CE-230: Hydraulics and Hydraulic Machinery

6th Semester, BSc Electrical Engineering (Power)

Spring 2020 Semester

Chapter 1

Introduction

Engr. Khurram Sheraz

Assistant Professor

University of Engineering & Technology Peshawar

Grading Criteria, Academic Integrity, Guidelines

Final Term Examination	60%
Mid Term Examination	20%
Assignments	10% (Plagiarism is strictly prohibited)
Quizzes	10% (Cheating is strictly prohibited)
Attendance	75% attendance is mandatory to sit in the Final Term Examination as per University rule

- Assignments should be submitted on A4 size sheets (plain/lined) hand written on both sides with cover page including:
  - Assignment No.
  - Title of Course
  - Name of Student
  - Registration No., Class No. and Section No.
  - Name of Teacher, Department, Faculty, and University
  - Date of Submission
  - Do not bind assignments in covers (just stapled pages together).
  - Diagrams/figures should be drawn neatly with pencil.
- Quizzes/Tests: Students must bring A4 size plain sheets for each quiz.

Course Objectives: The objective of this course is to familiarize students to the fundamentals and principles of hydraulics, and its applications to turbomachinery.

Course Learning Outcomes (CLOs): Upon successful completion of this course, the students will be able to:

1. Explain the fundamental properties of water, their relationships and measurement.
2. Apply principles and laws of hydraulics to hydrostatic and hydrodynamic phenomenon.
3. Estimate main operating parameters of hydraulic pumps and turbines (forces, torques, flow rates, efficiencies) for their selection for hydropower plants.

Textbook:

- Finnemore E.J. and Franzini J.B. (2016). Fluid Mechanics with Engineering Applications, 10^{th} Edition. McGraw Hill International, USA.

Reference Book:

- Bansal R.K. (2010). A Textbook of Fluid Mechanics and Hydraulic Machines. 9^{th} Revised Edition SI Units. Laxmi Publication (P) Ltd, New Delhi-110002, India.

Course Overview – Pre Mid Term Examination

Week #	***Contact Hours***	***Topics***	***Assignment / Quiz***
01	03	**Introduction:** History, Significance, Scope, Introduction, Development of Fluid Mechanics, Dimensions and Units, Fluid	
02	03	Properties of liquids, Types of fluids	
03	03	**Fluid Statics:** Static pressure due to liquids, Hydrostatic force on a plane area	
04	03	Devices for measurement of static pressure	A – 1
05	03	**Types of Flows:** Laminar and turbulent flows of water	Q – 1
06	03	**Energy in Steady Flow:** Energy of flowing water, Bernoulli's Equation	
07	03	**Fluid Flow Measurement:** Orifices, Notches, Weirs	A – 2 Q – 2
08	**MID-TERM EXAMINATION**		

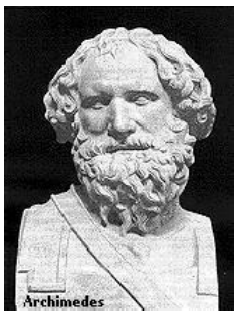
Contents

- History
- Historical Development
- Scope
- Introduction
- Fluid
- Properties of Liquids
- Types of Fluids

History

Al Biruni
(973-1048)

Al Khazini
(1115-1155)



Archimedes
(287-212 BC)

Newton
(1642-1727)

Leibniz
(1646-1716)

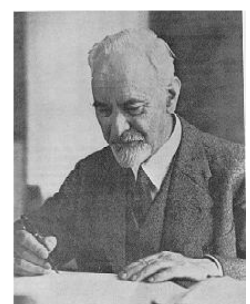
Bernoulli
(1667-1748)

Euler
(1707-1783)

Navier
(1785-1836)

Stokes
(1819-1903)

Reynolds
(1842-1912)



Prandtl
(1875-1953)

Taylor
(1886-1975)

Historical Development

- ✓ *Ancient civilizations' knowledge:* irrigation (6th millennium BC), water clocks 2nd BC, sailing ships
- ✓ *Ancient Rome:* built aqueducts, baths (4th century B.C.)
- ✓ *Ancient Greece:* Archimedes discovered and formulated; buoyancy (3rd century B.C.)
- ✓ *Islamicate Scientists; Abu Rayhan Biruni (973–1048) and later Al-Khazini (1115–1155):* applied experimental scientific methods to fluid mechanics (fluid statics, determining specific weights)
- ✓ *Al-Biruni:* discovered correlation between the specific gravity of an object and the volume of water
it displaces.
- ✓ *Leonardo (1452-1519):* experiments, research on waves, jets, eddies, streamlining, contributed to 1-D equation of conservation of mass
- ✓ *Newton (1642-1727):* laws of motion, law of viscosity, developed calculus
- ✓ *18th century mathematicians:* solutions to frictionless fluid flows (hydrodynamics)
- ✓ *17th and 18th century engineers:* empirical equations (empirical hydraulics)
- ✓ *Late 19th century:* dimensionless numbers, turbulence, dimensional analysis
- ✓ *Prandtl (1904):* proposes idea of the boundary layer
  - Flow fields of low-viscosity fluids divided into two zones:
  - A thin, viscosity-dominated layer near solid surfaces
  - An effectively inviscid outer zone away from boundaries
  - Explained former paradoxes
  - Allow analysis of more complex flows
- ✓ *20th century:* hydraulic systems, oil explorations, structures, irrigation, computer applications (CFD)

Scope

- A knowledge of the subject is required to properly design:
  - Water supply systems
  - Wastewater Treatment facilities
  - Dam Spillways
  - Valves, Windmills, Turbines, Pumps
  - Flow meters, Heating and Air-conditioning system
  - Hydraulic shock absorbers, Brakes, Clutches
  - Automatic transmissions
  - Aircrafts, Ships, Submarines
  - Windmills, Turbines, Pumps
  - Artificial organs
  - Automobiles
  - Sports items (golf balls, yachts, race cars, hang gliders)

Introduction

- The word '**Hydraulics**' has been derived from a Greek word (Υδραυλική) '**Hudour**', which means water.

- Thus the subject of **Hydraulics** may be defined as that branch of Engineering-science, which deals with the behavior of water (at rest or in motion).

- The subject **Hydraulic Machines** may be defined as that branch of Engineering-science, which deals with the machines run by water under some head, or raising the water to higher levels.

- The subject may be divided into three branches:
  1. **Fluid Statics;** the study of the mechanics of fluids at rest.
  2. **Fluid Kinematics;** deals with the motion (velocities and streamlines) without considering forces or energy causing the motion.
  3. **Fluid Dynamics or Kinetics;** is concerned with the relations between velocities and acceleration and the forces exerted by or upon fluids in motion.

Development of the Subject

- Broadly, the hydraulics is derived from **classical hydrodynamics** which is a subject in mathematics that deals with an imaginary ideal fluid that is completely frictionless (inviscid fluids).

- The results of such studies, without consideration of all the properties of real fluids, are of limited practical value.

- Therefore, the Engineers turned to experiments and developed empirical formulae giving solutions to practical problems.

- **Empirical hydraulics** was experimental science confined largely to water and limited in scope.

- The development of aeronautics, chemical engineering, and the petroleum industry led to the combination of classical hydrodynamics with empirical hydraulics, and this new science is called **fluid mechanics**.

Dimensions and Units

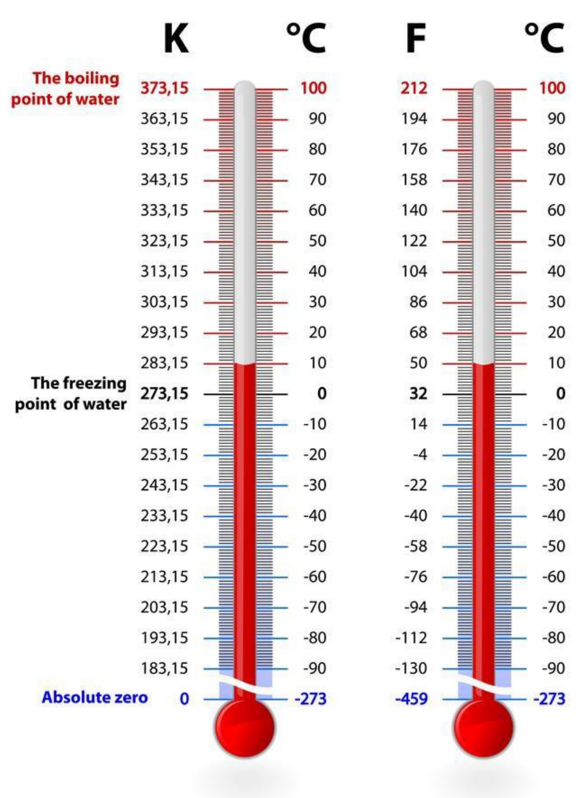
- To properly define a physical property or a fluid phenomenon, it must be expressed in terms of some set of units.
- The measurement of physical quantities is one of the most important operations in engineering.
- Every quantity is measured in terms of some arbitrary, but internationally accepted units called fundamental units.
- Two systems of units are used in this subject:

1. **English Units** (British Gravitational i.e. **BG** System or US Customary System **USCS** or **FPS** System)
2. **Metric Units** (Systeme Internationale d'Unites i.e. **S.I.** System) adopted in 1960

- In hydraulics, the basic dimensions are:

1. Length (L)
2. Mass (M)
3. Time (T)
4. Force (F)
5. Temperature (ϑ)

Dimension	BG System	SI Unit
Length (L)	Foot (ft)	Meter (m)
Mass (M)	Slug (= lb.sec^2/ft)	Kilogram (kg)
Time (T)	Second (sec)	Second (s)
Force (F)	Pound (lb)	Newton (N) (= kg.m/s^2)
Temperature (Θ)		
Absolute	Rankine (°R)	Kelvin (K)
Ordinary	Fahrenheit (°F)	Celsius (°C)



Quantity	Commonly used dimensions	BG Unit	SI Unit
Acceleration (a)	LT^{-2}	Ft/sec^2	m/s^2
Area (A)	L^2	Ft^2	m^2
Density	ML^{-3}	Slug/ft^3	Kg/m^3
Energy, Work or Heat	FL	Ft.lb	N.m = J
Flow rate (Q)	L^3T^{-1}	Ft^3/sec (cfs)	M^3/sec
Frequency	T^{-1}	Cycles/sec (sec^{-1})	Hz (Hertz, s^{-1})
Kinematic Viscosity(ν)	L^2T^{-1}	Ft^2/sec	M^2/sec
Power	FLT^{-1}	Ft.lb/sec	N.m/sec = W
Pressure(p)	FL^{-2}	Lb/in^2	N/m^2 = Pa
Specific weight (ɣ)	FL^{-3}	Lb/ft^3	N/m^3
Velocity (V)	LT^{-1}	Ft/sec	m/s
Viscosity (μ)	FTL^{-2}	Lb.sec/ft^2	N.s/m^2
Volume	L^3	ft^3	m^3

Fluid

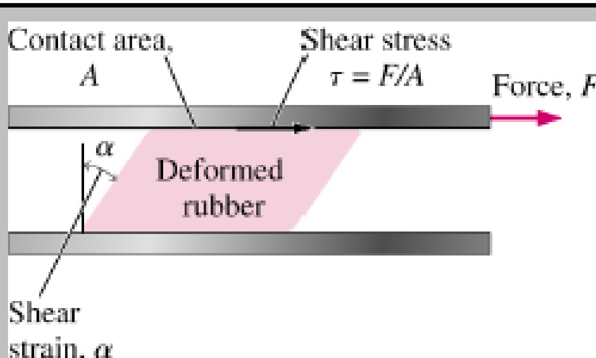
- A **Fluid** (either liquid or gas) is a substance that can flow and will continuously deform under the action of a *shear stress (tangential stress)* no matter how small that shear stress may be. The stress is proportional to strain rate.

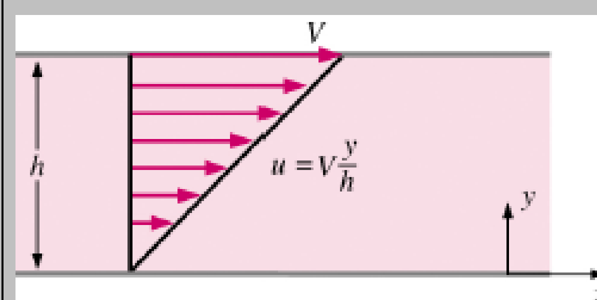
- In considering the action of forces on fluids on a mathematical basis, the fluid can be regarded as a **continuum** that is, a hypothetically continuous medium.

- A **solid**, on the other hand, can resist a *shear stress*, assuming, of course, that the shear stress does not exceed the elastic limit of the material. The stress is proportional to strain.

Solid

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





Fluid

$$\tau = \frac{F}{A} \propto \mu \frac{V}{h}$$

Properties of Fluids

- In hydraulics, water is mostly dealt with and has the following properties:

  1. Density, 2. Specific Weight, 3. Specific Gravity, 4. Compressibility,

  5. Surface Tension, 6. Capillarity, 7. Viscosity

1. Density:

- The density or mass density may be defined as the mass per unit volume at a standard temperature [Physicists 4°C (39°F); Engineers 15°C (60°F)] and pressure (1 atm), denoted by ρ (rho)

  $\rho = mass/volume\ (\mathrm{kg/m^3})$ ρ_{water} = 1000 kg/m³, ρ_{air} = 1.205 kg/m³

2. Specific Weight:

- The specific weight or weight density may be defined as the weight per unit volume at a standard temperature (60°F) and pressure, denoted by γ (gamma)

  $\gamma = weight/volume\ (\mathrm{N/m^3})$ γ_{water} = 9.81 kN/m³ γ_{air} = 11.82 N/m³

- Density and specific weight of water are related as follows:

  $\rho = \gamma/g$ or $\gamma = \rho\, g$

Properties of Fluids

3. Specific Gravity:

- The specific gravity of a liquid may be defined as the ratio of its specific weight to that of pure water at a standard temperature.
- For liquids. pure water is taken as a standard substance and at standard temperature (4°C or 15°C).

$s = \gamma_{liquid} / \gamma_{water}$ $s_{water} = 1$

4. Compressibility:

- The compressibility of a liquid may be defined as the variation in its volume with the variation of pressure.
- The variation in the volume of water, with the variation of pressure, is so small (1% per 21 MPa) that for all practical purposes it is neglected.
- Thus, the water is considered to be an incompressible liquid.
- The compressibility of a liquid is inversely proportional to its volume modulus of elasticity (E_υ), also known as the bulk modulus defined as

$E_v = -v\, dp/dv$ (N/m²) For Water: $E_\upsilon = 2.06 \times 10^6$ kN/m²

where, υ = specific volume ($1/\rho$), and

p = pressure.

If a certain liquid weighs 8600 N/m³, what are the values of its density, specific volume, and specific gravity relative to water at 15°C? Use Appendix A.

Eq. 2.1: $\rho = 8600/9.81 = 877\ \text{kg/m}^3$ ◀ Eq. 2.2: $\upsilon = 1/877 = 0.001\ 141\ \text{m}^3/\text{kg}$ ◀

Table A.1: ρ_{water} at 15°C = 999.1 kg/m³ ; $s = 877/999.1 = 0.877$ ◀

TABLE A.1 **Physical properties of water at standard sea-level atmospheric pressure**[a]

Temperature, T °C	Specific weight, γ kN/m³	Density, ρ kg/m³	Absolute viscosity,[b] μ N·s/m²	Kinematic viscosity,[b] ν 10^{-6} m²/s	Surface tension, σ N/m	Saturation vapor pressure, p_v kN/m² abs	Satur'n vapor pressure head, p_v/γ m abs	Bulk modulus of elasticity, E_v 10^6 kN/m²
0°C	9.805	999.8	0.001 781	1.785	0.0756	0.611	0.0623	2.02
5°C	9.807	1000.0	0.001 518	1.519	0.0749	0.872	0.0889	2.06
10°C	9.804	999.7	0.001 307	1.306	0.0742	1.230	0.1255	2.10
15°C	9.798	999.1	0.001 139	1.139	0.0735	1.710	0.1745	2.14
20°C	9.789	998.2	0.001 002	1.003	0.0728	2.34	0.239	2.18
25°C	9.777	997.0	0.000 890	0.893	0.0720	3.17	0.324	2.22
30°C	9.765	995.7	0.000 798	0.800	0.0712	4.24	0.434	2.25
40°C	9.731	992.2	0.000 653	0.658	0.0696	7.38	0.758	2.28
50°C	9.690	988.0	0.000 547	0.553	0.0679	12.33	1.272	2.29
60°C	9.642	983.2	0.000 466	0.474	0.0662	19.92	2.07	2.28
70°C	9.589	977.8	0.000 404	0.413	0.0644	31.16	3.25	2.25
80°C	9.530	971.8	0.000 354	0.364	0.0626	47.34	4.97	2.20
90°C	9.467	965.3	0.000 315	0.326	0.0608	70.10	7.40	2.14
100°C	9.399	958.4	0.000 282	0.294	0.0589	101.33	10.78	2.07

[a] In these tables, if (for example, at 32°F) μ is given as 37.46 and the units are 10^{-6} lb·sec/ft² then $\mu = 37.46 \times 10^{-6}$ lb·sec/ft².

[b] For viscosity, see also Figs. A.1 and A.2.

To two significant figures what is the bulk modulus of water in MN/m^2 at 50°C under a pressure of 30 MN/m^2? Use Table 2.1.

From inside cover: 50°C = 122°F; 30 MN/m^2 = 4351 psi

$$\frac{x - x_1}{x_2 - x_1} = \frac{y - y_1}{y_2 - y_1}$$

TABLE 2.1 Bulk modulus of water E_v, psi[a]

	Temperature, °F				
Pressure, psia	**32°**	**68°**	**120°**	**200°**	**300°**
15	293,000	320,000	333,000	308,000	
1,500	300,000	330,000	342,000	319,000	248,000
4,500	317,000	348,000	362,000	338,000	271,000
15,000	380,000	410,000	426,000	405,000	350,000

4351 (between 1,500 and 4,500); 122° (between 120° and 200°)

x = T

Y = E_v

[a] These values can be transformed to meganewtons per square meter by multiplying them by 0.006895. The values in the first line are for conditions close to normal atmospheric pressure; for a more complete set of values at normal atmospheric pressure, see Table A.1 in Appendix A. The five temperatures are equal to 0, 20, 48.9, 93.3, and 148.9°C, respectively.

From Table 2.1, by linear interpolation in two directions: $E_v \approx 360{,}400$ psi

$E_v \approx 360{,}400(6895/10^6) = 2485\ MN/m^2 \approx 2500\ MN/m^2$ ◀

At normal atmospheric conditions, approximately what pressure in MPa must be applied to water to reduce its volume by 3% ?

Table 2.1: At normal atmospheric conditions, $E_v \approx 320{,}000$ psi

$E_v \approx (320{,}000\ \text{psi})(6895) = 2.21\times10^9\ \text{Pa} = 2210\ \text{MPa}$

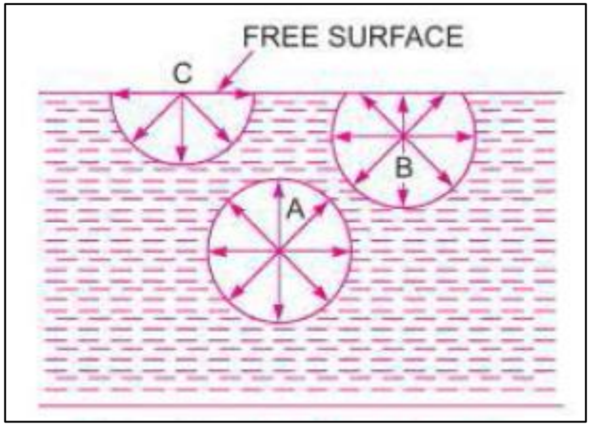
From Eq. 2.3a: $\frac{\Delta v}{v_1} = -0.03 = \frac{-\Delta p}{2210}$; $\Delta p = 66.2$ MPa ◀

$$\frac{\Delta \upsilon}{\upsilon} = -\frac{\Delta p}{E_\upsilon}$$

Properties of Fluids

5. Surface Tension:

- The surface tension of a liquid is its property, which enables it to resist tensile stress.
- Surface tension is defined as the tensile force acting on the surface of a liquid in contact with a gas or on the surface between two immiscible liquids such that the contact surface behaves like a membrane under tension.
- The magnitude of this force per unit length (N/m) of the free surface will have the same value as the surface energy per unit area (J/m^2).
- Liquids have **cohesion** and **adhesion**, both of which are forms of molecular attraction.
- **Cohesion** enables a liquid to resist tensile stress, while **adhesion** enables it to adhere to another surface.
- The surface tension is due to the cohesion between the molecules at the surface of a liquid where the cohesion forms an imaginary film capable of resisting tension between a liquid and a gas.

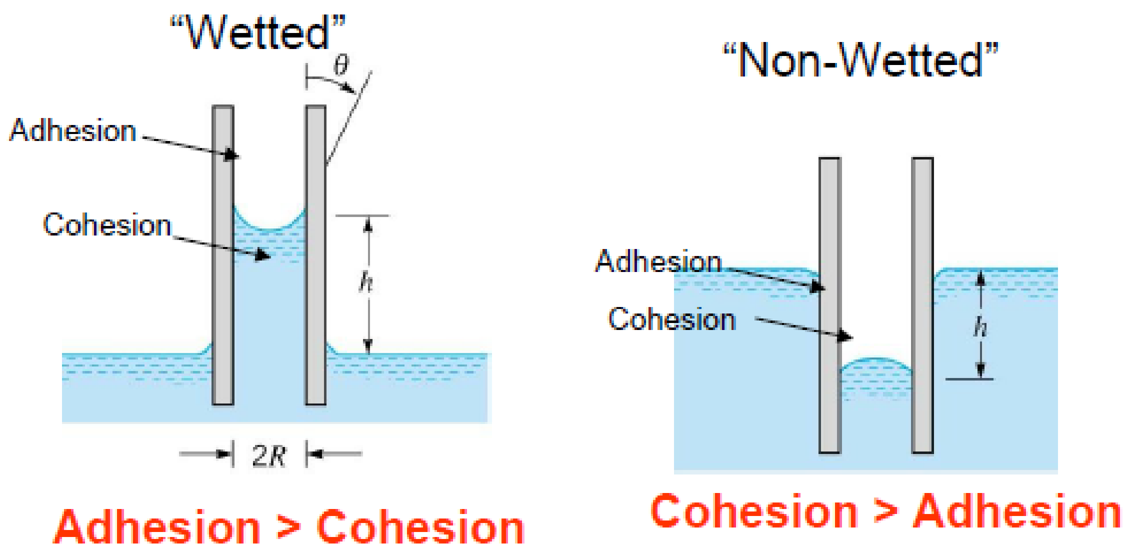


- For the purposes of all calculations, relating to Hydraulics, Fluid Mechanics and Hydraulic Machines, the effect of surface tension is generally neglected.
- (Surface tension of water at 4^oC = 0.0749 N/m)

The effect of surface tension may be easily seen in the case of tubes of smaller diameters open to the atmosphere.

For example, when a glass tube of small diameter is dipped in water, the water rises up in the tube with an upward concave surface as shown below (left), but when the same tube is dipped in mercury, the mercury depresses down in the tube with an upward convex shape (right).

Capillary action in small tubes which involve a liquid-gas-solid interface is caused by surface tension. The fluid is either drawn up the tube or pushed down.



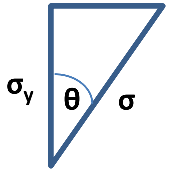
h is the height, R is the radius of the tube, θ is the angle of contact.

The weight of the fluid is balanced with the vertical force caused by surface tension.

Properties of Fluids

6. Capillarity:

- The phenomenon of rise or fall of a liquid surface in a small tube relative to the adjacent general level of liquid when the tube is held vertical, is known as capillarity (*rise is called capillary rise and fall is called capillary depression*).
- Capillarity is due to both cohesion and adhesion; when the cohesion is less than the adhesion, the liquid will rise at the point of contact and wet a solid surface with which it is in contact.
- Consider the Figure as shown, let



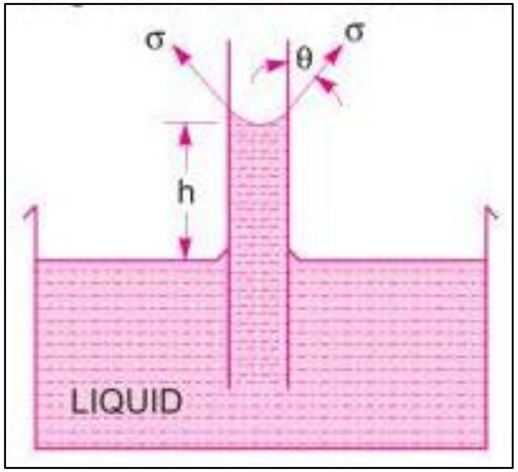
  σ = surface tension, force per unit length

  γ = specific weight

  r = radius of tube

  h = capillary rise

  θ = wetting angle, angle of contact of liquid surface



- Since, the weight of the liquid column in the tube above the liquid surface acting downwards

  $p = W/A \Rightarrow W = p\,A = \gamma h \times \pi r^2$

  and vertical component of the force of surface tension

  $\sigma_y = 2\pi r\, \sigma \cos\theta$

Properties of Fluids

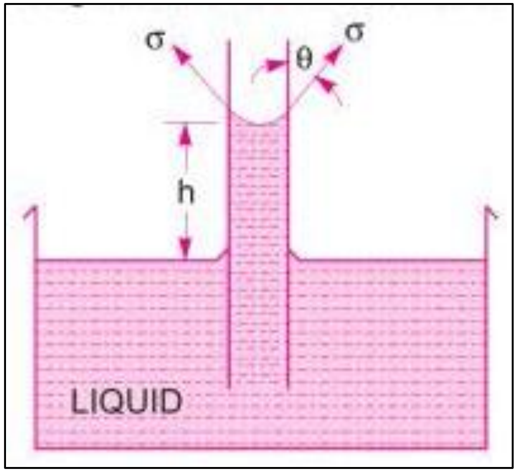
- Since the downward weight of the liquid column is balanced by the vertical component of the force of surface tension, therefore

$$\sum F_y = 0$$

$$W = \sigma_y$$

$$\gamma h \times \pi r^2 = 2 \pi r \sigma \cos\theta$$

$$h = 2 \sigma \cos \theta / \gamma r$$



- This expression can be used to compute the approximate capillary rise or depression in a tube.
- If the tube is clean, then $\theta = 0^o$ for pure water, and about 140^o for mercury.
- For tubes greater than 12 mm, capillary effects are negligible.
- Surface tension decreases slightly with increasing temperature.
- Surface tension effects are generally negligible in most engineering situations; however, they are important in problems involving capillary rise e.g. soil-water zone; water rise to crops, the formation of drops and bubbles, the breakup of liquid jets, and in hydraulic model studies where the model is small.

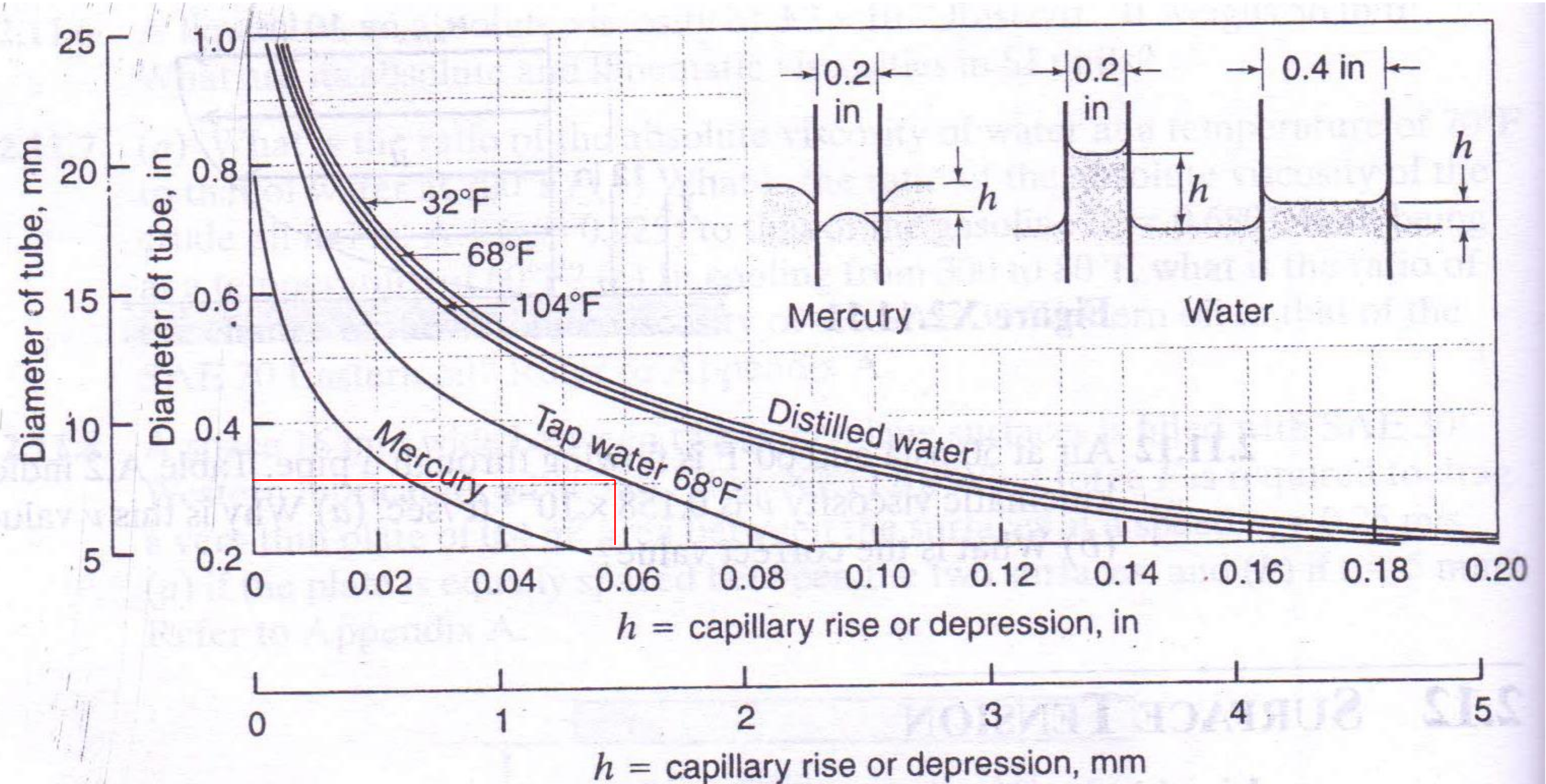


Figure 2.7
Capillarity in clean circular glass tubes, for liquid in contact with air.

Tap water at 68°F stands in a glass tube of 0.32-in diameter at a height of 4.50 in. What is the true static height?

Fig. 2.7: Capillary rise ≈ 0.058 in. True static height ≈ 4.50 − 0.058, say 4.44 in ◄

Distilled water at 20°C stands in a glass tube of 6.0-mm diameter at a height of 18.0 mm. What is the true static height?

20°C = 68°F; tube dia = 6.0 mm = 0.236 in. Fig. 2.7: Capillary rise ≈ 0.162 in = 4.11 mm

True static height ≈ 18.00 − 4.11 = 13.89 mm ◄

Use Eq. (2.12) to compute the capillary depression of mercury at 68°F (θ = 140°) to be expected in a 0.05-in-diameter tube.

Table A.4 for mercury at 68°F: $s = 13.56$, $\sigma = 0.032$ lb/ft.

Eq. 2.12: $h = \dfrac{2\sigma\cos 140°}{\gamma r} = \dfrac{2(0.032)0.766}{13.56\times 62.4(0.025/12)} = 0.0278 \text{ ft} = 0.334 \text{ in}$ ◄

Compute the capillary rise in mm of pure water at 10°C expected in an 0.8-mm-diameter tube.

Table A.1 at 10°C: $\sigma_{water} = 0.0742$ N/m, $\gamma = 9.804$ kN/m^3

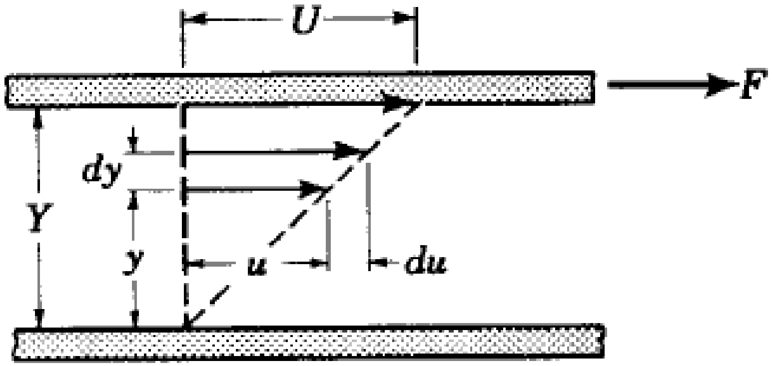
Eq. 2.12 with $\theta = 0$: $h = \dfrac{2\sigma}{\gamma r} = \dfrac{2(0.0742 \text{ N/m})}{(9804 \text{ N/m}^3)(0.0004 \text{ m})} = 0.0378 \text{ m} = 37.8 \text{ mm}$ ◄

Properties of Fluids

7. Viscosity:

- Viscosity is a property of a liquid, which controls its rate of flow.
- As a matter of fact, viscosity of a liquid is the property which resists *(i.e., retards)* the motion of translation of one layer relative to other.
- Or in other words, viscosity is the resistance to shear or angular deformation.
- It is thus obvious that a continuous supply of energy is required to overcome this resistance.
- It is fundamentally due to the cohesion between the liquid particles and is exhibited by the liquid when it is in motion.
- As the temperature increases, the viscosities of liquids decreases, while the viscosities of all gases increase.
- This is because, in liquids the force of cohesion dominates, and diminishes with temperature, while, in gases the molecular momentum dominates, and increases, causing increase in their viscosity due to shear or friction produced between adjacent layers.
- Absolute or dynamic viscosity of water at 4^{o}C = 1.518 x 10^{-3} N-s/m^2.
- The metric unit of viscosity is poise (P), named after Jean Louis Poiseuille (1799-1869), a French anatomist (1P = 0.1 N-s/m^2 = 0.1 Pa-s).
- The viscosity of water at 20.22^{o}C (68.4^{o}F) is equal to 1 centipoise (cP).

Properties of Fluids



- Consider two parallel plates as shown, sufficiently large so that edge conditions may be neglected, placed a small distance '**Y**' apart, the space between being filled with the fluid.
- The lower surface is assumed to be stationary, while the upper one is moved parallel to it with velocity '**U**' by the application of the force '**F**' corresponding to some area '**A**' of the moving plate.
- Particles of the fluid in contact with each plate will adhere to it, and if the distance 'Y' is not too great or the velocity 'U' too high, the velocity gradient will be a straight line.
- According to the Newton's law of viscosity "*The shear stress on a layer of a fluid is directly proportional to the rate of shear strain*"

  $F \alpha A U/Y$ or $F = \mu A U/Y$ or $F/A = \mu U/Y$

  Since, $\tau = F/A = \mu U/Y$ or $\tau = \mu du/dy$ (proportional triangles)
- This is called Newton's equation of viscosity where μ (mu) is called the *coefficient of viscosity* or *dynamic viscosity* or *absolute viscosity* of the fluid.

A flat plate 200 mm × 750 mm slides on oil (μ = 0.85 N·s/m²) over a large plane surface (Fig. X2.11.4). What force F is required to drag the plate at a velocity v of 1.2 m/s, if the thickness t of the separating oil film is 0.6 mm?

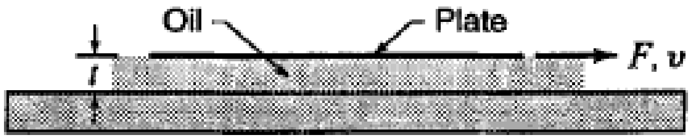


Figure X2.11.4

Eq. 2.9: $\tau = \mu \frac{dv}{dy} = 0.85 \frac{1.2}{0.000\,6} = 1700 \text{ N/m}^2$

From Eq. 2.9: $F = \tau A = 1700(0.20 \times 0.75) = 255 \text{ N}$ ◀

Assuming a velocity distribution as shown in Fig. X2.11.11, which is a parabola having its vertex 12 in from the boundary, calculate the velocity gradients for y = 0, 3, 6, 9, and 12 in. Also calculate the shear stresses in lb/ft² at these points if the fluid's absolute viscosity is 600 cP.

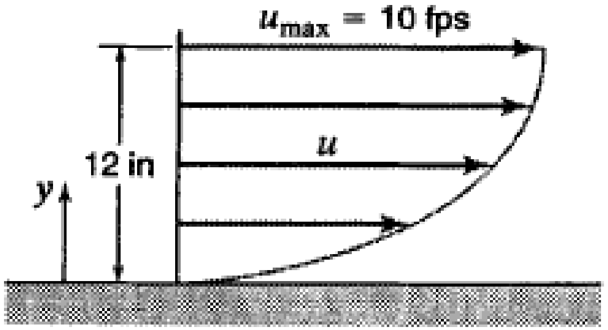


Figure X2.11.11

Back cover: $\mu = 600 \text{ cP} = 6 \text{ P} = 0.6 \text{ N·s/m}^2$

$\mu = 0.6(0.020\,885) = 0.012\,53 \text{ lb·sec/ft}^2$. Parabola: $Y = aX^2$

For u in in/sec and y in inches: $120 - u = a(12 - y)^2$

$u = 0$ at $y = 0 \rightarrow a = 120/12^2 = 5/6$; $u = 120 - (5/6)(12 - y)^2$; $du/dy = (5/3)(12 - y)$

Eq. 2.9: $\tau = 0.012\,53\, du/dy$

y (in)	0	3	6	9	12	
du/dy (sec⁻¹)	20	15	10	5	0	◀◀
τ (lb/ft²)	0.251	0.1880	0.1253	0.0627	0	◀◀

Types of Fluids

- The fluids may be classified into the following five types :

1. **Ideal Fluid:**

- A fluid, which is incompressible and is having no viscosity, is known as an ideal fluid. Ideal fluid is only an imaginary fluid as all the fluids, which exist, have some viscosity.

2. **Real Fluid:**

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

3. **Newtonian fluid:**

- A real fluid, in which the shear stress is directly proportional to the rate of shear strain (or velocity gradient), is known as a Newtonian fluid.

4. **Non-Newtonian Fluid:**

- A real fluid. in which the shear stress is not proportional to the rate of shear strain (or velocity gradient), known as a Non-Newtonian fluid.

5. **Ideal Plastic Fluid:**

- A fluid, in which shear stress is more than the yield value and shear stress is proportional to the rate of shear strain (or velocity gradient) is known as ideal plastic fluid.