Fluid Mechanics
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Lecture - 02
Properties of Fluid

Welcome to the second lectures on fluid mechanics. As last class we discuss about the basic concept of fluid mechanics and introductions level.

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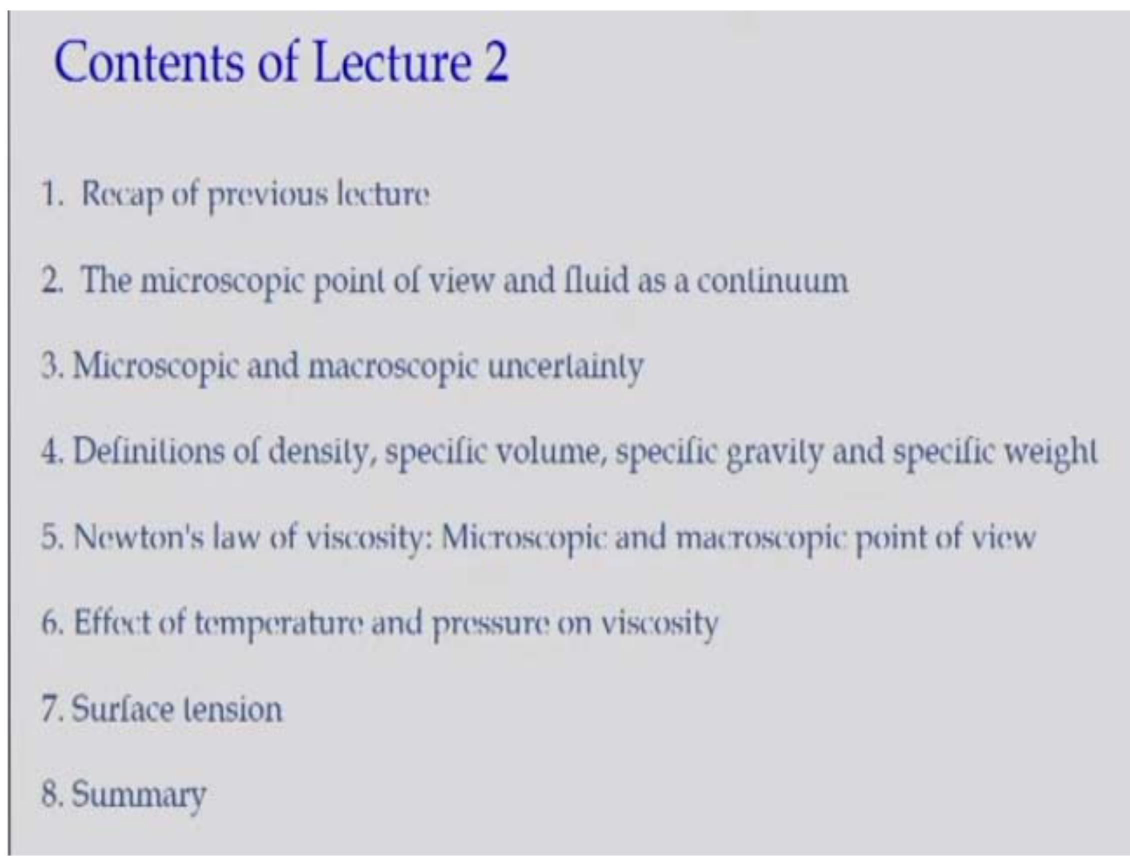

So today I will just have a recap of the previous lectures. Then we will go for the two concept what is prevails in fluid mechanics is microscopic and macroscopic. That the things we will discuss more details. Then we will go for the fluid properties like density, specific volume, specific gravity, and the specific weight. And very interesting well known Newton's laws of viscosity that what today we will derive at both the concept at microscopic level and the macroscopic point of view.

And then we will discuss about what is the effect of the temperature and pressures on the viscosities, then the surface tensions. So let us have a recap of the previous lecture, the first lectures what you studied, discussed.

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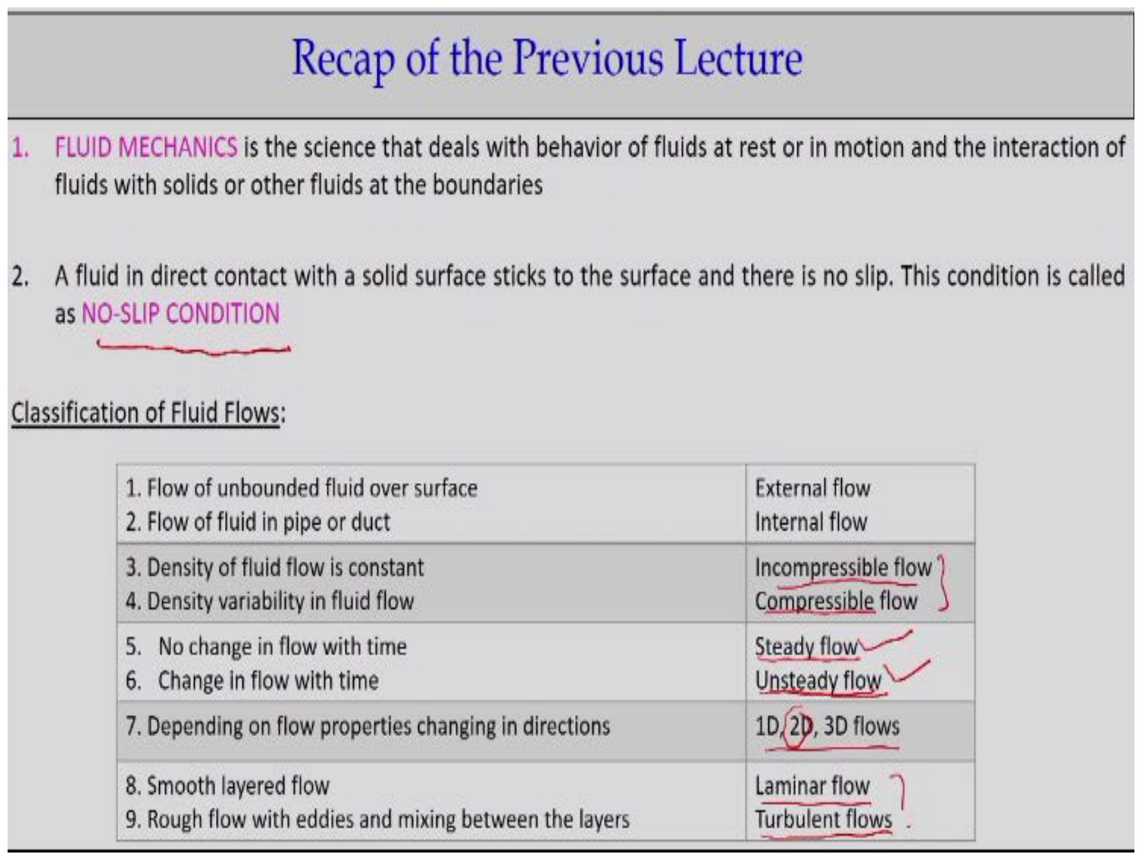

In fluid mechanics as you discussed is that we are talking about the behavior of the fluid either at the rest or in the motions and also the interaction of fluids with the solids or other fluids at the boundary. The more important concept what we have discussed is no-slip conditions. That means, when a fluid is moving fluid in a stick with a solid surface, the velocity of the moving fluid is equal to the velocity of the solid surface. That is what at that point the no-slip conditions exists.

So that is the very basic concept and that is what governs the fluid flow process what we will discuss many times about this no-slip conditions. As I in the last class I discussed so many problems of the fluid flows considering from engineering problems, flow through the pipes, the wind blow over the mountains, all what we can categorized or classified into different groups like external flow, internal flow, incompressible flow, comprehensible flow.

And when you talk about incompressible flow and compressible flow, the basic properties of the density that was a key factor decides as whether it is a fluid incompressible flow or the compressible flow. Similar way when the flow when you talk about the time component, if it is the time the flow properties do not vary with the time then we call the steady flow that means, we can consider some of the fluid flow problems where the flow properties do not vary with the time.

So that is the assumptions we can take it and solve the problems. So that is what the steady problem. Similar way we can have the unsteady flow where the flow properties like the density, velocity, the pressures they vary with time within the flow domains. If that is the case, then we have the unsteady flow. Then we have also discussed about one dimensional, two dimensional, and three dimensional flow.

That is what is talk about, when you talk about any flow conditions it is the three dimensional flow. But we can approximate it or into one dimensional flow behaviors based on the flow characteristics two dimensional flow behavior as we discussed in the last class and more instantly again I have to talk about that what in the last class we just I have given you a just a definition for the laminar flow and the turbulent flow.

The laminar flow in a pipes or in domain where it is well behaved field or the orderly behaved flow. The smooth layer type of the flow behavior happens it and when you come to the turbulent flow, where you have a lot of eddies formations will be there. There is a lot of flow ascends between the two layer of the fluids and the mixings will be there. That is what is the turbulent flow. And the more detail we will discuss it as we will proceed in the lectures on laminar flow and the turbulent flow.

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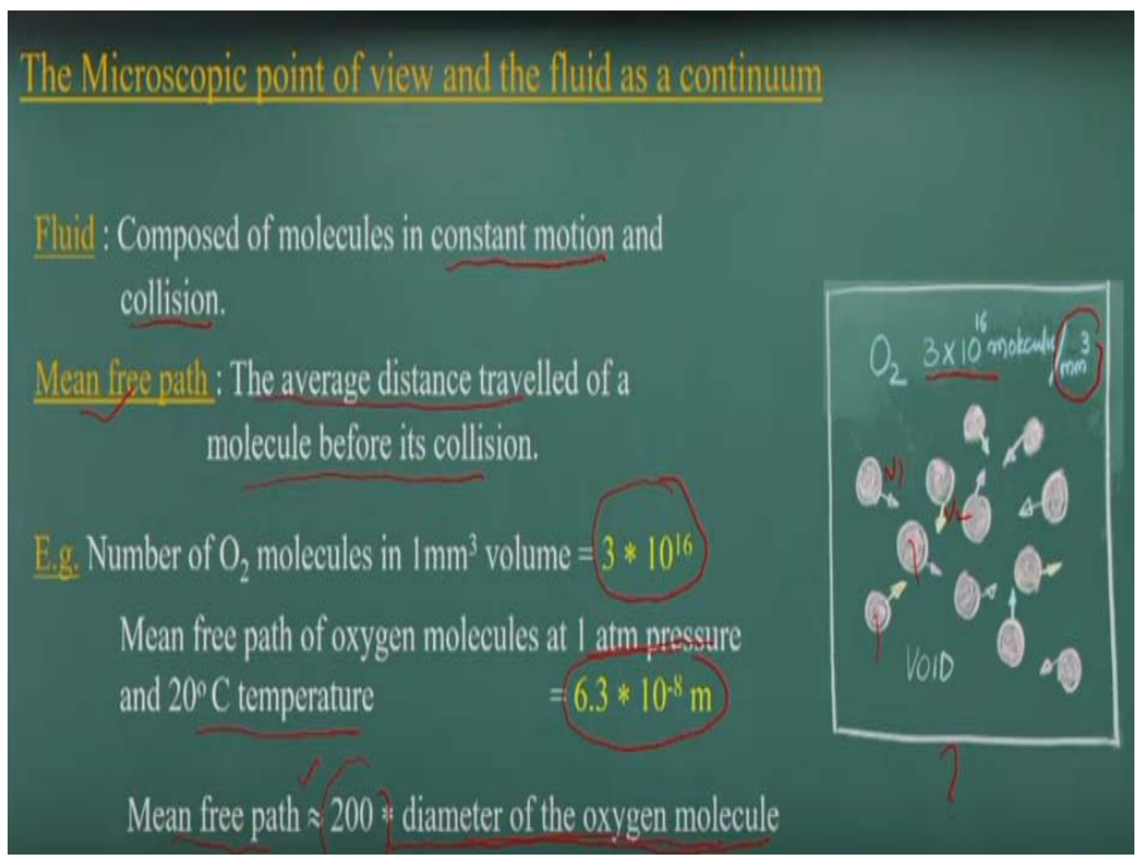

Now let us consider coming to the fluids, the definitions of the fluids and if you look it if fluid is composed of the molecules in constants, motions and collisions okay. Then you can just think it that the fluid flow what is happening it that is what the representations of million number of molecules are in motions, also they are colliding each other.

If it that is the conditions like for example, if you look at these figures, here I am very zoomed view of molecules what we are showing it where is having some sort of per oxygen 3×10^{16} number of molecules are present in a just a millimeter cube area volume. So that what is indicates how many molecules are there if you take a one millimeter cubic volume of oxygen.

That means so many molecules are there and these then molecules are having the random motions okay there will be velocity here and here. So they have the random motions each others and they are colliding each other okay. The manifest to what we get it the density variations or pressure variations or the velocity variations these are the molecules, the gross characteristics what we get it at the density or the pressure variations or the temperature variations.

Also they are relative properties, what we will discuss about viscosity and all. So if we look at that, if these are the molecules are there in a one millimeter cubic millimeters, this many molecules are there. They are having the random motions, they are colliding each other, very basic things which call that what is the average distance traveled by a molecule before collisions.

That is what is called the mean free path. Mean free path what is there, what is the distance traveled, on average distance traveled by these molecules before its collisions with another molecule. That is the mean free path. This is what gives us a very interesting phenomena to us. Like for example, if I look at the number of oxygen molecules in one millimeter cube is 3×10^{16}.

But the mean free path of this oxygen's molecules at one atmospheric pressures at the 20 º temperatures is equal to 6.3×10^{-8} meters. So if you look at that, this mean free path is about to 200 times of the diameter of oxygen molecule. That means there are lot of void space are there and the molecules are having random motions and colliding each others.

And the distance between average distance traveled by the molecules here, the oxygen molecules is a 200 times of the diameter of the oxygen molecules. So lot of void space are there. So you can imagine it that there are fluid molecules are there and they are having random motions. And there are the average distance they travel it.

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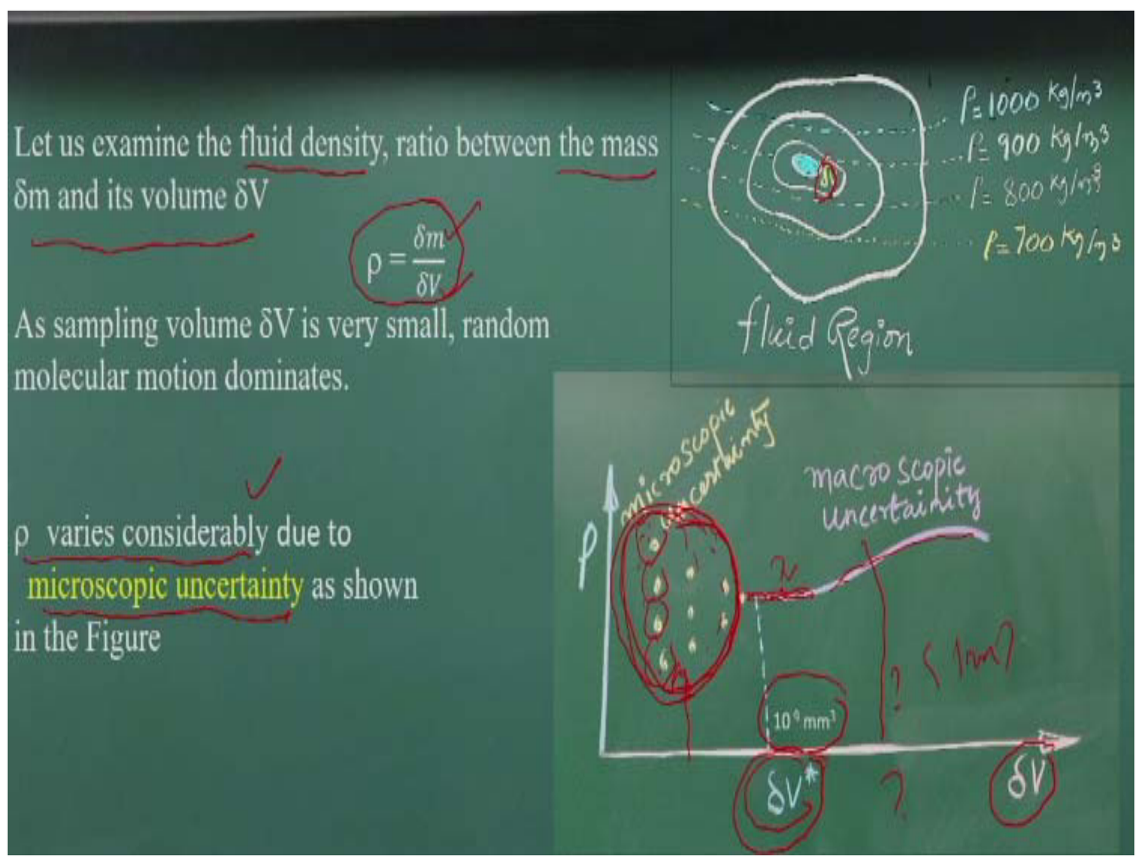

So these properties what is happening it at the molecules levels that is what is reflect us very interesting concept what let us consider very basic fluid properties is the fluid density, okay? That means that is what is the mass per unit volumes. That means, if I consider a very tiny δV and that δV is the sample volume for me. And if I consider that sample volumes, I will have the density the δm by δV, okay, mass per unit volume.

$$\rho = \frac{\delta m}{\delta V}$$

That is the density what will be there. Now if I look it as I am going to increase the delta v which is a sampling volumes, which is very less to go for the higher order as this figure is showing it that this side I have the density. Here I have the sampling volume. Okay let us consider it that the sampling volume δV, I have considered it to represent the density.

If I have a δV is very small okay and which is less than 10^{-9} cubic millimeters you can see these values are will be changed like this. That means, when you have a very small the sample volumes so the mean path, mean free path deviation, the molecular motion of the random motions that is what is changing the density value.

That means indirectly it indicates that the number of the molecules within that small sampling volume that what it changes drastically as instant to instant. As the number of molecules are coming in and number of molecules are going out that what is a give a random motion what is exhibited within the fluids, that what is give a lot of variations of the density value as the number of molecules coming in and going out, they are not balancing each other.

That is the reasons you have the uncertainty, the density will vary drastically. These are not a time dependent component but that is it will be vary as we will have the sampling measurement, it is lesser than a threshold value. Similar way, that is what is called the microscopic uncertainty as the density vary considerably as our sampling volume is lesser than this.

But there is a limiting conditions like the δV^*, it is a limiting conditions. At that limiting conditions if you look at these reasons the density fairly constant. That means what I am telling it that the sampling volumes as we increase it at a particular limiting value, we can see that the density is remains constant that what indicates is that the, with that the sampling volumes, the number of the molecules coming it as a random motion into that and going out more or less balanced each others.

So we will have a, the density the constants. So, we have to do a measurements or we have to do the analysis beyond this point, then the density remains fairly constant for regions, with respect to the sampling volumes. I am talking about with respect to sampling volume. But if I increase the sampling volumes, is much larger, okay. It could be one meters or the two meters like this.

So I can consider big sampling volumes. So in that case also we will not have the density constants. The density will vary it.

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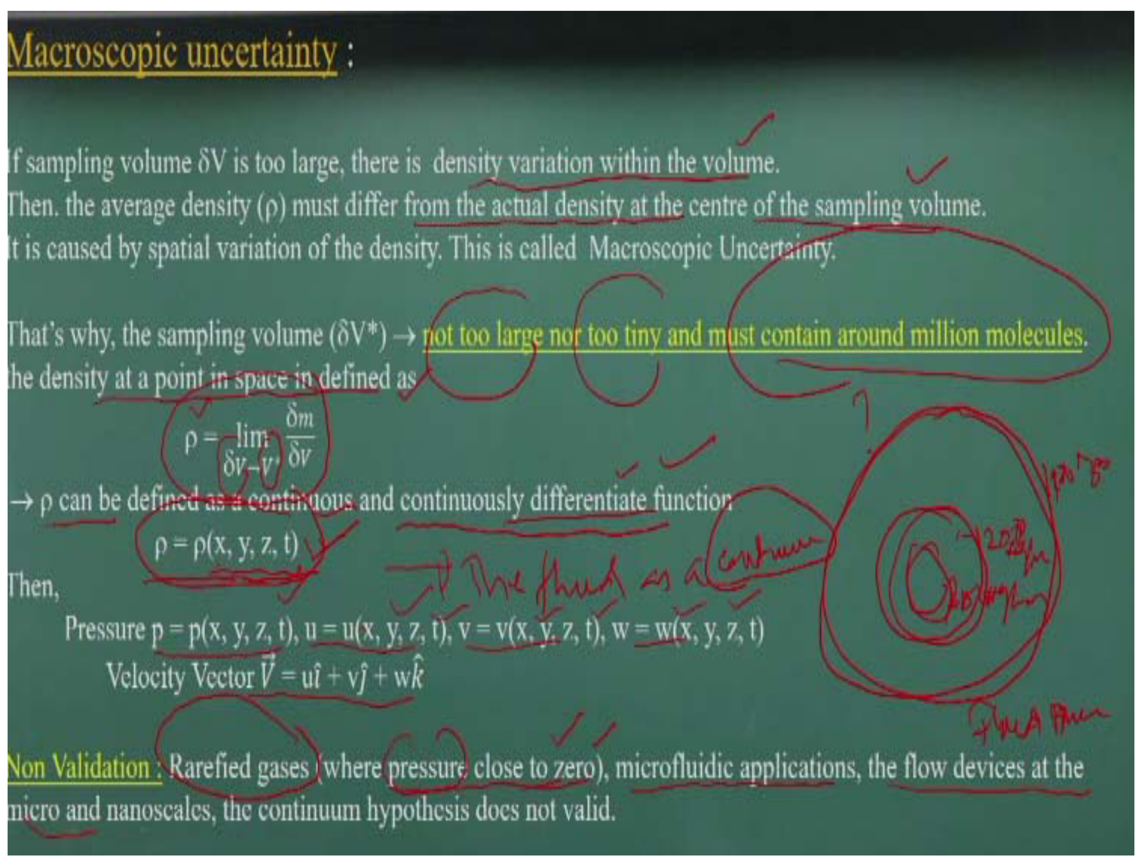

That means, we call the macroscopic uncertainty. That sampling volume is too large that like if you consider this is the room is a sampling volume for me see in that case what will happen it that the density variations within this room that what will play the rules that will not be a constant value. So the density will vary within this the sampling volume.

Because of that, if I consider the average density for this sampling volume will be different than the actual density at the center of the sampling volume. So that is the reasons we will have the variability this partial variability the locations variability is too high these sampling volume will not represent the density value what should be the required for the analysis.

So if you look at the two type of uncertainty happens it with respect to the sampling volumes. One if it is very lesser than the limiting conditions where 10^{-9} mm^3you will have a microscopic uncertainty. And if you go for a very large sampling volume, you will have a macroscopic uncertainty; microscopic and macroscopic uncertainty. So that is the reasons what we do it.

We work on the regions where the density does not vary with the sampling volumes. So that means our sampling volume such a way that the fluid characteristics does not vary as the random motions of the molecules are not playing the major roles to varying that properties. So that is the indicator here in the sampling volume, which is 10^{-9} mm^3.

More often in engineering applications like any measurements, we do it much larger than that. So any correct analysis what we do it for engineering applications that the sample volumes represent much larger than this part. So we can consider that the sampling volumes what you have neither to be a too large nor too tiny.

It must contain the million number of the molecules so that the random behavior of the molecular motions that the collisions that what will not reflect in our characteristics or properties of the fluids. So that is in a mathematical I can define it that we are looking the density, where the limit is tending the sampling volume tending towards the limiting velocities, volumes of these things.

So that is the density, the properties. So that means this what we consider there is a density variation, but that density variations our sampling volume is so large near to the limiting conditions, which does not have a effect of microscopic or macroscopic uncertainty. In that regions we can consider the density. Any fluid domain part I consider it okay.

Any fluid domains I consider it so if density is varying let be this is 1000 kg/m^3 this may be 1200 kg/m^3, this will be 1400 kg/m^3. This lines are representing 1400 kg/m^3, 1200 kg/m^3 and this. So on these fluid volume or fluid domain the we can consider the density is a functions of space dimensions that is x, y, z and also the time i.e.

$$\rho = \rho(x, y, z, t)$$

When you consider as a continuous and continuously differentiate functions that means it is now very easy we can use the integral concept differential concept as it is a functional behavior with a space and the time. We remember that if you have a microscopic or macroscopic uncertainty you cannot define it is a continuous function.

So now we call it as the fluid as a continuum, because we can use a continuous functions of the density of fluid properties, differentiated functions to define that flow process. So we define as a fluid as continuity. So similar way as the densities having a continuous function we can define is the pressure is also a continuous functions of the space and the time,

$Pressure\ p = p(x, y, z, t)$

The velocity, scalar velocity component like vectors u, v, w can have a space and the time the space and the time and space and the time component. So all these component the fluid flow characteristics we can define in a space functions, also the time functions x, y, z and the t provided consider as the fluid as continuum.

That means we do the analysis of the sampling volume such a way that the randomness behavior of the fluid molecules and they are collisions are not give any uncertainty at microscopic scale and the macroscopic scale. But the some of the case we cannot apply this fluid as a continuum hypothesis. For example, if you go to have very high altitudes in the space, you will see that places will come to very close to the zero.

So that is what the rarefied gas conditions where the pressure is very close to zero. There we cannot apply these because, the mean free path motions of that type of gas is much higher order as compared to the normal gas and the liquid what we consider in common engineering problems. So that is the reasons we cannot use this continuum concept of rarefied gases where the pressure is close to the zero.

Exactly same way there are micro fluid applications that the fluid devices at micro and nanoscales we cannot apply the continuum hypothesis. There are a lot of advanced research advances going on how to handle the fluid flow, which does not follow the continuum hypothesis okay. Let us go for the fluid properties, one of the basic properties as you know it mass, okay or the weight of the fluids.

As you can know it in different fluids have a different mass. Like the mass of the air, mass of the waters, mass of mercury that part will be different. So different fluids what we use it they have the different mass and any fluid flow problems analysis the mass is the primary component which we use it to analyze the fluid flow problems.

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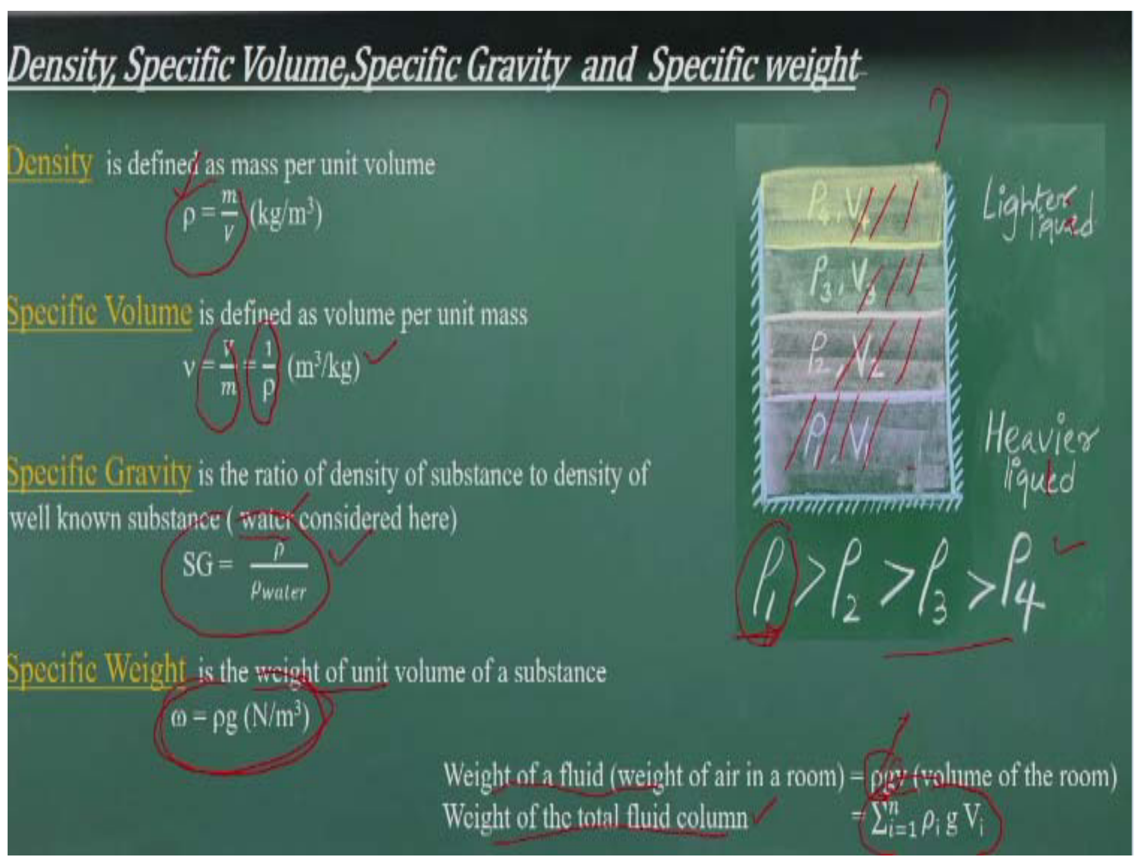

That is the reason as I told earlier that if I consider a small volume of the fluid the mass of the fluid if I measure it okay, as the volume of the sample in volume is larger than the limiting volumes for the continuum hypothesis. So if I consider that part and get a mass of that fluid and do a mass per unit volume. That means we are that is what is the density:

$$\rho = \frac{m}{V} \text{ (kg/m}^3\text{)}$$

So, mass per unit volume, if the volume is one unit, any cube of millimeter or cube of meters, that whatever the mass that is what will give us the density. So that is what we can get it in terms of kg. That means, if I take a $1m^3$ of water, whatever the mass of the $1000\ kg$ that what will be the density for me that means $1000\ kg/m^3$.

So the very basic thing is mass per unit volume, that is the density. I am just reemphasizing that any fluid flow problems you do it the first foremost requirement is to calculate what is the mass of the fluid. So if I know the volume of the fluid and the density, I can compute the mass. The very simple way, like if I know the volume we can convert it that and there are the tabulated values are available to that.

But there are the problems what like any gas flow and all where we do not talk about with respect to the mass per unit volume. Here we talk about mass is the fixed quantity. That means, we are looking it the volume per unit mass. That means one kg of hydrogen, what is that volumes it is coming it as volume is a variable in a much higher variable as compared to mass in a gas. So we use the specific volume. Specific Volume is defined as volume per unit mass

$$v = \frac{V}{m} = \frac{1}{\rho} \text{ (m}^3\text{/kg)}$$

That means, the volume per unit mass, okay. This is what the density, $\rho = \frac{m}{V}$ (kg/m^3)

Definitely it is a reciprocal to, the specific volume is reciprocal to the density. So you will have the unit is the m^3/kg. But many of the times either you know the mass or the density or you know the specific volume, you can solve the problems.

But to make it a very simple way to represent it which is one is heavier and the lighter, okay, so in that case we have to consider a reference liquid or reference gas. As we will I will focus more on liquid, we consider the reference liquid here is the water, okay? That means we are looking it the ratio of density of a liquid to the density of a reference of liquid which here is water that what is give us the specific gravity or relative density. Specific Gravity is the ratio of density of substance to density of well-known substance (water considered here)

$$SG = \frac{\rho}{\rho_{water}}$$

So this specific gravity gives us, it is heavier or lighter than the with respect to the water. So like a specific gravity of the mercury is 13.6 what does means that it is a 13.6 times heavier than the water. That is what indicate for us. So any of the textbook you can have you can see the table of specific gravity values or the densities or the specific volumes value.

Most often as I say that either you talk about the mass or you talk about the weight, that means force due to the mass. What is the gravity force is acting for that? We do the analysis for that. That is what is we consider the weight per unit volume of a substance is the unit weight. That means, this is very easily any fluid flow problems what is the weight of the fluid is there that what we can compute it just multiplying the volume of the fluids.

So specific weight and in relationship wise it will be the mass into the accelerations due to gravity. Specific weight is the weight of unit volume of a substance

$$\omega = \rho g \ (N/m^3)$$

That is what the specific weight of this thing. Now if you look at these examples, which are very simple examples what we have given here that there are the layers of the fluids are there and which is having a density $\rho_1, \rho_2, \rho_3, \rho_4$; V_1, V_2, V_3, V_4 are the volumes.

As you know it you will have a heavier liquid and lighter liquids you will have here okay. So you have a heavier liquid and lighter liquid as basic concept is that. So that means the density of ρ_1 will be larger than the ρ_4 as this is indicating that. So how much of mass of the fluids are there? If I take a like for example I take it what is the mass of air of this room?

I can get what is the density of the air here and the volume of this room, multiply that I will get the mass. And if I looking the weight of the fluid that what will be the $m \times g$, that what will give us the weight. Very simple concept, the density multiplications of the volume that what will give you a mass. Mass into the acceleration will give you the the gravity force or weight acting on that fluid mass.

Similar way as I said it if I have a layer of the fluids are there okay in generally it happens it is a layer of the fluids are there. They are having the density variations. We can just compute it what will be the weight. It is sum of the weight for each zone. We can compute for zone 1, zone 2, zone 3 and zone 4 and sum of that what is the total weight of the total fluid columns.

So this is what a very simple example what I have given it. I am not highlighting what is the density of different fluids which you can refer to any fluid mechanics book.

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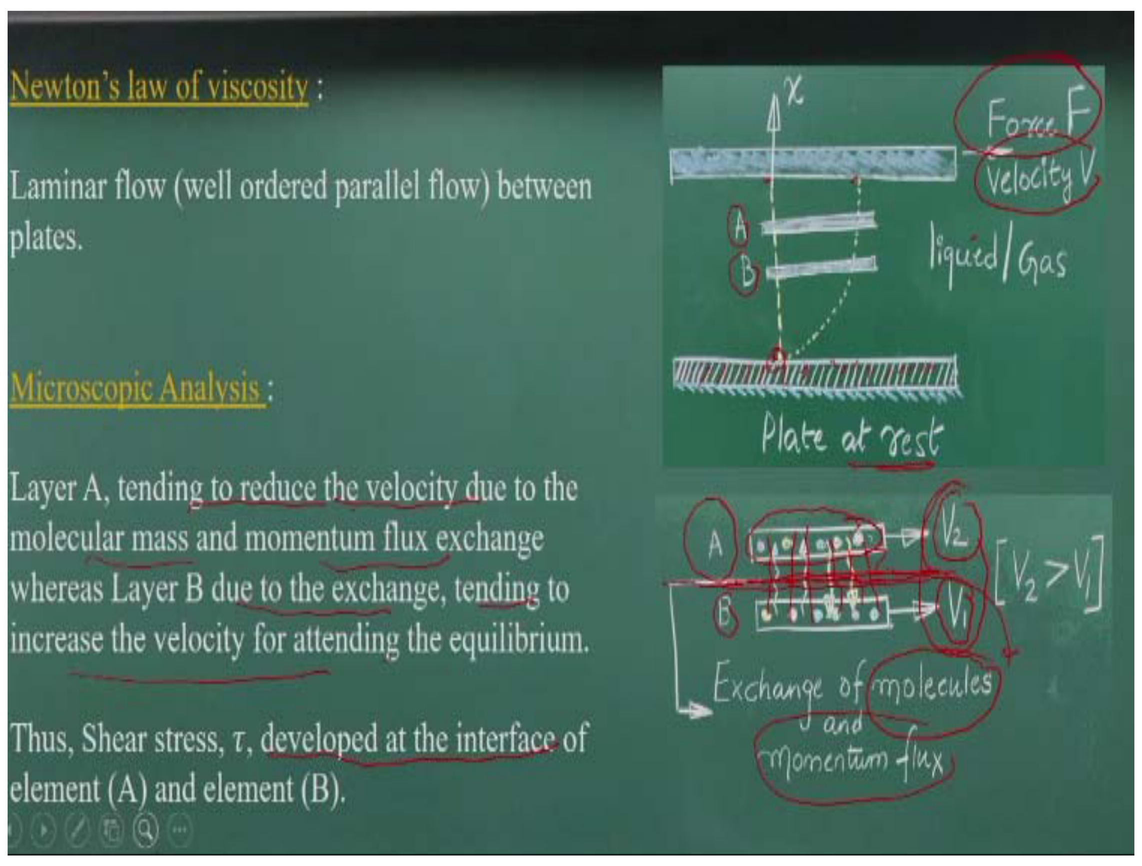

Now let us go to the very interesting concept, the Newton's laws of viscosities, okay, which is very simplified, simple common laws of viscosity which we use for solving many of the problems in laminar and also approximate for other flow conditions. Let us talk about this Newton's laws of viscosity. I am presenting you in two ways. One is microscopic analysis and the macroscopic analysis.

If you look it that you have the plate, okay. If you can look it which is at the rest conditions and you have in the top another plate is there, where you are applying a force F and the velocity V is it is moving this plate. As we know it that whenever we have the fluid flow conditions, we will have the no-slip conditions. That means, at these locations I will have the velocity zero.

At these locations the contact of the fluid particles on the solid surface will give a velocity equal to the velocity of the plate. So I have the velocity V, I have velocity zero at these points. So no-slip conditions prevail for these two points as we are dragging this one. Now if you look it if I consider A and B, two locations, okay. And in these two locations I consider a small representing volume of the fluids which is moving with let be a V_2 velocity and the V_1 velocity.

Try to understand it that I have the two fluids pockets. One is moving with V_1. Within that there are million number of molecules are there. The similar way the V_1 the next layer of the packet what the fluid is moving with a million number molecules is moving with V_1. So if you look it the nature wise we need two packets are moving it. One is higher velocity another is lower velocity.

At this interface, what we can say that it is a virtual interface. There is no real interface is there. We make it the flow representations as a two packets okay. Packets A and the packet B, they are containing million number of the molecules which are in a random motions and colliding each others. So if that is the conditions the definitely the basic concept what it comes it this fluid molecules what is there they are crossing each others going up okay from layer B to the A.

As they are the molecules are coming from the B going to A they are transporting the mass. Also they are transporting as a momentum flux to the next level. Because of that the packet B will try to reduce the velocity of V_1, packet A. Okay, just like that in nature what will happen if somebody running fast and other is slow. So slower one will try to make it other to reduce the speed okay.

Exactly same way happens here that molecules at the B pockets which are moving slower they are will try to reduce the velocity of the flow of the A. Where as the A what will do it that the same way the molecules in the A packet that what will be again exchange to the B. They will try to increase the velocity of these packets on average the velocity of this packet to this.

So in this the artificial boundary layers they are as we have not we cannot see it, we can visualize these problems okay. We cannot see these things how the molecules are, motions are happening it, as the random motions are happening it or colliding each other. That what we cannot see it, but in conceptually there are the mass flux are going up and the momentum flux is exchanging between that and the momentum flux mass exchange what it happens between these two layer of the fluid packets that what will cause a force on these layers, this interface layer.

And that force will act like a shear force, a resisting force between this two layers. That what will be act like a resisting force between these two packets of that. And that what it happens it the layer A tending to reduce the velocity, okay, due to the molecular mass and the momentum flux exchange, where as layer B due to these exchange tending to increase the velocity so that at the larger time steps these process it goes on.

After certain time maybe these two velocity is coming to equilibrium. That means they will be the same order, same value. So looking these the mass exchange and the momentum exchange of the molecules at this the artificial interfaces between two packets of the fluid of packets, we can see that definitely there will be the force will be act on that interfaces as the momentum flux is crossing each other.

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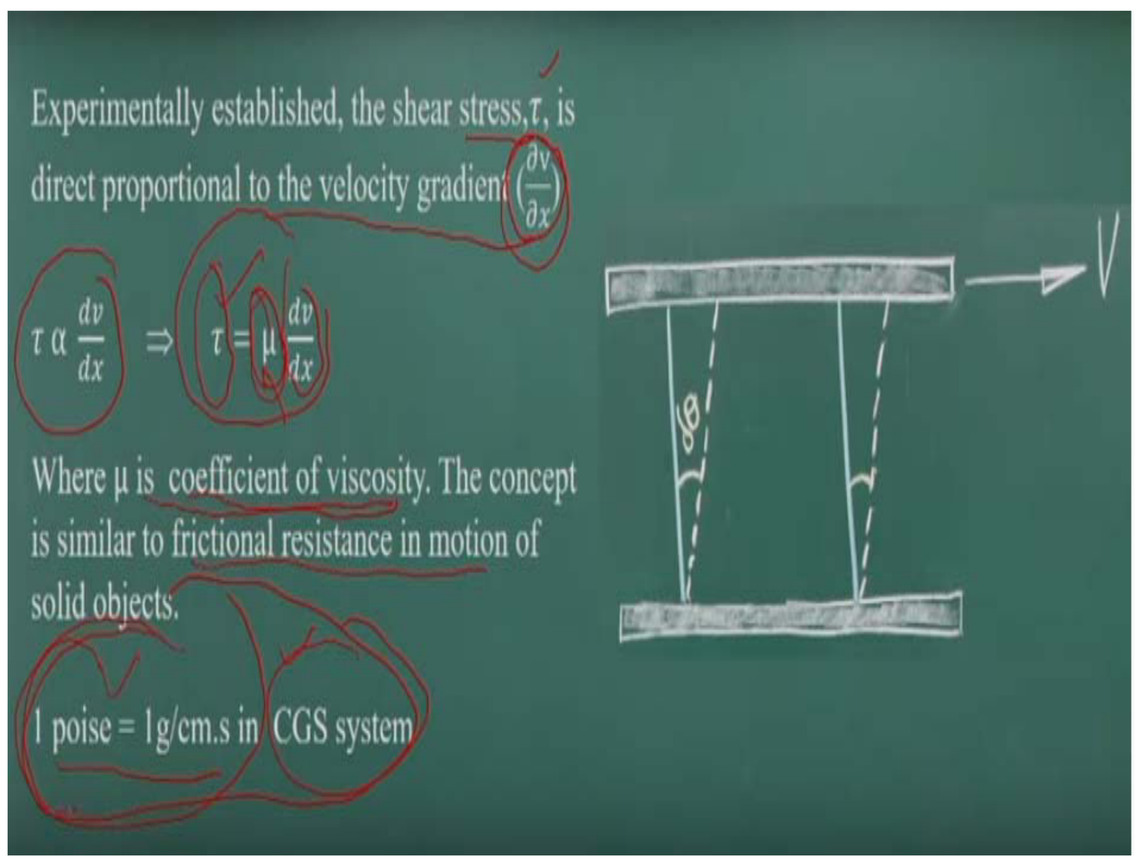

And shear stress will develop at this interfaces level and many of the studies the experimentally establish that this shear stress will have a directly proportional to the velocity gradient okay. If the more the they have the directly proportionality okay. That means more the velocity gradients is there so we will have the more shear stress. But it has a directly proportionality quantity.

And the proportionality is known as the coefficient of viscosity or dynamic of viscosity. That constant of proportionality constant is known as a coefficient of viscosity, μ. So that means, it varies from the fluid to fluid because their molecular motions, the exchange of molecules, the momentum flux, the random motions all it depends upon molecular structures of the fluid.

So when you apply a shear stress or a resulting a velocity gradient which will be will have the shear stress formations that what as a resistance of two layers, that what will be a constant proportionality which is a coefficient of viscosity which varies from fluid to fluid. As if you look it at the motion of the molecular point of view, considering as a mass exchange of the molecules and the momentum exchange that what will be there.

So the fluid to fluid will have a variability of the new value that is a coefficient viscosity, which as equivalent to that if a two solid objects are there as one is moving, and others you as you know that there will be a frictional resistance. So the hypothetical the same conditions are happening here that if I consider two fluid packets, and if they are moving with having a motions, the molecular motions between these two artificial layers will have the shear stress formations and that shear stress formations will have the proportionality to the velocity gradient.

And that proportionality constant is a coefficient of viscosity or some of the book is referred as the dynamic of viscosity. And what you can know it what will be the unit of these ones you can put the unit of shear stress, the velocity gradient, you can see that it will have the mass per length and time. So that means, for a CGS systems the gram centimeter second systems we for a 1g/cm.s that what we call the poise.

That means one poise is 1g/cm.s. That is what we consider it the poise is in a CGS systems unit of the coefficient of viscosity or dynamic of viscosity. Yes let us considers microscopic point of view.

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