Fluid Static and Its Applications

3.1 Introduction

Static fluids means that the fluids are at rest.

The pressure in a static fluid is familiar as a surface force exerted by the fluid ageist a unit area of the wall of its container. Pressure also exists at every point within a volume of fluid. It is a scalar quantity; at any given point its magnitude is the same in all directions.

3.2 Pressure in a Fluid

In Figure (1) a stationary column of fluid of height (h_2) and cross-sectional area A, where $A=A_o=A_1=A_2$, is shown. The pressure above the fluid is P_o, it could be the pressure of atmosphere above the fluid. The fluid at any point, say h_1, must support all the fluid above it. It can be shown that the forces at any point in a nonmoving or static fluid must be the same in all directions. Also, for a fluid at rest, the pressure or (force / unit area) in the same at all points with the same elevation. For example, at h_1 from the top, the pressure is the same at all points on the cross-sectional area A_1.

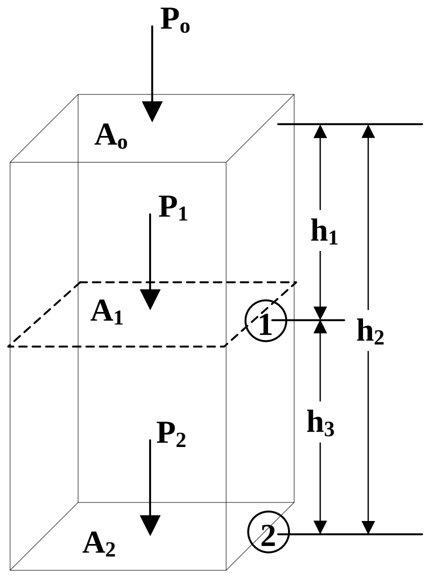


Figure (1): Pressure in a static fluid.

The total mass of fluid for h_2, height and ρ density is: - ($h_2 A \rho$) (kg)

But from Newton's 2nd law in motion the total force of the fluid on area (A) due to the fluid only is: - ($h_2 A \rho g$) (N) i.e. $F = h_2 A \rho g$ (N)

The pressure is defined as ($P = F/A = h_2 \rho g$) (N/m^2 or Pa)

This is the pressure on A_2 due to the weight of the fluid column above it. However to get the total pressure P_2 on A_2, the pressure P_o on the top of the fluid must be added,

i.e. $P_2 = h_2 \rho g + P_o$ (N/m^2 or Pa)

Thus to calculate P_1, $P_1 = h_1 \rho g + P_o$ (N/m^2 or Pa)

The pressure difference between points ① and ② is: -

$P_2 - P_1 = (h_2 \rho g + P_o) - (h_1 \rho g + P_o)$

⇒ $P_2 - P_1 = (h_2 - h_1) \rho g$ SI units

$P_2 - P_1 = (h_2 - h_1) \rho g / g_c$ English units

Since it is vertical height of a fluid that determines the pressure in a fluid, the shape of the vessel does not affect the pressure. For example in Figure (2) the pressure P_1 at the bottom of all three vessels is the same and equal to ($h_1 \rho g + P_o$).

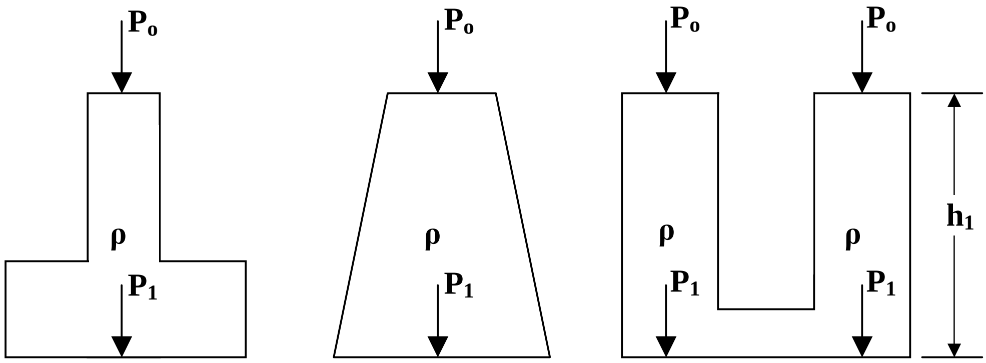


Figure (2): Pressure in vessel of various shapes.

3.3 Absolute and Relative Pressure

The term pressure is sometimes associated with different terms such as *atmospheric*, *gauge*, *absolute*, and *vacuum*. The meanings of these terms have to be understood well before solving problems in hydraulic and fluid mechanics.

1- Atmospheric Pressure

It is the pressure exerted by atmospheric air on the earth due to its weight. This pressure is change as the density of air varies according to the altitudes. Greater the height lesser the density. Also it may vary because of the temperature and humidity of air. Hence for all purposes of calculations the pressure exerted by air at sea level is taken as standard and that is equal to: -

1 atm = 1.01325 bar = 101.325 kPa = 10.328 m H_2o = 760 torr (mm Hg) = 14.7 psi

2- Gauge Pressure or Positive Pressure

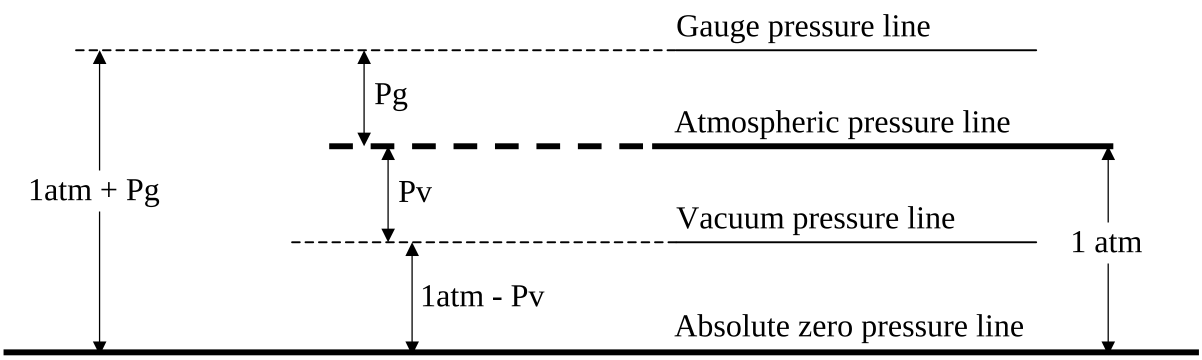
It is the pressure recorded by an instrument. This is always above atmospheric. The zero mark of the dial will have been adjusted to atmospheric pressure.

3- Vacuum Pressure or Negative Pressure

This pressure is caused either artificially or by flow conditions. The pressure intensity will be less than the atmospheric pressure whenever vacuum is formed.

4- Absolute Pressure

Absolute pressure is the algebraic sum of atmospheric pressure and gauge pressure. Atmospheric pressure is usually considered as the datum line and all other pressures are recorded either above or below it.



Absolute Pressure = Atmospheric Pressure + Gauge Pressure

Absolute Pressure = Atmospheric Pressure – Vacuum Pressure

For example if the vacuum pressure is 0.3 atm ⇒ absolute pressure = 1.0 – 0.3 = 0.7 atm

Note: -

Barometric pressure is the pressure that recorded from the barometer (apparatus used to measure atmospheric pressure).

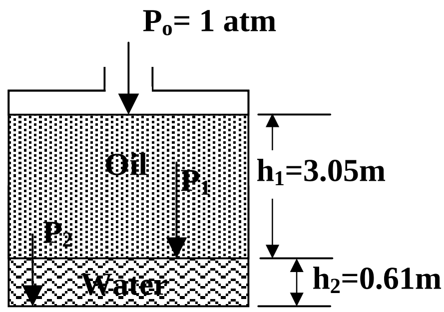
3.4 Head of Fluid

Pressures are given in many different sets of units, such as N/m^2, or Pa, $dyne/cm^2$, psi, lb_f/ft^2. However a common method of expressing pressures is in terms of head (m, cm, mm, in, or ft) of a particular fluid. This height or head of the given fluid will exert the same pressure as the pressures it represents. $P = h\,\rho\,g$.

Example -3.1-

A large storage tank contains oil having a density of 917 kg/m^3. The tank is 3.66 m tall and vented (open) to the atmosphere of 1 atm at the top. The tank is filled with oil to a depth of 3.05 m (10 ft) and also contains 0.61 m (2 ft) of water in the bottom of the tank. Calculate the pressure in Pa and psia at 3.05 m from the top of the tank and at the bottom. And calculate the gauge pressure at the bottom of the tank.

Solution:



$P_o = 1$ atm $= 14.696$ psia $= 1.01325 \times 10^5$ Pa

$P_1 = h_1\,\rho_{oil}\,g + P_o$

$= 3.05$ m $(917\ kg/m^3)\ 9.81\ m/s^2 + 1.01325 \times 10^5$ Pa

$= 1.28762 \times 10^5$ Pa

$P_1 = 1.28762 \times 10^5$ Pa $(14.696$ psia$/1.01325 \times 10^5$ Pa$)$

$= 18.675$ psia

or

$P_1 = h_1\,\rho_{oil}\,g + P_o$

$= 10$ ft m $[917\ kg/m^3\ (62.43\ lb/ft^3/1000\ kg/m^3)]\ (32.174\ ft/s^2/32.174\ lb.ft/lb_f.s^2)$ $1/144\ ft^2/in^2 + 14.696 = 18.675$ psia

$P_2 = P_1 + h_2\,\rho_{water}\,g$

$= 1.28762 \times 10^5$ Pa $+ 0.61$ m $(1000\ kg/m^3)\ 9.81\ m/s^2$

$= 1.347461 \times 10^5$ Pa

$P_2 = 1.347461 \times 10^5$ Pa $(14.696$ psia$/1.01325 \times 10^5$ Pa$)$

$= 19.5433$ psia

The gauge pressure = abs – atm

$= 33421.1$ Pa $= 4.9472$ psig