Basics of Mechanical Engineering-3

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Week 08

Lecture 34: Properties of Fluids

Welcome to the next lecture, where we will explore some properties of fluids. Properties of fluids is a very important topic. Once you understand the properties of fluids, you can see how they apply to real-world applications. For example, I try to use a polymer that is coated on top of a tire. Now, as soon as there is a leak in the tire, the polymer is expected to harden and seal the hole.

Now, I should choose a polymer that has flowability properties. I should choose a polymer that is lightweight and does not add weight to the tire. The coating thickness should be uniform. The fluid that forms the film must also be tailor-made. This is one application.

Let's take another example where I would like to place fluid in a container. Now, I have to plan the size of the container based on the fluid. So now, the weight of the fluid plays a very important role. So now you see, the properties of fluids are very important for us to understand. In the thermodynamics section, we studied boiling phenomena.

We observed vaporization phenomena. So, all these things are subject to temperature properties. So, if I want an application where the liquid should boil faster or vaporize faster, what I do is try to choose the properties required for this application. So, friends, the properties of a fluid are very important.

So here, we will try to see the majority of them. There are 100 different properties of fluid that can be characterized, or the properties play an important role. We will choose some that are very important for general applications.

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- Specific weight, Density
- Specific gravity
- Viscosity, Its types and units
- No-Slip Condition in Fluid Motion
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- Capillarity
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- Bulk Modulus and Its Indicator Role
- Specific heat and Thermal conductivity in fluids
- Cp and Cv in fluids
- Significance of thermal expansion
- Ideal vs Real Fluids, Ideal Fluid Assumption
- Applications, Effect of temperature

First, we will try to see specific weight and density. Then there is a terminology called specific gravity. We will see that also. Then, viscosity. Viscosity is very important because when you try to pour ketchup, you squeeze it, and then the ketchup flows. If the flowability property is very high, then what happens?

With a small press, a large amount of fluid will be discharged. So, viscosity plays a very important role. Then, there is the no-slip condition in fluid, surface tension, capillary action, compressibility in the fluid, vapor pressure and cavitation, bulk modulus and its indicator role, specific heat and thermal conductivity in a fluid, Cp, Cv in a fluid, then the significance of thermal expansion, and then ideal fluid and real fluid. Finally, we will see some applications with the effect of temperature.

Fluid

- A fluid is a substance that continually flows or deforms when we subject it to shear stress or external force.
- A solid can resist a shear stress by a static deflection.
- A fluid cannot resist a shear stress by a static deflection. Any applied shear stress, no matter how small, will cause the fluid to move and deform continuously as long as the stress is applied.
- A fluid at rest must be in a state of zero shear stress, known as the hydrostatic stress condition.


blood   honey   helium

air   water

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A fluid is a substance that continually flows or deforms when subjected to shear stress or external force. This is a recap of the previous lecture. A solid can resist shear stress by static deflection. A fluid cannot resist shear stress by static deflection. Any applied shear stress, no matter how small, will cause the fluid to move and deform continually as long as the stress is applied. So, in a fluid, if you try to push it, it will move. A fluid at rest must be in a state of zero shear stress, known as the hydrostatic stress condition.

Density

- Density is defined as the mass per unit volume of a fluid.
- For gases, density is highly variable and increases nearly proportionally to the pressure level.
- In liquids, density is nearly constant. For example, the density of water (about $1000 \frac{kg}{m^3}$) increases only 1 percent if the pressure is increased by a factor of 220.
- Generally, liquids are about three orders of magnitude more dense than gases at atmospheric pressure

Density and States of Matter

Gas   Liquid   Solid

Low Density   High Density
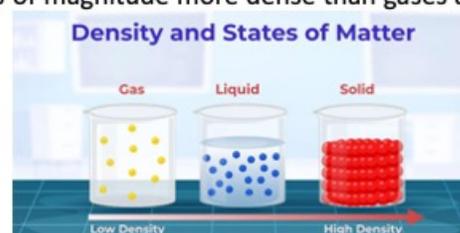
Density is defined as the mass per unit volume of a fluid. For gases, the density is highly variable and increases nearly proportionally with pressure. So, for gas, pressure plays an important role. In liquids, the density is nearly constant. For example, the density of water is 1000 kg per meter cubed, which increases only by 1% if the pressure is increased by a factor of 220.

So now it is clear that the density of gas can be increased by increasing the pressure. This is how you have LPG cylinders, CNG cylinders, and liquid nitrogen cylinders. Generally, liquids are about three orders of magnitude denser than gases at atmospheric pressure.

Specific Weight and its units

- The specific weight of a fluid, denoted by γ (lowercase Greek gamma), is its weight per unit volume.
- Density and specific weight are related by gravity: $\gamma = \rho g$.
- The units for specific weight are typically $\frac{lbf}{ft^3}$ or $\frac{N}{m^3}$

Specific weight and its unit. The specific weight of a fluid, denoted by the term γ, is its weight per unit volume. Density and specific weight are related by $\gamma = \rho g$. In SI units, it is represented as $\frac{lbf}{ft^3}$ or $\frac{N}{m^3}$.

- Specific gravity, also known as relative density, is used to describe the density of a substance compared to the density of water.
- To calculate specific gravity, divide the sample's density by the density of water.
- The formula for specific gravity:

$$\text{Specific gravity} = \frac{\text{Density of the object (or) the given fluid}}{\text{Density of water}} = \frac{\rho_{object}}{\rho_{water}}$$

When we talk about specific gravity, specific weight is different; specific gravity is different. Specific gravity, also known as relative density, is used to describe the density of a substance compared to the density of water. I know water's weight.

Now I compare and try to determine the existing fluid's weight or density. So this is what specific gravity is. And why is it important? Because many times the general fluid used is water. So now, if I know the specific gravity with respect to water, I can understand the difference and accordingly develop a system for it. To calculate the specific gravity,

$$\text{Specific gravity} = \frac{\text{Density of the object (or) the given fluid}}{\text{Density of water}} = \frac{\rho_{object}}{\rho_{water}}$$

- Density, denoted by ρ (lowercase Greek rho), is defined as the mass per unit volume of a fluid.
- Specific weight, denoted by γ (lowercase Greek gamma), is defined as the weight per unit volume of a fluid.
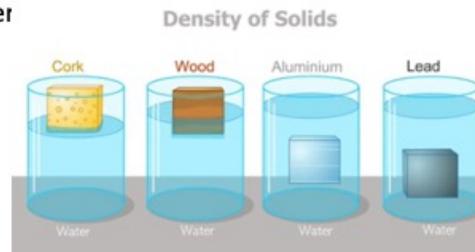

Density of Solids
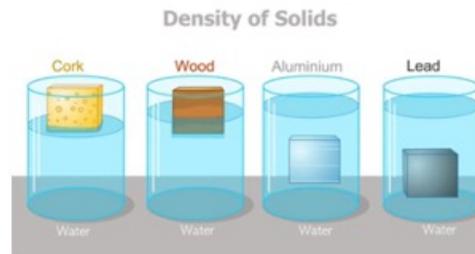
- Density and specific weight are related by gravity: $\gamma = \rho g$.
- Density is highly variable in gases, increasing nearly proportionally to the pressure level, while in liquids, density is nearly constant, increasing only slightly with pressure. Liquids are generally about three orders of magnitude more dense than gases at atmospher

Density of Solids

Then, friends, there is something called mass density and weight density. The density is denoted by the term rho, which is defined as mass per unit volume of the fluid. When we talk about weight, it is denoted by γ and is defined as the weight per unit volume of the fluid.

So density is an important parameter when we are trying to place cork on top of a fluid, wood on top of a fluid, aluminum on top of a fluid, or lead on top of a fluid. So density is very important. Generally, we are keeping the varying solids, but the liquid density is also very important. The density and specific weight are related by the term $\gamma = \rho g$. The

density is highly variable in gases, increasing nearly proportionally to the pressure levels, while in liquids the density is nearly constant, increasing only a very small percentage with pressure.

Viscosity

- Viscosity is described as a quantitative measure of a fluid's resistance to flow and relates the local stresses in a moving fluid to the strain rate of the fluid element.
- More specifically, viscosity determines the fluid strain rate generated by a given applied shear stress.
- Common fluids like water, oil, and air exhibit a linear relation between applied shear stress (τ) and the resulting strain rate ($\frac{d\theta}{dt}$ or $\frac{du}{dy}$).
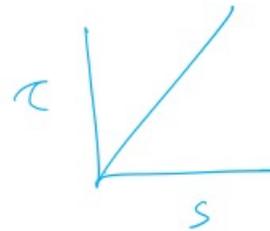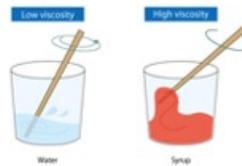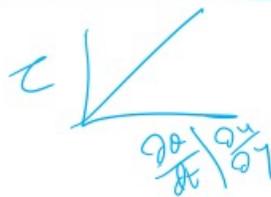
Viscosity

- The constant of proportionality in this linear relation is the viscosity coefficient, μ:
$$\tau = \mu\frac{d\theta}{dt} = \mu\frac{du}{dy}.$$
- Fluids that follow this linear relationship are called newtonian fluids. There are also non-Newtonian fluids where this linear relation does not hold.
- The magnitude of viscosity varies vastly among common fluids, spanning six orders of magnitude from hydrogen to glycerin

Viscosity. Viscosity is defined as a quantitative measure of the fluid's resistance to flow. When a medicine is poured into a plastic container, when a medicine is poured on a

spoon, when honey is taken from the container—all these things, if you see, there is a resistance for the fluid to flow. So the measure of the fluid's resistance to flow relates to the local stresses in a moving fluid to the strain rate of the fluid element. So this is very important. Viscosity plays a very important role.

When we try to paint a surface, the paint should have a viscosity such that it gives a small thin film thickness, plus it should also be able to flow. If it is fully flowing, then it is of no use. So you should have a combination of these two. A quantitative measure of the fluid resistance to flow relates to the local stresses in a moving fluid and the strain rate of the fluid element. More specifically, viscosity determines the fluid strain rate generated given an applied shear stress.

The common fluid like water or oil; oil has a different viscosity and air exhibit a linear relationship between applied shear stress. This is stress by strain. So, viscosity can be like this. So, common fluids like water, oil, and air exhibit a linear relationship between applied shear stress and resulting strain rates: $d\theta/dt$ or du/dy. The constant of proportionality in this linear relationship is the viscosity coefficient μ. So, τ is the shear stress, $\tau = \mu\frac{d\theta}{dt} = \mu\frac{du}{dy}$. Fluids that follow this linear relationship are called Newtonian fluids, and those that do not are called non-Newtonian fluids.

The magnitude of viscosity varies vastly among common fluids, spanning six orders of magnitude from hydrogen to glycerin. So, you can see glycerin is thick. It is six orders of magnitude higher. So, viscosity plays a very important role. What will be the time taken to fill a container?

Viscosity plays a very important role. Then, what will be the residue left in the container? Again, viscosity plays a very important role. So, if you take ghee, it is a viscous fluid. When it is used to coat a pan, it demonstrates the viscosity of the fluid, helping to form a thin film with minimal effort. On the other hand, people are very smart. What they do is heat the pan, pour ghee on it, and then rotate the pan to create a uniform coating. What happens is that ghee, which is somewhat viscous, becomes much thinner due to the effect of temperature, allowing it to spread easily.

- Dynamic viscosity, denoted by μ, is the viscosity coefficient discussed above. It relates shear stress directly to the velocity gradient.
- Kinematic viscosity, denoted by ν (lowercase Greek nu), is defined as the ratio of dynamic viscosity to density: $\nu = \dfrac{\mu}{\rho}$.
- It is called kinematic because the mass units cancel out in the ratio, leaving only dimensions of $\{L^2 T^{-1}\}$

The kinematic and dynamic viscosity. Viscosity has two parts: kinematic viscosity and dynamic viscosity. Dynamic viscosity, denoted by μ, is the viscosity coefficient discussed above. It relates shear stress directly to the velocity gradient.

Whereas kinetic viscosity, μ is the ratio between dynamic viscosity and density. Friends, look at this difference. Dynamic viscosity is different. Kinematic viscosity is different. Kinematic viscosity is a relationship, nu, which is equal to mu divided by rho.

So it is called kinematic because the mass units cancel out in the ratio, leaving only the dimensions $\{L^2 T^{-1}\}$. So that is why it is called kinematic viscosity. The dynamic viscosity is $\dfrac{\tau}{d\theta/dt}$ or $\dfrac{dy}{dy}$. This is dynamic viscosity, and you have kinematic viscosity.

- The SI unit for dynamic viscosity (μ) is kilograms per meter-second, $\frac{kg}{ms}$. This is equivalent to $\frac{Ns}{m^2}$.
- The SI unit for kinematic viscosity (ν) is meters squared per second, $\frac{m^2}{s}$.

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The SI units of dynamic viscosity, μ, are $\frac{kg}{ms}$. This is equivalent to $\frac{Ns}{m^2}$. The kinematic viscosity, (ν) is meters squared per second, $\frac{m^2}{s}$. So the units are different. So the understanding is different.

No-Slip Condition in Fluid Motion

- The no-slip condition is a characteristic of all viscous fluid flows.
- It states that the fluid velocity at a solid wall is zero relative to the wall.
- Inviscid flows, in contrast, do not satisfy this condition; they "slip" at the wall but do not flow through it.
- This condition is demonstrated experimentally by techniques like using hydrogen bubbles to visualize velocity profiles near a wall, showing zero velocity right at the surface.

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No-slip condition in fluid motion. The no-slip condition is a characteristic of all viscous fluid flows. It states that the fluid velocity at a solid wall is zero relative to the wall. So you have a wall, and you have a liquid which is sitting there. So, it states that the fluid

velocity at the solid wall is zero. There is no velocity relative to the wall. Inviscid flow, in contrast, does not satisfy this condition. So they slip at the wall but do not flow through it.

They slip at the wall and do not flow through it. These are inviscid flows. This condition is demonstrated experimentally by techniques using hydrogen bubbles to visualize velocity profiles near the wall, which show zero velocity right at the surface and subsequently keep moving. So, this condition is demonstrated experimentally by techniques like using hydrogen bubbles to visualize velocity profiles near the wall.

Viscosity Variation : Liquids and Gases

- For liquids, dynamic viscosity (µ) generally decreases as temperature increases.
- For gases, dynamic viscosity (µ) generally increases as temperature increases.
- The change in viscosity with pressure is also a factor, but temperature is often the dominant influence for many common fluids
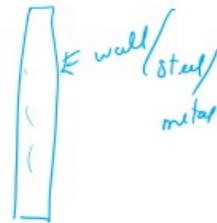
Viscosity variation in liquids and gases. For liquids, the dynamic viscosity µ generally decreases as the temperature increases. That's what I said. So when you try to heat the pan, put a spoon of ghee and heat it. What happens is it turns into a liquid so that it can flow. You take solid coconut oil during winter, put it in your hand, press it, and create frictional heat.

It becomes liquid. So this is a temperature, right? Viscosity decreases with temperature. For gases, dynamic viscosity increases with temperature. As the temperature increases, the dynamic viscosity of gas increases.

The change in viscosity—please understand, friends—you should make use of these properties. Don't just try to read it and memorize it. You should make use of these properties in your real-time applications. If I know that dynamic viscosity generally increases as temperature increases for a gas, and you're trying to use a gaseous medium to perform a task, you can choose gases where the viscosity—the resistance to flow—increases with temperature. So it can be used for shutting or slow diffusion.

You can plan like that. The change in viscosity with pressure is also a factor. It's not just the temperature. Temperature is the easiest factor. If I want to increase or decrease pressure, I have to take it to a higher or lower altitude.

At room temperature, a pressure increase will always be a challenge. That is why we use temperature to our advantage and keep playing with the viscosity. The change in viscosity with pressure is also a factor. But temperature is often the dominant influence for many common fluids.

For example, sometimes people also say that when you want to paint a wall made of steel or any metal, they suggest slightly preheating the surface so that the residual water, whatever is there, gets removed, and any entrapped gas is also removed, allowing the paint to be applied very quickly. So, temperature plays a very important role.

Surface Tension and Its Effects

- Surface tension is a property of a liquid interface with another liquid or gas.
- It can be conceptualized as a force per unit length (Y, with dimensions $\{MT^{-2}\}$, SI units of newtons per meter) acting normal to a cut in the interface and parallel to the surface.
- Alternatively, it can be viewed as surface energy per unit area $\frac{N}{m}$.
- Molecules at the surface attract each other more strongly than those deeper within the liquid, creating this tension.
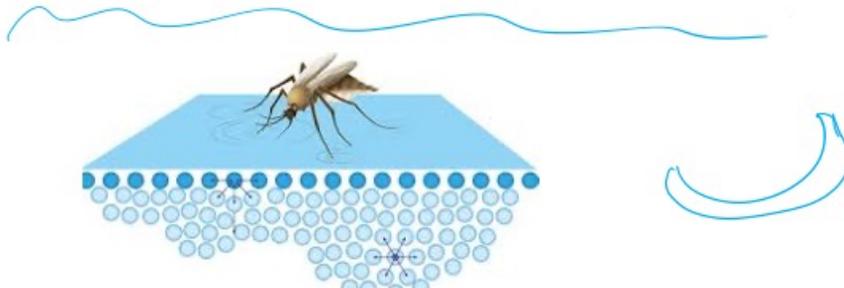
Surface Tension

- Molecules at the surface attract each other more strongly than those deeper within the liquid, creating this tension.
- If the interface is curved, surface tension causes a pressure difference across the interface, with the pressure being higher on the concave side.

The next important thing is surface tension. Surface tension is a property of a liquid interface with another liquid or gas. If the surface tension is very high, it is very difficult to create a thin film with a liquid. It can be conceptualized as a force per unit length, in SI units of N/m, acting normal to a cut in the interface and parallel to the surface. Cut to the interface.

So, this is the interface. So, this is the interface. Cut to the interface and parallel to the surface. Alternatively, it can be viewed as a surface energy per unit area, in newtons per meter. The molecules at the surface attract each other more strongly than those deeper within the liquid, creating a tension.

So because of this tension, only the mosquito is able to glide on the water surface or stay on a water surface. Molecules at the surface attract each other more strongly than those deeper within the liquid. So because of this, you have a surface tension which stays on the fluid. Molecules at the surface attract each other more strongly than those deeper within the liquid, creating this tension. If the interface is curved, the surface tension causes a pressure difference across the interface, with the pressure being higher on the concave surface. If you have a curved surface, then what is the phenomenon we are seeing?

If the interface is curved, the interface is mostly flat. When we do the wettability study, we always put a drop of water on top of a flat surface. You can also do it on an angled plate, but that's a different story. Now we are talking about a curved one. If the interface is curved, the surface tension causes a pressure difference across the interface, with the pressure being higher on the concave surface.

Capillarity

- Capillary rise or capillarity is a phenomenon in which liquid spontaneously rises or falls in a narrow space such as a thin tube or in the voids of a porous material.
- The surface adhesion forces or internal cohesion present at the interface between a liquid and a solid stretch the liquid and form a curved surface called a meniscus.
- It can be either concave or convex, depending on the liquid and the surface.

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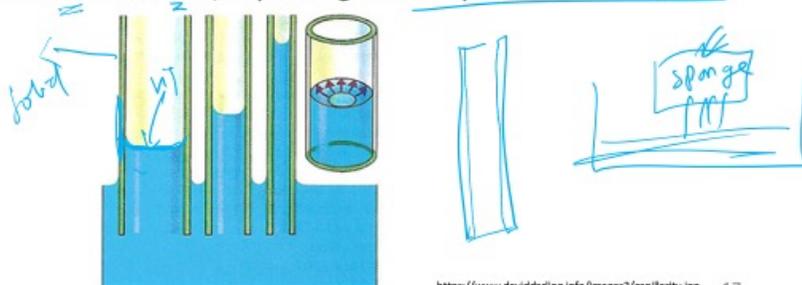
Next is capillarity. I take a water tank filled with water and keep a sponge on top of it. Now there is diffusion that happens to the sponge. So the water gets absorbed into the sponge, right? I replace it with oil, and nothing happens. Then I apply pressure on this sponge, and yes, oil seeps inside.

So, the next thing is capillary action. Nowadays, when we try to look at microchannels, we are trying to see if, by capillary action alone, the fluid can fill up against gravity inside a tube for any reaction or application. The capillary rise or capillarity is a phenomena in which liquid spontaneously rises or falls in a narrow space such as a thin tube or in the voids of a porous material. This is what I was talking to you about the sponge. So when we try to keep a straw on the surface. You should realize that there will be a surface tension.

So it is always better to push it little down where the surface tension are little low. Then you can apply vacuum and then drag the fluid into your straw. The surface adhesion force or internal cohesion present at the interface between a liquid and a solid stretch the liquid and forms a curved surface called meniscus on the top. This is the meniscus. The surface adhesion force or internal cohesion present at the interface between the solid and the liquid, this is a solid and the liquid, between a solid and a liquid stretch the liquid to form stretch the liquid to form a meniscus.

It can either be concave or convex depending upon the liquid and the surface. So you can try to play with the surface. For example, you try to take a straw or a pipe, internally coat it with some other fluid, allow it to dry, and then you can start playing with the stretch. The liquid forms a curved surface called a meniscus, which can be concave or convex.

Compressibility in Fluid Flow

- Compressibility refers to the change in fluid volume or density due to pressure changes.
- Two coefficients measuring compressibility at rest are the isothermal compressibility coefficient (χT) and the isentropic compressibility coefficient (χS), both having dimensions of inverse pressure.
- In fluid motion, the question arises whether pressure variations significantly influence the volume changes of fluid particles
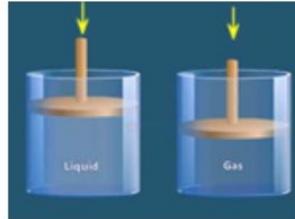
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Compressibility in Fluid Flow

- An iso-volume evolution is one where the fluid volume remains constant, characteristic of an incompressible fluid.
- While density changes can also occur due to temperature or composition, an isovolume evolution is equivalent to constant density evolution when the fluid is homogeneous and monophasic.
- The influence of fluid compressibility on the general flow pattern is related to the Mach number.
- Flows where compressibility effects are significant are called compressible flows. Liquids are typically treated as nearly incompressible, while gases are highly compressible.

Compressibility in fluid flow. Compressibility refers to the change in volume or density due to pressure change. For example, water, even when you apply pressure, will change very, very little.

Two coefficient measures compressibility at rest are the isothermal compressibility coefficient and isentropic compressibility coefficient. Both having the dimensions of inverse pressure. The fluid motion, the question arises whether pressure variation significantly influences the volume change of the fluid. It is very rare. That

compressibility of a fluid is going to change in liquids in gases. Yes. Right. There are two parameters which you have to know: the isothermal compressibility coefficient and the isentropic compressibility coefficient. Both are very important for a liquid. An iso-volume evolution is one where the fluid volume remains constant, and the characteristics of an incompressible fluid come into existence.

Density changes can also occur due to temperature or composition. An iso-volume evolution is equivalent to a constant density evolution when the fluid is homogeneous and monophasic. The influence of fluid compressibility on the general flow pattern is related to the Mach number. So in gases, we talk more about Mach 1, Mach 2, Mach 3. For example, fighter planes go at Mach 1, Mach 2, Mach 3. So the influence of the fluid—here, in airplanes and all—is gas.

But when we talk about fluid as a liquid, the influence of fluid compressibility on the general flow pattern is related to the Mach number. So we call this with respect to the Mach number. The flow where compressibility effects are significant is called compressible flow. Liquids are typically treated as incompressible, and gases are highly compressible.

Vapor Pressure and Cavitation

- Vapor pressure is the pressure at which a liquid boils and is in equilibrium with its own vapor.
- Cavitation is the process where vapor bubbles appear in the liquid when the liquid pressure falls below the vapor pressure due to a flow phenomenon.
- The cavitation number is a dimensionless parameter describing flow-induced boiling
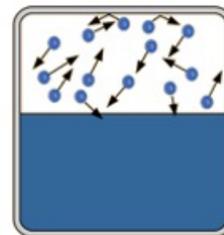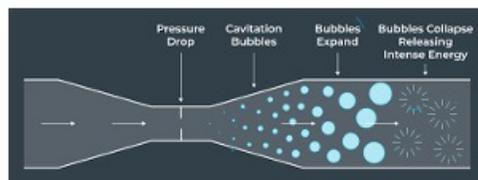
The next one is Vapor pressure and cavitation. Surface tension leads to cavitation. Vapour pressure is a pressure at which the liquid boils and is in equilibrium with the own vapor. Cavitation is the process where vapor bubbles appear in the liquid when the liquid pressure falls below the vapor pressure due to flow phenomena. So you have a flow, which is fluid flow, that is coming. There is a convergent-divergent nozzle. So it converges.

Then, in the middle, there is a pressure drop. Once there is a pressure drop, cavitation is formed. Bubbles are formed. Cavitation is a process where vapor bubbles appear. These are vapor bubbles appearing in the liquid.

When the liquid pressure here falls below the vapor pressure. The vapor pressure is very important. If it falls below the vapor pressure, then these bubbles are formed. And these bubbles, as you know, when they are formed, they have a vapor pressure, low pressure, and all. But when they try to expand and burst, they create a localized high pressure, bursting will happen. Like very small bombs, it will burst. And this cavitation can be used for killing germs. This cavitation can be used for removing dirt from the surface.

This cavitation can also be used for mixing. So, the moment there is turbulence created, mixing can happen. Thus, cavitation is a very important process. Cavitation is a process where vapor bubbles form. In the liquid itself—here, you are not blowing air.

By a pressure drop, you are manipulating the liquid. It appears in the liquid when the liquid pressure falls below the vapour pressure due to the flow phenomena. The cavitation number is a dimensionless parameter describing flow induced boiling. This is flow-induced boiling. So, cavitation bubbles are formed.
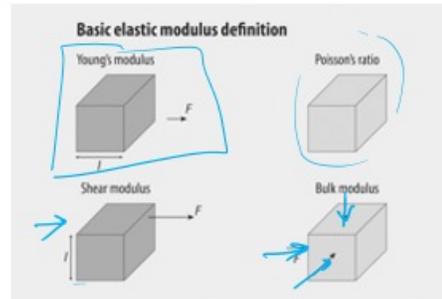
Then, the bubbles expand. Then the bubbles collapse releasing intense energy. That's what I said. Small bombs. So it can be used for multiple applications. So vapor pressure and cavitation are very important.

Bulk Modulus and Its Indicator Role

$E = \dfrac{Stress}{Strain}$

- The bulk modulus is related to resistance to compression (specifically, $K = \frac{1}{\chi}$).
- While not explicitly defined as the bulk modulus in the text, its units and context suggest it is a measure of a fluid's resistance to volume change under pressure
- Liquids are described as nearly incompressible, indicating a very high bulk modulus, meaning they require very large pressure changes to cause a small volume change.
- It is measured in SI units of $\dfrac{N}{m^2}$.

Basic elastic modulus definition
Young's modulus — Poisson's ratio — Shear modulus — Bulk modulus

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Next comes the bulk modulus and its indicator role. The bulk modulus is related to resistance to compression. And you know, liquid is incompressible. So here, the basic elastic modulus definition—Young's modulus—you can try to have.

Young's modulus we saw in the materials course, where E is nothing but stress by strain. Then we see here the Poisson's ratio. Poisson's ratio is: you try to compress, and you see what happens to it. Then you try to have a shear modulus, where you try to shear on the top and there is a bottom locking shear. You can see the shear modulus can be figured out. Then the bulk modulus is when you try to compress it from all sides, right?

From all sides, you see the bulk modulus. So you see here, you compress from the top, side, and the other side. So, the bulk modulus is related to resistance to compression, right? While not explicitly defined as bulk modulus in the text, its unit and context suggest it is a measure of fluid resistance to volume change under pressure. So, you are trying to put a fluid, compress it—like what happens to a fluid element—you take it deep into water.

Liquids are described as nearly incompressible, indicating a very high bulk modulus. This means that a very large pressure change can cause a very small change in volume. So, it is given in /m². The bulk modulus can be represented as K.

- The specific heat is defined as the energy required to raise the temperature of a unit mass of a substance by one degree.
- In general, this energy depends on how the process is executed.
- In thermodynamics, we are interested in two kinds of specific heats: specific heat at constant volume Cv and specific heat at constant pressure cp.
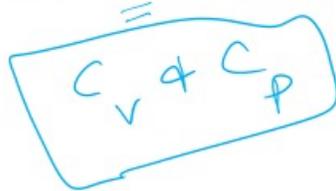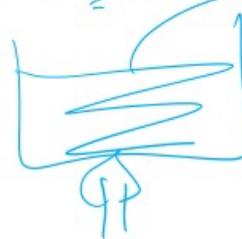
Specific heat is defined as the energy required to raise the temperature of a unit mass of a substance by 1 degree. This is specific heat. I keep a container filled with crude oil. So, what is the energy required to heat and raise the temperature of the unit mass by 1 degree? This is specific heat. In general, the energy depends on how the process is executed.

In thermodynamics, we are interested in two kinds of specific heat. One is specific heat at constant volume (Cv), and the other is specific heat at constant pressure (Cp). So, Cv and Cp are very important properties.

Thermal Conductivity in fluids

- Thermal conductivity (k) is a fluid property that characteristics specific fluid mechanical behaviour.
- It is a measure of the ability of a material to conduct heat.
- According to Fourier's law of conduction, the vector heat transfer per unit area is proportional to the vector gradient of temperature, with thermal conductivity being the constant of proportionality. This means that the heat flux is equal to -k times the temperature gradient

$$q = -k\nabla T$$

Where,   q – Heat flux vector

k – Thermal conductivity

∇T – Temperature gradient.

The thermal conductivity of a fluid is very important. I apply heat to a container, and how is the heat distributed? This is heat. How is the heat distributed in the container? That is the thermal conductivity of the fluid. Sometimes, the thermal conductivity is very high.

So, it can quickly conduct. Sometimes it is low. So, it takes a lot of time to heat up. So, thermal conductivity is a fluid property that characterizes specific fluid mechanical behavior. It is a measure of the material's ability to conduct heat. Many times, at room temperature or at 50–60 degrees, it does not conduct heat. Maybe once it crosses 70–80 degrees, then it starts slowly conducting heat.

According to Fourier's law of conduction, the vector heat transfer per unit area is proportional to the vector gradient of temperature. So, q is represented as minus k times delta T. This k is thermal conductivity. This means that the heat flux is equal to minus k times the temperature gradient. So, I repeat: Fourier's law of conduction states that the vector heat transfer per unit area is proportional to the vector gradient of temperature. With thermal conductivity being a constant of proportionality, this means that the heat flux is equal to minus k times the temperature gradient. So, if you see the effect of temperature on the thermal conductivity of a fluid, it can increase and then decrease.

For many fluids, it can increase and decrease. For some fluids, it can remain constant. It all depends. The thermal conductivity k of a fluid varies with temperature and pressure,
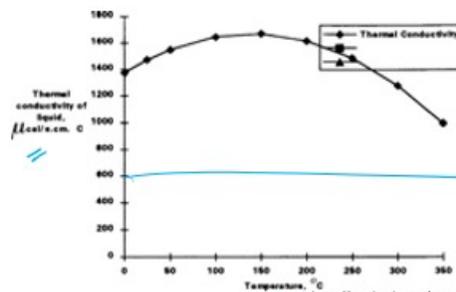
similar to viscosity. For a gas, thermal conductivity depends on the density and mean free path.

Because the temperature has to transfer, it depends on the mean free path, the gas constant, and absolute temperature. But in fluid, it varies with temperature and pressure, similar to viscosity.

The effect of temperature. Temperature generally has a significant effect on the density of the fluid. The density of the gas is inversely proportional to the temperature. This means as temperature increases, the density of the gas decreases. For example, the density of water at 1 atmosphere changes by 2.3% while the temperature increases from 20 to 75 degrees Celsius. So the effect of temperature.

- Temperature generally has a significant effect on the density of fluids.
- The density of gases is inversely proportional to temperature.
- This means as temperature increases, the density of a gas decreases.
- For example, the density of water at 1 atm changes by about 2.3 percent when the temperature increases from 20°C to 75°C
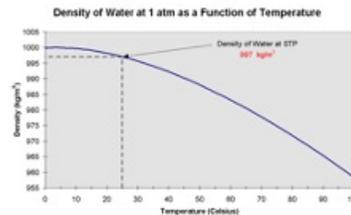

Density of Water at 1 atm as a Function of Temperature

Temperature generally has a significant effect on the density of the fluid. The density of the gas is inversely proportional to the temperature. When the temperature increases, the density decreases. This means as the temperature increases, the density of the gas decreases. For example, the density of water at 1 atmosphere changes by about 2.3% when the temperature increases from 20°C to 75°C, density of water at 1 atmospheric pressure. You can see what the percentage increase is.

- Temperature has a strong effect on the viscosity of liquids.
- Specifically, the viscosity of liquids decreases as temperature increases.
- This is why hot oil appears to flow faster than cold oil
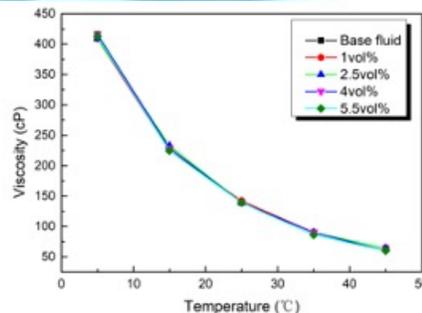
Temperature has a strong influence on viscosity. As I told you, viscosity decreases with an increase in temperature. Temperature has a strong effect on the viscosity of the liquid. Specifically, the viscosity of the liquid decreases as the temperature increases. This is why hot oil appears to flow faster than cold oil.

Cp and Cv are constant pressure and constant volume in a fluid. So, Cv can be viewed as the energy required to raise the temperature of a unit mass of substance by 1 degree while the volume is maintained constant. So, your container is filled with water. So now you are trying to heat it. The volume is constant, the mass is 1 kg, delta T increases by 1 degree Celsius, and Cv can be calculated this way. What is the heat required to increase it for a given fluid?

Cp can be defined as the change in the enthalpy of a substance per unit change in temperature at constant pressure. So here, we maintain co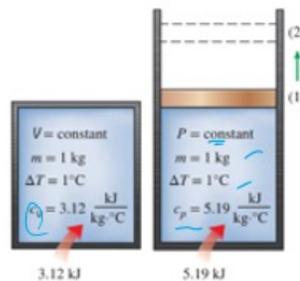nstant pressure. Pressure is constant, mass and temperature rise, and then you have Cp equal to 5.9 times kilojoule per kg per cent. So, you should know Cp and Cv are two different terms. Cp for a given condition can be higher or it can be lower.

- Thermal expansion refers to the phenomenon where the volume of a substance changes with temperature, typically discussed at constant pressure.
- When subjected to a temperature rise, a fluid medium undergoes a volume increase.
- This change can also be viewed as a decrease in density. Thermal expansion is significant in fluids because:
  - It affects density variations within the fluid.
  - In situations involving temperature differences, thermal expansion can lead to density gradients, which, under the influence of gravity, create buoyancy forces. These buoyancy forces are the driving mechanism behind natural convection, where fluid motion is caused by density variations resulting from temperature differences.

The significance of thermal expansion is that it can be used for raising an alarm, for ejecting, or reducing the pressure, whatever it is. Thermal expansion is a very important phenomenon. Thermal expansion refers to the phenomenon when the volume of a substance changes with temperature, typically discussed at constant pressure. At constant pressure, the volume increases when subjected to a temperature rise. The fluid medium undergoes a volume increase. It expands.

Friends, can you think of an example from your day-to-day applications? When you heat it, the volume expands, for a liquid. And when you try to reduce the heat, it shrinks. Many of the polymer does it. Polymer. They do this phenomena. You heat it, it expands. And you cool it, it shrinks, right? Like that you can also think of some examples with respect to your day to day applications. This change can also be viewed as a decrease in density. Thermal expansion is significant in fluids because it affects the density variation within the fluid. It affects the density variation.

In situations involving temperature differences, thermal expansion can lead to density gradients, which, under the influence of gravity, create buoyancy forces. Look at how things are related. These buoyancy forces are the driving mechanism behind natural convection, where fluid motion is caused by density variations resulting from temperature differences. See how everything is linked. You are linking the temperature in situations involving temperature differences. The thermal expansion occurs when you increase temperature.

The thermal expansion leads to a density gradient. True, right? The volume increases, which, under the influence of gravity creates buoyant forces. What are buoyant forces? Which you would have studied—why does a ship float? Buoyant force.

These buoyant forces are the driving force behind natural convection. Natural convection is hot at the top and cold at the bottom, creating convection. Fluid motion is caused by density variations resulting from temperature differences.

Why are Ideal Fluids Non-Viscous?

- Ideal fluids are considered non-viscous because their definition explicitly sets their viscosity coefficient (μ) to zero.
- This aligns with the Newton-Stokes scheme, which relates shear stress to the rate of strain; in an ideal fluid, this relationship implies no resistance to shear
- This absence of shear stress, or internal friction, is the defining characteristic that makes an ideal fluid non-viscous.
- Unlike real, viscous fluids where shear stress causes continuous deformation, an ideal fluid offers no resistance to deformation because $\mu = 0$, resulting in zero shear stress ($\tau = 0$)

Why are ideal fluids non-viscous? Ideal fluids are considered non-viscous because their definition explicitly states that the viscosity coefficient is zero. This aligns with Newton's stress-strain scheme, which relates shear stress to the rate of strain in an ideal fluid. This relationship implies no resistance to shear, which is why ideal fluids are non-viscous.

The absence of shear stress or internal friction is the defining characteristic that makes an ideal fluid non-viscous. Unlike real viscous fluids, where shear stress causes continuous deformation, an ideal fluid offers no resistance to deformation because μ equals 0, resulting in zero shear stress τ equals zero. That is why ideal fluids are non-viscous.

Ideal vs Real Fluids

- Viscosity: Real fluids have a non-zero viscosity ($\mu > 0$), offering resistance to flow and deformation. Ideal fluids are defined as inviscid ($\mu = 0$).
- Thermal Conductivity: Real fluids have a non-zero thermal conductivity ($\lambda > 0$), allowing heat transfer by conduction. Ideal fluids are non-heat conductive ($\lambda = 0$).
- Irreversibility: Real fluids exhibit intrinsic irreversibilities due to viscous dissipation and heat conduction. Ideal fluids develop no intrinsic irreversibility during discontinuity-free motion
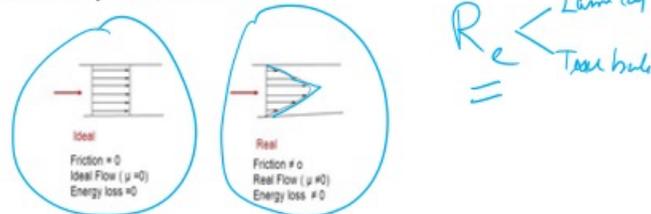
Ideal vs Real Fluids

- Boundary Conditions: Real fluids adhere to solid surfaces (the no-slip condition where both normal and tangential velocities are zero relative to the surface).
- Ideal fluids are assumed to slip along solid surfaces (the normal velocity is zero, but the tangential velocity is not necessarily zero).
- Reynolds Number: Ideal fluid motion corresponds to an infinite Reynolds number, while real fluid flows occur at finite Reynolds numbers

$$R_e < \begin{array}{l} \text{Laminar} \\ \text{Turbulent} \end{array}$$

Ideal
Friction = 0
Ideal Flow ($\mu = 0$)
Energy loss = 0

Real
Friction ≠ 0
Real Flow ($\mu \neq 0$)
Energy loss ≠ 0

What is the difference between an ideal fluid and a real fluid? Viscosity makes the biggest difference. Viscosity: real fluids have non-zero viscosity, μ is always greater than zero, offering resistance to flow and deformation. In the ideal case, μ equals zero. Thermal conductivity: real fluids have non-zero thermal conductivity where λ is greater than zero, allowing heat transfer by conduction in real fluids. But in ideal fluids, there is no heat conduction, so λ equals zero.

Irreversibility: real fluids exhibit intrinsic irreversibility due to the viscous dissipation and heat conduction. Because of these two, there is irreversibility in the real fluid. But an ideal fluid develops no intrinsic irreversible during discontinuity free motion. So this makes the difference between ideal versus real fluid. The real fluid adhere to solid surface, the non-slip condition where both normal and tangential velocities are 0 relative to the surface at the boundary condition.

Ideal fluid are assumed to slip along the solid surface. So this is ideal fluid, and this is real fluid. In real fluid, friction is not zero, so you will always have this distribution. Friction is not equal to zero; in real flow, mu is not equal to zero, and energy loss is not equal to zero. But here, everything is equal to zero.

The Reynolds number—ideal fluid motion corresponds to an infinite Reynolds number. We saw what the Reynolds number is in the last class. The Reynolds number will try to tell us about laminar flow and turbulent flow. Right. So, it is infinite for an ideal fluid, whereas for a real fluid, it will have a finite Reynolds number.

Ideal Fluid Assumption

Assuming a fluid is ideal significantly simplifies analysis by:
- Simplifying Governing Equations: Setting $\mu = 0$ and $\lambda = 0$ eliminates terms related to viscous stresses and heat conduction from the governing equations of motion. For an ideal incompressible fluid, the energy equation becomes trivial (temperature remains constant along particle paths if initially homogeneous).

- Simplifying Boundary Conditions: The no-slip condition, which is often mathematically complex, is replaced by the simpler condition that the normal velocity at a solid surface is zero, allowing slip in the tangential direction

The assumptions we make are based on the assumption that the fluid is ideal, which significantly simplifies analysis by setting mu equal to 0 and lambda equal to 0. It eliminates terms related to viscous stress and heat conduction from the governing equation of motion. For an ideal incompressible fluid, the energy equation becomes

trivial when temperature remains constant along the particle path if infinitesimally homogeneous. So, in order to generalize or simplify the governing equation, we always try to treat the fluid as an ideal fluid where we remove viscosity and thermal conductivity. Simplifying boundary conditions, the no-slip condition, which is often mathematically complex, is replaced by a simpler condition where the normal velocity at the solid surface is 0, allowing slip only in the tangential direction.

So, these two are the assumptions we make so that the problem can be solved. So, the governing equation is $\mu = 0$ and $\lambda = 0$ and the no-slip boundary condition will be activated, allowing only tangential direction forces and velocities.

Viscosity change of gases

- For gases, the viscosity also varies strongly with temperature.
- However, unlike liquids, the viscosity of gases increases with temperature.
- Kinetic theory suggests that the transport coefficients, including viscosity, tend to increase with temperature for gases
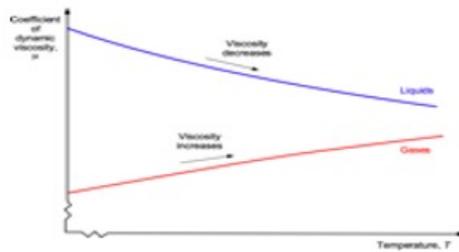
The viscosity of gas changes. For gas, the viscosity also varies strongly with respect to temperature. However, unlike liquids, the viscosity of gases increases with temperature. Kinetic theory suggests that the transport coefficients, including viscosity, tend to increase with a rise in temperature for a gas.

- The coefficient of surface tension (γ) of a liquid generally decreases with increasing liquid temperature.
- Surface tension is zero at the critical point.
- For common interfaces like water-air or mercury-air, measured surface tension values are provided at a standard temperature (20°C), indicating its dependence on temperature.
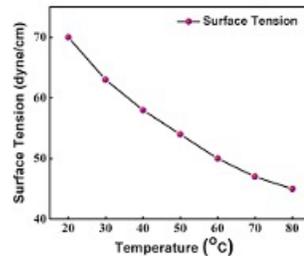
The influence of surface tension versus temperature: the coefficient of surface tension, gamma, of a liquid decrease with an increase in temperature. The surface tension is zero at a critical point. You can also reduce the surface tension to 0. What is surface tension 0?

The attraction between the molecules on the surface is 0. For common interfaces like water-air or mercury-air, measured surface tension values are provided at a standard temperature of 20 degrees Celsius, indicating its dependency on temperature. So, it plays a very important role in density, viscosity, and it also plays an important role in surface tension.

- Vapor pressure is the pressure at which a liquid boils and is in equilibrium with its own vapor.
- As temperature increases, the vapor pressure of a liquid rises.
- When the liquid pressure falls below the vapor pressure, vapor bubbles appear in the liquid, a process called cavitation.
- Water at normal atmospheric pressure will boil at 212°F (100°C) because its vapor pressure rises to atmospheric pressure at that temperature

So, the effect of vapor pressure—the vapor pressure is the pressure at which the liquid boils and is in equilibrium with its own vapor. As the temperature increases, the vapor pressure of the liquid also increases.

When the liquid pressure falls below the vapor pressure, the vapor bubbles appear and form cavitation. If you go back to the triple point, we studied, you can understand all these things. Water at normal atmospheric pressure will boil at 100 degrees Celsius because its vapor pressure rises to atmospheric pressure at that temperature.

Impacts of thermal expansion

- Thermal expansion is important in engineering systems, particularly in situations involving buoyancy forces.

- Density variations caused by thermal expansion, under the influence of gravity, create buoyancy forces. These buoyancy forces can drive fluid motion, known as natural convection.

- The Grashof number (Gr) is a dimensionless parameter that represents the ratio of buoyant forces squared to viscous forces squared, incorporating the thermal expansion coefficient and a reference temperature difference. Phenomena like Rayleigh-Bénard instability, which involves thermo-convective motions in a fluid layer subjected to a temperature gradient, are driven by these buoyancy forces resulting from thermal expansion

The last part is the impact of thermal expansion, which is important in engineering systems, particularly in situations where buoyancy forces are involved. The density variation causes thermal expansion under the influence of gravity, creating buoyancy force. These buoyancy forces can drive fluid motion, known as natural convection.

To Recapitulate

- What is Density and its units?
- Define Specific weight and Specific gravity.
- What is Viscosity and its various types?
- What is No-Slip Condition in Fluid Motion?
- Define and explain about Surface Tension.
- What is Capillarity of a fluid?
- State and explain Compressibility in Fluid Flow.
- What are Vapor Pressure and Cavitation?
- Explain about Specific heat and Thermal conductivity in fluids.
- What is Significance of thermal expansion in fluids?
- What is Ideal Fluid and Ideal Fluid Assumption?
- What are the effects of temperature?

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Friends, to recap what we saw in this lecture: we discussed density and its uses. Then we covered specific weight, specific gravity, and viscosity. In viscosity, we discussed different types: static viscosity, dynamic viscosity, and kinematic viscosity. Then we examined the no-slip condition, surface tension, capillary action, compressibility, vapor pressure, and cavitation.

Then we saw the importance of specific heat, thermal conductivity, and the significance of thermal expansion in fluids. What is an ideal fluid? What is the difference between a real and an ideal fluid? Finally, with most of the properties we discussed, we saw the effect of temperature. So, friends, we have used all these reference materials to prepare the slides.

Thank you very much.