Fluid Mechanics
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Lecture No. # 04

Welcome to this forth lecture on Fluid Mechanics for Chemical Engineering under graduate students. In the previous lecture, we described the continuum hypothesis and explained when it is valid and when it can break down potentially, and we also said that in most engineering applications, it is it is possible to use the continuum hypothesis without any problem. And in the continue hypothesis, we treat the variables in the fluid such as pressure, velocity, temperature, density and so on as smooth and continuous functions of position coordinates like x, y, z and as well as time.

Then, we started our discussion on what a fluid is. In order to do this, it is useful to contrast the mechanical behavior of a fluid with that of a solid.

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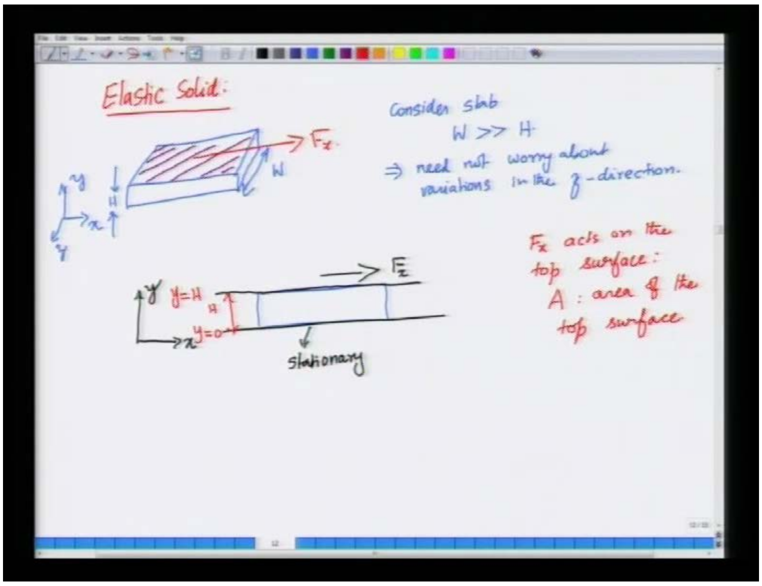

So, that is what we will do. We will start again with the notion of an elastic solid, and then, will contrast the behavior of fluid immediately after this discussion. So, what we did in the last lecture was to take a slab of a solid like a rubber, elastic solid light rubber, imagine you have a rectangular slab and this width of this slab in this third direction; let us put a coordinate system x, y and the third direction that is pointing out of the board is z.

So, this is w, and the thickness of the slab in the y direction is h, and we are going to consider a slab such that w is very very large compared to h. So, when w is very very large compared to h, you need not worry about the variations in the z-direction. So, all we will do is to consider a plane, the planar cross section in the x y plane.

So, we will take, we will assume that will take the x y coordinate system like this and we will assume that the slab is like here, just a cross section in the x y plane, and what we did was, we imagine that this slab, this piece of elastic material is kept between two plates, and the bottom plate is stationary, and the top plate; we want to apply a stress in the x direction which I will denote as f x.

So, essentially what we are doing is, let us consider this area of the top surface which I am going to shade, this force in the x direction is being acted upon the entire area. f x acts on the top surface and let the area of the top surface be a. So, f x is acted upon f x axis on the top surface which is at y equals h. And this at y equals zero, and this thickness is h.

This is the system. One can think of doing this experiment in lab, and I am going to discuss this as if we are doing this experiment in a mind and then, so we are doing a thought experiment, and then we are going to discuss how this solid is going to behave under the influence of applied forces.

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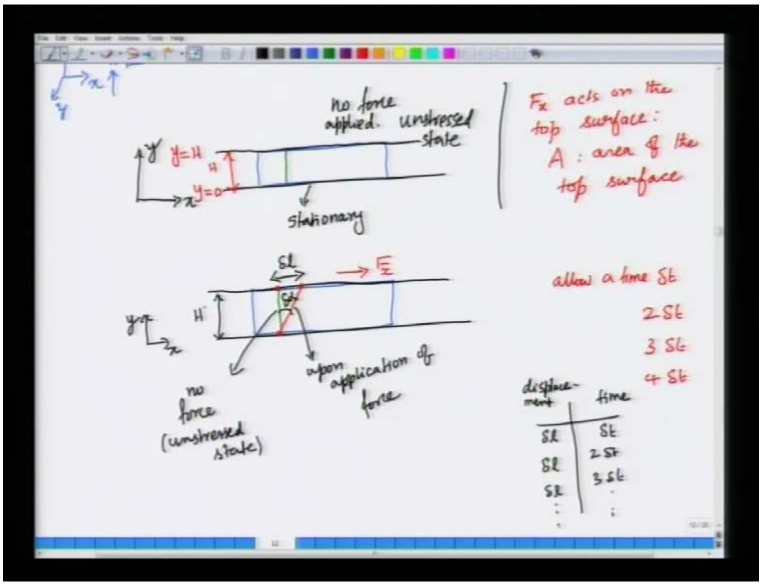

So, let us imagine, at in the… This is the unstressed, suppose at time, at some initial time, the solid is unstressed state before the force has been applied. No force has been applied in the unstressed state, and in the unstressed state, imagine that we are going to mark a line in the solid; a vertical line at a given location, and we are going to follow the position of this line as we are going to apply a force on the top surface. So, when there is no force, no stress in the solid. So, this line will be a vertical line.

Now imagine that we are going to consider the same rectangular slab in between two plates, and this is x and y as usual, and we are going to follow, this is in the undeformed state or the unstressed state, but now we imagine that you are applying a force. So, we start applying the force at some time t equals zero, and then we allow an interval delta t, a time interval delta t.

And then watch the evolution or the motion of this line. When you apply a force to the solid on the top surface, the solid responds by undergoing a deformation. So, what this solid will do is in fact, this line; force is being applied only on the top surface. So, this point that was here will move here, whereas, this point at the bottom surface is stationary, there is no force is applied; the solid is stuck to the bottom surface. So, this point will remain here. It would not deform. So, this line will move in general in the deformed. Upon application on force, this line will move like this.

So, this green line is no force in the unstressed state, whereas, this red line is when you apply a force, and then you record the motion or location of this line at a time delta t.

Now, imagine applying this force for continuously on the top surface, and what will and let us try to understand what will happened to this red line as you continuously apply the force.

So, even if you where to wait for more times; 2 delta t, 3 delta t, 4 delta t, a solid merely undergoes a deformation in response to an applied force, and once it undergoes, once it has once it has underwent a deformation, it will stop deforming due to resistant resisting elastic forces that are built in the solid.

So, this let us call this displacement of the point on top close to the top plate as delta l. This delta l will remain the same even at higher times, even suppose you have to measure the displacement of the top point versus a function of time. So, at time delta t, 2 delta t, 3 delta t and so on, in a solid, you will observe experimentally that the displacement of the top point remains delta l. And you can also characterize this deformation by this angle delta alpha. So, and this thickness is of course h.

So, a solid responds to an applied stress by undergoing a deformation, and this deformation, the solid if deformation stops after you know, it does not continue to increase.

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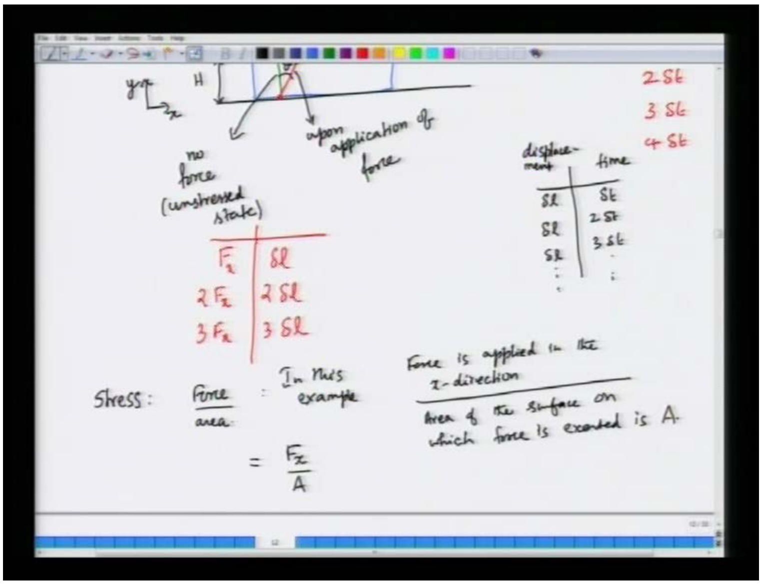

It undergoes a finite deformation and if you were to do experiments at different values of stresses, so, this is for a given value of stress if you want to do experiments at different values of stress or force sorry, so, if you have to do that experiment for f one, let us call it just f; a force f x, the displacement will be delta l, then if you were to do 2 f x, the displacement will be 2 delta l, and 3 f x.

If it is a purely a elastic solid, you find that the force that you applied will be directly proportional to the displacement the solid undergoes or the displacement which is a response to the forces is directly proportional to the force in a solid.

So, while this is how experimentally you will characterize the deformation in a solid, in order to make the information from experiments more general, it is useful to talk in terms of a stress rather than a force. Stress is force per unit area.

Now this force, in this example, in this example, the force is applied in the x direction; plus x direction and the area of the surface on which force is exerted is A.

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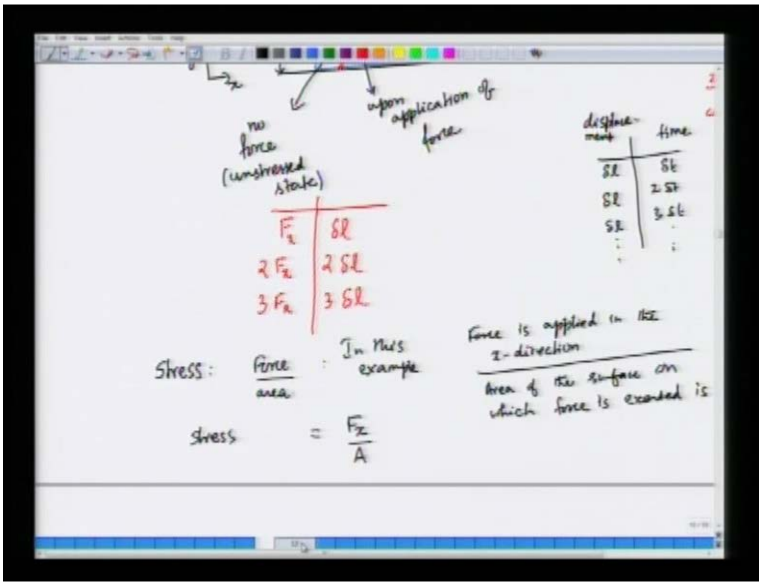

So, this is simply f x divided by A. So, that is what we said in the beginning that... So, the area is A. So, the area of surface is A and this is called as stress.

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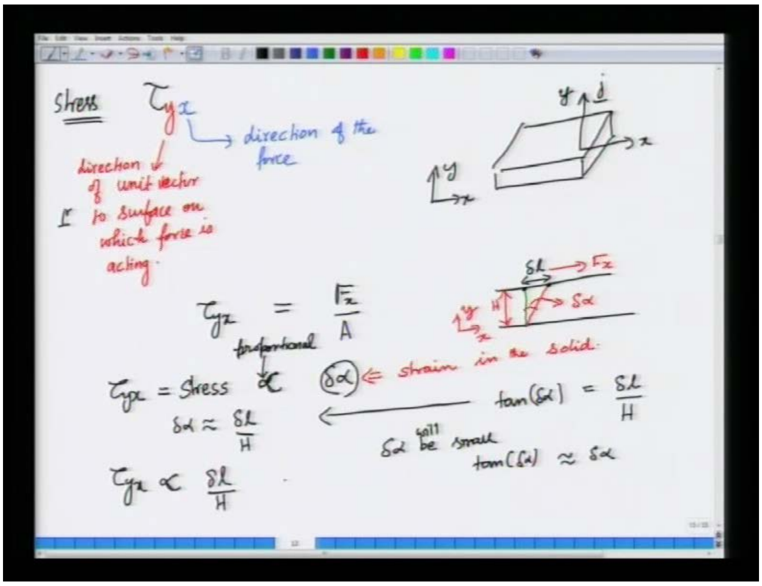

Now the stress is given denoted by the symbol usually tau in fluid mechanics; in mechanics in general, (( )) mechanics in general. And it is described with two subscripts. One is the subscript which is let me write down the subscripts and explain what those two subscripts mean.

The subscript x is the direction of the force. The stress is force acting on a surface per unit area. So, force itself has a direction. This y denotes the unit normal to the surface direction of the unit normal; unit vector if you want to the surface on which force is acting, force is acting. Now in our example, the surface; we took this slab and the force was in the x direction, and the direction of the unit normal in the plus y direction which is traditionally denoted by unit vector j.

So this y denotes a direction of the unit vector which is divide that unit vector along the y direction. So, it is a direction of the unit vector perpendicular to the surface. That is called unit normal, and x denotes the direction of the force. So, this is called stress. Stress is force by the area, but we have to specify the direction of the force on the surface as well as the orientation of the surface by specifying the unit normal or unit vector perpendicular to the surface. So, for a solid, you will find that tau y x in our example, tau y x is simply f x divided by A.

And you will find that this stress if you do experiments is directly proportional to the deformation which is characterized by the angle delta alpha. We call that you had this line, original line in stressed case and then deformed case.

The deformation can be characterized by the angle by which this line tilts upon application of force in the x direction. So, this is x, this is y. So, this angle can be taken as a suitable measure of the deformation or the strain in the solid.

Once a solid undergoes a deformation, we said that it is strained. So, the strained; a measure of the strain in the solid, deformation of solid is the angle delta alpha. So, you will find that delta alpha; the stress that you apply is directly proportional to the inclination of the this tilt of this line upon the application of stress and the stress will not change in a purely elastic solid as you wait long enough, sorry, the angle will not change if you wait long enough, even if you apply a stress continuously, the angle will still remain the same. That is because the nature of the solid to resist deformation. So, it resists deformation. It under undergoes some deformation that it does not continue to deform under the application of a force.

So, that is the definition of a purely elastic solid. So, let us do some simple geometry. So, this high course, h. So, from this and this, displacement of this line from here to here was delta l at the top plate. So, tan delta alpha from this figure is delta l by h, but when you apply small enough forces, delta alpha will be small.

So, when delta alpha is small, tan delta alpha is roughly proportional to delta alpha. So, this equation tells you the delta alpha is approximately delta l by h or I can write… So, that is a delta l by h, that is fine. So, this stress; tau y x is proportional delta alpha. So, I can write tau y x is proportional to delta l by h, because delta alpha this is, please do not confuse this, this is a proportionality sign. This alpha is the angle. So, let me try to write it like this. The proportionality sign slightly different from alpha. So, tau y x is proportional to delta l by h.

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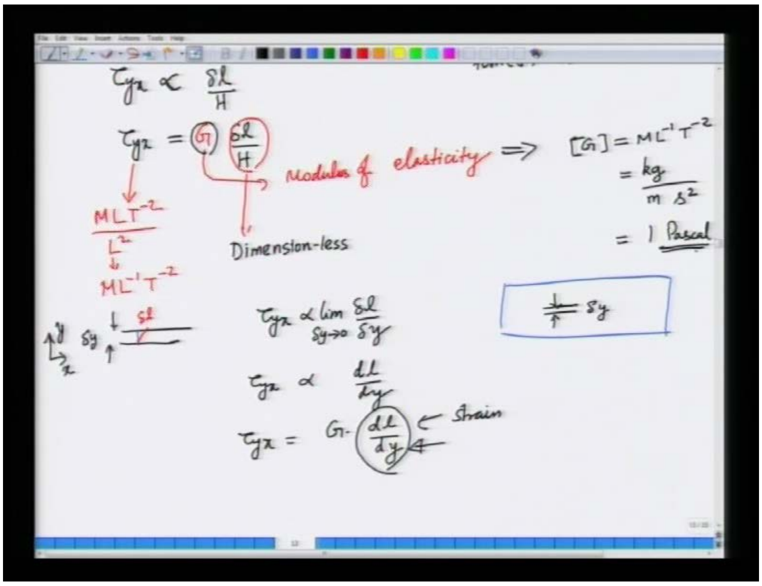

And you can replace the proportionality constant, the proportionality sign with a constant of proportionality. That is called a modulus of elasticity. This is called the modulus of elasticity. So, and we can work out the dimensions or units of this quantity tau y x is of dimensions of stress. Stress is force per unit area. Force is mass times acceleration divided by area.

So, stress becomes m l to the minus 1 t to the minus 2, and this group is a ratio of two lengths is dimensionless. It has no dimensions because it is length divided by length. So, strain in a solid is a dimensionless. So, the modulus of elasticity will have the same dimensions of stress. So, the mod normally the dimensions of a quantity are denoted by this square bracket.

So, m l to the minus 1 t to the minus 2. This is the dimension; these are the dimensions of modulus of elasticity and or stress for that matter.

And in SI units, g is, so if you put m as k g, per meter for l to the power minus 1 and t to the minus 2 second square, this is called one pascal. So, stress and modulus of elasticity everything is measured in pascal.

So, now this stress is therefore, directly proportional to the strain. Now previously, in this simple thought experiment, we considered a slab of the thickness h, but we could take the tiny thickness delta y in the y direction, within the slab itself, we will take a tiny thin slice, sorry take just to illustrate, this is your slab and even within this slab, you can take a tiny slice of the slab.

And then worry about what is the stress with respect, what is a how does the deformation change with respect to stress within this slice. So, we will do the same thing. So, we will find the tau y x is proportional to… So, this within this thin slice, line that was original like this would have moved like this. Lets called as delta l. So, again it will be proportional to delta l by delta y.

So, in the limit, now if you take the limit when the thickness of the slice goes to zero, this becomes a derivative in calculus. So, tau y x is proportional to d l by d y. And we can write this as a constant proportionality as d l by d y. This is called a strain in the solid.

So, while the previous discussion where you took a finite piece of material h is the valid for the particular experiment alone. This is this expression is valid in general because you can take a solid of any thickness and look at the deformation at the point or within the continuum approximation, a tiny slice of volume around a point, and then you will find this equation is valid.

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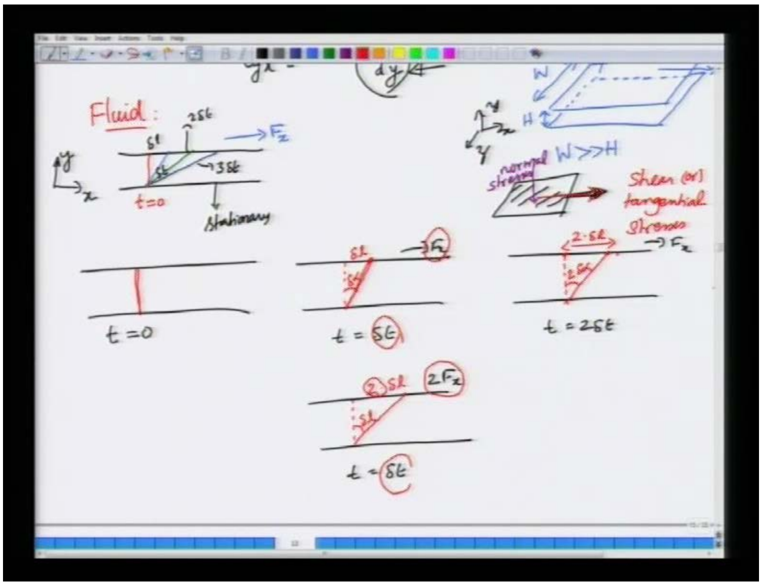

So, now let us contrast this behavior with a fluid. I am going to do the same thought experiment have a fluid between a two slabs like a viscous liquid; lets imagine a viscous liquid like honey. Take two slabs; let us mark the coordinate systems. Again I am going to assume as before that in principle, it is two slabs, and on the top slab, you apply a force f x. This width is very very large compared to the thickness edge in which the fluid is present. So, we need not worry about the variation in the z direction. So, in our scheme of thing, this is x, this is y and this is z. So, we will just consider the x y plane and we will put a colored dye in the fluid at time t equal 0, when there is no force that is exerted.

Now a time a time t is equal to 0 plus, we start applying a constant force f x. Now what we are going to do in this discussion is look at the evolution of this colored line as a function of time, when the force is being applied on a top plate and as before, the area of the top plate is A.

Now, so, let us imagine that after a time delta t, we look at this line. So, the bottom plate is stationary. There is no force. So, the fluid here close to the bottom plate, just adjacent to the bottom plate will not move, while the top plate; fluid process a top plate since you are exerting a force, this line would have deformed like this.

So, this is at a time let say delta t, but a fluid continues to deform under the application of stresses, especially shear stresses. So, here we are applying a force on a surface and the force is parallel to the surface. So, the force is parallel. This is the surface on which the force is being applied. And these are called shear or tangential stresses. Tangential forces or stresses are force per unit area is a stress; shear or tangential stresses because it is tangential to the surface on which the force is acting. The force is tangential to the surface itself.

In contrast to normal stresses which are perpendicular; as the name suggest, so, here we are applying a shear stress or a shear force on a tiny slice of a fluid with between two plates and we are finding that you will find that, if you do this experiment, if you watch this evolution of this colored line as a function of this line, it will continue to move at later and later times. A fluid continues to deform under the application of shear stress in contrast to solid which deforms to some extent and then stop deforming.

So, the fluid continues to deform. So, what you will find in experiment is that, at 2 delta t, this line will become like this, at 3 delta t, this may become like this. So, if you think of this distance as delta l, and this is a 2 delta t, this line is a 3 delta t and so on. So, this line continues to deform; that means, the fluid continuous to move under the application of shear stresses. We say that a fluid flows under the application of shear stress.

So, you will find that if you do this experiment, that if you were to plot at t equal to 0, this line will be here. So, I am going to draw different snap shots, t equals delta t, this line which was originally here would have moved like this. It would have moved by an angle delta alpha. And the top point would have moved by the length delta l and at a later time; t equal 3 delta t, it would have moved, I am sorry just 2 delta t; just keep 2 for simplicity. It would have more than two alpha. The angle would have increased to 2 delta alpha and the length of this point from which original position is known to be 2 delta l.

So, a fluid cannot resist any shear stress. So, it continues to move upon application of shear stress. So, clearly, this thought experiment suggest; this can be done really in a lab also, that one can do it, but here for the sake of illustration I am just doing a thought experiment.

So, the stress in a fluid, unlike a solid cannot be a proportional to deformation. The reason is you can get any amount of deformation if you are prepared to wait a long enough. This slice which was originally here underwent a deformation of delta l at time delta t, 2 delta l at time two delta t and so on. So, it would keep deforming as you wait long enough. So, stress really cannot be proportional to deformation. So, what is then stress a function of?

Let us slightly change the experiment. Instead of keeping... So, here I am applying a force f x; same force. So, here I mean a time t equal to 0, there is no force. So, there is no force, but at later times, we are applying the same force.

But now let us take this experiment. Instead of applying f x, I am applying 2 f x. You will find that even a time delta t, this line would have moved by 2 delta l. So, if you increase the force, for the same amount of time that your waiting, the deformation will increase for the same amount. So, for example, here f x was the force here, the force is 2 f x. For the same delta t, we are finding that the deformation has doubled.

So, the stress is not proportional to deformation for say because the same amount of deformation can be obtained in a fluid at you know, if you are prepared to wait long enough. So, even if you apply a very very tiny amount of force, you can get the same amount of a deformation delta l, if you wait sufficiently long enough.

So, clearly stress is not directly proportional to deformation. Indeed, it is proportional to how fast the fluid deforms or we say more clearly or more specifically; the rate at which the fluid deforms. So the stress is proportional in a fluid as this experiment suggest.

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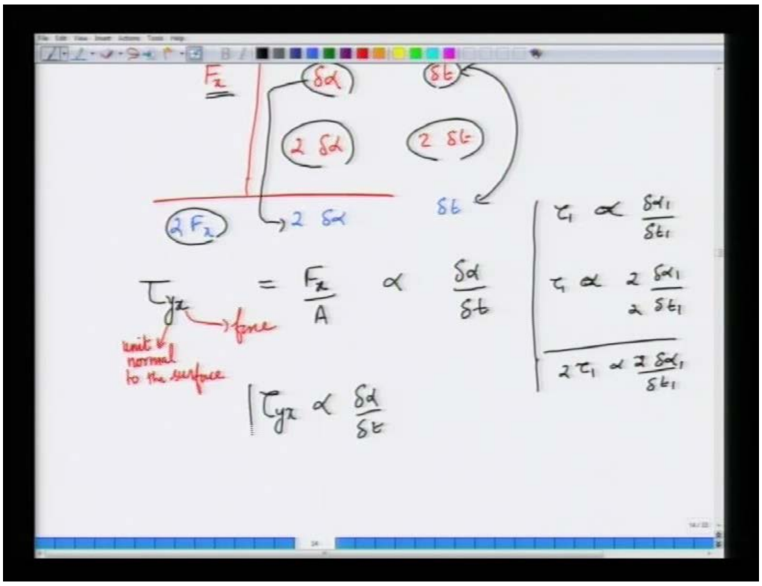

So, we have that for force f x, the deformation; this is applied force, this is the deformation that one gets as we measure through the angle was delta alpha at time delta t, 2 delta alpha at time 2 delta t. And similarly, if you apply 2 f x, you get 2 delta alpha at delta t itself.

So, the stress tau y x which is the same which has the same meaning as what we had in the previous illustration from elastic solid, this is the force in the x direction; on a surface whose perpendicular is in the y direction to the surface.

So, tau y x is the stress that you are exerting on the top plate. This is simply equal to f x by A divided by A. It cannot be a proportional to delta alpha, but infact, it proportional to the rate at which alpha changes with time; delta alpha by delta t

Then this, because this what the experimental result would suggest, if you wait for delta t for the same f of x, you get delta alpha. If you wait 2 delta t, you have 2 delta alpha. But if you double this stress, for the same delta t, the deformation doubles. So, all this is captured by simple hypothesis or propotion that the stress must be proportional to the rate of deformation.

For example, in this proportion, if I double the stress, so, let say tau 1 was the stress, the delta alpha 1 was the deformation at time delta t 1. If aware to wait for 2 delta t 1, for the same stress, then proportional to, then I would get 2 delta alpha 1; because I am keeping stress constant. If I wait 2 delta t 1; since it directly proportional, it will be 2 delta alpha 1.

But if I keep 2 tau 1 and I keep delta t 1 the same; since is directly proportional, the angular displacement has to be increased by 2 delta alpha 1. So, all this is captured by this simple relation that tau y x must be directly proportional to delta alpha by delta t in a fluid.

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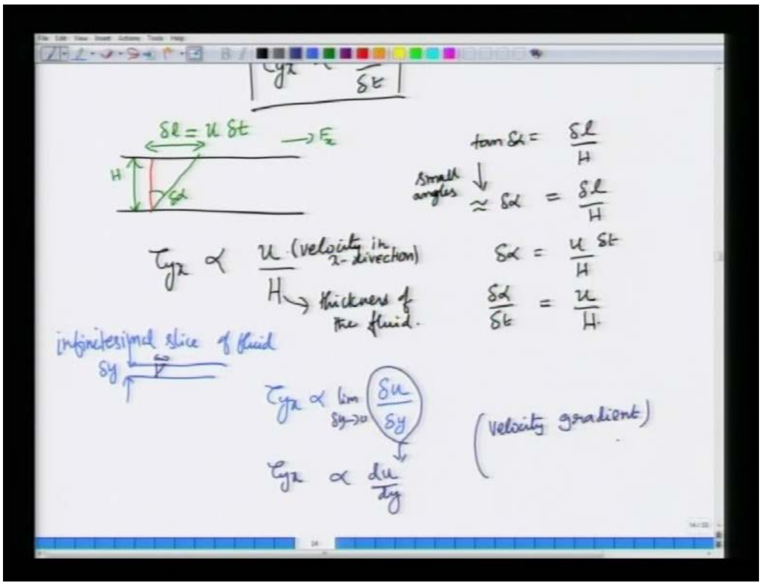

Now, let us look at the geometry again, once again. So, this was the original line. This was the deformed line, this is delta alpha, this is delta l, but in a fluid, the top plate continues to move because the fluid is also moving. The top plate will also; if you exert a force, top plate will continue to move. So, this delta l, so, the top plate will acquire a velocity, if you apply a force to the fluid.

So, it is u times; delta l will be u times delta t, and this is h. So, from geometry, we know that tan alpha is delta l by h, tan of delta alpha, sorry and for small delta alpha, tan delta alpha is approximately delta alpha; small angles. This we discussed few a minutes back for the case of elastic solid also. So, delta alpha is delta l by h, delta l is delta u times delta t divided by h. So, delta alpha by delta t is equal to u by h.

So, u is a velocity of the plate; top plate, and h is the thickness. So, tau y x is proportional to u by h, where u is the velocity. Suppose you have exerted a force in the x direction on the top plate, this plate will start moving if whatever is the material that present between the two plates is a fluid, and you can characterize that motion with a velocity u of the top plate. So, this is the velocity of top plate, and in the x direction, h is the thickness of the fluid.

So, instead of taking finite thickness, we can also consider an infinitesimal thickness delta y, then tau y x will be proportional to… So, infinitesimal slice of fluid will be proportional to delta u by delta y, which is essentially the velocity of this top layer with respect to the bottom layer.

And when all the things when in the limit delta y tending to 0, tau y x will be proportional to; this will become a derivative, will be proportional to d u d y. This is called the velocity gradient. It is the derivative of the x velocity u with respect to the y coordinate. It is called the velocity gradient.

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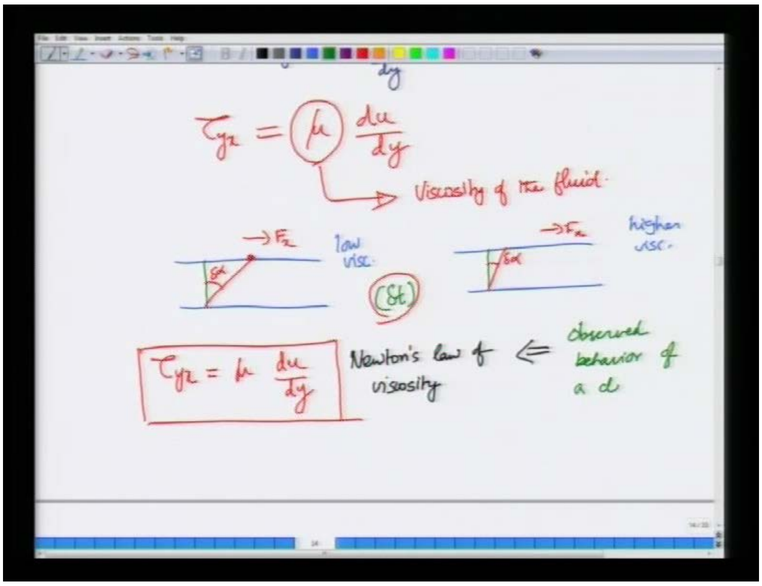

So you can replace the proportionalities six symbol with a constant of proportionality. And that constant proportionality is denoted by the greek symbol mu. It is called the viscosity of the fluid.

So, a fluid; in a fluid, the stress is not proportional to deformation. It is proportional to rate of deformation and through this simple geometric analysis or argument, they have shown that the rate of deformation is proportional to the velocity gradient, that is equal to the velocity gradient.

Therefore tau y x which is proportional to the velocity gradient, can be replaced by a constant mu, the proportionality sign can be replaced with a constant which is called a viscosity of the fluid.

So, what this says is that suppose we were to do this experiment of two fluids; one with higher viscosity, and the other with lower viscosity, and you apply the same force of f x on the top layer, and you watch the motion of these lines at a time, after a time delta t.

So, if you do that, you will find that the lower viscosity fluid would have deformed more compared to the higher viscosity fluid at the same time, but if you are prepared to wait long enough at higher values of delta t, even the higher viscosity fluid will achieve the same amount of deformation as low viscosity fluid.

So, in simple terms, a solid cares how much you deform. The stress is proportional to the deformation, the amount of deformation while liquid cares how fast you deform. So, a fluid resists deformation not in the sense, a fluid resist deformation by the rate at which it is deforming, not by the deformation itself.

If you take a solid like steel which is very very rigid, and if you take a soft material like a rubber, then if you apply the same amount of stress, both of these materials will deform, but the extent of deformation will be more in rubber than in steel.

Whereas, here in a fluid, if you take two different fluids; one with very high viscosity and other with low viscosity, if you apply the same amount of stress, the amount at which, the rate at which the fluid deforms will be different which is given by suppose you keep the time interval constant, then that is given by angle delta alpha.

So, this delta alpha will be small for a higher viscosity fluid, while it will be larger for low lower viscosity fluid. But this delta alpha will continue to increase in both the cases. So, it is a matter of this how fast a fluid deforms, and a higher viscosity implies that the fluid is going to resist deformation more compared to the case where when the fluid has lower viscosity, where it deforms very quickly. So, it is the rate of deformation; that is the crucial factor you know fluid. And the stress is directly proportional to rate of deformation.

Now tau y x is mu d u d y, where the stress is equal to the viscosity times rate of deformation is sometimes called Newton's law of viscosity, but you should understand that this is merely an observed material behavior, observed behavior of a class of fluids.

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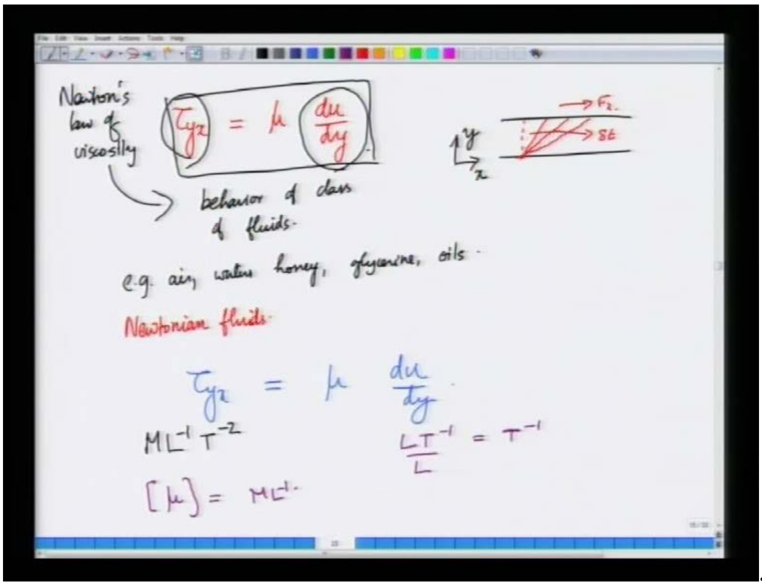

So, a Newtonian fluid is merely (( )) or the Newton's law of viscosity; let me write this as the Newton's law of viscosity which is merely a behavior of a class of fluids materials. It is not a fundamental law and there are of course, there are fluids need not obey Newton's law of viscosity. So, but, it turn out that many simple fluids like air, water, honey, then glycerin and several oils; they all observe, they all obey this behavior.

So, it is a pattern of behavior that is followed by wide class of fluids, but there are always, there are lots of exceptions to this behavior, but this one of the simplest possible relations between the stress and the rate of deformation in a fluid. So, and fluids which obey this behavior, they are called Newtonian fluids. They are called Newtonian fluids.

Now, let us workout the dimensions of viscosity because we are encountering this for the first time in this course. So, tau y x is mu d u d y. tau y x is stress and stress is force per unit area. So, this has dimensions. We already saw this few minutes back in the context of modulus of elasticity, and velocity gradient is basically l t to the minus 1 divided by l. So, this is simply t to the minus… It has dimensions of 1 over time. So, if you work this out, the dimensions of the mu is m l to the minus 1 t to the minus 1.

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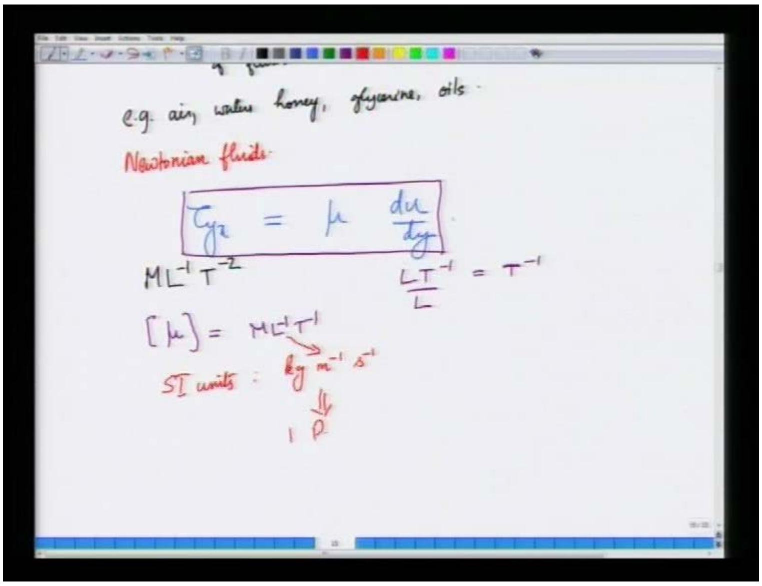

Just compare these two. In order for this equation to be dimensionally consistent, then mu has to have this dimensions; viscosity as to have this dimensions. In SI units, mass is measured in kilogram, length in meter, and time in seconds. So, the unit of viscosity is k g per meter second. So, this also equal to one pascal second.

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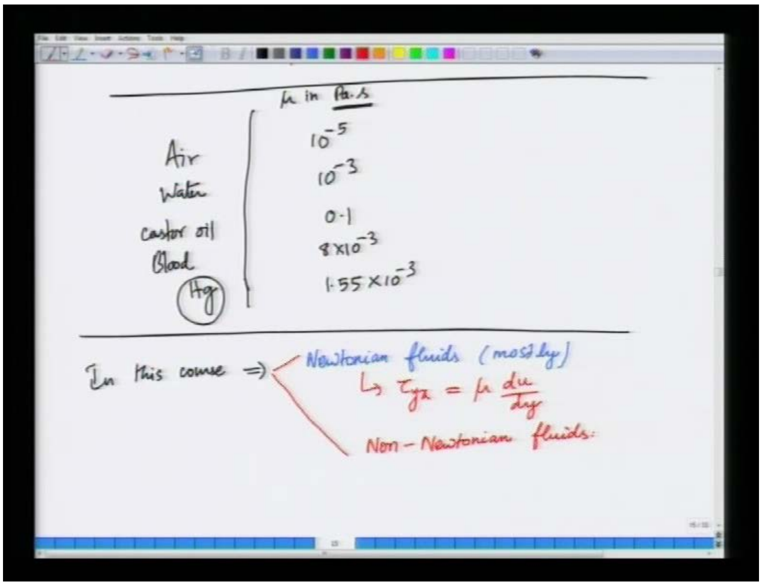

Now, just to give you some example of various viscosity values that one sees in common fluids, suppose you have air, all the viscosity values are in pascal seconds. Viscosity value of, viscosity of air is about 10 to the minus 5 in pascal second units. Water is about 10 to the minus 3 and castor oil 100 times more viscous than water; 0.1, and blood is which is a bodily fluid has viscosity of 8 times to the minus 3, eight times to viscosity of water.

But interestingly, if you consider mercury which is a liquid metal, the viscosity is very close to that of water. It is only 1.55 times larger than water. So, mercury has large density we know that, but the viscosity is a completely different property. It is not correlated with density in any direct way as you can see here. Even though mercury is very very dense, the viscosity of mercury is not very different from that of the viscosity of water.

So, in this course, which is about fluid mechanics applied to chemical process industries, we will largely restrict ourselves to Newtonian fluids mostly. But, at the end of the course…, so, when we say Newtonian fluids, we mean that the stress is proportional to or is equal to viscosity times the rate of deformation, which is the velocity gradient.

Mostly, but at a later point of time, at the end of the course, we will have opportunities to talk about fluids which do not obey this behavior. They are called Non-Newtonian fluids.

So, we will have an opportunity to discuss the behavior of fluid that do not follow the Newton's law of viscosity, but for the initial part, we will certainly restrict ourselves to Newtonian fluids.

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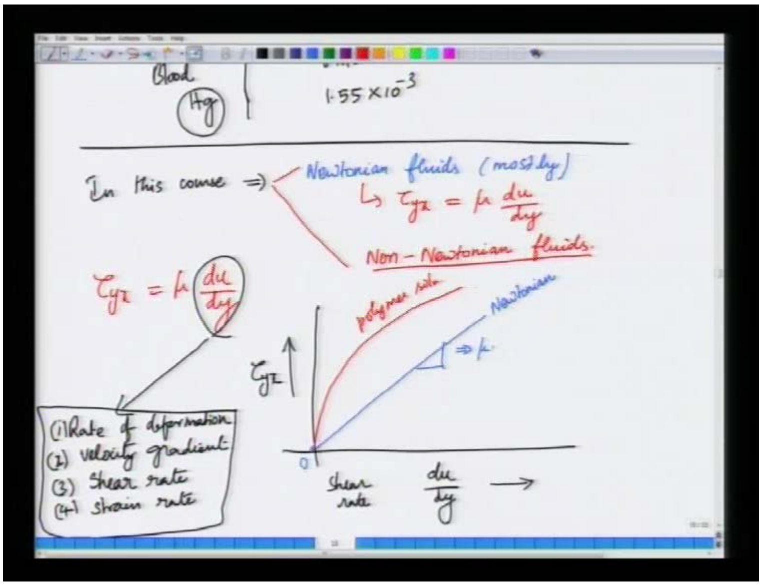

Now, what this is saying is if tau y x is nu d u d y, if you have to do this experiment in a lab and plot the data that you get for tau y x versus d u d y, this is variously called as rate of deformation because that is what it is. It is rate at which the fluid deforms.

But since the rate of deformation we showed is equal to velocity gradient, it is also called as velocity gradient, and since the deformation; the way in which the fluid is deforming by shear; that is, you are applying a tangential force. This also called shear rate or rate of shear or shear rate. You should be… sometimes it is also called the strain rate because delta alpha is a measure of strain, and this is delta alpha divided by delta t. So, these are all various descriptors that are used to signify the same quantity which is mathematically d u by d y, which is a velocity gradient.

So, if you plot the shear stress versus shear rate, so this is the shear rate; the rate of the deformation for Newtonian fluid, you will get a straight line that passes through the origin, and slope of this line will be the viscosity mu.

This is not to say that all fluids will have the same behavior. I have told you that there are many fluids which do not follow this behavior. Let me tell you the experimental behavior that is commonly seen. Suppose you take…, so these are, I am going to… the blue line is Newtonian. So, let me write this in blue.

So, let us suppose you take a solution of water and a polymer like poly ethylene oxide. You dissolve very very small quantities less than one weight percent polymer in water; polymer such as poly ethylene oxide, so, polymer solution, and if you plot tau y x; if you do this experiment in a lab, you will find that it is not linear. It is going to behave like this, if you take a polymer solution. This is a polymer solution.

Now, for a Newtonian fluid, if you have to plot the viscosity, so, let me just go a little below.

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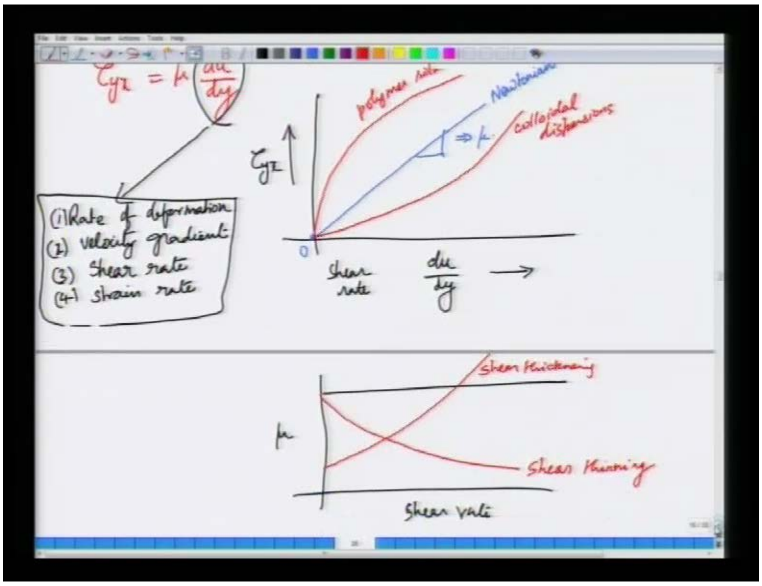

If you plot the viscosity as a function of shear rate, it is a constant because tau is directly proportional to d u d y, and it is a straight line. So, the slope is a constant, but if you take a polymer solution, the viscosity will decrease with shear rate. So, such fluids are called shear thinning because the viscosity decreases with shear rate.

But there are also fluids that shear thicken. These are colloidal dispersions. By shear thickening, we mean that the viscosity increases with shear rate. So, you could also have this behavior. Both are non-newtonian; that is, the viscosity is not a constant, that is, our tau is not linear in d u d y, but there are different classes of non-newtonian behavior and there is one more type a non-newtonian behavior which I will draw in a separate graph.

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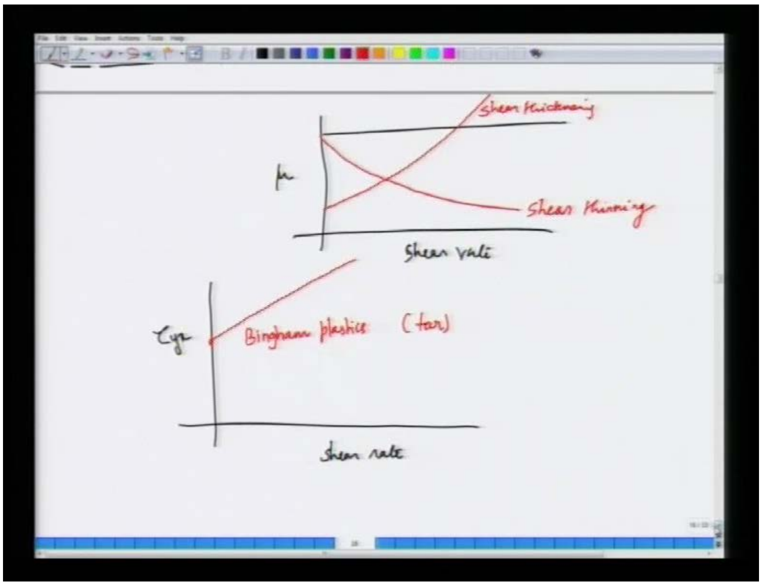

So, you can have a material like tar, where if you plot tau y x versus shear rate, the material does not flow up to a critical value of shear rate, and it flows after that like a Newtonian fluid. Such fluid such materials are called Bingham plastics. Example is tar. So, appears like a solid up to a critical shear stress, after that, it starts flowing like fluid. So, such materials are called Bingham plastics.

So, this discussion is to just tell you what a fluid is, what is a fluid, why is it, how does it differ from a solid in terms of its deformation nature, and we saw that a fluid fundamentally differs from a solid in the way it responds to shearing stresses. Fluids; we say it cannot resist any shear stresses unlike a solid because if you apply a shear stress to a solid, it undergoes a deformation and it stops deformation after some time. It does not continue to deform unlike a fluid which keeps on deforming as long as the force is applied, as long as the shear stress is applied.

So, a solid cares how much you deform, while liquid cares about a how fast you deform. So, if viscous if the constant of proportionality between the stress and rate of deformation is called viscosity and fluids with different viscosity offer varying resistance to rate at which they deform. Just as solid with different moduli offer varying amounts of resistant to how much they deform. For example, if you apply a stress of 100 pascals to a steel bar, it will deform very very little in contrast to let say a piece of soft rubber.

So there, these two materials; steel and rubber are characterized by different elastic moduli and material with lower elastic moduli deforms much more compared to material with larger elastic moduli, whereas in a fluid, a fluid with higher viscosity deforms at a much smaller rate than fluid with a much lower viscosity for the same stress that you apply because in a fluid, you can get the same amount of deformation regardless of the stress applied because you can always wait long enough.

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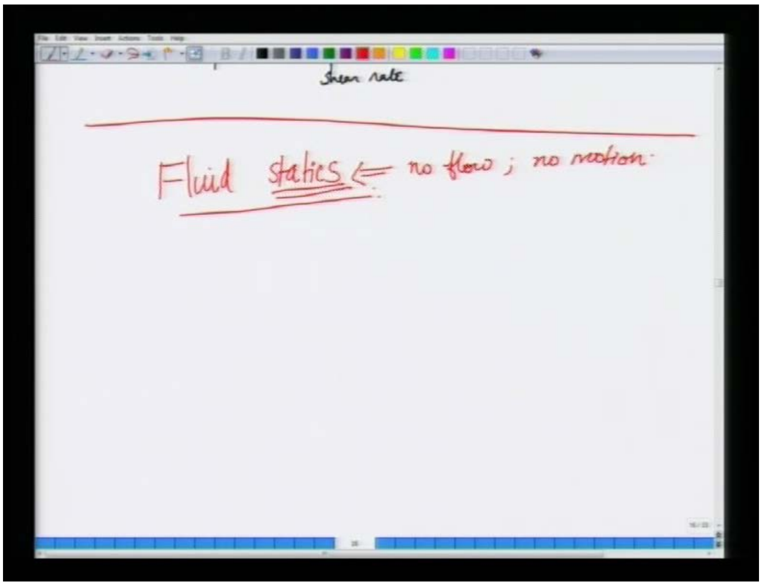

Now, the next topic that we are going to worry about is fluid statics. Now so, this is the first series of topics we are going to cover in fluid mechanics. So, far we are been introducing the subject and introducing the notions of continuum hypothesis, what a fluids is and so on.

The first topic that we are going to discuss is fluid statics and what are the forces that are… How force distribution happens when a fluid is completely static. Static means there is no flow, there is no motion.

So, this is the topic that we are going to first discuss, and we will start from next the lecture. So, we will see you in the next lecture to discuss this new topic on the force distributions and static fluids. Good bye.