If I consider the same fluid flow through a parallel plate, okay. One of the plate the velocity is zero which is at the rest conditions and other the top plate is moving with a velocity V. So as a microscopic point of view I am not talking about the molecular motions or exchange of the molecular motions or the momentum flux that what is resulting a shear stress. Here what we consider that fluid element.

That means, I consider some space of A, B, C, D, this is what the fluid element. That means, whatever the fluids are there that reasons, I am defined as a fluid element. As you know it that at the A point we will have the velocity V as the no-slip conditions. At the B point we will have velocity zero. So velocity assuming it, it will have a linear velocity variation from B to A.

That linear velocity from zero to V as the y increases, the velocity will increase it and maximum velocity will be the V. If it that the conditions now if you look it that if a point which is the y distance from the plate which is at the rest conditions you will have velocity U, okay. So as a linear proportionally we can find out what is the velocity of that one.

So next one is the velocity lesser than that or above one will go moving with the fluid is more than that. So if as a linear velocity distribution as you assume it as we got it some of the parallel flow conditions after Δt time these fluid element will be deformed as a angular deformations will happen it that there will be angle θ will come it at the B and E, F and D.

That is a new positions of the fluid element after Δt time. And the angular deformations at this point is $\delta\theta$. Similar way the $\delta\theta$at this point. So at the Δt time we have a angular deformations of $\delta\theta$. So consider a very simple geometry of these problems. I can consider these distance of AE is V into delta t divide by the l will be the 10 $\delta\theta$or since $\delta\theta$is very small, I can consider

$$\delta\theta = \frac{V\Delta t}{l}.$$

So that is what will consider. Just rearranging that we can see that the rate of change of angular deformations of this fluid element is

$$\frac{\partial\theta}{\partial t} = \frac{V}{l}$$

v is a constant, l is the thickness of these two plates. That is a constant quantity what is coming it.

Now if I consider the at the y distributions and the angular velocity distributions if I consider it I will get it the u, the velocity at these points and ratio of the distance as a linear velocity distributions concept, we can get it,

$$\frac{u}{y} = \frac{\mathrm{V}}{l}$$

simple geometry of this what gives us relationship. That is what if I differentiate it I will get it this part.

$$\frac{du}{dy} = \frac{V}{l}$$

We remember this is what is indicating us is that the velocity gradient.

If I consider this is the y directions how the velocity varies along the y directions that is the constant which is equal to the shear strain rate. The shear deformations per unit time. So we can now consider it that the shear rate strain rate and the velocity gradient is equal for these conditions.

Then the shear rate is

$$\frac{\partial \theta}{\partial \mathrm{t}} = \frac{\mathrm{du}}{\mathrm{dy}}$$

These parallel flow conditions when you have velocity is linear distributions the shear strain rate and the velocity gradient they are equal.

So now we are coming to the exactly the solid mechanics concept the stress having the proportionality with the strain. But here, we are talking about the stress is proportionality to the strain rate. That means the change of the shear strain rate with respect to time, not the absolute value of the shear strain. That is the basic difference between the fluid mechanics and the solid mechanics.

So same shear strain relationship we are doing it but in this case, we are telling it that the shear stress is a proportionality to the shear strain rate and that is the Newton's laws of viscosity that shear strain is having a, this experimentally proved it. That is what it happen this shear strain is a proportionality to the shear strain rate. Again I can emphasis to that shear strain rate not the shear strain.

That is the difference between the fluid mechanics and the solid mechanics as they have the proportionality and we can define as

$$\tau \, \alpha \, \frac{\partial \theta}{\partial t}$$

$$or, \qquad \tau \, \alpha \, \frac{du}{dy} \quad \Rightarrow \quad \tau = \mu \, \frac{du}{dy}$$

So the same concept, we can use a fluid element at the macroscopic levels define this relationship between the shear stress and the velocity gradient or at the microscopic levels, the fluid molecules movements in terms of mass and momentum exchange. Also, the experimental finding also give the same concept that the relationship between the shear stress and the velocity gradient.

We remember it here we are talking about velocity gradient along the y directions and the shear stress is a normal to that. That the point what you can look it. So that is the shear stress is equal to $\mu \, \frac{du}{dy}$. This is very basic equations used to solve many of the problems if you just have a basic concept is the stress is having a proportionality constant with constant proportional constant. That is what is the dynamic viscosity of the coefficient of viscosity.

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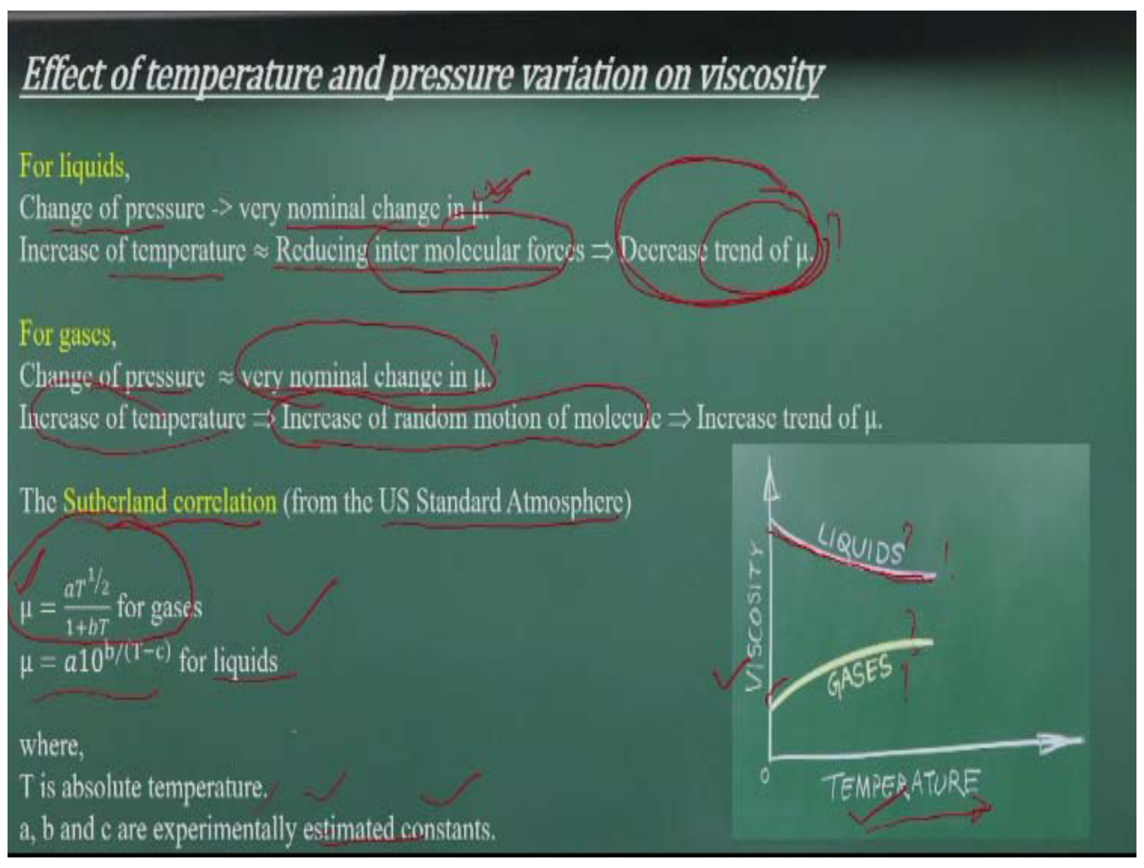

Effect of temperature and pressure variation on viscosity

For liquids,

Change of pressure -> very nominal change in μ.

Increase of temperature ≈ Reducing inter molecular forces ⇒ Decrease trend of μ.

For gases,

Change of pressure ≈ very nominal change in μ.

Increase of temperature ⇒ Increase of random motion of molecule ⇒ Increase trend of μ.

The Sutherland correlation (from the US Standard Atmosphere)

$$\mu = \frac{aT^{1/2}}{1+bT} \text{ for gases}$$

$$\mu = a10^{b/(T-c)} \text{ for liquids}$$

where,

T is absolute temperature.

a, b and c are experimentally estimated constants.

Now let us commit that how how does the temperature effect on the coefficient of the viscosity. Now we have to look at the molecular levels okay. So if you look at this molecular levels, when you talk about the liquids, they will have a molecular bonding forces between two molecules okay. But that is much weaker when talk about the gases.

So gas is at more random motions as compared to the molecules are more random motion as compared to the liquids. So when you increase the temperatures okay or increase the pressures, like if I increasing the pressures that means I am compressing the fluid things. A fluid volume I am just compressing it. As I compress it whether these molecular motions exchange of the molecular motions in terms of mass and momentum does it change drastically?

What is experimental find that if you let it is this now having a one atmospheric pressure. This is the if I increase to the 50 atmospheric pressure the coefficient of the viscosity on this room will not change that high. That may change it less than 0.5% of the at the one atmospheric value. So change of the pressures if you try to understand it that what does not change that significantly the molecular motions or exchange of the molecular motions mass or the momentum flux as mu will not change drastically.

So you look at in terms of molecular motion as a mass exchange and the momentum exchange. But if you look at the temperatures, the temperatures related is that how much of collisions are happening it. If you look it the fluid mass or the liquid mass whatever the temperature of the fluid, I am getting it that is indicating me the how the molecular motions are sustaining that temperatures.

So because of that, it is when you increase this the temperatures the definitely you increase the random motions of these things okay. For liquids, let us look it that change of the pressures will not change that significantly through coefficients of viscosity which represent as a proportionality constant of mass exchange of the molecules or momentum exchange of molecules from one layer to other layers.

If you increase the temperature which manifests to the molecular motions to sustain that temperatures. In that conditions what it will happen it, it will reduce the binding force, the intermolecular binding force between two molecules. Because of that, there will be a decreasing trend of coefficient of viscosity. If you look it at respect of the molecular mass motions and that what is causes us the mass transport and the momentum flux transport.

If it that the conditions if you are looking it then increase of temperatures will reduce the intermolecular forces and the definitely to reduce the decrease trend of the μ values like this case what is shown it here, decreasing trend will be there. That will vary from the liquid to liquid. We will discuss that. Let us talk about the gases where the intermolecular binding force are not that significant.

The molecular motions are much of the higher order as compared to the molecular motions in the liquid. The same way the change of the pressures will not much give a significant change of the dynamic viscosity but the change of the temperatures if I increase the temperature like 20º to the 40º or the 40º to 100º C temperatures then there will be a increases the random motions of the molecules.

As it is increasing the lot of motions of the molecules the definitely it does the mass transport, also the moment transport. Because of that, you will see that in a gas as is given here, the viscosity and temperatures, the viscosity increases as the temperatures increases. Whereas is in the liquid, because the temperature increase reduces the internal nuclear forces, you will have a decreasing trend.

So the liquid and gas that what they are the coefficient of the viscosity that is what varied with respect to temperature, one is increasing trend and other is decreasing trend. Any of the gas or the liquids we can find out what is this effect as the functions. Now if you look at this for the gases already established by with standard of atmospheres that for the Sutherland correlation technique, which gives a relationship between the dynamic viscosity and the temperatures. The Sutherland correlation (from the US Standard Atmosphere)

$$\mu = \frac{aT^{1/2}}{1 + bT} \quad \textit{for gases}$$

$$\mu = a10^{b/(T-c)} \quad \textit{for liquids}$$

where,
T is absolute temperature.

a, b and c are experimentally estimated constants.

That is what for and a, b are the constant coefficients. These coefficients will be differing from the fluid to gas to gas. And that is what conducting any experiment we can get it what is the value the what is the value of the a and b as we are increasing or decreasing trend with respect to the μ value.

So simple experiment of the gases with different temperatures and using a viscometer we can quantify it, how the dynamic viscosity varies with the temperature. As I said it, it will have a increasing temperature, increasing with the temperatures, but this a, b coefficients will vary from gas to gas.

Similar way for the liquids if you look at that, it will have the 10 to the power the functions and b and the c will be the constants and these things what we can compute get it from experimental or any reference book and text book you can see for the different fluids you will have a different value of a, b, c for the gases and these for the liquid and gas we have a different functions as the temperature dependent functions of with a dynamic viscosity and the temperatures and these coefficients will be differ from fluid to fluid.

So based on the gas and the liquid we will decide that which equations you have to follow it what are the coefficient. Mostly it is available in a textbook and the reference book. Let us come to the next one. How does the coefficient of viscosity vary for different fluids.

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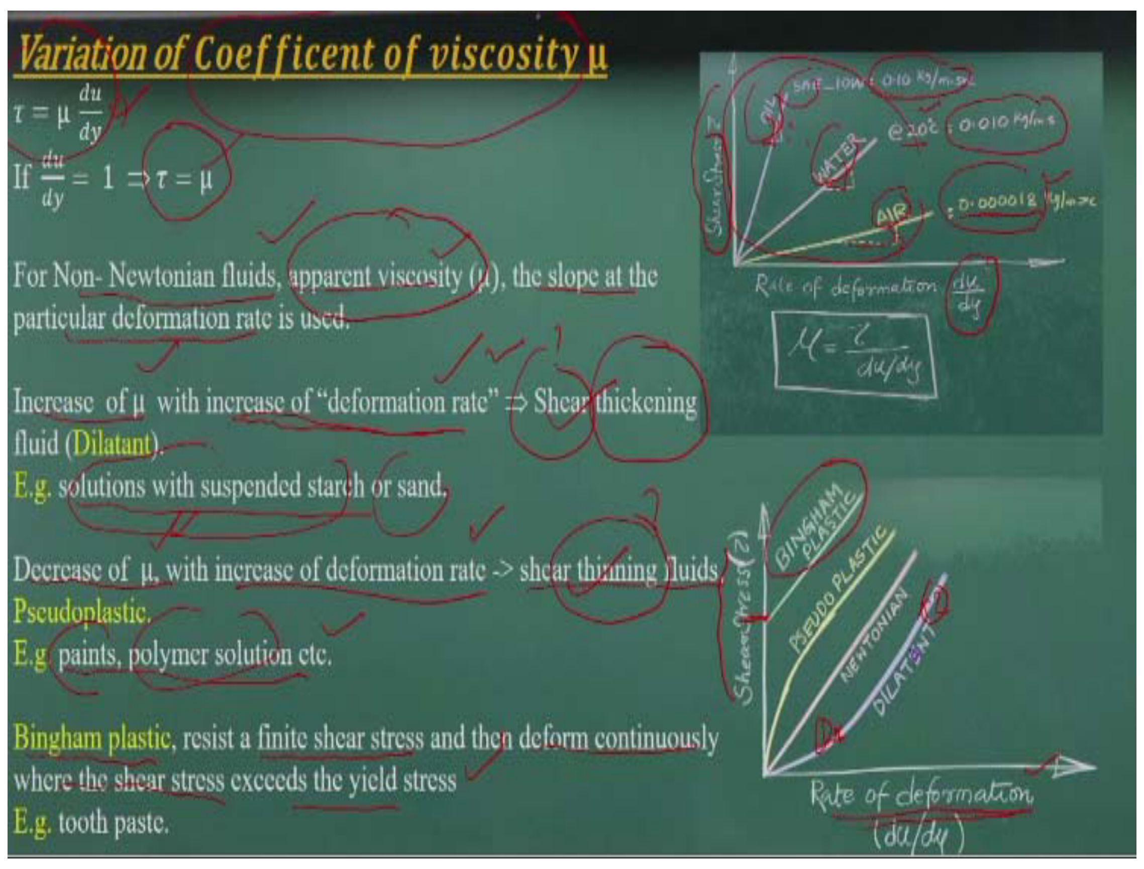

Variation of Coefficent of viscosity μ

$\tau = \mu \frac{du}{dy}$

If $\frac{du}{dy} = 1 \Rightarrow \tau = \mu$

For Non- Newtonian fluids, apparent viscosity (μ), the slope at the particular deformation rate is used.

Increase of μ with increase of "deformation rate" ⇒ Shear thickening fluid (Dilatant).
E.g. solutions with suspended starch or sand.

Decrease of μ, with increase of deformation rate -> shear thinning fluids, Pseudoplastic.
E.g paints, polymer solution etc.

Bingham plastic, resist a finite shear stress and then deform continuously where the shear stress exceeds the yield stress
E.g. tooth paste.

Let us take it same very simple equations what we have defined it

$$\tau = \mu \frac{du}{dy}$$

$$if \quad \frac{du}{dy} = 1 \quad \Rightarrow \tau = \mu$$

That means the shear stress what will be equal to the μ. This very interestingly what is giving it that if I have a system where we can create a velocity gradient equal to 1 the whatever amount of the shear stress that what will be the coefficient of viscosity.

That means, we can easily compute what will be the coefficient of viscosity if you have a just make $\frac{du}{dy}$. So this coefficient of viscosity can consider as a force as a shear force when you have the velocity gradient is equal to 1. So if you look at that concept, that means if I plot the rate of deformations, the velocity gradient and the shear stress at these points and if I have a two common fluids like air, water, and the oil.

As you experience is that whenever you drag okay any solid surface on water or air or the oil definitely you need a more force to drag when you are dragging on oil mass as compared to the water. When you drag that object in a water definitely that what will be a more force required that means it has a more frictional resistance what we get it when you go for the water as compared to the air.

Okay, so that is the very common way every time we experience that when different fluids give a different drag force that means different amount of frictional resistance what we define in terms of shear resistance here. The shear stress and the rate of the deformations if I look it and if I look in the slope of the curve it gives me the miu value.

That is for air, if you look at the value is 0.00018. When you talk about the waters at atmospherics and the 20 º temperatures will be 0.01010 case, but when you come to the engine oils okay which will be 0.10 kg. So if you look it from these figures, they are order you can understand it as how these, the coefficient varies from the fluid to fluid. And these slopes are indicating for us and these are constants.

So they have a straight line, what we will get it and the slope will give us the coefficient viscosity. The fluids those follow this relationship, this constant the proportionality relationship between the shear stress and the velocity gradient, we call them Newtonian fluids, okay. That group of the fluid flow problems we call Newtonian fluid, where you have the shear stress causing by any shear forces is directly proportional to the velocity gradient or the shear strain rate.

Those fluid flow problems we call the Newtonian fluids. That means what the coefficient of viscosity which is a directly proportionality constant, that does not vary as the rate of deformations are, or the time is changing. So that is a constant. So that is the reason so we have a directly proportional and we can get it a very simplify the shear stress is μ is equal to μ times of the velocity gradient.

Most of the common fluid flow problems also follows Newtonian fluids but some of the case it does not follow the Newtonian fluids. So we call them non-Newtonian fluids or fluid flow problems. In that case what you do it like for examples as given here the rate of deformations and the shear stress if you look at the straight line, what is representing that straight line whatever the if the straight line between these two relationship and in this graph which are Newtonian fluids.

But there are two types the different type of fluids will be there. Like if you look at this pseudoplastic and dilatant okay. In case of the dilatant if you look it the slope of these curves are increasing it okay at rate of deformations. That means if it is a dilatant objects, okay the fluids in that case, as the deformation rate is increasing where slope of the curve is increasing and that slope of curves is we call, do not call it the viscosity here.

We call apparent viscosity. It is not, this viscosity has a depending upon the deformation rate. So that is the reason we call them as apparent viscosity, which is the slope at the particular differentiation rate what we consider it that what is if it is increasing with the deformation rate then what is happening it the shear thinning process is happening it. You can understand it that more shear force is necessary as you go for more the slope.

That means you need a more shear force to do the same amount of deformations as compared to the point A and the point 2. So shear thinning process are happening it. That means as the rate of deformation increases the more shear forces is required to do the same deformation one unit of deformations rate as compared to the deformation rate when in the low level.

So this is a thinning process, thickening process happening okay. The more the shear forces we did it. But if you look at this curve which is a pseudoplastics, what it indicates that the slope is decreases as the rate of deformations is increasing trend. That means you need a less shear force as at the higher deformation state as compared to the you look it the deformations rate when you have the low deformation rate you need the less as compared.

So though your slope is the shear force what is necessary is going to decreases it for doing the same amount of deformations at two different rate levels. That means is a decreasing of this dynamic of viscosity with increase of deformation. So thinning process happening okay. And shear thinning fluids happen it and that the process happening the shear thickening and the thinning process happening the more forces.

There are the fluids like the toothpaste and all as you know it the when you apply a force to a toothpaste initially it does not come out. That means it need a limiting of force okay. That limiting force would be there, that what is the a finite shear stress there. After that the flow starts it. That is what it happens if you just squeeze a toothpaste.

You can feel that initially when you apply the low force there is no toothpaste is coming out. But when you apply more and more force after a certain force you look it the toothpaste is coming out. The fluid is starting the flowing it. So responding to the shear force as deformation starts it. So that is the reasons you will have a limiting finite stress, shear stress after that you will have the shear stress and the rate of the deformations will be there.

This is what Bingham plastic what we talk about, which resist a finite shear stress and deform continuously when shear stress exceeds this yield stress okay. That is the way what you do it we the toothpaste flow mechanisms what is there but in case of pseudo plastics we have a paints, polymer solutions whereas dilatant is basically the solutions with a suspended starch and the sand.

So in these representations what I am talking about that the coefficient of viscosity which is indicates us that in a fluid element, how the deformation takes place between the deformation rate and the shear stress relationship can be linear can be nonlinear.

If it is a nonlinear we talk about non-Newtonian fluids and depending of the slope increasing with respect to the deformation rate we call shear thickening process or thinning process or we have a particular threshold value after that the fluid start deformations, shear deformation thing then we call Bingham plastic.

So the basically you try to understand it that we define a Newtonian fluid, non-Newtonian fluids the coefficient of viscosity, which is directly proportionality constant or we consider as a apparent viscosity when defining the fluid flow problems, if it is a non-Newtonian fluid flow problem. Let us discuss about another property of the fluid is the surface tension.

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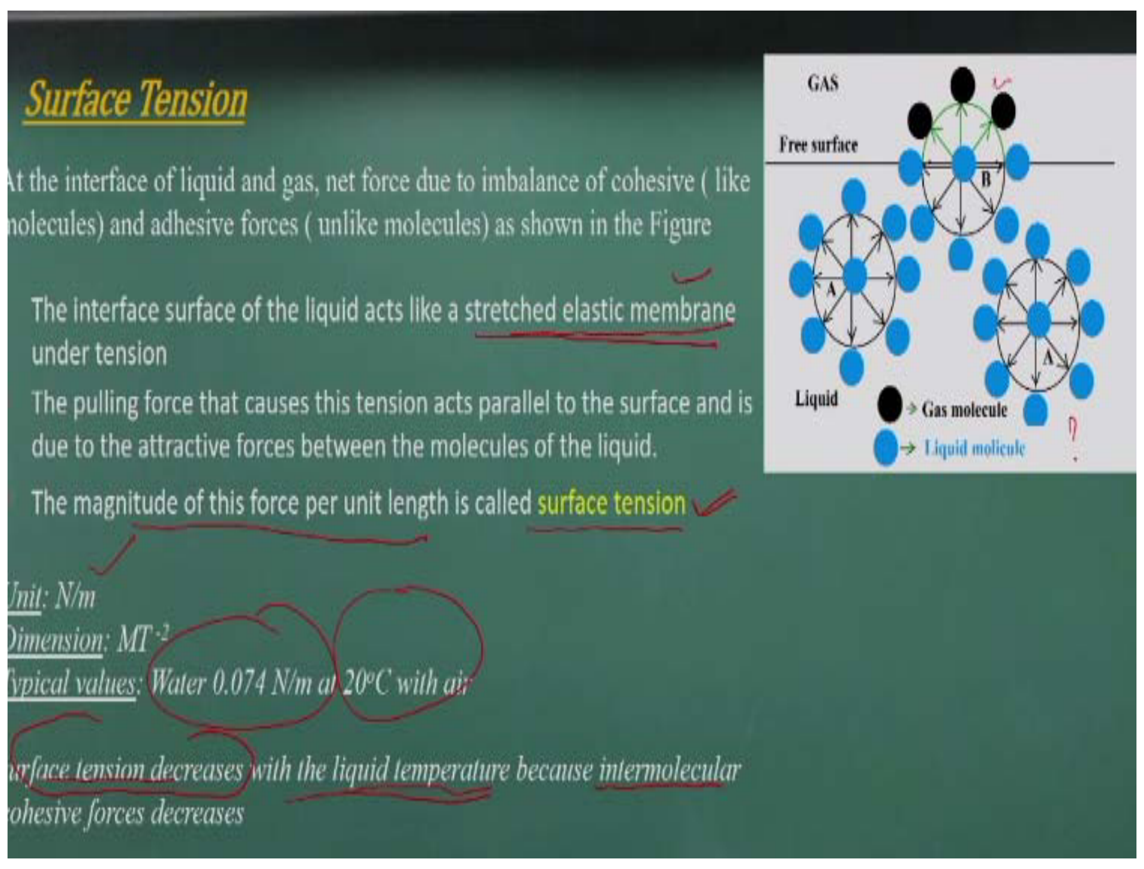

Surface Tension

t the interface of liquid and gas, net force due to imbalance of cohesive (like olecules) and adhesive forces (unlike molecules) as shown in the Figure

The interface surface of the liquid acts like a stretched elastic membrane under tension

The pulling force that causes this tension acts parallel to the surface and is due to the attractive forces between the molecules of the liquid.

The magnitude of this force per unit length is called surface tension

nit: N/m

imension: MT^{-2}

ypical values: Water 0.074 N/m at 20°C with air

urface tension decreases with the liquid temperature because intermolecular ohesive forces decreases

As the name implies that at the interface of the two fluids or fluid with two liquids or fluid and the gas what it actually happens it if you look at it that way that I have the liquid molecules if you look at this figures okay. I have the liquid molecules and this is the free surface I have the gas. So if I look at what is the intermolecular forces is there, okay like for example if fluid is at rest conditions, the molecules at these points is having the attracting force between the surrounding molecules.

There is a same molecules are there so the cohesive force are acting on this. So this cohesive force are making these fluid molecules in moment, moment considerations. But when you have the at the surface levels, if you look it that these molecules will have the cohesive force the molecular bounding force between the two like molecules and the adhesive force between the gas molecules and the water molecules.

So those will have the adhesive force. See, if you imagine it that if these force, the cohesive force is much larger than the adhesive force what is there. That means the molecules which is at the surface, they are going to have a net imbalance force is going to work it. Like you have a surface when which the top of the molecules they are having a pulling effect of the cohesive forces what is working it or bounding forces is acting on that. So this the surface will act like an elastic membranes.

That means you just stretch it. Give a force, the more, net force is more so that is what is a will be like a stretched elastic membrane with having the tension. So for example, if we look it that you have a roof is connected with a two pillars and if you apply the force uniformly you will see that there will be tension force will act on that.

So the similar way as you can visualize that when you have the molecules at the surface, they have a net imbalance force between these the cohesive and adhesive. Because of that, that surface will be act like a stretched elastic membrane and under the tensions. That is what will be cause it. So that because of these effects, the force what will be resultant per unit length will define as a surface tension forces okay.

So this is what it happens it. Because of that if you look at the small insects they can walk on the waters, because of the surface tension forces that what is give the force component because of that small insect can they can walk on the on a water and even if they are having the density is more than that, that is because of the surface tension forces that what resulting surface tension force can result in that ones.

It has a lot of applications of surface tension forces but here I will not give a more emphasis on that and if you look at that as the surface tensions is defined is a force acting per unit length and that is what will be *N/m*, and the at the surface tension the water with air interference $0.074\ N/m$ at $20^{o}C$. And if you look at the molecular perspective view that as the temperature is going to increase it so you will have a decrease of the cohesive forces.

As the cohesive forces decreases, you can know if the net force is going to decrease. So resulting effect the surface tensions will have a decreasing trend. So we can when you have a interface between the liquid to liquid or the gas to liquid, you will have a the surface will be act like a elastic membranes with a tension forces.

That is what we call the surface tension and it has a dependency with the temperature as increasing of the temperatures that is what reduces the cohesive forces and as a result the surface tension force also decreasing trend.

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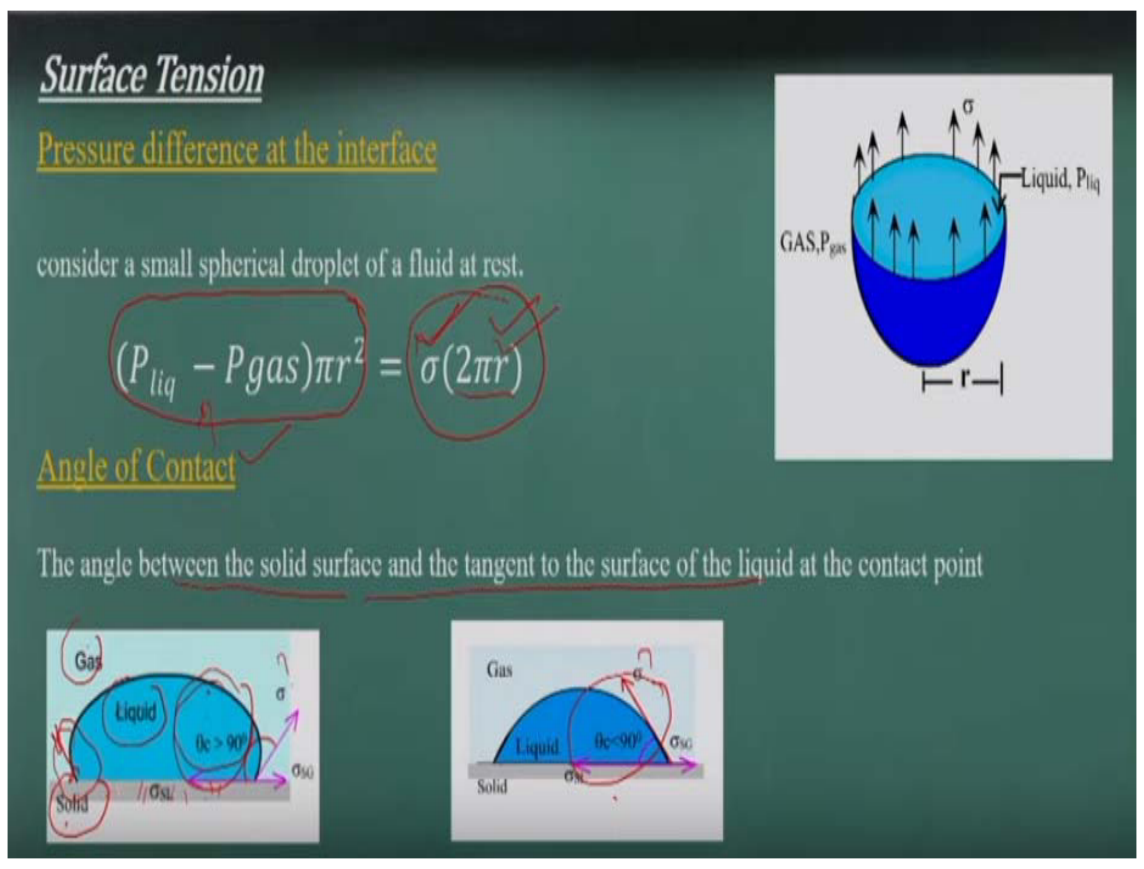

Surface Tension

Pressure difference at the interface

consider a small spherical droplet of a fluid at rest.

$$(P_{liq} - Pgas)\pi r^2 = \sigma(2\pi r)$$

Angle of Contact

The angle between the solid surface and the tangent to the surface of the liquid at the contact point

If you have the surface tension if you can now there will be a net balancing effect of the force component which results us the pressure difference. Let us consider it is the surface tension is given very simple examples of raindrops okay. Any raindrop if you look at that, if you take that drop and make it two splits. At the interface surface there will be surface tension is working it.

The surface tension force is acting between the water and the air. I have considered a water droplet. So if I consider the just half the this things. If I consider this pressure inside is P_{liquid} and the P_{gas}, the outside is P_{gas}. There will be difference of the pressures because of these tensional forces. And if I just equate the net force acting on this the pressure into the area, that is what is the net force will be acted, there will be a pressure difference will be there.

That what will be the force per unit length and the length is a circumference on which the surface tension is working it is a $2\pi r$ × the surface tension these force will be created. So similar way we can have a water droplet we can have a soap bubbles we can look it the surface and find out what will be the surface tension force.

$$(Pliq - Pgas)\pi r^2 = \sigma(2\pi r)$$

This net force the balancing you can result as a pressure difference what it happens it and you can compute the pressure difference if you know the surface tension if I know the radius. Next interesting point is coming is that if a liquids interfacing with the solids whether it will be wet or not wet, the wetting condition or not wetting condition. That what is a interface between the three of things.

Like if you look it there is a interface between liquid to the gas, the liquid the solids. And that what is a at equilibrium at the point of the contact. And that equilibrium force is make a angle of resulting force the contact angles. So the surface tension which will be the gas and the liquid, the liquid and the solid. This net force what is acting it here that makes a angle to that. This is what angle of contact.

So you can look it if you take a liquid and you have the angle of contact more than 80 degrees more than 90 degrees, then this liquid will going to wet this solid surface. Whereas if this angle is less than that, this liquid can come into the solids. So that can come into the solids and can have the wetting front. So very simple way we can find out which are the liquids going to wet the solid surface or not based on the angle of contact.

The mostly this the surface tension the force because of the gas and liquid and the liquid and solid interference. We are not going more details because as you have a more understandings if you are looking for surface tension for mostly these chemical engineering and all but here we will not go more detail here. So with this, let me conclude this lectures two.

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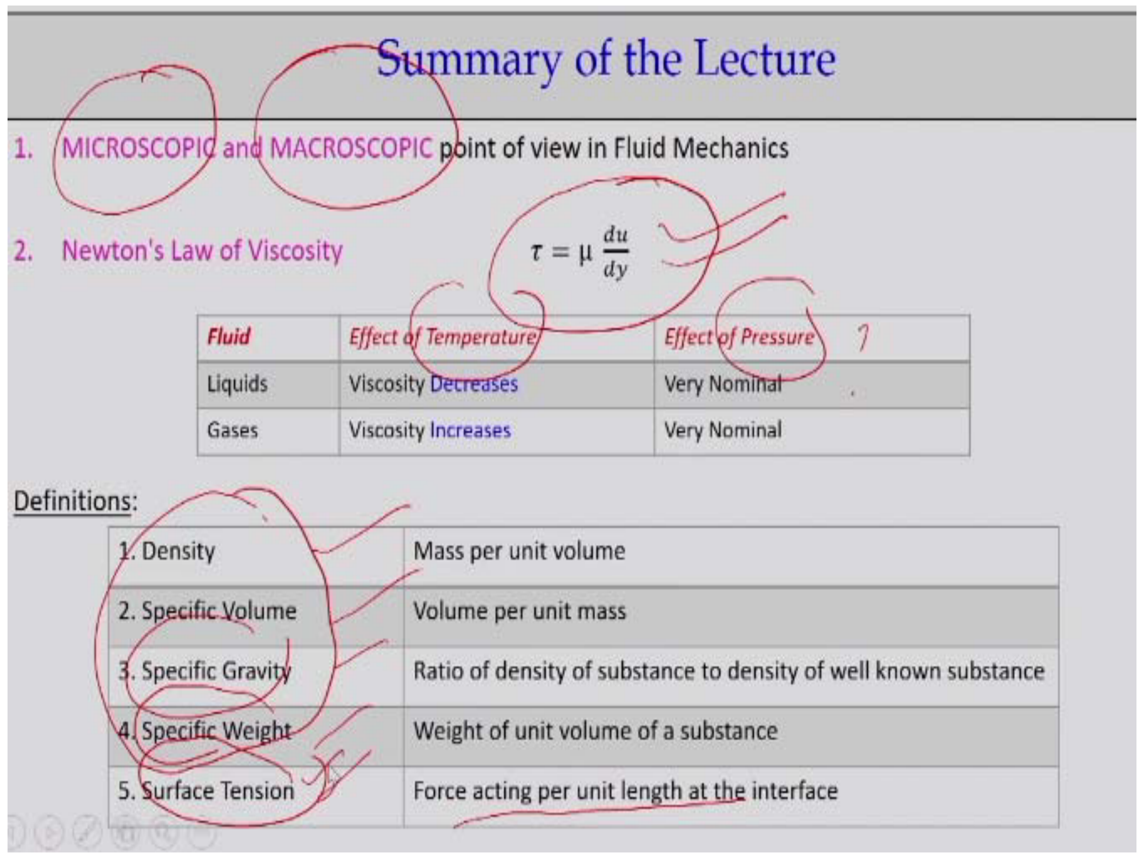

Summary of the Lecture

1. MICROSCOPIC and MACROSCOPIC point of view in Fluid Mechanics
2. Newton's Law of Viscosity $\tau = \mu \frac{du}{dy}$

Fluid	Effect of Temperature	Effect of Pressure
Liquids	Viscosity Decreases	Very Nominal
Gases	Viscosity Increases	Very Nominal

Definitions:

1. Density	Mass per unit volume
2. Specific Volume	Volume per unit mass
3. Specific Gravity	Ratio of density of substance to density of well known substance
4. Specific Weight	Weight of unit volume of a substance
5. Surface Tension	Force acting per unit length at the interface

And with the summary is that the very basic equations is that we derive today which is called Newton's laws of viscosities. That what we have look it microscopic and macroscopic point of view, the molecular motion point of view or a deformations of the fluid element that what we have considered to define the shear stress and proportional to the velocity gradient or shear strain rate.

Then we also discuss is that, how does the viscosity increases or decreases with respect to the temperatures or the pressures. That what we have discussed it. And some of the fluid properties, what we discuss it with respect to the mass we discuss and the weight we discuss the density specific volume, specific gravity, specific rate and the force acting on this interfaces.

That what is a surface tension force as a interactions. I conclude that. With this I conclude this lecture. Thank you.