



AFE
BABALOLA
UNIVERSITY
ADO-EKITI (ABUAD)
KM. 8.5, AFE BABALOLA WAY,
ADO-EKITI, EKITI STATE, NIGERIA.
P.M.B 5454 ADO-EKITI.

Department of Physical and Mathematical Sciences

Olawumi R. Kaka

2.0 HYDROSTATICS, HYDRODYNAMICS, BOUYANCY, ARCHIMEDES' PRINCIPLES AND SURFACE TENSION.

2.1 HYDROSTATICS:

Hydrostatics simply refers to as fluid statics is the branch of fluid mechanics that studies the characteristics of fluids at rest. In particular, it deals with the pressure exerted by a fluid on an immersed body.

2.1.1 Applications of Principles of Hydrostatics

Some of the applications of Hydrostatics Principles:

1. The study of atmospheric pressure i.e. the pressure reducing with an increasing altitude
2. They are used for problems relating to pressure in deep water i.e. the study of the pressure as it increases with depth
3. It is used in studying capillary action i.e. the phenomenon in which the surface of a liquid is observed to be elevated or depressed when it comes in contact with a solid

2.1.1.1 Atmospheric Pressure

Atmospheric Pressure is the force per unit area exerted against a surface by the weight of air above that surface. It is equivalent to the pressure at the bottom of the sea air. It is denoted by P_o . The pressure varies with weather changes and with elevation.

The average value of atmospheric pressure at sea level

$$1P_o = 1 \text{ atmosphere} = 1.013 \times 10^5 P_a$$

2.1.1.1.1 Various Pressures at Different Altitudes

Low pressure areas have less atmospheric mass above their location, whereas high pressure areas have more atmospheric mass above their location. Similarly, as elevation increases there is less overlying atmospheric mass, so that pressure decreases with increasing elevation.

On the top of Mt. Everest, the tallest mountain on earth, the air pressure is just about a third of what it is at sea level. At 16km or almost 10 miles above the surface, slightly higher than the cruising altitude of a typical jet liner, pressure is only 1/10th of what it is at sea level. Because low air pressure can be very unpleasant for humans due to low oxygen content, all areas of aircraft that contain passengers are artificially pressurized, Figure 2.1.1.1.1.

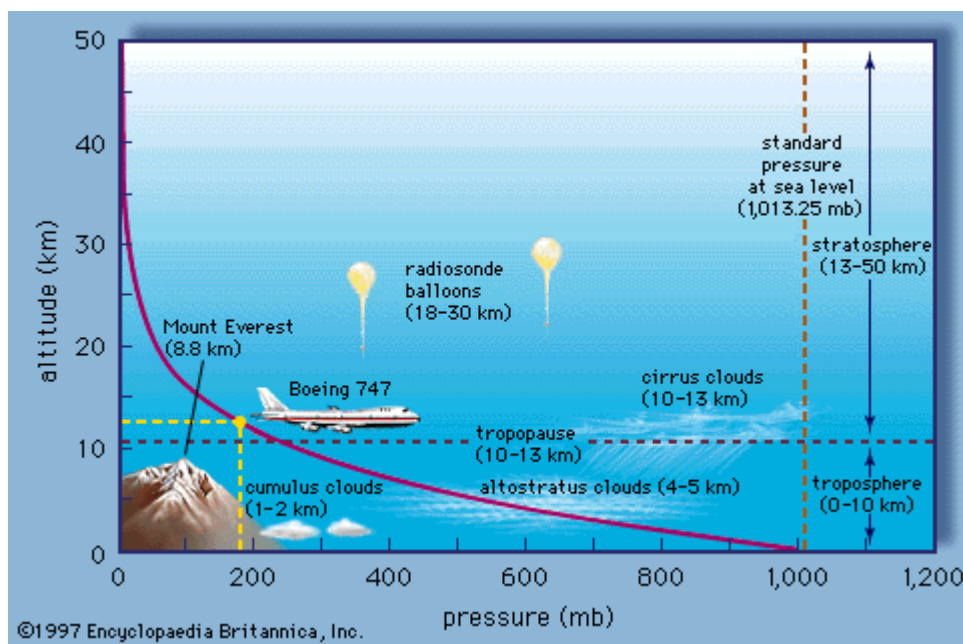


Figure 2.1.1.1.1: Pressures as it varies with Altitudes

2.1.1.2 Hydrostatic Pressure in a Liquid

The pressure of a liquid can easily be expressed in terms of its density, ρ and the height h of its column.

$$\begin{aligned} \text{mass of liquid} &= \text{volume} \times \text{density} \\ &= hA \times \rho \\ &= hA\rho \end{aligned} \tag{1}$$

From Newton's 2nd Law;

$$F = Ma = Mg \tag{2}$$

The force exerted by liquid column on area A is ;

$$F = hA\rho g \tag{3}$$

Where g is the acceleration due to gravity.

Thus,

The pressure exerted by hg at the bottom of the column is ,

$$\begin{aligned} P &= \frac{\text{force}}{\text{area}} \\ &= \frac{hA\rho g}{A} \\ P &= h\rho g \end{aligned} \tag{4}$$

2.1.1.2.1 Variations of Pressure with Depth in a Fluid

Suppose we have an object submerged in water with the top part open to the atmosphere. The 3 forces acting on the object are:

- i. The force of the atmosphere pressing down
- ii. The weight of the object
- iii. The force of the water pressing up

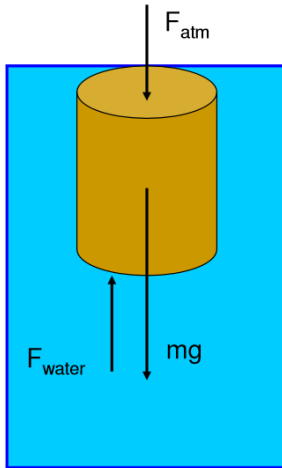


Figure 2.1.1.2.1a: Forces acting on the object submerged in water

Considering the above forces, we can show how the pressure in a liquid increases linearly with depth. Let us consider a fluid of density ρ at rest and open to the atmosphere, as shown in Figure 2.1.1.2.1a. We assume that ρ is constant; this means that the fluid is incompressible. Let us select a sample of the liquid contained within an imaginary cylinder of cross-sectional area A extending from the surface to a depth h ; Figure 2.1.1.2.1b.

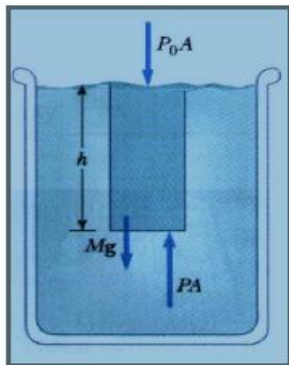


Figure 2.1.1.2.1b: How pressure varies with depth in a fluid

Therefore,

Pressure exerted by the outside liquid on the bottom face of the cylinder is P ,

Pressure exerted on the top face of the cylinder is the atmospheric pressure P_0 .

The upward force exerted by the outside fluid on the bottom of the cylinder is PA

The downward force exerted by the atmosphere on the top is P_oA .

The mass of liquid in the cylinder is $M = \rho V = \rho Ah$

The weight of the liquid in the cylinder is $w = M\rho V = M\rho Ah$

Because the cylinder is in equilibrium, the net force acting on it must be zero.

But recall, pressure is force per unit area. So if we solve for force we can insert our new equation as:

$$P = \frac{F}{A} \quad F_{water} = F_{atm} + mg$$

$$PA = P_oA + mg$$

$$\rho = \frac{m}{V} \rightarrow m = \rho V$$

$$PA = P_oA + \rho Vg$$

$$V = Ah$$

$$PA = P_oA + \rho Ahg$$

$$P = P_o + \rho gh$$

Note: The initial pressure in this case is atmospheric pressure, which is a CONSTANT.

$$P_o = 1 \times 10^5 \text{ N/m}^2$$

*

Equation * shows the pressure P at a depth h below the surface of a liquid open to the atmosphere is *greater* than atmospheric pressure by an amount ρgh . This implies that the pressure is the same at all points having the same depth, independent of the shape of the container. And the concept was first recognized by the French scientist Blaise Pascal (1623-1662) and is called ***Pascal's law which states that "a change in the pressure applied to a fluid is transmitted undiminished to every point of the fluid and to the walls of the container"***.

An important application of Pascal's law is the hydraulic lift illustrated in Figure 2.1.1.2.1c. A piston with small cross-sectional area A_1 exerts a force of magnitude F_1 on the surface of a liquid such as oil. The applied pressure $p = F_1/A_1$ is transmitted through a liquid to a larger piston of surface area A_2 . Because the pressure must be the same on both sides; therefore, the force F_2 is greater than the force F_1 by a factor A_2/A_1 , which is called the ***force-multiplying factor***.

That is:

$$p = \frac{F_1}{A_1} = \frac{F_2}{A_2}$$

And

$$F_2 = \frac{A_2}{A_1} F_1$$

Car lifts and jacks, elevators also make use of this principle.

Example on Pascal's Law:

Pascal's Principle

Like a liquid lever, changing areas in an enclosed fluid permit multiplication of force

$A_1 = 5 \text{ cm}^2$

$F_1 = 10 \text{ N}$ Applied force to the stopper

$P_1 = \frac{10 \text{ N}}{5 \text{ cm}^2} = 2 \text{ N/cm}^2$

$P_1 = P_2$

$\frac{F_1}{A_1} = \frac{F_2}{A_2}$

Pressure is transmitted undiminished in an enclosed static fluid.

$F_2 = P_2 A_2 = (2 \text{ N/cm}^2)(500 \text{ cm}^2) = 1000 \text{ N!!}$ plus the force from the weight of the liquid.

Resulting force on bottom of jug.

$A_2 = 500 \text{ cm}^2$

2.1.1.2.2 Absolute Pressure and Gauge Pressure

$P = P_o + \rho gh$

Depth below surface

Initial Pressure – May or MAY NOT be atmospheric pressure

ABSOLUTE PRESSURE

$\Delta P = \rho gh$

Gauge Pressure = CHANGE in pressure or the DIFFERENCE in the initial and absolute pressure

Example on Absolute Pressure and Gauge Pressure:

A storage tank 12.0m deep is filled with water. The top of the tank is open to air. What is the absolute pressure at the bottom of the tank? Hence, find the gauge pressure?

Solution:

$$P_o = 1 \text{ atm} = 1.01 \times 10^5 \text{ Pa}$$

From equation *, the absolute pressure is

$$P = P_o + \rho gh$$

∴

$$\begin{aligned} P &= 1.01 \times 10^5 \text{ Pa} + 1000 \text{ kgm}^{-3} \times 9.8 \text{ ms}^{-2} \times 12.0 \text{ m} \\ &= 2.19 \times 10^5 \text{ Pa} \end{aligned}$$

The gauge pressure:

$$\begin{aligned} \Delta P &= P - P_o \\ &= (2.19 - 1.01) \times 10^5 \text{ Pa} \\ &= 1.18 \times 10^5 \text{ Pa} \end{aligned}$$

Assignment:

Suppose piston A has an area of 0.01 m^2 and piston B an area of 0.5 m^2 . If a force of 1 N acts downwards on piston A. Find the pressure transmitted through the liquid? And, the total upward force on piston B.

