Fluid Mechanics I /2nd stage
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1st Course Contents		
	Subject	**المحتويات**
1	General Introduction to Fluid Mechanics	مدخل الى علم الموائع
2	Fluid Static and Pressure Applications	الموائع في حالة السكون وتطبيقات الضغط
3	Forces on Immersed Bodies and Surfaces	القوى على الاجسام والسطوح المغمورة
4	Equilibrium of Floating Bodies	استقرارية الاجسام الطافية
5	Accelerated Fluid and Relative Motion	الموائع عند التعجيل وحركتها النسبية
6	Dimensional Analysis and Similarity	التحليل البعدي والتشابه
2nd Course Contents		
1	Introduction to Fluid Motion	مدخل الى حركة الموائع
2	Continuity Equation	معادلة الاستمرارية
3	Equation of Motion and Their Applications	معادلات حركة الموائع و تطبيقاتها
4	Motion of Viscous Fluids in Conduits	حركة الموائع اللزجة في المسالك
5	Friction Losses in Pipes	خسائر الجريان في الانابيب
6	Analysis of Piping System	تحليل شبكات الانابيب
7	Definition of Boundary Layer	تعريف الطبقة المتاخمة

Recommended books

1- "Fluid mechanics" by V.L. Streeter
2- "Fluid Mechanics" Frank. M. White, 6th edition.
3- "Fundamentals of Fluid Mechanics" 5th edition B. R. Munson et al - John Wiley and Sons.
4- "ميكانيك الموائع" د. كامل الشماع طبعة دار الكتب في جامعة البصرة

Brief History

The need to have some understanding of fluid mechanics started with the need to obtain water supply. For example, people realized that wells have to be dug and crude pumping devices need to be constructed. Later, a large population created a need to solve waste (sewage) and some basic understanding was created. At some point, people realized that water can be used to move things and provide power. When cities increased to a larger size, aqueducts were constructed. These aqueducts reached their greatest size and grandeur in those of the City of Rome and China.

Fluids in technology

1. Internal combustion engines—all types of transportation systems
2. Turbojet, scramjet, rocket engines—aerospace propulsion systems
3. Waste disposal
   (a) chemical treatment
   (b) incineration
   (c) sewage transport and treatment
4. Pollution dispersal—in the atmosphere (smog); in rivers and oceans
5. Steam, gas and wind turbines, and hydroelectric facilities for electric power generation
6. Pipelines
   (a) crude oil and natural gas transferal
   (b) irrigation facilities
   (c) office building and household plumbing
7. Fluid/structure interaction
   (a) design of tall buildings
   (b) continental shelf oil-drilling rigs
   (c) dams, bridges, etc.
   (d) aircraft and launch vehicle airframes and control systems
8. Heating, ventilating and air-conditioning (HVAC) systems
9. Cooling systems for high-density electronic devices—digital computers from PCs to supercomputers
10. Solar heat and geothermal heat utilization
11. Artificial hearts, kidney dialysis machines, insulin pumps
12. Manufacturing processes
    (a) spray painting automobiles, trucks, etc.
    (b) filling of containers, e.g., cans of soup, cartons of milk, plastic bottles of soda
    (c) operation of various hydraulic devices
    (d) chemical vapor deposition, drawing of synthetic fibers, wires, rods, etc.

Chapter 1

General Introduction to Fluid Mechanics

Dimensions:

Mass	Length	Time	Force
M	L	T	F

Types of Systems:

i: M-L-T

ii: F-L-T

Units:

System/Quantity	Mass	Length	Time	Force
Standard International (S.I)	kg	m	sec	N
British System (English)	slug	ft	sec	lb
French system (c.g.s)	gm	cm	sec	dyne
Kilogram weight system	kg	m	sec	kgw

Length

1 ft = 12 inches or 12”

1 inch = 2.54 cm

1 ft = m

mile = 1609 m

Mass

1 slug = 14.59 kg

1 ton = 1000 kg

1 kg = 1000 g

Volume

1 m^3 = 1000 liters = 10^6 cm^3

1 gallon = 3.785 liters

Gravitational acceleration

g = 9.81 m/sec^2 = ft/sec^2

Force

1 N = 1 $kg.m/sec^2$

1 N = 10^5 dyne

1 N = (1/4.44) lb

1 N = (1/9.81) kgw

1 kgw = lb

Definition of Fluid

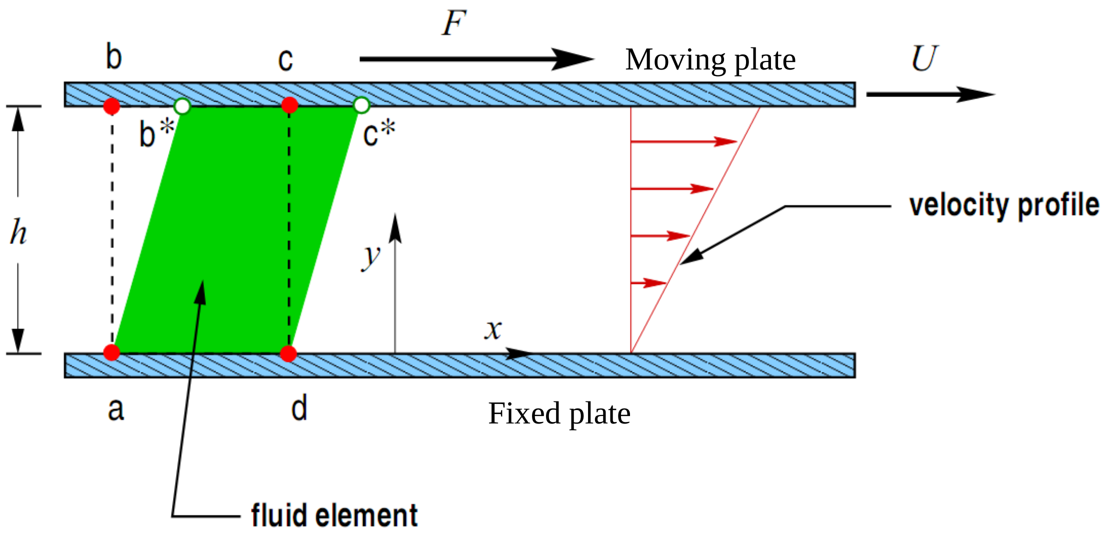
A fluid is a substance that deforms continuously when subjected to a shear stress.

Shear force

The force component tangent to a surface, and this force divided by the area of the surface is the average shear stress over the area.

Note :

The fluid in immediate contact with a solid boundary has the same velocity as the boundary i.e. there is no slip at the boundary.



The fluid in the area a-b-c-d flows to the new position a-b*-c*-d, each fluid particle varying uniformly from zero at the fixed plate to *U* at the moving plate.

$$F\alpha \frac{A\,U}{h}$$

Where *A* is the surface area of the moving plate. The proportionality constant depends on fluid type, it is generally termed as μ.

$$Let \quad \tau = \frac{F}{A} : is\ the\ shear\ stress$$

$$\therefore\ \tau = \mu \frac{U}{h} : is\ the\ shear\ stress$$

$\frac{U}{h}$: is the ratio of angular velocity of line ab or it is the *rate of deformation* of fluid

$$\frac{U}{h} = \frac{du}{dy}\ \ for\ linear\ velocity\ distribution\ only$$

$$\rightarrow \tau = \mu \frac{du}{dy} = \mu \frac{U}{h}$$

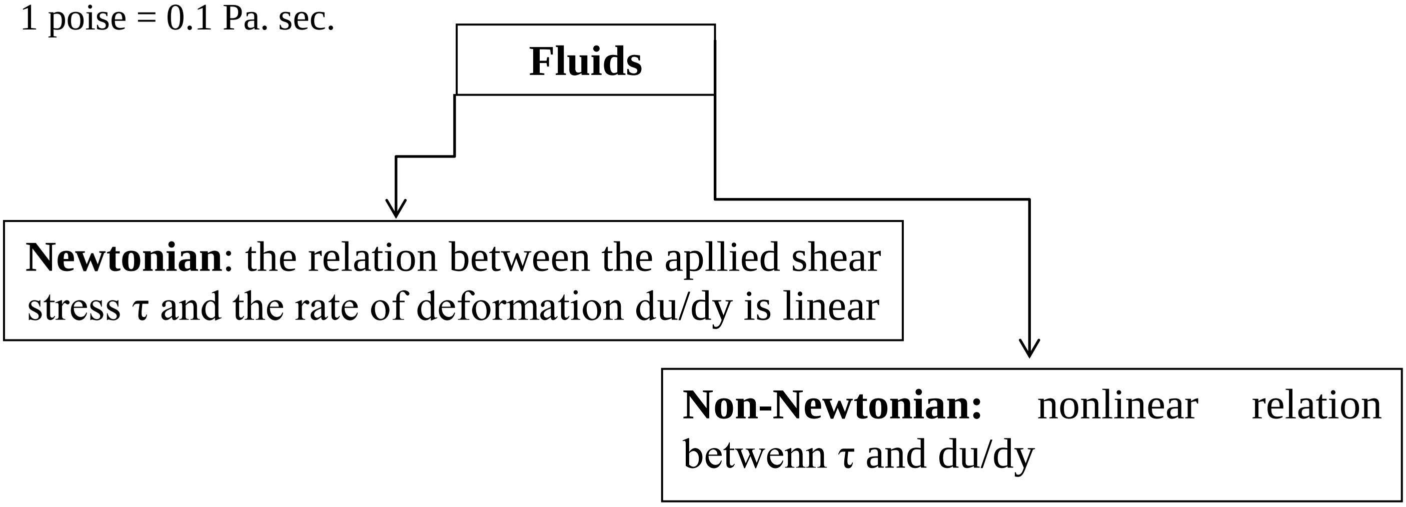
Now, μ is called the viscosity (or dynamic viscosity) of fluid, and the relation above is the Newton’s law of viscosity.

Units of viscosity:

μ =τ/(U/h) : (N/m^2)/(m/sec/m) = $\frac{N}{m^2}.sec$ = Pa. sec (in SI)

or $\mu\ =\ \frac{gm}{cm.sec} = \frac{dyne\ sec.}{cm^2} = poise$

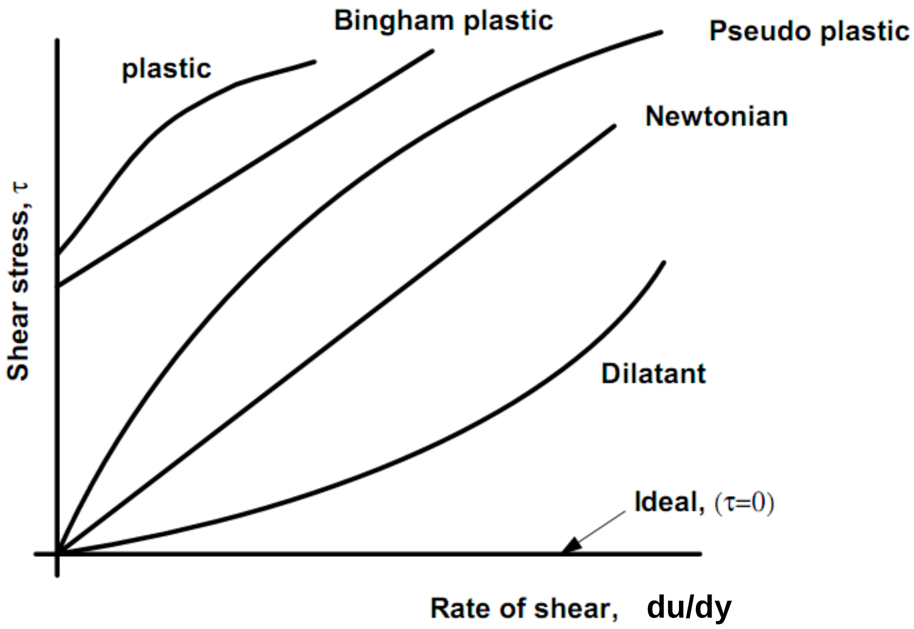
1 poise = 0.1 Pa. sec.

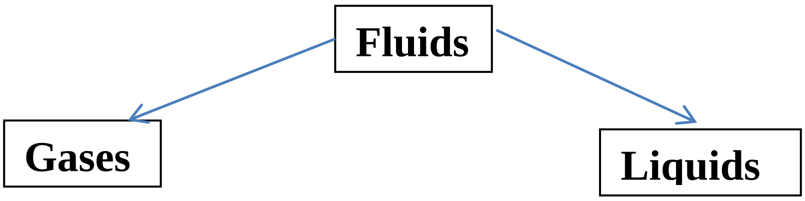


Fluids

Newtonian: the relation between the apllied shear stress τ and the rate of deformation du/dy is linear

Non-Newtonian: nonlinear relation betwenn τ and du/dy





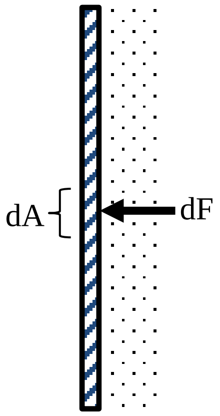
<u>Gases:</u> occupy the whole volume of container. The viscosity increases with increasing temperature, due to the increase of momentum change between layers.

<u>Liquids:</u> form a free surface. The viscosity decreases with increasing temperature. Because in liquids, the molecules are so much closer than in gases, so with temperature increase, the cohesive forces hold the molecules may decrease.

Important Variables in Fluid Mechanics:

Pressure

is the normal force pushing against a plane area divided by the area. It results from the continuous movement of molecules.



$$P = \frac{dF}{dA}$$

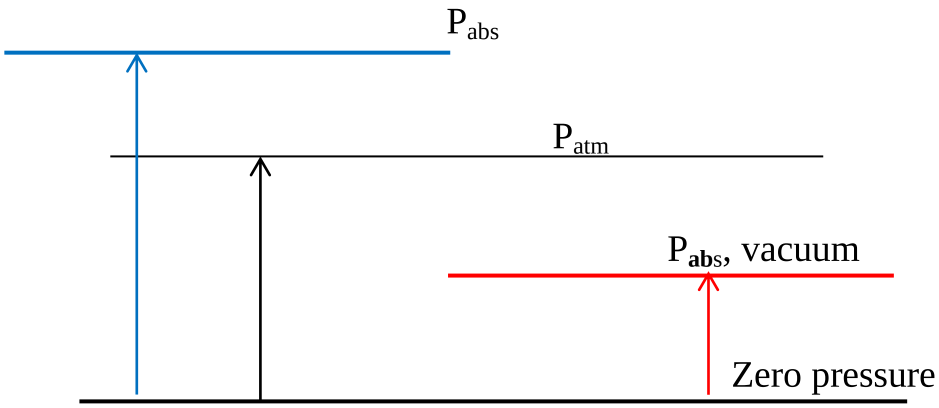
Units:

- N/m^2 (Pascal), lb/ft^2 (psf), lb/in^2 (psi), or bar
- 1 bar = 10^5 Pascal
- Sometimes, the pressure is expressed as a pressure head, m-fluid
- In industrial, they may used $\frac{kg}{cm^2} = \frac{kgf}{cm^2} = \frac{1 \times 9.81\ N}{cm^2} = 98.1\ kPa$

The pressure is measured by device called, Barometer, the reading of Barometer is called: gauge pressure, Pg. The gauge pressure is referenced by the atmospheric pressure (as zero pressure). The summation of the gauge and atmospheric pressure is called the absolute pressure.

$$P_{abs} = P_{atm} + P_g$$

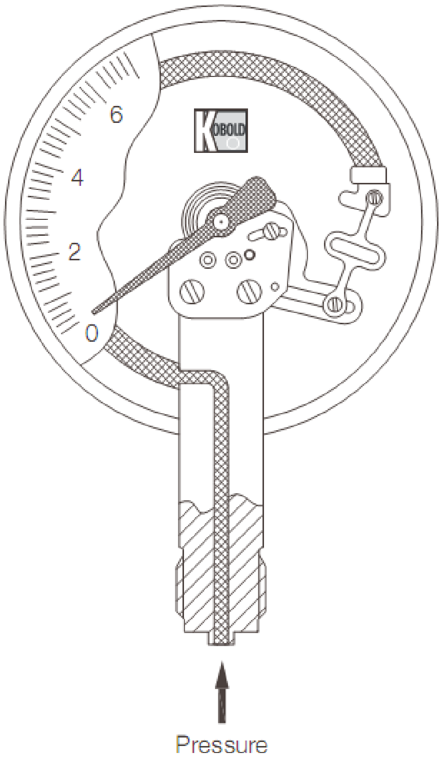
Note: when the absolute pressure is less than the atmospheric pressure (i.e. Pg is negative value), we say ***vacuum pressure***. Hence the maximum possible vacuum that can be attained equals to P_{atm}.



*The atmospheric pressure is 101.7 kPa or 1.017 bar

Bourdon Gauge

Bourdon gauge is a typical device used for measuring gauge pressure. It consists of a hollow, curved, flat metallic tube closed at one end; the other end in connected to the pressure to be measured. A scaled plate and pointer are needed for indication.



Mass density (ρ): the quantity of matter contained in a unit volume of the substance.

$$\rho = \frac{Mass}{Volume} = \frac{m}{V} : \text{kg/m}^3$$

Kinematic viscosity (ν): is the dynamic viscosity μ divided by the density ρ

$$\nu = \frac{\mu}{\rho}$$

Units:

$$\frac{N.sec/m^2}{kg/m^3} = \frac{m^2}{sec}$$

$1\text{cm}^2/\text{sec}$ = St (Stokes)

1 St = 10^{-4} m^2/sec

1 cSt = 10^{-6} m^2/sec

Relative density or specific gravity(S of S.g): the ratio of mass density of a substance to a standard mass density. Generally, the standard mass density is taken of water at 4 ^{o}C. ρ_{wtare} at 4^{o}C = 1000 kg/m^3 .

Specific Volume (v): is the reciprocal of the density; that is, the volume occupied by unity mass of fluid

$v = \frac{1}{\rho}$, m^3/kg

Specific weight (γ): is the weight per unit volume.

$$\gamma = \frac{weight}{Volume} = \frac{mg}{V} = \rho g$$

Units: N/m^3

Bulk Modulus of compression (E)

$$E = \frac{Change\ in\ pressure}{volumetric\ strain} = \frac{dP}{\left|\frac{dV}{V}\right|}$$

Units: N/m^2

Perfect Gas

The perfect gas is defined as a substance that satisfies the perfect gas law.

$$P\,v = R\,T , \qquad \text{or} \qquad P = \rho\,R\,T$$

T: must be absolute (in Kelvin)

R is the gas constant (J/kg.K)

Vapor pressure (**Pv*****)***

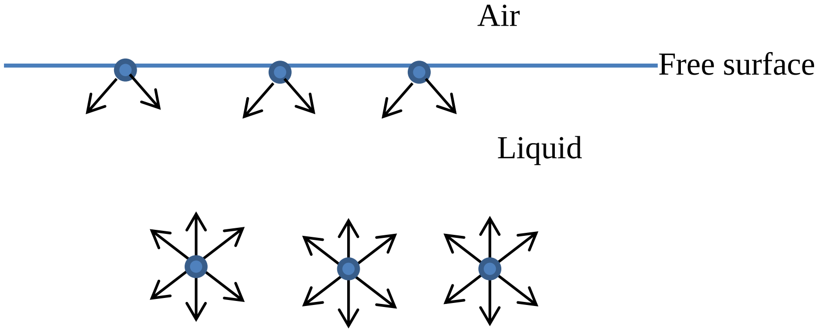
The pressure value at which the liquid molecules escaping from the liquid surface. The vapor pressure of a given fluid increases with temperature. For example, table below, displays some values of water vapor pressures at different temperatures,

Temperature (^oC)	Pv (Pa)
0	588.3
5	882.54
10	1176.36

Surface Tension (σ)

Surface tension of liquid is due to the force of attraction between similar molecules, called cohesion, and those between different molecules, called adhesion.

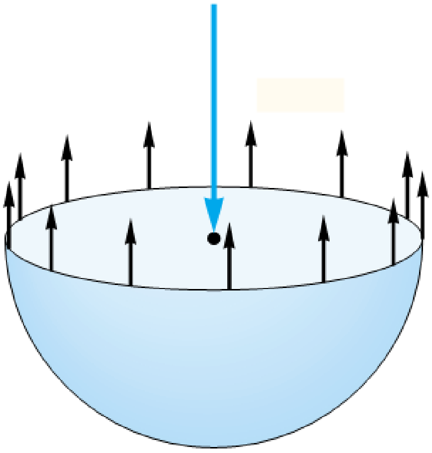
- The interior molecules are in balance.
- Near a free surface, the cohesion force between liquid molecules is much greater than that between an air molecule and a liquid molecule, hence, there is a resultant force on a liquid molecule acting toward the interior of the liquid. This force called surface tension.
- It is the force that holds a water droplet or mercury globule together.
- It is the force that form a film at the interface between a liquid and gas or two immiscible liquids
- This force is proportional to the product of the surface tension coefficient σ and the length of the free surface.



For a spherical droplet: radius R, internal pressure P, the force balance on a hemispherical free body gives:

$$\pi R^2 P = 2\pi R \sigma$$

$$\therefore P = \frac{2\sigma}{R}$$

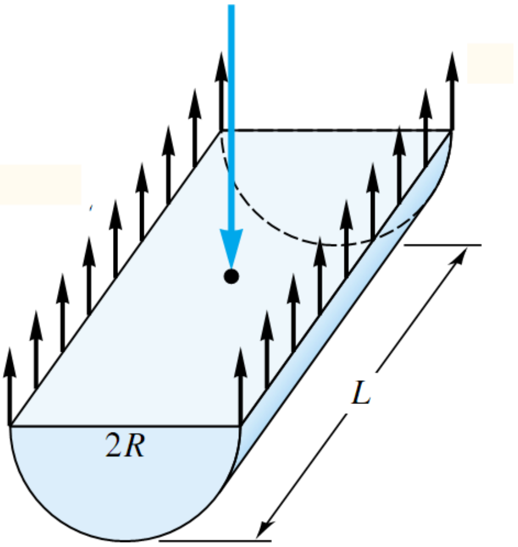


Fore a cylindrical liquid jet of radius R, the force balance gives:

$$2RL\,P = \sigma\, 2L$$

$$\therefore P = \frac{\sigma}{R}$$

Hence, the action of surface tension is to increase the pressure within a droplet of liquid or within a small liquid jet.

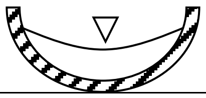
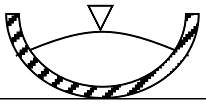


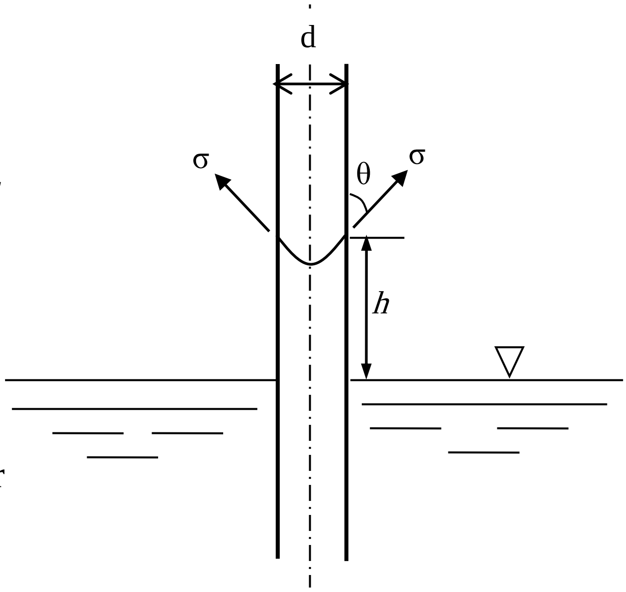
Capillarity: capillarity is mainly caused by the surface tension action. It is useful to re-mention here the attraction force types.

Attraction force

Adhesion: between the fluid and the boundary

Cohesion: between the fluid particles

Adhesion > Cohesion	Cohesion > Adhesion
	



Capillarity in a tube:

Balancing forces in y direction:

1- Surface tension force = $\pi d\sigma\ cos\theta$

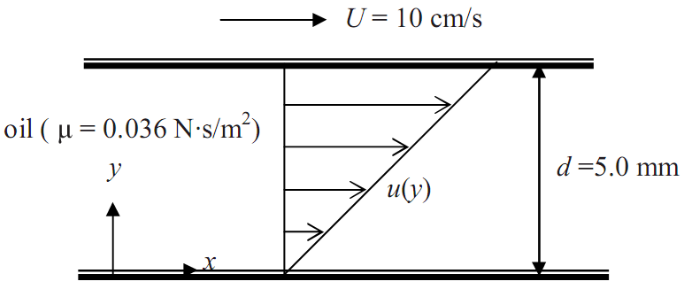
2- Force due to weight = $mg = \rho V g = \rho \frac{\pi}{4} d^2 hg$

$$\pi d\sigma\ cos\theta = \rho \frac{\pi}{4} d^2 hg$$

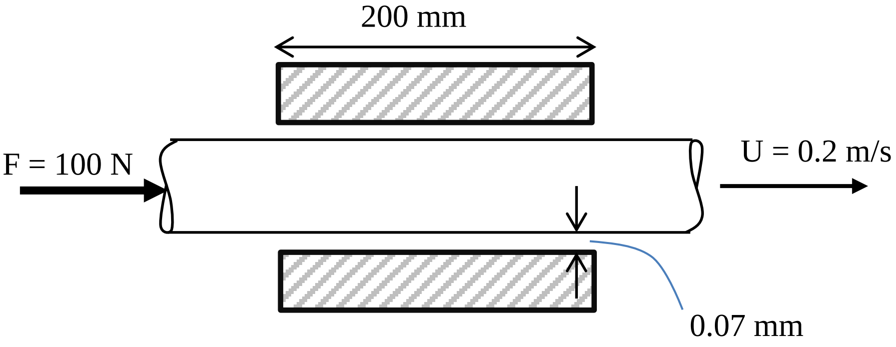
$$\therefore h = \frac{4\sigma \cos\theta}{\rho g d}$$

For example: the surface tension coefficient of water Equals to 0.074 N/m at 20 ^{o}C.

example 1.1: Determine the shear stress exerted on the bottom fixed surface shown in figure.



Example 1.2: Determine the dynamic viscosity of fluid between the 75 mm-diameter shaft and sleeve shown in figure. The clearance between the shaft and sleeve is 0.07 mm



Example 1.3: A disk of radius R rotates at angular velocity ω inside an oil bath of viscosity μ as shown in figure. Derive an expression for the viscous torque on the disk. Neglect shear stress on the outer disk end.