Hydraulics & Pneumatics

Chapter 01 :

Generality on the properties of Fluids

1/ Introduction

Fluid mechanics is the science that studies the flow of fluids (liquid and gas) when they are subjected to external forces. It is the basis for the dimensioning of fluid lines and fluid transfer mechanisms. Two cases can be distinguished :

- **the statics of fluids ,** or hydrostatics which studies fluids at rest.
- **fluid dynamics** who studies fluids in motion.

2/ Definition of liquids

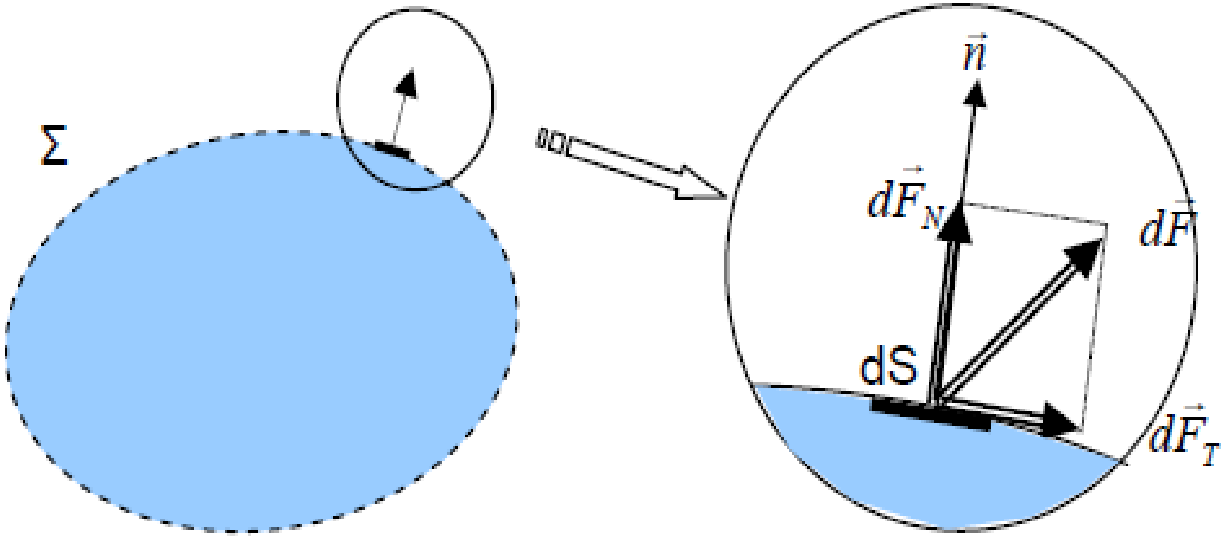
A liquid is an assembly of material particles that move relative to each other .

Consider a fluid system, ie a volume delimited by a closed surface ∑.

Consider $d\vec{F}$ the interaction force at the elementary surface dS of normal й between the fluid and the external medium.

We can always decompose $d\vec{F}$ into two components:

- a component $d\vec{F}_T$ tangential to dS.
- a component dFy normal to dS.



Perfect fluid:

- A fluid is said to be perfect if it is possible to study its motion without taking into account the effects of **friction** .
- That is to say the **Tangential** component dF_T is zero. In other words, the force *dF* is normal to the surface element dS .

Real fluid:

In a real fluid the tangential forces of internal friction are taken into consideration.

At rest, we will admit that the real fluid behaves like a perfect fluid, (The statics of real fluids merges with the statics of perfect fluids).

Incompressible fluid

A fluid is said to be incompressible when the volume occupied by a given mass does not vary according to the external pressure.
Liquids can be considered as incompressible fluids (water, oil, etc.).

Compressible fluid

A fluid is said to be compressible when the volume occupied by a given mass varies according to the external pressure. **Gases are compressible fluids.**
For example: air, hydrogen ,… are considered as compressible fluids.

3/ Physical characteristics

3.1 . Density :

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

ρ : Density in (kg/m3),
m: mass in (kg),
V : volume in (m3).

Examples:

Fluid	Density (kg/m³)	Type of fluid
Benzene	0.880. 103	Incompressible
Water	10^3	
Olive oil	0.918. 103	
Mercury	13,546. 103	
Air	0.001205. 10^3	compressible[1]
Hydrogen	0.000085. 10^3	
Methane	0.000717. 103	

3.2. Volume weight:

$$\varpi = \frac{m.g}{V} = \rho.g$$

ϖ: Volume weight in (N/m3).
m: mass in (kg),
g: acceleration due to gravity in (m/s2),
V: volume in (m3).

3.3. Density :

$$d = \frac{\text{fluid density}}{\text{density of a reference fluid}} = \frac{\rho}{\rho_{ref}}$$

- In the case of liquids, **water will be taken** as the reference fluid .
- In the case of gases we will take **the air** as reference fluid.

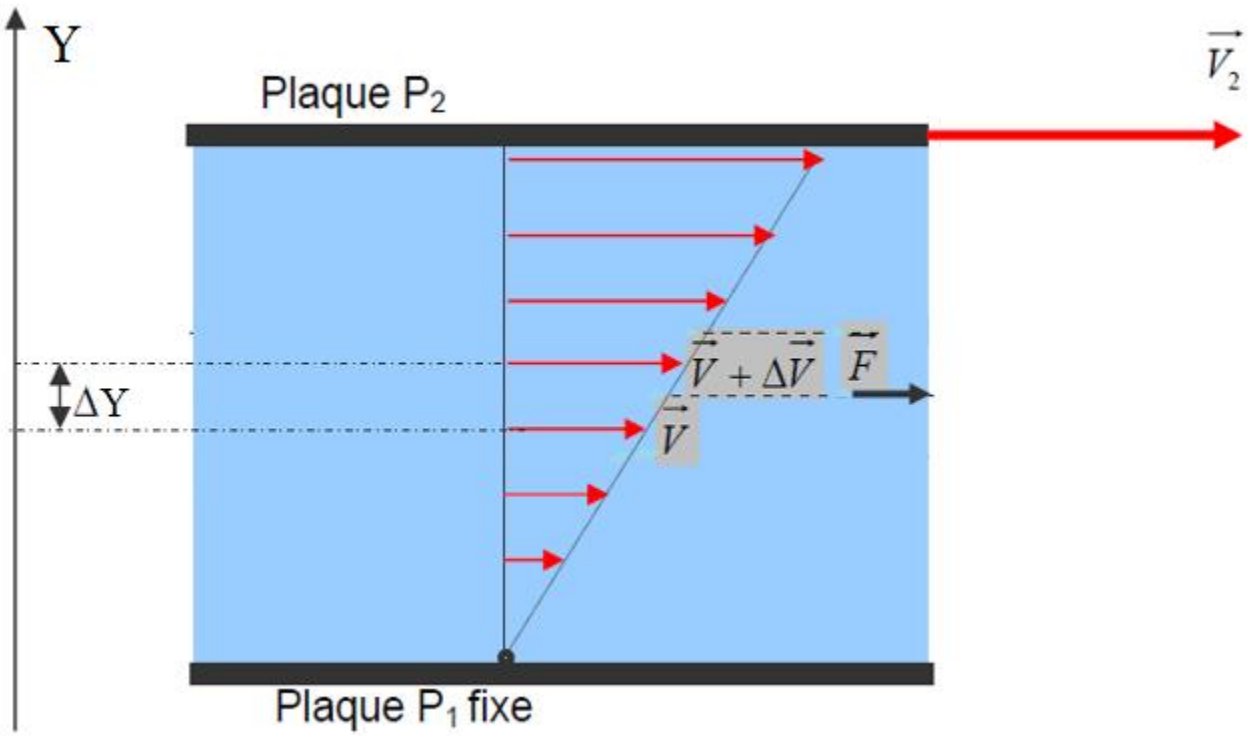
3.4 . Viscosity

It is a quantity that characterizes the internal friction of the fluid, in other words its ability to flow.

For example, if we consider a viscous fluid placed between two plates P1 and P2, such that the plate P1 is fixed and the plate P2 is driven by a speed V_2 .

- motion can be thought of as resulting from the sliding of fluid layers over each other.

- The speed of each layer is a function of the distance Y.

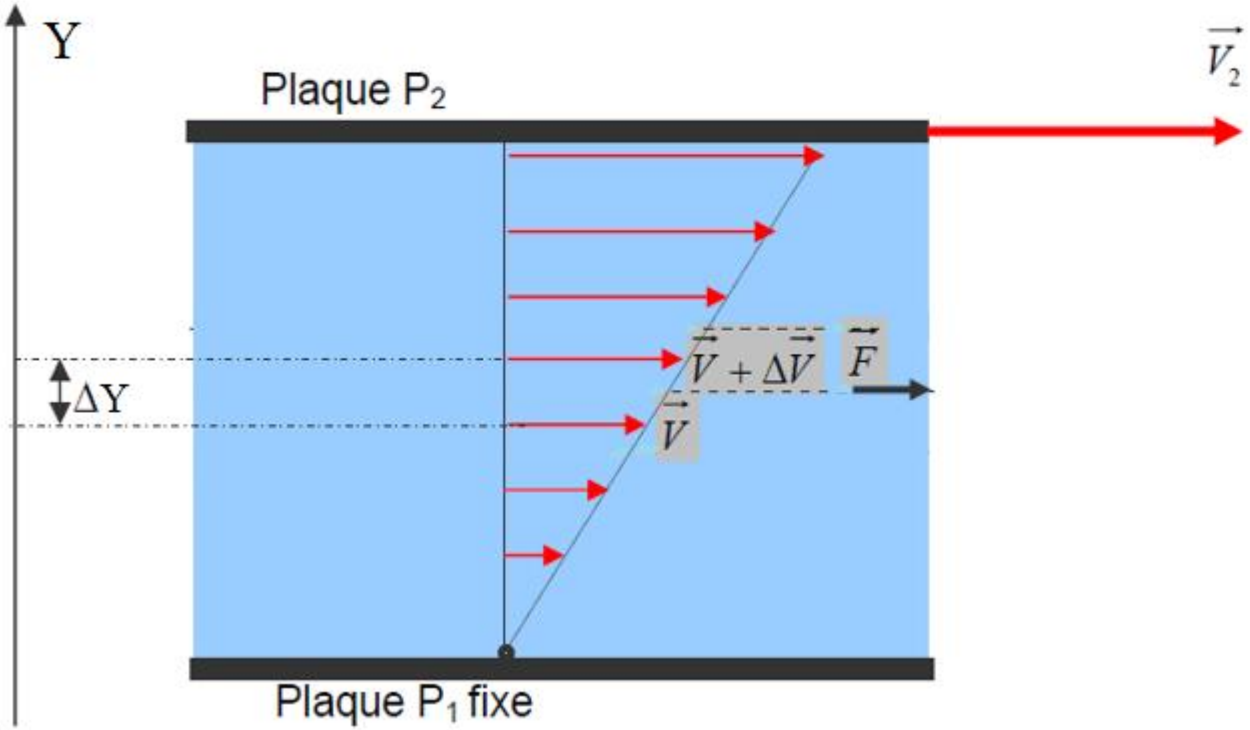


3.4.1 . Dynamic viscosity (Newton's law)

The dynamic viscosity expresses the proportionality of the frictional force F which is exerted on the surface of separation of two adjacent layers distant from Δ Y.

$$\tau = \mu \frac{dV}{dy}$$

$$F = \mu . S . \frac{dV}{dy}$$



F : sliding force between the layers in (N),
μ : Dynamic viscosity in (kg/ ms),
S : contact surface between two layers in (m2),
dV : Velocity difference between two layers in (m/s),
there _ : Distance between two layers in (m).
(d V / dy): Strain rate.

1 Pa·s = 1 Poiseuille (Pl) = 1

Dynamic viscosity corresponds to the physical reality of the behavior of a fluid subjected to stress (force).

3.4.2 . Kinematic viscosity

The kinematic viscosity characterizes the flow time of a liquid.

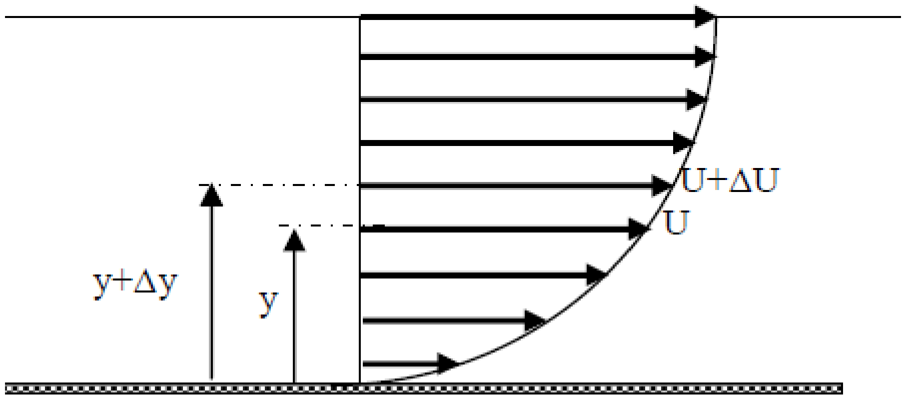
$$\upsilon = \frac{\mu}{\rho}$$

The unit of kinematic viscosity is the (m^2/s) or the Stokes (St).

1 St= 10^{-4} m^2/s

a/ Velocity profile in a cylindrical tube:

Under the effect of the interaction forces between the fluid particles and the interaction forces between the fluid particles and those of the wall, each fluid particle does not flow at the same speed. **We say that there is a *velocity profile (figure).***



Let us consider two adjacent layers of fluid distant from Δy , the force of friction F which is exerted on the surface of separation of these two layers opposes the sliding of a layer on the other . It is proportional to the difference in speed of the layers, i.e. ΔU, to their surface S and inversely proportional to Δy :

The proportionality factor μ is the dynamic viscosity coefficient of the fluid.

$$F = \mu S \frac{\Delta U}{\Delta y} \Rightarrow \tau = \frac{F}{S} = \mu \frac{\Delta U}{\Delta y}$$

Or :

F : frictional force between the layers in (N),

τ : shear stress (N/m^2),

μ : Dynamic viscosity in (kg/m.s),

S : contact surface between two layers in (m^2),

ΔU : Velocity difference between two layers in (m/s),

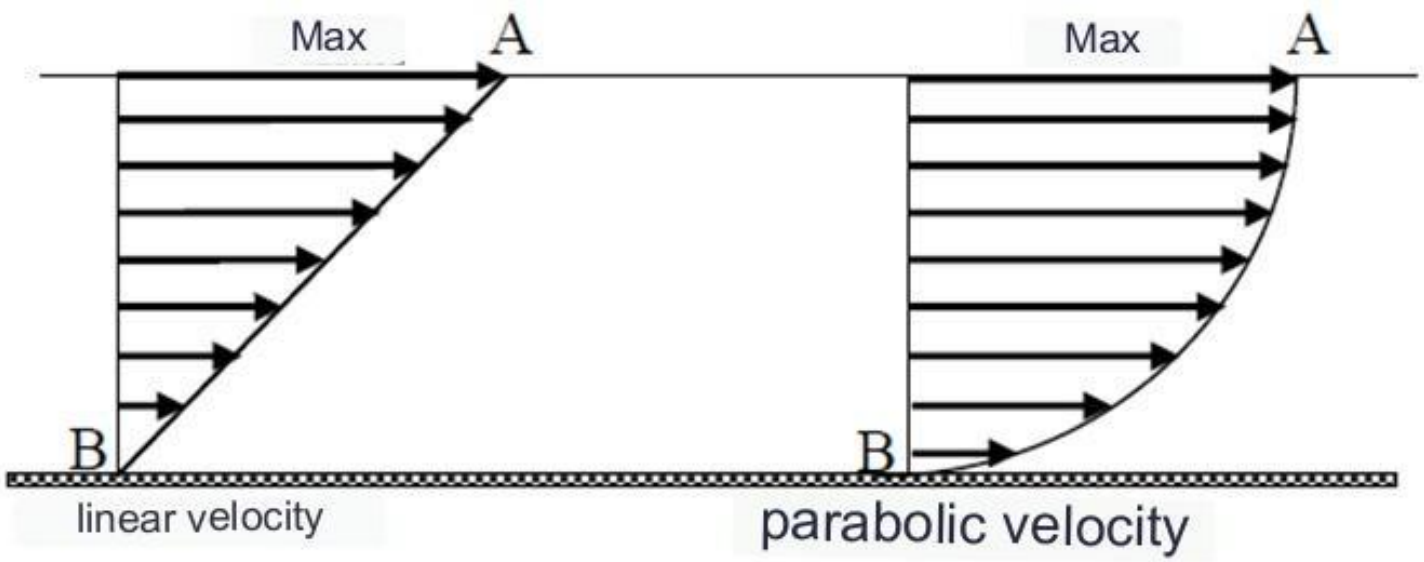
Δy : Distance between two layers in (m).

When Ay tends to zero we have:

$$F = \mu S \lim_{\Delta y \to 0} \frac{\Delta U}{\Delta y} = \mu S \frac{\mathrm{d}U}{\mathrm{dy}} \Rightarrow \tau = \frac{F}{S} = \mu \frac{\mathrm{d}U}{\mathrm{dy}}$$

Example:

A Newtonian fluid (u= 0.048 Pa.s) flows along a wall. At 75 mm from the wall, the fluid particle has a speed equal to 1.125 m/s. Calculate the intensity of the shear stress, at the level of the wall, at 25 mm, at 50 mm and at 75 mm from it, assuming a linear velocity distribution and a parabolic velocity distribution. The parabola of the figure has its vertex at A.



Solution :

1. Linear speed

U=Ay+B

For y=0.0, we have U=0 then B=0

For y=0.075m, we have U=1.125, then $U=1,125=A \times 0.075$ therefore A=15

We finally get U=15 * y

The velocity gradient: $dU/dy=15\ S^{-1}$ and $\tau=\mu\ dU/dy=0.048 \times 15=0.72\ Pa$ for all values of including between 0 to 75 mm.

2. Parabolic velocity

$U = Ay^2 + By + C$

For y=0.0, we have U=0 then C=0

For y=0.075, we have U=1.125, then $U = 1.125 = A \times (0.075)^2 + B \times 0.075$ (1)

So for y=0.075 U=Umax i.e. dU/dy=2*A*y+B=0.0

$\rightarrow dU/dy = 2\,A \times 0.075 + B = 0.0 \rightarrow B = -0{,}15A$

By substituting the value of B in the equation (1) of the speed, we obtain A=-200

$U = -200\,y^2 + 30\,y$ et $dU/dy = -400\,y + 30$

y (m)	**U (m/s)**	**dU/dy (s^{-1})**	$\tau = 4{,}8\ 10^{-2}\ dU/dy$ (Pa)
0.0	0	30	1,44
0.025	0,625	20	0,96
0.05	1,0	10	0,48
0.075	1,125	0	0

5 . Variation in viscosity as a function of T°:

- When the temperature increases, the viscosity of a liquid decreases because its density decreases.

Example :

Fluid	μ(Pa s)
water (0°C)	$1,787 \cdot 10^{-3}$
water (20°C)	$1,002 \cdot 10^{-3}$
water (100°C)	$0,2818 \cdot 10^{-3}$

6. Density variation as a function of T°:

The variation of the density during a change of temperature is given by :

$$\rho = \frac{\rho_i}{1+\beta t\,(t-ti)}$$

With $\boldsymbol{\beta}_t$ is the coefficient of thermal expansion .

7. The SI System of Units:

In fluid mechanics, the SI system of units (International System) has 3 primary units from which all other quantities can be described:

Basic size	Unit name	Symbol
Length	Meter	m
Mass	Kilogram	kg
Time	Second	s

The following table summarizes the SI units of the different characteristics used in fluid mechanics:

Features	Units
Speed	m/s
Acceleration	m/s^2
Force	$kg.m/s^2$ où N (Newton)
Energy	$kg.m^2/s^2$ où J (Joule)
Power	$kg.m^2/s^3$ où W (Watt)
Pressure	$Kg/m/s^2$, N/m^2 où Pa (Pascal)
Specific weights	$Kg/m^2/s^2$, N/m^3
Viscosity	$Kg/m/s$, $N.s/m^2$ où Pa.s