Applied hydraulics

basic principles and water properties

Hala Rawabdeh

Hydraulics

- The Greek origin of the word "Hydraulics" is "*hydraulikos*" which means "water + pipe".
- It is the science of water at rest and in motion. In principle, it can also be applied to other fluids.

Units (Basic and Derive)

- Basic units

Dimensions	International System	English System	cgs
Length (L)	Meter	Foot	centimeter
Mass (M)	kg	Slug	gram
Time (t)	Second	Second	second
Temperature (T)	Kelvin degree(K°)	Fahrenheit (F°)	(K°)

- Derived units

1. Force (F) = Mass (m) x acceleration (a)

Force		
International System	$kg.m/s^2$	Newton (N)
English System	$Slug.ft/s^2$	Pound (Ib)
cgs	$g.cm/s^2$	Dyne (dyn)

$N = 10^5$ dyn

Weight and Force

Weight with gravitational acceleration

$F = m \times a$

$W = m \times g$ $g = 9.81 \ m/s^2$

Mass and Weight

Mass	Weight
Amount of material in an object	Gravity force to pull an object
Not change with position or movement	Change with gravity (earth, moon)
≠ zero	= zero in space

2. Pressure (p) = force (F) / Area (A)

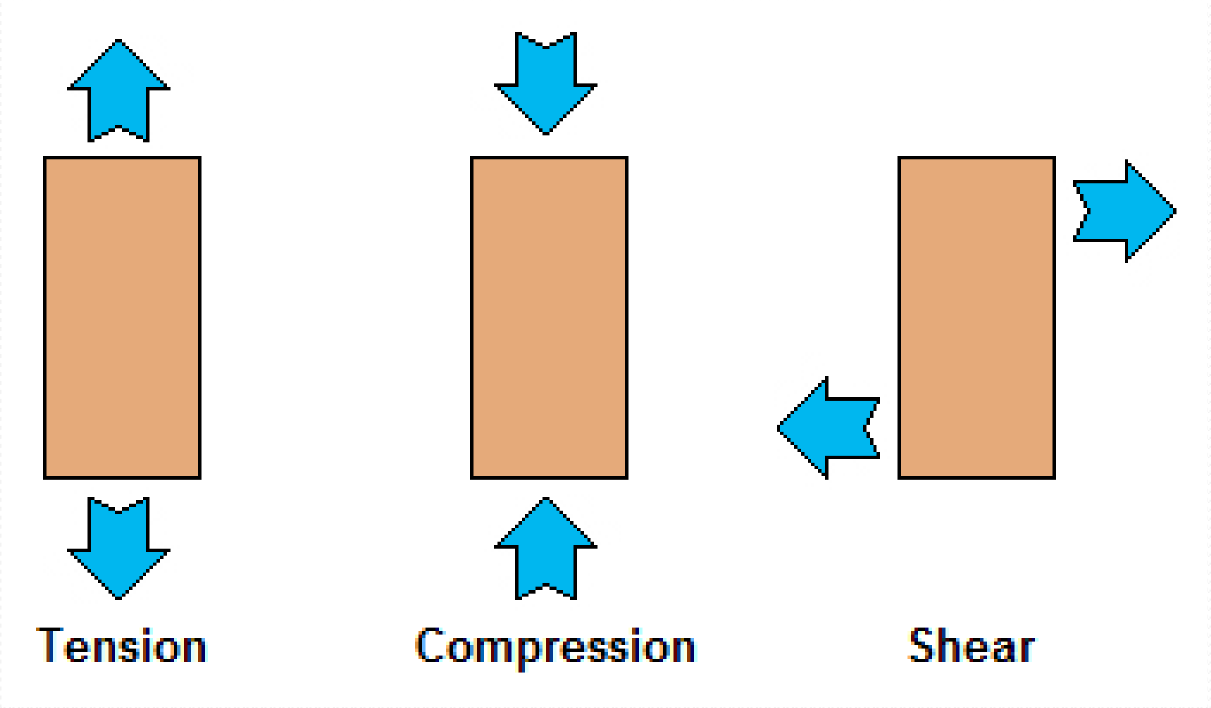
pressure		
International System	N/m^2	Pascal (Pa)
English System	Ib/ft^2	
cgs	$g/cm.s^2$	Barye

1 atm	= 101325 Pa = 101.325 kPa
1 bar	= 10^5 Pa
1 bar	= 10.2 m water = 0.76 m Hg

Pressure → normal → tension

normal → compression

Pressure → shear



3. Work: move the object from point to another

Work = force x distance

Work		
International System	N.m	Joule (J)
English System	Ib.ft or BTU	
cgs	Dyn.cm	Erg

4. Energy : the capacity to do work (Joule)

5.Power (P) : is the rate of doing work, the amount of **energy** transferred per unit time

Power = energy / time

Power		
International System	J/s	Watt (W)
English System	Ft.lb/s	
cgs	Dyn.cm/s	Erg/s

horse power (hp)

1 hp =	745.7W
1 W =	0.7376 Ft.lb/s
1 W =	0.001341 hp

Properties of water

A. Phases of water
B. Density
C. Specific weight
D. Surface tension
E. Viscosity

A. Water phases

- Water phases (ice, water and vapor)
- Latent heat : the heat required to convert water from phase to phase without change of temperature. (cal/g)

Latent Heat		
Fusion	79.7 cal/g	add energy
Freeze	79.7 cal/g	remove
Vaporization	597 cal/g	add energy
Condensation	597 cal/g	remove

- Specific heat : the heat required to raise the temperature 1C°

Specific heat	
Water	1 cal/g.C°
Ice	0.465 cal/g.C°

Example 1

Compute the heat energy(cal) required to evaporate 1200g of water at 45 C° to 100 C°

45 C° water ⟶ 100 C° water = (100-45) x 1 x 1200

= 66000 cal

100 C° water ⟶ 100 C° vapor = (1) x 597 x 1200

= 716400 cal

total	= 782400 cal

example 2 : 250 L: -20 C° ice to 100 C° vapor

answer= 196500 kcal

B. Density of Water

$$density = \rho = \frac{Mass}{Volume}$$

Temperature (^{o}C)	**Density (Kg/m^3)**
0 (ice)	917
0 (liquid)	999
4	1000
10	999
20	998
40	992
60	983
80	965

C. Specific weight of water (ɣ)

- $\gamma = \frac{\text{Weight}}{\text{Volume}}$

$\gamma = \rho \times g$ …………………prove

2^{nd} Newton law

$$\frac{\text{Weight}}{\text{Volume}} = \frac{m}{\text{Volume}} \times g$$

$\gamma = \rho \times g$

$\gamma\ 4C^{\circ} = 1000\ (kg/m^3) \times 9.81\ (m/s^2) = 9810\ N/m^3$

$= 9.81\ kN/m^3$

Specific gravity

Specific gravity (SG) of a fluid is equal to:

$$SG = \frac{Sepcific\ weight\ of\ fluid}{Specigic\ weight\ of\ water} = \frac{ɣ\ liquid}{ɣ\ water}$$

Or:

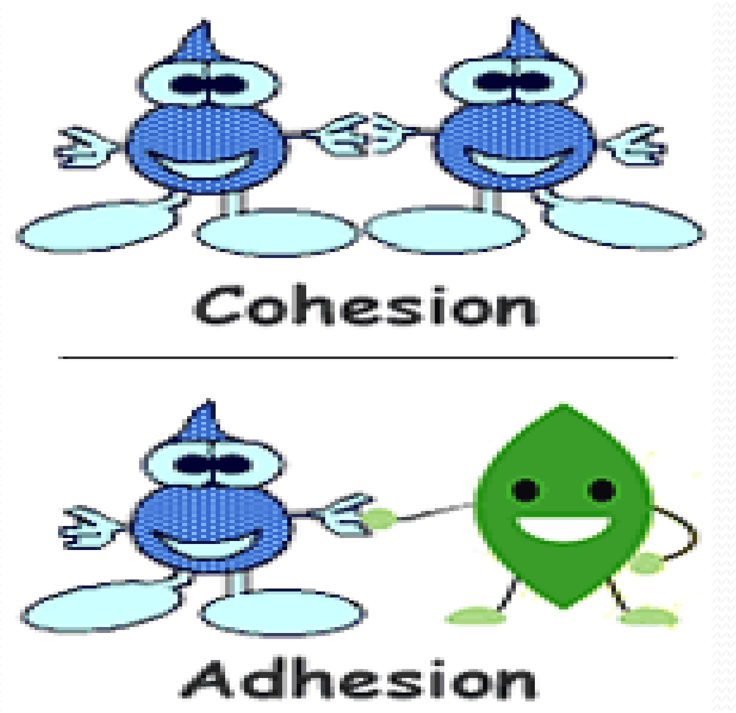
$$SG = \frac{Densty\ of\ fluid}{Density\ \ of\ water} = \frac{ρ\ liquid}{ρ\ water}$$

D. Surface tension

Steel needle floating on water, spherical shape of dewdrops, rise and fall in capillary tube......... result of surface tension

Because of

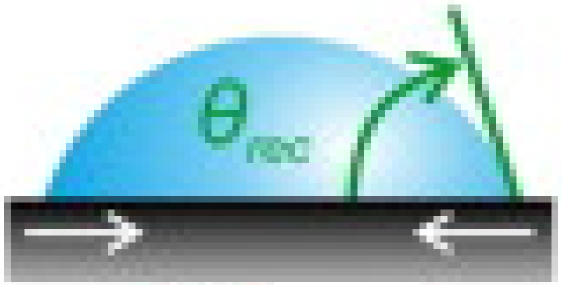
- Cohesion forces: the **force** of attraction between molecules of the same substance.
- Adhesive forces: the **force** of attraction between different substances, such as glass and water.



- No wetting surface
- oily surface
- Mercury

cohesion > adhesion

- Wetting surface

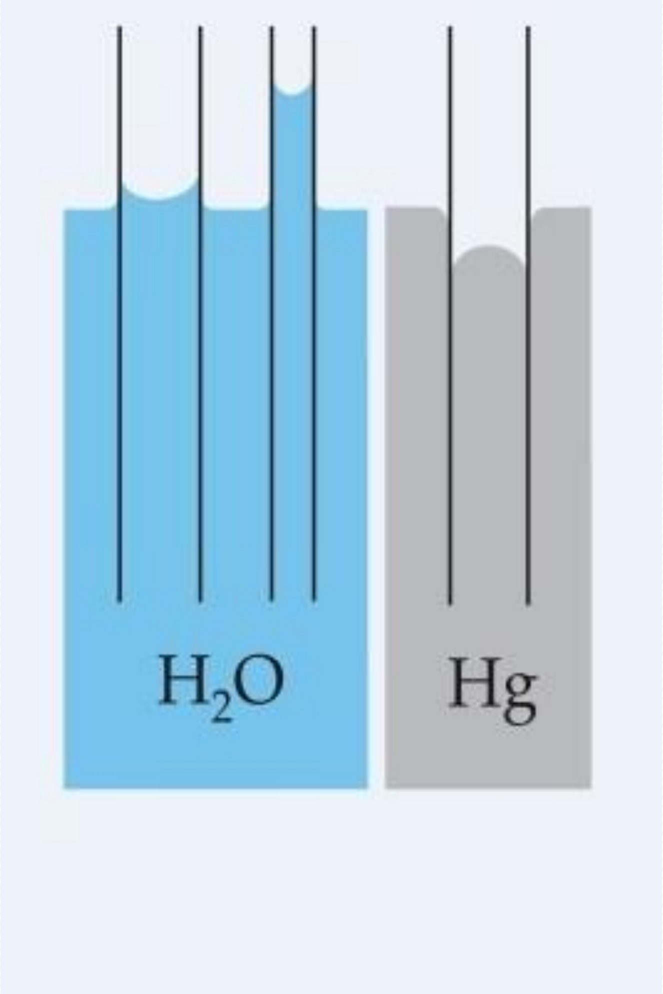


adhesion > cohesion

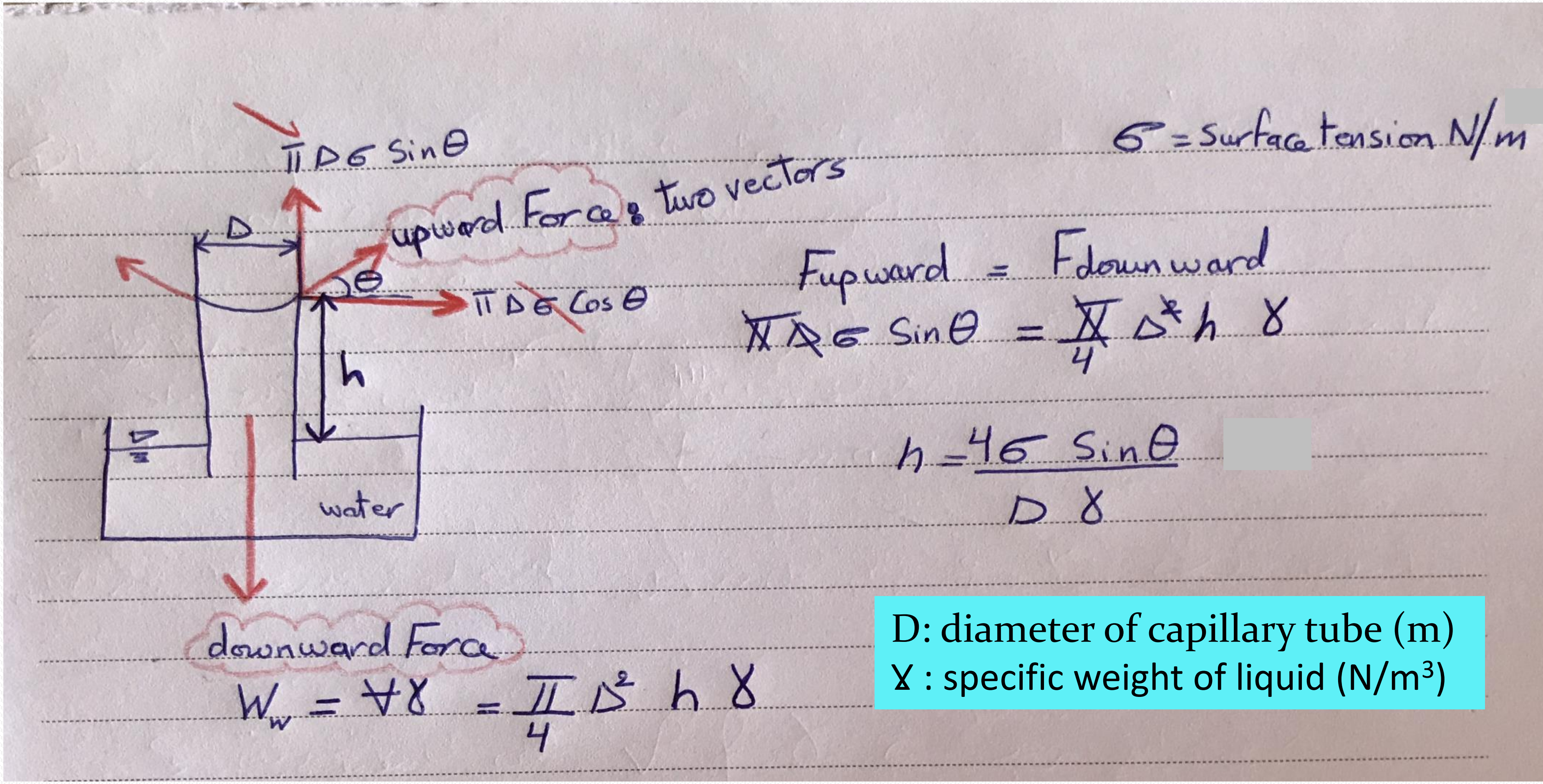
Capillary action

- Mercury : cohesion > adhesion

- Water : adhesion > cohesion



Capillary height (h)



D: diameter of capillary tube (m)

γ : specific weight of liquid (N/m^3)

Surface tension

Temperature (^oC)	Surface tension (x 10^{-2}N/m)
0	7.416
10	7.279
20	7.132
30	6.975
40	6.818
50	6.786
60	6.611
70	6.436
80	6.260
90	6.071

Example

- Determine the height in capillary tube of 1.8mm. The contacting angle is 45˚. T = 20 ˚C.

Answer : 0.0114 m = 11.4 mm

- Water is observed to rise to a height of 1.8 mm in 1 cm glass tube. The contacting angle is 90˚. Determine the surface tension of the water in N/m if its density is 1000 kg/m^3

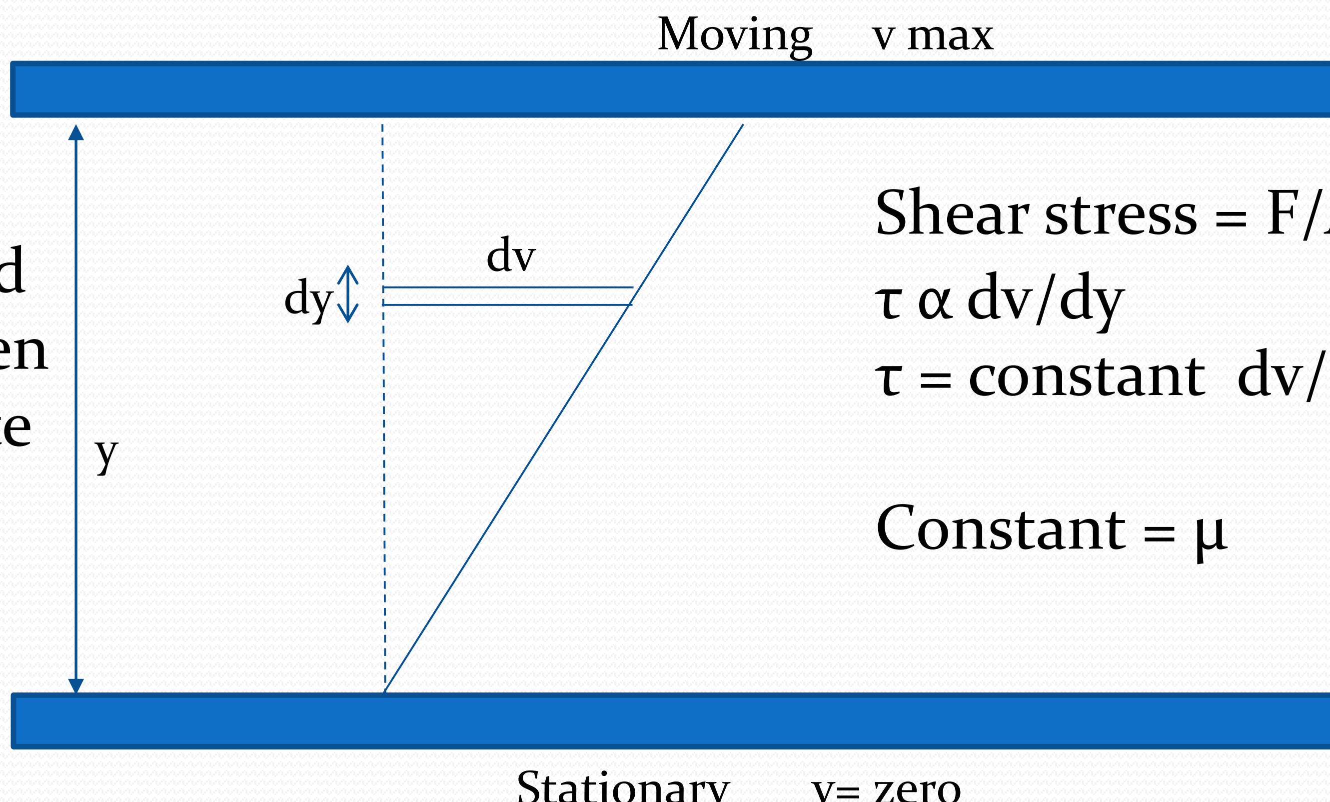
Answer: 0.044 N/m

E. Viscosity

Fluids (water, vapor) deforms when subjected to force

Solid (ice) resist deformation

Water is affected by shearing when moving the plate



Shear stress = F/A

$\tau \; \alpha \; dv/dy$

τ = constant dv/dy

Constant = μ

- According to Newton's law of viscosity
- $\tau = \mu \frac{dv}{dy}$
- μ is viscosity
- Units of viscosity :

  1 poise =100 cP= 0.1 N.s/m^2 ➔ 1000 cP = Pa.s

- Then $\tau = \frac{N\ .s}{m^2}\ x\ \frac{\frac{m}{s}}{m} = \frac{N}{m^2} = shear\ stress$

- Under the action of force the fluid moves and shearing stress develop
- Water particles are arranged in layers Like a pack of cards
- The layer close to the surface sticks to it.
- The upper above will move but friction or shear stress will develop with the layer below
- Shear stresses between layer cause water in pipe to move in different velocities.

Viscosity

- Absolute or dynamic viscosity
- $\mu = \frac{N\,.\,s}{m^2}$
- Kinematic Viscosity:
- $v = \frac{\mu}{\rho} = \frac{\frac{N\,.s}{m^2}}{\frac{kg}{m^3}} = \frac{\frac{kg\,.m\,.s}{s^2\,m^2}}{\frac{kg}{m^3}} = \frac{m^2}{s}$

- Example:

A rectangle piece of wood(4 x 4 m) is pulled at a speed of 1.3 m/s in shallow channel. The depth of the channel is 0.12 m and the force need to pull the piece of wood is 0.2 N. Determine the dynamic viscosity of the water ?

- Solution:

$$\tau = \frac{F}{A} = \frac{0.2}{16} = 0.0125\ Pa$$

$$\tau = \mu \frac{dv}{dy}$$

$$0.0125 = \mu \frac{1.3}{0.12}$$

μ=1.154 x 10^{-3} N.s/m^2

Viscosity of water

Temperature ^oC	Dynamic 10^{-3} (N.s/ m^2)	Kinematic 10^{-6} m^2/s
0	1.781	1.785
10	1.307	1.306
20	1.002	1.003
30	0.798	0.800
40	0.653	0.658
50	0.547	0.553
60	0.466	0.474
70	0.404	0.413
80	0.354	0.364
90	0.315	0.326
100	0.282	0.294