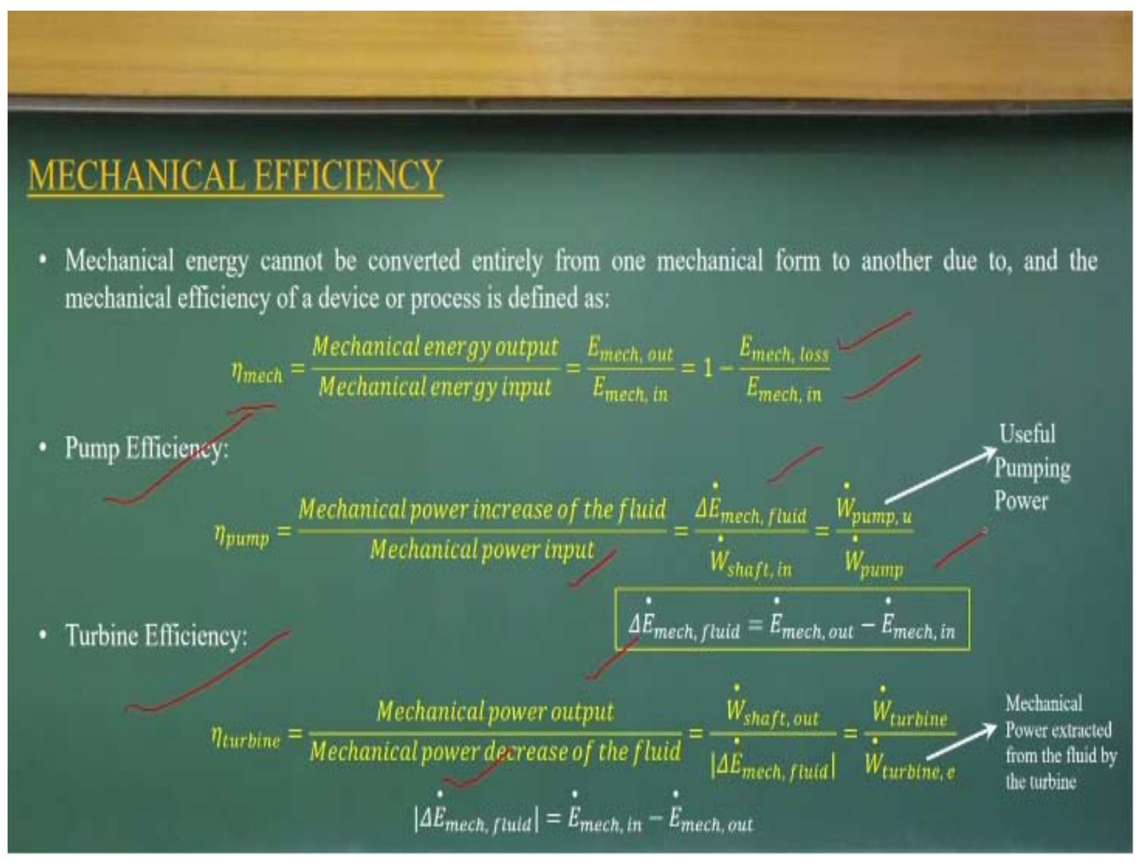

Now, whenever we have a system, there is energy losses. We cannot convert total mechanical energy entirely from mechanical pump or pump. There will be some heat energy losses, the sound energy losses, will have the energy losses from that. Because of that, there is an efficiency looped to that.

$$\eta_{mech} = \frac{Mechanical\ energy\ output}{Mechanical\ energy\ input} = \frac{E_{mech,\ out}}{E_{mech,\ in}} = 1 - \frac{E_{mech,\ loss}}{E_{mech,\ in}}$$

If efficiency equal to 1, that means whatever input that what we get the output. Like we are quantifying what is the mechanical efficiency of the systems. If mechanical energy input and output, the ratio, that is what is efficiency of that.

Or in terms of loss, we can also quantify it, like this, very simple. Similar way, pump efficiency and the turbine efficiency, input and output.

$$\eta_{pump} = \frac{Mechanical\ power\ increase\ of\ the\ fluid}{Mechanical\ power\ input} = \frac{\Delta\dot{E}_{mech,\,fluid}}{\dot{W}_{shaft,\,in}} = \frac{\dot{W}_{pump,\,u}}{\dot{W}_{pump}}$$

$$\Delta\dot{E}_{mech,\,fluid} = \dot{E}_{mech,\,out} - \dot{E}_{mech,\,in}$$

The ratio is between output to input, that is what is the efficiency of the pump or the turbine. The mechanical power increases of the fluid, by mechanical power input, turbine mechanical power output by mechanical power decreased by of the fluid. That is what will gives the turbine, the efficiency of the turbine systems.

$$\eta_{turbine} = \frac{Mechanical\ power\ output}{Mechanical\ power\ decrease\ of\ the\ fluid} = \frac{\dot{W}_{shaft,\,out}}{|\Delta\dot{E}_{mech,\,fluid}|} = \frac{\dot{W}_{turbine}}{\dot{W}_{turbine,\,e}}$$

$$|\Delta\dot{E}_{mech,\,fluid}| = \dot{E}_{mech,\,in} - \dot{E}_{mech,\,out}$$

And these are the basic powers, in terms of powers also we have defined them as a efficiency components.

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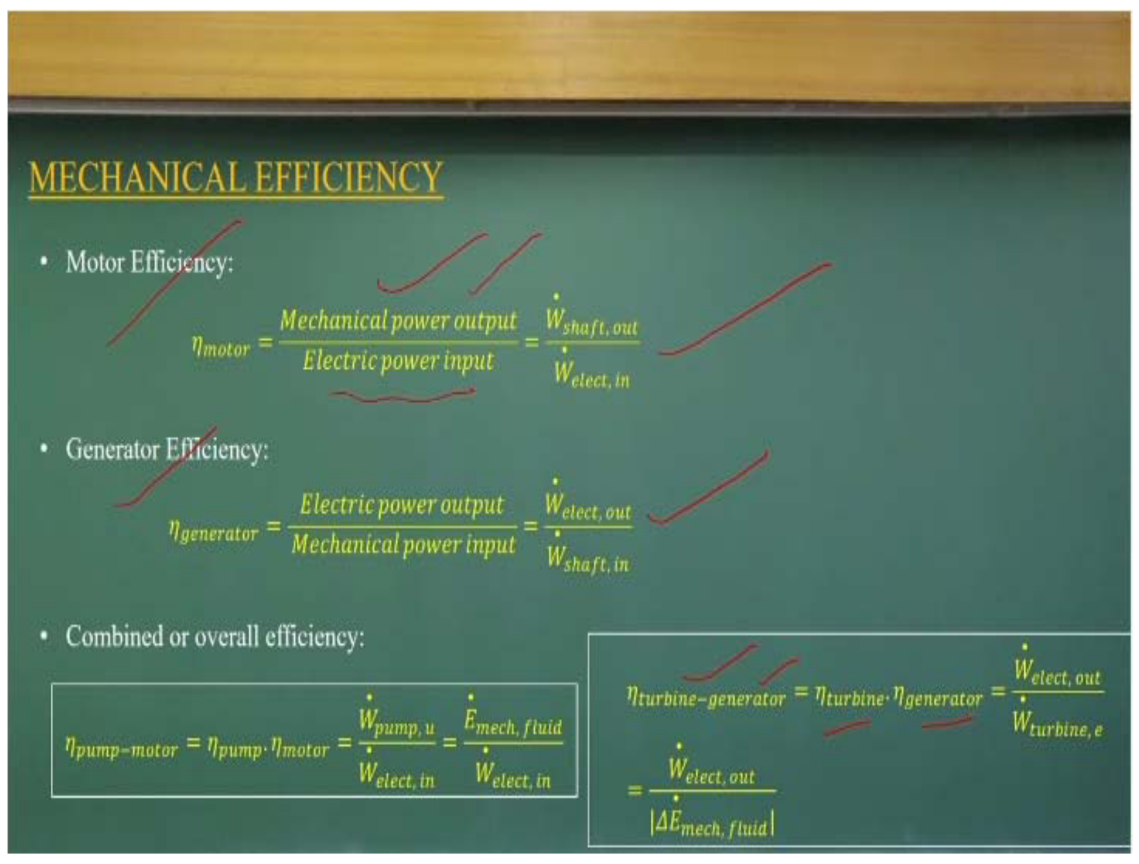

Similar way, you can have a motor efficiency and the generator efficiency. Electrical power input for the motors, what is the mechanical power output. Motor generates from electric to the mechanical power. That is the reasons you have a input is electrical power, output is mechanical power. That ratio we get it.

$$\eta_{motor} = \frac{Mechanical\ power\ output}{Electric\ power\ input} = \frac{\dot{W}_{shaft,\,out}}{\dot{W}_{elect,\,in}}$$

Similar way, generators we have the mechanical power to electrical, but when you have a combined systems, pump on motors, then you have a efficiency of the both the systems you have to input.

$$\eta_{generator} = \frac{Electric\ power\ output}{Mechanical\ power\ input} = \frac{\dot{W}_{elect,\,out}}{\dot{W}_{shaft,\,in}}$$

Pump and the motors, that is what we will define it. Similar way, if you have a turbine and generator, you have efficiency up to the things which are independent, you need to know the combined efficiency, that means you have to have a multiplication factor for that and that what is given here.

$$\eta_{pump-motor} = \eta_{pump} \cdot \eta_{motor} = \frac{\dot{W}_{pump,\,u}}{\dot{W}_{elect,\,in}} = \frac{\dot{E}_{mech,\,fluid}}{\dot{W}_{elect,\,in}}$$

$$\eta_{turbine-generator} = \eta_{turbine} \cdot \eta_{generator} = \frac{\dot{W}_{elect,\,out}}{\dot{W}_{turbine,\,e}} = \frac{\dot{W}_{elect,\,out}}{|\Delta \dot{E}_{mech,\,fluid}|}$$

Now let us come it to the example problems, okay, which are GATE and engineering service problems.

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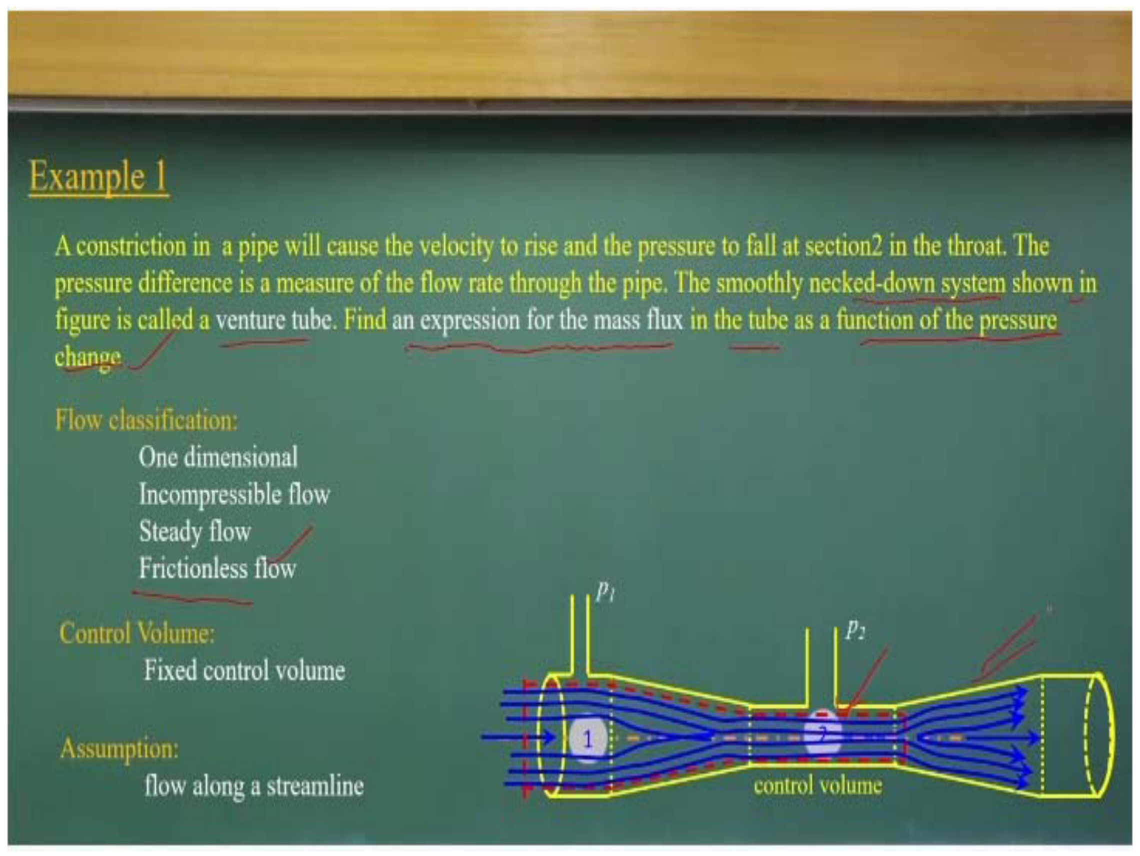

These are very easy problems, here we will apply mass conservations and Bernoulli equations, that is all. We are not going to do much here. Mass conservations and the Bernoulli equation what will be use it. But I always encourage you gauge the control volumes as well as draw streamlines. After the drawing the streamlines, the apply the Bernoulli equation for the two points, okay. That to be looked it this part and always highlight it, what are the assumptions behind that.

[A constriction in a pipe will cause the velocity to rise and the pressure to fall at section2 in the throat. The pressure difference is a measure of the flow rate through the pipe. The smoothly necked-down system shown in figure is called a venture tube. Find an expression for the mass flux in the tube as a function of the pressure change]

What are the assumptions you have put it, that should be highlighted before solving any fluid flow problems. Now, look at this example one, which is a constrict in a pipe will cause the velocity to rise it definitely. Okay, there are, just like a venturimeter, here there is a converging zones and the diverging zone, okay. And because it is converging zones, the velocities to rises, pressure to be fall it. That is what we know it very beginning of Bernoulli equations.

Flow classification:

One dimensional

Incompressible flow Steady flow

Frictionless flow

The pressure difference is a measured of flow rate through the pipe. The smooth neck down system shown in the figure is called venturi tube. Find an expression for the mass flux in the tube as a function of the pressure and the pressure change, which is very simple things. Will just highlight it how to use mass conservation equation and Bernoulli equations. Now, let us gauge it, what are the flow classifications. Here we can assume it one dimensional flow because incompressible, steady and frictionless.

That is what is our strength is, because we are directly applying the Bernoulli equations as there is no energy loss component, we are not including that. Fixed control volumes and we need to apply this Bernoulli equations along a streamline. The streamlines could be like this. There will be converging zones and the diverging zones, streamlines will be the converging and the diverging. Or you put the virtual fluid balls you can have the track of the flow path.

The path lines of the virtual fluid balls also could be like this, okay. They will converge it, more or less parallel in these regions. So, there will be no curvatures of streamlines in this regions. Then they will be the divergence on the streamlines, okay. So that the flow structures what we get it in venturi tube.

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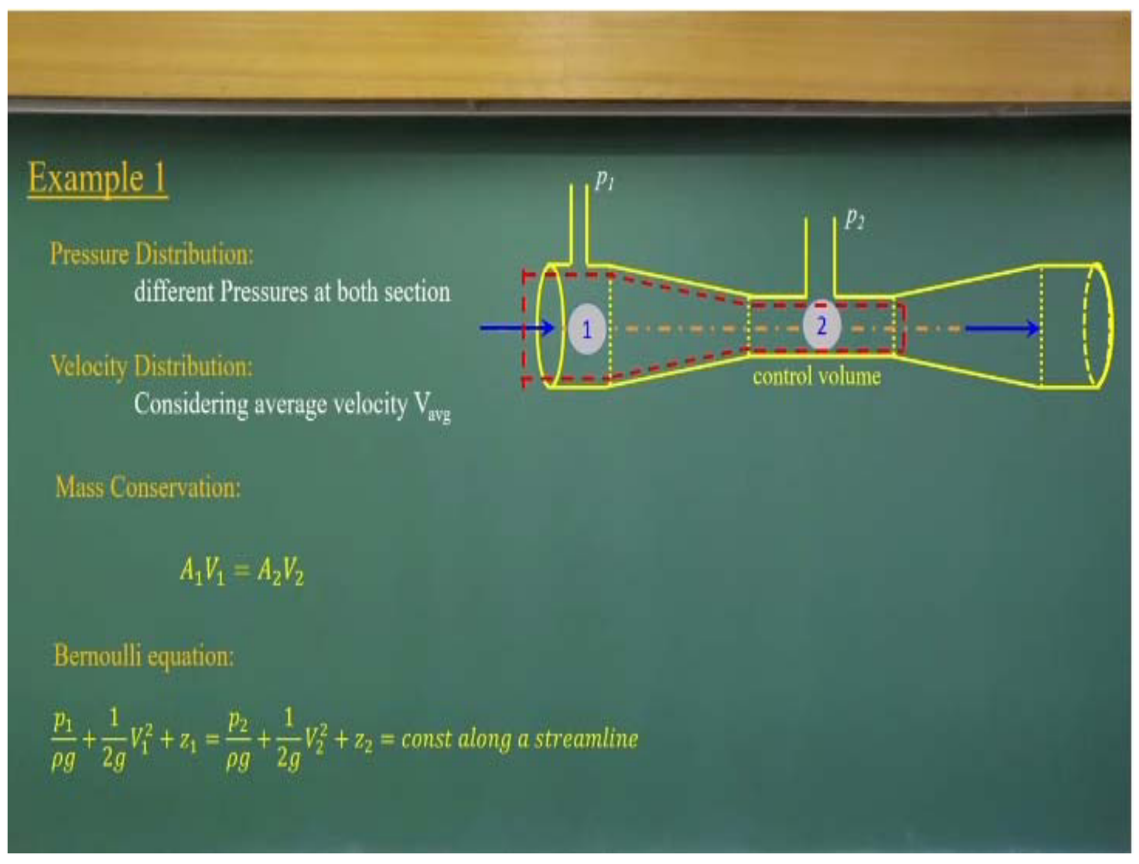

And we need to compute it in terms of average velocities. So, we are not considering is turbulent or laminar velocity things. We are not putting any kinetic energy correction factors, which supposed to be done it, but in this case we have not done it. We just apply the mass conservations and the Bernoulli equations assuming that there is a uniform flow distribution, it does not happen like that. We use the average velocity here.

$$A_1V_1 = A_2V_2$$

$$\frac{p_1}{\rho g} + \frac{1}{2g}V_1^2 + z_1 = \frac{p_2}{\rho g} + \frac{1}{2g}V_2^2 + z_2 = const\ along\ a\ streamline$$

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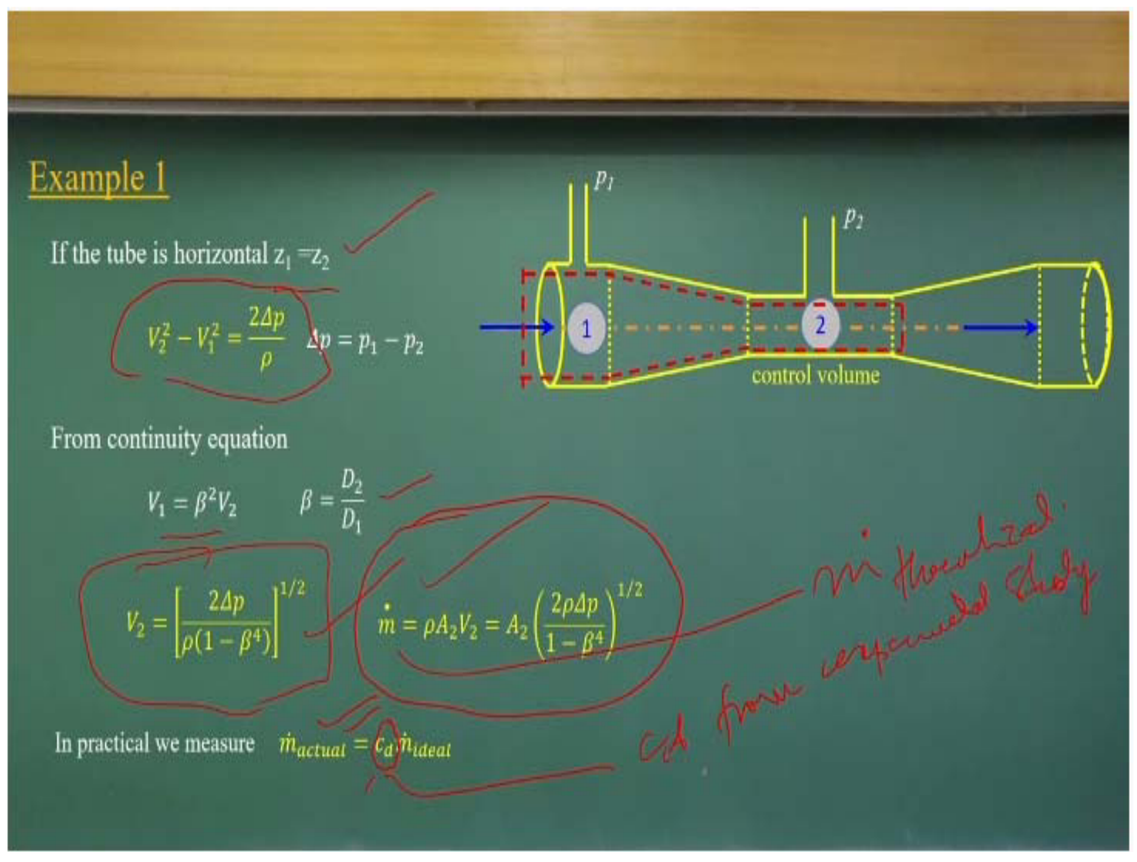

And applying this, as the tube is horizontal, z1 = z2, you can write in terms of velocity difference in terms of pressure and you apply the continuity equations to get it V2 in terms of pressure difference and the beta which the ratio between the d2 and d1, representing the diameters and the sections 2 and the diameter at the sections 1, respectively. That is what we will get it and finally, the mass flux will be rho AV, rho AV. So, area at the sections 2 you know it, V2 you know it, then we can compute it what will be the mass flux.

If the tube is horizontal $z_1 = z_2$

$$V_2^2 - V_1^2 = \frac{2\Delta p}{\rho}$$

$$\Delta p = p_1 - p_2$$

From continuity equation

$$V_1 = \beta^2 V_2$$

$$\beta = \frac{D_2}{D_1}$$

$$V_2 = \left[\frac{2\Delta p}{\rho(1-\beta^4)}\right]^{1/2}$$

$$\dot{m} = \rho A_2 V_2 = A_2 \left(\frac{2\rho\Delta p}{1-\beta^4}\right)^{1/2}$$

In practical we measure

$$\dot{m}_{actual} = c_d \dot{m}_{ideal}$$

But please remember, as we have not considered energy losses, we need to incorporate a Cd value, which is the coefficient of discharge to these computations to find out what will be the actual value. This is what is m dot theoretical value. And this Cd comes from experimental study. The Cd comes from the experimental study.

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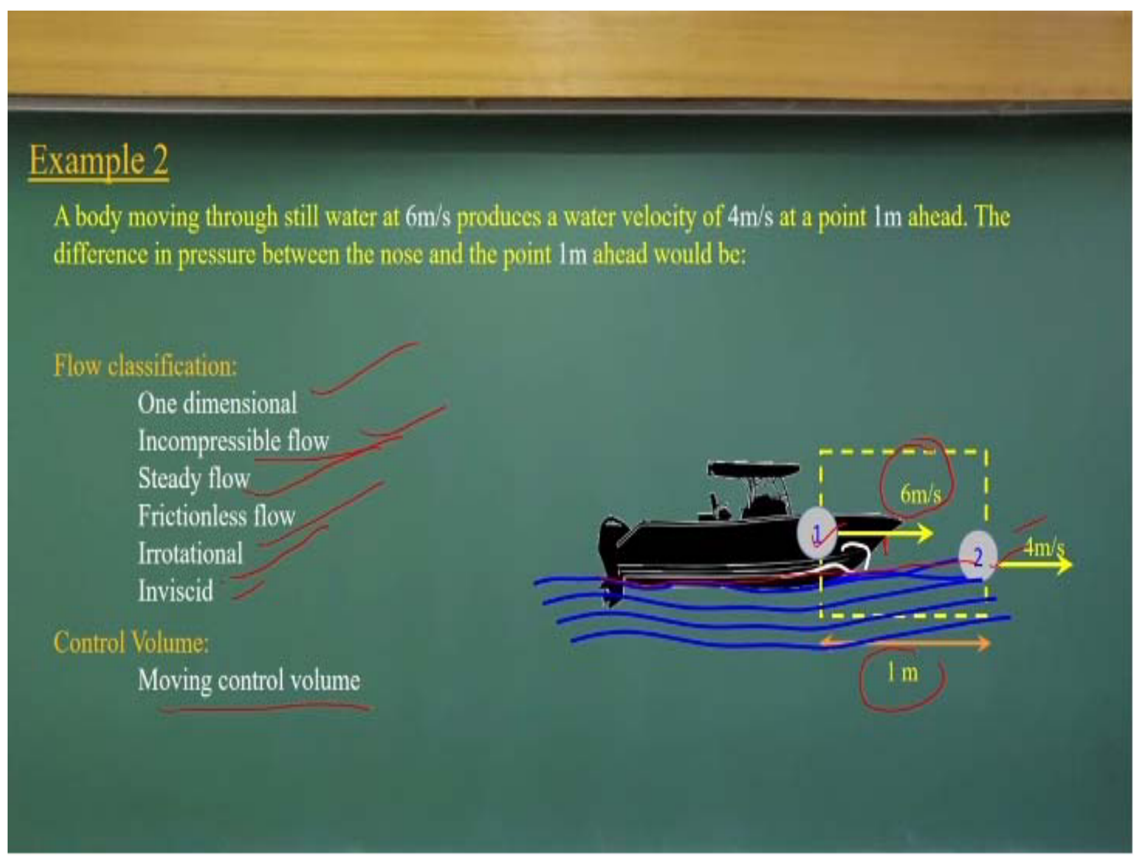

Let us have another examples very, interesting examples that a body is moving with a still waters of 6 meter per second produces water velocity 4 meter per second at 1 meter ahead. That means there is a distance between these two points is 1 meters, this is what 6 meter per second, the flow is, there is a reservoir type of conditions where the still waters are there and the velocity at this point is 4 meter per seconds.

[A body moving through still water at 6m/s produces a water velocity of 4m/s at a point 1m ahead. The difference in pressure between the nose and the point 1m ahead would be:]

Flow classification:

One dimensional

Incompressible flow   Steady flow

Frictionless flow

Irrotational

Inviscid

Now, we have to compute it, what could be the pressure difference between the nose and the point 1 meter ahead could be. So, we can assume, draw the streamlines, which is passing through this point 1 and point 2, incompressible flow, steady, frictionless, irrotational, inviscid, okay. It is a moving control volume, but we are not looking it as a moving control volume, we are just looking the pressure difference, we are not looking at the mass fluxes here.

So, we will just apply the Bernoulli equation between one and two, because they are at the same horizontal levels.

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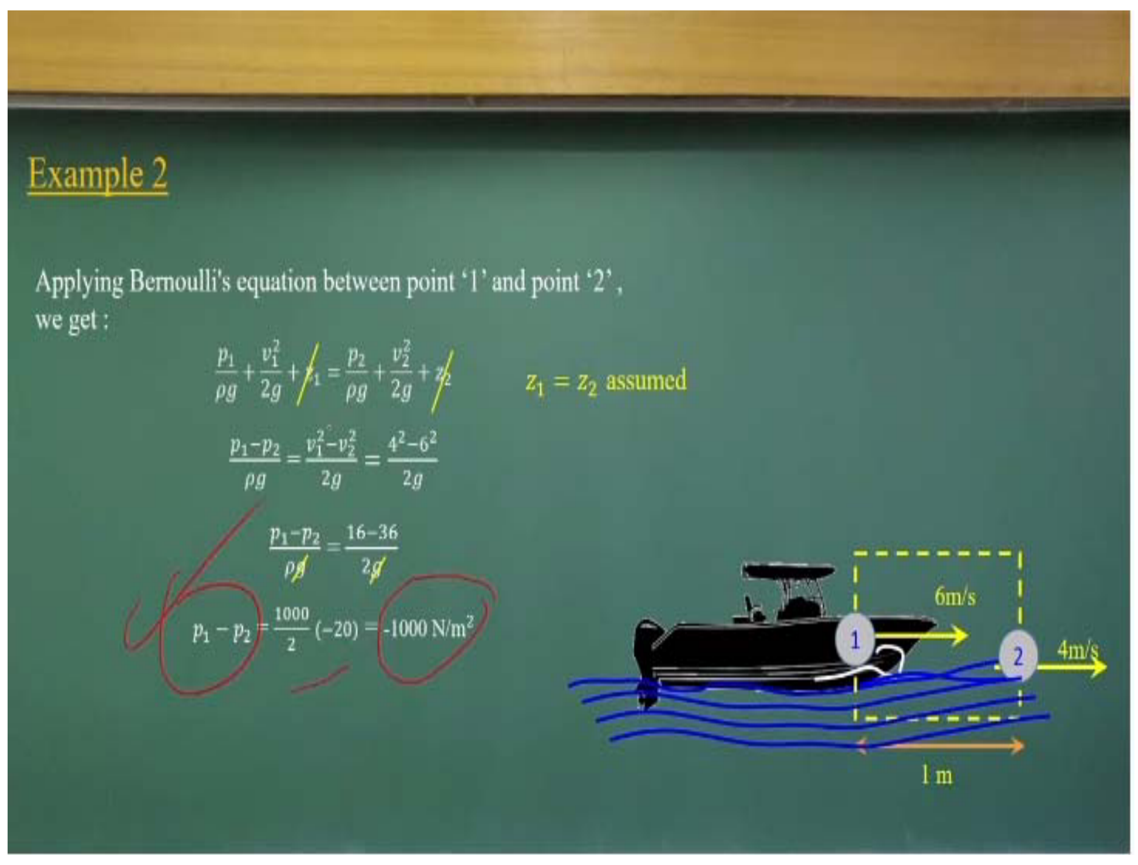

The z1 = z2 only will have the pressure difference will be equate with the pressure head is equate with the velocity head. And by substituting the pressures and the velocity, we will get it what will be pressure difference. It is very simple problems, but only you have to visualize the problems, how it looks like this. We have to sketch for that.

$z_1 = z_2$ assumed

Applying Bernoulli's equation between point '1' and point '2' , we get :

$$\frac{p_1}{\rho g}+\frac{v_1^2}{2g}+z_1=\frac{p_2}{\rho g}+\frac{v_2^2}{2g}+z_2$$

$$\frac{p_1-p_2}{\rho g}=\frac{v_1^2-v_2^2}{2g}=\frac{4^2-6^2}{2g}$$

$$\frac{p_1-p_2}{\rho g}=\frac{16-36}{2g}$$

$p_1-p_2=\frac{1000}{2}(-20)=-1000\ N/\mathrm{m}^2$

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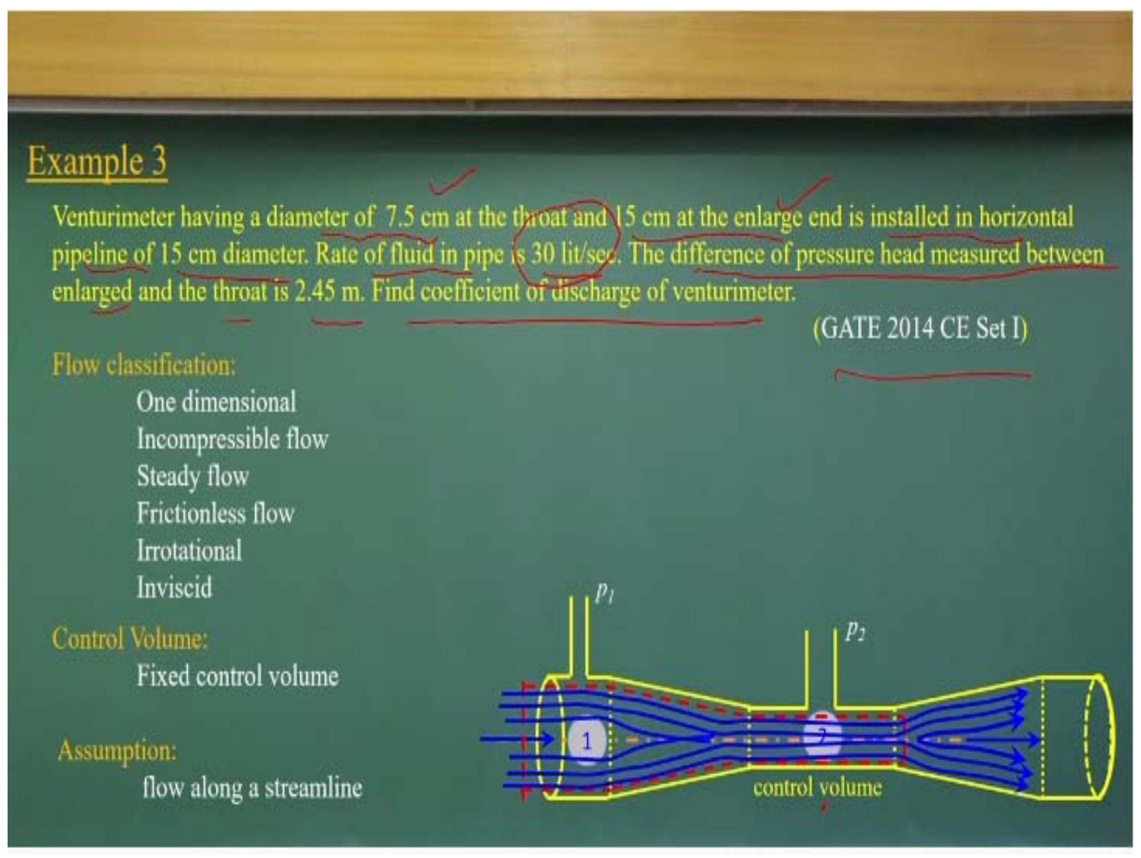

Third problems, which is very easy. The similar way as we discuss for the venturimeter problems in example one, where in this, this is the GATE 2014 questions, where we have a venturimeter having a diameter 7.5 centimeters at the throat levels and 15 centimeter at enlarge is installed in a horizontal pipelines of 15 centimeter dia. Rate of the fluid pipe flow is 30 liters per second. The difference of presser head measure between the enlarged and the throat locations is 2.45 meters. Find the coefficient of discharge of venturimeters.

[Venturimeter having a diameter of 7.5 cm at the throat and 15 cm at the enlarge end is installed in horizontal pipeline of 15 cm diameter. Rate of fluid in pipe is 30 lit/sec. The difference of pressure head measured between enlarged and the throat is 2.45 m. Find coefficient of discharge of venturimeter.]

Flow classification:

One dimensional

Incompressible flow Steady flow

Frictionless flow

Irrotational

Inviscid

If you look at this problems, we already discussed in example one, the same problems only, the numerical values are given for us to solve it. So, I will not take much time for this, only you can see the same streamline you have to draw it and you apply mass conservation equations and the Bernoulli equations to solve it to find out because here, the actual discharge is given to us, we have to compute theoretical discharge. Once you know this theoretical discharge, you can compute the coefficient of discharge.

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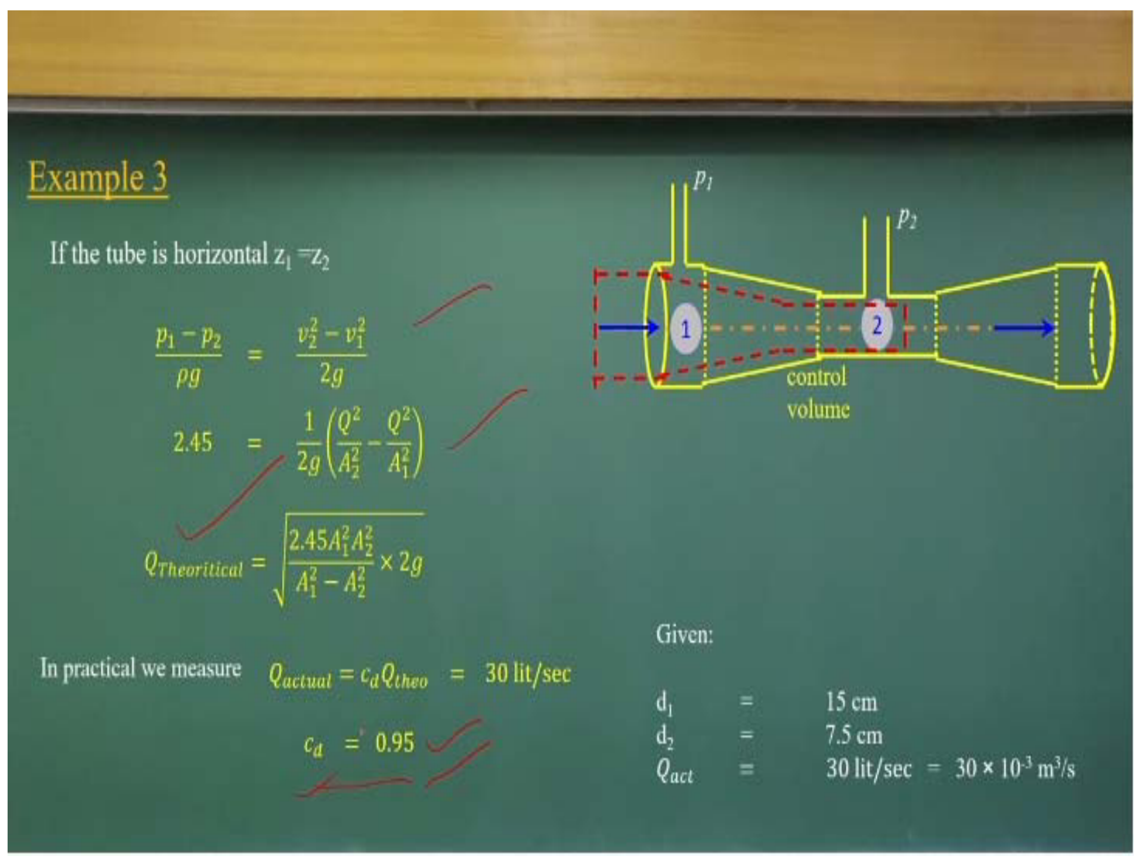

$$A_1V_1 = A_2V_2 = Q\text{theoritical}$$

$$\frac{p_1}{\rho g} + \frac{1}{2g}V_1^2 + z_1 = \frac{p_2}{\rho g} + \frac{1}{2g}V_2^2 + z_2 = const\ along\ a\ streamline$$

Given:

d_1 = 15 cm

d_2 = 7.5 cm

Q_{act} = 30 lit/sec = 30×10^{-3} m³/s

If the tube is horizontal $z_1 = z_2$

$$\frac{p_1 - p_2}{\rho g} = \frac{v_2^2 - v_1^2}{2g}$$

$$2.45 = \frac{1}{2g}\left(\frac{Q^2}{A_2^2} - \frac{Q^2}{A_1^2}\right)$$

$$Q_{Theoritical} = \sqrt{\frac{2.45A_1^2A_2^2}{A_1^2 - A_2^2} \times 2g}$$

In practical we measure

$$Q_{actual} = c_d Q_{theo} = 30\ \text{lit/sec}$$

$$c_d = 0.95$$

So, this is a very simple things. Again, we are putting the mass conservations equations and the Bernoulli equations, which is a energy conservation equations and by just putting the substituting these will get a theoretical discharge and we will get the actual discharge you know it, so you will get the Cd value, which comes out with 0.95.

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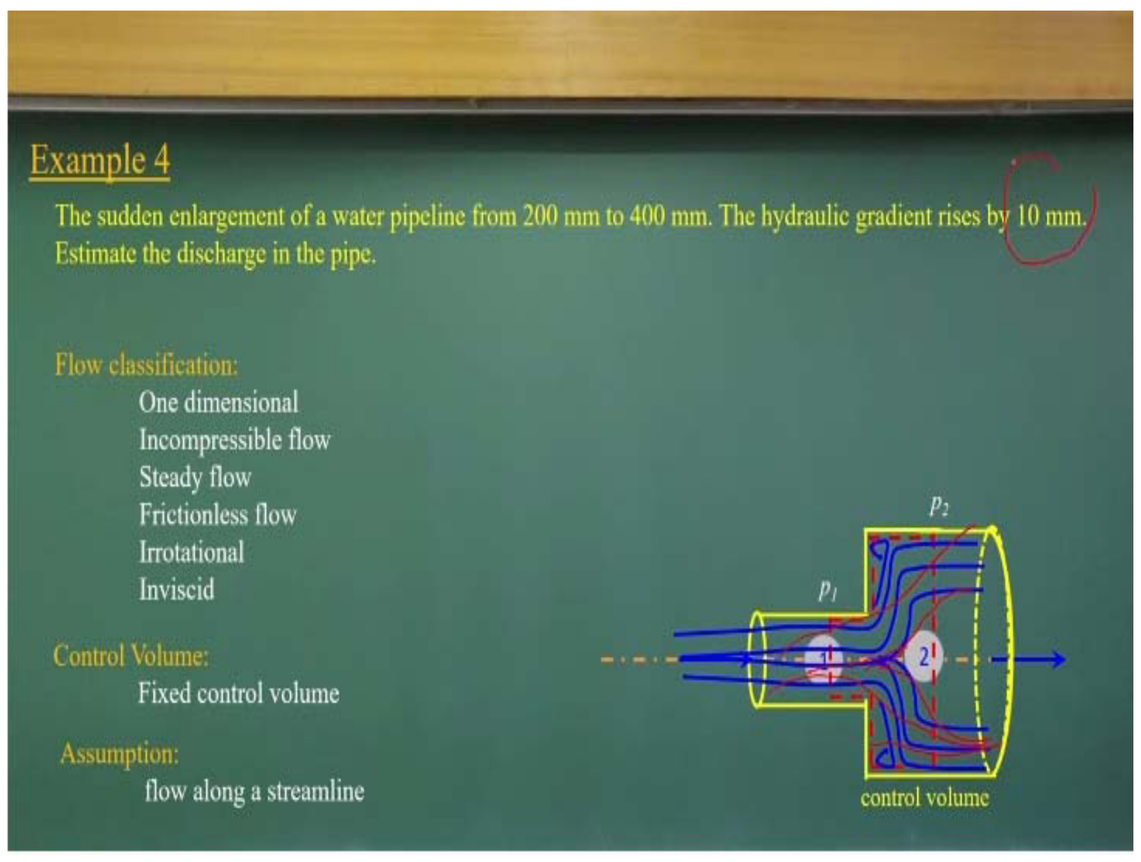

Another problems, we are very interesting problem, here there is sudden enlargement of pipeline from 200 millimeter to 400 millimeters. The hydraulic gradient raises by 10 mm okay. It is just given, their hydraulic gradient lines has increased by 10 mm. Then, we can estimate what will be the discharge in the pipe. So, again we will apply same mass conservation equation and the energy conservation equations around the streamlines. You can see that mostly the streamlines will have a divergent.

[The sudden enlargement of a water pipeline from 200 mm to 400 mm. The hydraulic gradient rises by 10 mm. Estimate the discharge in the pipe.]

Flow classification:

One dimensional

Incompressible flow Steady flow

Frictionless flow

Irrotational

Inviscid

And there will be energy distributions on these systems, but let us, we do not know how much of energy distribution, but we know it from data, there is the hydraulic gradient rise by the 10 mm.

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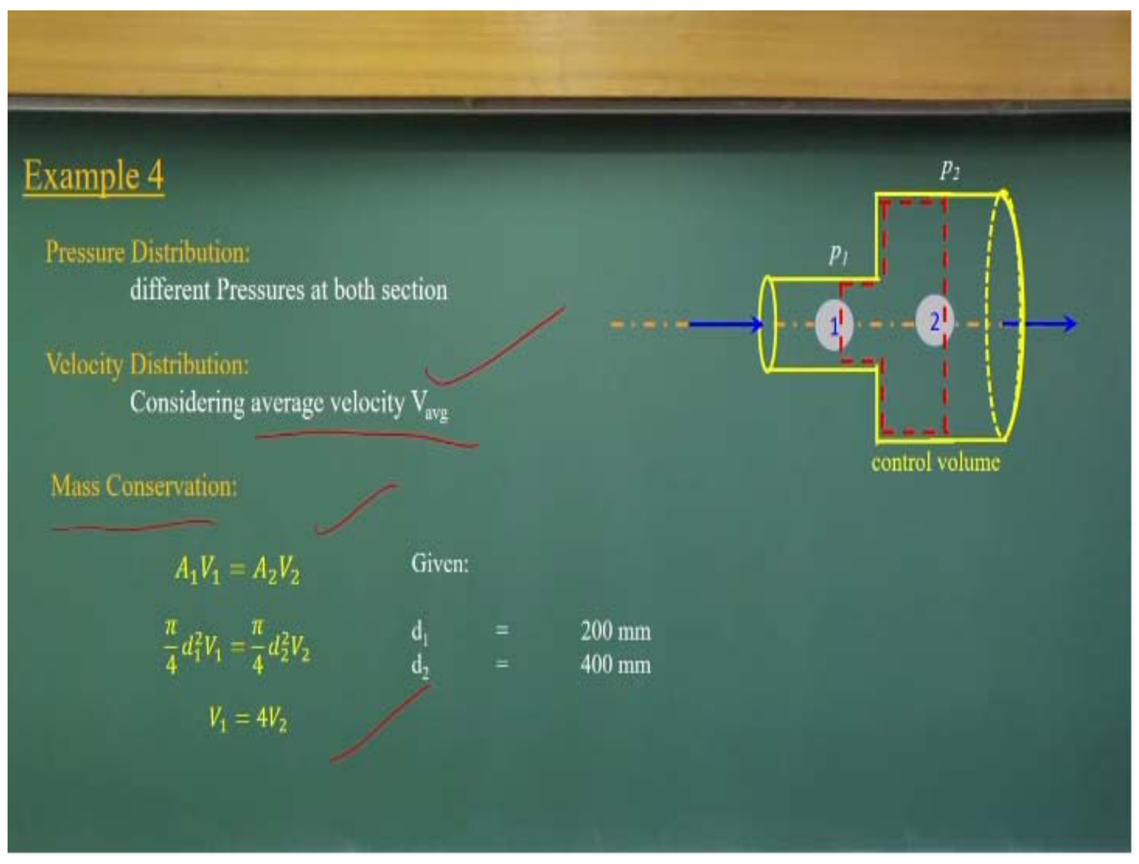

So, you have a mass conservations equations and considering the average velocity not considering kinetic energy correction factors, so you can know it. This mass conservations equations as you know it, $A_1V_1 = A_2V_2$

$$\frac{\pi}{4}d_1^2V_1 = \frac{\pi}{4}d_2^2V_2$$

Given:

d_1 = 200 mm

d_2 = 400 mm

$$V_1 = 4V_2$$

substituting this diameter we can get it the relationship between V1 and the V2.

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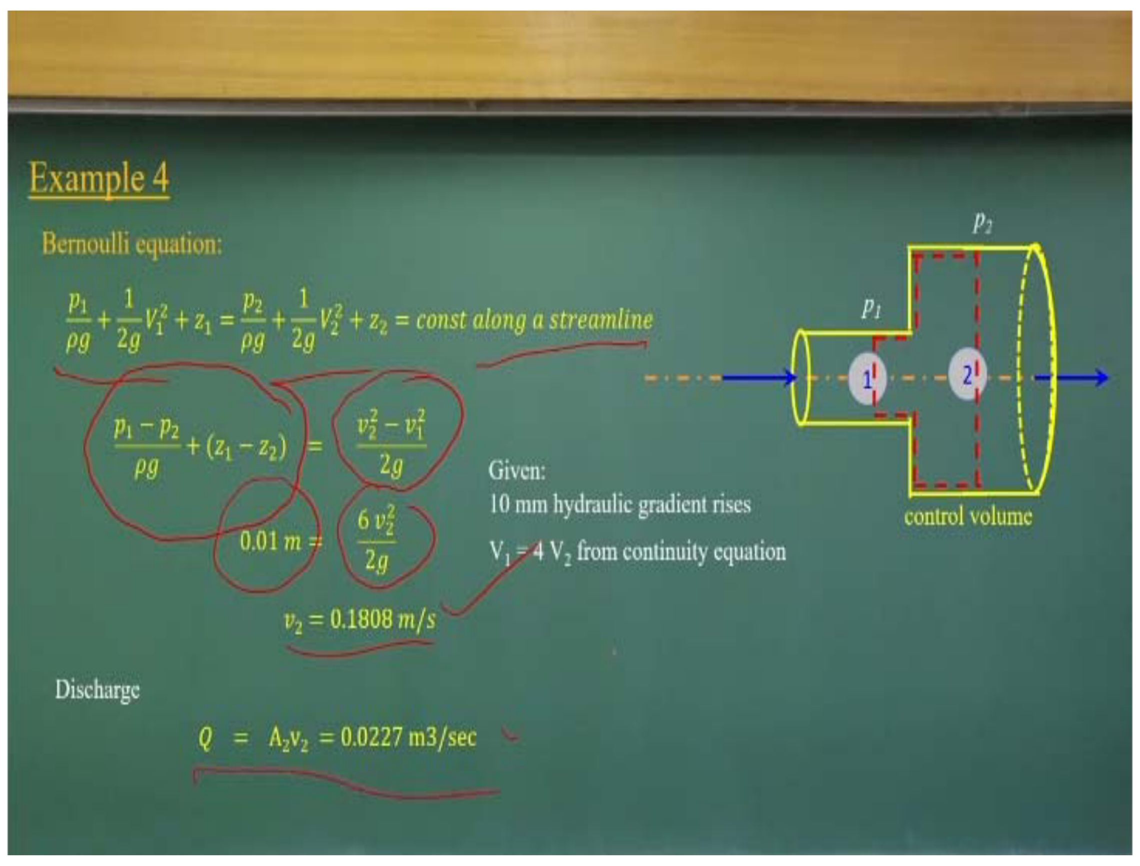

And then if I substitutes the Bernoulli equations, okay, along this constant lines. So basically if you look it, these two head, the pressure head and the z1 z2 is not given to us, but that is what will be reflect in terms of piezometric head.

$$\frac{p_1}{\rho g} + \frac{1}{2g}V_1^2 + z_1 = \frac{p_2}{\rho g} + \frac{1}{2g}V_2^2 + z_2 = const\ along\ a\ streamline$$

$$\frac{p_1 - p_2}{\rho g} + (z_1 - z_2) \quad = \quad \frac{v_2^2 - v_1^2}{2g}$$

That is what is given the difference between the piezometric head is 0.01 meters. So we are substituting directly on that. We know this, the velocity and their relationship, we can compute the velocity. And once you know the velocity, we can compute the discharge. Given:

10 mm hydraulic gradient rises

$$0.01\ m = \quad \frac{6\ v_2^2}{2g}$$

$$v2 = 0.1808\ m/s$$

$$Q \quad = \quad \text{A2v2} \ = 0.0227\ \text{m3/sec}$$

So this way, it is very easy problems, only you have to look it, it has given the hydraulic gradient rise, that means it is representing us the pressure head and the elevations head. These two are we are including it when you put the two piezometers, what will be the raise, because of that, that is what we have of 10 mm hydraulic gradient raise and that is what we have substitutes.

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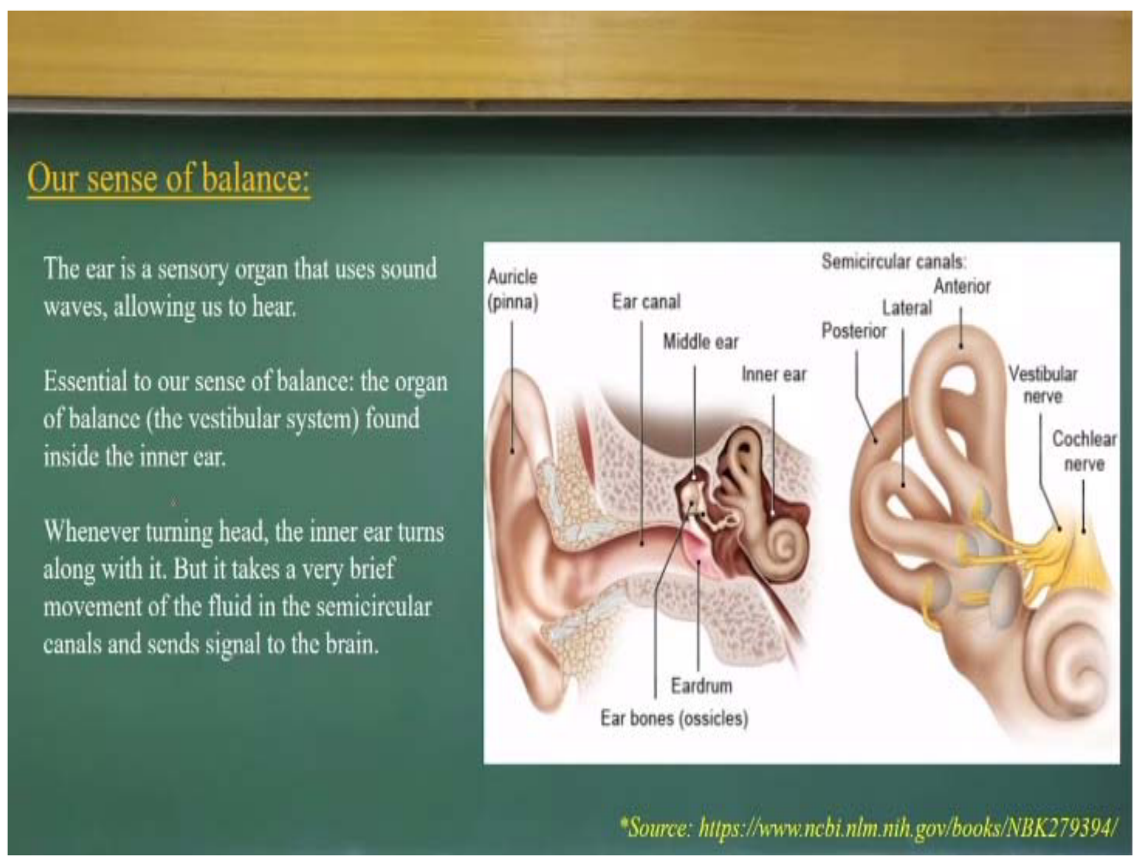

Let me conclude this lectures with the sense of balance of a organ systems. If you know it, many of, we know it this ears is for the acoustic sound waves. That is the reasons we can hear it. And whatever I am speaking you can hear because of the ear, which is sensory organ to uses the sound waves allow us to hear it. But this ear also have a composition organ of balance inside the ear, which gives up the sense of balance.

Like, if I tilt it, I can get it from my brain, I am tilting it, okay. That is what the sense of balance. I'm not going to talk much details, but I am just telling you that the nature has given so beautiful arrangement of our body structures and the brain, which we cannot replicate it and this is what it happens all in the fluid flow sensorial organ systems. So, that way, we look it very smaller components what we teach in the fluid mechanics, but the human body is the structure still give us lot of lessons to be learnt about the fluid, about the sensing organs and all.

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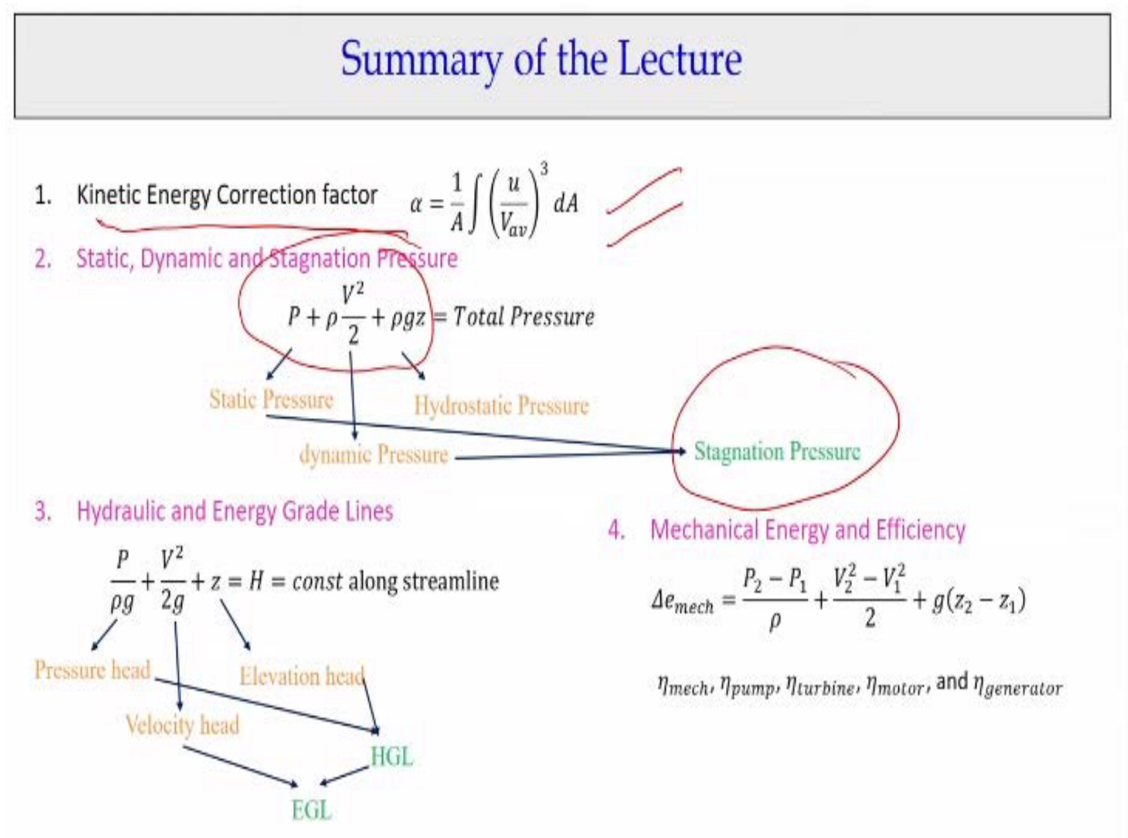

And that is the same things and this times we talk about the kinetic energy corrections factors, how we need to be compute when you have the velocity distributions is uniform. And we also seen Bernoulli equations, we can represent it in terms of the pressures, static pressures, dynamic pressures and hydrostatic pressures and two of the components that can represent us the stagnation pressures.

$$\alpha = \frac{1}{A}\int\left(\frac{u}{V_{av}}\right)^3 dA$$

$$P + \rho\frac{V^2}{2} + \rho g z = Total\ Pressure$$

$$\frac{P}{\rho g} + \frac{V^2}{2g} + z = H = const \text{ along streamline}$$

$$\Delta e_{mech} = \frac{P_2 - P_1}{\rho} + \frac{V_2^2 - V_1^2}{2} + g(z_2 - z_1)$$

And we also discussed about the hydraulic gradient line and the energy gradient lines and the mechanical energy and the efficiency. With this, let us thank you all for this presence here.