Fluid Flow Operations

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Lecture – 02
Characteristics of fluid-continued

Key words: Characteristic of fluid; Fluid properties; Ideal and Perfect fluid; Newtonian fluids; Non-Newtonian fluids; Units and dimensions;

Welcome to Massive Open Online Course on Fluid Flow Operations. Today the lecture will be on Characteristics of Fluid, in the previous lectures you have discussed something about application of the fluid flow operations and the history of the fluid flow phenomena. So, in this lecture of course, some characteristics of the fluid that is what is the fluid how it behaves and also flow characteristics of the fluid will be discussed. So, what is fluid? Fluids actually are a subset of the phases of matter that continually deforms under an applied shear stress.

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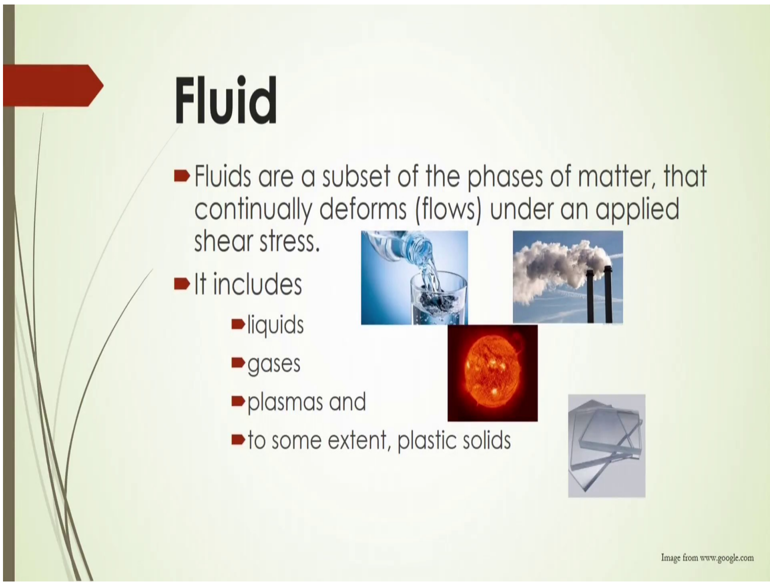

So, this is the basic definition of the fluids. So, so, any fluid whenever you are applying any shear stress on it you will see there will be a deformation of this fluid of one its layer from its another layer whenever it will be flowing. So, that is why the definition of the fluids can be given in this way like that it is a method and it will be a subset of the phases of the matter and it will be continually deforms under an applied shear stress.

So, what are the different type of fluids actually fluid includes like liquids, gases, plasmas and some extent the liquid the fluid is defined as a plastic solids also. So, liquids are generally you will see that in different description of the phenomena of the fluids sometimes the common names of the fluid is being used as a liquids. So, in that case we are not saying that the fluid is only that liquids as a water or some other liquids, but this under this fluid of course, these liquids, gases, plasmas and plastics solid come out. So, here see the some pictures so, that the fluid that is as a liquid here just and also gases which is coming out from the chimney as a carbon dioxide gas or some other mixture of gases also.

And pure there will be pure oxygen gas, nitrogen gas, sulfur dioxide, carbon dioxide, other gases of course and plasma like if you see the sun and the sun there will be a state of matters as a plasma. And also you will see if we are seeing that volcanoes and the fluids are coming from that volcano so, we are the volcanos so, materials will be considered as a plasmas and also sometimes in the real life you will see that some plastics like Perspex or PVC that is transparent PVC. If you are heating that PVC pipe above 100 degree centigrade its I think melting point is about 105 degree centigrade and if you melt this solid transparent polyvinyl chloride you will see this polyvinyl chloride will be just melting and it will behave like a liquid and it is a solid liquid.

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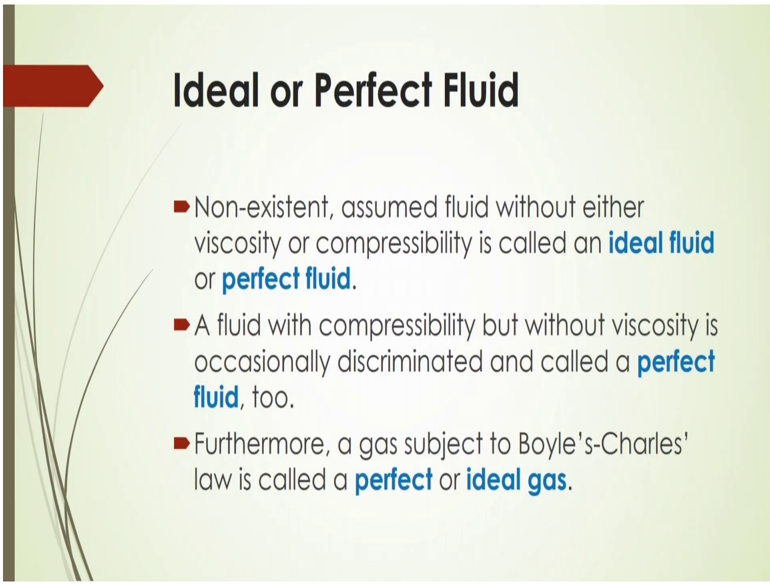

And you will see the fluids are of course, classified into different categories like some fluids you will see that it will not be existent though it will be considered as a perfect or ideal fluid. So, in that case this ideal fluid will be defined as that the fluid which has no viscosity and also it has no compressibility. So, in that case this fluid will be called as perfect fluid. So, though it is not that existence in the real life ideally we can define that there will be no viscosity, there will no compressibility of this fluid. And also you will see that some fluid who has compressibility some extent, but there is no viscosity. So, that type of fluid also to be called as perfect fluid. Occasionally this discriminated and it is called as perfect fluid.

Also, you will see that gas it will be considered as a perfect or ideal gas when this gas will be following the Boyles and Charles law. So, those gases will be following this Boyles and Charles law will be called as perfect or ideal gas we will be discussing later on also while Boyles Charles law all those things. So, we are defining that what is the ideal fluid or perfect fluid. So, for the liquid you can say that if it has no viscosity or it does not have compressibility factor then you will see that it will be called as ideal fluid or perfect fluid. Whereas, for the gaseous the gas should follow the Boyles or Charles law.

The Boyles law it is I think pv is equal to RT that we have I think learned in our schools levels also the Boyles law pv is equal to RT; that means, products of this pressure and volume in a system will be constant there at a particular temperature.

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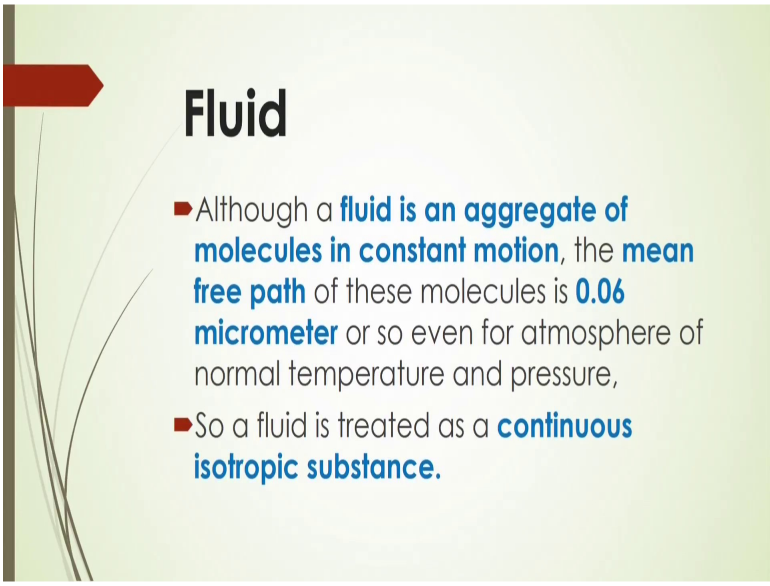

And also you will see that sometimes fluid is considered as an aggregate of molecules when in a constant motion. So, in that case fluid is an aggregate of the molecules in constant motion and in that case the molecules the free parts of the molecules to be considered of that fluid is about 0.06 micrometer. Even if you are just considering that atmosphere or normal temperature and pressure. So, in that case the fluid should be considered as an aggregate molecules in constant motion in that case the mean free path of the molecules will be 0.06 micrometer approximately.

And otherwise, you will see some fluid since its molecules free paths is very small. So, this type of fluid will be treated as a continuous isotropic substance. So, fluid also will be called as an isotropic substance. So, the molecular level whenever you are going to define this fluid this in terms of molecules. So, the fluid molecules will have the mean free path of 0.06 micrometer and it will be considered as that continuous isotropic substance.

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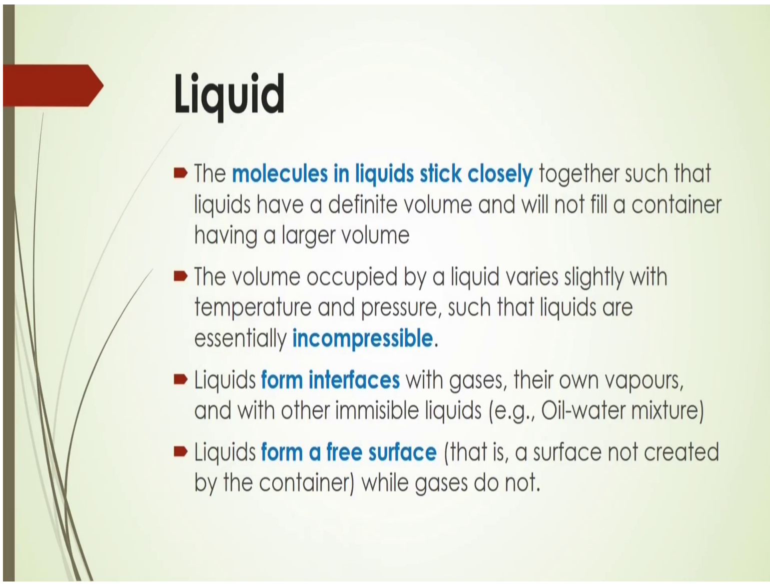

So, under this fluid we are getting that liquid, gas, plasmas and also solid plastics like that so, liquid in that case molecules and liquids stick very closely to each other.

And in that case such type of liquids have a definite volume and will not feel a container having a large volume. And the volume occupied by the liquid that varies slightly with temperature and pressure in that case liquids are essentially incompressible. So, liquids form sometimes interfaces with gaseous even with its own vapour and also the liquid which are immiscible to this liquid. So, these liquids will form the interface like suppose in the practical life we are see that whenever bubble is forming suppose any jet is just falling down from the tap in a bucket you will see there will a formation of a bubble thus it is formed just by breaking the surface and entraining the gas from the atmosphere by this liquid jet energy.

And this jet energy whenever it will form these bubbles you will see there will be a surface interface between this bubble surface and liquid. So, that is why the liquids will form the interfaces with the gases. And also you will see that liquid whenever it will boiled you will see the bubbles will be forming from the bottom of this container and that gas that bubbles actually is formed because of the vapour of that particular liquid at a particular temperature that is at its boiling point. So, that the vapour bubbles will have the surface with a liquid. So, it is called interfaces between the phases; that means, a liquid and gas and also liquid and its vapour. Also some liquids will form the surfaces with the another liquid like immiscible liquids like suppose oil and water mixture.

If suppose kerosene is flowing through the water you will see the formation of kerosene droplet in the liquid in that case you will have the surface of that is kerosene liquid and water. So, this the droplet will form the surface of the liquid and liquid there. And also whenever liquid is flowing through the cannel or you can say that whenever it will be a kept in a container it will have some free surface of course, not have that surface will not be formed by that container. So, liquids form if we free surface there with the gaseous and that is to the atmosphere there. And in that case you will see the gaseous in a container does not have any surfaces. So, here the difference between liquid and gas that gas does not make any specific surface whereas, liquid will form a specific surface with the atmosphere.

Even with some other gases whenever it will be mixed very well as a fine that is form of bubbles and also you will see there are the forms of droplets and also forms of what is that the vapour bubbles with the liquid.

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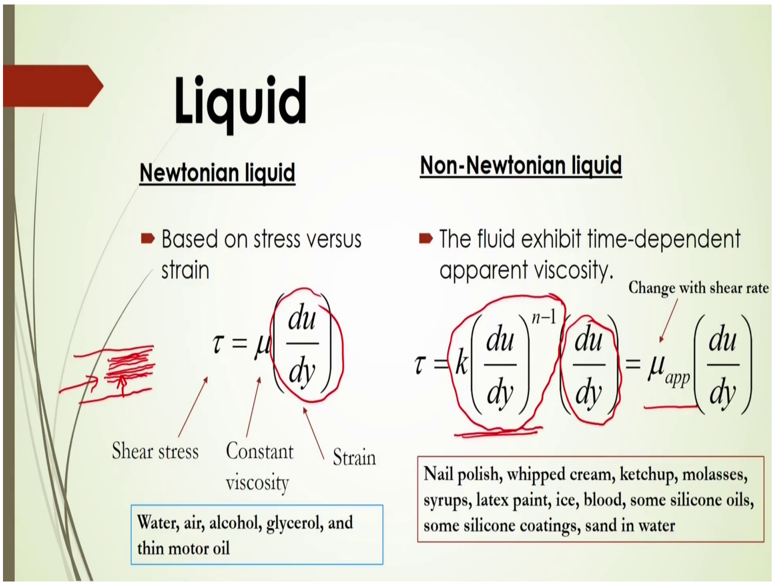

Now, if we classified the liquid we will have two types generally these two types of liquids; one is called Newtonian fluid and another is called non Newtonian fluid. So, that means, Newtonian and non Newtonian how it will be defined this is generally defined based on the stress applied on the fluid if you apply some stress that is force per unit area on the liquid you will see liquid will have exposed to the expose with a shear stress.

And that is due to that shear stress liquid will have some velocity that is liquid layer will move forward in the direction of the application of the force on the surface of the fluid. So, in that case you will see whenever fluid is moving the velocity of the fluid layer it will vary from the bottom of the container to its surface. So, in that case the velocity change with respect to the height of the container here you will see if we consider that liquid is flowing at a velocity u and if it is kept in a container and it is flowing like if it is flowing through the pipe then if we consider that if it is a pipe there like this and fluid is flowing at a velocity u you will see that and in this direction y direction the velocity of the fluid will be changing.

And at the centre you will see there will be a maximum velocity whereas, at the adjacent to the wall of the pipe the velocity will be very less. So, in that case there will be some gradient of this velocity. So, this gradient of this velocity is represented by d u by d y though will be it will be described in details later on how this actually layer velocity will be changing. So, in this case we are just saying that this velocity will be changing with respect to y direction that is perpendicular to the velocity of the fluid. So, in it is called a velocity gradient or it is called the strain or it is called sometimes shear rate this is shear stress what is applied to the fluid will be proportional to the strain or shear rate.

So, this proportionality constant it is called this viscosity it is represented by mu. So, in case of Newtonian liquid in that case the viscosity of the liquid do not be changed with respect to time and also some other factors. So, in that case we are getting that the constant viscosity whenever any force is the applied on the fluid. So, this constant viscosity those liquid will give you this constant viscosity it will be called as Newtonian liquid and it follows this Newton's law of viscosity and it is represented by tau is equal to mu into d u by d y. So, d u by d y it is called strain and mu is called constant viscosity and tau is called shear stress. Example of this liquid is like water, air, alcohol, glycerol and thin water oil are generally we consider as Newtonian liquid.

Whereas, non-Newtonian liquid you will see the viscosity here mu will be changing with respect to time. So, whenever the non Newtonian liquid will be flowing through the pipe you will see that the viscosity will not remain constant. So, in that case it will change with respect to time and for that the behavior of this non Newtonian fluid will be represented by this power law it is simply by tau is equal to k into du dy d to the power n. Here if we just aggregate these or rearrange these like this tau is equal to k into d u by dy to the power n minus 1 into d u by dy. So, in this case d u by dy is the strain here if we compare this with the Newtonian liquid if we consider this one as what is that d u by d y which is d u by dy the remaining factor is this k into d u by dy to the power n minus 1. So, this k into d u by dy to the power n minus 1 it is called apparent viscosity.

So, in this case if we compare with the Newtonian liquid mu should be represented as this k into d u by dy to the power n minus 1. So, it is apparent and its you will see that with respect to time whenever it will be flowing this viscosity will be changing and of course, this change of viscosity with respect to time it will be represented as that apparent and viscosity the effective viscosity.

Now, since this viscosity with a shear rate it is called d u by dy generally given by the fluid like nail polish and also whipped cream ketchup, molasses and also sometimes syrups you will see latex paint even the blood which will be considered as a non Newtonian liquid and also sometimes some silicone oils, even some coating materials for the silicon coating and those materials would be represented also as a non Newtonian liquid. And sometimes will be whenever sand very fine particles will be flowing through the pipe the viscosity of that mixture of that solid and water it is called slurry. So, slurry viscosity will be considered a change with respect to time. So, in that case the viscosity of the slurry will not be that as like that Newtonian viscosity. So, it will be totally non Newtonian liquid ok, but whenever you are mixing the bigger sized particles with water it will not be moving like that non Newtonian liquid.

It is simply there will be no flow of solid particles, if there is a solid particles flowing with slurries in a slurry system you will see if you are adding some more solid particles or concentration of the solid particles in the fluid then or in a slurry then you will see there will be change of viscosity. So, this type of slurry it is represented as a non-Newtonian liquid. So, we are having two types of liquid; one is Newtonian another is non Newtonian liquid based on the shear stress applied and how the how its internal property like viscosity will be changing.

So, for Newtonian liquid there will be there will be no change of viscosity with time whereas, in non Newtonian liquid there will be change in viscosity with time. But this Newtonian and non Newtonian viscosity you will see there will be again change with respect to temperature and pressure, if you increase the temperature you will see the viscosity of the liquid will change. So, if you increase the temperature there will be a decrease in viscosity and also for the gaseous it is also the same way, but opposite effect of the viscosity change with respect to temperature.

In case of air if you increase the temperature the viscosity will increases whereas, in the water the viscosity of that is water with respect to temperature it will decrease and also there is an effect in effect with pressure also. In case of gaseous, if you increase the pressure there will be a that is more stickiness of the molecules and will come to each other and there will be more viscous. So, in that case if you increase the pressure the viscosity will increase whereas, in the liquid also it is seen that that if you increase the pressure the viscosity will change. So, this is one important properties of the liquid based on the viscosity you can you can classify or based on the shear stress and strain relationship by the Newtonian law and even power law or model you can classify this liquid.

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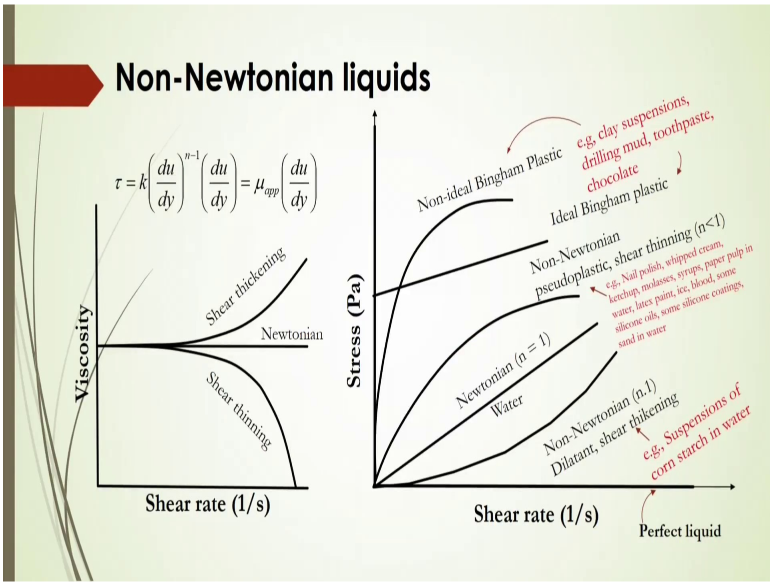

So, in that case see you will see here also in this figure we can have this relationship of viscosity change with respect to shear rate for not in non Newtonian liquids you will see so, this viscosity will be changing with respect to shear rate it is increasing for shear thickening liquid and here it is called shear thinning liquid and for Newtonian liquid there are no change of viscosity. So, how this shear thickening and shear thinning liquid will be classified we have seen this right side figure. So, here this figure is represented by this stress that is shear stress to the shear rate. Here in this case we are having the different profiles. I think we have shown here the coefficient of k and n here.

So, n if it is n is equal to 1 then it will be called as Newtonian liquid like water, if n greater than 1, you will see it will be considered as a dilated shear thickening liquid like suspension of corn starch in water. Even if you will see that if n is less than one then it will be called as pseudo plastic or shear thinning liquid so like nail polish and also you see that molasses, syrups, paper pulp and also a slurry system those are called as pseudo plastic or shear thinning liquid. Some other liquid like if this power law if it is not following then some other fluid they are related with some straight line not in power law this is simply y is equal to mx plus c that is called Bingham plastic fluid.

So, that is so, all those things will be described in later on also later on this description will be discussed and for non ideal Bingham plastic like clay suspensions, drilling mud, toothpaste, those also will be behaving like non Newtonian liquid and those will have some other characteristics like it will the viscosity of those fluid also changing with respect to time. So, we are getting two types of fluids Newtonian and non Newtonian, but you will see if there is no change of stress with respect to shear rate we can consider this type of liquid as a perfect liquid.

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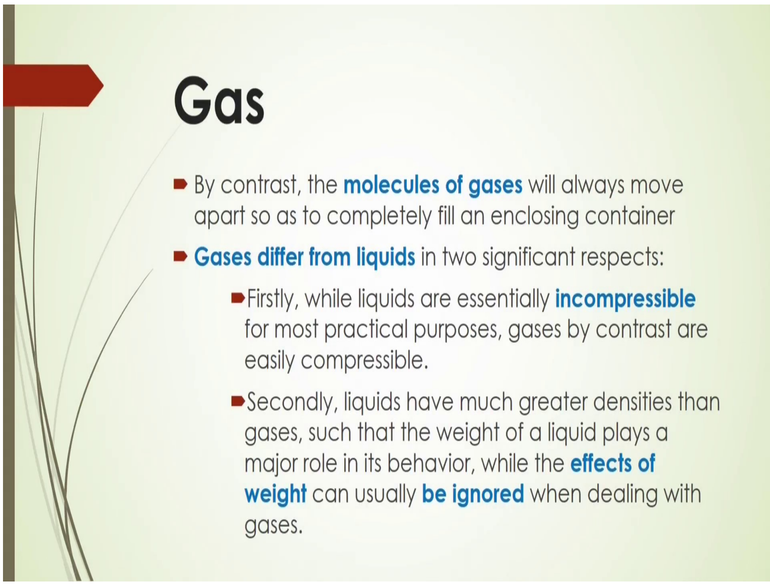

Now, gas we will see by contrast the molecules of gases will always move apart so, as to completely fill an enclosing container. The gases differ from the liquids and in 2 significant respects first is while liquids are essentially incompressible for most practical purposes you will see gaseous by contrast are easily compressible. And also secondly, we can say that liquids have much greater densities than gaseous such that the weight of a liquid plays a major role in its behavior, when the effects of weight can usually be ignored by dealing with gases. So, this is the things the how gases differs from the liquid. And also you will see that different types of gases some gases will be naturally occurred that is natural gases it is called that is present in nature and it can be divided into two categories like elemental gaseous, like compound gaseous.

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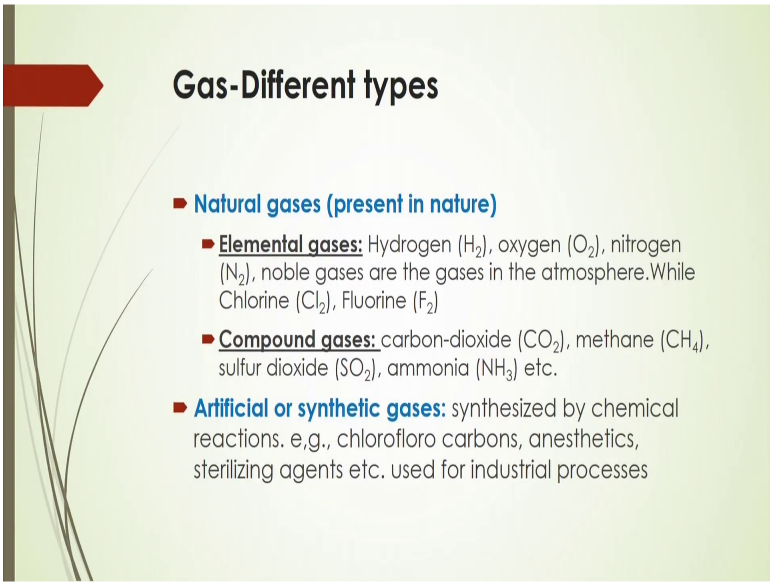

Elemental gases like hydrogen, oxygen, nitrogen, noble gases and also you can say that chlorine, fluorine, all those gases are considered as a natural gaseous these are naturally I think available. And also, the some other gases which will be compound like carbon dioxide, methane, sulfur dioxide, ammonia those are created by some or combination of the different gases also even some other synthesized gases also it is there.

So, carbon dioxide, methane and sulfur dioxide those are called compound gases and also some gases which will be synthesized by chemical methods by chemical reactions like chlorofluorocarbons, anesthetics, sterilizing agents etcetera this type of things are called synthetic gases and used for industrial processes. Plasma; the plasma can be obtained by heating or subjecting a natural gases.

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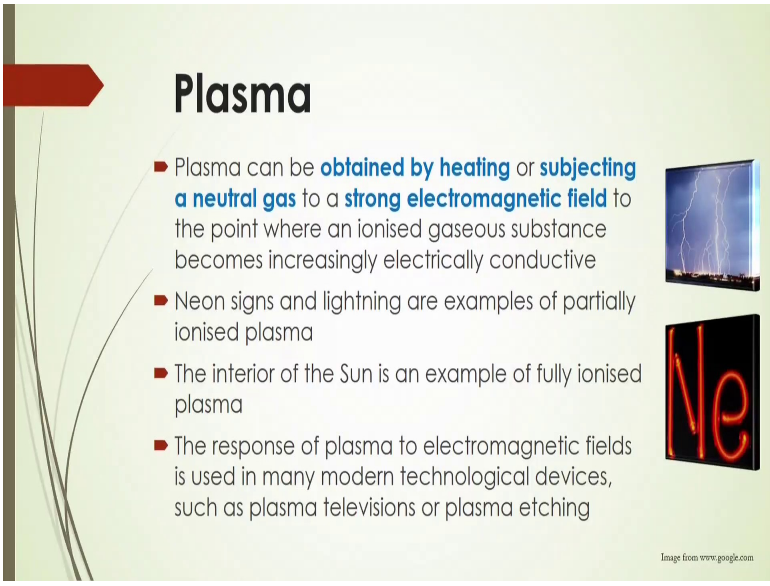

So, this is another type of liquid and it will be a strong electromagnetic nature; that means, it will give you the if you apply some strong electromagnetic field on this type of liquid or by heating you will see there will be a some ionized state of these materials. So, this ionized state of materials you will see it will become some nature in such a way that it will electrically conduct and it will be represented as a plasma.

So, neon signs and lightning are example of this type of fluids and also you will see if you are considering if you are seeing that interior of the sun that will be one example of fully ionized plasma. Also this plasma whenever you are applying some electromagnetic fields on it will be used for many modern technological device manufacturing and such as plasma televisions and plasma etching in that case of course, this fluid flow operations is very important.

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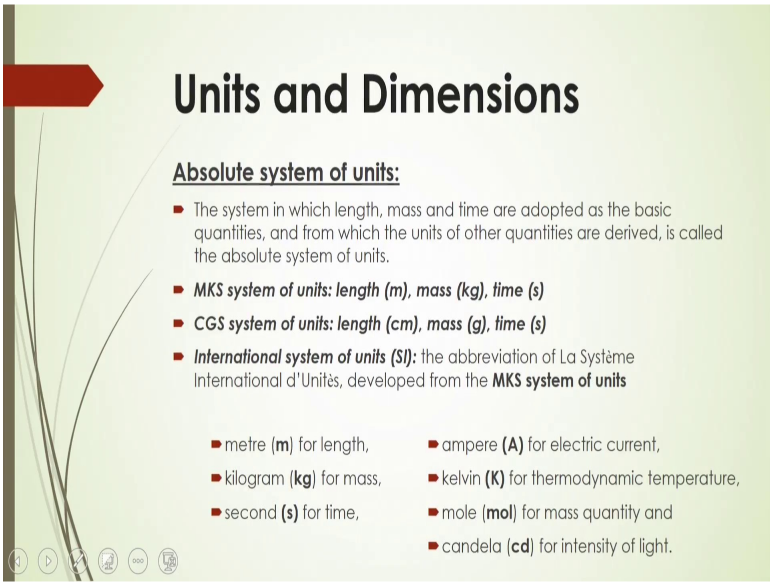

Now, next part is that we have actually defined the fluid based on its applied shear stress and shear strain and also some other factor molecular labels when molecules mean free path will be around 0.06 micrometer. So, we got this now we are coming to the representation of the calculations of the fluid behavior in that case we have to use some unit or dimensions to represent the mathematical formula to represent the behavior of the fluid. So, in that case we are of course, to know that is the different systems.

Like we know that already we have already learned earlier also in our schools levels that what should be the units for different I think by units like; now what is the unit for length, what is the dimensions for length, what is the unit for what is mass, what is the unit for gravitational acceleration? Like this.

So, we are actually going to represent all those things by three systems; that means, units can be represented by three systems one is MKS system, CGS system and SI system. The SI system is the most important one which is actually accepting internationally to represent all the behavior of the fluid in a common platform.

So, international systems is the that is widely used unit or units for system for representing the fluid flow operation even other mechanical and civil engineering process and other electrical or different units also. So, the system in which length, mass and time are adopted as the basic quantities and from which the units of other quantities are derived it will be called as the absolute system of units. So, in that case MKS system of units like length, mass and time and CGS system of units like what is that again length, mass and time.

But in this case the length of unit per length will be centimeter and unit for mass should be gram and unit for time should be second. International system of units in that case the abbreviation of the law system is international unit developed from the MKS system of units and it is widely used and it is generally used nowadays in any representation of the mathematical expression for the any process parameters.

Now, in that case you will see we are getting some MKS that is SI system like meter will be represented as m and kilogram for mass second for time and for electrical electric current it will be by ampere, Kelvin for the thermodynamic temperature, and mole for mass quantity and candela for the intensity of light. So, these are unit, but what should be the dimensions they are in generally the dimension for the meter is represented by m and for mass it is kg and for time it is s and for ampere it is generally A and Kelvin per K mole for mole and candela that is cd. So, these are dimensions.

So, fundamental three dimensions are very important that is called length, mass and time that is m that is you can say kg or that is called yeah kg and second yes and other units of dimensions that whenever you are representing an equations all that means or all variables will have some dimensions and units.

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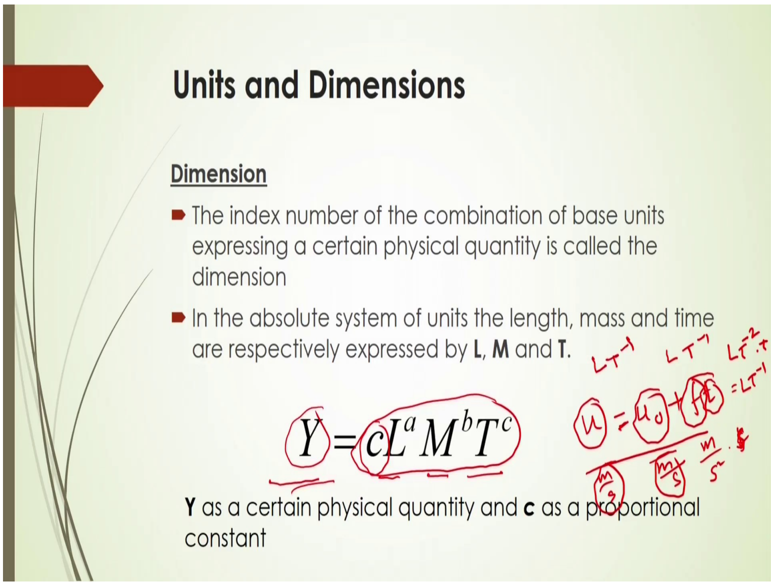

And an equation, whenever it will be represented by some index number and then the index number of the combination of the base units that will express a certain physical quantity and which will be called as dimension.

So, in that case in the absolute system of units by the length, mass and time are respectively expressed by LM and T. So, here if I represent that Y is equal to Y is a function of LMT and it is represented by cL to the power a M to the power b and T to the power c then we are considering here Y is a dependent variables and as a certain physical quantity and those are depending on this some length and mass and time. And in that case what should be the proportionality constant this is represented by c, c as a proportional constant it is also one important parameter and which has some dimensions to equalize or you can say that to equal the dimensions to both sides of this equation.

So, of course, for consistency of the equations you have to check whether the dimensions of both the side of this equations are same or not. So, you have to verify any equations like suppose u is equal to u 0 plus f t. So, this is also you will see one equations here u the velocity of the fluid and u 0 the initial velocity of the fluid and f t, f is the acceleration of the fluid and t is the time. So, in this case what should be the units in both sides of this equation, u is the width for unit is meter per second u 0 what is the unit that is also meter per second this is meter per second and here meter per second.

And also this what is the unit for acceleration that is meter per second square and time is second, the unit for time is second. So, see whether the dimensions or unit on the both sides of this equations are same or not. So, here that I will say m by s here m by s that is meter per second here also you will see if we this f is meter per second square here t is s so s will be canceled. So, one s will be remain say m by s.

So, here since it is the additive properties this meter per second, meter per second, here also meter per second. So, what should be the dimension here dimension is here M that is length T to the power minus 1, here it will be again here LT to the power minus 1 here also it will be LT to the power minus 2 into T.

So, it will be coming as LT to the power T to the power minus one. So, on the both sides of this equation we are seeing that the dimensions or units are same. So, whenever you will represent any mathematical expression behavior of the fluid by mathematical expression by any equation you have to check whether both sides of the equations are same or not both sides of dimensions of the both sides of the equations are same or not.

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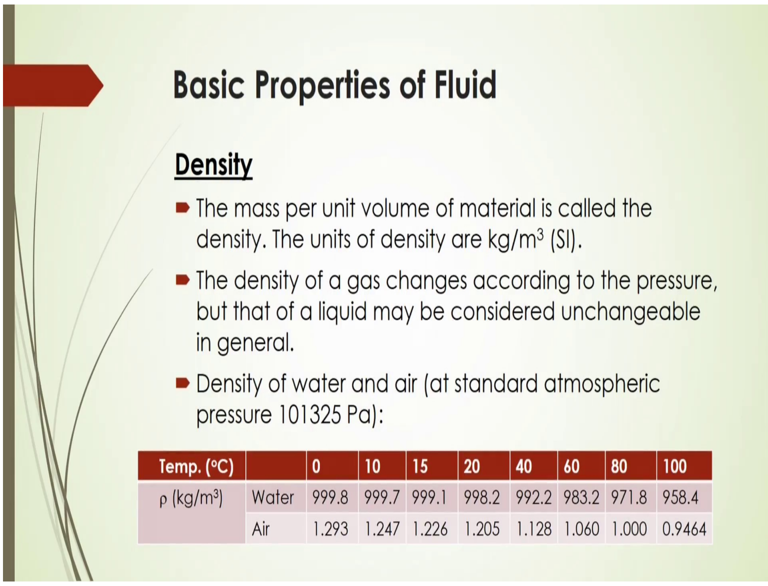

Next, we will discuss something about the basic properties of the fluid. Now you know that everybody the density of the fluid, density of the fluid was important property. So, the mass per unit volume of material is called the density the units of density are and units are per density is kg per meter cube.

Even this is in SI system in MKS system it will be I think gram per centimeter cube and FPS system there is another that is called feet per second square sorry pound per feet cube and this is not generally being expressed nowadays all our SI units should be the most acceptable. So, we will represent all these in SI units. The density of a gas whereas, it will be changing according to the pressure, but that of a liquid may be considered unchangeable in general. Density of water and air at standard atmospheric pressure that is 101325 Pascal it is given in this table and with respect to time how this density of the water and air is changing.

At a higher temperature it is change it is seen that the density of water will be changing and it will be decreasing at 0 degree centigrade it is coming 999.8 and whereas, 100 degree centigrade is are reduced to 958.4. Whereas, air density will increase sorry will decrease again here, but at 80 degree centigrade it will be 1. Whereas, at 0 degree centigrade to be 1.293. What is specific gravity? The ratio of the density of the material rho to the density of the reference substance will be represented by specific gravity; that means, here this is nothing, but the relative density compared to the water. So, it will be represented as S true like this that is specific gravity that is true specific gravity; that means, here that is ratio of density of what of any liquid to it is to the density of the water at certain temperature.

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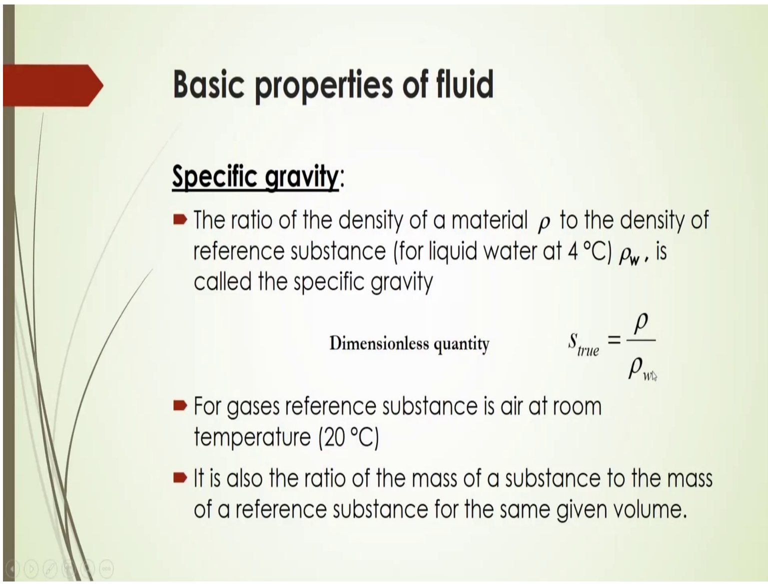

For gaseous reference substance will be air at room temperature 20 degree centigrade. Specific gravity sometimes it is represented by notation like gamma also. So, gamma will be is equal to rho by rho w, it is also the ratio of the mass of a substance to the mass of a reference substance for the same given volume. In this case, ratio will be in terms of mass not in a density. So, generally it is represented by in terms of density, but sometimes it is expressed by in terms of mass also.

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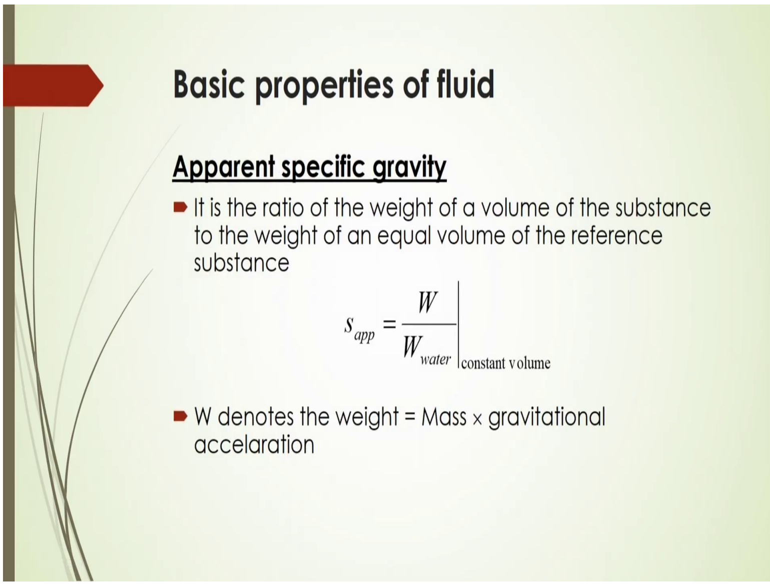

And apparent specific gravity it is also the ratio of the weight of a volume of the substance to the weight of a an equal volume of the reference substance, here same way in it will be represented by mass instead of density and it will be represented by weight not in terms of mass not in terms of density. So, it will be as that what is that, W by W water at constant volume, where W denotes the weight is equal to mass into gravitational acceleration.

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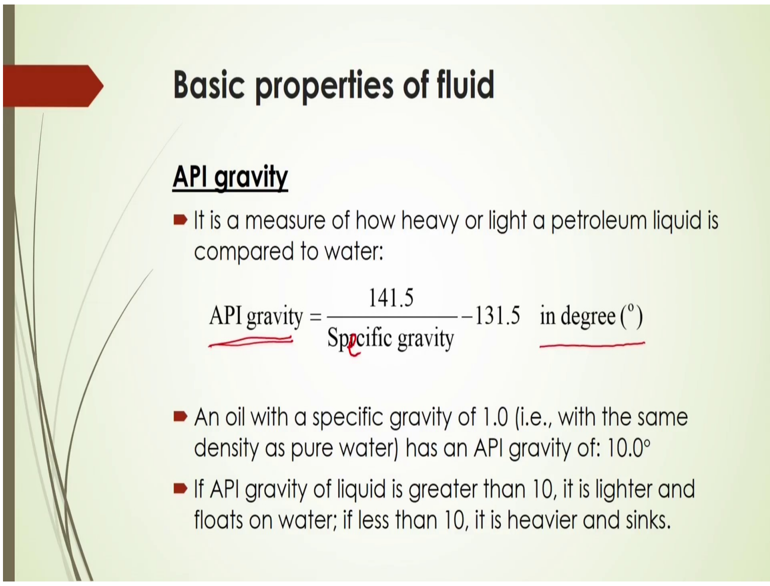

Another important unit for representing the density of the fluid is called API gravity. So, it is being used in petroleum industry to measure the liquid how much heavier or lighter this liquid is. So, in that case this it is represented by API gravity API means American Petroleum Institute in that case this API gravity is defined by this one point 141.5 divided by its a specific gravity minus 131.5. So, it will be represented in degree. So, API gravity is one important you need to represent the density of the fluid or gravity of a specific gravity of the fluid.

And an oil with a specific gravity if it is 1, then you can say that will have the same density as pure water, but has an API gravity will be API gravity will be 10.0 degree. So, if I represent that by any oil with specific gravity 1 its equivalent API gravity will be 10.0 degree centigrade. Also, if API gravity of the liquid if it is greater than 10 it will be called as lighter liquid and it will float on the water and if its API gravity is less than 10 it will be called as heavier liquid and it will sink. So, it is obviously, we can actually relate this to specific gravity with the API gravity. So, here on important that it will be corrected as a specific not in a specific gravity there is a mistake. So, API gravity will be 141.5 divided by specific gravity, if I know the specific gravity what should be the API we can easily calculate by this formula.

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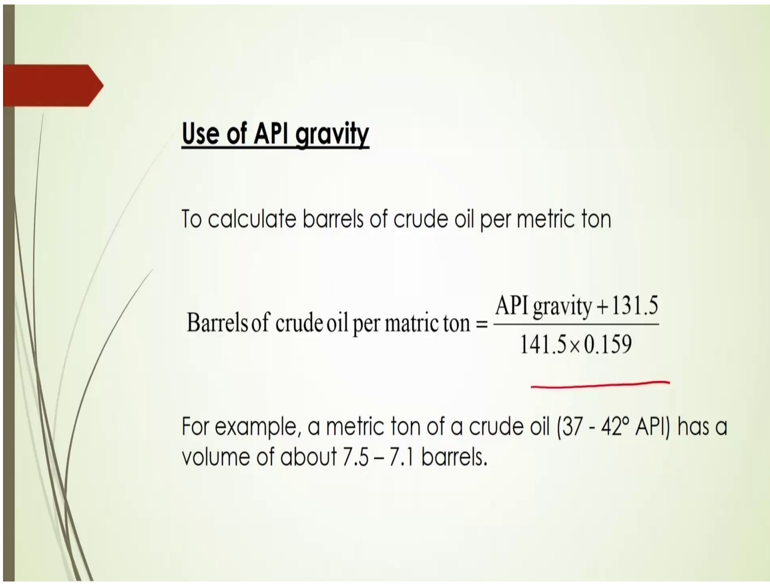

Now, to calculate the barrels of crude oil per metric ton this API gravity is extensively used, in that case one example is there some barrels of crude oil per metric ton will be equals to API gravity plus 131.5 divided by 141.5 into 0.159.

So, by this equation you can calculate what will be the capacity or what will be the amount of crude oil is being transported or it is being poured in a particular storage. So, here for example, a metric ton of a crude oil if it is API that is 37 to 40 degree in that case it will have the volume of about 7.5 to 7.1 barrels. So, the barrels will be represented by this degree API if you know this API degree how much barrels of crude oil per metric ton you can easily represent by this formula.

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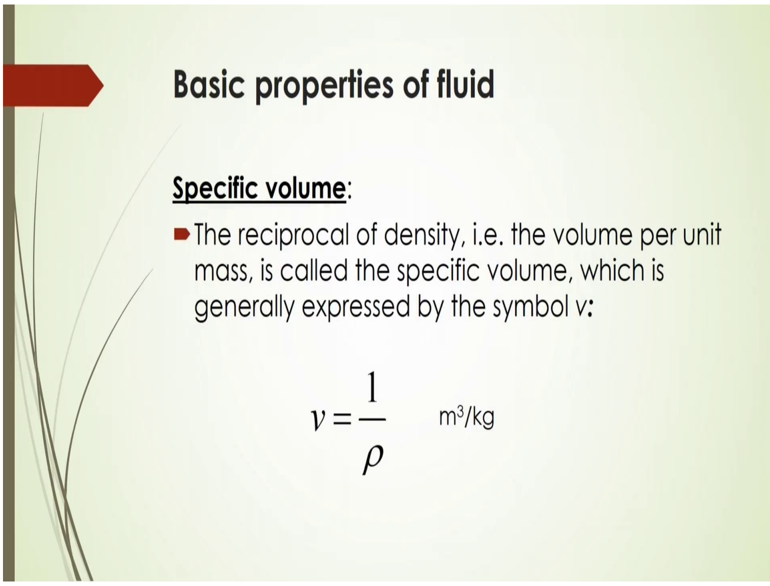

Another important basic properties of the fluid is called specific volume the reciprocal of the density. The volumes per unit mass that is called the specific volume which is generally expressed by the symbol v and it will be simply inverse of the density like this and its unit will be meter cube per kg.

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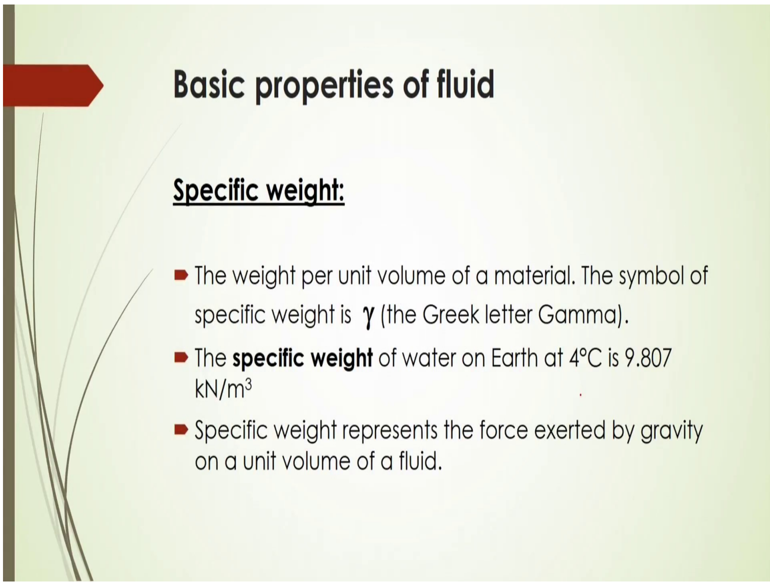

And another one is specific weight the weight for unit volume of material the symbol of specific weight is gamma and the specific weight of water on earth at 4 degree centigrade is 9.807 kilo Newton per meter cube and also specific weight that represents the force exerted by gravity on a unit volume of fluid.

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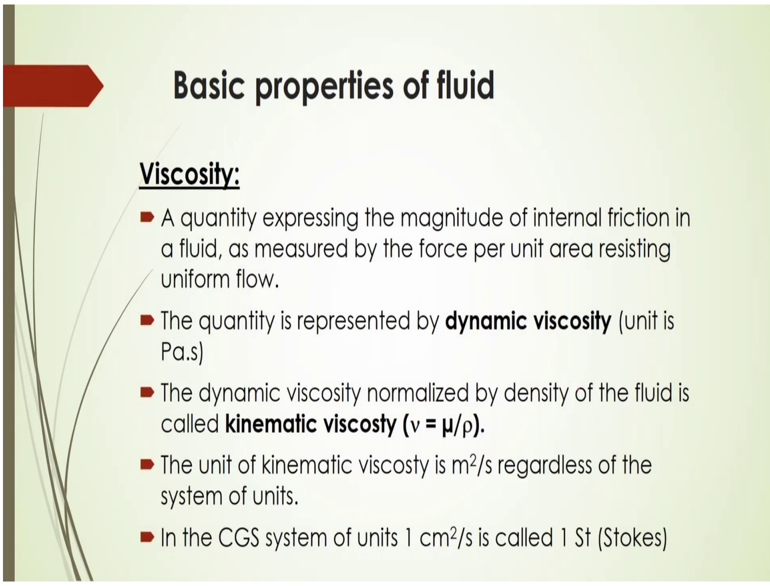

So, some other viscosity some other physical properties you can say that viscosity we have already discussed some extent that viscosity what is that. So, it is a quantity that expressing the magnitude of the internal friction in a fluid as measured by the force per unit area resisting uniform flow.

So, whenever the fluid will be flowing uniformly through the pipe then you will see there will be some resistance that given by the fluid to the wall and that resistance what is the degree of resistance that would be represented by this viscosity. So, the quantity to be represented and the quantity is represented by the dynamic viscosity whose unit will be Pascal second.

The dynamic viscosity normalized by the density of the fluid is called kinematic viscosity, the definition of this kinetic viscosity or you can have this formula for this kinetic viscosity thus simply viscosity by density. The unit of kinetic kinematic viscosity is meter square per second and also in the CGS systems of units you will see the unit for viscosity is represented by stokes.

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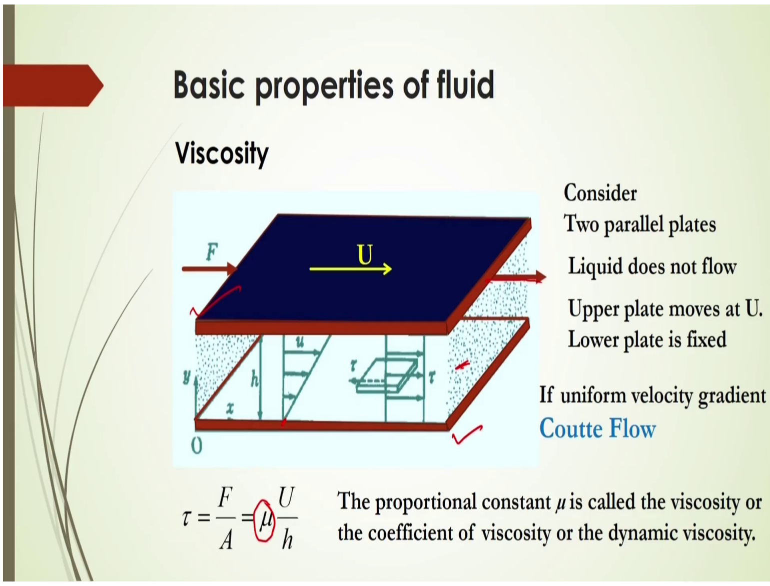

That means the 1 centimeter square per second is called 1 stokes. And now see viscosity basic properties, if we consider two parallel plates like this diagram you will see in between these plates liquid does not flow just holding the liquid between this parallel and upper plate moves at U in that case the plate upper plate of this over this liquid surface it is moving at a velocity U whereas, lower plate is fixed. In the case if the velocity is very low or very small you can say the velocity gradient over the; that means, width of the liquid volume it will be I think constant or the uniform; that means, here if we consider these 2 plates, this one and this one 2 plates and this plates upper plates is moving at a velocity U in between there is liquid and if we consider this liquid layer here one liquid layer and if it is moving this plate is moving you will see that adjacent to the plate there will be a toss of the liquid that liquid also will be trying to move in the same direction of the plate, and because of that there will be a distortion of the there will be distortion of the fluid layer compared to the bottom layer and this upper layer whenever it will be distorting at a certain velocity then we change our velocity with respect to height or width of this ; that means, 2 plate gap. So, in that case the gradient of the velocity of this fluid will be fluid distortion equals to d u by d h.

And that means, if we represent that if it is uniform then it will be simply u by h if it is starting from 0; that means, bottom plate is fixed; that means, here with contact with this bottom layer the fluid will not be moving fluid layer will not be moving. So, in that case the velocity will be here 0. So, at the upper layer there will be a velocity of this plate. So, there will be a difference is u minus 0 that will be u minus 0 is simply u. So, u by h is the gap between these two plates.

So, velocity gradient would be u by h and it will be uniform there it is not changing with respect to time also and so, what are whenever we are applying any force. So, what this upper plate we are getting this velocity u and due to this change of velocity there will be a velocity gradient and this is called strain of this flow and this shear stress; that means, force the applied per unit area over the surface it is called shear stress, this is shear stress will be proportional to this gradient of the flow.

So, this proportionality constant will be represented by this mu. So, tau is equal to mu into U by h we have already discussed earlier that this Newtonian flow that tau is will be equals to constant viscosity into strain. So, this proportionality constant mu is called the viscosity or the coefficient of viscosity or the dynamic viscosity.

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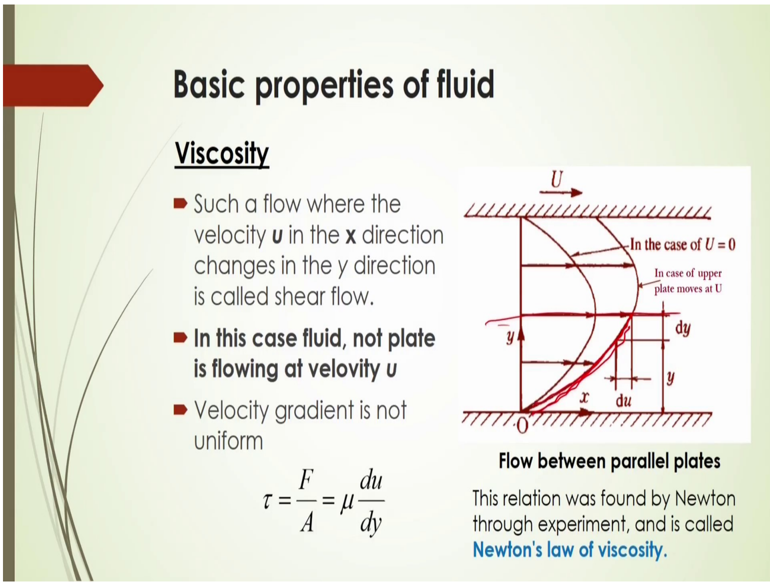

And of course, whenever you will see the flow where the velocity U in the x direction changes to the y direction it will be called as shear flow. So, in this case the fluid when not plate is flowing at velocity U so, only fluid is flowing.

See this picture only fluid is flowing not plate is moving. So, in that case velocity gradient will be is equal to d u by dy because the both end of this liquid contact with the wall it will be fixed whereas, the in between; that means, they are center line there will be maximum velocity. Whereas, this velocity will be changing from this contact to this mac center region in such a way that there will be some slope changing with respect to y direction.

So, that is called d u by dy. So, in that case tau will be equals to mu into d y by dy again. So, in this case fluid also is moving in a previous case there will be no movement of fluid whereas, the upper plate of the surface of the fluid will be moving. So, in the both cases you will see that the Newtonian behavior of the fluid which will be which is represented by this shear stress and it is simply mu into shear strain.

So, this relation was found by Newton through experiment and is called Newton's law of viscosity. So, you have to remember what is the Newton's law of viscosity how it will be expressed by a mathematical expression like tau is equal to mu into d u by dy.

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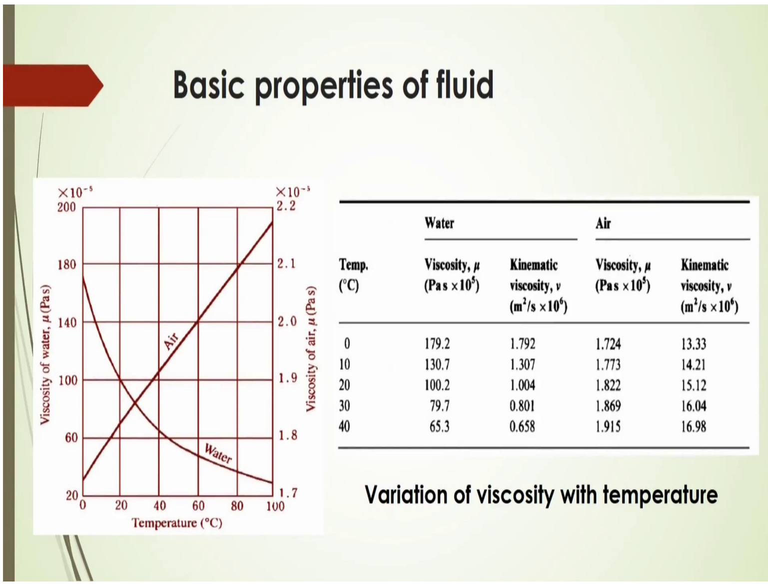

Temp. (°C)	Water Viscosity, μ (Pa s ×10⁵)	Water Kinematic viscosity, ν (m²/s ×10⁶)	Air Viscosity, μ (Pa s ×10⁵)	Air Kinematic viscosity, ν (m²/s ×10⁶)
0	179.2	1.792	1.724	13.33
10	130.7	1.307	1.773	14.21
20	100.2	1.004	1.822	15.12
30	79.7	0.801	1.869	16.04
40	65.3	0.658	1.915	16.98

Here some properties again it is seen that the variation of viscosity with temperature we have already discussed that if you increase the temperature the viscosity of the fluid will be changing viscosity of the liquid will decrease with temperature. So, here in this graph you seen that the viscosity how it will be changing with respect to temperature. And again you will see some viscosity of gas in that case if you increase the temperature the molecular interaction will be more higher and their kinetic energy even the mean free path of the molecules will come to each other more contact and; that means, gap will be more less and in that case the viscosity will be higher.

Whereas, in case of pressure if you increase the pressure the viscosity will increase which is really totally opposite to the temperature effect.

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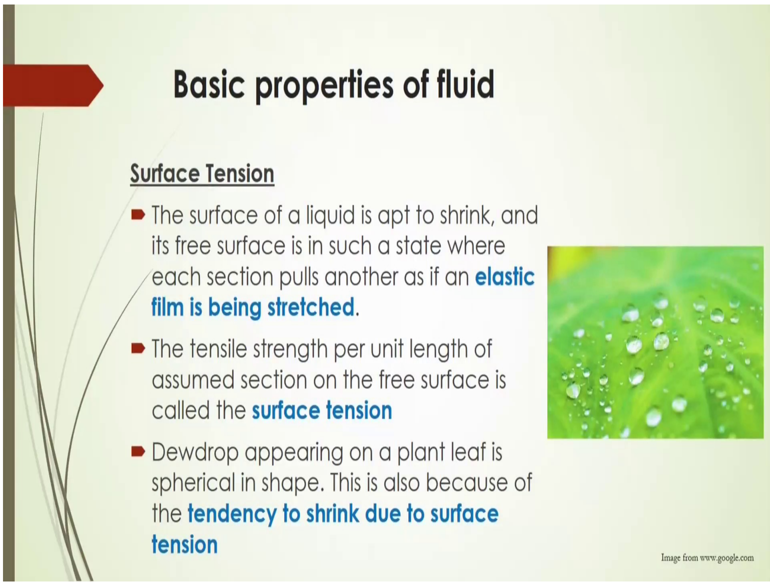

Now, another important properties of the fluid is called surface tension. The surface tension of a liquid is apt to shrink and its free surface is in such a state where each section pulls another as if an elastic film is being stretched. See the picture here this some droplet over the surface of any leaf plant leaf here see how this surface tension effect this the droplet is just becoming a spherical in shape that; that means, here the contact of the droplet to the surface is like bend towards the surface here.

So, the tension strength per unit length of the droplet assumes section on the free surface is called the surface tension. So, dew drop appearing on a plant leaf is spherical in shape this is also because of the tendency of shrink due to the surface tension.

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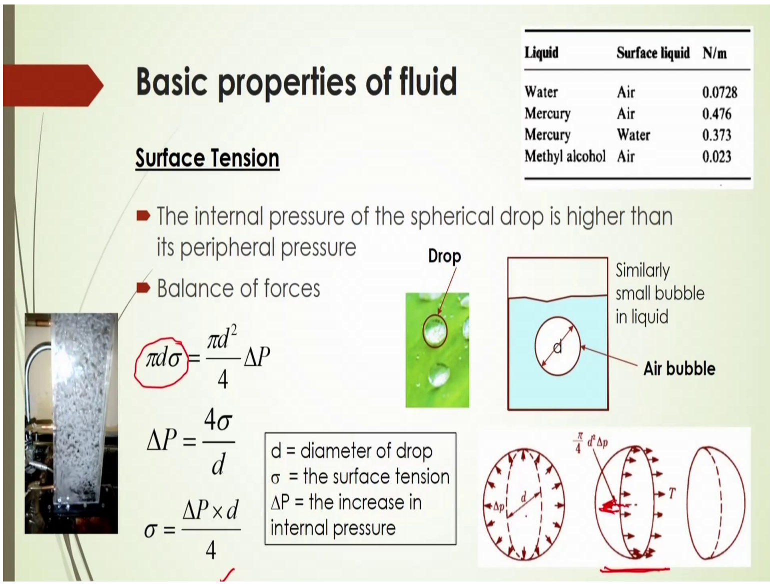

Another important point here that the internal pressure of the spherical drop is higher than its a peripheral pressure. So, if you are considering one drop you can say that what will be the internal pressure of the spherical drop and it will be higher than the peripheral pressure what of the peripheral pressure, peripheral pressure is nothing, but the surface tension here.

So, if we balance these two forces of this peripheral pressure and the internal pressure you will see that here this pi d sigma here d is the diameter of the drop and the sigma is called the surface tension which is which units is Newton per meter and it will be equal to pi d square by four; that means, here the area of the that is drop that is projection view and into delta P; that means, here a pressure drop. So, delta P will be is equal to this 4 sigma by d. So, sigma is equal to 4 P into d by 4, d is the diameter of the drop, sigma is the surface tension, delta P is the increase in internal pressure here.

If we consider one air bubble they are similarly we can say there is a small bubble in the liquid in this case also there will be inter phase and there will be interfacial tension that interfacial tension because of the surface tension of the liquid that is contacting with this gas. So, in this case you will see how this surface tension is acting here in this figure you will see that this pi d square by 4 into delta P well the surface force is acting in this direction and all this force will be see the peripheral from the internal portion there will be a change of this pressure drops will be represented by delta P.

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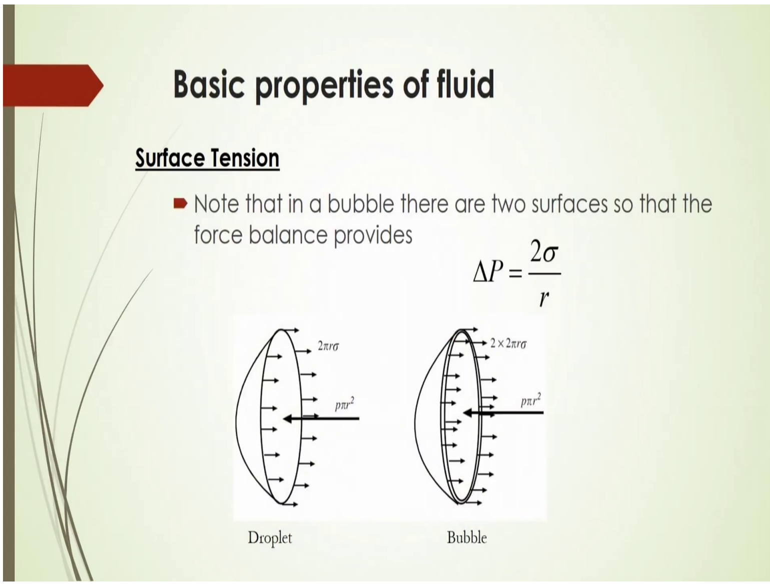

And note that in a bubble there are two surfaces so, that the force balance provides this delta P will be equals to 2 sigma by r; that means, here 4 sigma by diameter instead of what is that here again 4 sigma by diameter same.

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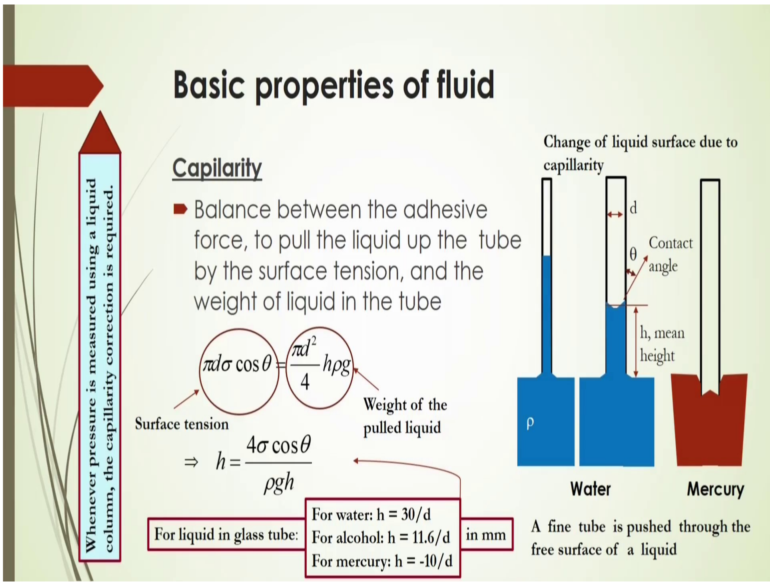

So, the droplet and bubble like this here. Another important properties of the fluid is capilarity if you find tube is pushed through the free surface of a liquid, the liquid rises half or falls in the tube going to the relation between the surface tension and the adhesive force between the liquid and the solid this phenomena is called capilarity. You see here this picture very interesting the density of the liquid here rho this density this liquid is you know that pushed through the free surface of liquid and it is pulled up due to the surface tension and here also we are with you will see that the liquid surface is pulled off in the with the contact with this wall due to the surface tension and here also some other liquid it will behave oppositely like this here the shape that is sharp of the surface shape will be what is that different way that is totally different here if I use the water and if I use mercury as shown in figure like this. So, a fine tube is pushed through the free surface of a liquid here.

So, we are saying that if you fine tube is pushed through the free surface of liquid the liquid rises up or falls in the tube so, here this false this is here off. So, into this relation between the surface tension and the addressee force between the liquid and the solid it will be called as a capilarity. Now if we balance between this adhesive force to pull the liquid of the tube by the surface tension and the weight of the liquid in the tube we can have this pi d sigma cos theta, theta is here contact angle it is shown in the picture like this here and it will be balanced to this what is that weight of the pulled liquid to be pi d square by 4 this is cross sectional area into h.

So, this is the (Refer Time: 55:54) I think in to h this is volume into density this is called mass into g that means here weight. so, this surface tension force will be balancing with this gravitational force. So, from which you can calculate what should be the h here h is nothing, but it is shown that how much; that means, liquid will be pulling off here that is mean height it is given.so, based on this equation balance of this force you can calculate what will be the height of the liquid is pulled through this tube. So, for liquid in glass tube for water is generally related to this diameter of this tube if you increase the diameter h should be decreased, if you decrease the diameter you will see more height of the liquid you can obtain engine in the tube.

So, for water h will be is equal to 30 by d and for alcohol it will be typically 11.6 by d whereas, for mercury it will be 10 minus 10 by d since it is I think in opposite direction this; that means, it will be fall down.

So, that is why it will be minus 10 by d all this diameter will be in millimeter here that is g this is h the h will be in terms of millimeter. So, in this case capillary how we can calculate the how much liquid will be pulled off by the surface tension you can easily calculate by this force balance.

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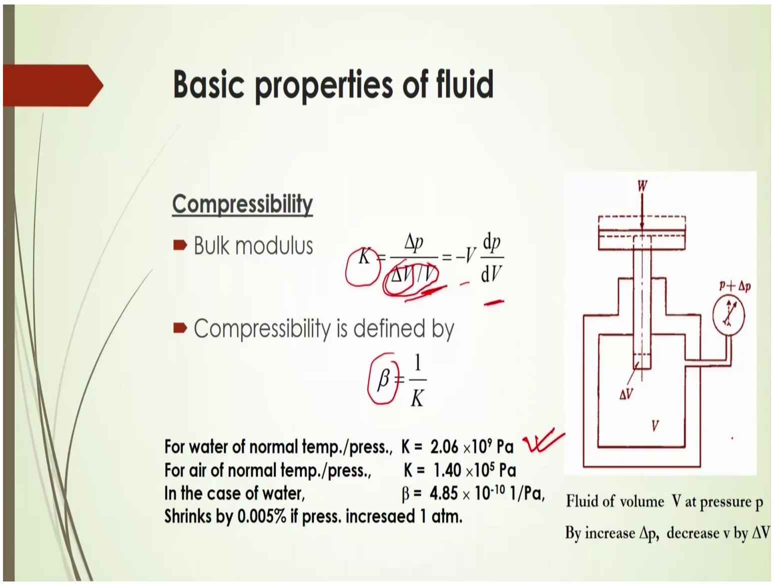

Another important properties is called compressibility we know that bulk modulus if we apply some pressure there will be change in volume inside a system and in that case by applied pressure how much volume is change with respect to initial volume that is delta p by, this is how volume is changed by applying this pressure from its initial volume. So, it will be represented by this ratio it is called bulk modulus and this is nothing, but minus p into dp by dV and this is represented by the symbol K and compressibility is defined by beta which is inverse of this bulk modulus.

For water of the normal temperature and pressure this bulk modulus is generally 2.06 into 10 to the power minus Pascal as 10 to the power sorry 9 Pascal it is given in the slides. And for air of normal temperature and pressure this bulk modulus is 1.40 into 10 to the power 5 Pascal and in the case of water this compressibility is 4.85 into 10 to the power minus 10 1 by Pascal these things by 0.005 percent if pressure is increased to the one atmosphere.

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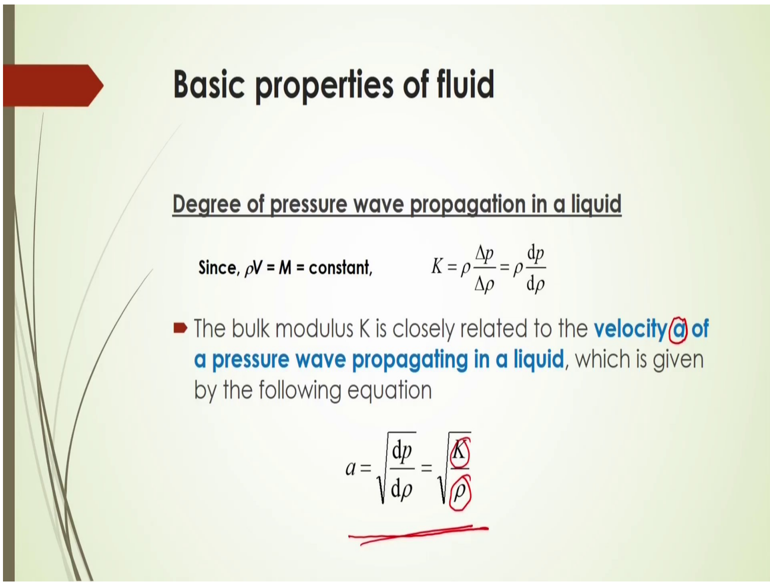

Another important thing is that how the pressure wave propagated in a liquid and how it can be measured. So, degree of pressure wave propagation in a liquid is very important if you consider that velocity of a pressure wave propagating in a liquid will be related to this what is that bulk modulus. So, since we know that rho V is equal to M is equal to constant; that means, density into rho density into volume is a mass of course, the total mass of the liquid is constant. So, in that case we can express this bulk modulus by this rho into delta p by delta rho here rho into dp by d rho. So, the bulk modulus K is closely related to the velocity of a velocity it is represented by a of a pressure wave that is propagating in a liquid.

So, that velocity of this pressure wave can be calculated by this bulk modulus since this bulk modulus in this case is represented by dp by d rho and it can be simplified to its by bulk modulus by rho here root over bulk modulus by rho. So, this is the equation by which if you suppose drop any solid particles over the surface of the liquid you will see there will be a wave formation over the surface of the liquid. So, that wave how it will be propagating what will be the velocity of the wave propagation that will be represented by that can be related to the bulk modulus of the liquid and it should be calculated by this equation.

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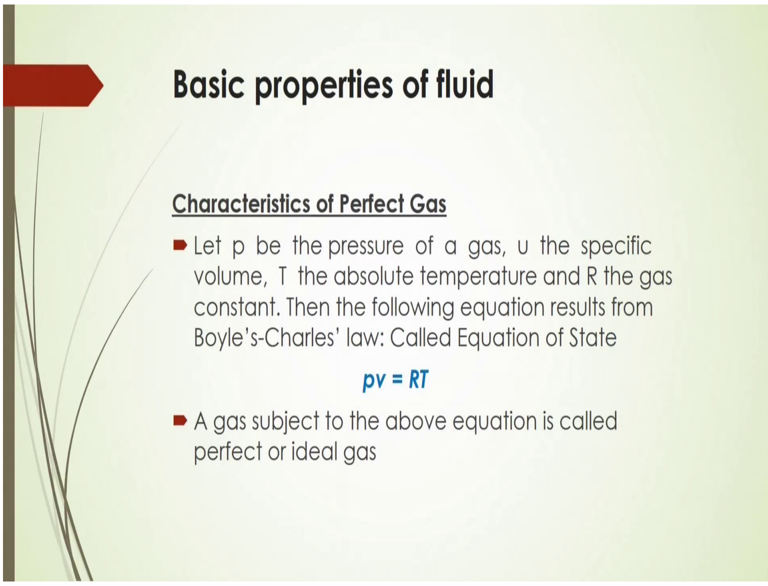

Another important characteristics of the fluid for the gas is that Boyles law Charles law for that how the equation of state of the gas should be represented a gas whenever subject to the equation pv is equal to RT it will be represented as a perfect or ideal gas. So, if we apply some p or pressure of a gas and there will be a specific volume v at temperature T then we can say that pv is equal to RT as per Boyles and Charles law.

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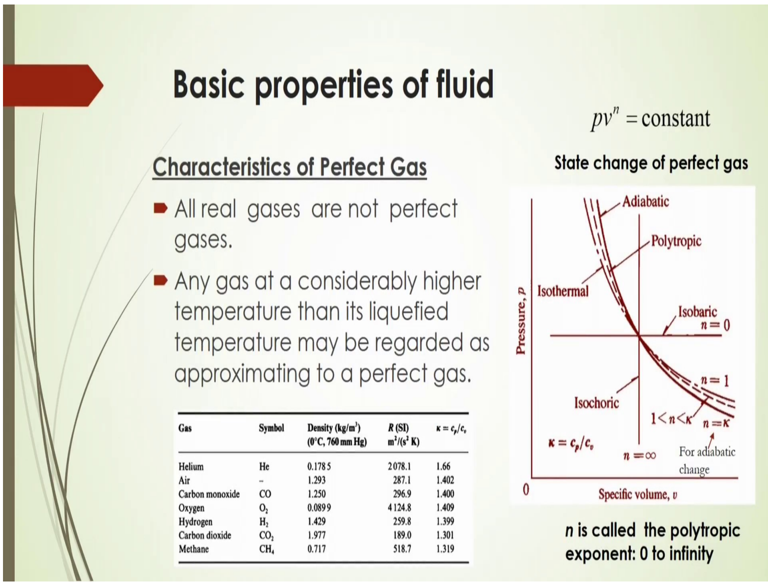

And characteristics of the perfect gas it is also shown here for the higher temperature in any gas if it is considerably higher temperature then its a liquefied temperature it may be regarded as a approximately to a perfect gas.

So, in that case; that means, equation of state to be considered as a pv to the power n is going to constant. So, here there are different actually categories for this that is the behavior of the fluid to the adiabatic, polytrophic, isothermal, isobaric, even isochoric as far this pv to the power n is equal to constant. And if it is perfect then n should be is equal to 1. So, if n is equal to 0, then it will be represented as an isobaric gas and also polytropic gas it is there if I think if n if it is the greater than one and if it is less than K then we can represent it as what is that polytropic gas.

Even for isothermal n will be is equal to what till one and also for adiabatic change n should be is equal to K what is K, K is nothing but the ratio of specific heat capacity of the gaseous to the specific I think at capacity at the constant volume. So, Cp by Cv this K so, if n is equal to K it will be represented as adiabatic change of the gas is there. And also n is called the polytrophic exponent which will be 0 to infinity and some polytropic constant and also what is that some k value the Cp by Cv it is given here in the table and for helium air carbon monoxide, oxygen, hydrogen, carbon dioxide, methane.

This ratio of the specific heat capacity at constant pressure and volume it is like for helium it will be 1.66 and for air it will be 1.402 and for hydrogen gas I think it is 1.399 whereas, methane gas it will be 1.319.

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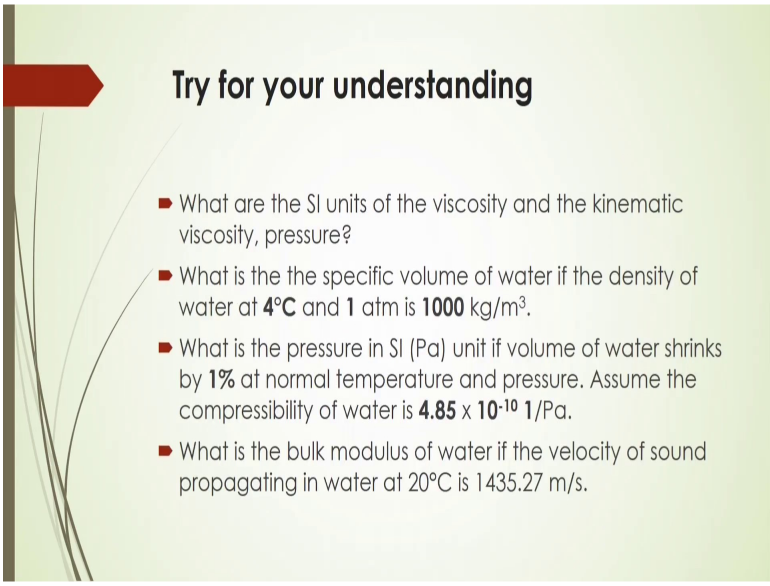

And so, I am suggesting to practice some problems so, based on these small equations whatever given for the physical properties of the fluid to represent. So, in that case some questions are given for practicing you have to find out the SI units of viscosity and the kinematic viscosity and pressure you please try it and what is the specific volume of water is the density of the water at 4 degree centigrade and 1 atmosphere is 1000 kg per meter cube.

And also what should be the pressure in SI unit, if the volume of water shrinks by 1 percent at normal temperature and pressure in also you please calculate the bulk modulus of water if the velocity of sound propagation in water at 20 degree centigrade is 1435.27. It is very simple that you can use the previous equation here bulk model here a is equal to root over dp by d rho that will be is equal to K by rho if you know that K if you rather know the rho it is easily will give you it will you it will give you the what is the bulk modulus of the or what is that the propagating velocity. And also if you know the propagating velocity you can calculate what will the bulk modulus there and also.

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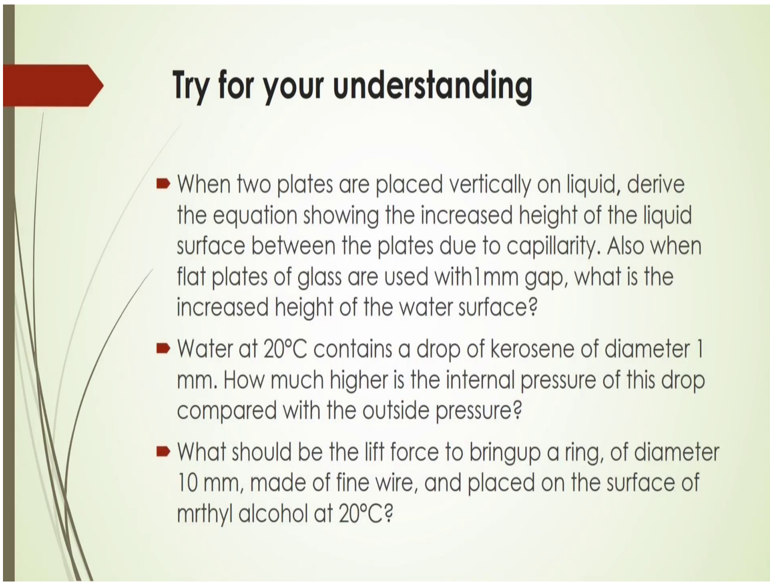

For the viscosity measurement what is the capillary effect and also what will be the drop for contains suppose water at 20 degree centigrade contains a drop of kerosene of water 1 millimeter. how much higher is the internal pressure of this drop compared to the outside pressure; that means, you have to calculate the delta p, we know that delta p will be is equal to a force sigma by d if you know the diameter that is 1 millimeter you have to convert it to meter and then sigma surface tension you have to know the surface tension of the kerosene and then what is that by diameter it is known to you. So, what should be the internal pressure there. And what should be the lift force to bring up a ring of diameter 10 millimeter made of fine where and placed on the surface of the methyl alcohol at 20 degrees and again here it is the same surface tension you have measure. You have to know that what is that how much course is applied toward the surface and what is the surface area and what is the length or perimeter of this that if you know all those parameter you can easily calculate what should be the lift force there.

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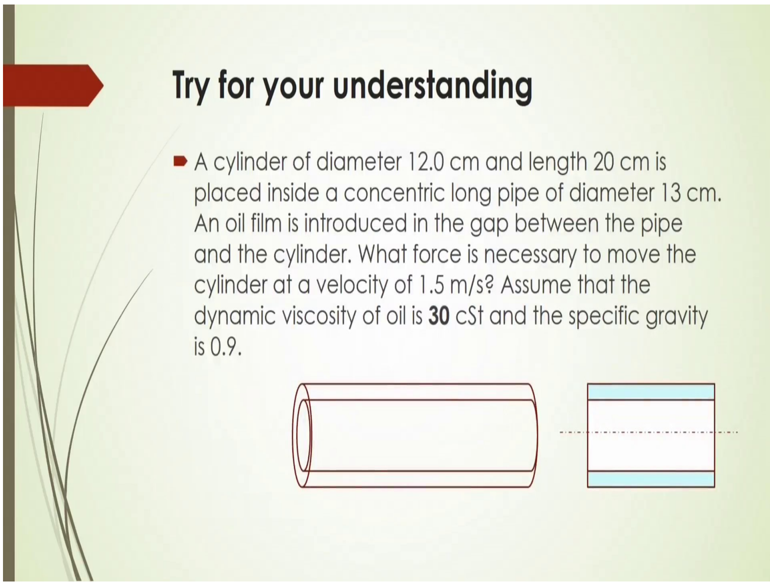

And also like here what should be the necessary force to move here the cylinder at a velocity of 1.5 meter per second, if the cylinder of diameter at 12.0 centimeter and length 20 centimeter is placed inside a concentric long pipe of diameter here. So, an oil field is introduced in the gap between the pipe and the cylinder then what should be the force to move the cylinder at a velocity of 1.5 meter per second to be calculated.

So, for that what will be the I think shear stress that you have to calculate there. So, for more reading you can read more other textbook also introduction to fluid mechanics and that is a fox McDonald and other books here.

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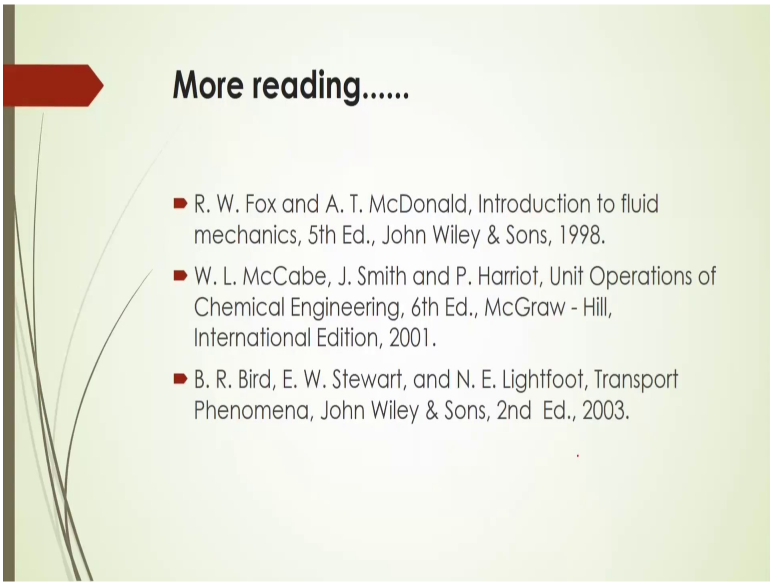

So, thank you for hearing this lecture next class onward we will be describing about the fluid statics and how it will be behaving whenever there will be some pressure is exerted on the fluid. And if it is a fluid if the fluid is moving and if the fluid is in static condition what will the pressure all those things will be discussed in the next lecture.

Thank you.