Transport Phenomena in Biological Systems
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Lecture - 21
Rheology

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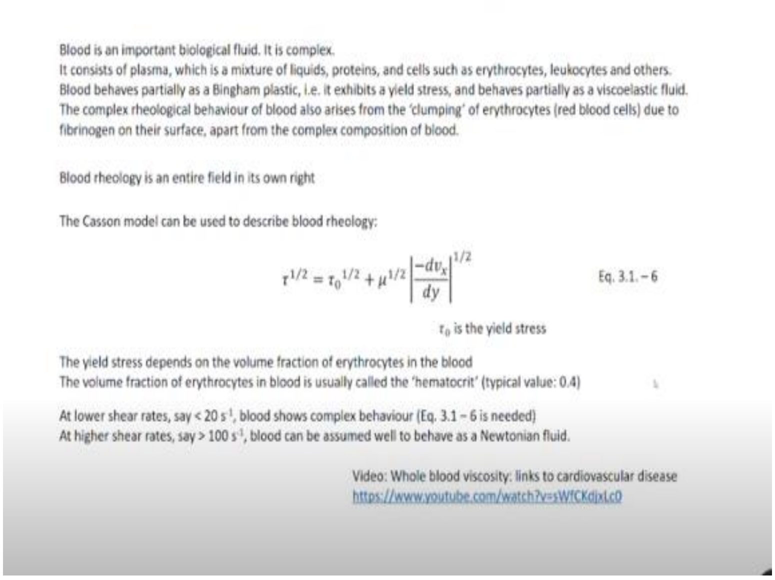

The next thing we need to understand about fluids or note about fluids to be able to at least approach them is that the type of flow determines a lot of things. It is a very fundamental aspect. We need to know what type of flow is occurring to be able to make sense of what is happening, to understand what is happening, to predict what could happen, okay.

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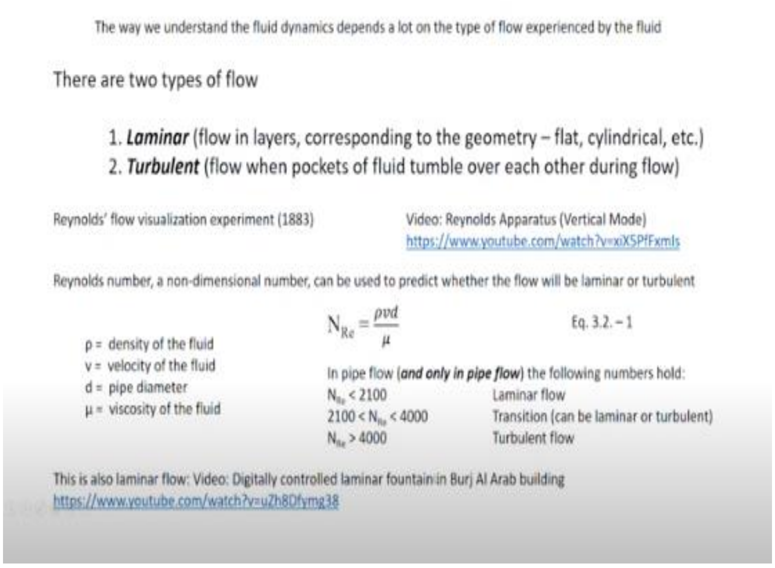

There are two broad types of flow. One is called laminar flow. Laminae means layers, so this flow happens in layers. The layers depend on the kind of geometry that we have. If it is a flat geometry over a flat plate let us say the layers are like this as we initially saw in this class. You know you had two parallel plates and the fluid and then the lower plate started moving and there was a flow that was induced due to the moving of the lower plate.

And in that kind of flow the layers are flat and parallel to each other. If you have a tube and you have fluid flow in the tube, the layers are all cylindrical, okay. Outermost cylinder just next to it, the layer just next to it, the third layer just next to it, the fourth layer and so on so forth okay. So if you look at it from the end, it will be a set of concentric circles, the various layers.

So you need to take into account the geometry when you try to visualize the layers in laminar flow. It is just not flat layers alone. The other type of flow is turbulent where the flow occurs when pockets of fluid tumble over each other and the flow happens, okay. Or when the flow happens the pockets of fluid tumble over each other.

There is no layered flow either like this or like this or whichever geometry you want to look at okay. So there is tumbling and therefore, there are no layers at all. So this characterization is essential for us to first make some sense of the flow, complete sense is still not done; some sense of the flow and more importantly to predict things for our applications.

As early as 1883 Reynolds okay, Reynolds is the name and this is a possessive terms so Reynolds flow visualization. He showed or he visualized the flow and that apparatus actually you can watch in this video or a modified form of that apparatus you can actually watch in this video. I think the layers are visualized using a certain dye, the central layer is visualized using a dye.

Very carefully dye molecules are introduced at the center point of a laminar flow. And if there is no intermixing of the layers or in other words the flow remains laminar, the dye will remain a straight line at the center, there is no intermixing. As you change the conditions of flow, let us say the velocity changes and the flow moves from laminar to the turbulent region.

This dye gets mixed okay, which shows the intermixing of the various layers of flow, the parallel layers of flow. That is what is shown here. Please watch this video. **(Video Starts: 04:04) (Video Ends: 06:43).** There is a non-dimensional number. We have already seen use of non-dimensional numbers to generalize some solutions. Here this is in a different context.

A non-dimensional number called the Reynolds number can be used to predict whether the flow will be laminar or turbulent. That Reynolds number is defined as the product of density, velocity, the diameter or a characteristic dimension let us say divided by the viscosity of the fluid okay. So it depends on the fluid properties, the flow property, velocity and the geometry, let us say(a characteristic dimension).

If it happens to be a tube, the characteristic dimension is the diameter of the tube. If it is floor or flat plate it could be the distance along the flat plate and so on so forth. So essentially this is the density of the fluid, the viscosity of the fluid, the velocity of flow and a characteristic dimension. And you can check the dimensions of this. It will be dimensionless, it is a non-dimensional number.

$$N_{Re} = \frac{\rho v d}{\mu} \qquad (3.2\text{-}1)$$

If okay let us call this equation 3.2-1 first. If the Reynolds number happens to be less than a certain value, then laminar flow would occur. If it is higher than a certain value, then turbulent flow occurs, okay. If we increase the velocity for a given geometry and given fluid then the flow will move from laminar to turbulent. The layers will start intermingling to give you a turbulent flow later.

If we look at pipe flow, okay this transition Reynolds numbers is there for all geometries, all flow situations and so on. If we focus on pipe flow alone, then there are some numbers that you can put to this, which are good to remember. For other situations the numbers are different. In pipe flow and only in pipe flow, the following numbers hold.

If the Reynolds number is less than 2100, some books say 2000. We will stick to 2100 for this course. The flow will be in layers the flow will be laminar flow. If the Reynolds number is between 2100 to 4000 we really cannot say what kind of a flow it is. It could be laminar or it could be turbulent and so on so forth. So it is called the transition regime. If the Reynolds number is greater than 4000 it will be in turbulent flow in a pipe alone. So these numbers 2100 and 4000 are valid only for the pipe. Different numbers are valid for different flow situations.

In pipe flow (*and only in pipe flow*), the following numbers hold:

$N_{Re} < 2100$	Laminar flow
$2100 < N_{Re} < 4000$	Transition
$N_{Re} > 4000$	Turbulent flow

I think that is what we have. Yeah, before we finish, it is a very nice video that I would like you to see. The laminar flow is not just in the context of this alone. There are different situations where laminar flow occurs, okay. Laminar flow flows in layers but there are totally different situations, not just a pipe flow or a flow over a flat plate and so on and so forth. In this video there is a dancing fountain that is shown okay in Burj Al, Arab building. This digitally controlled laminar fountain exists and here also the flow is laminar. It is a very nice video to watch, an interesting video to watch. Take a look at that and appreciate that is also laminar flow, okay.

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(Video Starts: 10:42) (Video Ends: 18:32). With that, let us finish up today. It was just an introduction to momentum flux. We saw how shear stress can be looked at as momentum flux. Then some rheological characterization and the types of flows. When we meet next we will take things forward. See you.