

**University of Djilali BOUNAAMA-Khemis Miliana
Faculty of Matter Sciences and Computer Science
Department of Physics**

Course of Fluid Mechanics.

Level: 2nd year Physics

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Chapitre 1 : Généralités

Définition du milieu continu, caractéristique du milieu fluide, notion de particule fluide. Forces de volume et force des surfaces appliqués à un domaine fluide. Fluide parfait, fluide visqueux.

Chapitre 2 : Statique des fluides

Equation générale de la statique des fluides. Cas particulier de l'hydrostatique. Forces de poussée d'Archimède. Statique des gaz.

Chapitre 3 : Cinématique des fluides

Repérage d'une particule fluide. Point de vue de Lagrange, point de vue d'Euler, dérivée particulaire.

Lignes de courant, ligne d'émission, trajectoire. Tenseur des déformations lois de comportement. Cas d'un fluide newtonien. Ecoulements rotationnels et irrotationnels. Ecoulements plans à potentiel des vitesses : exemple classique.

Chapitre 4 : Dynamique des fluides parfaits

Théorèmes généraux. Equations fondamentales pour un fluide parfait. Equation de Bernoulli : applications. Etude des débitmètres (venture, tube de Pitot...).

Chapitre 5 : Dynamique des fluides visqueux Equation intégrale du mouvement. Equation locale, équation de Navier-Stokes, applications Résolution de quelques problèmes classiques instationnaires.

Chapitre 6 : Introduction à la dynamique des gaz

Equation de barré de St-Venant. Ecoulement dans un convergent-divergent. Ecoulement supersonique, ondes de chocs.

Chapter 1: Generalities

Definition of the continuous medium, characteristic of the fluid medium, notion of fluid particle. Volume forces and surface forces applied to a fluid domain. Perfect fluid, viscous fluid.

Chapter 2: Fluid Statics

General equation of fluid statics. Special case of hydrostatics. Archimedes' thrust forces. Gas Statics.

Chapter 3: Fluid kinematics

Locating a fluid particle. Lagrange's point of view, Euler's point of view, particle derivative. Streamlines, emission line, trajectory. Tensor of deformations laws of behavior. Case of a Newtonian fluid. Rotational and irrotational flows. Planar flows with velocity potential: classic example.

Chapter 4: Perfect Fluid Dynamics

General theorems. Fundamental equations for a perfect fluid. Bernoulli's equation: applications. Study of flow meters (venture, Pitot tube...).

Chapter 5: Viscous Fluid Dynamics

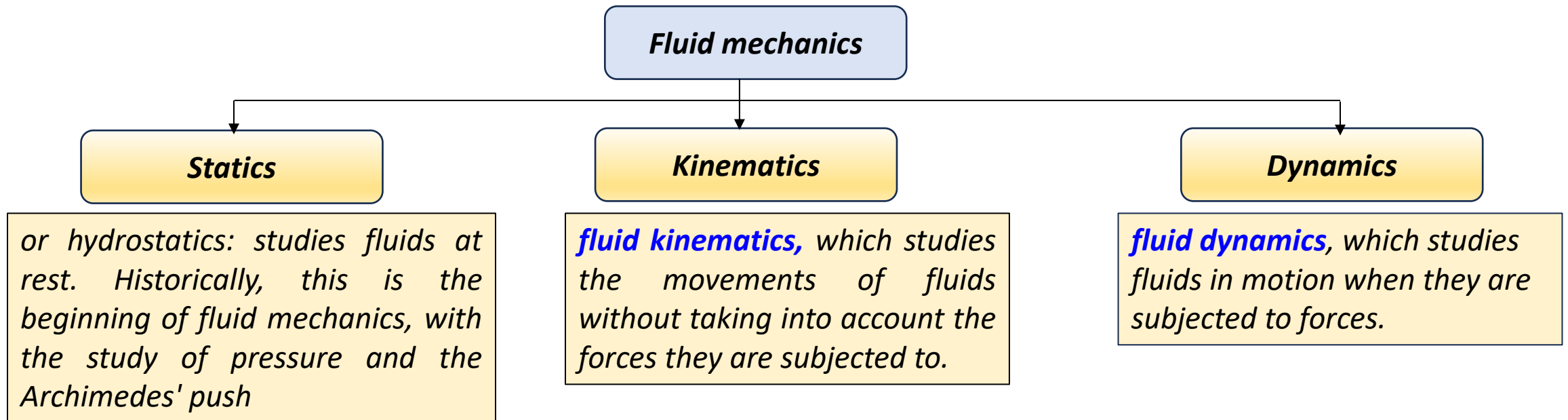
Integral equation of motion. Local equation, Navier-Stokes equation, applications Solving some classical unsteady problems.

Chapter 6: Introduction to Gas Dynamics

St-Venant's barre equation. Flow in a convergent-divergent. Supersonic flow, shock waves.

Introduction to Fluid Mechanics

- Fluid mechanics is a fundamental branch of physics that studies the behavior of fluids (liquids and gases) at rest and in motion, as well as the forces acting on them.
- It plays a central role in many scientific and engineering fields, including mechanical and energy engineering, aeronautics, hydraulics, meteorology, medicine, and environmental sciences.
- Fluids are everywhere around us: air, water, fuel, and even blood. Studying their behavior helps us understand phenomena such as flow in pipes, aircraft flight, pollution spread, and heat transfer.
- It comprises two main branches: **Hydrostatics, Hydrodynamics**

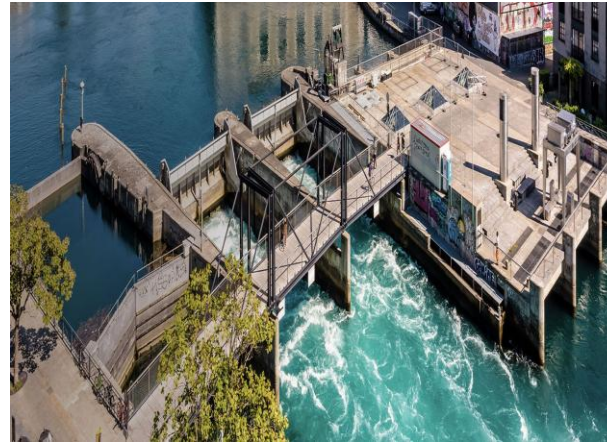


Applications: Fluid mechanics has many applications in various fields such as:

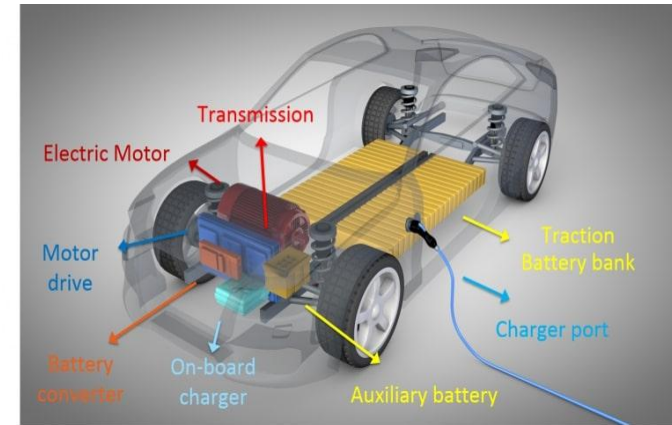
Aerospace Engineering



Civil & Environmental Engineering



Mechanical & Automotive Engineering



Biomedical Engineering



Meteorology & Oceanography



Marine Engineering



Definitions:

What is a fluid....?

- A fluid is a substance that can flow and continuously deform under an applied force.
- Unlike solids, a fluid has no fixed shape and it takes the shape of its container.
- On a microscopic scale, a fluid is a substance formed by a large number of material particles, very small and free to move in relation to each other.
- A fluid is a substance that primarily exists in two physical states:

Liquid state:

- ✓ Have a definite volume but no fixed shape
- ✓ Conform to the shape of their container

Gaseous state

- ✓ have neither a fixed shape nor a fixed volume
- ✓ Expand to fill the entire space available.

Both liquids and gases are able to flow and continuously deform under the action of a shear force, which distinguishes them from solids.

Continuous Medium

- A continuous medium is a material assumed to **be continuous at all points**, ignoring its molecular structure.
- Properties like density, velocity, and pressure vary smoothly from point to point.
- This assumption allows the use of differential equations to describe fluid behavior.

Characteristic of a fluid medium: All fluids have characteristics that describe their physical conditions in a given state.

□ Compressibility:

- Compressibility is the ability of a fluid to change its volume under the action of pressure.
- It measures how much a fluid's density changes when subjected to variations in pressure.
- When a fluid is subjected to an increase in pressure, its volume decreases.
- The relationship between the pressure change (ΔP) and the resulting volume change (dV) is expressed using the compressibility coefficient (β):

$$\beta = -\frac{dV/V}{dP} = -\frac{dV}{dP V} \quad [\beta] = Pa^{-1} \text{ or } m^2/N$$

We distinguish:

Incompressible fluid:

- Is a fluid whose occupied volume does not vary with external pressure, meaning it cannot be compressed into a smaller space.
- Liquids are incompressible fluids (e.g., water, oil, mercury, etc.)

Compressible fluid:

- fluid whose volume can be changed, i.e. it can be compressed into a smaller space by exerting pressure on it.
- All gases are compressible fluids (air, oxygen, hydrogen, nitrogen, etc.).

□ Mass density and density:

1. Mass density: The mass density ρ is an intrinsic property of a material that represents the **mass per unit volume**.

Fluids are characterized by their mass density $\rho = \frac{\text{mass}}{\text{volume}} = \frac{M}{V}$ $[\rho] = \text{kg}/\text{m}^3$

Fluid	Mercury	Sea water	Pure water	Oil	Gasoline	Butane	Air
$\rho(\text{kg}/\text{m}^3)$	13600	1030	1000	900	700	2	1,293

2. Density (d): is a **dimensionless quantity** that compares the mass density of a fluid to that of a reference fluid.

$$d = \frac{\rho}{\rho_{\text{reference}}}$$

✓ The reference fluid depends on the physical state of fluid (usually water for liquids and air for gases).

Examples: $d_{\text{Water}} = \frac{1000}{1000} = 1$ $d_{\text{Fuel}} = \frac{700}{1000} = 0,7$

❖ Liquids are characterized by a relatively high mass density: $\rho_{\text{Liquids}} \gg \rho_{\text{Gaz}}$

❖ For gases, the mass density depends on temperature and pressure

□ Specific weight: is a physical quantity that represents the weight per unit volume of that fluid. It is denoted by γ (gamma) and is expressed in newtons per cubic meter (N/m^3) in the International System of Units (SI).

where:

$$\gamma = \frac{w}{V} = \frac{mg}{V} \Rightarrow \gamma = \rho \cdot g$$

✓ γ is the specific weight (N/m^3),

✓ ρ (rho) is the mass density of the fluid (kg/m^3),

✓ g is the acceleration due to gravity ($g \approx 9.81 m/s^2$ at the Earth's surface).

□ Specific volume: is a physical property that represents the volume occupied per unit mass of that substance.

It is denoted by v and is expressed in cubic meters per kilogram (m^3/kg) in the International System of Units (SI).

$$v = \frac{V}{m} = \frac{1}{\rho}$$

The specific volume is the inverse of **mass density** (ρ).

Notes: ✓ For gases, specific volume depends strongly on temperature and pressure.

✓ For liquids, it is generally less variable, except under extreme conditions.

□ Viscosity: is a physical property that describes a fluid's resistance to flow or deformation under the influence of an applied stress.

- It characterizes the internal friction between layers of fluid in motion.
- There are two main types of viscosity:

1. Dynamic Viscosity (μ):

Dynamic viscosity (μ) measures a fluid's internal resistance to flow under an applied **shear stress**. It quantifies the fluid's resistance to relative motion between adjacent layers.

Shear Stress: Force applied tangentially to a surface per unit area. $\tau = \frac{F}{S}$

It is expressed in Pascals (Pa) or N/m².

Example: Spreading honey on bread :

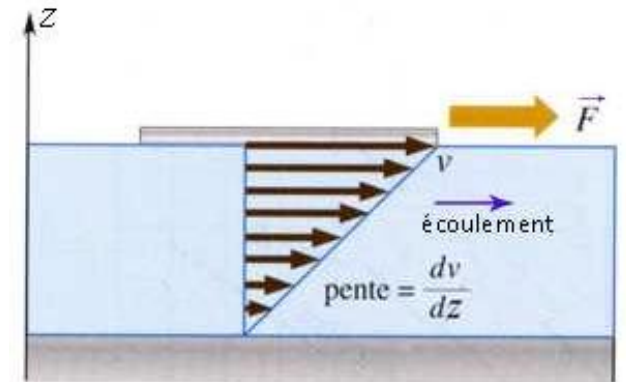
your fingers apply a tangential force, causing the honey to flow

Physical Meaning:

- ✓ In a fluid at rest, layers do not move relative to each other.
- ✓ When a shear force is applied (parallel to a surface), the **layers slide past each other**, and the fluid resists this motion.
- ✓ This resistance is the dynamic viscosity.

Definition: Dynamic viscosity (μ) is defined as the ratio of shear stress (τ) to the velocity gradient (dv/dy) in a fluid.

Mathematically, it is expressed as: $\mu = \frac{\tau}{dv/dz}$



In the SI system, the unit of dynamic viscosity is **(Pa.s)** or **(kg/ms)** or Poiseuille $1\text{Pl (Poiseuille)}=1 \text{ Pa.s} =1\text{kg /ms}$

2. Kinematic Viscosity (ν): is defined as the ratio of dynamic viscosity to the mass density.

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

It represents the ability of a fluid to flow under the influence of gravity

In the SI System : $[\nu] = m^2/s$

In the CGS system: $[\nu] = Stokes (st)$, : $1m^2/s = 10^4 St$

✓ Unlike dynamic viscosity, kinematic viscosity accounts for the fluid density:

❖ Low kinematic viscosity (ν) → fluid flows easily (water)

❖ High kinematic viscosity (ν) → fluid flows slowly (honey, oil)

Remark:

The viscosity of liquids decreases significantly as the temperature increases

Fluid	Water (0°)	Water (20°)	Water (100°)	H ₂ (20°)	O ₂ (20°)
$\mu(\text{Pas.s})$	$1,787 \times 10^{-3}$	$1,002 \times 10^{-3}$	$0,2818 \times 10^{-3}$	$0,860 \times 10^{-5}$	$1,950 \times 10^{-5}$

Notion of a Fluid Particle:

A fluid particle is a small, imaginary portion (volume) of fluid that is:

1- Small enough to be considered a point in space.

2- Large enough to contain a sufficient number of molecules so that its properties (density, velocity, pressure, temperature, etc.) can be defined as continuous quantities.

A fluid particle is a mass of fluid defined by a volume of mesoscopic size

- ❖ **Microscopic scale:** Deals with individual atoms, molecules, or nanoparticles (typically on the order of nanometers (10^{-9} m)).
- ❖ **Mesoscopic scale:** Refers to sizes ranging from a few nanometers to a few micrometers (μm , or 10^{-6} meters).
- ❖ **Macroscopic scale:** Refers to sizes visible to the naked eye (larger than micrometers).

Forces acting on a fluid particle

In fluid mechanics, the forces acting on a fluid can be classified into two main categories: **body forces** (or volume forces) and **surface forces**.

1. Body Forces (Volume Forces): are forces that act on **the entire volume** of the fluid. They are proportional to the mass (or volume) of the fluid.

Examples : Gravity, Electromagnetic Forces, Inertial Forces.

Characteristics:

1. They act at a distance.
2. They are distributed uniformly throughout the volume of the fluid.

2. Surface Forces: are forces that act on the **surface** of a fluid element.

They result from interactions between adjacent fluid particles or between the fluid and a solid boundary.

Examples: Pressure Forces, Viscous Forces,

Characteristics:

1. They act locally, on the surfaces of the fluid
2. They depend on the properties of the fluid (such as viscosity) and boundary conditions.

Types of fluid:

- Perfect Fluid: In fluid mechanics, a fluid is said to be perfect if it is possible to write its motion without taking into account the effects of friction to facilitate calculations (Dynamic viscosity equal 0)
 - ✓ A perfect fluid is an idealized fluid that has no viscosity and no thermal conductivity
 - ✓ It offers no resistance to shear stress \Rightarrow it cannot resist tangential forces.

- Real Fluid (Viscous): A fluid is said to be real when viscous friction is taken into account during the movement of this fluid
 - ✓ A viscous fluid has internal friction, meaning it resists shear stress.
 - ✓ The flow of viscous fluids is affected by viscosity, which causes energy dissipation.
 - ✓ Examples: Water, oil, honey

At rest, we will assume that the real fluid behaves like a perfect fluid, i.e. the statics of real fluids merges with the statics of perfect fluids