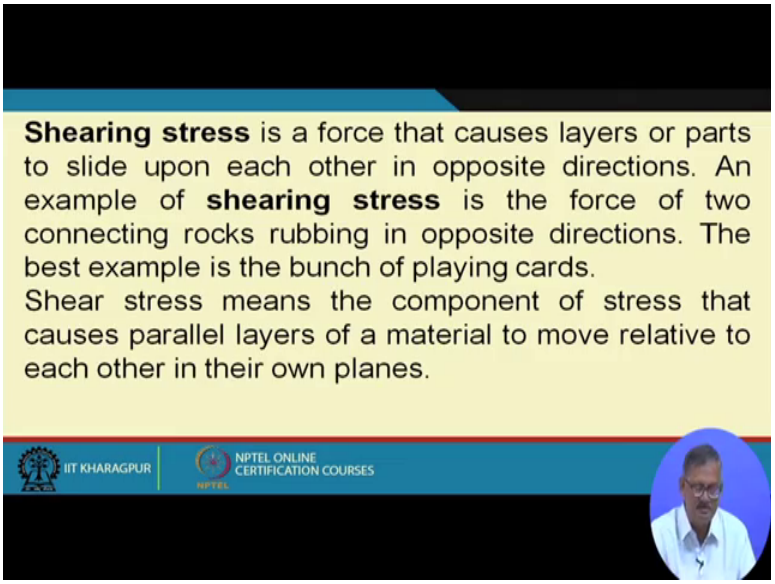
Course on Momentum Transfer in Process Engineering
By Professor Tridib Kumar Goswami
Department of Agricultural & Food Engineering
Indian Institute of Technology, Kharagpur
Lecture 39
Module 8
Non Newtonian fluid flow part-1

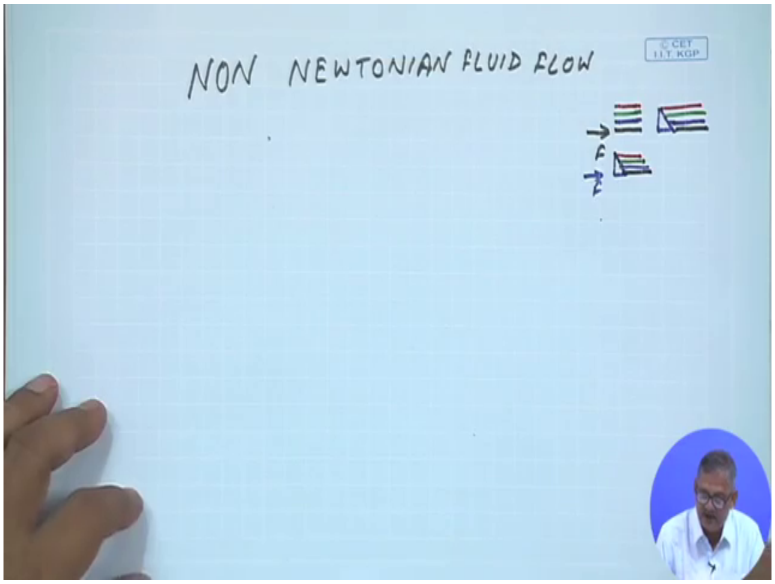
So we have done some problem on pneumatic conveying which we have perhaps seen and done at your home also. Now let us go to another very important aspect that is called Newtonian we have seen till now all fluid where Newtonian, but if the fluid becomes Non-Newtonian, right?

(Refer Slide Time: 1:13)



Then, we call it to be non-Newtonian fluid flow, right? So we call it to be non-Newtonian fluid flow, right? Now, to do that, let us recapitulate a little recapitulate a little in the sense we had said that shear stress, right? If you remember in many classes earlier we had said shear stress and in this non-Newtonian flow when we define what is the non-Newtonian, why we call it to be Non-Newtonian etcetera.

(Refer Slide Time: 2:03)

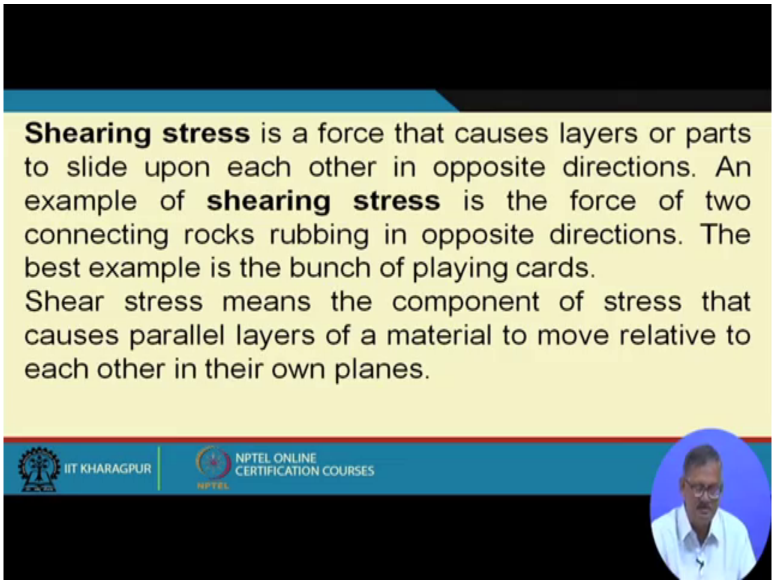


Before we go into that, let us also look into this aspect that a little recapitulation that you remember we had said that if we take a bunch of cards like this, this is one card this is another card playing cards I am referring to this is another card these are all (ex) I mean enlarged picture, right? In reality by this term the whole card bunch will come up, right? But if we assume that this kinds of cards are there and then if we apply a force in here force at the bottom of card, then what will happen? This card will move a little, right?

Then, the next card will move a it should have been a little more so that we understand it easily, then the third one would have moved even a less and the fourth one would have moved might not have moved at all, right? So we get a distribution of these cards it looks like this, right? Whereas, originally it was like that. So movement of it has occurred the main card that remained actually if you would have done it right below then it could have been more easily understandable that the first card moved like this, the second card moved did moved a little or the top most card this did not moved at all and next to that moved a little next to that moved even like this, right?

So there would have been a movement like this which we call this, right?

(Refer Slide Time: 5:02)



This because we gave the force f this card movement is the right example of giving the shear force where the layers by definition you see that shearing stress is a force that causes layers of parts to slide often each other in opposite directions, right? An example of shearing stress is a force of two connecting rocks rubbing in opposite directions, right? As we said the best example could have been the cards playing cards example, right?

Now when we are saying it, we remember that in couple of months or years there where many earthquake all over the world, right? There also the same thing happens the two plates of the earth there where on one over other, suddenly they there is a movement, right? This kind of friction movement is there and one plate is trying to hold the other, other plate is trying to go out because of the force applied and that made the whole earth making where this place it happened that place quake or which we known as which we know as earthquake, right?

So similar to that or if two stones are like this, they are one over other getting rather some force you are applying like this that is called the shear force, right? The best example we have given with the card, right? So this card example is the best one which we can easily understand because playing cards you may have in all the houses so you take that bunch, put a little with another very very thin one give a sudden force to the bottom most and you will see that there will be a distribution like that, right?

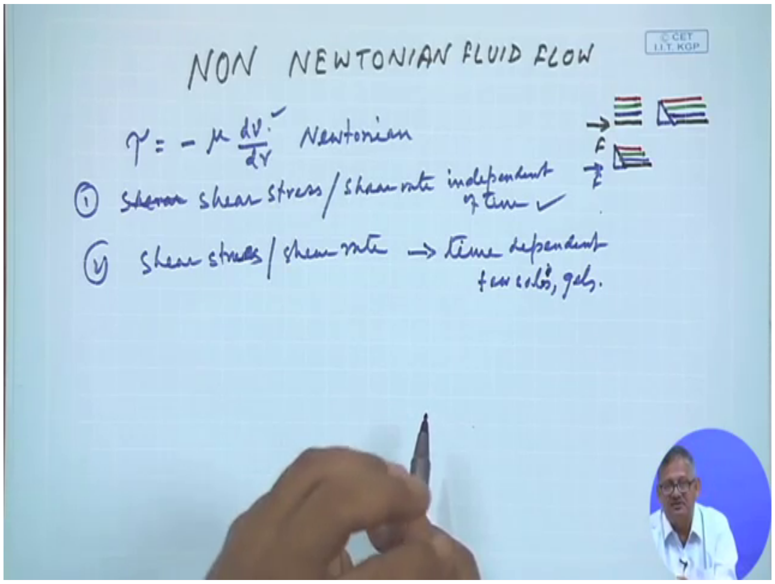
So the distribution of cards will be like that the bottom most which one you have given the force it has moved a little and then the next, then the next one like that and maybe the top one did not moved at all because by that time it raised to the top the force was nullified so it could not move. So this kind of thing happens in liquids also both in liquid as well as in gases or more prevalent in gases than that of the liquid, but still it is in the fluid, right?

So by definition we can say that shear stress means the component of stress that causes parallel layers of a material to move relative to each other in their own planes, right? So this cards if we consider them to be each one of them to be one of the plane, right? Each one to be one of the planes, then these planes are again this stress that causes parallel layers of the material to move relative to each other, right? With respect to the bottom most the top most did not move at all the next to that moved a little, next to that moved even a little like that it is happening that is the layers are moving with the force given, right?

So this is a relative movement of the layers when they are together, right? In different planes, so keeping this in mind keeping background in mind we now move on to the Non-Newtonian fluid flow through the Non-Newtonian fluid it is also a big one, so hopefully may not be in one class it will be over maybe several classes will be required, so as an when the time will permit till that point we will continue and maybe in the following class or next class we will do a little recapitulation and go on proceeding, right?

Now let us look how the definition says, non-Newtonian fluid this is this follows the (())(10:00) law equation, right?

(Refer Slide Time: 10:16)

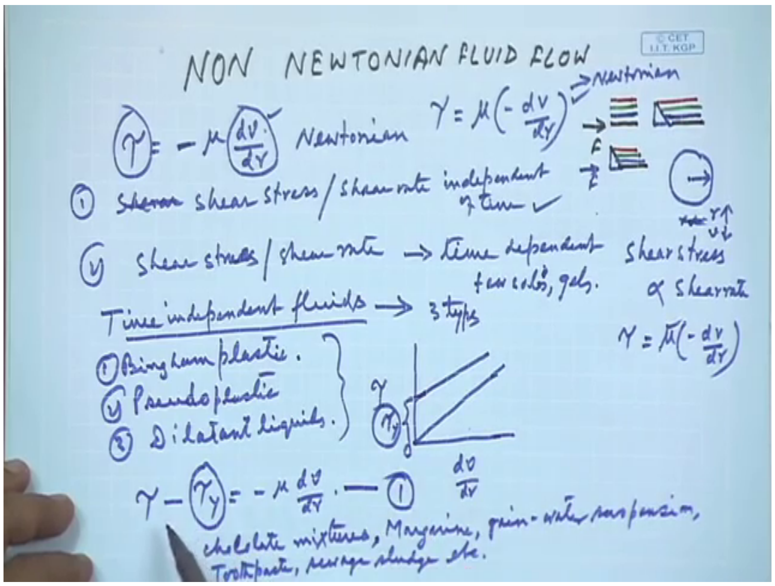


So Newton's power law equation that which we called Newtonian or non-Newtonian fluid that relates that shear stress tau is equals to minus mu dv dr, right? So this minus mu dv dr this is the very simple relation of the fluid, right? That is given by the Newton and this the liquid or fluid which follows this relations straight forward they are known as Newtonian fluid, right? They are simply known as the Newtonian fluid and they follow this simple relation of the power law, right?

There are two types of liquids like that, one where shear stress oblique that is rate of shear stress to rate of shear rate, this relation follow is independent of time this is one type of fluid and most of the liquid or foods are they follow are this type of relation and the other that shear stress to shear rate this relationship is time dependent, right? So when it is time dependent then another one type for example few sols, gels they follow this type of relation, right? So now this or the two that is shear stress to shear rate independent of time one type of fluid and shear stress to shear rate is dependent of time that is another type of fluid. So one is time independent and another is time dependent means time dependent means at 11 o clock if it is one value maybe at 12 o clock it will have another value maybe at 1 o clock it will have another value.

So that is time dependent, but if it is time independent then we will say at 11 o clock whatever value was there of the fluid same value is there at 12 o clock or the same value is there at 1 o clock. So this we have to keep in mind that time dependent and time independent meaning that shear stress to shear rate ratio the value does not change with time that is time independent 11 o clock, 12 o clock, 1 o clock, 2 o clock all the time the value remains same then it is time independent and if the value changes at 12 o clock, or at 11 o clock or at 1 o clock then we call it to be time dependent where shear stress, shear rate ratio varies, right?

(Refer Slide Time: 14:09)



Now shear stress is this and shear rate is called this one dv dr is known as shear rate and the this shear stress shear rate ratio normally we call, why this negative? Because as the shear stress goes up the shear rate goes down that is why that is indicating negative exactly this is says mu minus dv dr, right? So this rate ratio is known as the viscosity which we call as mu, right? For the Newtonian fluid we call it to be mu, right? So let us go into those where it is time independent fluids and there are 3 types of such fluids, right?

And these 3 types are known as Bingham plastic, right? Then the other one is known as Bingham plastic then other one is known as pseudo plastic, right? And third one is known as dilatant liquids, right? So these are the 3 types which are time independent fluids, right? And all of them follow the power law equation. So let us go back to that power law equation which we started with that is tau is minus mu dv dr or mu minus dv dr, right?

So we said shear stress is proportional to shear rate, right? And this we said to be equals to a proportionality constant mu minus dv dr, right? And we also said that negative term implies that as the shear stress is increasing, shear rate is decreasing, right? So and the proportionality constant we said it to be mu or that is normally denoted as the viscosity, right? So now as we said that Bingham plastic this is unlike Newtonian fluid if we plot shear stress versus shear rate tau versus dv dr if we plot, then unlike Newtonian fluid it is because this is Newtonian we said, right?

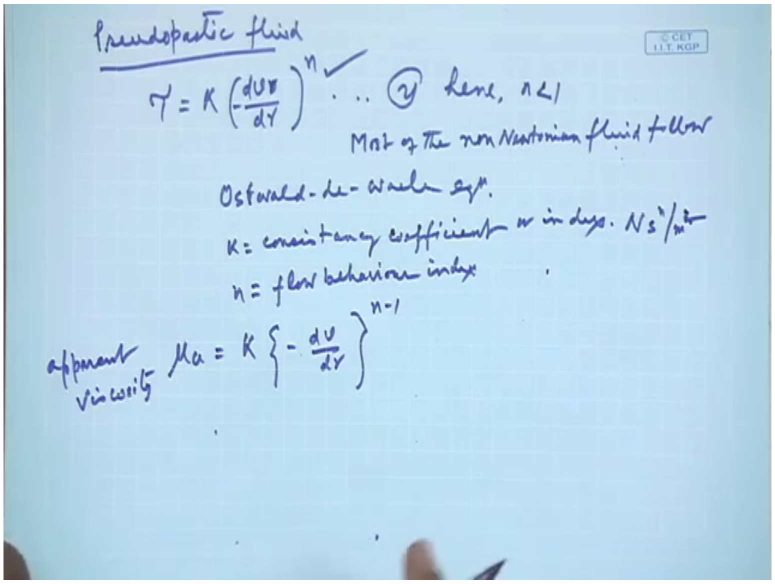
So unlike this where it is shear rate and shear stress is as it is increasing, right? So like this it is following almost 45 degree line, but for the Bingham plastic it is unlike that this one where it is 0 starting from 0, then we dv dr, right? dv dr minus dv dr with increasing of r v is decreasing that is the minus negative with increasing of r v is decreasing, right? So if we take this is the pipe, this is the center, if this is the r, so as r is increasing rather we write this way r is increasing v is decreasing, right? So, we say that for the Bingham plastic unlike this Newtonian fluid you need a minimum threshold shear stress which is required once it is there then it follows the similar way as it is in the Newtonian fluid, right? But that means you need a initial push that let it start then it will follow, right? Let start then it will follow one of the example is that say your toothpaste when it is there so in the tube it is there unless you put a press it will not flow, right?

So give a thrust to that so that it flows and it starts flowing, so that is what is required and this is similar to the Newtonian fluid but you need an initial stress has to be given initial push has to be given so that it moves like that. Generally we say for many students that okay unless and until they are giving (())(21:01) they do not study, right? So a similar behavior can be said, right? So Bingham plastic like that, then here this we can related in terms of shear stress as tau minus tau yield is equals to minus mu dv dr where this tau y is the yield stress, that is minimum which you need to give to the for the flow of the fluid, once it starts flowing then it follows the Newtonian fluid, right?

Example is chocolate mixtures or margarine, margarine is a similar like butter, a substitute of butter in many cases it is said, right? So that is the margarine, okay. Then grain-water suspension as we said toothpaste or it could be sewage sludge etcetera. In sewage sludge also you will see that unless there is a push, unless there is a stress given, unless there is a force given that sewage sludge also does not move, right? Same as we said for the toothpaste so in that toothpaste you give a pressure then it comes out from there, so that is the yield stress or tau y which we are referring to, right?

Same is true with chocolate mixture, same is true with margarine, grain-water suspension, sewage etcetera, right? So it follows this relation that tau minus tau y is minus mu dv dr or this is called the shear stress versus shear rate relation for the Bingham plastic fluid, right? So next we go to the second type that is called the pseudo plastic, right?

(Refer Slide Time: 24:17)



For pseudo plastic fluid we write the relation as tau is equals to k dv dr with a negative, right? To the power n, right? Say this is equation number 2, here n is less than 1, right?

And most of the Non-Newtonian fluid follows this relationship, right? So there the general power law equation can be written like this, right? And this is commonly known as Ostwald-de-waele equation, right? Where, k is the consistency coefficient or index and n is flow behavior index, right? The unit of this k is there it is Newton second to the power n by meter to the meter square, right? And n is flow behavior index, right?

Apparent viscosity can be obtained from this equation 1 and equation 2 as mu apparent is equals to k into minus dv dr to the power n minus 1, right? This is called apparent viscosity, right? So today we have then discussed about the types of Non-Newtonian fluids or even Newtonian fluid and the relation between this shear stress and shear rate for this type of fluids power law equation Ostwald-de-waele equation, so this we complete today here and next day we will continue for the following aspects following subject rather I should say that the it will take some more time some time rather to cover up the entire Non-Newtonian fluid flow, okay thank you.