Fluid Mechanics and its Applications
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Lecture 18A
Flow measurement (Continued)

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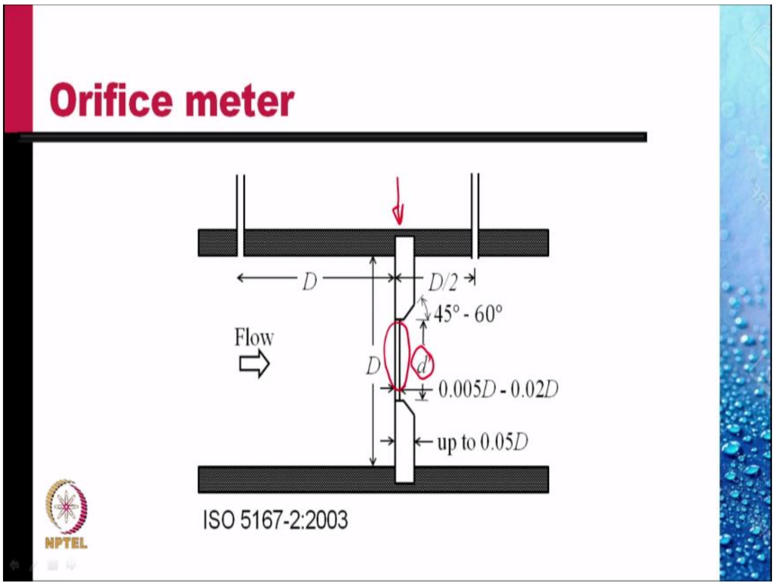

Orifice meter is another type of meter. It is an obstruction meter again, and it consists of a plate with a hole, with an orifice. The tube has a diameter D and the orifice has a diameter d. These are the recommendations for a design of orifice meter contained in ISO 5167. But an orifice meter of almost any design works, only that you will have to worry about its calibration more.

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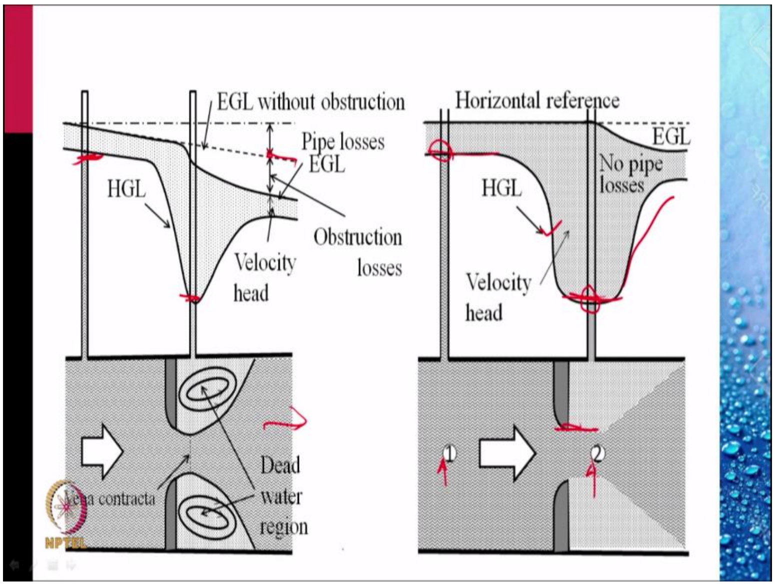

To analyse this orifice meter, let us look at the flow through such a device. The two piezometric tubes connected, one ahead of the orifice plate, and one slightly behind the orifice plate. The liquid rises up to this height in the first tube, and up to this height in the second tube. As the flow comes out of the orifice, it first contracts, and as we have discussed earlier, it first decreases in the area and forms a vena contractor, the cross sectional area where the diameter of the jet is the minimum.

There is a dead water region, a ring-shaped dead water region, just behind the orifice plate, and the liquid that comes out now slows down and fills up the tube completely. In an actual flow, the hydraulic grade line, which is the pressure plus the elevation variation of that, looks something like this. The energy grade line without obstruction is this. It is inclined towards the right because the total energy is decreasing slightly because of the losses in the open pipe.

There is a pressure gradient in the pipe as we have discussed, and because of that pressure gradient, the total energy is decreasing. So, this difference measures the pipe losses, losses because of the motion of the fluid in the pipe. But because of obstruction there are further losses, and the energy grade line, the true energy grade line with obstruction, is like as shown.

These are the obstruction losses. This then, the shaded area, then represents the velocity head. The velocity head in the beginning is the same as at the end. It is the maximum at the location of the vena contract. This flow is very difficult to analyse. So, we make a model flow, a simplified model, and we assume there is no vena contracta. The fluid comes out as a jet of constant diameter. There are no losses. So, the energy grade line till the second pipe is horizontal, and then, it is because of the losses in the eddies, that the energy decreases.

There are no pipe losses. The hydraulic grade line is quite a bit like this. The constant pressure in the upstream region, constant pressure at this portion, and then pressure increases as the flow slows down. So, we pick up these two pressures, pressure here and pressure there. Pressure at 1 and pressure at 2, and then those two pressures are related to the velocity in the pipe.

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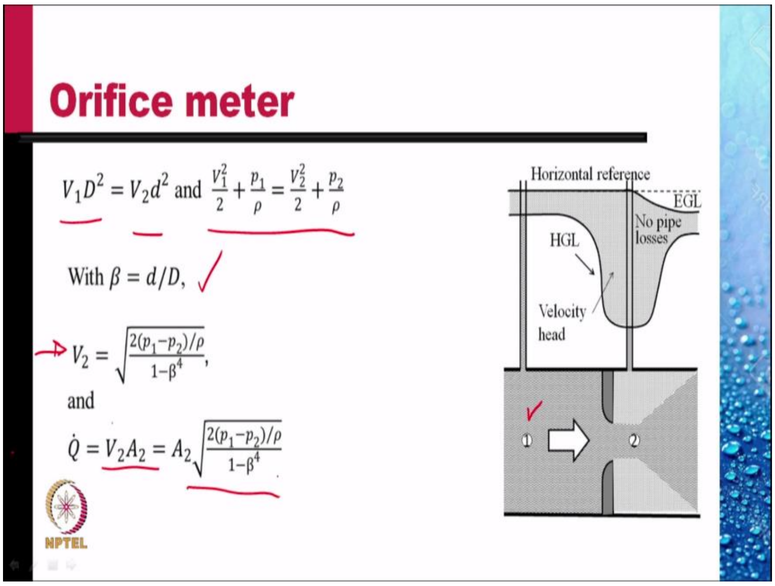

How? First of all, by the mass balance equation, V_1, the velocity at 1 times the D^2, the diameter of the pipe, is equal to V_2 times lowercase d^2, the diameter of the orifice. This equation, and the Bernoulli equation between these two points. It is easy to solve this equation, and with $\beta = d/D$, we get the velocity V_2 as this velocity at the orifice. And the flow rate is $V_2 A_2$, which is also $V_1 A_1$, and we get this flow rate in terms of Δp, the density of the fluid ρ, and β, the diameter ratio, the diameter orifice to the diameter of the tube.

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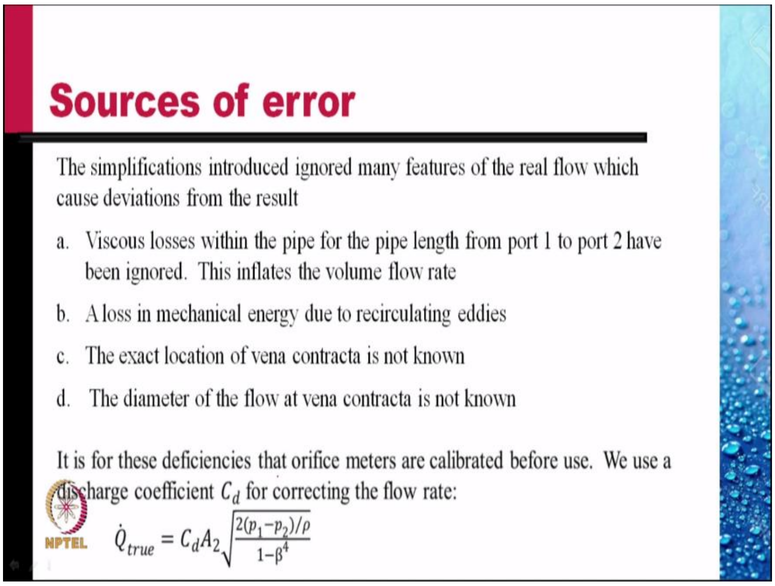

The simplification introduced ignored many features of the real flow which cause deviation from the result. The viscous losses within the pipe that were neglected for the pipe length between port 1 to port 2, and ignoring this, these viscous losses inflates the volume flow rate.

A loss in mechanical energy due to re-circulating eddies, the exact location of the vena contactor is not known, the diameter of the flow at vena contractor is also not known. There are too many factors about which we are ignorant and so, we cover ignorance by introducing coefficient C_d, we multiply the theoretical $\dot{Q}$ the volume obtained by C_d to get the true volume flow rate and that C_d is obtained by calibration before use.

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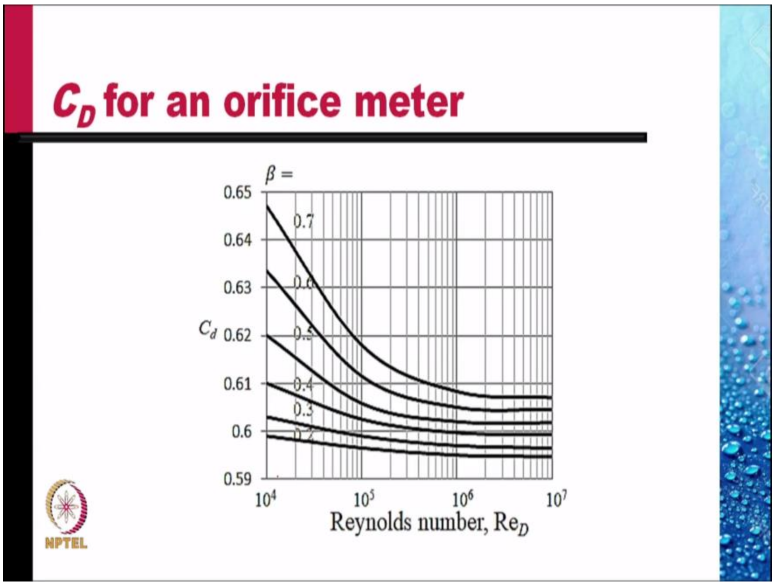

Typical values of C_d are given in the chart. The C_d value depends upon the Reynolds number and on the value of β. As β decreases, that is, as the orifice become narrower, the C_d decreases but the typical value is around 0.6. Not a very good value, and this tends to become constant if the Reynolds number increases beyond about $\times 10^5$.

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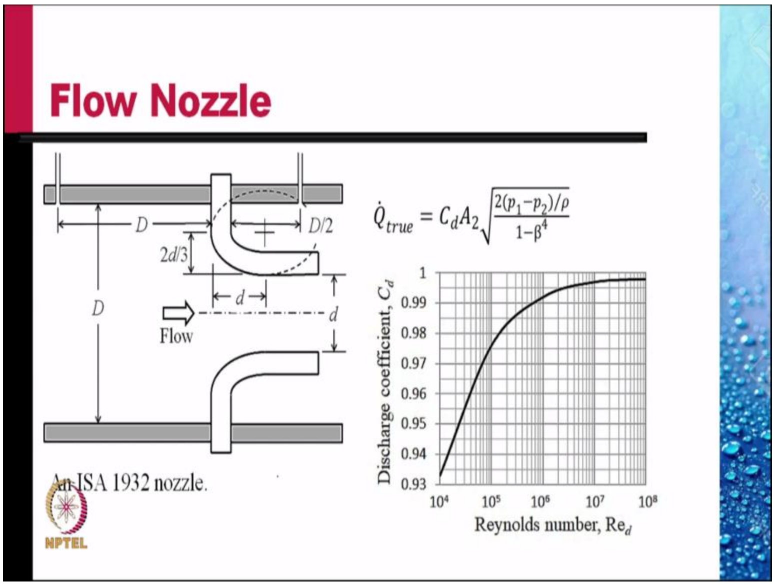

Another variation of an orifice meter which makes it much better, is what is called a flow nozzle. Given here are the specifications of an ISA 1932 nozzle. It just works on the same principle, causes an obstruction in the flow, which reduces the cross-sectional area, and increasing the velocity. Application of Bernoulli equation would then give a decreased pressure, and we will get the same equation for the volume flow rate as we got for an orifice meter.

$\dot{Q}_{true} = C_d A_2 \sqrt{\frac{2(p_1 - p_2)/\rho}{1-\beta^4}}$. But in this case because of the nozzle and the radius of the nozzle at the inlet, the flow goes in smoothly. There is no vena contracta formed. The jet comes out as a constant diameter jet. Of course, there are losses after that when the flow re-attaches with the wall.

So, the discharge coefficient is now a much higher value, and the discharge coefficient you see is better than 0.93, or one and a half times the discharge coefficient we got there between 0.93 and 0.99, and about 5 into 10 raised to the power 6, it becomes constant at about 0.995, a very good discharge coefficient. And because of this, a flow nozzle is the preferred flow measurement device, except that is more expensive to construct and more expensive to install.

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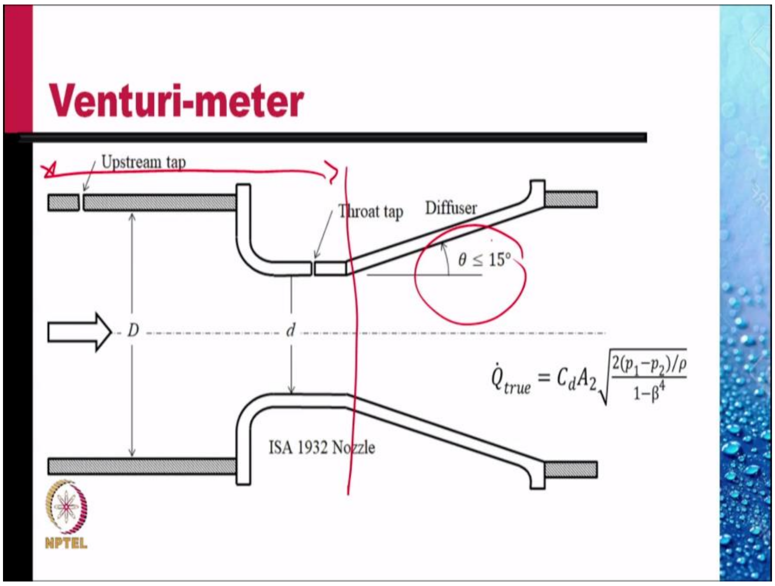

Another variation on the orifice meter in the fluid nozzle is a venturi meter. Venturi meter is nothing but a flow nozzle constructed with a divergent section in which the divergence angle is less than 15°. So, there the jet that comes out of the nozzle expands slowly and does not separate from the wall. So, the recirculating eddies are not formed in that region, and because they are not formed in that region, there is very little pressure loss. So, venturi meter is a very good device except it is long, it is expensive, and it is difficult to install. It uses the same equation for the volume flow rate as we obtained for the earlier two devices, because the same mass balance and the same Bernoulli equation applied with the same parameters.

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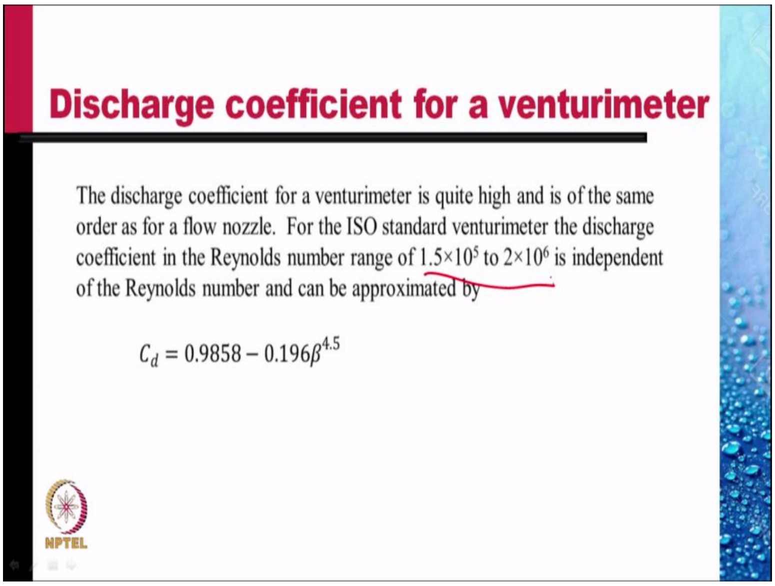

The discharge coefficient is very good, of the same order as for a flow nozzle in the Reynolds number range of 1.5×10^5 to 2×10^6. It is independent of the Reynolds number and can be approximated by $C_d = 0.9858 - 0.196\beta^{4.5}$. This is beta is less than 1. So, the second term is really quite small and C_d is very large. The beauty lies in the fact that for this Reynolds number range, C_d is constant. So, the volume flow rate is directly related to the pressure difference measured by this.

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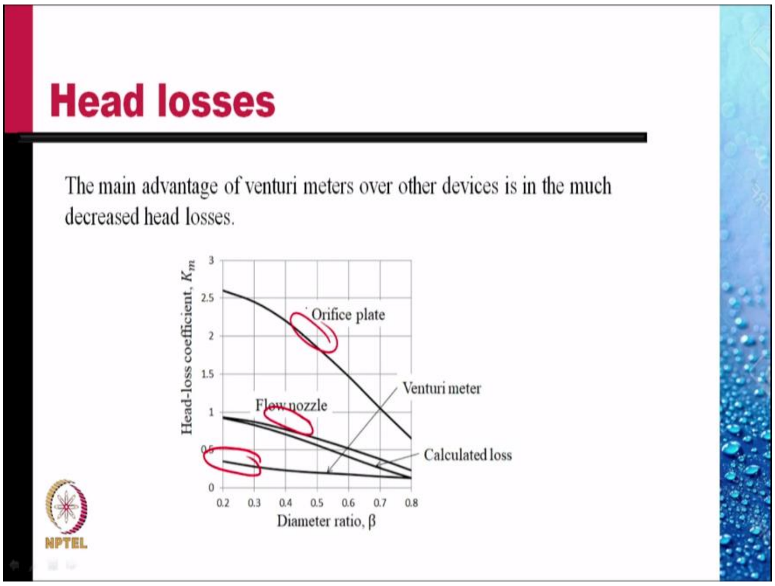

The main advantage of a venturi meter over other devices is the much-decreased head loss. The head loss coefficient for venturi meter is way below that of flow nozzles and the orifice plate.

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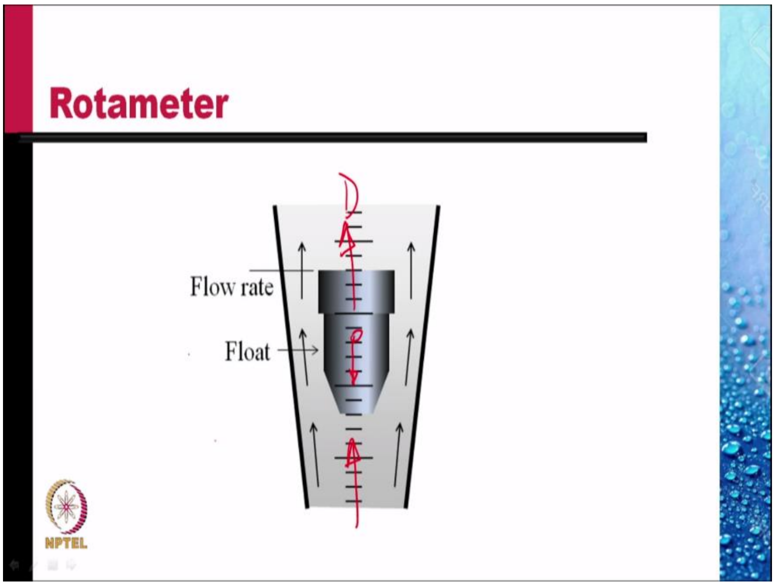

Another flow measuring device is what is known as a rotameter. It is very interesting. It has to be oriented vertically as the flow takes place. This float is in equilibrium under two kinds of forces. One is the weight of the float, downwards, and the other is the drag on the float because of the fluid motion. The drag changes with the velocity of the flow and with the location of the float within the diverging passage of the rotameter.

When the float is down, the passage around is narrower and there is more drag. When this is for a given flow, for the same flow, when the float moves up, the passage around it is more, so drag reduces. For a given flow, the float adjusts its location such that it experiences drag equal to its own weight. We read the location of the float on the graduations on the transparent tube which carries the flow, and is directly calibrated into volume flow rate. This is very commonly used in process industry.

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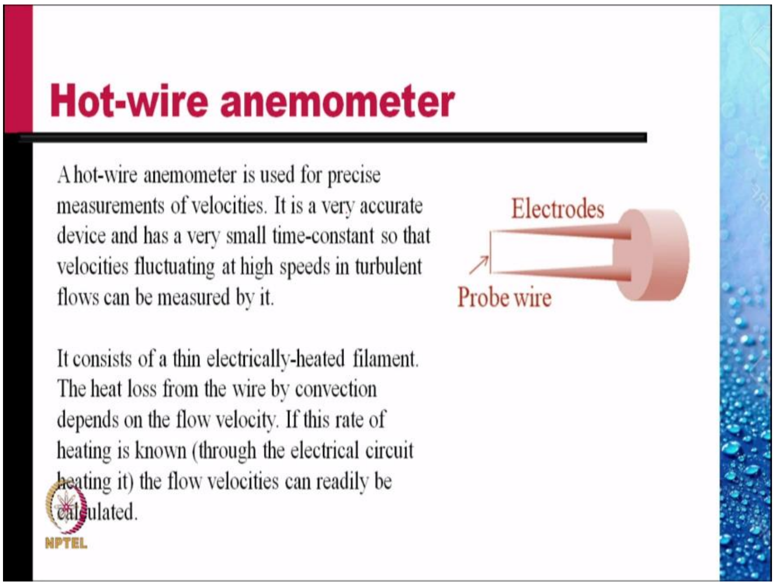

Another very accurate device for flow measurement is a hot wire anemometer. It is a very accurate device and has a very small time constant so that the velocities fluctuating at high speeds in turbulent flows can be measured by it. It consists of a thin electrically-heated filament. The heat loss from the wire by convection depends upon the flow velocity. If this rate of heating is known through the electrical circuit heating it, the flow velocities can readily be calculated. It is a device of choice for measuring the turbulence parameters. Its time constant is small because the volume and the mass of the wire, the active element, is very small. So, the temperature of this changes very quickly as the flow velocity changes.

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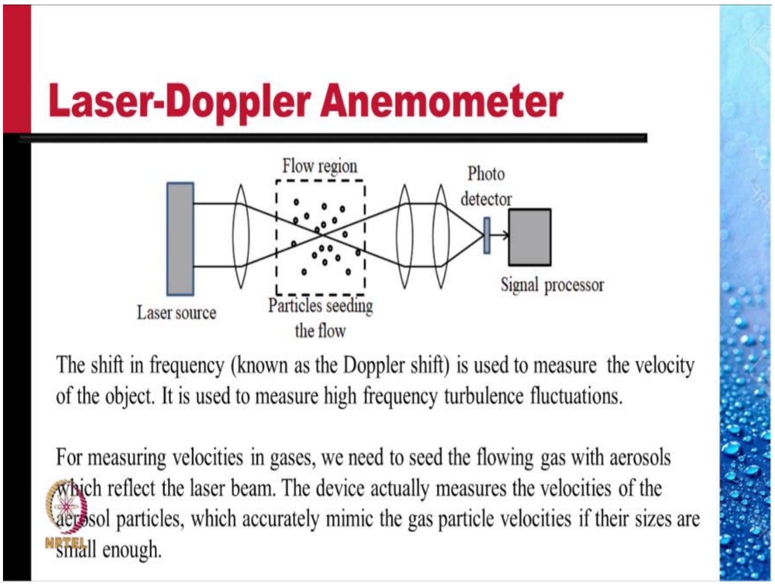

Another device is based on the Doppler principle. The Doppler principle states that the frequency of the waves traveling through the medium changes as the flow velocity changes. This is known as the Doppler effect. The shift in frequency is used to measure the velocity. We have a laser passing through passing across the flow sections. The flow section is seeded with particles very small in size and the particles are assumed to move with the velocity of the flow.

So, laser beam is reflected from those particles and there is the frequency shift that occurs because of the velocity of the particles. So, if we can electrically pick up the frequency shift, we can relate this to the velocity of the particles, which is related to the velocity of the flow, if the particle velocities are very small.

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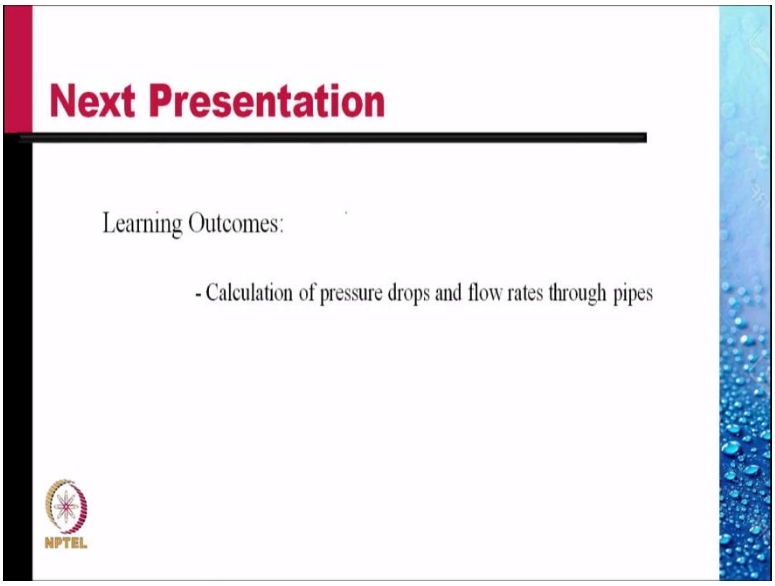

Thank you very much.