III. Fluid Mechanics

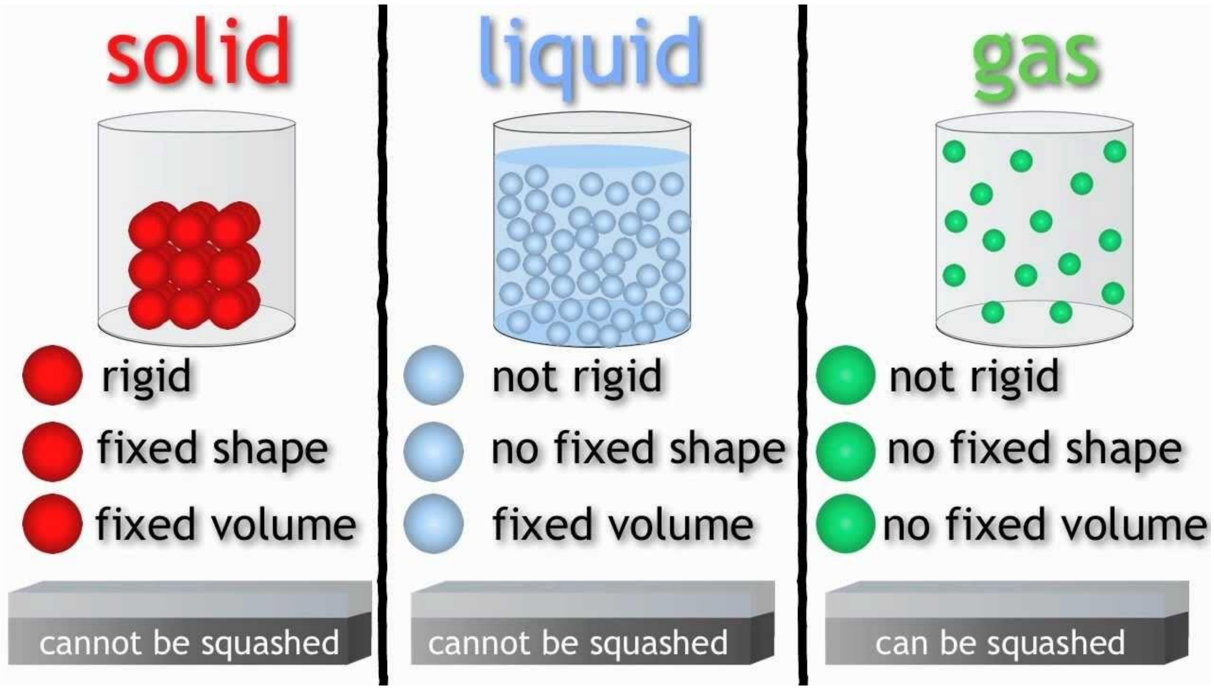
III.1. Introduction

Fluid mechanics plays a crucial role in various fields such as naval engineering, aeronautics, the study of blood flow (hemodynamics), meteorology, climatology, and oceanography. This fascinating field is primarily dedicated to the study of the behavior of fluids (liquids, gases, and plasmas) and the associated internal forces within the mechanics of continuous media.

At the microscopic level, a fluid can be considered as being composed of a large number of very small, free particles that move relative to one another. A fluid is therefore a continuous, deformable material medium without rigidity, which can flow easily. In order to determine the type and state of a fluid, it is very useful to understand the three fundamental states of matter for a simple substance:

1. **Solid state**: In the material at low temperature, the particles are close together, bound by very strong forces.
2. **Liquid state**: In the material at medium temperature and sufficiently high pressure, the particles are disordered, close together, and weakly bound.
3. **Gaseous state**: In the material at sufficiently high temperature and low pressure, the particles are disordered, spaced apart, and unbound.

It should be noted that the solid state is an organized state of matter, i.e., the arrangement between molecules shows a partially stable order over time.
In contrast, the gaseous and liquid states represent disordered states of matter, meaning there is no order that favors the arrangement of molecules, as these molecules are constantly in motion.



Solid | Liquid | Gas

Fig. III.1

In other words, fluids can be classified into two major families according to their viscosity:

- The **"Newtonian" fluid** family (such as water, air, and most gases) has a constant viscosity, which can only vary with temperature.
- The **"Non-Newtonian" fluid** family (virtually everything else... blood, gels, muds, pastes, suspensions, emulsions...) is characterized by having a viscosity that varies depending on the velocity and the stresses they experience during flow.

At this stage, we can mention the different types of fluids, often distinguished by whether they are liquids or gases, such as:

- **Perfect fluid**: A fluid is said to be perfect if its motion can be described without taking frictional effects into account.
- **Real fluid**: In a real fluid, the internal tangential frictional forces that oppose the relative sliding of fluid layers are taken into consideration. This phenomenon of viscous friction appears during fluid motion.

- **Compressible fluid**: A fluid is said to be compressible when the volume occupied by a given mass varies depending on the external pressure. Gases are compressible fluids. Examples include air, hydrogen, methane in gaseous state, etc.
- **Incompressible fluid**: A fluid is said to be incompressible when the volume occupied by a given mass does not vary with external pressure (constant density). For example, liquids can be considered incompressible fluids (water, oil, etc.).

III.2. Properties of Fluids

a. Density:

Density is defined as the amount of matter contained in a unit volume of a given substance. It is expressed as:

$$\rho = \frac{M}{V} \text{ unit } \frac{kg}{m^3}$$

where ρ is the density, M is the mass, and V is the volume.

b. Relative Density:

Relative density, also known as specific gravity, is the ratio of the density of a substance to the density of a reference substance (typically water for liquids, or air for gases). It is given by:

$$D = \frac{\rho}{\rho reference}$$

This is a dimensionless quantity (i.e., it has no units).

c. Fluid Pressure:

Hydrostatic: v = 0

Pressure force $\vec{F}$ (normal to the surfaces), due to the impacts of the fluid particles on the surface. The molecules of the fluid have disordered movements, which causes shocks on the surfaces of objects immersed in the fluid. With each shock, there is a change in the momentum of the molecule, and therefore a force is exerted on the surface.If we change the orientation of the surface on which this force is exerted, we always obtain a force of the same standard, which leads to using another modeling, and we instead define a new scalar quantity (therefore without orientation):

the pressure: **P = F / S,**

where F is the norm of the force which would be exerted on the surface S of an object if we placed this object at this location, but it is not necessary that there be an object in the fluid to calculate a pressure.

unité :

-SI : Pascal (Pa) -l'atmosphère, 1 atm = 101 300 Pa , 1bar=10^5 Pa

Forces of cohesion and adhesion= force between the molecules of the liquid (cohesion) and between the molecules of the liquid and those of its container (adhesion).

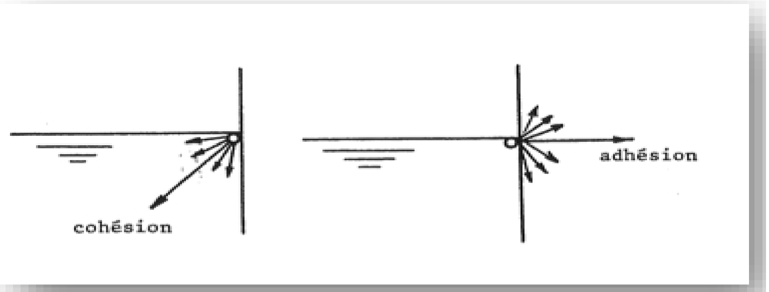
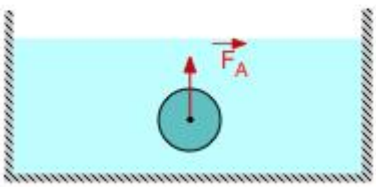


Fig. III.2 : **Forces of cohesion and adhesion**

CONSEQUENCES OF PRESSURE FORCES -Archimedes' force-

1-Archimedes' force: resulting from pressure forces on the walls of an object. It is vertical upwards, and $\pi_A = \rho . g . V$



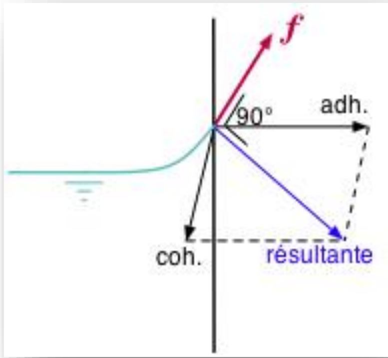
FUNDAMENTAL RELATIONSHIP OF HYDROSTATIC:

- At two points located at the same height relative to the bottom, if we have the same liquid, we will have the same hydrostatic pressure.

- If we descend from a depth x in a liquid of density ρ, we have an increase in the hydrostatic pressure: $\Delta p = \rho . g . x$

CONSEQUANCES OF COHESION AND ADHESION FORCES- SURFACE TENSION:-

1-SURFACE TENSION:



The liquid rises (or falls) along the wall of the container AS IF there was a force γ pulling on the surface. In this model, this force is the capillary force acting on the surface of the liquid, tangentially to it.
This force tends to minimize the surface area of the liquid.
In practice, we use surface tension instead: $f = \gamma / l$

Another definition is often preferred: $\gamma = dW / dS$ work per unit of surface that must be provided to enlarge the surface.SI unit: **N/m** or **J/m²**

Jurin's law : Capillaries: difference in liquid level with the outside of the capillary of $h = 2\gamma \cos\theta / r\rho g$ (Jurin's law)

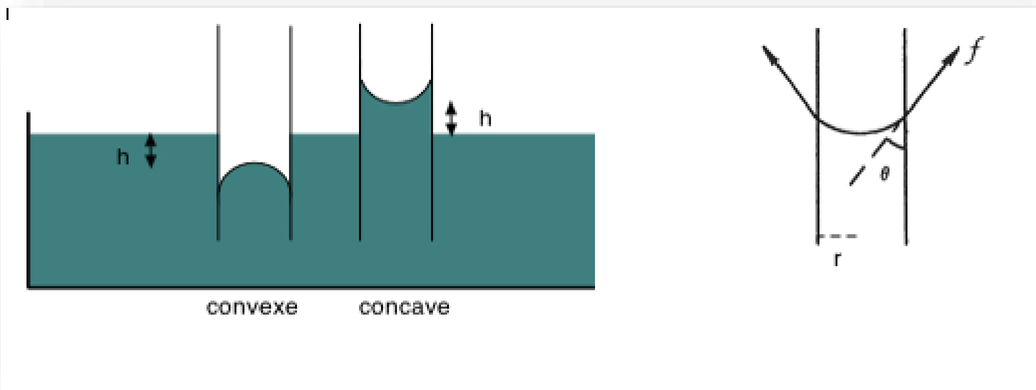
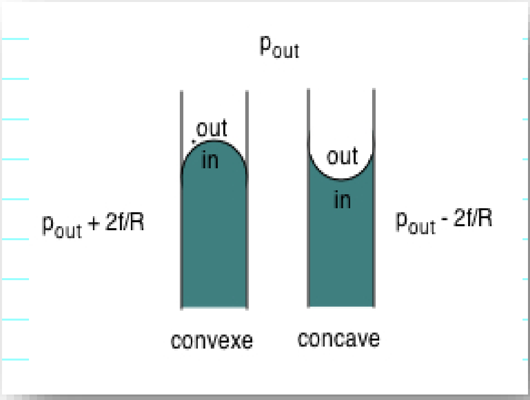


Fig. III.3 : Difference in liquid level with the outside and inside of the capillary.

Pressure variation at the surface of a liquid:



• if flat surface, $P(in) = P(out)$

• if convex surface,

$$\boldsymbol{P(in) = P(out) + 2\,\gamma/R}$$

• if concave surface,

$$\boldsymbol{P(in) = P(out) - 2\,\gamma/R}$$

In the last 2 cases, we have:

$$\boldsymbol{P(concave\ side) - P(convex\ side) = 2\,\gamma/R}$$

$(\boldsymbol{Laplace's\ law})$.

where R is the radius of curvature of the surface.

DYNAMICS OF INCOMPREHENSIBLE FLUIDS

Definitions:

The principle of continuity expresses the conservation of mass, which means that no fluid cannot be created nor disappear in a given volume.

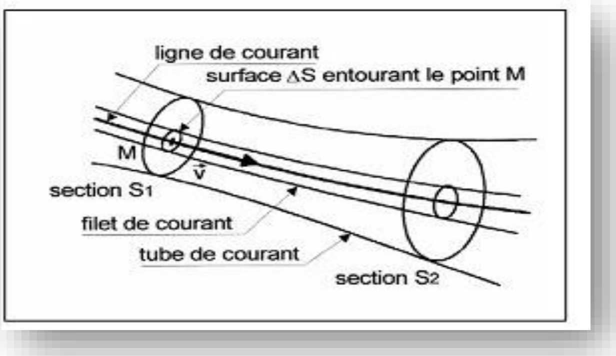


Fig. III.4 :**:** The principle of continuity expresses the conservation of mass.

- Flow: is the quantity of material that passes through a straight section of pipe during the unit of time.
- Mass flow: If dm is the elementary mass of fluid having traveled a straight section of the carried out during the time interval dt, the mass flow is written:

$$q_m = \frac{dm}{dt} [Kg. s^{-1}]$$

- Volume flow: If dV is the elementary volume of fluid having traveled a straight section of rolling during the time interval dt, the volume flow is written:

$$q_V = \frac{dV}{dt} [m^3. s^{-1}]$$

- The relation between $q_m and\ q_V$: The density ρ is given by the relation:$\rho = \frac{dm}{dV}$.

  from where : $q_m = q_V$

  Since the flow rate always remains constant in a steady state), **the continuity equation** is written as: $\boldsymbol{Q = S_1 V_1 = S_2 V_2}$

GENERAL Flow EQUATION OR Bernoulli EQUATION

A flow regime is said to be permanent or stationary if the parameters, which characterize (pressure, temperature, speed, density, etc.), have a constant value over time:

a- Case of Perfect Fluids (non-viscous)

Bernoulli's equation expresses that, all along a fluid stream

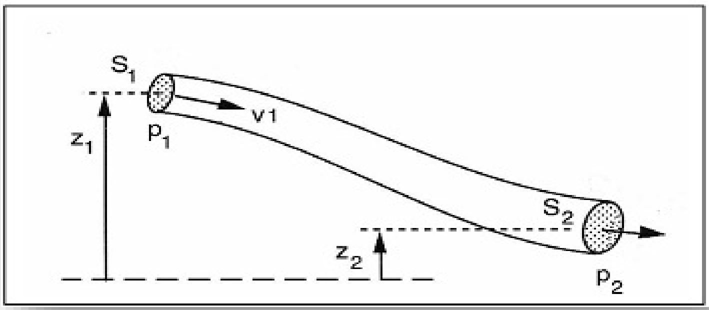


Fig. III.5 :: A flow regime permanent or stationary

Bernoulli's equation expresses that, throughout a fluid stream in permanent (stationary) motion, the total energy per unit weight of the fluid remains constant and the equation is written:

$$z_1 + \frac{P_1}{\rho g} + \frac{v_1^2}{2g} = z_2 + \frac{P_2}{\rho g} + \frac{v_2^2}{2g} = H = constant$$

b- Case of real fluids (viscous)

In the case of real fluids, the energy decreases in the direction of flow. this is due to the viscous nature of the fluid which dissipates part of the energy: this loss of energy is called pressure loss and the equation is written:

$$z_1 + \frac{P_1}{\rho g} + \frac{v_1^2}{2g} = z_2 + \frac{P_2}{\rho g} + \frac{v_2^2}{2g} + h$$

h: which is the consequence of the viscosity of the fluid and the roughness of the walls of the section flow.