I. FLUID MECHANICS

I.1 Basic Concepts & Definitions:

Fluid Mechanics - Study of fluids at rest, in motion, and the effects of fluids on boundaries.

Note: This definition outlines the key topics in the study of fluids:

(1) fluid statics (fluids at rest), (2) momentum and energy analyses (fluids in motion), and (3) viscous effects and all sections considering pressure forces (effects of fluids on boundaries).

Fluid - A substance which **moves** and **deforms continuously** as a result of an **applied shear stress.**

The definition also clearly shows that viscous effects are not considered in the study of fluid statics.

Two important properties in the study of fluid mechanics are:

Pressure and Velocity

These are defined as follows:

Pressure - The **normal stress** on **any** plane through a fluid element **at rest.**

Key Point: The direction of pressure forces will **always** be perpendicular to the surface of interest.

Velocity - The rate of change of position at a point in a flow field. It is used not only to specify flow field characteristics but also to specify flow rate, momentum, and viscous effects for a fluid in motion.

I.4 Dimensions and Units

This text will use both the International System of Units (S.I.) and British Gravitational System (B.G.).

A key feature of both is that neither system uses g_c. Rather, in both systems the combination of units for mass * acceleration yields the unit of force, i.e. Newton's second law yields

S.I. 1 Newton (N) = 1 kg m/s^2 **B.G**. 1 lbf = 1 slug ft/s^2

This will be particularly useful in the following:

Concept	Expression	Units
momentum	$\dot{m}V$	kg/s * m/s = kg m/s^2 =N
		slug/s * ft/s = slug ft/s^2 = lbf
manometry	ρ g h	kg/m^3*m/s^2*m = (kg m/s^2)/ m^2 =N/m^2
		slug/ft^3*ft/s^2*ft = (slug ft/s^2)/ft^2 = lbf/ft^2
dynamic viscosity	μ	N s /m^2 = (kg m/s^2) s /m^2 = kg/m s
		lbf s /ft^2 = (slug ft/s^2) s /ft^2 = slug/ft s

Key Point: In the B.G. system of units, the mass unit is the slug and not the lbm. and 1 slug = 32.174 lbm. Therefore, be careful not to use conventional values for fluid density in English units without appropriate conversions, e.g., ρ_w = 62.4 lb/ft^3

For this case the manometer equation would be written as

$$\Delta P = \rho \frac{g}{g_c} h$$

Example:

Given: Pump power requirements are given by

$\dot{W}_p$ = fluid density*volume flow rate*g*pump head = $\rho\, Q\, g\, h_p$

For ρ = 1.928 slug/ft^3, Q = 500 gal/min, and h_p = 70 ft,

Determine: The power required in kW.

$\dot{W}_p$ = 1.928 slug/ft^3 * 500 gal/min*1 ft^3/s /448.8 gpm*32.2 ft/s^2 * 70 ft

$\dot{W}_p$ = 4841 ft-lbf/s * 1.3558*10^{-3} kW/ft-lbf/s = 6.564 kW

Note: We used the following: 1 lbf = 1 slug ft/s^2 to obtain the desired units

Recommendation: In working with problems with complex or mixed system units, at the start of the problem convert all parameters with units to the base units being used in the problem, e.g. for S.I. problems, convert all parameters to kg, m, & s; for BG problems, convert all parameters to slug, ft, & s. Then convert the final answer to the desired final units.

1.5 Properties of the velocity Field

Two important properties in the study of fluid mechanics are

Pressure and Velocity

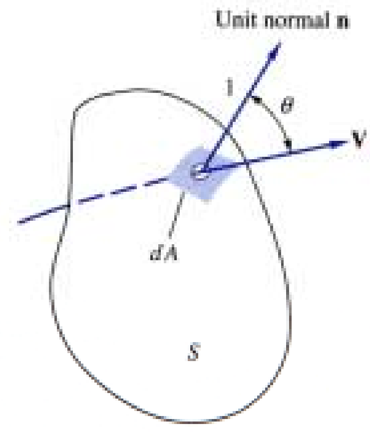
The basic definition for velocity has been given previously, however, one of its most important uses in fluid mechanics is to specify both the volume and mass flow rate of a fluid.

Volume flow rate:

$$\dot{Q} = \int_{cs} \bar{V} \cdot \bar{n}\, dA = \int_{cs} V_n\, dA$$

where V_n is the normal component of velocity at a point on the area across which fluid flows.

Key Point: Note that only the normal component of velocity contributes to flow rate across a boundary.

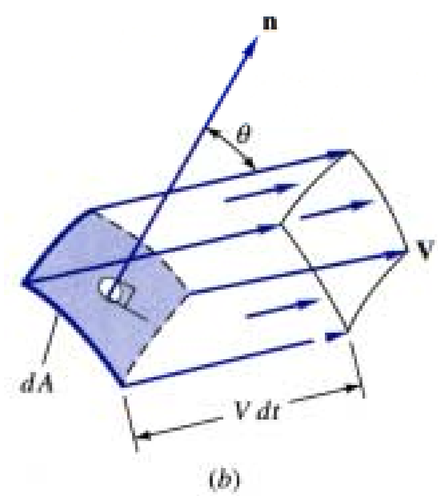


(a)

Mass flow rate:

$$\dot{m} = \int_{cs} \rho \bar{V} \cdot \bar{n}\, dA = \int_{cs} \rho V_n\, dA$$

NOTE: While not obvious in the basic equation, $\mathbf{V_n}$ must also be measured relative to any flow area boundary motion, i.e., if the flow boundary is moving, $\mathbf{V_n}$ is measured **relative to** the moving boundary.



(b)

This will be particularly important for problems involving moving control volumes in Ch. III.

1.6 Thermodynamic Properties

All of the usual thermodynamic properties are important in fluid mechanics

P - Pressure	(kPa, psi)
T- Temperature	(^oC, ^oF)
ρ ñ Density	(kg/m^3, $slug/ft^3$)

<u>Alternatives for density</u>

γ - specific weight = weight per unit volume (N/m^3, lbf/ft^3)

$\gamma = \rho g$ H_2O: $\gamma = 9790\ N/m^3 = 62.4\ lbf/ft^3$

Air: $\gamma = 11.8\ N/m^3 = 0.0752\ lbf/ft^3$

S.G. - specific gravity = ρ / ρ (ref)

where: ρ (ref) = ρ (water at 1 atm, 20˚C) for liquids = 998 kg/m^3

= ρ (air at 1 atm, 20˚C) for gases = 1.205 kg/m^3

Example: Determine the static pressure difference indicated by an 18 cm column of fluid (liquid) with a specific gravity of 0.85.

$$\Delta P = \rho g h = S.G.\ \gamma h = 0.85 * 9790\ N/m^3\ 0.18\ m = 1498\ N/m^2 = 1.5\ kPa$$

I.7 Transport Properties

Certain transport properties are important as they relate to the diffusion of momentum due to shear stresses. Specifically:

$\mu \equiv$ coefficient of viscosity (dynamic viscosity) {M / L t }

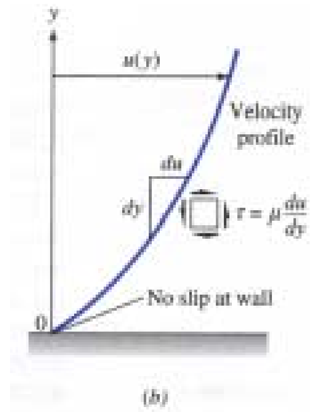
$\nu \equiv$ kinematic viscosity (μ / ρ) { L^2 / t }

This gives rise to the definition of a Newtonian fluid.

Newtonian fluid: A fluid which has a **linear** relationship between shear stress and velocity gradient.

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

The linearity coefficient in the equation is the coefficient of viscosity μ.



Flows constrained by solid surfaces can typically be divided into two regimes:

a. Flow near a bounding surface with
   1. significant velocity gradients
   2. significant shear stresses

This flow region is referred to as a "**boundary layer**."

b. Flows far from bounding surface with
   1. negligible velocity gradients
   2. negligible shear stresses
   3. significant inertia effects

This flow region is referred to as "free stream" or "inviscid flow region."

An important parameter in identifying the characteristics of these flows is the

$$\text{Reynolds number} = \text{Re} = \frac{\rho V L}{\mu}$$

This physically represents the ratio of inertia forces in the flow to viscous forces. For most flows of engineering significance, both the characteristics of the flow and the important effects due to the flow, e.g., drag, pressure drop, aerodynamic loads, etc., are dependent on this parameter.