Fluid Flow Fundamentals

An Online Continuing Education Course for Engineers

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INTRODUCTION

Fluid flow is an important part of most industrial processes, especially those involving the transfer of heat. Frequently, when it is desired to remove heat from the point at which it is generated, some type of fluid is involved in the heat transfer process. Examples of this are the cooling water circulated through a gasoline or diesel engine, the air flow past the windings of a motor, and the flow of water through the core of a nuclear reactor. Fluid flow systems are also commonly used to provide lubrication.

Even though a detailed analysis of fluid flow can be extremely difficult, the basic concepts involved in fluid flow problems are fairly straightforward. These basic concepts can be applied in solving fluid flow problems through the use of simplifying assumptions and average values, where appropriate. Even though this type of analysis would not be sufficient in the engineering design of systems, it is very useful in understanding the operation of systems and predicting the approximate response of fluid systems to changes in operating parameters.

There are three basic principles of fluid flow: The first is the principle of momentum (leading to equations of fluid forces); the second is the conservation of energy (leading to the First Law of Thermodynamics); and the third is the conservation of mass (leading to the continuity equation).

PROPERTIES OF FLUIDS

A *fluid* is any substance which flows because its particles are not rigidly attached to one another. This includes liquids, gases and even some materials which are normally considered solids, such as glass. Essentially, fluids are materials which have no repeating crystalline structure.

Temperature is defined as the relative measure of how hot or cold a material is. It can be used to predict the direction that heat will be transferred. *Pressure* is defined as the force per unit area. Common units for pressure are pounds force per square inch (psi). *Mass* is defined as the quantity of matter contained in a body and is to be distinguished from weight, which is measured by the pull of gravity on a body. The *specific volume* of a substance is the volume per unit mass of the substance. Typical units are ft^3/lbm. *Density*, on the other hand, is the mass of a substance per unit volume. Typical units are lbm/ft^3. Density and specific volume are the inverse of one another. Both density and specific volume are dependent on the temperature and somewhat on the pressure of the fluid. As the temperature of the fluid increases, the density decreases and the specific volume increases. Since liquids are considered incompressible, an increase in pressure will result in no change in density or specific volume of the liquid. In actuality, liquids can be slightly compressed at high pressures, resulting in a slight increase in density and a slight decrease in specific volume of the liquid.

Buoyancy

Buoyancy is defined as the tendency of a body to float or rise when submerged in a fluid. We all have had numerous opportunities of observing the buoyant effects of a liquid. When we go swimming, our bodies are held up almost entirely by the water. Wood, ice, and cork float on water. When we lift a rock from a stream bed, it suddenly seems heavier on emerging from the water. Boats rely on this buoyant force to stay afloat. The amount of this buoyant effect was first computed and stated by the Greek philosopher Archimedes. When a body is placed in a fluid, it is buoyed up by a force equal to the weight of the water that it displaces.

If a body weighs more than the liquid it displaces, it sinks but will appear to lose an amount of weight equal to that of the displaced liquid, as our rock. If the body weighs less than that of the displaced liquid, the body will rise to the surface eventually floating at such a depth that will displace a volume of liquid whose weight will just equal its own weight. A floating body displaces its own weight of the fluid in which it floats.

Compressibility

Compressibility is the measure of the change in volume a substance undergoes when a pressure is exerted on the substance. Liquids are generally considered to be incompressible. For instance, a pressure of 16,400 psig will cause a given volume of water to decrease by only 5% from its volume at atmospheric pressure. Gases on the other hand, are very compressible. The volume of a gas can be readily changed by exerting an external pressure on the gas.

Relationship between Depth and Pressure

Anyone who dives under the surface of the water notices that the pressure on his eardrums at a depth of even a few feet is noticeably greater than atmospheric pressure. Careful measurements show that the pressure of a liquid is directly proportional to the depth, and for a given depth the liquid exerts the same pressure in all directions.

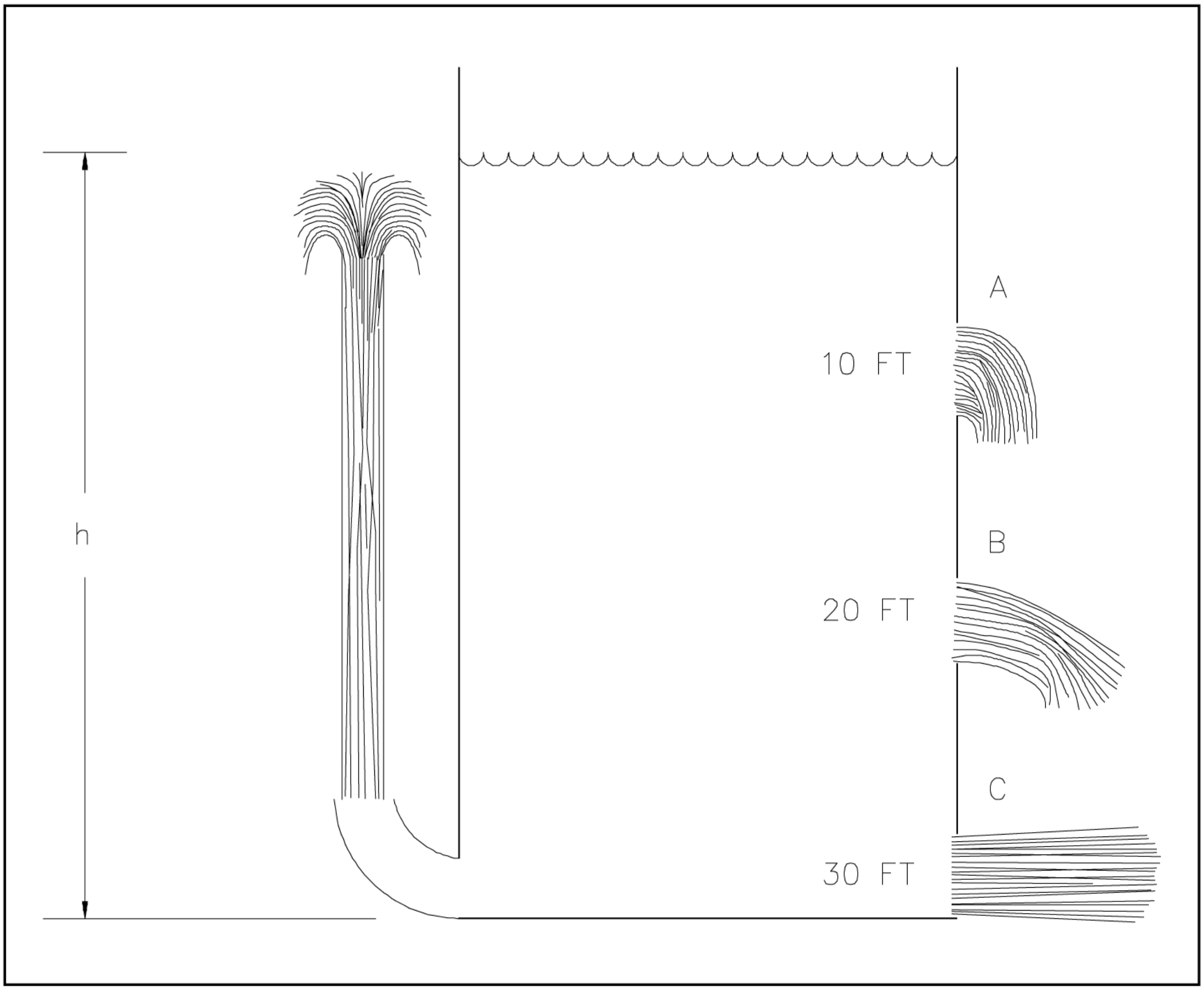


Figure 1 Pressure Versus Depth

As shown in Figure 1, the pressure at different levels in the tank varies and this causes the fluid to leave the tank at varying velocities. Pressure was defined to be force per unit area. In the case of this tank, the force is due to the weight of the water above the point where the pressure is being determined.

Example:

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$$

$$= \frac{\text{Weight}}{\text{Area}}$$

$$P = \frac{m\ g}{A\ g_c}$$

$$= \frac{\rho\ V\ g}{A\ g_c}$$

where:

m = mass in lbm

g = acceleration due to earth's gravity $32.17 \frac{\text{ft}}{\text{sec}^2}$

$g_c = 32.17\ \frac{\text{lbm-ft}}{\text{lbf-sec}^2}$

A = area in ft^2

V = volume in ft^3

ρ = density of fluid in $\frac{\text{lbm}}{\text{ft}^3}$

The volume is equal to the cross-sectional area times the height (h) of liquid. Substituting this in to the above equation yields:

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

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

This equation tells us that the pressure exerted by a column of water is directly proportional to the height of the column and the density of the water and is independent of the cross-sectional area of the column. The pressure thirty feet below the surface of a one inch diameter standpipe is the same as the pressure thirty feet below the surface of a large lake.

Example 1:

If the tank in Figure 1 is filled with water that has a density of 62.4 lbm/ft3, calculate the pressures at depths of 10, 20, and 30 feet.

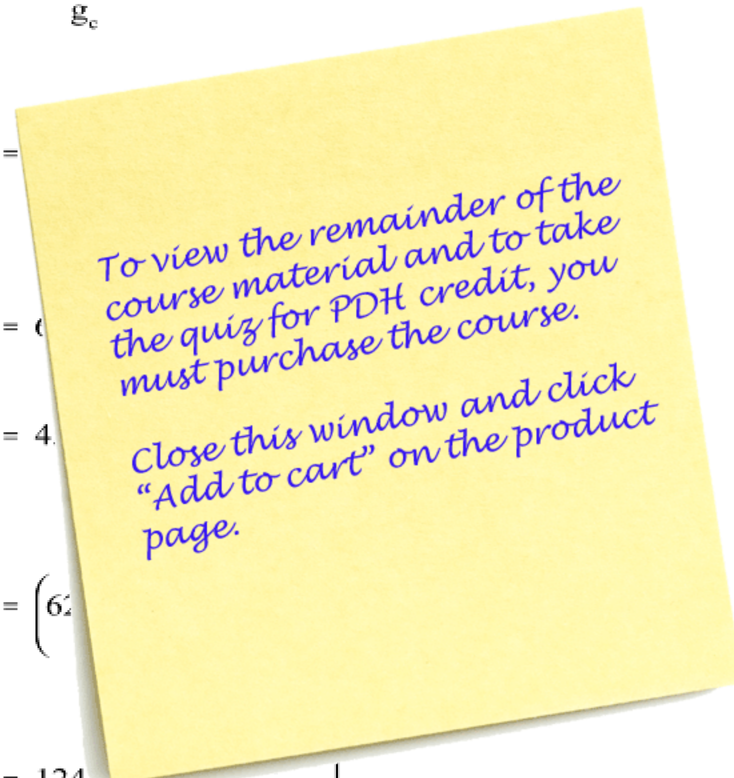
Solution:

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

$P_{10\ \text{feet}} =$

$= 6$

$= 4.$



$P_{20\ \text{feet}} = \left(62\right.$

$= 124 \ \text{ft}^2 \left(\frac{}{144\ \text{in}^2}\right)$

$$= 8.67\ \frac{\text{lbf}}{\text{in}^2}$$