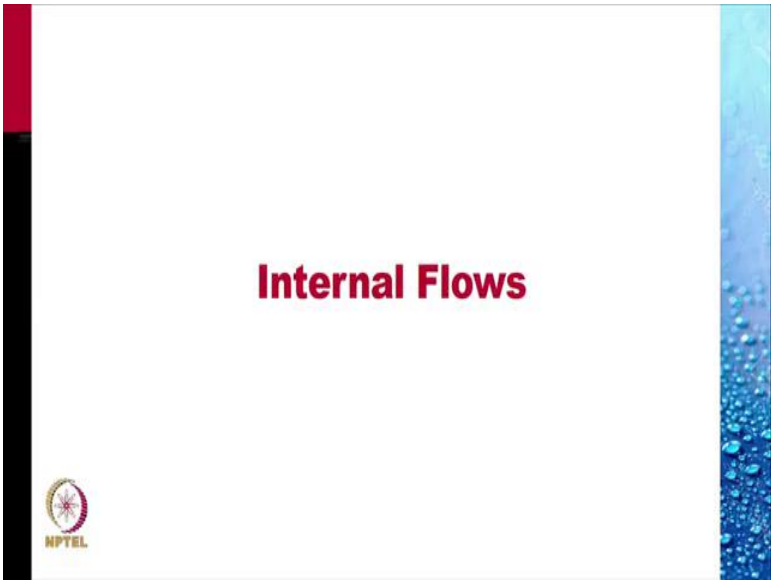
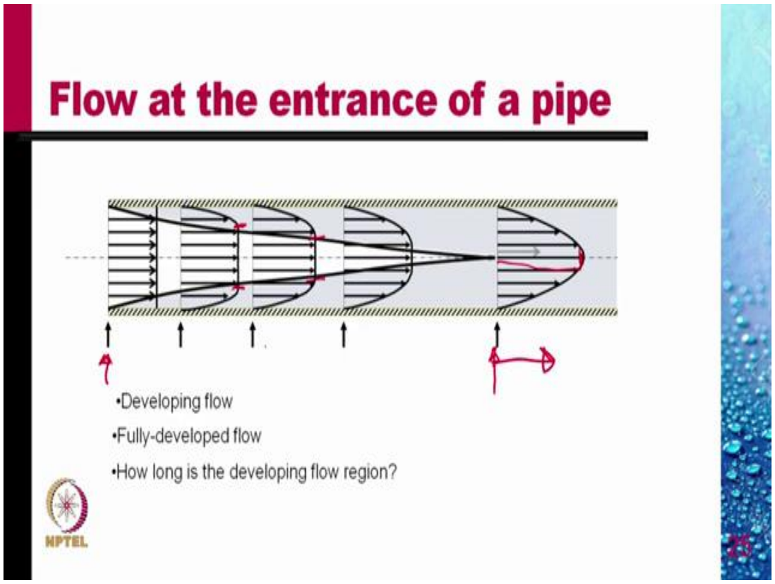
Fluid Mechanics and Its Applications
Professor Vijay Gupta
Department of Chemical Engineering
Indian Institute of Technology, Delhi
Lecture 2A
Internal Flows

(Refer Slide Time: 00:17)





Now we will discuss the flow inside a tube, called a pipe flow or an internal flow. Let us consider a circular pipe. Let us assume that as the fluid enters the pipe it has a uniform velocity across the section of the pipe. Now, we have studied the no slip condition at the wall. We mentioned in the last lecture that any fluid adjacent to a solid wall does not slip at the wall. It has the same speed as the wall speed.

So, if the wall is stationary, the fluid exactly adjacent to the wall would be stationary, would have zero velocity. This fluid which entered this pipe at a uniform velocity would see an immediate stop to a layer of fluid in the immediate vicinity of the pipe wall. And so, after a little time, the velocity profile would look like this.

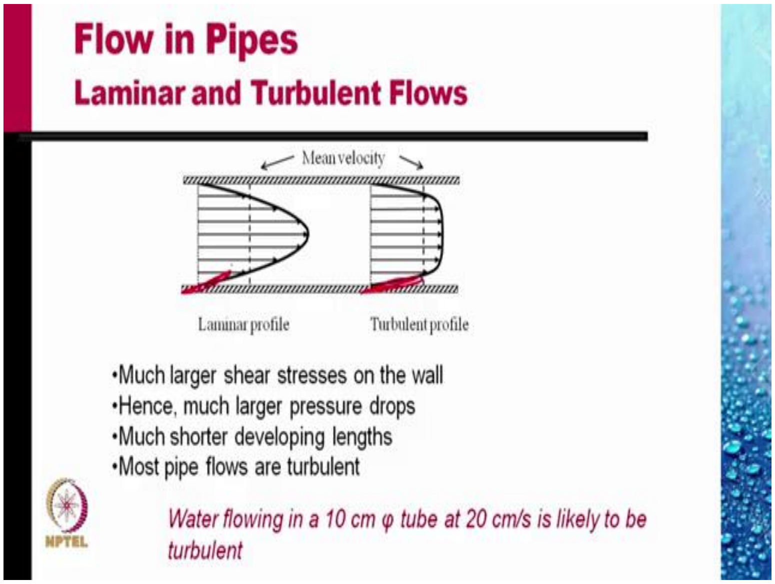
The effect of viscosity has penetrated up to this depth from both walls. At a little further distance, this penetration would further down, till all the fluid in the pipe is affected by the viscosity. This penetration of the viscous effect is the same thing that we discussed in the last lecture: the diffusion of vorticity.

Thus, ultimately, in this pipewe will develop a parabolic velocity profile, that you studied in high school. Notice one thing: The velocity at the center, which is maximum, is increasing as you go from left to right. Why? Because, the same amount of fluid must be flowing across each section. And since in the later sections, more of the fluid is slowing down, so the fluid at the center must have speeded up. In fact, as you would study later, that the maximum velocity at the center is twice the velocity of the flow at the entrance of the pipe. In this picture, this shaded area is the area that has been affected by viscosity. The remaining area is the unaffected area. It is called the core area.

After this length, the velocity profile does not change, and we say that the flow is fully-developed. It is between this and this, that the velocity profile changes. We call this the developing length or entrance length of the pipe, where the flow is developing. Developing flow, and then fully-developed flow. After the velocity profile has become parabolic, the viscous flow covers the whole region.

How long is this developing flow region? The calculations have shown that this is proportional to the diameter of the pipe multiplied by the Reynolds number. For laminar flows this length could be quite a bit. This length could be up to 100 diameters in laminar flow. But in turbulent flows, this length is quite low. We will discuss this too later.

(Refer Slide Time: 05:21)

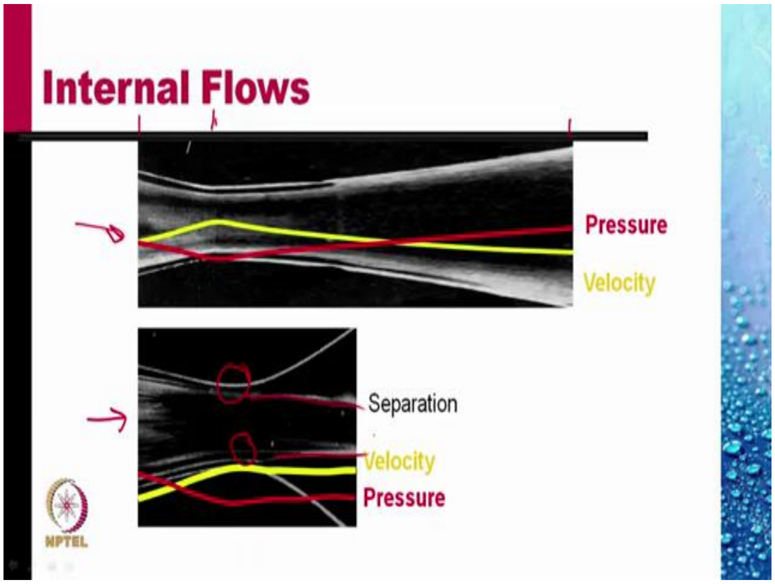


Here we are comparing the flow profiles in the laminar flows and the turbulent flows. In laminar flow, the maximum velocity is much larger than the average velocity. Not so in the turbulent flow. In turbulent flows, the central region is quite flat. The gradient of velocity at the wall is much larger in the case of turbulent flows than in the case of laminar flows.

Since the shear stresses are related to the velocity gradients, so, shear stresses on the wall in the turbulent flows are much more than the shear stresses in the laminar flows for the same mean velocity. Much larger shear stresses on the wall have much larger pressure drops and much shorter developing lengths in turbulent flows, as was discussed earlier. Most pipe flows are turbulent.

In fact, we would later on learn that the pumping cost when the flow is turbulent is least. We will discuss that issue later on. Water flowing in a 10 cm diameter tube which is about four inches in diameter at 20 cm/s is likely to be turbulent. Most flows in the pipes are turbulent.

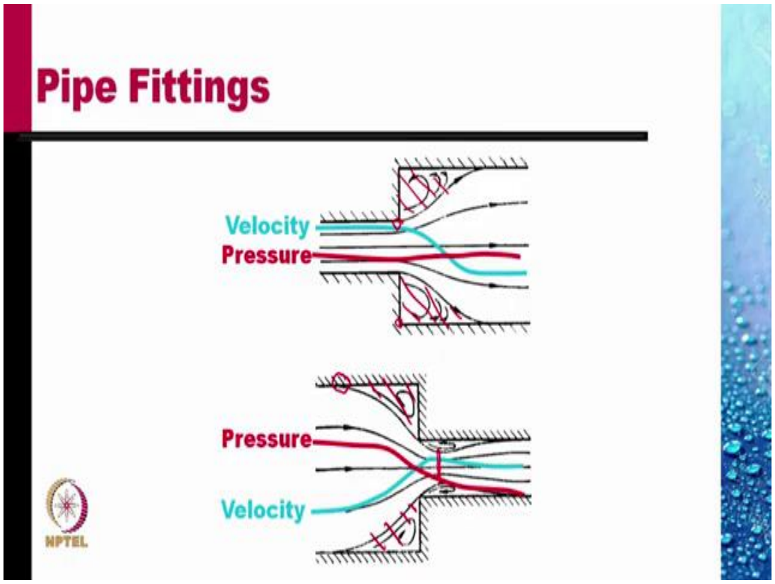
(Refer Slide Time: 07:11)

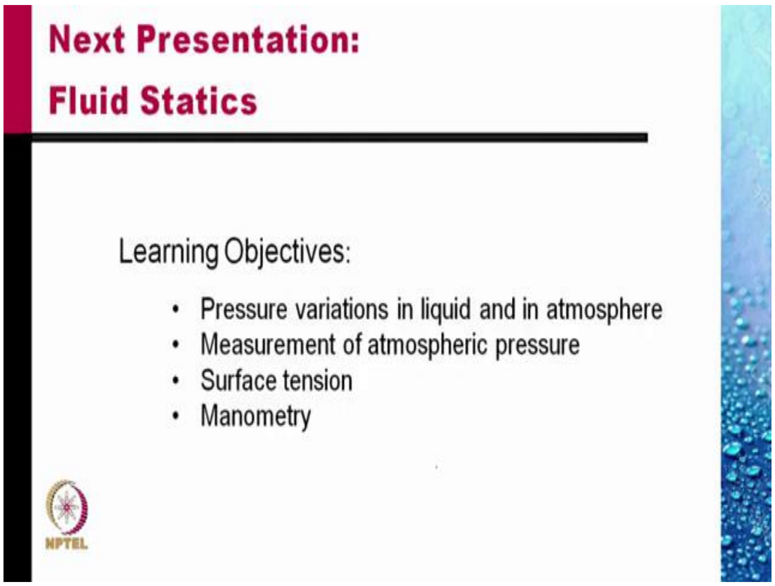


There is another property of internal flows that we want to discuss. Consider the first picture here. We have a flow in a converging-diverging pipe. The length of the converging portion is much smaller than the length of the diverging portion. Let us assume the fluid is water, an incompressible fluid. As the flow enters from the left, the velocity of the flow must increase. Because if we are passing the same flow, as the cross sectional area decreases up to the throat, the velocity must increase. The yellow line shows the variations in velocity. Then in the diverging portion, the velocity decreases again. What happens to pressure? As the velocity increases, the pressure decreases in accordance with the Bernoulli theorem that you studied in high school, and which we will cover here in much more details in a later chapter. The pressure decreases as the velocity increases, and the pressure increases again after the throat as the velocity decreases.

But if the length of the diverging section is reduced, like in the lower picture, you see a very interesting thing. The flow here separates at the throat, and comes out as a jet. And it comes out as a jet, the velocity does not decrease. So, while in the converging portion the velocity is increasing (the yellow line), in the diverging portion the velocity does not decrease. And because of this, the pressure does not recover. Pressure does not increase. And so, there is a decrease in pressure down this short nozzle, and this results in loss of energy. We have to be very careful about the diverging portions, because the flow tends to separate.

(Refer Slide Time: 10:10)





I end this lecture with a description of two pipe fittings. One is in which there is sudden increase in the cross-section of the pipe: sudden expansion of the pipe. The flow tends to expand, but, the flow separates at this region, developing an annular dead-water region. The fluid in this region does not move forward. It is just re-circulating there. The velocity decreases like this.

But, because of losses, the pressure does not change very much. Since the velocity is decreased, if there was no flow separation, the pressure would have increased, but the pressure does not increase. This means there is a pressure drop at a sudden expansion. If we were pumping water, that would mean we have to apply more pressure difference, we have to expend more power in pushing the water through the sudden expansion. Similarly, in a sudden contraction: Because the flow is slowing down here, there is a separation here. There is an annular vortex here. Then at the sharp corner, there is separation again. The fluid cannot turn sharply, and so we have an annular vortex sitting right there.

All this results in head losses. This is a minimum cross-section of the flow. It is called vena contracta in fluid mechanics. Pressure decreases because the velocity increases.

Thank you very much.