Hi and welcome to Engineering Earth. The topic of this video is Newtonian Fluids.

In Chapter 2 we learned about a fluid property, called viscosity and we defined this property as the internal resistance to flow within a fluid. So, you can think of it as the stickiness of the fluid molecules against one another. In your prior engineering studies, you've learned about friction coefficients that help predict resisting frictional forces when two solid materials move relative to one another. Viscosity can be thought of as a friction coefficient for fluids, but viscosity is actually way cooler because viscosity is not a coefficient. ItÂ's an actual physical property of matter, it has units, and it can be derived from analysis of force. As fluid viscosity increases, so does the magnitude of force exerted on a body in the flow. The viscosity of air is lower than the viscosity of water and that's why we get such a better workout when we do aqua-jogging in a pool than if we were to jog the same distance on a sidewalk or a treadmill through air. So, our runner here running through air is exerting uh her body less than the aqua jogger in the water. Now just imagine we filled that pool up with a much higher viscosity fluid like honey or motor oil and then tried to jog through that. So just like our jogger in this cartoon we would have to um use a lot more of our body's energy to force it through that fluid so we can think of um viscosity increasing like this and then the force that the fluid is acting on a body is also increasing.

In the last video we revisited the no-slip condition between solids and fluids, and we drew up velocity profile that we might expect in a number of situations. So, for instance, if I have two solid plates like this and there's some kind of fluid in between them and the distance between the two plates I'll call Y, and our bottom plate is stationary so it's moving at a velocity zero and then our top plate is moving from left to right like this, at some velocity that's greater than zero, u. Um so we learned in our last video that the fluid that is touching the bottom plate down here is moving at a velocity of zero, the same velocity as the bottom plate, because of the no slip condition: the first layer of molecules touching the bottom plate have to move at the same speed as the plate, and that solid plate is moving at zero, so the bottom layer is also moving at velocity zero, right. So this is my first layer of the fluid, my velocity is equal to the velocity of the plate, zero, and then the next layer up is moving just a little bit faster than zero and the next layer beyond that moves just a little bit faster, all the way up until we get to uh the layer the last layer of molecules that are touching this top plate up here and those are moving at a velocity of u, the same velocity is the top plate. So, we've got this distribution of velocity from the bottom plate to the top that looks like this. And so, we can describe the velocity gradient as the change in velocity, du, over the change in distance, dy. So now I have a question for you. What is the magnitude of the force that was applied to that top plate that allowed it to move at a speed of u and create the velocity gradient du dy that resulted? So this force that's moving the top plate is being applied tangentially to the plate, um so that means it's being applied from the side not you know down from the top, which would kind of create a compressing force on the fluid, instead it's being applied on the side, creating a tangential force. And so that force is being transmitted to the fluid everywhere that the moving plate is touching the fluid, so that would be the area A of the plate, and of course we know that a force divided by an area, force per unit area, is stress and because this stress is being applied tangentially, it is a shear stress. So now that we're able to relate the force per unit area, or shear stress applied to its effect on the fluid, this velocity gradient, um but if I want to relate that shear stress to the velocity gradient, du dy, I know somehow that they're related to each other but I don't know exactly how they're related yet. And then I remember that aqua-jogger example. So, if the fluid that is touching the plate has a low viscosity it's going to require less of that applied force to achieve the same velocity gradient than in a fluid with a greater viscosity like honey right. So, I know that it's not just as simple as something like the applied shear stress is equal to the velocity gradient right, I know that can't be true because I could apply the same shear stress to different fluids and see different velocity gradients. So, there's got to be something else in here that is happening.

So if I think about the relationship between the force per unit area applied, that would be the shear stress, shown on this graph on the Y-axis, and the velocity gradient that's created on the x-axis, I can imagine that this relationship is going to look different for fluids that have different viscosities. So, if I compare the three fluids of different viscosity that we looked at in the first slide, um then I may see some differences. So, for instance, my relationship for air might look something like this, and then my relationship for water may look like this, and my relationship for honey may be like that. So, a small applied force right, let's look at you know applied force around this magnitude right here and see where it intersects all three of my curves, so that small applied force will create a relatively larger velocity gradient in air than it will in water and then an even smaller velocity gradient is going to result when I apply that same force to honey. So now we have arrived at the definition of a Newtonian fluid. So, any fluid where the rate of deformation, the velocity gradient, is linearly related to the shear stress applied, this is a Newtonian fluid. So, all three of my Newtonian fluids: air, water, and honey; have the same linear relationship, but the slopes of these three lines are quite different. So the slope of the line defining the relationship between velocity gradient and shear stress of honey is much steeper than that of water, which is steeper than that of air. So, the constant of proportionality that is relating shear stress and velocity gradient is the fluid viscosity, and now we can finally draw that equal sign. So, the greater the fluid's viscosity uh the greater shear stress that's going to be enacted for any given velocity gradient. So, fluids where the relationship between shear stress and velocity gradient is not linear are non-Newtonian fluids, right. So, you can imagine a nonlinear relationship might look something like this, or like that. So, these would be curves for non-Newtonian fluids. Right, so, these types of nonlinear curves would not be able to be predicted by this relationship right here, that has a linear proportionality between shear stress and velocity gradient that corresponds to the fluid's viscosity. So most common fluids are Newtonian: water, air, oils, ethanol, uh most gases all are Newtonian fluids. So, an example of a non-Newtonian fluid might be something like uh a fluid that has a starch dissolved in it, like corn starch, or something like that a liquid plastic a fluid that has a lot of suspended solid particles in them they would have a non-Newtonian behavior. But all of the other fluids that are Newtonian we would be able to predict the relationship between shear stress and velocity gradient, based on the fluids viscosity.

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Great job reaching the end of this video and please reward yourself with a moment of Zen. I study fluid mechanics because I love water and healthy aquatic ecosystems. Whatever your passion is, I hope it motivates you to continue your study of fluid mechanics.