Fluid Properties

Vapour Pressure

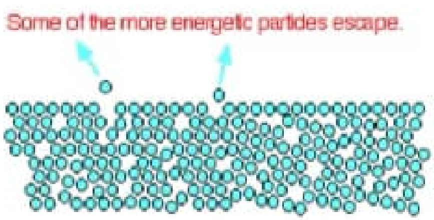
- ***Vapour pressure (P_v):*** Pressure exerted by its vapour in phase **equilibrium** with its liquid at a given temperature.

- P_v is a property of the pure substance.

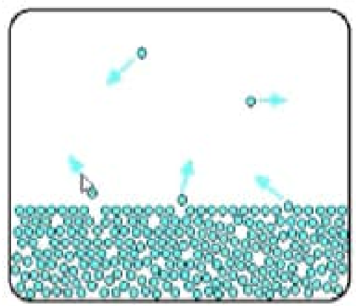
- $P_v = P_{sat}$ (Saturation pressure of the liquid)

- $P_v = f(T)$

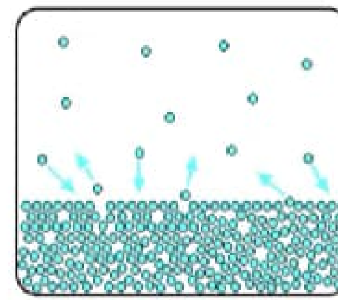
In equilibrium, when these particles hit the walls of the container, they exert a pressure. This pressure is called the vapour pressure of the liquid.



Some of the more energetic particles on the surface of the liquid can be moving fast enough to escape from the attractive forces holding the liquid together. They evaporate



Particles continue to break away from the surface of the liquid - but this time they are trapped in the space above the liquid



As the gaseous particles bounce around, some of them will hit the surface of the liquid again, and be trapped there. There will rapidly be an equilibrium set up.

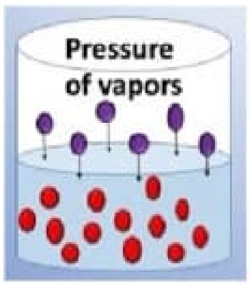
No. of particles leaving the surface = No. rejoining it.

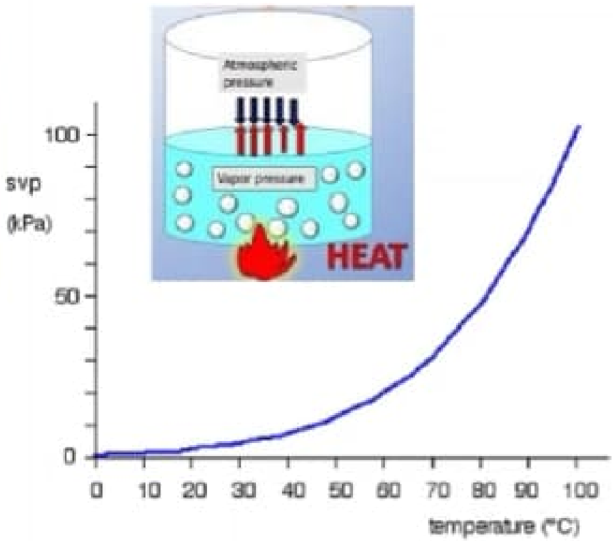
Fluid Properties

Vapour Pressure

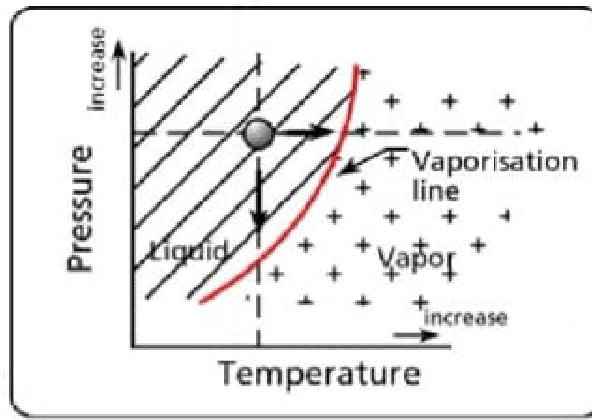
- $P_v = f(T)$ $\quad T \rightarrow \uparrow \quad$ *Average energy of particles* $\rightarrow \uparrow$

Number of particles escaped from surface $\rightarrow \uparrow \quad P_v \rightarrow \uparrow$





Vapour pressure of water vs. temperature



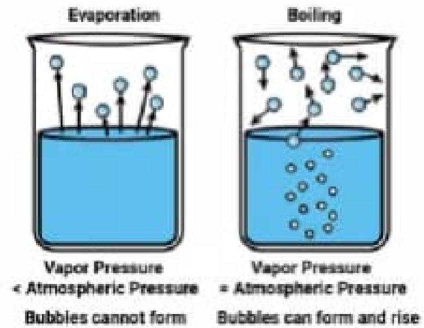
Vapor pressure vs. temperature

Fluid Properties

Vapour Pressure

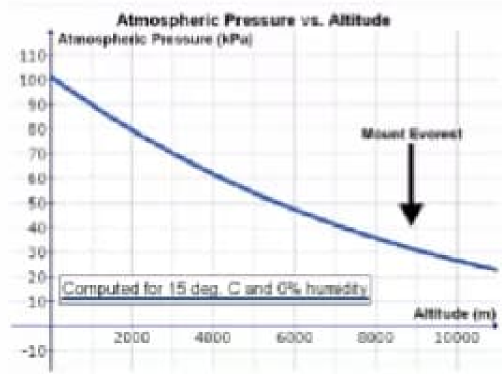
- **Liquid evaporates: Liquid pressure > P_v** (only exchange between liquid and vapour is at the interface)

- **Liquid boils: Liquid pressure < P_v** (vapour bubbles begin to appear in the liquid)



- ***At atmospheric conditions (30 °C) for water:***
- Liquid pressure = P_{atm} = 101325 Pa; P_v = 4248 Pa
- Liquid pressure > P_v
- **Water can only evaporate!**

- ***When water is heated to 100 °C under atmospheric conditions:***
- Liquid pressure = P_{atm} = 101325 Pa; P_v = 101421 Pa
- Liquid pressure < P_v
- **Water starts boiling and vapour bubbles can be seen!**



- ***At Mount Everest Summit (72 °C):***
- Liquid pressure = P_{atm} = 33700 Pa; P_v = 34002 Pa
- Liquid pressure < P_v
- **Water starts boiling and vapour bubbles can be seen!**

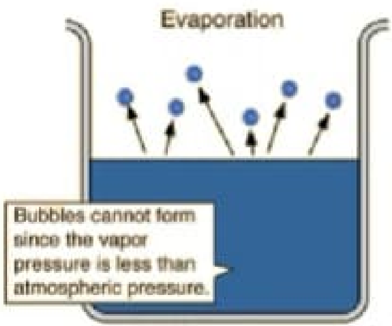
Fluid Properties

Evaporation

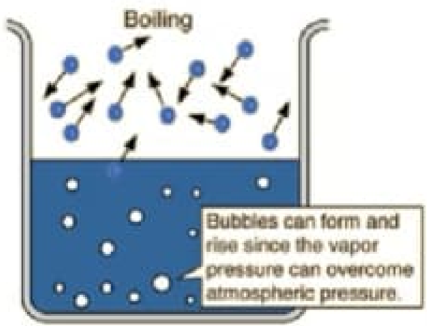
- Occurs at any temperature.
- Takes place on the surface of the liquid.
- No bubbles are formed.
- Happens slowly.
- Thermal energy supplied by the surrounding.
- Causes cooling.
- Condition: **Liquid pressure > P_v**
- Decreasing the P_{atm} increases the rate of evaporation.

Boiling

- Occurs at a definite temperature (T_b).
- Takes place throughout the liquid.
- Bubbles of vapours formed.
- Happens quickly.
- Thermal energy supplied by an energy source.
- Temp. remains constant during boiling.
- Condition: **Liquid pressure < P_v**
- Decreasing the P_{atm} lowers the boiling point.



❑ **Evaporation and boiling require latent heat of vaporization.**



Fluid Properties

Cavitation

- Local vapourization (or bubble formation) takes place in liquid flow systems if pressure drops below the vapour pressure.

- ***The vapour bubbles (cavitation bubbles) collapse as they are swept away from the low-pressure regions.***

- It results in the generation of highly destructive, extremely high-pressure waves.

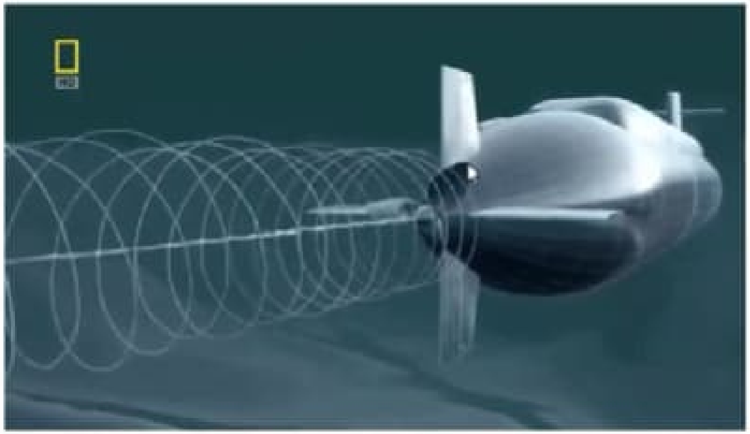
- This phenomenon is called **cavitation**.

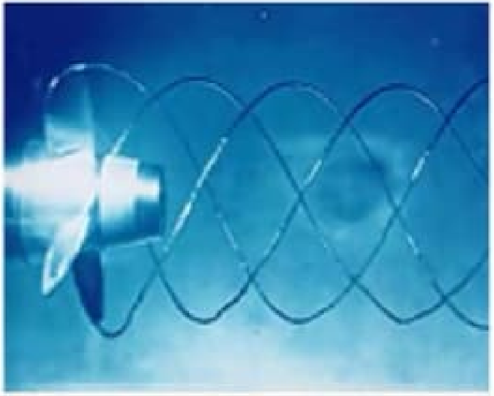
- Cavitation results in **drop in performance** and even **corrosion of the impeller blades**.

- Cavitation is **noisy** and can cause **structural vibrations**.

- So, it is one of an **important criterion or consideration in the design of hydraulic turbines and pumps.**

Fluid Properties

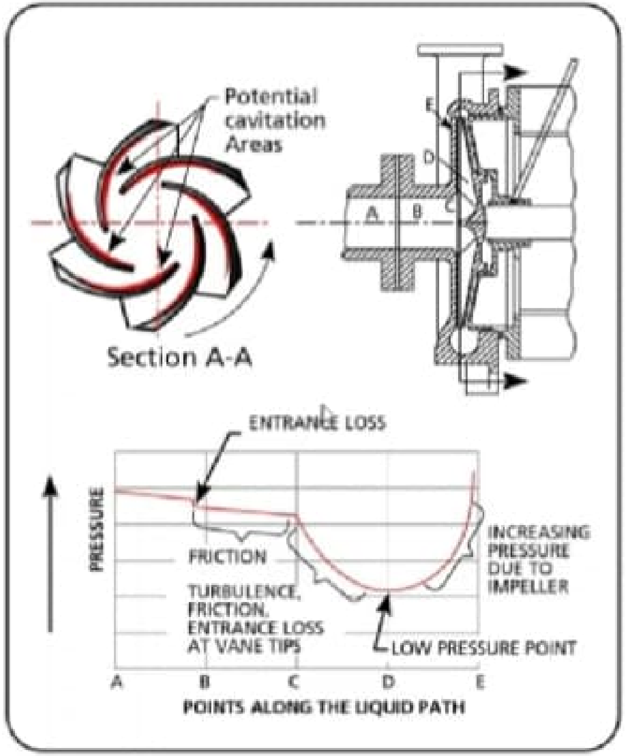




Fluid Properties

Cavitation

- The same effect can sometimes be seen in control valves because they have a similar pressure drop profile, if the pressure is insufficient at the control valve inlet cavitation will also occur.



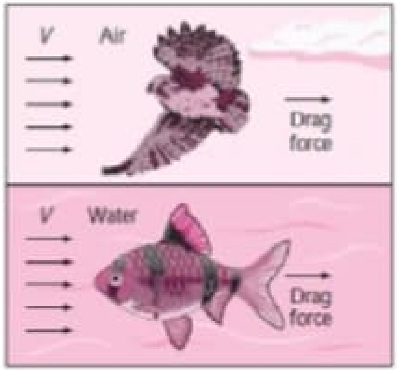
Pressure profile at the pump entrance

Fluid Properties

Viscosity

- **Viscosity:** *Property of fluid that represents the internal resistance of a fluid to motion.*

- **Drag force:** It is the force exerted by a flowing fluid on a body in the flow direction.

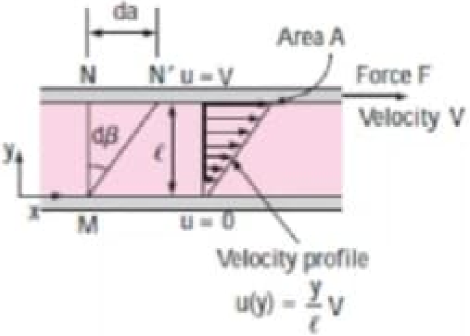


- Amount of drag force also depends on viscosity.

- Consider two parallel plates separated by distance l immersed in fluid. Shear stress (τ) acting on the fluid layer in contact with upper layer is

$$\tau = \frac{F}{A}$$

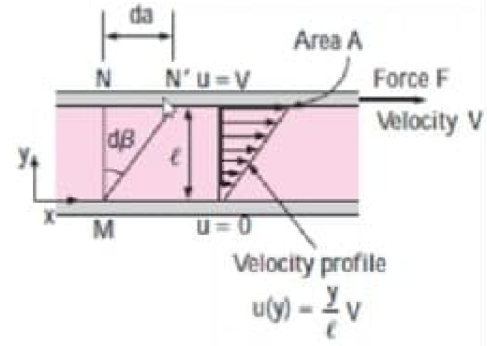
F: parallel force applied to upper plate
A: contact area between the plate and the fluid.



- The fluid layer deforms continuously under the influence of shear stress.

Fluid Properties

Viscosity



- In steady, laminar flow, the fluid velocity varies linearly between 0 and V.

$$u(y) = \frac{y}{l}V \qquad \frac{du}{dy} = \frac{V}{l}$$

- Fluid particles along the line MN rotate through a differential angle $d\beta$ during a differential time dt. Upper plate moves a differential distance da ($=Vdt$).

- ***Angular displacement/deformation/shear strain:*** $$d\beta \approx tan\beta = \frac{da}{l} = \frac{Vdt}{l} = \frac{du}{dy}dt$$

- **Shear strain rate (rate of deformation):** $$\frac{d\beta}{dt} = \frac{du}{dy}$$

- **For most fluids (Newtonian)**, shear stress is directly proportional to the rate of deformation (shear strain rate). $$\tau \propto \frac{d\beta}{dt} \qquad \tau \propto \frac{du}{dy}$$

- ***Most common fluids like air, water and oils are Newtonian fluids.***

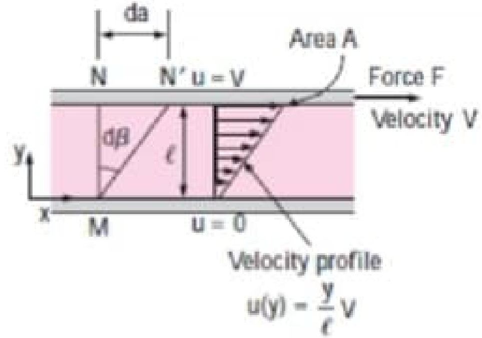
Fluid Properties

Viscosity

- In 1-D shear flow of Newtonian fluids:

$$\tau \propto \frac{du}{dy} \qquad \tau = \mu \frac{du}{dy} \qquad (N/m^2)$$

Newton's law of viscosity



- **μ:** proportionality constant called ***coefficient of viscosity*** or **dynamic viscosity** or **absolute viscosity** of the fluid.

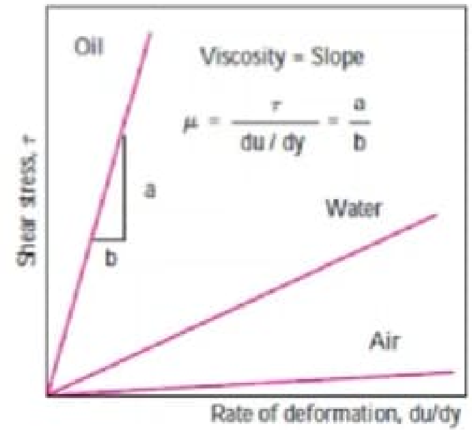
- ***Unit of μ: kg/m.s or N.s/m² or Pa.s or poise.***

- *1 poise = 0.1 Pa.s; 1 centipoise = 0.01 poise*

- ***Viscosity is independent of the rate of deformation.***

- Shear force acting on a Newtonian fluid layer (or force actir on the plate):

$$F = \tau A = \mu A \frac{du}{dy} = \mu A \frac{V}{l} \qquad (N)$$



For water at 20 °C:
μ = 1 centipoise = 0.001 Pa.s

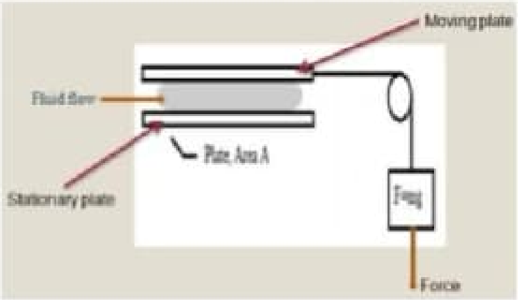
Fluid Properties

Viscosity

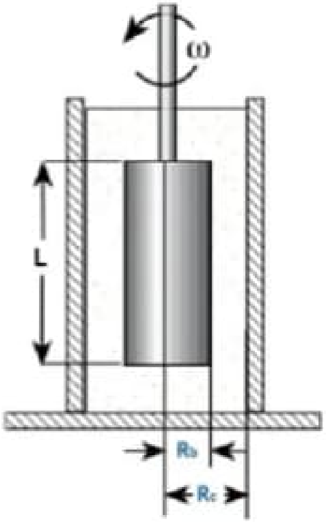
$$F = \tau A = \mu A \frac{du}{dy} = \mu A \frac{V}{l} \qquad (N)$$

- ***Viscosity determination:*** Above relation can also be used to calculate μ when force F is measured.

- *Under identical conditions, the force F will be different for different fluids.*



Parallel plate viscometer



Rotational viscometer

Fluid Properties

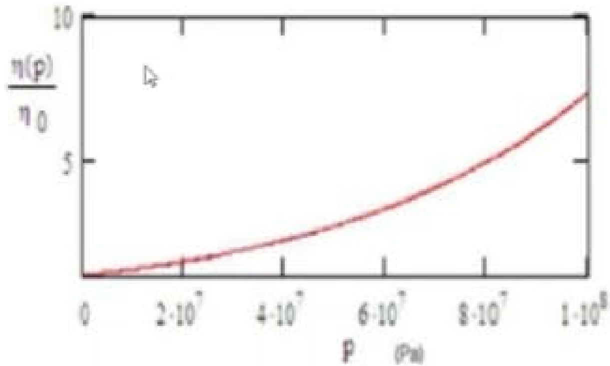
Dynamic viscosity: Effect of Pressure

- ***In general,*** $\mu = f(T, P)$ $\tau = \mu \frac{du}{dy}$
- Although the dependence on pressure is rather weak.
- ***Liquids:*** *Dynamic viscosity is practically independent of pressure (except at extremely high pressure)*

The Barus equation for lubricants

$$\mu_p = \mu_o e^{\alpha p}$$

μ_p: viscosity at pressure 'p' (Pa.s)
μ_o: viscosity at atm pressure (Pa.s)
α: pressure-viscosity coefficient (Pa^{-1})
p: pressure of concern (Pa)

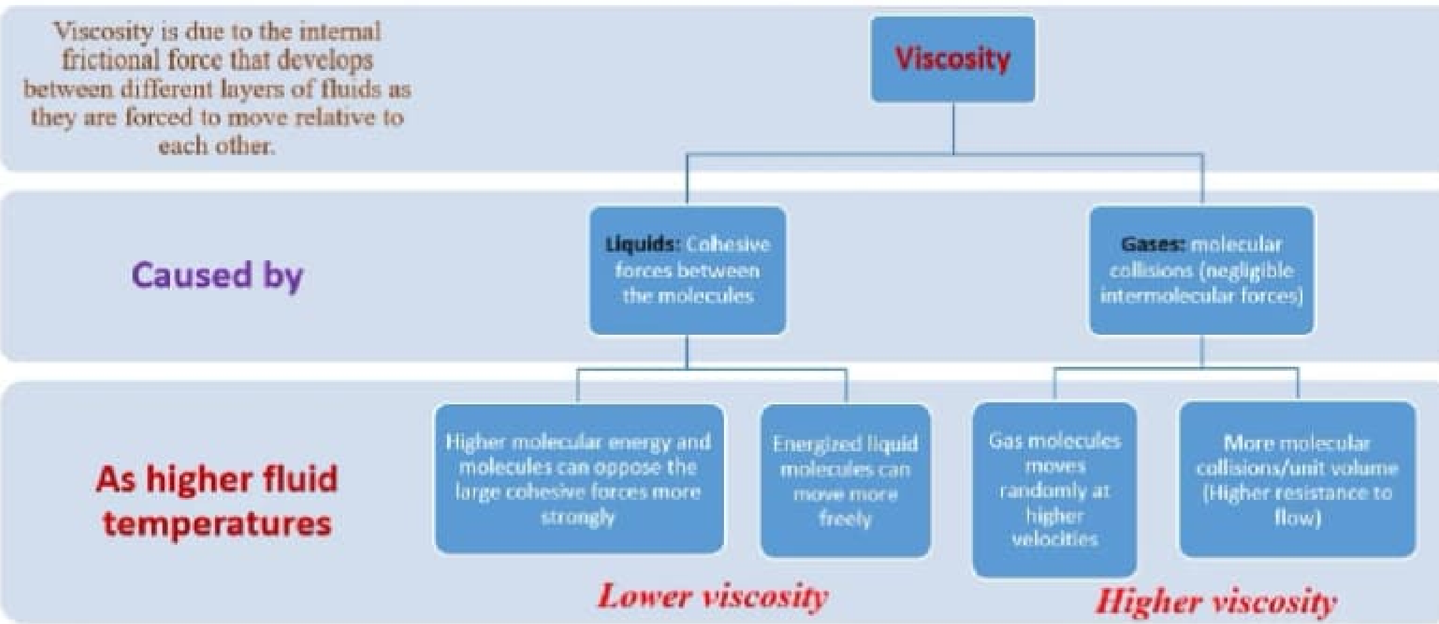


- ***Gases:*** *Dynamic viscosity is independent of pressure (except at high pressure).*

Fluid Properties

Dynamic viscosity: Effect of Temperature

- *In general,* $\mu = f(T, P)$ $\qquad \tau = \mu \dfrac{du}{dy}$
- *Viscosity varies greatly with temperature.*



Fluid Properties

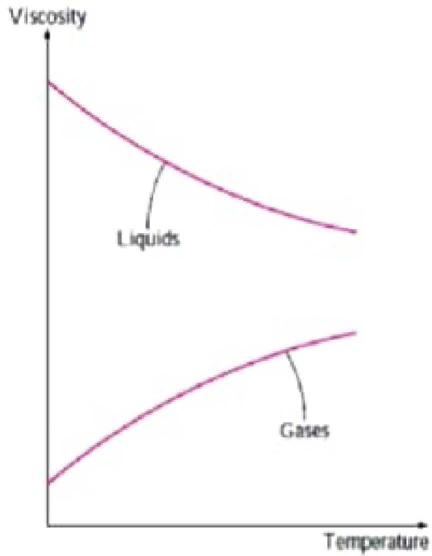
- In general, $\mu = f(T, P)$
- ***Viscosity varies greatly with temperature.***
- ***Liquids:***

$$\mu = a10^{b(T-c)}$$

- ***Gases:***

$$\mu = \frac{aT^{1/2}}{1 + b/T}$$

Sutherland correlation



- Liquids, in general, are much more viscous than gases.

Dynamic viscosities of some fluids at 1 atm and 20°C (unless otherwise stated)

Fluid	Dynamic Viscosity μ, kg/m · s
Glycerin:	
−20°C	134.0
0°C	10.5
20°C	1.52
40°C	0.31
Engine oil:	
SAE 10W	0.10
SAE 10W30	0.17
SAE 30	0.29
SAE 50	0.86
Mercury	0.0015
Ethyl alcohol	0.0012
Water:	
0°C	0.0018
20°C	0.0010
100°C (liquid)	0.00028
100°C (vapor)	0.000012
Blood, 37°C	0.00040
Gasoline	0.00029
Ammonia	0.00015
Air	0.000018
Hydrogen, 0°C	0.0000088

Fluid Properties

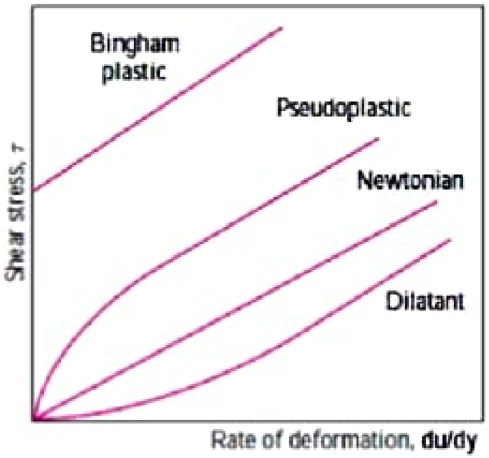
Newtonian Fluids

- In 1-D shear flow of Newtonian fluids:

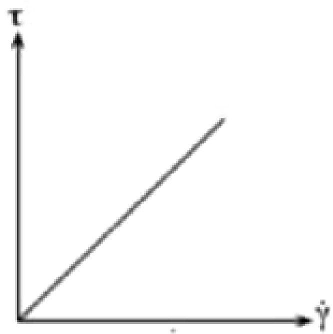
$$\tau \propto \frac{du}{dy} \qquad \tau = \mu \frac{du}{dy} \qquad (N/m^2)$$

- μ: proportionality constant called *coefficient of viscosity* or **dynamic viscosity** or **absolute viscosity** of the fluid.

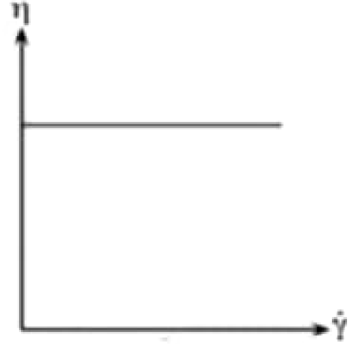
- ***Most common fluids like air, water and thin motor oils are Newtonian fluids.***



Slope of a curve at a point is the apparent viscosity of the fluid at that point



Shear stress (τ) vs rate of shear strain (du/dy)



Dynamic viscosity (μ) vs rate of shear strain (du/dy)