Fluid Mechanics

Prof. Madivala G. Basavaraj
Department of Chemical Engineering
Indian Institute of Technology, Madras

Lecture – 20
Fluids properties and its behavior

So, Sumesh is not here today, so I am just substituting for him. So, we are going to talk about I mean I kind of titled this you know this particular lecture as something about different fluids viscosity and its measurement. A lot of contents that are you know kind of compiled from different sources, the references you can see that ok. If you want to know more about each of some of the things that are going be discussed today you would have to go to those sources and then you know a little bit ok.

We will just begin by just defining what is viscosity ok. I think Sumesh in the last class about the viscosity of the gases right and you know talked about their T power one and half relationship that you get for gases ah. In a Layman's term you know you could just say that you know viscosity is def you know you can think about it as a resistance to flow right that is a Laymanish definition of viscosity. And, in SI units, what is the unit of viscosity? Yes.

What is that?

Student: Pascal second

It is Pascal second right. It is Pascal second and so, you see a list here basically there are different fluids and the viscosity of each of these fluids are kind of listed there.

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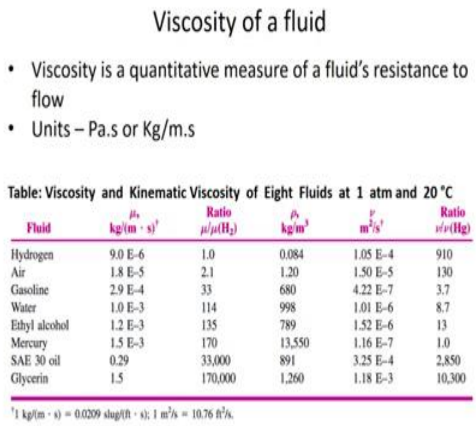

Viscosity of a fluid

- Viscosity is a quantitative measure of a fluid's resistance to flow
- Units – Pa.s or Kg/m.s

Table: Viscosity and Kinematic Viscosity of Eight Fluids at 1 atm and 20 °C

Fluid	μ, $kg/(m \cdot s)$[†]	Ratio $\mu/\mu(H_2)$	ρ, kg/m^3	ν m^2/s[†]	Ratio $\nu/\nu(Hg)$
Hydrogen	9.0 E-6	1.0	0.084	1.05 E-4	910
Air	1.8 E-5	2.1	1.20	1.50 E-5	130
Gasoline	2.9 E-4	33	680	4.22 E-7	3.7
Water	1.0 E-3	114	998	1.01 E-6	8.7
Ethyl alcohol	1.2 E-3	135	789	1.52 E-6	13
Mercury	1.5 E-3	170	13,550	1.16 E-7	1.0
SAE 30 oil	0.29	33,000	891	3.25 E-4	2,850
Glycerin	1.5	170,000	1,260	1.18 E-3	10,300

[†] 1 $kg/(m \cdot s)$ = 0.0209 $slug/(ft \cdot s)$; 1 m^2/s = 10.76 ft^2/s.

You know think about water has a viscosity of like 1 10 power minus 3 Pascal second ok. And, so now, there are two columns here right. There is one is viscosity another one is density if you take a closer look at these in the numbers for you know different fluids it turns out that you know it is not necessary that something that is highly dense need not be more viscous right.

I hope all of you know this fact that, for example, if I take a look at say mercury for example, the density is really high right because its viscosity it is just about that of water right whereas, the density of water is about 1000 right. So, therefore, your density and viscosity you know they do not go you know hand in hand ok. So, it is need not be that you know something that is more dense is more viscous that is really not true.

So, if you want to tell somebody that when people say that you know viscosity is a kind of a quantitative measure of resistance have you kind of experienced you know if you want to tell you in a in a practical way, how would you tell somebody what is viscosity? You could think of like if like say a simple case of running right. If I take two cases, one is I am running in water other one is running in air right the fact that you know it is much more difficult for you to run in water ok you can think about this in terms of the viscosity right, the resistance that the fluid offers.

And, actually that is kind of quite clear if you look at the viscosity values if we take water is 1E-3, if you take air it is 1.8E-5 ok; the ratio of viscosity is about 50 ok. The fact that you know the water is definitely 50 times more viscous than you know air basically you know gives you this additional resistance which because of which you kind of run much much slower in spite of putting the same effort right. So, that is you know you could think of you know arguments like that to really you know think about the resistance that you know that a fluid offers right.

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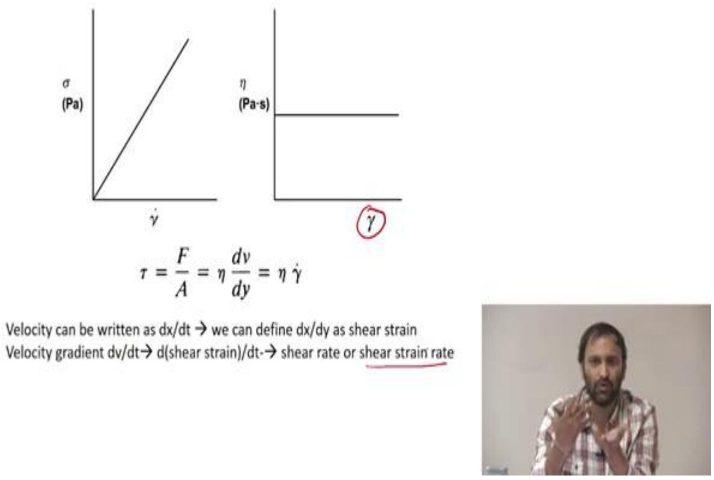

Now, there are different types of fluids I am sure all of you have kind of a learned this at some point for sure. So, there is actually a plot of you know your shear stress as a function of a shear rate and then there is another plot next to it which is your viscosity is a function of you know shear rate right. Do you know what these you know do you know typical class of fluids that kind of obey such behavior your what is that?

Student: Newtonian fluids.

Newtonian fluids right. All of you have heard of Newtonian fluids and you know you know your stress is proportional to you know shear rate plus if you measure viscosity is a function of you know shear rate it turns out that you know the viscosity should be a constant right. So, all of you know about this. If you are not familiar with the terms you will see that you know a lot of people use you know your γ dot that you see here right γ dot you can actually you can call it as rate of shear shear rate sorry, shear rate strain right. Sorry, you can call it as a shear rate or you can also call it as you know a shear strain rate that kind of comes from the simple argument right.

If you have this dv by you know dy which is the velocity gradient ok. I can express this dv as a as dx by dt right, distance by time ok. The change in length by original length, I can actually express it in terms of strain and that strain divided by time is going to give you the strain rate ok. So, your γ dot people either call it as strain rate or you can also call it as a shear strain rate as well ok.

$$\tau = \frac{F}{A} = \eta \frac{dv}{dy} = \eta \dot{\gamma}$$

You will you will see there are different books use different kind of terminology and you would have to be a little bit aware of these terms and as you know this is a classic case of Newtonian fluids ok.

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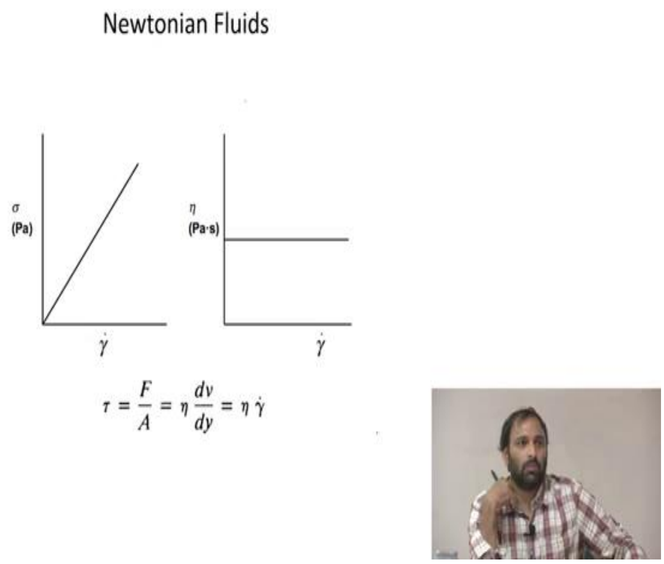

And, it turns out that you know a lot of things that we use they are not Newtonian type there are different.

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Shear Rates for different processes

TABLE 2.3.2 / Shear Rates Typical of Some Familiar Materials and Processes

Process	*Typical Range of Shear Rates* (s^{-1})	*Application*
Sedimentation of fine powders in a suspending liquid	$10^{-6} - 10^{-4}$	Medicines, paints
Leveling due to surface tension	$10^{-2} - 10^{-1}$	Paints, printing inks
Draining under gravity	$10^{-1} - 10^{1}$	Painting and coating; emptying tanks
Screw extruders	$10^{0} - 10^{2}$	Polymer melts, dough
Chewing and swallowing	$10^{1} - 10^{2}$	Foods
Dip coating	$10^{1} - 10^{2}$	Paints, confectionery
Mixing and stirring	$10^{1} - 10^{3}$	Manufacturing liquids
Pipe flow	$10^{0} - 10^{3}$	Pumping, blood flow
Spraying and brushing	$10^{3} - 10^{4}$	Spray-drying, painting, fuel atomization
Rubbing	$10^{4} - 10^{5}$	Application of creams and lotions to the skin
Injection mold gate	$10^{4} - 10^{5}$	Polymer melts
Milling pigments in fluid bases	$10^{3} - 10^{5}$	Paints, printing inks
Blade coating	$10^{5} - 10^{6}$	Paper
Lubrication	$10^{3} - 10^{7}$	Gasoline engines

Adapted from Barnes et al. (1989).

So, before you go to different kinds of fluids I just want to make a point about something called as a shear rates that are typically kind of exist in different processes ok. So, what you see is the first column it is a it lists processes. The second one is what is called as a typical range of shear rates and the third one is application ok.

So, it turns out that you know depending upon the processing conditions your shear rates are going to be very very different ok. What I mean by that is if you have like say a cream that you are trying to apply to your you know your body for example and when you put your cream onto your you know and the body and then if you are trying to rub it the kind of shear rate the material feels is very very different ok, then maybe putting an oil onto your hair for example, ok. So, therefore, so for example, a typical you know there is a list called rubbing you know the typical shear rate would be 10 power 4 to 10 power of 5 second inverse, that is really fast ok. That is really doing a you know very fast shearing ok.

And, there are also applications, for example; if you look at sedimentation of you know fine powders you have a column of liquid under you know the particles is settling ok. In such cases you know the shear rates are very very low, 10 power minus 4 to 10 power minus 6 ok, that is too low.

So, therefore, there is also need to look at different fluids and then have an idea as to how does the material respond to different shear rates ok. So, and again it depends on the kind of fluids that you are dealing with and stuff like that ok

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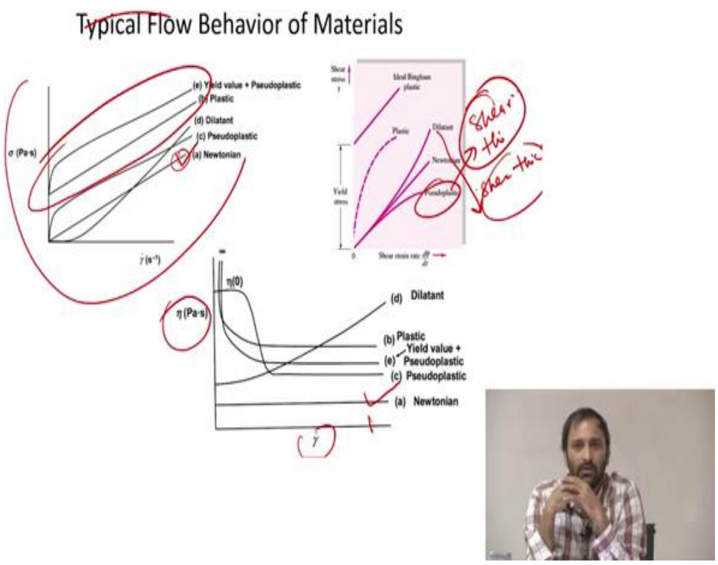

Now, again I think I am sure all of you know this particular plot that there are typical material flow behavior that fluids exhibit. The top two plots are basically plots of you know shear stress was a shear rate both of them basically taken from different sources and I am sure all of you are familiar with these terms right; dilatant fluid, pseudo plastic, you know yield stress fluids and stuff like that ok. I hope all of you know these terms right. No? Do not know? ok These are fairly simple ok.

So, now let us think about toothpaste ok. Every morning you just go on take a toothpaste and then you know if you open the lid and if you to want it to fall by gravity it is never going to fall right and of course, if you have you know if I take like say again there are different types of toothpaste, but typically most toothpaste if you want it to come by itself you know it would not right under the action of gravity it would not. So, for that for that to come out you would have to apply some kind of pressure right ok. Now, such materials what happens you know they would not come out until you apply a particular force or you can think about it in terms of a until you apply a certain stress they would not come out ok.

So, if you look at you know the class of flow is represented by these two fluids you clearly see that you know I would have to apply a nonzero stress for the materials to start flowing and such fluids are called as yield fluids or it is also called as a pseudo plastic fluids and stuff like that ok. So, therefore, if you want them to flow they would have you would have to apply some minimum stress for them to start flowing ok, those are some class of fluids.

Of course, you have this you know the Newtonian fluid right. Again, it is very similar to what we saw in the previous plot your stress versus shear rate is a linear variation that is your you know Newtonian fluid. And, you can think about when you whenever you have this stress versus shear rate plot you can think about slope of these plots ok. At any instant of you know shear rate you can think about it you know it as giving a resistance and as I mentioned that resistance is you know you can think about that in terms of viscosity ok.

Therefore, if I take you know a Newtonian fluid like here you know your slope is constant therefore, if I were to measure viscosity the viscosity of my fluid is going to be constant right because you know my slope is constant ok. Now, if you take other type of fluids your viscosity could be changing as a function of shear rate for most for all non-Newtonian fluids your viscosity is going to be a function of your shear rate ok.

Now, depending upon whether the viscosity of the fluid is decreasing if you increase the shear rate if that is the case such fluids are what is called a shear thinning fluids ok. These are the fluids where if you take these fluids and if you start shearing them the viscosity goes down with shear rate such fluids are what are called as shear thinning fluid. On the contrary, there are fluids where the viscosity could increase as a function of shear rate such fluids are what are called as a shear thickening fluids that is. So, basically your dilatant you know is also same as shear thinning and pseudo plastic is same also same as shear thickening.

I think it is the reverse; I think it is a reverse, so I am sorry about that. It is the reverse right because if I take a slope of these plots, now if I take say pseudo plastic for example, right slope is initially constant. Now, if I increase the shear rate strain my slope is going to decrease right that is it is a shear thinning fluid. Sorry about that, that is your shear thinning ok. And, if I take a dilatant fluid if I take slope at different points with shear rate my slope is increasing therefore, my viscosity is going to be increasing if I increase the shear right there what is called a shear thickening.

So, just to you know I just want to make a point that you know there are different class of fluids and their viscosity need not be constant you know. It could be varying as a function of shear rate and depending upon whether it increases, decreases or remaining the constant you can basically think about fluids in different you know and the most of the fluids that you come across in daily life or you know and or in industrial processes they kind of you know kind of fall into some of these categories ok.

So, now, ok. So, the question would be can you think of; can you think of a fluid that could exhibit all different behavior, one fluid which can be both shear thinning, shear thickening, a Newtonian? So, can you think can you name some example of a Newtonian fluids? What is that? A lot of fluid that you use right; water, you know honey for example, you know all of that right. So, for them you know if you measure viscosity as a function of shear rate it is going to be a constant value they are all Newtonian fluids.

Any example of some fluid where you know the viscosity need not be constant? Have you thought of some example? Should go back and take a look at some nice videos on YouTube ok. There is a nice video of you take a take water ok, then you mix what is called as a cornstarch ok. If you go on adding some cornstarch at some point it starts behaving you know very some funny way ok.

So, there are there are nice videos where people are made you know like say bathtub you know made of this fluid and you can actually walk through the fluid that is because you know at the instant of if you are running through this fluid at the instant of contact between your foot and the you know bathtub the viscosity goes are very high and that can actually support the whole weight of the person who is walking on the who is running on the on the back ok.

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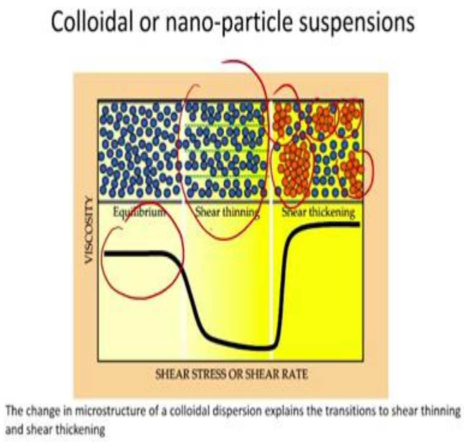

So, a classic case of fluids which exhibit all this you know properties in one you know in the same fluid is an example of something called as a colloidal dispersions or nano particles dispersions ok. Simple way to think about this would be these are slurries; so, liquid with some particles. The particles could be very small in size nano particles it could be micron in size or it could be even larger macroscopic particles ok. So, what you are seeing in this plot is actually it is a plot of viscosity as a function of shear stress. You could also have a instead of shear stress I could have also plotted a shear rate as well ok.

What you should note is that for each plot that you have there is a parameter that is defined that is called phi and that phi is what is called as a volume fraction of particles in the fluid ok. Phi is equal to 0 corresponds to a pure fluid without any particles if I say like say phi is equal to 0.09 that basically corresponds to a case where I have 9 percentage of particles in the fluid. Similarly, if I say phi is equal to 50, .50 you know your 50 percent fluid and 50 percent particles right.

So, all that has been done here is they have subjected this fluid to a similar test of basically measuring viscosity as a function of you know your shear stress and as a function of different concentration what you know is a is a result right and if you look at the low concentration data that is you know from about 0 to 0.18 you can see that you know the viscosity versus you know your shear rate it is a flat line ok. So, basically that is your Newtonian behavior right that is your Newtonian behavior.

Now, if you go a little bit higher in concentration you know 0.34 and 0.28 ok what you see is initially you know your viscosity is constant and that is basically followed by a very small decrease and that small decrease it is an example of a case where you know there is a shear thinning behavior right. Now, if I go a little bit higher up in the concentration it turns out that there is of course, a decrease followed by increase at a higher shear stress that is an example of a case where you have both shear thinning in this region and shear thickening in this region ok.

So, and this phenomena of shear thickening actually has been exploited in a lot of applications. So, I kind of you know given you some applications that one common example is a body armor ok. So, whenever people have this bulletproof you know jackets what is there are recent developments where in between different layers of cloth what they put is you know these fluids which when you know a bullet penetrates at a very high you know force, it basically in locally solidifies the material and thereby stopping you know the you know the bullet from penetrating into the vest ok.

So, there are applications of such material, so I just wanted to you know give you a little ok. So, now, there is a there is an understanding as to why this happens yeah ok. So, the common you know the picture that people kind of think about is that the case where you have your shear you know your Newtonian behavior is a case where you know you have kind of a randomly distributed particles in your fluid and you are subjecting them to you know your shear flow right.

And, then if you go for a higher shear rate or shear stress, it turns out that there is some kind of a ordering and kind of particle from these lanes lines of you know particles and these lines of particles essentially you can think about them as offering less resistance for the flow ok. One way to think about this would be you know a randomly moving traffic versus traffic in a lane ok.

So, now, if you go higher up in the shear rate or shear stress what happens is you know you are basically forming what are called as particulate clusters when you are trying to you know kind of shear them at a very high shear rate all the particles are kind of brought together and you kind of form locally these clusters and these clusters kind of interlock and this interlocking of these clusters in a way leads to enhanced resistance there by the viscosity goes up ok. So, this is a kind of understanding that people have about such fluids ok.

So, that is about different types of you know fluids you know just to give you a picture of you know different class of fluids ok. So, all that we have done so far is we have just said something about what is viscosity and then you have kind of discuss different class of fluids and I just took one example of a particular class of fluid where you see the Newtonian, non-Newtonian you know a behavior in the same fluid right. That is what we have done.