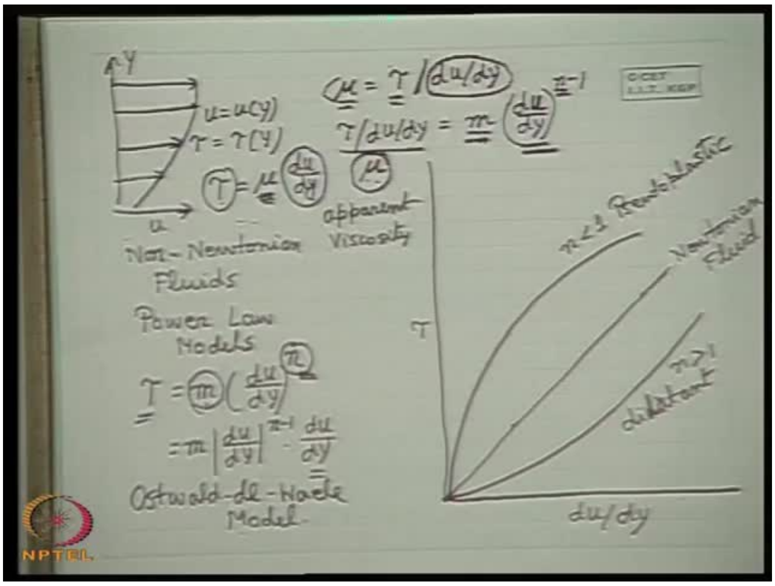
**Fluid Mechanics**
**Prof. S. K. Som**
**Department of Mechanical Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture - 2**
**Introduction and Fundamental Concepts – II**

Good morning, I welcome you all to this session of fluid mechanics. Well last class if we recall we discussed the constitutive equations of a fluid, which is basically a mathematical relationship between the shear stress and the rate of shear strain, which in a simple case we have shown it is a velocity gradient. Well in a simple case of parallel flow where the velocity component takes place in one direction, it is the velocity gradient. This class of fluids obeys a linear relationship between the shear stress and the velocity gradient known as Newtonian fluids.

(Refer Slide Time: 01:12)




If you see, recall it, we see that the shear stress look, if we consider a velocity field like this, if this be the velocity field, u is the velocity field in this direction, which is a function of y, where y is this direction y. Then we have seen that tau at any location y, which is also a function of y tau. We have seen that tau for a class of fluid is proportional to d u d y and this proportionality constant is, this is the velocity gradient. So, tau is the shear stress, this is the velocity gradient in this type of problem, which is basically the rate of shear strain, which I will explain afterwards when we will come to fluid kinematics.

So, this constant of proportionality is known as viscosity or the coefficient of viscosity. If we recall, we also discuss that if we show these in a tau versus d u d y plane then definitely this linear relationship is shown by a straight line like this. This is the fluids which obey this law is known as Newtonian fluid. Since, the law is known as Newton's law discovered first by Newton. Well, so constitutive equation is linear through origin, this is the Newtonian fluid. And the slope of this line determines the value of the viscosity coefficient. On the other hand, we recognize that there are a classes of fluids, which do not obey these linear relationship known as non-Newtonian fluids and this fluids in general behave differently from this.

And in fact no just single module, can be established for a class of non-Newtonian fluids. So, we discussed a very simple power law model for a class of fluid, power law model for a class of fluids which is very simple that this relationship between tau and d u d y bears a power law type relation. That means, m into d u d y to the power n or we expressed it in a little different way, m into d u d y to the power n minus 1 into d u to give the sign of tau with this d u d y. Here m and n are the constant parameters of this equations, this is know these are known as I told you in the last class, m as the flow consistency index n as the flow behavior index. So, this power law models are formed by the scientist his name Ostwald-De-Waele model, Waele model, Ostwald-De-Waele model. So, the fluids obey a power law model a class of fluids with the values of n greater than 1 and less than 1.

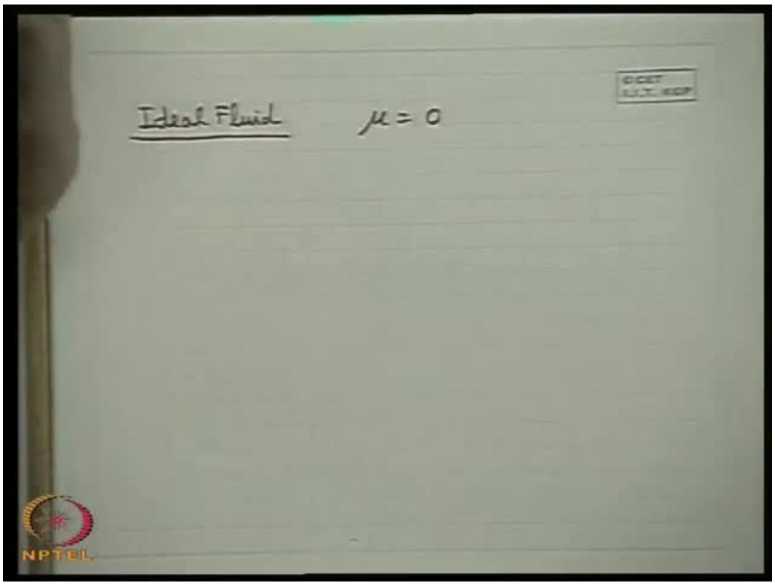
So, if we plot the power law curve with the in this index n greater less than one, the curve is like this and with the n greater than one, the curve is like this difference is that the slope decreases in this case tau for divided by d u d y with an increase in d u d y. In this case when n is greater than 1, the slope increases with the increase in d u d y slope means tau by d u d y that means, this slope decreases.

So, therefore you see these are the 2 curves. So, the liquids or the fluids which follow this n less than 1 is known as Pseudoplastic fluid, Pseudoplastic fluid. Whereas n greater than 1 is known as dilat sorry latant, dilatants, dilatants, but one interesting feature is that viscosity for any fluid is defined as tau divided by d u d y. That means, it is the ratio of shear stress divided by the velocity gradient, in this case of flow or we will see afterwards, the shear strain the rate of shear strain that is the definition of viscosity. So, if it does not bear a linear relationship then the ratio is not constant, which simply means for any fluids, whose constitutive equation is not linear this ratio is not constant.

For example here, if we see this ratio from this expression tau by d u d y will be simply equal to m d u d y simple school level mathematics n minus 1 tau by d u d y here which means we see that the definition of viscosity. If we write tau by d u d y as mu since the see mu precisely depends upon the velocity gradient that means, depends upon the flow situation. So, therefore it is no longer a constant and seizes to be a property of the fluid.

So, therefore for Newtonian fluids only mu if the property of the fluid, but for non-Newtonian fluids mu is not a property of the fluid. Since, it depends upon the flow situation not only these are the properties, this parameters flow behavior index and flow consistency index in them. So, therefore these mu is seizes to be a property of the fluid. In this case this mu is known as apparent viscosity, apparent viscosity, viscosity, apparent viscosity mu is known as apparent viscosity. Now, after this I will come to the definition of two very important things.

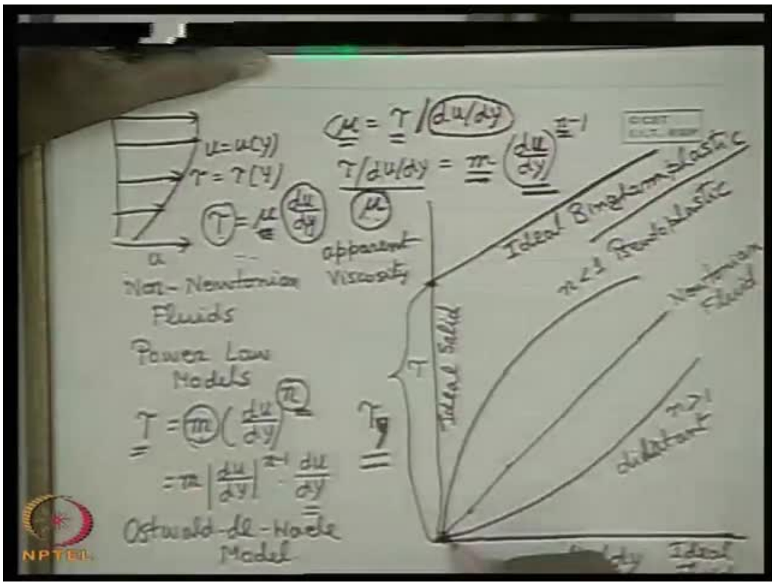
(Refer Slide Time: 06:56)




One is ideal fluid. What is meant by ideal fluids? Ideal fluid, the simple definition of ideal fluid is a fluid whose viscosity is 0. That means, we consider a fluid hypothetical fluid, whose viscosity is 0, but to be very frank all fluids in reality of a viscosity greater than 0, there is no fluid whose viscosity is 0, but we consider an ideal fluid. Define ideal fluid whose viscosity is 0, but this moment definitely the query comes why such an hypothetical fluid is defined and why there are certain laws and principles relating to ideal flow of fluids because in your course curriculum, I have shown that ideal flow of fluid there is a chapter like ideal flow of fluids.

So, at this junction you just know this that real fluids have viscosity, greater than zero. So, real fluids are known as viscous fluids. Now, under certain situations of flow at very high velocities for viscous fluids, the flow field away from the solid surface can be very accurately generated by the principle of ideal fluid. And the theories and principles of ideal fluid from the common sense, as it appears will be much simpler from that of real fluids, which have viscosity, because the parameter viscosity is not coming into picture. So, this is that is in for which theory of ideal fluid becomes so important. So, at the present moment we may not know all those thing, this is just for your interest we can simply know ideal fluid is a hypothetical fluid, whose viscosity is 0.

(Refer Slide Time: 08:31)




So, therefore if we see this curve the abscissa represent ideal fluid, why? If the viscosity is 0, this ideal fluid whatever may be its flow condition or whatever may be its velocity gradient or, rate of shear strain whatever you tell, there will be no shear stress developed in the flow field. That means, an ideal flow of fluid or flow of ideal fluid is divide of any shear stress in the flow of fluid, the shear stress will not be generated.

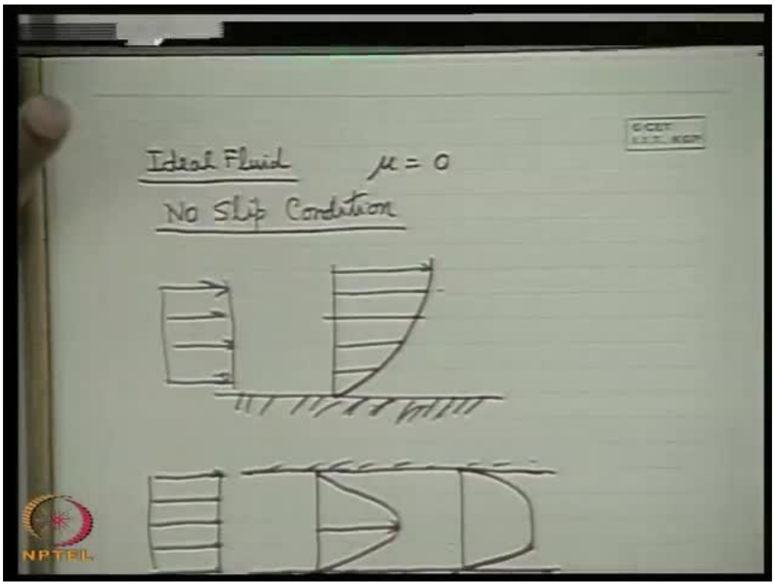
Similarly, if we see the ordinate will represents ideal solid, this is ideal solid obviously this you know from your earlier knowledge that ideal solid is a solid where if you increase the stress to a very high value there will be no deformation, this is an ideal solid concept. So, ideal therefore the ordinate represents the ideal solid and the abscissa represents ideal fluid.

Well another class of fluids, occur in nature they behave like this that a definite amount of stress is required to cause the motion. That means, the flow takes place after a definite stress is applied to those classes of fluids or substances, that represent moment I tell and this stress value is known as the yield stress tau e yield’s tau y rather, yield stress this is known as yield stress. After which the flows takes place and the relationship then between the stress and the velocity gradient may be of different nature, but a ideal relation will be a straight line and this substances are known as ideal Bingham plastic.

So, Bingham plastic, Bingham plastic is are those substances which requires certain yield stress to flow, you know our paste and this type of liquid they require, this type of substance. They require certain minimum stress for the flow to takes place and in case of ideal Bingham plastic. Ideal Bingham plastic the stress and velocity gradient or strained relationship becomes linear, but there is a little reservation for this class of substances to tell us fluid, this is because they do not start from the origin. You know that this physical significance of any curve either linear or non-linear start from the origin is that under a infinite small shear stress, the liquid starts flowing. That means or fluid starts flowing that means, fluid cannot resist even an infinite small shear stress under static condition.

That means, a very small shear stress if we apply a non-zero value any infinite small shear stress liquid starts flowing. That means, the shear strain is developed and the flow develops, which means, analytically that the stress and rate of strain relationship or curve passes through origin, so therefore the classes of substance which do not follow these. That means there is an yield stress, they violate the basic definition of the fluid. Therefore, for these reasons Bingham plastic is not considered as a fluid.

(Refer Slide Time: 11:46)




Well next I go to a very important one, another important information no slip condition this throughout the lifetime, throughout the lifetime for the people who work in the field of fluid mechanics, will require this no slip condition. What is meant by no slip condition? When fluid flows past a solid surface, when there is a contact between the fluid and the solid. You know in all practical applications the flow of fluid takes place in such a way, there is a contact of the fluid at the solid surface for example, flow pass cylinder, flow pass solid bodies, aircraft wings, flow through circulars cylinders, flow through any closed dart.

So, anywhere you see the flow interacted with a solid body, there is a contact between the fluid flow and the solid body. The velocity of the fluid at the solid surface relative to the solid is 0 which means that if solid body is at rest, if there is a plate at rest and the fluid flows over it, then the that actual or absolute velocity of the fluid at the solid surface is 0. That means, the fluid can never slip pass a solid surface.

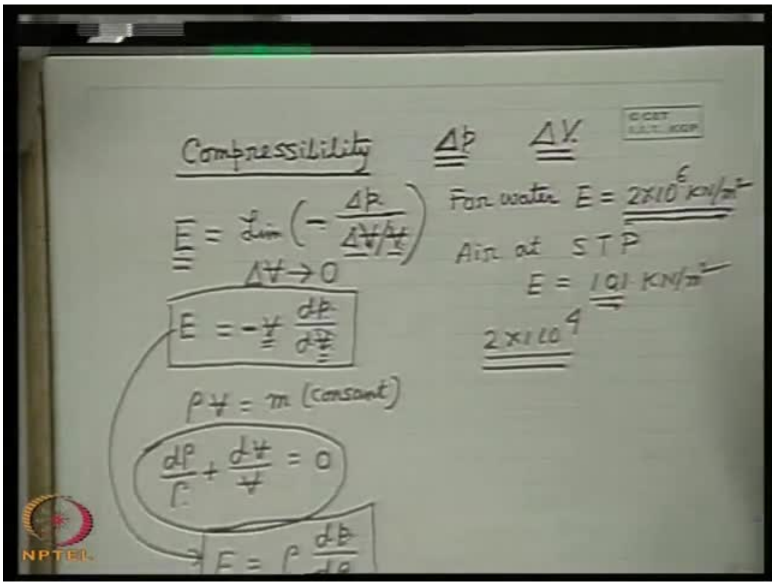
If solid surface moves with some velocity, the fluid will also move with the same velocity which means, the relative velocity of the fluid with respect to a solid surface is 0 at the solid surface this is precisely because of the friction and interaction between the solid and the liquid. We may not go in details of how it occurs, this is beyond the domain of an engineer studying fluid mechanics. This is a molecular phenomena by virtue of which solid never allows any liquid or fluid particle rather fluid particles to flow past it to have a velocity of slip over it. That means, fluid velocities will be arrested to 0 with respect to the solid at a surface, this is precisely what is known as no slip condition of a fluid flow.

Whereas, let us see that if there is a flow of fluid takes place approaches a fluid with a high velocity approaches a solid surface, then what happens at any section of a solid surface, you will see the velocity variation will be like that. That means, the velocity from its high value will be brought or dragged to a lower value, due to the viscous interaction between the liquid layers. And due to the strong frictional interaction between the solid and the fluid, the fluid velocity these velocity will be 0.

Similarly, in a pipe flow I just give you the picture which will be taught in detail afterwards. That in case of flow of a pipe flow of fluid through a pipe, if the flow approaches first with a very high velocity, uniform high velocity. Whenever it comes in contact with the solid at any section, the fluid velocity will be like this there will be a distribution a maximum velocity usually occurs at the centre. So, the velocity at the solid surface will be 0.

So, depending upon the flow of velocity, level of flow velocity, the variation will vary sometimes we get this type of d shaped variation, a little uniform at the centre, the little uniform at the centre. This is the case, when the flow is turbulent this is the turbulent flow condition, this will be taught afterwards, this is the turbulent flow condition, this is the laminar flow condition. So, whatever may be the velocity variation, difference in their trend for laminar flow or turbulent flow. This depends upon the flow velocity then the flow velocity is very high, the flow becomes turbulent. In both the situations, the flow velocity is 0 at the solid surface, this is precisely the no slip condition of fluid.

(Refer Slide Time: 15:35)




Now, I come to the well another property of the fluid compressibility, compressibility, compressibility. Compressibility of a fluid probably, you have come across this term at your school level, this is very simple again a recapitulation of your basic things. Compressibility of any substance is a measure of its change in volume or density with the application of external pressure. Simply how much it can change in its volume or density with the application of pressure.

So, this is precisely the definition of compressibility and it is quantitatively characterized by a parameter known as bulk modulus of elasticity. As we have already read earlier. So, how do you define then the bulk modulus of elasticity E, it is defined as limit a minus sign delta p by delta v, I used a cut with v to denote the volume to make a difference from the velocity. So, v with a cut represents the volume. When delta v tends to 0 or v tends to 0 does not matter.

That means, this is the limiting value of delta p delta v by v where, delta p is the change of pressure and delta v is the change in volume with an original volume v. That means, we can define that coefficient of elasticity is the ratio of the change in pressure, to the change in volume per unit volume. That means, if we take change in pressure delta p the volume change is delta v then the definition of elasticity it is a point variable that is why, it is defined in terms of limit delta v tends to 0. That means, if this is contractible or a substance contractible into a point.

So, this definition is valid so delta v tends to 0 a minus sign is deliberately given to assign a positive value of E that you know, that it is the law of nature for all substances. The delta p and delta v are in opposite sign that means an increase in pressure causes a reduction in volume and vice versa. Therefore, a minus sign is used. So, this is the basic definition of bulk modulus of elasticity. This we can write in differential form as v simply d p d v.

Well, so this is the definition of E sometimes, it is convenient to deal with density rather than volume. So, you know that we can change this in terms of the density. Well how to do for a given mass of a body rho into v is constant. That is the mass, which is constant that means for a given mass, a change in volume and the change in density are very well related in the opposite way. That means, if we make a differentiation you get that d rho by rho a logarithmic differentiation, which is very simple to you. I have done everything at the school level. So, 0 that means there is a minus sign I am sorry because this minus sign is there, which means, the minus d v by v is d rho by rho that means with the help of this equations. I can write this equation as E is equal to rho into d p by d rho that means, minus d v by v is replaced as d rho by rho. So, these 2 equations define the bulk modulus of elasticity.

Now, you see the substances for which the bulk modulus of elasticity is very high, it requires a very high pressure to change a definite amount of density or volume or other way. We can say for a given d p or delta p change in pressure, the change in volume or change in density will be very small, if value of E is very high. An example I give for water, the value of E which is almost constant with pressure and temperature is 2 into 10 to the power 6 kilo Newton per meter square.

So, unit you can see that the value of E unit is the pressure d p because v by d v cancels. So, here also you see rho d p d rho so the unit is that of the pressure so this is the value of E for water, whereas, for air at standard temperature and pressure at S T P, the value of E is equal to simply 101. That is the standard pressure itself the atmospheric pressure kilo Newton per meter square.

Now, you see this way that air is 2 into 10 to the power 4 times more compressible than water. Air is more compressible 2 into 10 to the power 4 times more compressible than water. So, such high value of E for water does not allow water to shrink in volume or to cause a change in density by an application of the pressure. A huge pressure difference is required to cause a very small change in volume or density. Whereas, in case of air it is just the reverse because a the value of E is very less for air. So, less the bulk modulus of elasticity, more is the compressibility of the substance, well it is clear.

Now, the question comes in engineering applications a very interesting question. Now, we define the substance fluids by the compressibility parameter. We apply the pressure and we find out what is the change of volume and density and we find it a value of bulk modulus of elasticity, we are qualitatively we see that it is very less with a very high pressure. So, it is less compressible, it is incompressible. Usually liquid exhibits very high value of E so liquids are incompressible we know it is a common sense since, our childhood and gases are compressible because gases suffers, a finite change in volume and density with an application of pressure.

Now, question comes if this way we define the compressible and incompressible fluids. Usually, liquids are incompressible fluids and gases are compressible fluids, but question comes whether, the flow of fluids will be incompressible or compressible according to this. That means, I like to say whether it is such that flow of all incompressible fluids that means, liquids will be incompressible flow or flow of compressible fluids. That means, flow of gases will be compressible flow.

Probably this two things should not go synonymous because you just think in this way, it may so happen that in case of a particular flow. Just consider a hypothetical case, the pressure difference is so large in some situation of flow, the pressure difference because pressure difference is an arbitrary quantity, which is in our hand is so large that even for the flow of liquids. The density changes are sufficient so that we cannot consider, this as an incompressible flow.

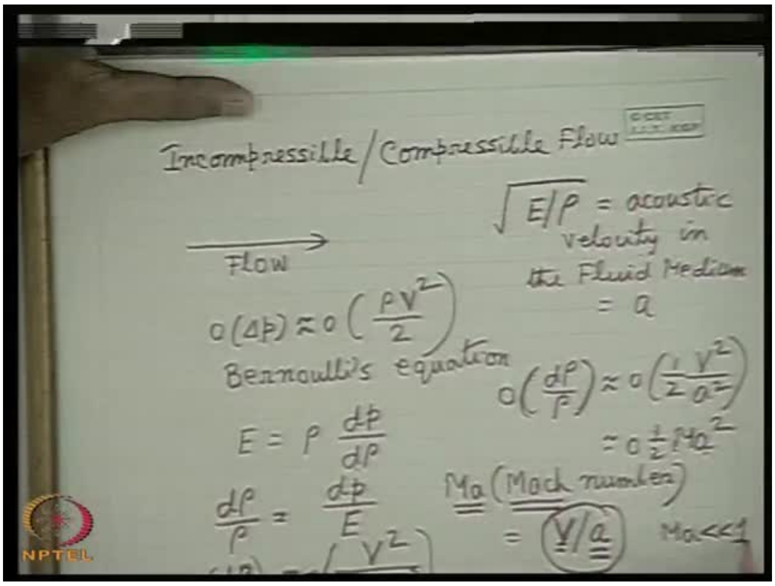
So, a incompressible or compressible flow will be determined whether, the change of density brought about by the pressure difference caused by the flow is sufficient or not. On the other hand, if the flow of compressible fluids takes place in such a way that the pressure difference due to flow is very small. That means, flow takes place with the very small velocity. So, pressure difference is so small that even if the fluid itself inherently compressible. That means, its bulk modulus of elasticity is less, but with that small difference in pressure even with that less value of E. The change in density or volume is very less so that we can considered the flow as incompressible.

So, therefore whether a flow will be incompressible or compressible, will depend upon the fact whether, the change in density or volume will be appreciable due to the change in pressure brought about by the flow. Now, it happens in practice that if a liquid are so high to change to have a significant change at least 5 percent, change in density or volume. The pressure difference which is required if you make a calculations with the value of v is so high is never encountered in any engineering or any practical flows.

So, therefore we can tell almost synonymously that the flow of incompressible fluids that means, the liquids are incompressible flow, but it is not other way for example, the flow of compressible fluids that gases, may occur under certain situations as incompressible flow. That means, if the flow velocity is at so less that the pressure difference caused by the flow velocities are also very less, which are unable to cause a change in the volume or density very high.

So for example, 1 or 2 percents as any engineering approximation, we can neglect it and we can take that in the entire flow, the density and volume remains same so flow becomes incompressible. Therefore, flow is a incompressible or compressible depends upon the fact whether the density or volume changes in the flow itself. Let us find out a quantitative criteria for it.

(Refer Slide Time: 24:41)



So, incompressible therefore now it is clear to you between the definition of incompressible and compressible flow, incompressible and compressible flow. So, it is now clear to you incompressible and compressible flows. Now, in any flow, in any flow at the present moment this again will be discussed afterwards. You will have to just accept it, the order of delta p that pressure difference caused in any flow is equal to the order of rho v is the flow velocity, if we consider the characteristic velocity of flow as v by 2. This comes from a principle or theory known as Bernoulli’s, Bernoulli’s, Bernoulli’s equations or Bernoulli’s theorem.

This is found from some equation or theorem known as Bernoulli’s theorem, which we will discuss afterwards. which gives us this idea that the order of pressure difference brought about by the flow is in the order of rho v square by 2. How does it relate that means, it is true qualitatively that more is the flow velocity, more will be the pressure difference caused by the flow. Now, if we use this simple relationship from Bernoulli’s equation or Bernoulli’s theorem, in our definition of E. You see what is the definition of E is rho d p d rho.

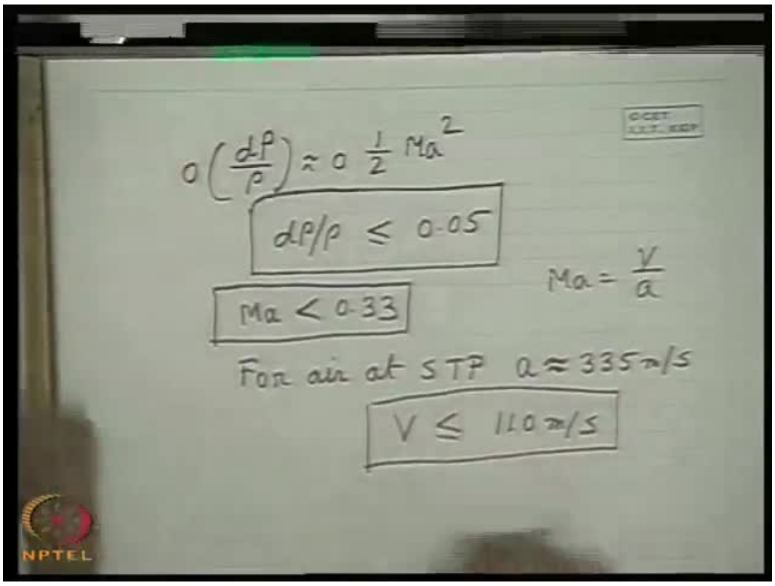
So, therefore we can write d rho by rho from these equation is d p by E simply and this d p is delta p, the same thing the change in pressure it is written in differential form I just substitute this. This will be v square by 2 E by rho E by rho therefore, you see the order of d rho by rho in terms of order, we can write because this is not exactly the same, but the order of d p d rho by rho. That is the change in density, divided by the initial density becomes equal to the order of square of the flow velocity divided by 2 E by rho, it is a simple school level mathematics.

Now, you know probably from physics that this E by rho root over E by rho is what? Can you recall, does it relate to some velocity. The dimension is a velocity dimension, it is acoustic velocity very good. So, root over E by rho is the acoustic speed or acoustic velocity, velocity of sound in that fluid medium at that condition, very good. So, this is acoustic, acoustic velocity, velocity in the fluid medium, in the fluid medium. So, it is the acoustic velocity in the fluid medium at that particular condition so which is denoted by a.

So, therefore we see the order of d rho by rho simply becomes equal to almost equal to the order of half v square by a square. That means, the ratio of the square of the flow velocity to the square of the acoustic velocity in that fluid medium. It is written as we define a quantity m a that is Mach number m a, that is known as Mach number, Mach number. Mach is a German scientist, was German scientist by his name which is defined as the ratio of the velocity of a fluid to the acoustic velocity, in that fluid at that particular condition of flow. So, this ratio is a dimensionless quantity, velocity of the fluid flow to the velocity of the sound or acoustic velocity, in the fluid medium and it is known as Mach number.

So, therefore we see the change in density to the initial density is half m a square. Now, as an engineer I can tell you that theoretically, there will be always a change in density whatever may be the value of Mach number or the pressure difference, but now practically if we consider that the change in, if the change in density is very small we neglect its change then we can give a criteria. Just visually, we can say that when Mach number is very, very less than one obviously this quantity is very less, this quantity is very less.

(Refer Slide Time: 29:23)



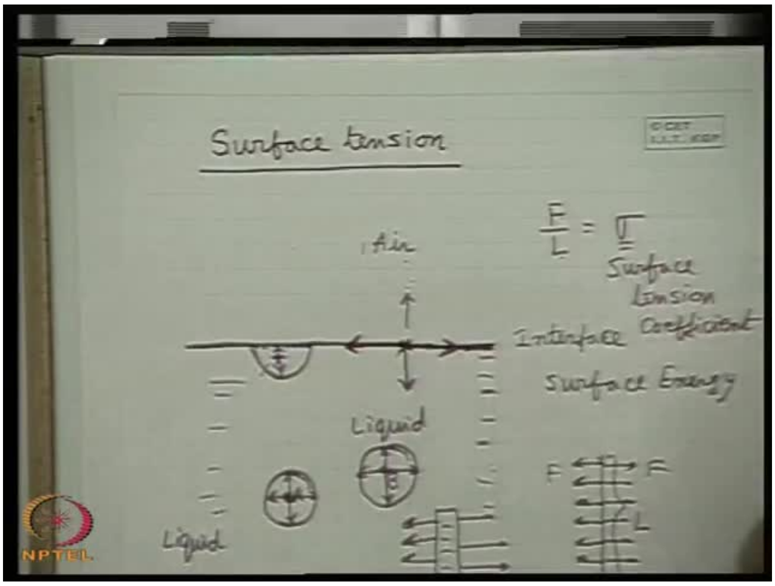

So, now if we make a criteria now again I write order of d rho by rho is equal to the order of half m a square. Now, if I put a criteria which is usually an engineering criteria that if the change in density, relative change in density less than equal to 0.05. That means, if the relative change in density is less than equal to 5 percent. I consider it to be constant that means, it is not changing at all. So, then we consider the flow to be incompressible for that it is the change in density, relative density is within the 5 percent, within 5 percent less than equal to 5 percent. I considered the flow to be incompressible.

Then if we put this we will get a value of m a that is less than 0.33. So, this is a very useful conclusion that for flow of any gases at any condition, if we just verify that Mach number is less than 0.33 then the flow is incompressible, it is not the velocity, it is not the velocity only it is the non-dimensional term Mach number. So, we check that if the Mach number is less than 0.33 the flow is incompressible. Let us see an example for air at S T P, for air at S T P our flow acoustic speed in air is approximately 335. I always write this, because these figures are not as accurate as 1 percent approximately 335 meter per second. Now, if we pose this 0.33 Mach number criteria with the definition of Mach number is v by a. So, flow velocity limit will be less than equal to 110 meter per second. That means, it is multiplied with 0.33.

So, this serves as a thumb rule that for a flow of air at standard temperature and pressure. If the flow velocity is less than 110 meter per second, we can locate for these velocity at a S T P conditions, the change in pressure which will be generated in the flow will not be sufficient to cause a change in density 5 percent, relative change in density 5 percent, but this velocity 110 meter per second depends on S T P condition. This is derived from Mach number physically also, when you change the condition the flow velocity may change. That means for example, when the just common sense you think when the pressure is very low, not at a S T P at sub atmospheric pressure fluid becomes more compressible so there a Much less pressure drop relatively, it can cause a more change in density.

So, therefore, a lower velocity may cause a change substantial change in density. So, obviously the criteria is fixed by the dimensionless quantity Mach number so in that case, what will happen at that low pressure, the acoustic speed will also change this is a function of pressure. So, if you multiply with that criteria by Mach number you will get a velocity which will be definitely lower so it is not the velocity of the flow it is the Mach number of the flow which we will finally, decide whether the flow will be compressible or incompressible.

(Refer Slide Time: 32:24)




Well now next I come to the very important property surface tension. Surface tension now, you see surface tension these are again recapitulations of your basic physics that you have read at your school level. Now, there are two kinds of intermolecular forces, one is molecular cohesion another is molecular adhesion. Now, molecular cohesion are the attractions between the molecules attractive forces between the molecules of a given substances, whereas the molecular adhesion is the attractive force between the unlike molecules. That means, between the molecules of different substances whereas it is the molecule of a same substances, where the force of cohesion and force of adhesion is the attraction between the molecules of different substances.

So, it is the cohesive force or force of cohesion intermolecular attractive forces, that allow the substance to behave as a single body as an assembled of particles where it is more strong. This is more so where it is less strong this is not so more. So, as we know since our childhood that these intermolecular cohesive forces are very strong in solid. So, it is very difficult to have a deformation, relative deformation in a solid body because molecules are in strong cohesion with each other. It is relatively lesser in liquid and than in gases and for gases also, it depends upon its thermodynamic state that is the pressure and temperature as you know.

Now, this molecular cohesive force creates, defines a property surface tension in a fluid. Let us see how it is now let us consider a bulk of liquid, let us consider a bulk of liquid which is separated from air at the top. Let us consider a situation a bulk of liquid this is a liquid a bulk of liquid, which is separated from an air and this is the surface of separation which is known as interface. That means, the surface of separation between the liquid and the air this is interface.

Now, what happens a molecule inside let a molecule A inside this liquid is attracted by the intermolecular cohesive forces, from the molecules surrounding this A which are in random motion and from statistical theory. As you know the kinetic theory of Mach that the average attractive force over a time is same in all directions is same in all directions.

And moreover, if we consider a particular point A a molecule it is being attracted by the molecules, which are few distance away from it not by a molecule which are much away from it, this distance usually varies from two to three times the distance between the two molecules therefore, we can assume a sphere of influence for this attractive forces that means, it is being attracted by molecular attraction from each directions by a sphere of attraction similarly, from this here if you consider another molecule B, we can consider another sphere of influence.

Sphere of influence means all the molecules within the sphere is attracting this molecule at the centre in all directions equally. So, therefore, each and every molecule is attracted by the neighboring molecules in the liquid. Now, what happens if we take a molecule very near to the, if we consider a molecule very near to the surface. What happens, you see that if we draw the sphere of influence it will be like this which means, that it is attracted by more molecules from inside, but the force of attraction is less from the upper side, this is because there are less number of molecules in the upper side.

So, therefore a molecule near the surface experiences a net inward forces, when the molecule come at this surface you see it is being attracted in both the sides by the molecules and here so there is no molecule which will attract him from this side. This is also not true the attraction from this side comes by the molecules of air that separates this liquid.

So, if at the present moment we consider this liquid and air the adhesive forces is from by air is not that i as the cohesive forces, which occurs here. So, what happens in this case, we see that if we now draw any molecules or try to bring any molecule from inside the liquid to a surface, what we are doing? We are, we have to do work against inward force that is the molecular cohesive force, which is going to be lesser and lesser as the molecule travels near the surface.

So, therefore, we see the mechanical work is being done, when we bring a molecule from interior of the liquid to the surface which means, physically that means if we want to create a surface or interface or if we want to extend or increase the area of the interface which is already existing a work is being done, why? Because the work is done against the inward attractive force of the molecules and when this work is done to bring the molecules in the surface.

That means, to create a surface interface then what happens? This work is being stored as the energy, when the work is done to move a particular system from one point to another point, what happens? The system stores that work in the form of energy that is basically, the definition of potential energy to in a conservative force field. So, therefore this work is being stored in the surface in the form of energy, which is known as surface energy.

And this implies, the existence of a tensile force on the surface and surface is in fact under a stretched condition. You see here this surface energy this is known as surface energy that means, to create a surface we have to do work. That means, a surface energy stored in the surface and surface is under a tensile under a state of tensile state, it is stretched. Now, if we see a cut part of the surface here, we will see that if we see the plan view that we will see that a cut surface of this here, this is the liquid surface. So, you see the surface is under the stretched condition, under the stretched condition, under the stretched condition. So, these are the tensile forces.

Now, if we considered or imagine a line element perpendicular to this plane, that means a linear element short linear element, if we look from the top this will be perpendicular to this surface. Then we will see these linear element will be stretched, or under a state of tensile force in both the directions. If we consider a linear element in isolation, we will see that this F and F in both directions. That means, a linear element is under such tensile state of tensile forces.

The surface tension is defined as this force divided by if I define a length L per unit length of such short linear element, and it is found that this is denoted by sigma, this is known as surface tension. And this is a constant for a given liquid, let this example give a liquid in contact with air. So, this force per unit length of this linear element is defined as surface tension or surface tension coefficient. Sometimes the surface tension coefficient is used and its unit is simply the unit of force by length.

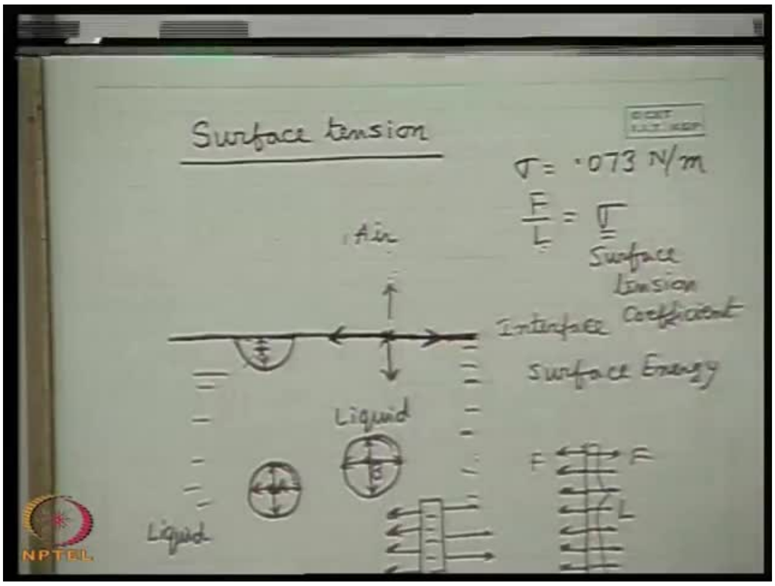
Now therefore, two very important things have to be remembered, we may not go much detail in the surface tension mechanism, which is beyond the scope of an engineer it is much with the physicist than with the engineers, but engineers must know the information and very two important information's, which engineers or applied scientist should know. That surface tension should occur or should come into picture, when there is a surface of separation between two fluids. That means, a surface of separation or an interface has to be created without an interface for a single expanse of a fluid, the concept of surface tension does not come, if anybody as it is you can ask anybody fluids.

First of all let us see a surface of separation, then only a concept of surface tension comes. Usually, if the two fluids separates a surface if two fluids or two liquids or two gases we usually call it as interfacial tension. In case of two liquids or two gases more commonly or conventionally, the surface tension word is used in case of liquid and gas separation between liquid and gas. That means therefore, the surface tension comes into picture, when there is a separation or separating surface between liquid and gas. That means, liquid and gas should define a interface. A interface has to be defined by the liquid and gas then only the concept of surface tension comes.

The next point is very important, this surface tension of the liquid is not the property of the liquid itself, it is a binary property of the liquid and the gas because the surface tension does not come until and unless the another liquid that is fluid, that is the gas comes into picture to define the interface. And you see the stretched condition at the surface depends upon the attract force, that is the force of adhesion that is the attractive force of the molecules of the gas defining the interface. That is above the liquid therefore, it has to depend on that how much work you will do to bring the particle onto the surface, depends not only on the interior force of attractions by the molecules of the liquid, but also by the force of attraction of the molecules of the gases above it, which defines the interface.

So, therefore sigma that is the surface tension coefficient or surface tension force is not a property of the liquid only, it is the binary property. It appears only when there is an interface between liquid and a gas and therefore, surface tension sigma is always specified for a liquid with respect to a gas.

(Refer Slide Time: 42:54)




For an example, the surface tension of water with respect to air is this value, you may know or you may not remember it, there is nothing great 0.73 Newton per meter it is unit is force by distance. Well so this is the basic definition of surface tension now it is the surface tension phenomena, which gives rise to very different interesting phenomena in practice, which you will discuss in the next lecture. That it is because of surface tension, a curved interface of a liquid creates a high pressure on its concave side as compared to that on its convex side. It is because of the surface tension we will see that there is a capillary rise and a capillary depression of the liquid, in a tube. So, these are the phenomena of surface tension, it is because of the surface tension a liquid wets a surface or a liquid does not wet a surface.

Sometimes you see that some liquid even water flow over a surface, we see after the water flows the surface the water sticks over the surface, surface is wet, but you see that a mercury flows over a surface after the mercury flow, the surface is as dry as anything. That means, mercury does not wet the surface. So, these are the manifestation of the property surface tension of the fluid or in case liquid here.

Well, thank you so we will discuss it again in the next class any query please.

Student: Sir, what are the surface tension between the interface of say kerosene and water?

Sure that I just like to tell, I told earlier that conventionally we tell surface tension between liquid and gases, we tell here interfacial tension definitely there will be a tension between any two liquids. Immiscible liquids, separating this two defining an interface there usually, we call it as interfacial tension. Between two gases also not only between two liquids between water and kerosene between two any immiscible fluids, a surface of separation will be created and the concept of surface tension will come. Usually, we refer it to as interfacial tensions. Commonly or conventionally, we call surface tension with this liquid and gas separations where this interface the separation between liquid and gas is defined as a free surface alright well. Thank you.

**Fluid Mechanics**

**Prof. S. K. Som**
**Department of Mechanical Engineering**
**Indian Institute of Technology, Kharagpur**

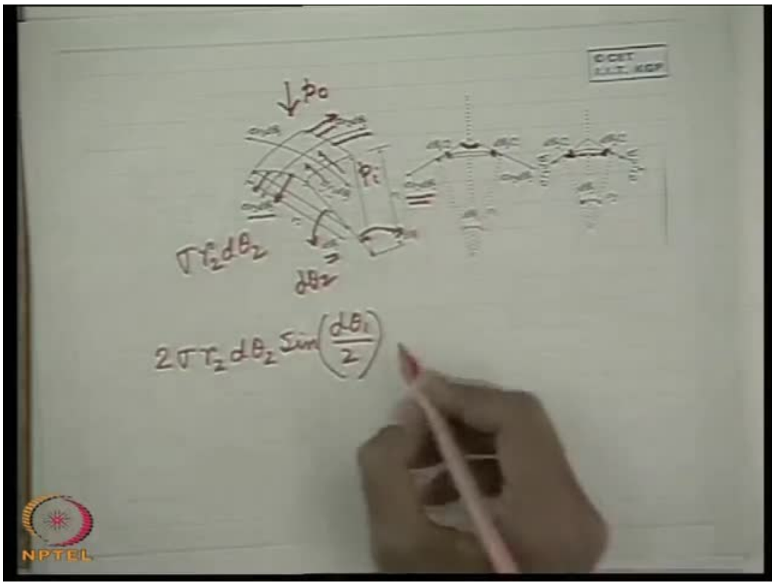
**Lecture No - 03**

**Introduction and Fundamental Concepts - III**

Well good afternoon to all of you to this session of fluid mechanics, our last class we were discussing about the surface tension. And we ultimately came to the conclusion, when two immiscible fluids define a interface then the concept of surface tension comes. That means, the interface is under a stretched conditions and mechanical energy stored in the surface that we recognize from the fact, that we if we create an interface.

That means, interface of a liquid for example, separating a gas then liquid molecules have to be brought from the interior of the bulk of the liquid to the surface, where work is done against the inner intermolecular force of cohesion by virtue of which, a mechanical energy stored in this surface. So, therefore the interface is in stretched condition and surface tension is the force exerted on the on a imaginary line, on the surface per unit length of the surface, this we appreciated in the last class. Now, it is because of the surface tension effect, a curved liquid surface separating a liquid and a gas creates a higher pressure in the concave side as compared to that in the convex sides. This is one phenomena observed.

(Refer Slide Time: 46:49)



Now, let us see this thing here, let us see here this is a curved, elemental curved liquid surface, which distinguishes or separates the bulk of the liquid on its concave side. That means, this side is the bulk of the liquid and this is the convex sides, this side is the air. For example, air or any immiscible fluid and a gas. So, this is a small curved elemental liquid surface.

Now, let us see that the surface is curved in both the directions, in such a way that the radius of curvature in this direction is r 2 which is less. That means, it is more curved and in another direction is r 1. And the lengths of the curved surfaces are such that, this obtained angles of d theta 2. That means, this is d theta 2, this angle is d theta 2, this is d theta 2 and this is d theta 1, this is d theta 1, this angle d theta 1 and d theta 2 at the respective centre of curvature. These are the respective center of curvature, this is r 1, this is r 2, this is curved in both the directions elemental curved surface. So, this side that means the convex side, this is gas and in the concave side is the bulk of the liquid. We only consider a small elemental curved portion of the surface.

Now, we see the surface tension force acts on these four sides. Now, this two sides which are of radius of curvature r 2, the surface tension force acts perpendicular to this linear element you see, whose lengths are r 2, d theta 2. Therefore, this force is sigma r 2, d theta 2 which is written here. I think you can see so this is the surface tension force acting which is perpendicular to this curved element and it is sigma r 2 d theta 2 r 2 d theta 2 is the length of this element.

Similarly, the surface tension force which acts over these elements, these lengths. This is sigma r 1 d theta 1 because the length of this curved line is the r 1 d theta 1. So, according to the definition of surface tension, the total force is sigma r 1 d theta 1, in this direction. Now, if we look this is a three dimensional view, if you look two dimensional view. That means if you look from this angle therefore, we see only this part of the curve like this, where this forces acting, this forces acting on like this we are I am showing it by only one arrow. So, this is acting like this so this is sigma into r 2 d theta 2 all the forces some of with this sigma n 2 r 2 d theta 2. So, this will appear like that sigma n 2 r 2 d theta 2. So, this is d theta 1 that means you see this figure.

Well, so from very simple geometry you see this is d theta 1, so this angle will be d theta 1 by 2 this angles, these angles. Why? This is because this angle will be this is 90 degree because this is tangent this direction so this and this radius of curvature will be perpendicular. So, this angles are 90 degree so that this is 180 degree minus d theta 1 therefore, this angles will be d theta 1 by 2. Similarly, if we see a view from this direction we will see the forces are acting, which comes that which are the forces this forces. So, if you see this view, this forces are acting sigma r 1 d theta 1 sigma r 1 d theta 1 and this angles are d theta 2 by 2 because this is d theta 2 from simple geometry this angle, this is d theta 2 by 2, this is d theta 2 by 2.

So, if you can recognize this then a simple force balance. Now, let us write assuming that the convex side of this liquid surface is acted on by an uniform pressure p 0. That is the pressure of the gas, which demarcates this liquid. Similarly, the interior of the liquid the pressure is p i, which is acting perpendicular to this surfaces. That means, in its concave side let this is p i. Now, therefore if we make a force balance in the vertical direction then we get the surface tension forces acting sigma r 2 d theta 2, 2 surfaces. So, 2 sigma r 2 d theta 2 into sin d theta 1 by 2 sine component, this is d theta 1 by 2 vertical direction.