CHPTER ONE

Introduction

1.1 Introduction

Chemical engineering has to do with industrial processes in which raw materials are changed or separated into useful products.

The chemical engineer must develop, design, and engineer both the complete process and the equipment used; choose the proper raw materials; operate the plants efficiently, safely, and economically; and see to it that products meet the requirement set by the customers**.**

A Fluid is any substance that conforms to the shape of its container and it may be defined as a substance that does not permanently resist distortion and hence, will its shape. Gases and liquids and vapors are considered to have the characteristics of fluids and to obey many of the same laws.

Fluid : is a substance which deforms continuously under the influence of shearing forces or shear stress, it includes liquid and gases.
A stress is defined as a force per unit area, acting on an infinitesimal surface element. It has both magnitude (force per unit area) and direction , and the direction is relative to the surface on which the stress acts.

Solid and Fluid Distinction

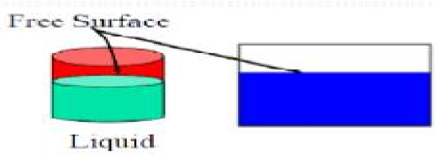
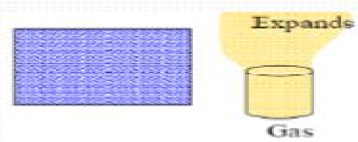
□-Molecular of solid are much closer together than fluid

□-Solid tries to return to its original shape due to large attraction between solid molecules

□-Fluids have very week inter-molecular attraction so that fluids flow under the applied force.

□**Fluid Mechanic** is a study of what will happen when a force applied on a fluid when its rest or moving.

□ Liquids differs greater resistance to compression change while gases are easily to compressed

Liquid	Gas
Almost incompressible Forms a free surface area	Easy to compressed Fills any vessel in which it placed
	

Dimension: Generalization of "unit" telling us what kind of units are involved in a quantitative statement.
The primary quantities of fluid are:

Quantity	**Dimension**	**Units**
Mass	M	kg, gm, Ib
Length	L	km, m, ft
Time	T	s, hr
Temperature	θ	C, K, cal
Derived quantity		
Force (mass*acceleration)	$F=MLT^{-2}$	N, dyn, Ib_f

System Unit

System	**Mass**	**Length**	**Time**	**Force**
System International (SI)	kg	m	s	N
French System	gm	cm	s	dyn
British Gravitational (BG)	slug	ft	s	Ibf
English Engineer (EE)	Ibm	ft	s	pdl

In the process industries, many of the materials are in fluid form and must be stored, handled, pumped, and processed, so it is necessary that we become familiar with the principles that govern the flow of fluids and also with the equipment used. Typical fluids encountered include water, acids, air, Co_2, oil, slurries.

If a fluid affected by changes in pressure, it is said to be "compressible fluid", otherwise, it is said to be "incompressible fluid".

Most liquids are incompressible, and gases are can considered to be compressible fluids. However, if gases are subjected to small percentage changes in pressure and temperature, their densities change will be small and they can be considered to be incompressible fluids. The fluid mechanics can be divided into two branches;

"Fluid static" that means fluid at rest, and "Fluid dynamics" that means fluid in motion.

Basic Concepts

I. FUNDAMENTALS

A. Basic Laws

The fundamental principles that apply to the analysis of fluid flows are few and can be described by the ''conservation laws'':

1. Conservation of mass

2. Conservation of energy (first law of thermodynamics)

3. Conservation of momentum (Newton's second law)

To these may also be added:

4. The second law of thermodynamics

5. Conservation of dimensions (''fruit salad'' law)

6. Conservation of dollars (economics)

These conservation laws are basic and, along with appropriate rate or transport models (discussed below), are the starting point for the solution of every problem. Although the second law of thermodynamics is not a ‘‘conservation law,’’ it states that a process can occur spontaneously only if it goes from a state of higher energy to one of lower energy. In practical terms, this means that energy is dissipated (i.e., transformed from useful mechanical energy to low-level thermal energy) by any system that is in a dynamic (non equilibrium) state. In other words, useful (mechanical) energy associated with resistance to motion, or ‘‘friction,’’ is always ‘‘lost’’ or transformed to a less useful form of (thermal) energy. In more mundane terms, this law tells us that, for example, water will run downhill spontaneously but cannot

run uphill unless it is ‘‘pushed’’ (i.e., unless mechanical energy is supplied to the fluid from an exterior source).

1.2 Physical Properties of Fluids

1-Mass density or density [symbol: ρ (rho)]

It is the ratio of mass of fluid to its volume,

$$\rho = \frac{Mass\ of\ fluid}{Volume\ of\ fluid}$$

The common units used of density is (kg/m^3), (g/cm^3), (lb/ft^3).

2-Specific Volume [symbol: υ (upsilon)]

It is the ratio of volume of fluid to its mass (or mole); it is the reciprocal of its density,

$$v = \frac{Volume\ of\ fluid}{Mass\ of\ fluid}$$

The common units used of density is (m^3/ kg), (cm^3/g), (ft^3/lb).

3-Weight density or specific weight [symbol: sp.wt.]

It is the ratio of weight of fluid to its volume,

$$sp.wt = \frac{Weight\ of\ fluid}{Volume\ of\ fluid}$$

The common units used of density is (N/m^3), ($dyne/cm^3$), (lbf/ft^3).

4-Specific gravity [symbol: sp.gr.]

It is the ratio of mass density or (density) of fluid to mass density or (density) of water, Physicists use 39.2°F (4°C) as the standard, but engineers ordinarily use 60°F (15.556°C)

$$sp.gr = \frac{Mass\ density\ \ of\ fluid}{Mass\ density\ \ of\ water}$$

The common density used of water is (1000 kg/m^3), (1.0g/cm^3), (62.43 lb/ft^3).

5-Dynamic viscosity [symbol: µ (mu)]

It is the property of a fluid, which offers resistance to the movement of one layer of fluid over another adjacent layer of the fluid.

The common units used of dynamic viscosity is (kg/m.s), (g/cm.s), (lb/ft.s), (poise) ($N.s/m^2 \equiv Pa.m$), ($dyne.s/cm^2$). [poise ≡ g/cm.s ≡ $dyne.s/cm^2$] [poise = 100 c.p]

6-Kinematic viscosity [symbol: ν (nu)]

It is the ratio of the dynamic viscosity to mass density of fluid,

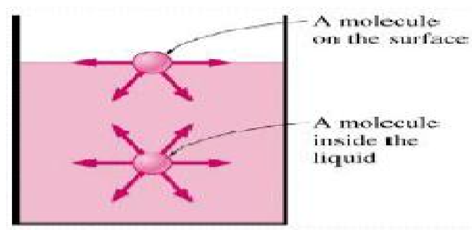
$$\nu = \frac{\mu}{\rho}$$

The common units used of kinematics viscosity is (m^2/s), (cm^2/s), (ft^2/s), (stoke). [stoke ≡ cm^2/s] [stoke = 100 c.stoke]

7-Surface tension [symbol: σ (sigma)]

It is the property of the liquid, which enables it to resist tensile stress. It is due to cohesion between surface molecules of a liquid.

$$\sigma = \frac{force}{lenght}$$



The common units used of Surface tension is (N/m), (dyne/cm), (lbf/ft).

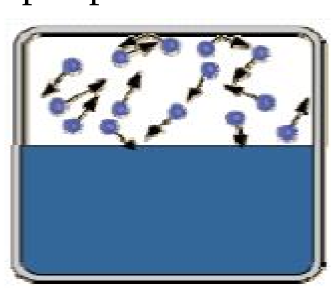
□Cohesion : molecular attraction between the molecules of the same material. Forms an imaginary film capable of resisting tensile stress at the interface.

□ Adhesion : molecular attraction between the molecules of the liquid and the solid surface which is in contact with the liquid.

8-Vapor Pressure

When a liquid in a closed container ,small air space, a pressure will developed in the space as a result of vapor that is formed by escaping molecules.

□When equilibrium is reached so that the molecules leaving the surface is equal to the entering – vapor is said to be saturated and the pressure exerted by the vapor on the liquid surface is termed as vapor pressure.



It increase with temperature

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- Its called vapor pressure or vapor saturated pressure
- Its called partial pressure when its mixed with other gases
- The temperature at which the vapor pressure is equal to the atmospheric pressure is called the boiling point.

1.3 Useful Information

1-The shear stress [symbol: τ (tau)]

It is the force per unit surface area that resists the sliding of the fluid layers. The common units used of shear stress is ($N/m^2 \equiv Pa$), ($dyne/cm^2$), (lbf/ft^2).

2-The pressure [symbol: P]

It is the force per unit cross sectional area normal to the force direction.

The common units used of shear stress is ($N/m^2 \equiv Pa$), ($dyne/cm^2$), (lbf/ft^2) (atm) (bar) (Psi) (torr ≡ mmHg). The pressure difference between two points refers to (ΔP).

The pressure could be expressed as liquid height (or head) (h) where,

$$P = h\,\rho\,g \quad \text{and} \quad \Delta P = \Delta h\,\rho\,g$$

h: is the liquid height (or head), units (m), (cm), (ft).

3-The energy [symbol: E]

Energy is defined as the capacity of a system to perform work or produce heat.

There are many types of energy such as [Internal energy (U), Kinetic energy (K.E), Potential energy (P.E), Pressure energy (Prs.E), and others.

The common units used for energy is (J ≡ N.m), (erg ≡ dyne.cm), (Btu), (lbf.ft) (cal).

The energy could be expressed in relative quantity per unit mass or mole (J/kg or mol).

The energy could be expressed in head quantity [(m) (cm) (ft)] by dividing the relative energy by acceleration of gravity.

4-The Power [symbol: P]

It is the energy per unit time. The common units used for Power is (W ≡ J/s), (Btu/time), (lbf.ft/time) (cal/time), (hp).

5- The flow rate

5.1-Volumetric flow rate [symbol: Q]

It is the volume of fluid transferred per unit time.

$$Q = u\,A$$

where A: *is the cross sectional area of flow normal to the flow direction. The common units used for volumetric flow is (m^3/s), (cm^3/s), (ft^3 /s).*

5.2-Mass flow rate [symbol: *m]*

It is the mass of fluid transferred per unit time.

$$\dot{m} = Q\,\rho = u\,A\,\rho$$

The common units used for volumetric flow is (kg/s), (g/s), (lb/s).

5.3-Mass flux or (mass velocity) [symbol: G]

It is the mass flow rate per unit area of flow,

$$G = \frac{\dot{m}}{A} = u\,\rho$$

The common units used for mass flux is ($kg/m^2.s$), ($g/cm^2.s$), ($lb/ft^2.s$).

6-Ideal fluid

An ideal fluid is one that is incompressible It is a fluid, and having no viscosity ($\mu = 0$). Ideal fluid is only an imaginary fluid since all the fluids, which exist, have some viscosity.

7-Real fluid

A fluid, which possesses viscosity, is known as real fluid. All the fluids, an actual practice, are real fluids.

1.4 Important Laws

1-Law of conservation of mass

“ *The mass can neither be created nor destroyed, and it can not be created from nothing”*

2-Law of conservation of energy

“ *The energy can neither be created nor destroyed, though it can be transformed from one form into another”*

Newton’s Laws of Motion

Newton has formulated three law of motion, which are the basic postulates or assumption on which the whole system of dynamics is based.

3-Newton’s first laws of motion

"Every body continues in its state of rest or of uniform motion in a straight line, unless it is acted upon by some external forces"

4-Newton's second laws of motion

"The rate of change in momentum is directly proportional to the impressed force and takes place in the same direction in which the force acts"[momentum = mass × velocity]

5-Newton's third laws of motion

"To every action, there is always an equal and opposite reaction"

6-First law of thermodynamics

"Although energy assumes many forms, the total quantity of energy is constant, and when energy disappears in one form it appears simultaneously in other forms"

1.5 Flow Patterns

The nature of fluid flow is a function of the fluid physical properties, the geometry of the container, and the fluid flow rate. The flow can be characterized either as **Laminar or as Turbulent flow.**

Laminar flow is also called "viscous or streamline flow". In this type of flow layers of fluid move relative to each other without any intermixing.

Turbulent flow in this flow, there is irregular random movement of fluid in directions transverse to the main flow.

1.6 Newton's Law of Viscosity and Momentum Transfer

Consider two parallel plates of area (A), distance (dz) apart shown in Figure (1). The space between the plates is filled with a fluid. The lower plate travels with a velocity (u) and the upper plate with a velocity (u-du). The small difference in velocity (du) between the plates results in a resisting force (F) acting over the plate area (A) due to viscous frictional effects in the fluid.

Thus the force (F) must apply to the lower plate to maintain the difference in velocity (du) between the two plates. The force per unit area (F/A) is known as the shear stress (τ).

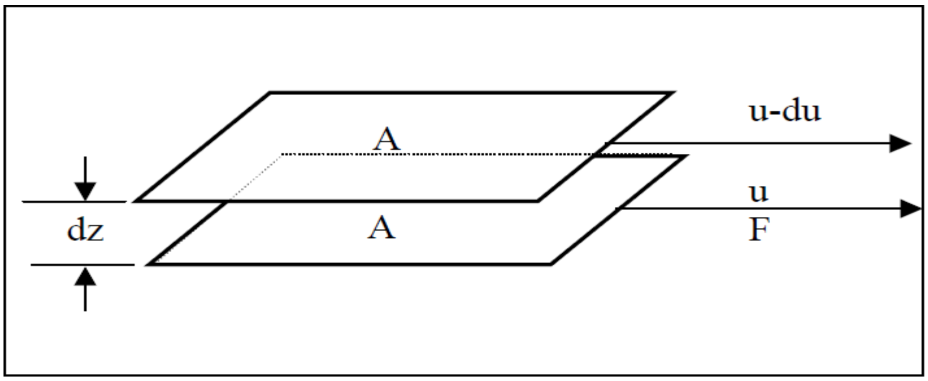

Figure (1) Shear between two plates

Newton's law of viscosity states that:

$$\tau \propto -\frac{du}{dz} \Rightarrow \tau = -\mu \frac{du}{dz}$$

Fluids, which obey this equation, are called "Newtonian Fluids" and Fluids, don't obey this equation, are called "non-Newtonian Fluids".

Note: Newton's law of viscosity holds for Newtonian fluids in laminar flow.

Momentum (shear stress) transfers through the fluid from the region of high velocities to region of low velocities, and the rate of momentum transfer increase with increasing the viscosity of fluids.

1.7 Newtonian and non-Newtonian fluids

$$\tau = -\mu \frac{du}{dz}$$

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The plot of shear stress

against shear rate

$$\dot{\gamma} \equiv \frac{du}{dz}$$

is different in Newtonian fluids than that in non-Newtonian fluids as shown in Figure (2). For Newtonian fluids the plot give a straight line from the origin but for non-Newtonian fluids the plot gives different relations than that of Newtonian some of these relations are given in Figure. (2).

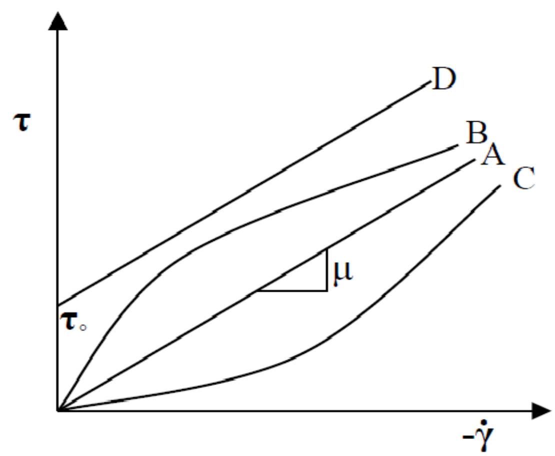


Figure (2): Shear stress against shear rate

A-Newtonian fluids

B-nonNewtonian (pseudoplastic)

C-non-Newtonian (dilatant)

D-non-Newtonian (Bingham)

Example -1.1-

One liter of certain oil weighs 0.8 kg, calculate the specific weight, density, specific volume, and specific gravity of it.

Solution:

$$sp.gr = \frac{Mass\ density\ of\ fluid}{Mass\ density\ of\ water} = \frac{(0.8\ kg)(9.81\ m/s^2)}{1 \times 10^{-3}\ m^3} = 7848\ N/m^3$$

$$\rho = \frac{(0.8\ kg)}{1 \times 10^{-3}\ m^3} = 800\ kg/m^3 \qquad v = (1/800) = 1.25 \times 10^{-3}\ m^3/kg$$

$$sp.gr = \frac{\rho_{liquid}}{\rho_{water}} = \frac{800\ kg/m^3}{1000\ kg/m^3} = 0.8$$

Example -1.2-

Determine the specific gravity of a fluid having viscosity of 4.0 c.poice and kinematic viscosity of 3.6 c.stokes.

Solution:

$$\mu = 4\,c.p\,\frac{poice}{100\,c.p} = 0.04\,p0ice = 0.04(g/cm.s)$$

$$v = \frac{\mu}{\rho} \Rightarrow \rho = \frac{\mu}{v} = \frac{0.04\,\frac{g}{cm.s}}{0.036\,\frac{cm^2}{s}} = 1.1111\left[\frac{g}{cm.s}\times\frac{s}{cm^2}\right]$$

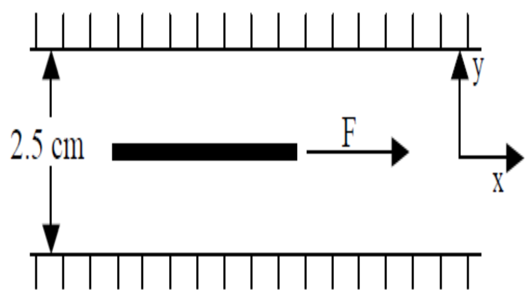
$$= 1.1111\,\frac{g}{cm^3}\times\frac{kg}{1000g}\times\frac{100^3 cm^3}{m^3} = 1111.1\,\frac{kg}{m^3}$$

$$sp.gr = \frac{\rho_{liquid}}{\rho_{water}} = \frac{1111.1\;kg/m^3}{1000\;kg/m^3} = 1.1111$$

Example -1.3-

The space between two large plane surfaces kept 2.5 cm apart is filled with liquid of viscosity 0.0825 kg/m.s. What force is required to drag a thin plate of surface area 0.5 m2 between the two large surfaces at speed of 0.5 m/s, (i) when the plate is placed in the middle of the two surfaces, and (ii) when the plate is placed 1.5 cm from one of the plates surfaces.

Solution:



(i) Shear stress on the upper side of the plate is

$$\tau_1 = -\mu\,\frac{du}{dy} = \frac{F_1}{A}$$

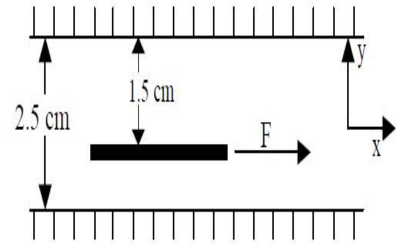
$$F_1 = A - \mu\,\frac{du}{dy} = 0.5\,m^2[-0.0825\,Pa.s(-40S^{-1}] - 1.65\,N$$

$$\frac{du}{dy}\tau \cong \frac{\Delta u}{\Delta y} = \frac{u|_{y=1.25} - u|_{y=0}}{1.25\times 10^{-2} \ -0} = \frac{0-0.5\ m/s}{1.25\times 10^{-2}} = -40\ s^{-1}$$

Likewise on the lower surface F_2=A τ_2 =*1.65N*

The total force required =3.3 N

(ii) Shear stress on the upper side of the plate is



$$\tau_1 = -\mu\frac{du}{dy} = \frac{F_1}{A}$$

$$\frac{du}{dy} \simeq \frac{\Delta u}{\Delta y} = \frac{u|_{y=1.5} - u|_{y=0}}{1.5\times 10^{-2} - 0} = \frac{-100}{3}\ s^{-1}$$

$$F_1 = A\left(-\mu\frac{du}{dy}\right) = 0.5\,m^2\left|-0.0825\,Pa.s\left(\frac{100}{3}\ s^{-1}\right)\right| = 1.375\,N$$

$$\tau_2 = -\mu\frac{du}{dy} = \frac{F_2}{A} \quad and\ \frac{du}{dy} = \frac{0-0.5}{0.01} = -50s^{-1}$$

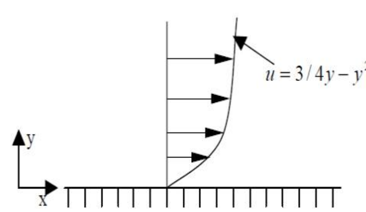
$$F_2 = 0.5\ m^2[-0.0825\ Pa.s(-50s^{-1})] = 2.0625\ N$$

The total force required= F_2-F_1= *3.4375 N*

<u>Example -1.4-</u>

The velocity distribution within the fluid flowing over a plate is given by where u is the velocity in (m/s) and y is a distance above the plate in (m). Determine the shear stress at y=0 and at y=0.2 m. take that μ=8.4 poise.

$$\mu = 3/4y - y^2 \Rightarrow\Rightarrow \frac{du}{dy} = \frac{3}{4} - 2y \Rightarrow \left.\frac{du}{dy}\right|_{y=0} = \frac{3}{4}\ s^{-1}$$



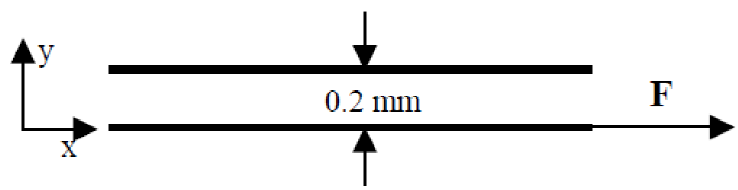
$$\text{and } \left.\frac{du}{dy}\right|_{y=0.2} = \frac{3}{4} - 2(0.2) = 0.35\ s^{-1} \quad \tau|_{y=0} = 0.84\,\mathrm{Pa.s}\left(\frac{3}{4}\ s^{-1}\right) = 0.63\ \mathrm{Pa}$$

$$\text{and } \tau|_{y=0.2} = 0.84\,\mathrm{Pa.s}\left(0.35\ s^{-1}\right) = 0.294\ \mathrm{Pa}$$

Example -1.5-

A flat plate of area $2\text{x}10^4$ cm2 is pulled with a speed of 0.5 m/s relative to another plate located at a distance of 0.2 mm from it. If the fluid separated the two plates has a viscosity of 1.0 poise, find the force required to maintain the speed.

Solution:



$$\tau = -\mu \frac{du}{dy} = \frac{F}{A}$$

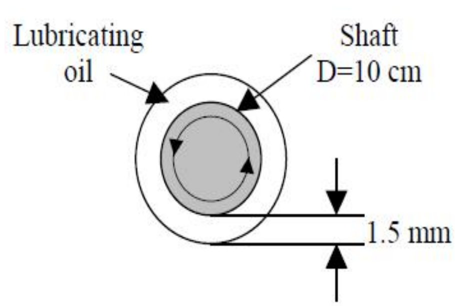
$$\frac{du}{dy} \cong \frac{\Delta u}{\Delta y} = \frac{u_2 - u_1}{y_2 - y_1} = \frac{0 - 0.5\ m/s}{1.5 \times 10^{-3}\ m - 0} = -2500\ s^{-1}$$

$$\mu = 1.0\ \frac{g}{cm.s}\left(\frac{100\ cm}{m}\right)\left(\frac{kg}{1000\ g}\right)$$

$$\tau = 0.1\ Pa.s(-2500\ s^{-1}) = 250\ Pa \rightarrow F = 250Pa(2m^2)$$
$$= 500N$$

Example -1.6-

A shaft of diameter 10 cm having a clearance of 1.5 mm rotates at 180 rpm in a bearing which is lubricated by an oil of viscosity 100 c.p. Find the intensity of shear of the lubricating oil if the length of the bearing is 20 cm and find the torque.



Solution:

The linear velocity of rotating is

$$u = \pi\, D\, N = \frac{\pi(0.1m)180\ rpm}{60\ \ s/min} = 0.9425\ m/s$$

$$\mu = 100\, c.p = \mu = 1.0\ \frac{g}{cm.s}\left(\frac{100\ cm}{m}\right)\left(\frac{kg}{1000\ g}\right) = 0.1\ pa.s$$

$$\Rightarrow F = \tau(\pi DL) = 62.83\ pa(\pi\, 0.1(0.2)) = 3.95\ N$$

$$\tau = \mu\ \frac{du}{dy} = \frac{F}{A} = 0.1\ pa.s\left(\frac{0.9425\ m/s}{0.0015m}\right) = 62.83\ pa$$

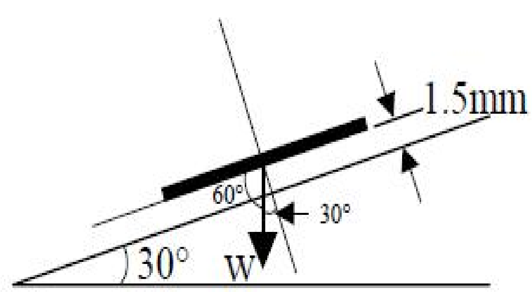
The torque is equivalent to rotating moment

$$\Gamma = F\frac{D}{2} = 3.95\ N\left(\frac{0.1}{2}\right) = 0.1975\ J$$

Example -1.7-

A plate of size 60 cm x 60 cm slides over a plane inclined to the horizontal at an angle of 30°. It is separated from the plane with a film of oil of thickness 1.5 mm. The plate weighs 25kg and slides down with a velocity of 0.25 m/s. Calculate the dynamic viscosity of oil used as lubricant. What would be its kinematic viscosity if the specific gravity of oil is 0.95.

Solution:



Component of W along the plane

=W cos(60) =W sin(30)

= 25 (0.5) = 12.5 kg

F = 12.5 kg (9.81 m/s2) =122.625 N

τ = F/A = 122.625 N/(0.6 x0.6) m2 = 340.625 Pa

$$v = \frac{\mu}{\rho} = \frac{2.044\,pa.s}{950\,kg/m^3} = 0.00215\ m^2/s = 21.5\ stoke$$

$$\mu = \frac{\tau}{(du/dy)} = \frac{340.625Pa}{(0.25/0.0015)s^{-1}} = 2.044\ pa.s = 20.44\ poise$$

Home Work

P.1.1

Two plates are kept separated by a film of oil of 0.025 mm. the top plate moves with a velocity of 50 cm/s while the bottom plate is kept fixed. Find the fluid viscosity of oil if the force required to move the plate is 0.2 kg/m^2. Ans. $\mu = 9.81\times10^{-5}$ Pa.s

P.1.2

If the equation of a velocity profile over a plate is $u=3\,y^{(2/3)}$ in which the velocity in m/s at a distance y meters above the plate, determine the shear stress at y=0 and y=5 cm. Take μ= 8.4 poise

Ans. $\tau_{y=0} = \infty$, $\tau_{y=5} = 4.56$ Pa.s

P.1.3

The equation of a velocity distribution over a plate is $u=1/3\,y - y^2$ in which the velocity in m/s at a distance y meters above the plate, determine the shear stress at y=0 and y=0.1 m. Take μ= 8.35 poise

Ans. $\tau_{y=0}$ =2.78, $\tau_{y=0.1}$= 4.56 dyne/cm^2

P.1.4

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A cylinder of diameter 10 cm rotates concentrically inside another hollow cylinder of inner diameter 10.1 cm. Both cylinders are 20 cm long and stand with their axis vertical. The annular space is filled with oil. If a torque of 100 kg cm is required to rotate the inner cylinder at 100 rpm, determine the viscosity of oil. Ans. μ= 29.82poise

Conversion Factor Table

http://vertex42.com/edu/kinematics.html

	Multiply	by	To Get
	inch	2.54	cm
	This can also be written as: 1 inch = 2.54 cm		
A	acre	43,560	ft^2
	ampere·hr (A·h)	3,600	coulomb (C)
	ångstrom (Å)	$1x10^{-10}$	m
	atm (atmosphere)	1.01325	bar
	atm, std	76.0	cm of Hg
	atm, std	760	mm of Hg at 0°C
	atm, std	33.90	ft of water
	atm, std	29.92	in of Hg at 30°F
	atm, std	14.696	lbf/in^2 abs (psia)
	atm, std	101.325	kPa
	atm, std	$1.013x10^5$	Pa
	atm, std	1.03323	kgf / cm^2
	atm, std	14.696	psia
B	bar	0.9869	atm, std
	bar	$1x10^5$	Pa
	Btu	778.169	ft·lbf
	Btu	1055.056	J
	Btu	5.40395	psia·ft^3
	Btu	$2.928x10^{-4}$	kWh
	Btu	$1x10^{-5}$	therm
	Btu / hr	1.055056	kJ / hr
	Btu / hr	0.216	ft·lbf / sec
	Btu / hr	$3.929x10^{-4}$	hp
	Btu / hr	0.2931	W
	Btu / lbm	2.326*	kJ / kg
	Btu / lbm	25,037	ft^2 / s^2
	Btu / lbm·R	4.1868	kJ / kg·K
	Btu / lbm·°F	4.1868	kJ / kg·°C
	Btu / lbmol·R	4.1868	kJ / kmol·K
C	cal (g-calorie)	$3.968x10^{-3}$	Btu
	cal	$1.560x10^{-6}$	hp·hr
	cal (IT calorie)	4.1868	J
	Calorie (Cal)	4.1868	kJ
	cal / sec	4.1868	W (watt)
	cm (centimeter)	0.03281	ft
	cm	0.3937	in
	cP (centipoise)	0.001	Pa·sec
	cSt (centistokes)	$1x10^{-6}$	m^2 / sec
D	degree	π/180	radian
	dyne	10	µN (micronewton)
E	eV (electronvolt)	$1.602x10^{-19}$	J
	[illegible]	[illegible]	[illegible]
	hp	2544.5	Btu / hr
	hp	745.70	W (watt)
	hp	0.74570	kW
	hp	33,000	ft·lbf / min
	hp	550	ft·lbf / sec
	hp·hr	2544	Btu
	hp·hr	$1.98x10^6$	ft·lbf
	hp·hr	$2.68x10^6$	J
	in	2.54*	cm
	in of Hg	0.0334	atm
	in of Hg	13.60	in of water
	in of Hg	3.387	kPa
	in of water	0.0736	in of Hg
	in of water	0.0361	lbf / in^2 (psi)
	in of water	0.002458	atm
J	J (joule)	$9.4782x10^{-4}$	Btu
	J	$6.2415x10^{18}$	eV
	J	0.73756	ft·lbf
	J	1	N·m
	J	$1x10^7$	ergs
	J / s	1	W
K	kg (kilogram)	2.2046226	lbm (pound mass)
	kg	0.068522	slug
	kg	$1x10^{-3}$	metric ton
	kg / m^3	0.062428	lbm / ft^3
	kgf	9.80665	newton (N)
	kip	1000	lbf
	kip	4448	N
	kJ	1	1 kPa·m^3
	kJ	1000	N·m
	kJ	0.94782	Btu
	kJ	737.56	ft·lbf
	kJ / kg	1000	m^2 / s^2
	kJ / kg	0.42992	Btu / lbm
	kJ / kg·K	0.23885	Btu / lbm·°R
	kJ / kg·°C	1	kJ / kg·K
	kJ / kg·°C	1	J / g·°C
	kJ / kg·°C	0.23885	Btu / lbm·°F
	kJ / kg·°C	0.23885	Btu / lbm·R
	km	3280.8	ft
	km	0.6214	mi
	km/hr	0.6214	mi / hr (mph)
	km/hr	0.2778	m/s
	km/hr	0.9113	ft/s
	kPa (kilopascal)	$9.8693x10^{-3}$	atm
	kPa	0.14504	lbf / in^2 (psi)
	m / s	3.60	km / h
	m / s	3.2808	ft / s
	m / s	2.237	mi / h (mph)
	m / s^2	3.2808	ft / s^2
	metric ton	1000	kg
	mil	0.001	in
	mi (mile)	5280	ft
	mi	1.6093	km
	mi^2 (square mile)	640	acres
	mph (mile/hour)	1.6093	km / hr
	mph	88.0	ft / min (fpm)
	mph	1.467	ft / s
	mph	0.4470	m / s
	micron	$1x10^{-6}$	m
	mm of Hg	$1.316x10^{-3}$	atm
	mm of Hg	0.1333	kPa
	mm of water	$9.678x10^{-5}$	atm
N	N (newton)	1	$kg·m / s^2$
	N	$1x10^5$	dyne
	µN (microN)	0.1	dyne
	N	0.22481	lbf
	N·m	0.7376	ft·lbf
	N·m	1	J
P	Pa (pascal)	1	N / m^2
	Pa	$1.4504x10^{-4}$	lbf / in^2 (psia)
	Pa	0.020886	lbf / ft^2
	Pa	$9.869x10^{-6}$	atm
	Pa·s	10	poise
	psi (pounds per square inch) — see lbf / in^2		
R	radian	180/π	degree
S	short ton	2000	lbm
	short ton	907.1847	kg
	slug	32.174	lbm
	slug	14.5939	kg
	$slug / ft^3$	0.5154	g / cm^3
	stokes	$1x10^{-4}$	m^2 / s
T	therm	$1x10^5$	Btu
	ton of refrigeration	200	Btu / min
W	W (watt)	3.4121	Btu / hr
	W	0.7376	ft·lbf / sec
	W	$1.341x10^{-3}$	hp
	W	1	J / s
	W / cm^2	$1x10^4$	W / m^2
	W / cm^3	$1x10^6$	W / m^3