Chapter1: Properties of fluids

1) Introduction :

Fluid Mechanics is the study of fluids:

- At rest, it is the statics of fluids,
- In movement, we then speak of fluid dynamics.

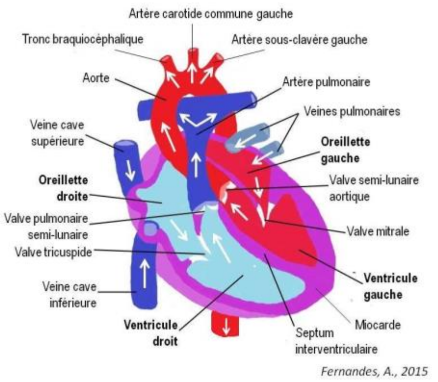
The fluid mechanics also studies the effects of fluids on the limits (boundaries) which can be:
- Solid surfaces such as pipes, dams, reservoirs, etc,
- Interfaces with other fluids such as gas-liquid, gas-gas, mixtures, ...

The number of applications involving fluids in engineering is enormous, for example: Breathing, blood flow, swimming, pumps, propellers, fans, planes, boats, rivers, pipes, missiles, icebergs, engines, filters and jets, ...

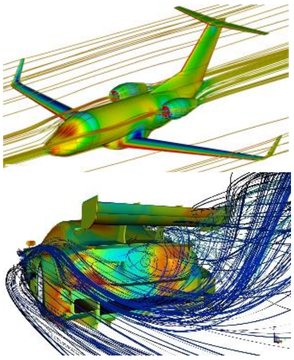
Beni Haroun dam

Hydraulic cylinder

Water flow



Blood flow

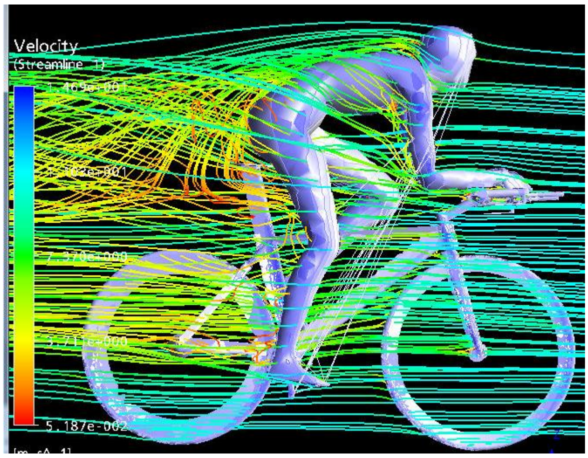


CFD of (plane, car)

Turbojet and pipelines

We can notice that most objects on the planet are fluids or moving near fluids. The flow of a fluid is a branch of mechanics, it obeys the laws of mechanics. The two great obstacles of fluid theory are

- Geometry
- Viscosity



Example of complex geometry

Fluids with different viscosities

In complex geometries, the equations of fluid motion are very difficult to solve. Most books focus on simple geometries such as plates, circular tubes and other simple geometries. However, it remains possible to solve the equations for complex geometries numerically by computer, this branch of FM is called CFD (Computational Fluid Dynamics) or digital fluid mechanics.

The second obstacle of FM is **viscosity** and its action, it can be neglected only in the case of an ideal fluid. The intervention of viscosity destabilizes the flow of fluids and gives turbulent flows, which increases the difficulty of the equations which describe the phenomenon.

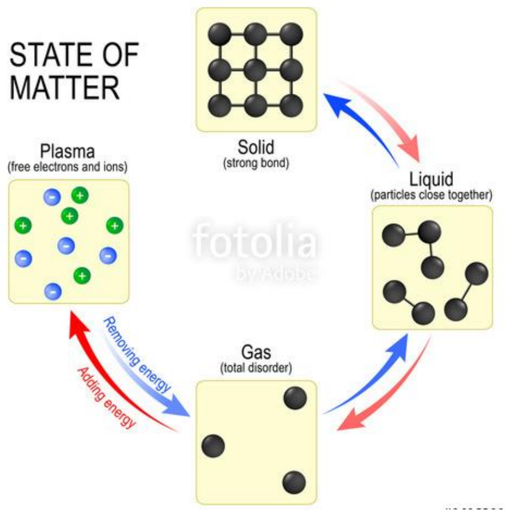
2. Definition of a fluid

In general, matter exists in three states for a simple body:

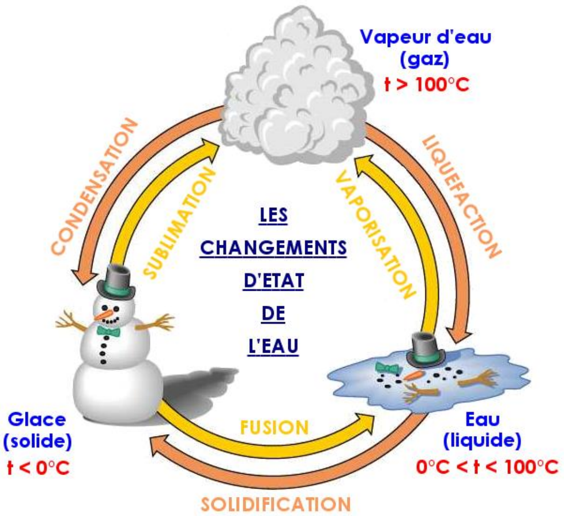
- Solid or material at low temperature,
- Liquid which is a material at medium temperature and sufficiently high pressure,
- Gas or material at sufficiently high temperature at low pressure.

Gaseous and liquid states have similarities, they are called fluids. A fluid has the following characteristics:

- It does not have its own shape, if it is placed in a container, it adopts the shape of the container.
- A liquid has a free surface in the field of gravity, if we place a liquid in a bowl, we observe a clear interface with the air called a free surface. A gas tends to occupy all the volume available to it, so the gas has no free surface.

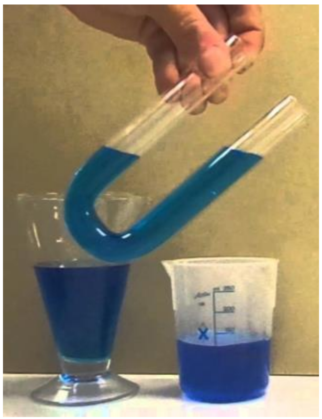


States of matter

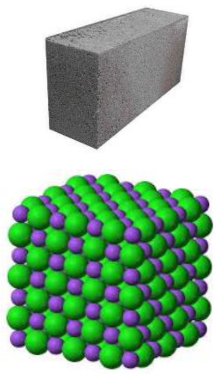


Example of water

A gas occupying a space



Free surface of a liquid



Solid body

A solid can resist a deformation stress; on the other hand, the fluid cannot. Any stress, even small, applied to the fluid, causes movement of the fluid. The latter moves and deforms continuously as long as the stress is applied. As a corollary, one can say that a fluid at rest must be in the state of zero strain stress.

As we have seen, fluids are divided into two classes which are liquids and gases:

- A liquid is composed of molecules relatively close together and stacked with strong cohesive forces. The latter attempt to maintain the volume and form a free surface in the gravity field.

- A gas has molecules spaced apart with negligible cohesive forces, the gas is free to expand until it occupies all of the volume, it cannot form a free surface.

Most fluid mechanics engineering problems concern:

- Liquids such as water, oil, mercury, diesel, alcohol, etc.
- Gases such as air, helium, hydrogen, steam, etc.

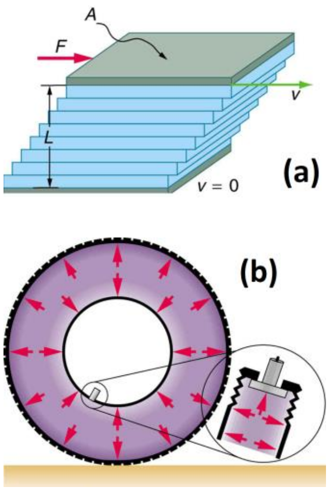
3. <u>Perfect fluid and real fluid:</u>

Fluids can be classified according to the forces acting during their motion. In a fluid motion, two types of forces can be distinguished, volume forces and surface forces.

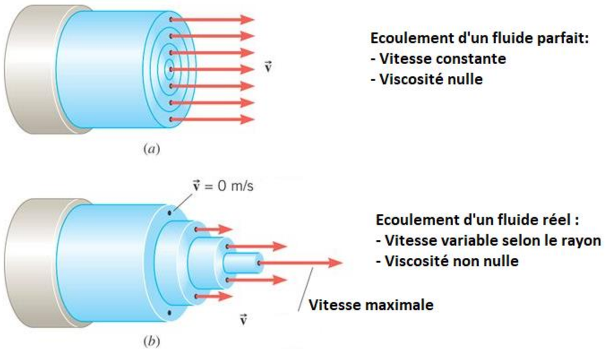
- **Volume forces** are those generated **by a field**, for example gravity, electric, magnetic fields, etc.
- **Surface forces** are those acting on fluid surfaces, they are divided into **friction** and **pressure** forces.
  - Friction forces are caused by viscosity, they are tangential to the surface.
  - The forces produced by pressure are normal to the surface.

A perfect fluid is one where there is **no friction**, that is to say the viscosity is zero or negligible. If we also neglect the volume forces, this implies that the internal forces at any section of the fluid are normal to this section, even during movement. So, the forces are generated by pressure, such a fluid does not exist in reality.

A real fluid is one in which tangential or **shear forces are present** during its movement (flow), this increases the friction of the fluid, because these forces oppose the movement of the particles relative to each other. These friction forces are due to the viscosity of the fluid.



(a) Friction force (b) Pressure force



(a) Perfect fluid (b) Real fluid

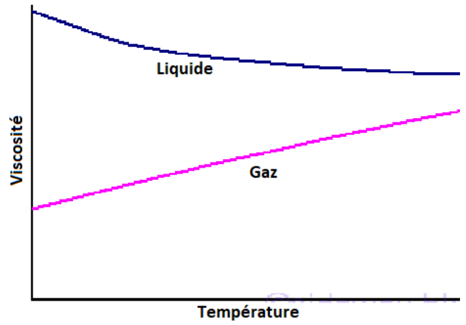
4. Viscosity of a fluid:

The viscosity of a fluid is the measurement of its resistance to angular deformation. Friction forces in a fluid are the result of cohesion and the exchange of momentum between the molecules of the fluid.

For liquids, the cohesive force between molecules is predominant. Increasing temperature decreases this force, which decreases viscosity. On the other hand, for gases it is the inter-exchange of molecules between the different layers which predominates. This inter-exchange increases with temperature, which brings the fast hot particles into contact with the slow cold ones. The result is the decrease in general movement and the increase in viscosity.

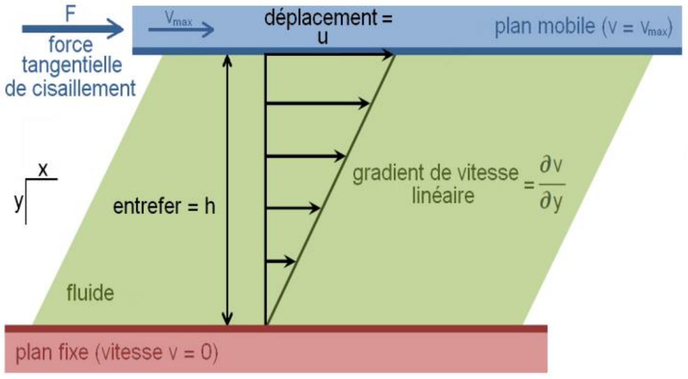
When the temperature increases:

- The viscosity of liquids decreases,
- The viscosity of gases increases:



Variation of viscosity as a function of temperature

To study the phenomenon of viscosity, take two sufficiently large parallel plates of surface S and separated by a distance (gap) h; the space between the plates is filled with a fluid. The lower plate is fixed, we apply a force F to the upper one which starts moving with a velocity $v=v_{max}$ parallel to the lower plate.



We note that F is proportional to S

→ F α S

Also, F α v

and F α 1/h

→ $F\ \alpha\ \frac{Sv}{h}$

Then $F = \mu\ \frac{Sv}{h}$

With μ proportionality coefficient also said viscosity.

If the profile v(y) is linear, from the figure and the similarity of the triangles, we can replace v/h by ∂v/∂y which is the velocity gradient. We introduce a constant of proportionality μ, this makes it possible to obtain the friction constraint between two thin layers of fluid τ with:

$$\tau = \frac{F}{S} = \mu\,\frac{v}{h} = \mu\frac{\partial v}{\partial y}.$$

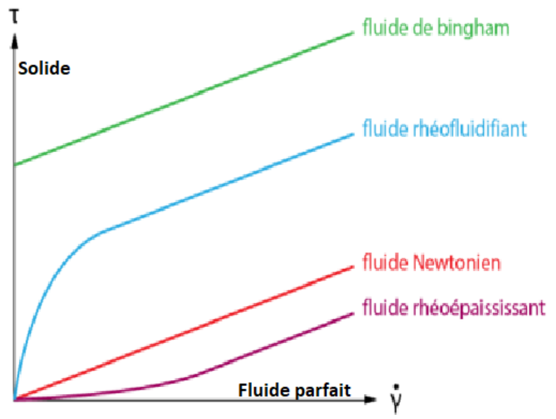
The term ∂v/∂y is called angular deformation rate it is denoted by $\dot{\gamma}=\partial v/\partial y$ its unit is (1/s).

The equation $\tau = \mu\frac{\partial v}{\partial y}$ is said "NEWTON equation of viscosity", we can find the viscosity $\mu = \frac{\tau}{\frac{\partial v}{\partial y}}$.

μ is said viscosity, coefficient of viscosity, absolute viscosity or dynamic viscosity (it implies force).

Fluids and solids can be classified by their reactions to deformation shear stresses. We know that in the equation $\tau=\mu\,\partial v/\partial y=\mu\dot{\gamma}$ the shear stress is proportional to the rate of angular deformation.

A fluid for which the viscosity does not depend on the angular strain rate is called Newtonian fluid. The shear stress for this fluid is represented by the straight line which passes through the origin, its slope is the viscosity. For the perfect fluid, the viscosity is zero which is represented by the horizontal axis. On the other hand, the elastic solid is represented by the vertical axis.



- The viscosity dimension is the force per unit area (stress) divided by the velocity gradient: $(N/m^2)/((m/s)/m)$=Pa s.
  A common unit of viscosity is the Poise: 1 Poise = 0.1 Pa s.
- In many application problems the term viscosity divided by density is common. We thus define the kinematic viscosity by: $\nu=\mu/\rho$ its unit $(N/m^2)/((m/s)/m)\,m^3/kg=m^2/s$.
  We also use the Stoke (st): 1 st= $1(cm^2)/s$

5. Compressible fluid and incompressible fluid:

Definition of density, specific gravity and specific weight:

The density of a fluid is its mass per unit volume: $\rho = \frac{m}{V} \equiv \left[\frac{kg}{m^3}\right]$

While the specific weight is its weight per unit of volume: $\gamma = \frac{W}{V} = \frac{mg}{V} = \frac{\rho V g}{V} = \rho g \equiv \left[\frac{N}{m^3}\right]$

So the density is in (kg/m3) and the specific weight is in (N/ m3).

The specific gravity d of a fluid is its divided by a reference density : $d = \frac{\rho_{fluid}}{\rho_{ref}}$

In the case of gases, we use air as a reference and in the case of liquids we use water. The density of water at 4°C is 1 g/cm^3 or 1000 kg/m^3.

Fluid mechanics deals with compressible and incompressible fluids, i.e. with variable or constant density. In reality there are no incompressible fluids; this term is applied to the case where the variation in density is negligible, this is the case for liquids. Gases can also be considered incompressible if the pressure variation is small compared to the absolute pressure.

For gases, if the flow velocity is not very high, the density can be considered constant. On the other hand, if the velocity is high and approaches that of sound, the gas is considered compressible because the variation in density is significant.

5.1 Bulk modulus of elasticity: It is a property that is commonly used to characterize compressibility.

Bulk modulus for liquids:

The compressibility of a liquid is inversely proportional to its volume modulus of elasticity, also known by global modulus, it is defined by Ev or K:

$$K = -V\frac{dP}{dV} = -V\frac{\Delta P}{\Delta V}$$

The modulus of steel is 170,000 MN/m^2, that of cold water is 2200 MN/m^2, water is 80 times more compressible than steel. Since the variation of this modulus is not important for the same fluid, the following approximate equation can be used:

$$\frac{P_2 - P_1}{K} = -\frac{v_2 - v_1}{v_1} = -\frac{V_2 - V_1}{V_1} = \frac{\rho_2 - \rho_1}{\rho_1}$$

K in this case is the average value of the modulus for the pressure range ΔP.

Modulus of elasticity for gases:

To calculate the elastic modulus of gases, assuming that they are perfect. For an ideal gas, the equation of state is written:

$$PV = NR_uT \rightarrow \frac{P}{\rho} = Pv = RT \text{ et } R = \frac{R_u}{m}$$

We introduce the specific weight $\gamma = \frac{mg}{V}$ which gives $\gamma = \rho g$ and from $\rho = \frac{P}{RT}$ where $\gamma = \rho g = \frac{Pg}{RT}$ which is the specific weight of the gas.

Another fundamental equation of the ideal gas is PV^n=Cte with n polytropic coefficient, n varies from 0 to ∞, depending on the thermodynamic process. We have n=1 for the isotherm, n= Cp/Cv =k for the adiabatic. Let's take the equation PV^n=Cte and calculate the differential:

$$d(PV^n) = Pd(V^n) + V^n dP = d(Cte) = 0$$

$$d(PV^n) = nV^{n-1}PdV + V^n dP = 0 \quad \text{then} \quad dP = -PnV^{n-1}\frac{dV}{V^n} \qquad (1)$$

Also, we have $K = -dP\frac{V}{dV}$ (2). Replacing (1) in (2) we will have:

$$K = PnV^{n-1}\frac{dV}{V^n}\frac{V}{dV} = nP$$

For an isothermal process K=P and for an isentropic process K=nP. For a pressure of 1 atm the modulus of elasticity has a value of 103KPa in an isothermal transformation. For cold water this module has a value of 2206 106 Pa which means that air is 21000 times more compressible than cold water in an isothermal process or 15000 times adiabatically.