<u>A Fluid</u> is any substance that conforms to the shape of its container and it may be defined as a substance that does not permanently resist distortion and hence, will its shape. *Gases and liquids and vapors* are considered to have the characteristics of fluids and to obey many of the same laws.

In the process industries, many of the materials are in fluid form and must be stored, handled, pumped, and processed, so it is necessary that we become familiar with the principles that govern the flow of fluids and also with the equipment used. Typical fluids encountered include water, acids, air, Co_2, oil, slurries.

<u>Fluid mechanics:</u> is defined as the science that deals with the behavior of fluids at rest **(*<u>fluid statics</u>*)** or in motion **(*fluid dynamics*),** and the interaction of fluids with solids or other fluids at the boundaries.

If a fluid affected by changes in pressure, it is said to be *"<u>compressible fluid</u>"*, otherwise, it is said to be *"<u>incompressible fluid</u>"*.

Most liquids are incompressible, and gases are can considered being compressible fluids. However, if gases are subjected to small percentage changes in pressure and temperature, their densities change will be small and they can be considered to be incompressible fluids.

Real fluid can be divided into:

- <u>Newtonian</u> يتبع قانون نيوتن
- <u>Non Newtonian</u> لا يتبع قانون نيوتن

1-1 Physical Properties of Fluids

1. DENSITY AND SPECIFIC GRAVITY

- **Density** is defined as *mass per unit volume* [symbol: ρ (rho)]

$$\rho = \frac{m}{V} \qquad (\frac{\mathrm{kg}}{\mathrm{m^3}}, \frac{\mathrm{g}}{\mathrm{cm^3}}, \frac{\mathrm{Ib}}{\mathrm{ft^3}})$$

- **Specific Volume [symbol: υ (upsilon)]**

Is defined as the *volume per unit mass,* that is

$$\boldsymbol{\upsilon} = \frac{V}{m} = \frac{1}{\rho} \qquad (\frac{\mathrm{m^3}}{\mathrm{kg}}, \frac{\mathrm{cm^3}}{\mathrm{g}}, \frac{\mathrm{ft^3}}{\mathrm{Ib}})$$

- **Weight density or specific weight [symbol: γ (gamma).]**

Is defined as weight per unit volume, that is,

$$\gamma = \rho g \qquad \frac{kg}{m^3}\,\frac{m}{sec^2} \quad (\frac{N}{m^3}, \frac{dyne}{cm^3}, \frac{lb_f}{ft^3})$$

- **Specific gravity** or **relative density[symbol: SG]**

Is defined as the ratio of the density of a substance to the density of some standard substance at a specified temperature (usually water at 4°C, for which ρH_2O = 1000 kg/m3). That is,

$$\boldsymbol{SG_{liquid}} = \frac{\rho_{liq}}{\rho_{water}} = \frac{\rho_{liq}}{1000\ (\frac{kg}{m^3})}$$

- **Density of Ideal Gases:**

Any equation that relates the pressure, temperature, and density (or specific volume) of a substance is called an **equation of state.** The simplest and best-known equation of state for substances in the gas phase is the ideal-gas equation of state, expressed as

$$PV = nRT \qquad \rightarrow \qquad \rho = \frac{PM_w}{RT}$$

Where: R is the **universal gas constant** whose value is R= 8.314 kJ/kmol · K or 1.986 Btu/lbmol · R, and *M* is the molar mass (also called *molecular weight*) of the gas.

2- Pressure

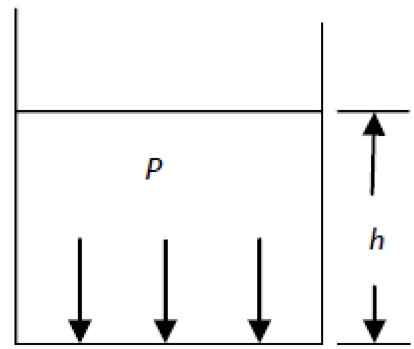
Pressure is the (compression) force exerted by a fluid per unit area.

$$\boldsymbol{P} = \frac{F}{A} \qquad \left(\frac{\mathrm{N}}{\mathrm{m}^2}\right) = Pa$$

The pressure developed at the bottom of a column of any liquid is called hydrostatic pressure and is given by

$$P = \rho g\, h \quad or \qquad \Delta P = \rho g\, \Delta h$$

$$P = \gamma\, h$$



3- Energy and specific heats

Energy can exist in numerous forms such as thermal, mechanical, kinetic, potential, electrical, magnetic, chemical, and nuclear, and their sum constitutes the **total energy** *E* (or *e* on a unit mass basis) of a system.

- **The internal energy U** represents the microscopic energy of a non-flowing fluid per unit mass,

- ***Potential energy*** is the work required to move the system of mass *m* from the origin to a position against a gravity field *g*:

$$PE = mg\, z$$

- ***Kinetic energy*** is the work required to change the speed of the mass from zero to velocity *u*.

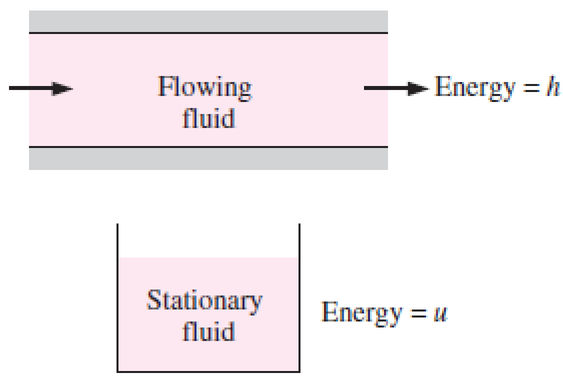
$$KE = \frac{1}{2} m u^{\,2}$$

In the analysis of systems that involve fluid flow, we frequently encounter the combination of properties *U* and *Pv*. For convenience, this combination is called **enthalpy** *h*. That is,

$$h = U + p\boldsymbol{v} = U + \frac{p}{\rho}$$

Where P/ρ is the *flow energy*, also called the *flow work*, which is the energy per unit mass needed to move the fluid and maintain flow.

Whereas enthalpy *h* represents the microscopic energy of a flowing fluid per unit mass as shown in figure below



The total energy of a simple compressible, E of a substance is the sum of the internal, kinetic, and potential energies on a unit-mass basis, it is expressed as ($e = U$ + KE+ PE). The fluid entering or leaving a control volume possesses an additional form of energy the *flow energy* P/ρ. Then the total energy of a **flowing fluid** on a unit-mass basis becomes

$$e_{flowing} = \frac{p}{\rho} + e = \frac{p}{\rho} + U + KE + PE = h + gz + \frac{u^2}{2} \qquad KJ/Kg$$

Where $h = P/\rho + U$ is the enthalpy, *u* is the velocity, and *z* is the elevation of the system relative to some external reference point

4- Dynamic viscosity [symbol: μ (mu)]

The ***viscosity*** of a fluid is a measure of its resistance to shear or angular deformation.

$$\left(\frac{\text{kg}}{\text{m. sec}}, \frac{\text{g}}{\text{cm. sec}}, \frac{\text{Ib}}{\text{ft. sec}}, poise\right)$$

$$poise = 100\ c.p = 0.1\ Pa.sec \quad ,poice = \frac{g}{cm.sec}$$

<u>5- Kinematic viscosity [symbol: ν (nu)]</u>

It is the ratio of the dynamic viscosity to mass density of fluid,

$$\boldsymbol{\nu} = \frac{\mu}{\rho} \qquad (\frac{\mathrm{m}^2}{\mathrm{sec}}, \frac{\mathrm{cm}^2}{\mathrm{sec}}, \frac{\mathrm{ft}^2}{\mathrm{sec}}\ , stoke)$$

$$stoke = 100\ c.stoke \quad ,stoke = \frac{cm^2}{sec}$$

<u>1-2 the flow rate</u>

- **Volumetric flow rate [symbol: Q]**

It is the volume of fluid transferred per unit time.

$$\boldsymbol{Q = uA} \qquad (\frac{\mathrm{m}^3}{\mathrm{sec}}, \frac{\mathrm{cm}^3}{\mathrm{sec}}, \frac{\mathrm{ft}^3}{\mathrm{sec}})$$

Where: A is the cross sectional area of flow normal to the flow direction.

- **Mass flow rate [symbol: $\dot{m}$]**

It is the mass of fluid transferred per unit time.

$$\boldsymbol{\dot{m} = Q\rho = uA\rho} \qquad (\frac{\mathrm{kg}}{\mathrm{sec}}, \frac{\mathrm{g}}{\mathrm{sec}}, \frac{\mathrm{Ib}}{\mathrm{sec}})$$

- **Mass flux or (mass velocity) [symbol: G]**

It is the mass flow rate per unit area of flow,

$$\boldsymbol{G = \frac{\dot{m}}{A} = u\rho} \qquad (\frac{\mathrm{kg}}{m^2\mathrm{sec}}, \frac{\mathrm{g}}{cm^2\mathrm{sec}}, \frac{\mathrm{Ib}}{ft^2\mathrm{sec}})$$