University of Ghardaia
Faculty of Sciences and Technology
Department of Hydraulics and Civil Engineering

General Hydraulics
(Course and Exercises)

Handout of General Hydraulics "Course and Exercises" intended for 2nd year Engineer's students (Semester 4) Science and Technology (ST)

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Foreword

This course and exercises introduce the fundamental principles of fluid mechanics and their applications in Civil Engineering, and it is intended for second-year undergraduate engineering students in Civil Engineering. The course is structured progressively, starting from the study of fluids at rest and advancing toward more complex flow phenomena encountered in hydraulic engineering as follows:

- The first chapter focuses on the study of fluids at rest, emphasizing the physical properties of fluids, pressure distribution, hydrostatic forces acting on submerged surfaces, and buoyancy principles governing floating bodies;
- The second chapter addresses the motion of fluids by introducing flow descriptions and classifications, and by developing the governing equations based on the conservation of mass, momentum, and energy, with particular attention to the Bernoulli equation and its applications to ideal fluid flow;
- The third chapter extends the analysis to real fluids by accounting for viscosity and energy losses. This chapter examines flow regimes, friction losses, local head losses, and the differences between ideal and real fluid behavior in practical engineering systems;
- The fourth chapter IV concentrates on flow measurement and discharge phenomena through hydraulic openings. It analyzes the characteristics of orifices, flow coefficients, and discharge under constant and variable head conditions, highlighting their relevance in hydraulic structures and water control systems;
- The fifth chapter explores the calculation of frictional pressure losses using the Manning equation, a cornerstone of open-channel hydraulics. It details the interaction between flow velocity, slope, and the Manning roughness coefficient, while introducing the Reynolds number to characterize the flow regime;
- The sixth chapter deals with open-channel hydraulics, focusing on free surface flow characteristics, flow regimes, critical conditions, and basic principles of spillway hydraulics, which are essential for the design and analysis of channels, dams, and water conveyance structures;

At the end of this course and exercises, students will be able to understand and analyze the behavior of fluids at rest and in motion, apply the fundamental equations of fluid mechanics, and solve practical hydraulic problems related to civil engineering structures and water flow systems.

This handout was drawn from existing documentation available in all libraries and websites.

Dr. ABDELKEBIR Brahim

Summary

Foreword

Summary

Chapter I Hydrostatics

Chapter II Fundamental Equations of Hydrodynamics

Chapter I
Hydrostatics

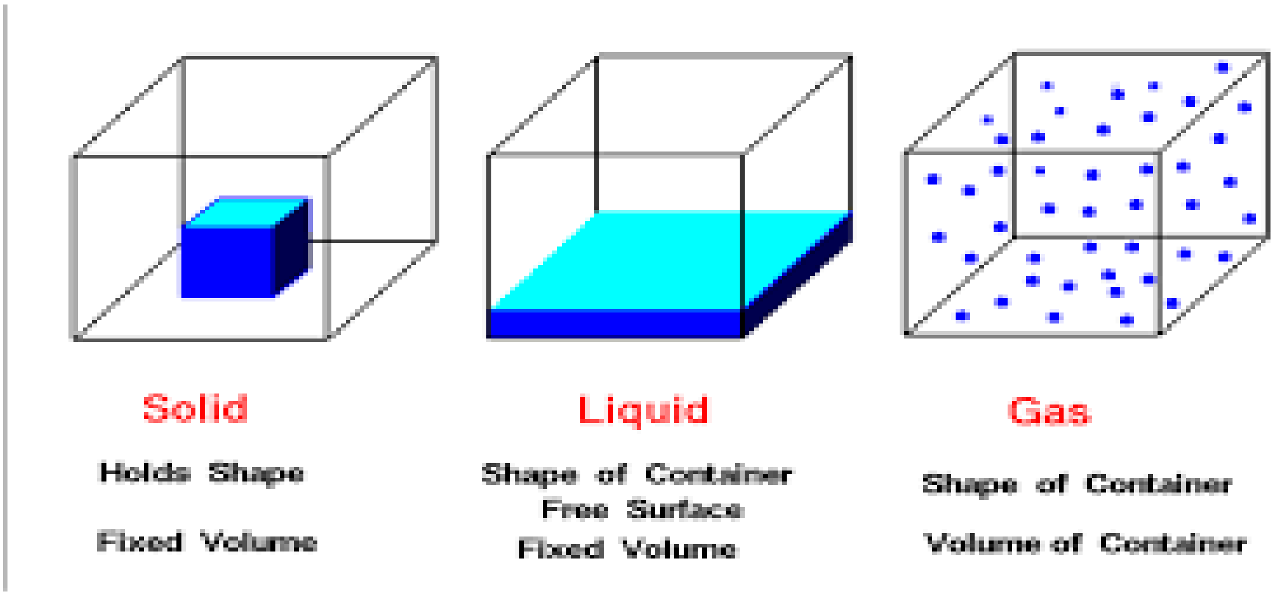
Introduction

Hydrostatics is the branch of fluid mechanics that studies fluids at rest. It deals with understanding how forces are distributed within a fluid and how these forces act on surfaces in contact with the fluid. This chapter covers fundamental principles, concepts, and applications of hydrostatics.

I.1 Physical characteristics

a. Volume but Indefinite Shape

Liquids have a fixed volume but take the shape of their container. Example: Water poured into a glass takes the shape of the glass, but its volume remains constant. This is because the intermolecular forces of attraction in liquids are quite weak as compared to the solid states.

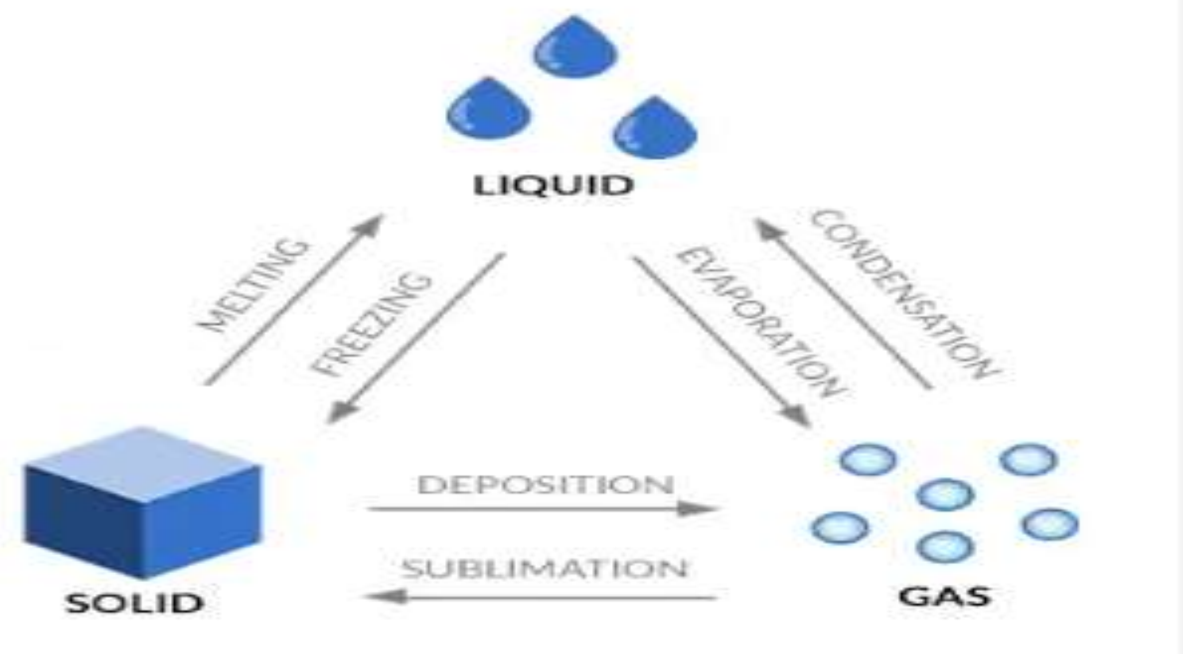


(a)

b. Fluidity

The fluidity of water refers to its ability to flow and take the shape of its container, a characteristic of liquids. Scientifically, fluidity is the reciprocal of viscosity, meaning that water's high fluidity corresponds to its low resistance to flow. Fluidity is a measure of how easily a substance flows. Water's fluidity is relatively high compared to substances like oil or honey.

The fluidity of water increases with temperature, as higher temperatures reduce its viscosity. Water's fluidity arises from its molecular structure and hydrogen bonding, which allow water molecules to move freely relative to one another. For example, at standard conditions (25°C), water has a low viscosity (about 0.89 mPa·s), which contributes to its high fluidity.



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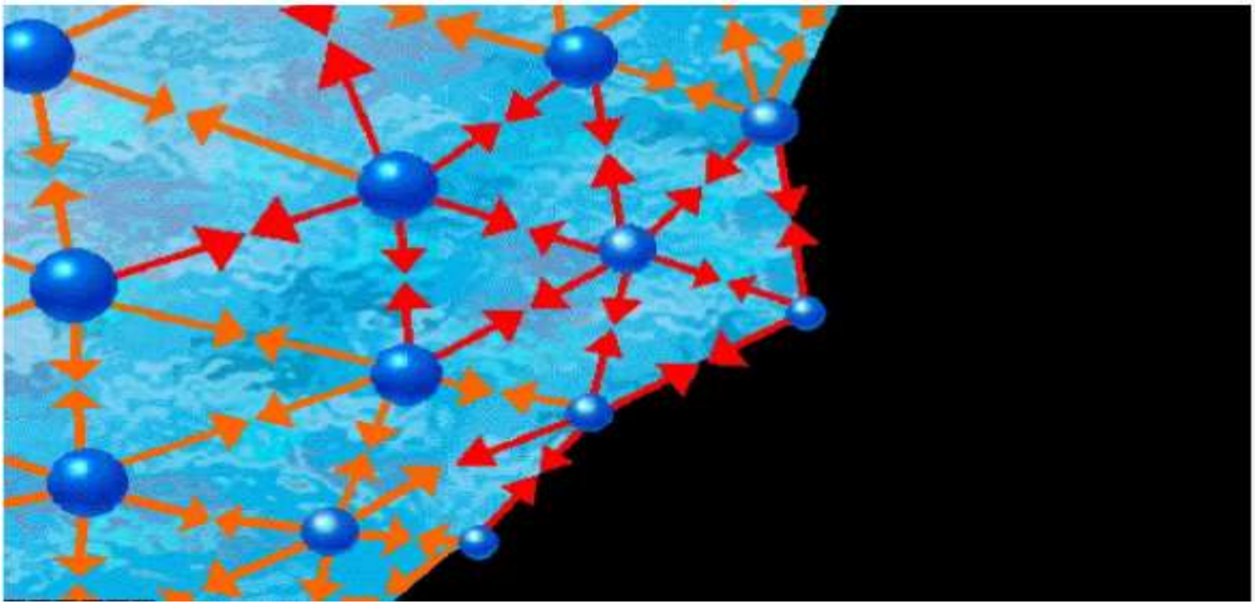
c. Surface Tension

Surface tension is the property of a liquid's surface that allows it to resist external forces, due to the cohesive nature of its molecules. In the case of water, its surface tension is relatively high compared to most other liquids, largely due to hydrogen bonding between water molecules.



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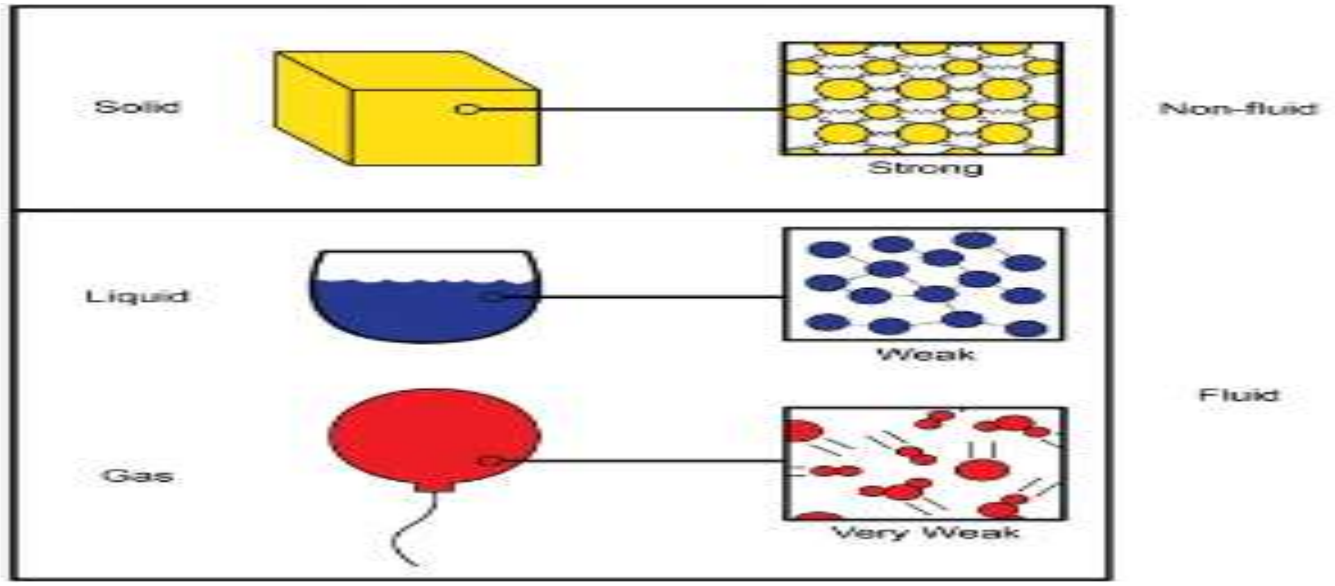
d. Compressibility

Compressibility refers to the measure of how much a substance decreases in volume under pressure. It is an important property of materials, especially in fluids (liquids and gases)

Liquids are nearly incompressible because their molecules are closely packed. Any pressure applied does not significantly change their volume. Liquids are nearly incompressible because their molecules are closely packed. Any pressure applied does not significantly change their volume.



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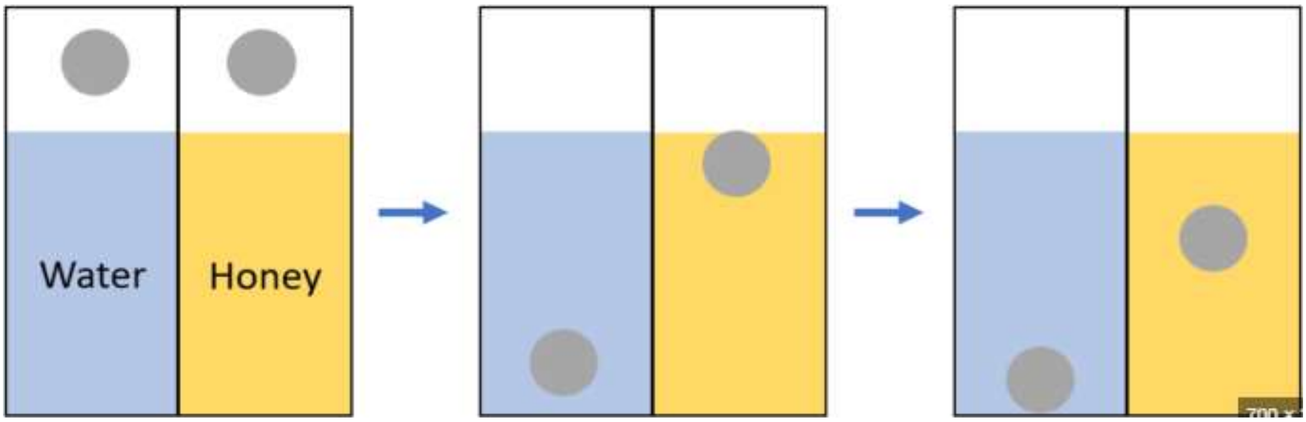
e. Viscosity

Viscosity is a measure of a fluid's resistance to flow. It describes how thick or sticky a fluid is and how easily it moves when subjected to an external force. Fluids with high viscosity flow more slowly (like honey), while those with low viscosity flow more easily (like water). For gases, viscosity increases with increasing temperature due to the way temperature affects the kinetic energy of gas molecules. In contrast to liquids, where viscosity generally decreases with temperature due to reduced intermolecular forces, gases behave differently because their viscosity is more sensitive to changes in molecular motion and collisions rather than the molecular bonding.



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f. Cohesion and Adhesion

Cohesion and adhesion are two fundamental properties of liquids that relate to the interactions between molecules.

Cohesion is the attraction between molecules of the same substance. This property causes molecules to stick together. For example, water molecules are attracted to each other due to hydrogen bonding, which is why water forms droplets on surfaces and exhibits surface tension. Cohesion is responsible for phenomena like the rise of water in plants (capillary action).

Adhesion is the attraction between molecules of different substances. It occurs when molecules of a liquid are attracted to the molecules of a different material, such as glass. This is why water climbs up the sides of a glass container or adheres to a plant's surface, helping with processes like capillary action and the wetting of surfaces.

Both cohesion and adhesion play crucial roles in various natural phenomena, from the movement of water in plants to the behavior of liquids in containers.

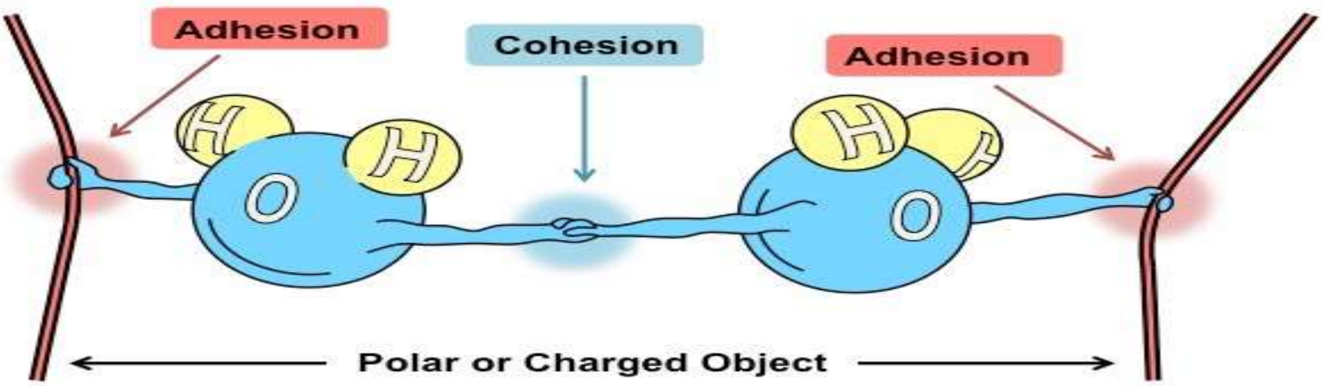

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Fig I.1 Physical characteristics of liquids a,b,c,d,e and f

I.2 Properties of Liquids

a. Density

Density is a physical property that describes the mass of an object per unit volume. It is typically expressed using the formula:

$$Density = \frac{Mass}{Volume}$$

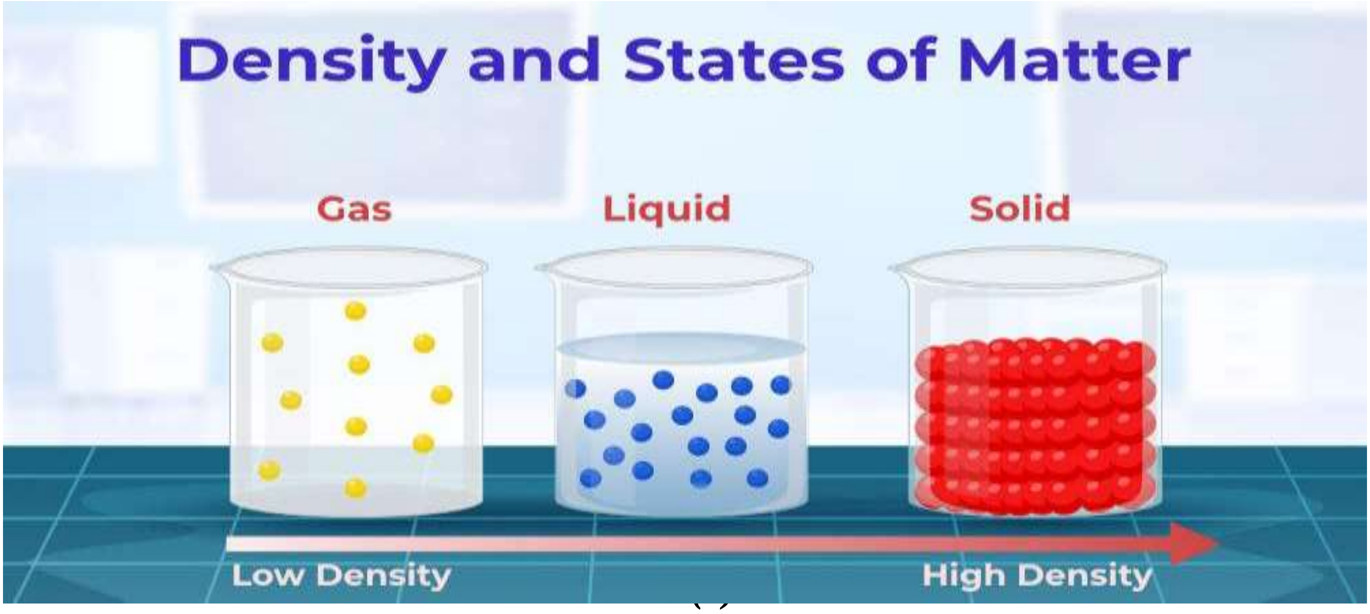
Where:

- Mass is the amount of matter in an object (usually measured in grams or kilograms),
- Volume is the amount of space the object occupies (usually measured in cubic centimeters or liters).

The unit of density depends on the units of mass and volume. Common units include:

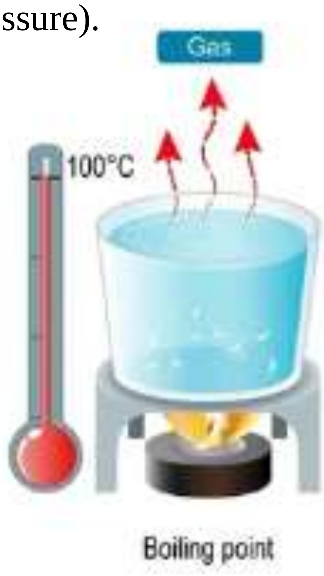
- grams per cubic centimeter (g/cm^3), or
- kilograms per liter (kg/L).

For example, the density of water is approximately 1 g/cm^3, which means that 1 cm^3 of water has a mass of 1 gram.



b. Boiling Point

The boiling point of a substance is the temperature at which its vapor pressure equals the external pressure surrounding the liquid, causing the liquid to turn into gas (vaporize). The boiling point depends on the substance's properties and the pressure of the environment. The boiling point is the temperature at which a liquid's vapor pressure equals external atmospheric pressure. Example: Water boils at 100°C (at 1 atm pressure).



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c. Freezing Point

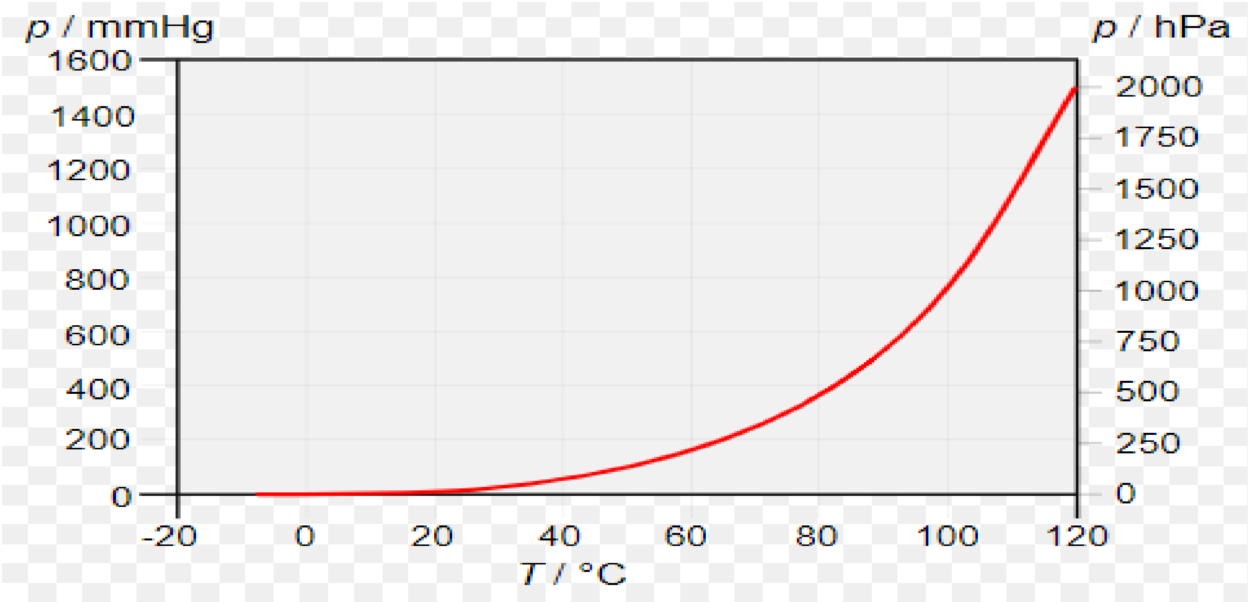
The freezing point of a substance is the temperature at which it changes from a liquid to a solid. For water, the freezing point is typically 0°C (32°F) at standard atmospheric pressure (1 atm). However, the freezing point can vary depending on the substance and the pressure it is under. For example:

Saltwater has a lower freezing point than pure water due to the presence of salt, which disrupts the formation of ice crystals. Many liquids, like alcohol or mercury, freeze at much lower temperatures.

(c)

d. Vapor Pressure

Vapor pressure is the pressure exerted by the vapor (gas) phase of a substance in equilibrium with its liquid or solid phase at a given temperature. It is an indicator of the tendency of a substance to evaporate or sublime. The higher the vapor pressure, the more volatile the substance is. Vapor pressure is typically measured in units like pascal (Pa), millimeters of mercury (mmHg), or atmospheres (atm).



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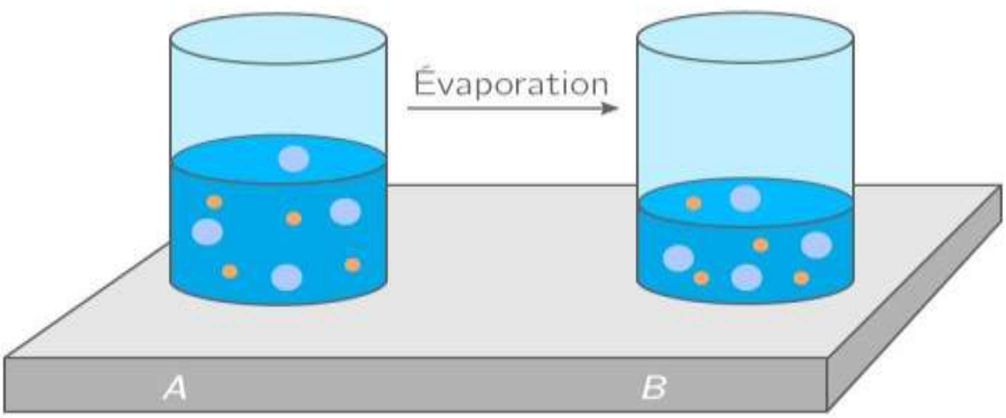
e. Evaporation

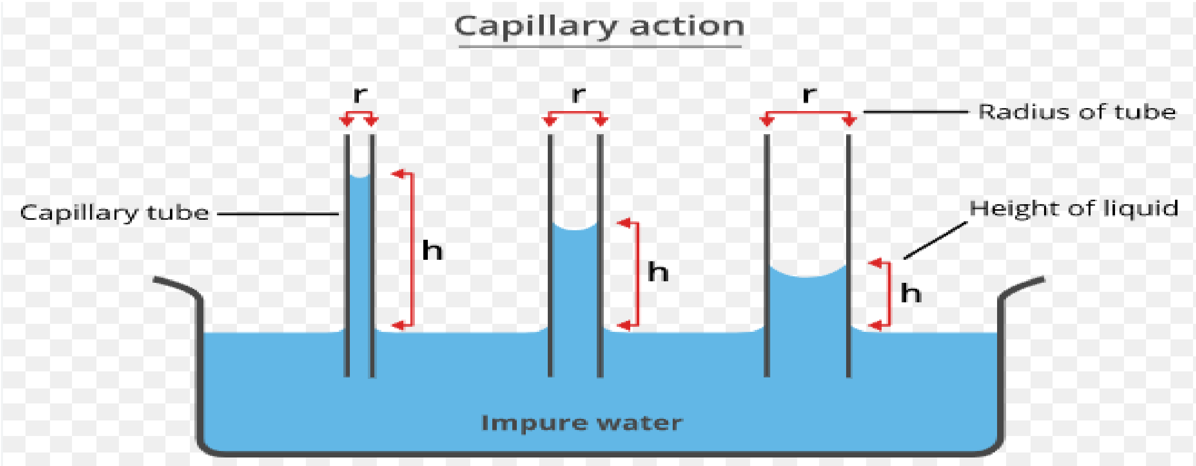
Evaporation is the process by which a liquid turn into a gas or vapor, typically due to an increase in temperature or a decrease in pressure. It occurs at the surface of the liquid, and unlike boiling, it can happen at any temperature, as long as the conditions allow for the molecules at the surface to overcome the attractive forces binding them to the liquid.



(e)

f. Capillary Action

Capillary action (also known as capillarity) is the ability of a liquid to flow in narrow spaces without the assistance of external forces (like gravity). It is a result of intermolecular forces, particularly adhesion and cohesion, which play key roles in how the liquid behaves in the presence of small spaces, such as thin tubes or porous materials.



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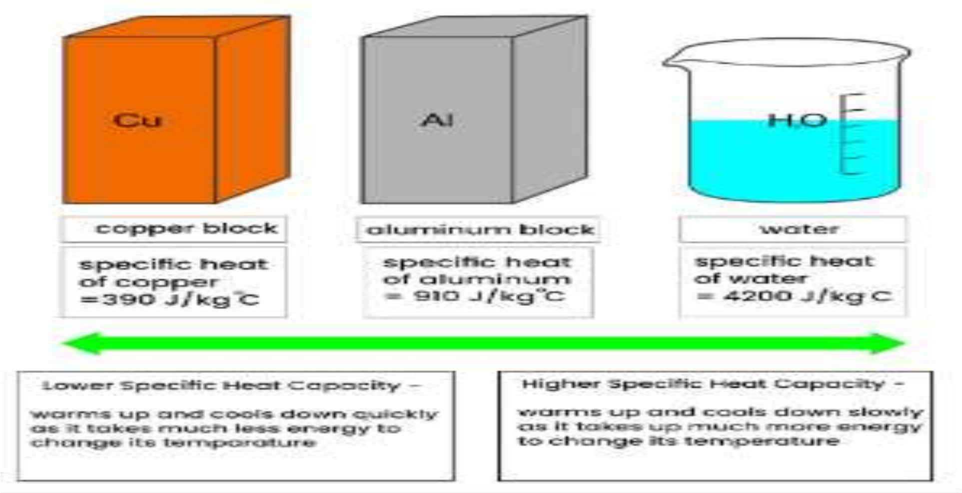
g. Heat Capacity and Specific Heat

Heat Capacity and **Specific Heat** are two important concepts in thermodynamics that describe how materials respond to changes in temperature when heat is added. Heat capacity is the amount of heat energy required to raise the temperature of an object or substance by one degree Celsius (or one Kelvin). While Specific heat (or specific heat capacity) is the amount of heat required to raise the temperature of one-unit mass of a substance by one degree Celsius (or one Kelvin). It is a more specific measure than heat capacity.



(g)

h. Diffusion

Diffusion refers to the process by which particles (atoms, ions, molecules) spread from regions of higher concentration to regions of lower concentration due to their random thermal motion. This movement continues until the system

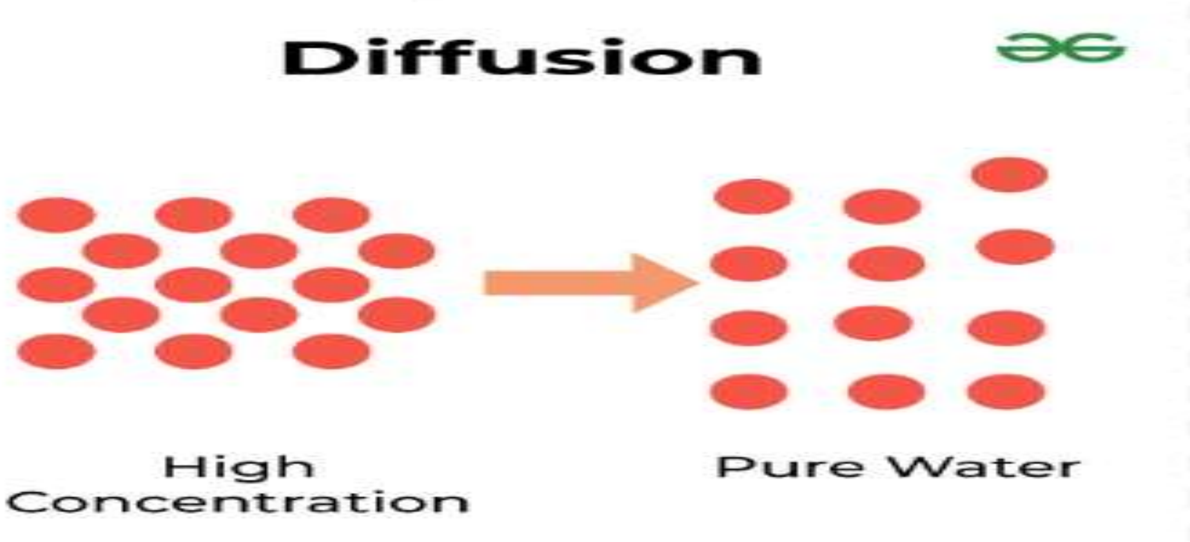


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Fig I.2 Properties of liquids a,b,c,d,e,f,g and h

I.2 Concept of pressure

I.2.1 Hydrostatic Pressure

In fluid mechanics, the concept of pressure plays a pivotal role in understanding the behavior of fluids at rest. Hydrostatic pressure is the pressure exerted by a static (non-moving) fluid due to the weight of the fluid above a given point. It is particularly important in the study of water bodies, such as oceans, lakes, and reservoirs, where fluids remain at rest under the influence of gravity.

In the hydrostatic phase, the fluid is at rest, meaning there is no relative motion between the fluid particles. The pressure exerted by the water at any given point depends on the depth of the fluid, the density of the fluid, and the gravitational force acting on the fluid.

I.2.2 Fundamental Equation of Hydrostatic Pressure

The general equation to calculate the hydrostatic pressure P at a depth h in a fluid of density ρ is given by:

$$P = P_0 + \rho g h$$

Where :

- P = hydrostatic pressure (Pa or N/m²),
- P_0= is the pressure at the surface (or reference level),
- ρ = density of the fluid (kg/m³),
- g = acceleration due to gravity (approximately 9.81 m/s^2)
- h = depth from the surface of the fluid (m).

The equation reveals that the hydrostatic pressure increases linearly with the depth of the fluid and is directly proportional to the fluid's density.

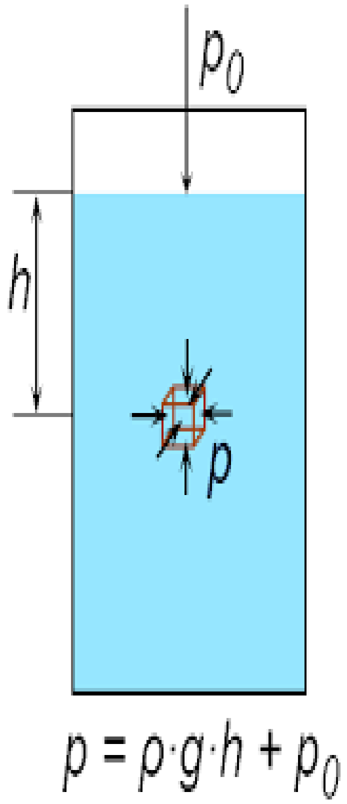
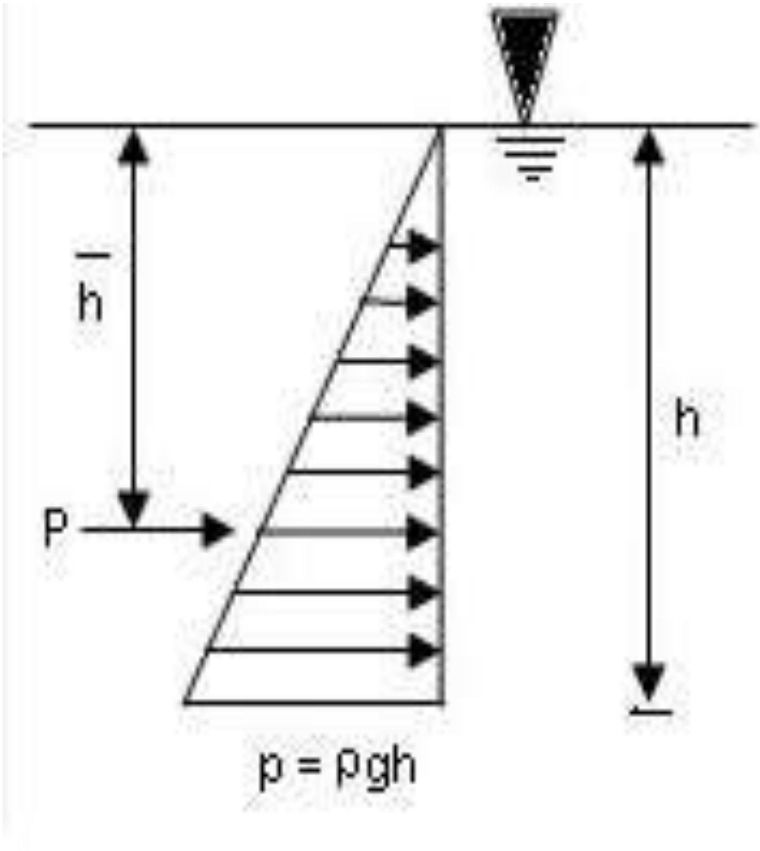


Fig I.3 schema of Hydrostatic Pressure

I.3 Pressure at a point on a wall

The pressure at a point on a wall depends on several factors, including the type of fluid or gas in contact with the wall, the height of the point relative to the surface, and the nature of the wall itself (e.g., vertical, horizontal).

a. <u>Pressure in a fluid:</u> If the wall is in contact with a fluid (like water), the pressure at a point on the wall can be determined using the hydrostatic pressure formula, this formula assumes the fluid is incompressible and at rest.



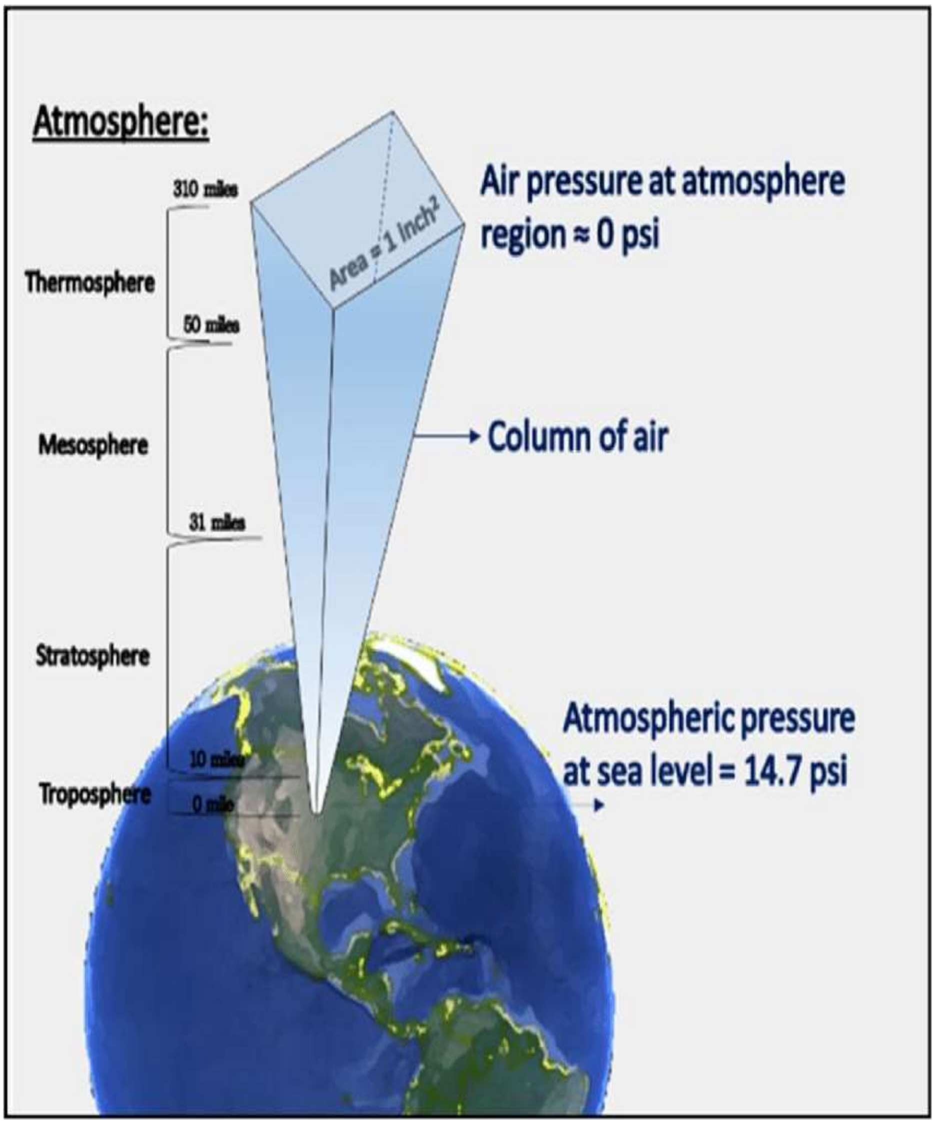
(a)

b. **Pressure in a Gas (Atmospheric Pressure):** If the wall is exposed to a gas (such as air), the pressure at the point can typically be considered as the atmospheric pressure unless the gas is under specific conditions (e.g., in a pressurized container). Atmospheric pressure at sea level is approximately 101,325 P_a but this value can change with altitude and weather. For a gas in a confined space, the pressure can be calculated using the ideal gas law:

$$P = \frac{nRT}{V}$$

Where :

- P is the pressure,
- n is the number of moles of the gas,
- R is the universal gas constant,
- T is the temperature in Kelvin,
- V is the volume of the gas.



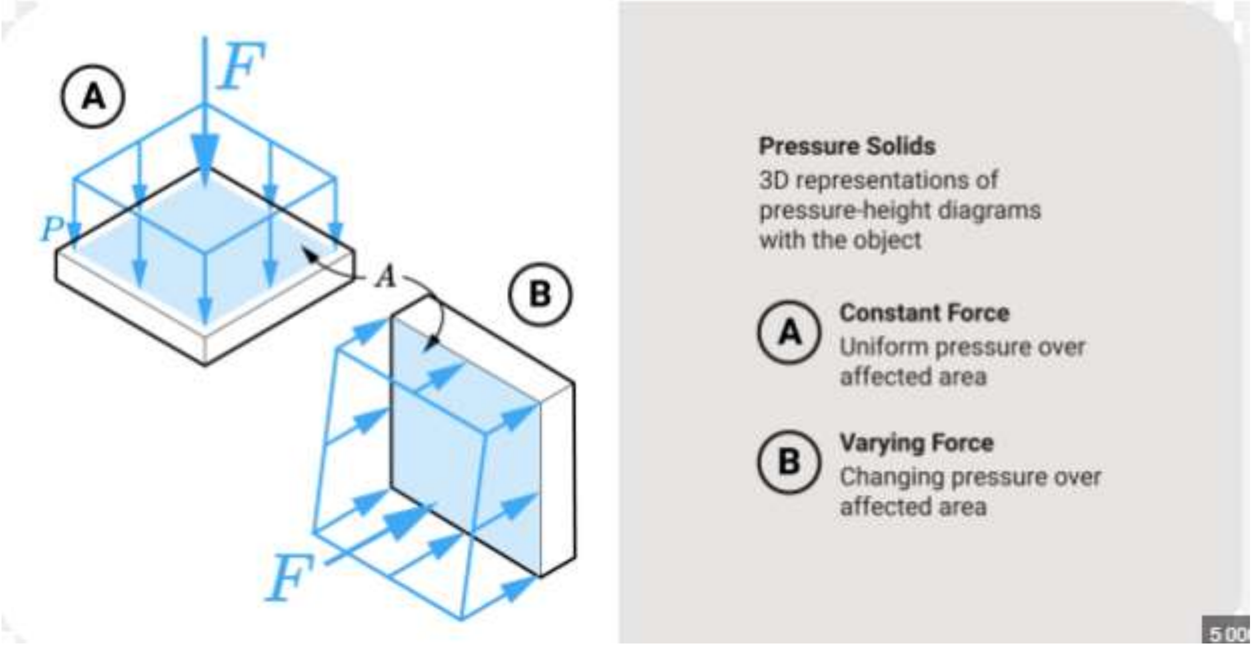
(b)

c. **<u>Pressure due to uniform force:</u>** If there is a uniform force acting on the wall (such as from a mechanical system), In this case, the force is distributed over the area of the wall, and the pressure is uniform across the area.the pressure at any point can be calculated as:

$$\boldsymbol{P = \frac{F}{A}}$$

Where :

- P is the pressure,
- F is the force applied to the surface,
- A is the area of the surface.



(c)

Fig I.4 Pressure' types on a wall a,b and c

I.3 Measuring Hydrostatic Pressure

The Hydrostatic pressure is often measured using a **manometer** or pressure gauge, this mesure could be with difference units. A simple manometer consists of a tube containing a liquid, with one end connected to the fluid being measured and the other exposed to the atmosphere. The difference in the liquid levels in the tube corresponds to the pressure at the give depth.

Fig I.5 Pressure gauge

COMMON UNITS OF PRESSURE

Units	Symbol	Equivalent to 1 atm
Atmosphere	atm	1 atm
Millimeter of Mercury	mmHg	760 mmHg
Torr	Torr	760 Torr
Pascal	Pa	101326 Pa
Kilopascal	kPa*	101.326 kPa
Bar	bar	1.01325 bar
Millibar	mb	1013.25 mb
Pounds per square inch	psi	14.7 psi

Fig I.6 Pressure units

I.4 Archimedes' Principle

Ah, Archimedes' Principle! This fundamental concept in physics explains why objects float or sink in a fluid. principle states:"A body fully or partially submerged in a fluid experiences an upward buoyant force equal to the weight of the fluid it displaces."

Where :

- Buoyant Force: The upward force exerted by the fluid on the object.
- Displaced Fluid: The volume of fluid that is pushed aside by the submerged part of the object.
- Weight of Displaced Fluid: The buoyant force is equal to the weight of the displaced fluid, which depends on the fluid's density.

The buoyant force can be calculated as:

$$F_b = \rho . V . g$$

Where:

- ρ: Density of the fluid (kg/m^3)
- V: Volume of the displaced fluid (m^3)
- g: Acceleration due to gravity ($\approx 9.81 m/s^2$)

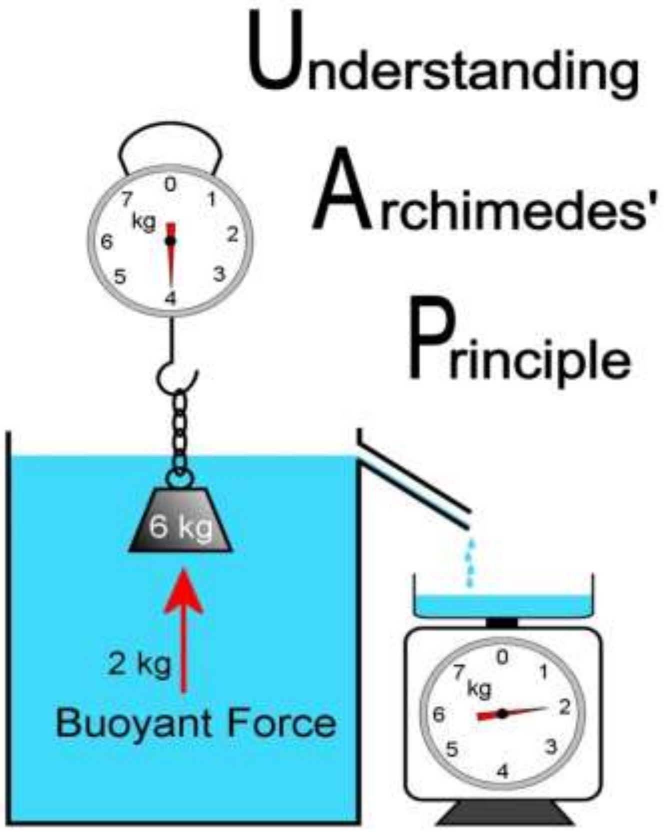


Fig I.7 Archimedes' Principle

Directed works

Exercise 01

Water is stored in a tank. Calculate the pressure at a depth of 5 m below the free surface

Given:

Density of water ρ=1000 kg/m^3

Gravity g=9.81 m/s^2

<u>Solution</u>

P= ρgh

P=1000*9.81*5

P=49050 Pa=49050 KPa

Exercise 02

A vertical rectangular gate (width = 2 m, height = 3 m) is submerged in water with its top edge at the free surface. Calculate the total hydrostatic force

Solution

Formula of hydrostatic force:

$F = \rho g A h_c$

were:

$A = 2*3 = 6m^2$

$h_c = 3/2 = 1.5m$

$F = 1000*9.\ 81*6*1.5$

F=88290 N=88.29 KN

Exercise 03

A solid cube of side 0.5 m is submerged in water. Find the buoyant force acting on the cube. Assume water density is 1000 kg/m^3.

Solution

Buoyant force is given by Archimedes' Principle:

$F_B = \rho g V$

$V = 0.125\ m^3$ (Volume of the tube)

$F_B = 1000*9.81*0.125$

$F_B = 1226.25$

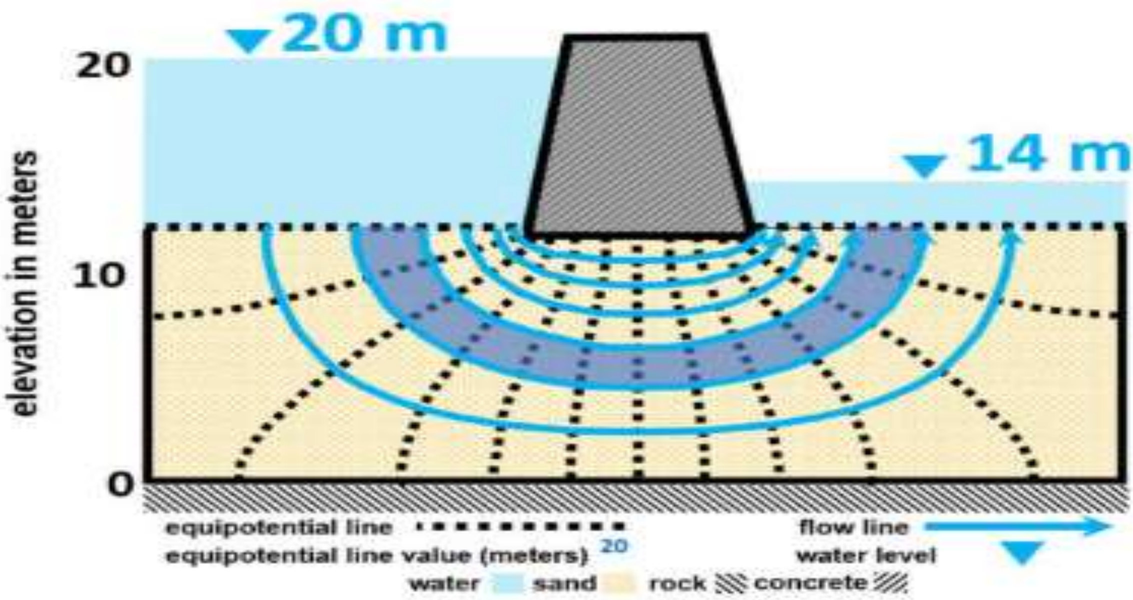
Chapter II

Fundamental Equations of Hydrodynamics

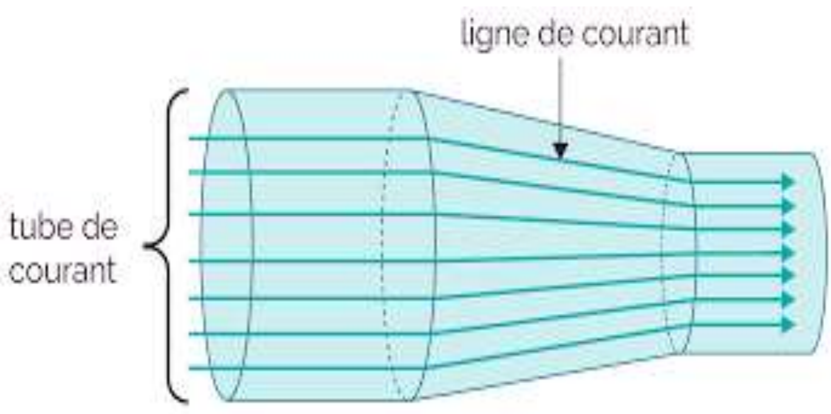
Hydrodynamics is the branch of fluid mechanics that studies the motion of fluids (liquids and gases) and the forces acting on them. The fundamental equations of hydrodynamics are mathematical formulations that describe the behavior of fluids based on the principles of conservation of mass, momentum, and energy. These equations serve as the foundation for analyzing a wide range of phenomena, including fluid flow in pipelines, weather patterns, ocean currents, and aerodynamics.

II.1 Current lines and current tube

A streamline is any curve whose tangent at each of its points is, at each instant and locally, collinear with the velocity vector of the flow field. The current tube is the set of streamlines resting on a closed contour.



II.1 Current lines



II.2 current tube

II.2 Continuity equation

The continuity equation is a fundamental principle in physics and engineering that expresses the conservation of a quantity (such as mass, energy, or charge) within a given system. It is widely used in fluid dynamics and other fields to describe how a conserved quantity behaves in space and time.

The general form of the continuity equation in terms of a conserved quantity *q* is:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{v}) = 0$$

Where :

- ρ: Density of the conserved quantity (e.g., mass per unit volume for fluids).
- v: Velocity vector of the flow.
- ∇·(ρv): Divergence of the flux.
- $\frac{\partial \rho}{\partial t}$: Time rate of change of the density.

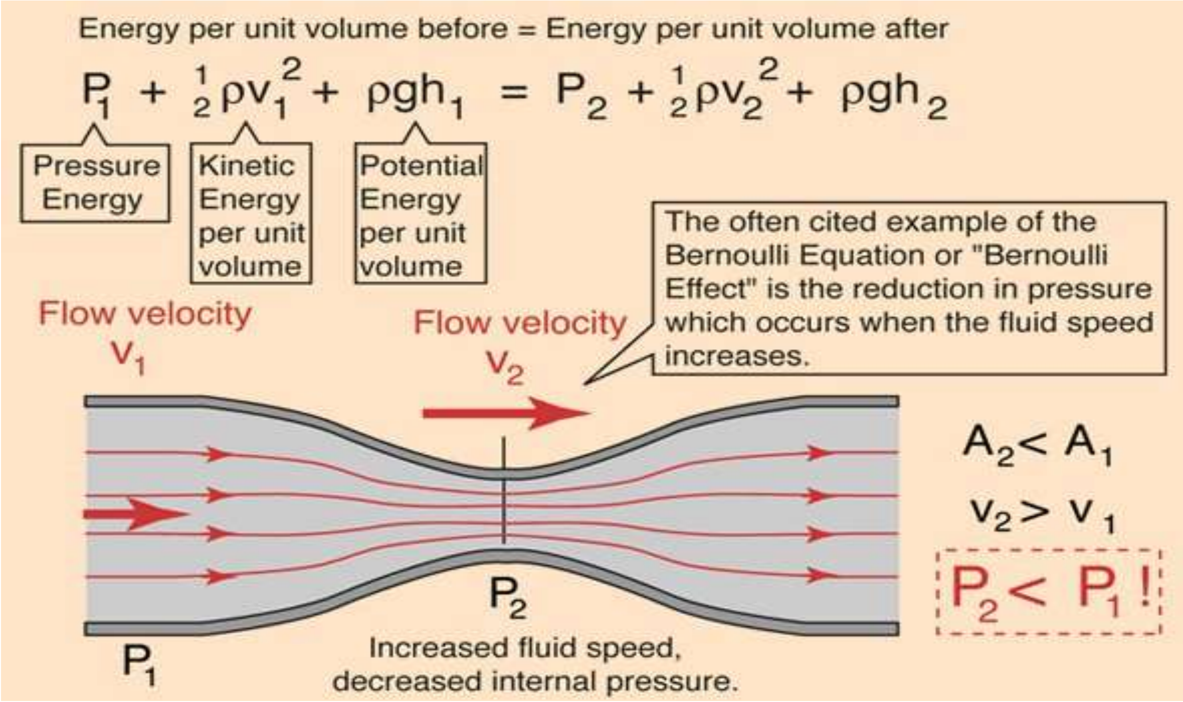
II.3 BERNOULLI's theorem

Bernoulli's Theorem, commonly referred to as Bernoulli's Principle, is a fundamental concept in fluid dynamics. It describes the behavior of a fluid (liquid or gas) in motion, providing a relationship between its pressure, velocity, and elevation. The Statement of Bernoulli's Theorem is "In *a steady, incompressible, and non-viscous flow of fluid, the sum of the following three quantities remains constant along a streamline*"

$$P + \frac{1}{2}\rho v^2 + \rho g h = Constante$$

Where :

- P = Pressure of the fluid
- ρ = Density of the fluid
- v= Velocity of the fluid
- g = Acceleration due to gravity
- h = Height above a reference point



II.3 Schema explicative of BERNOULLI's principle

II.4 VENTURI phenomenon

he Venturi phenomenon is a physical principle that occurs when a fluid flows through a constricted section of a pipe or tube, resulting in a decrease in pressure and an increase in velocity. This principle is based on the Bernoulli equation, which relates pressure, velocity, and elevation in a moving fluid, same time are based on three hypotheses:

a. Constriction: When the cross-sectional area of a pipe narrows, the fluid must accelerate to maintain a constant flow rate (continuity principle).

b. Pressure Drop: As the velocity of the fluid increases in the constricted area, its pressure decreases (Bernoulli principle).

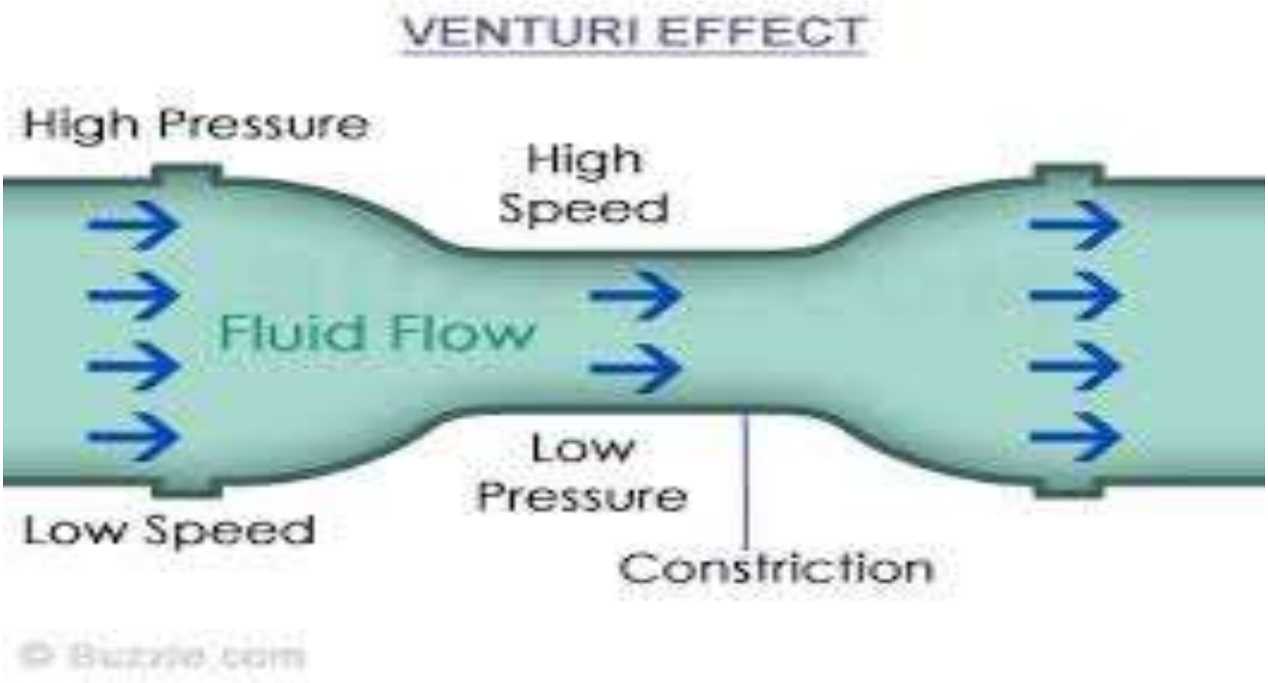
c. Restoration: After passing through the constricted section, the fluid slows down, and the pressure increases again.

The Venturi effect can be derived from the Bernoulli equation as following:

$$P_1 + \frac{1}{2}\rho {v_1}^2 = P_2 + \frac{1}{2}\rho {v_2}^2$$

Where :

- P_1, P_2: Pressure at the wide and narrow sections.
- v_1, v_2: Velocity at the wide and narrow sections.
- ρ: Fluid density.



II.4 Schema explicative of VENTURI principle

II.5 PITOT tube

A Pitot tube is an instrument used to measure the fluid velocity in a flow, often in the context of airspeed measurement in aviation or fluid dynamics experiments. It works by comparing the stagnation pressure (the pressure of the fluid when brought to rest) to the static pressure (the pressure in the fluid at rest). This difference, known as the dynamic pressure, is used to calculate the velocity of the fluid.

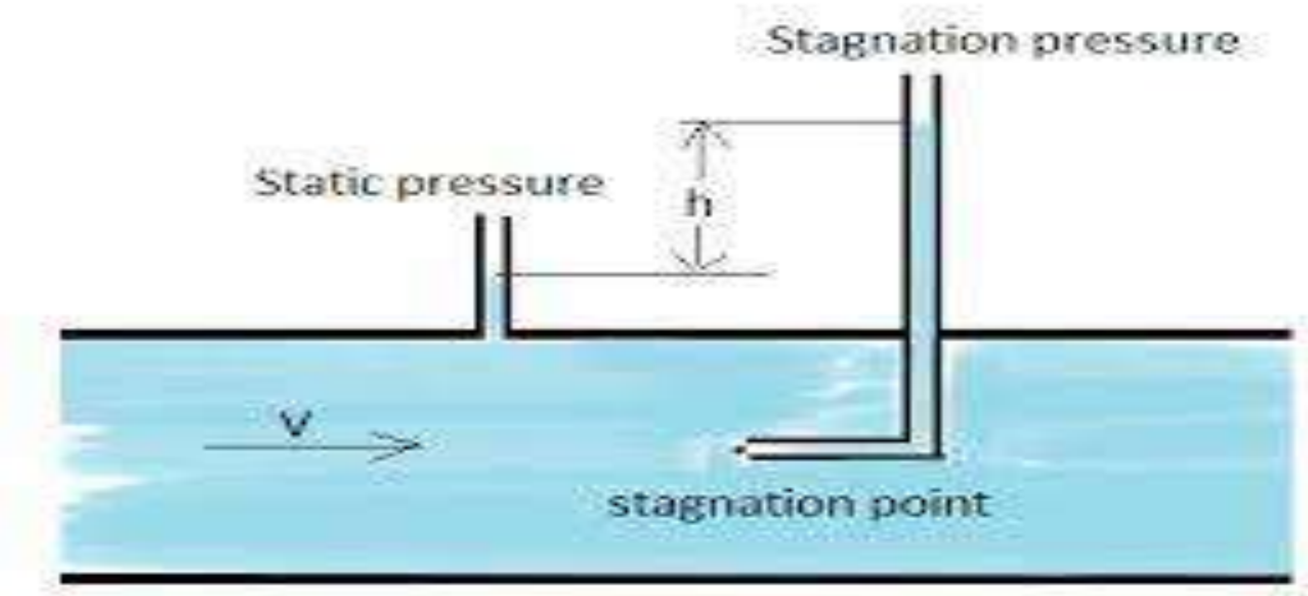
The principle of fonctionnement of PITOT tube as following:

- The Pitot tube consists of a tube with one opening facing directly into the fluid flow (called the ram opening) and a side port or other opening to measure the static pressure (called the static port).
- As the fluid flows over the tube, the air in the ram opening is brought to rest, causing an increase in pressure. The static port measures the surrounding fluid's pressure.
- The difference between the stagnation and static pressure gives the dynamic pressure. Using Bernoulli's equation, the flow velocity can be derived:

$$\boldsymbol{V} = \sqrt{\frac{\mathbf{2}.\left(\boldsymbol{P_{stagnation}} - \boldsymbol{P_{static}}\right)}{\boldsymbol{\rho}}}$$

Where :

- V: is the velocity of the fluid
- $P_{stagnation}$: is the stagnation pressure
- P_{static}: is the static pressure
- P : is the density of the fluid (air, in aviation applications)



II.5 Schema explicative of PITOT tube

Exercice 01

Water flows through a horizontal pipe with diameters 10 cm and 5 cm at sections 1 and 2, respectively. The velocity at section 1 is 2 m/s. Find:

1. The velocity at section 2.
2. The pressure difference between the two sections.

Solution

$A_1V_1=A_2V_2$

- $A_1=\pi\ (0.1/2)^2=7.85\times10^{-3}\ m^2$
- $A2=\pi\ (0.05/2)^2=1.96\times10^{-3}\ m^2$

Solving for V_2:

$V_2=\frac{A_1*V_1}{A_2}= 8$ m/s

Bernoulli equation (assuming horizontal flow, no height difference):

$$\boldsymbol{P_1+\frac{1}{2}\rho v_1{}^2=P_2+\frac{1}{2}\rho v_2{}^2}$$

$$\boldsymbol{P_1+\frac{1}{2}\rho v_1{}^2=\frac{1}{2}*(1000)*(2^2)=2000\ Pa}$$

$$\boldsymbol{P_2+\frac{1}{2}\rho v_2{}^2=\frac{1}{2}*(1000)*(82)=32.000\ Pa}$$

Pressure difference:

$$\boldsymbol{P_2-P_1=32.000-2000=30.000\ Pa=30\ KPa}$$

Chapter III

Dynamics of real liquids

III.1 Flow of fluid

Fluid flow refers to the movement of liquids (and gases) through pipes, channels, and other structures. The study of fluid dynamics involves understanding how fluids behave under different conditions and how they interact with the surfaces they flow over. The flow can be either laminar or turbulent, and each type of flow has distinct characteristics.

III.2 Types of Fluid Flow

The types of fluids are classified by calculating the Reynolds number, which is expressed as follows:

$$Re = \frac{\rho v D}{\mu}$$

Where :

- ρ = Density of the liquid
- v = Velocity
- D = Diameter of the pipe
- μ = Viscosity

a. **Laminar flow**: This occurs at low velocities where the fluid flows smoothly in layers with little or no mixing between them. The flow is orderly, and the fluid moves in parallel layers. Laminar flow generally occurs when $Re<2000$

b. **Turbulent flow:** At higher velocities, the flow becomes chaotic and irregular, with eddies and vortices forming in the fluid. This is known as turbulent flow. Turbulent Flow typically occurs when $Re>4000$

c. **Transition flow:** This occurs between laminar and turbulent flow, where the flow can fluctuate between the two, ie $2000<Re<4000$

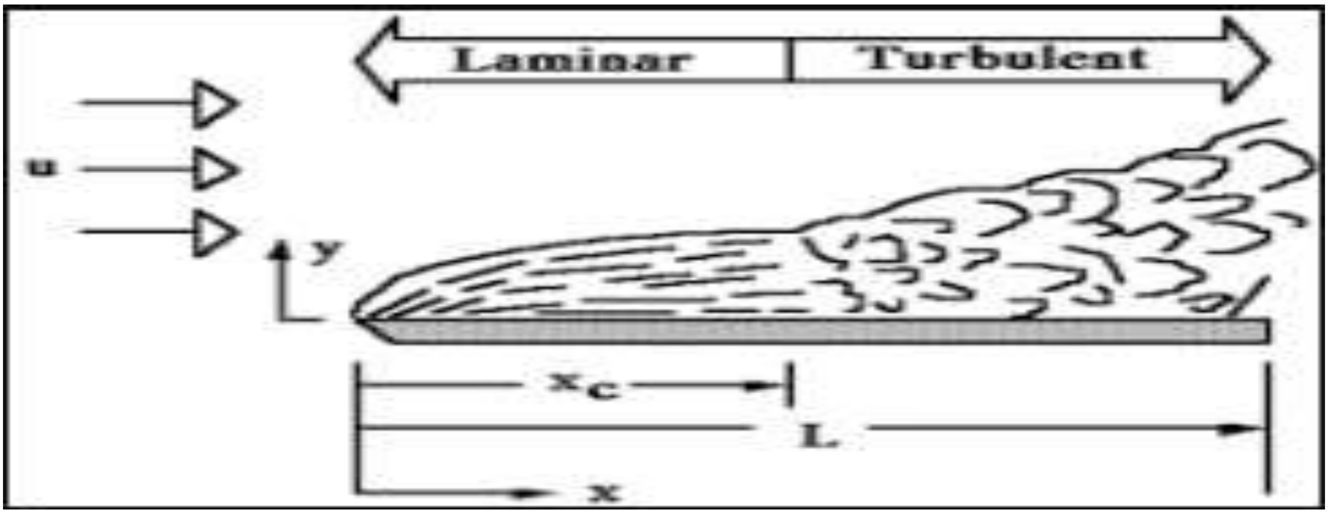


Fig III.1 Reynolds number

III.3 Flow in Pipes and Ducts

Flow in pipes and ducts refers to the movement of fluids (liquids or gases) through a closed or open system, typically designed to transport these fluids from one location to another. The study of flow in pipes and ducts involves understanding the forces, characteristics, and behaviors of the fluid, as well as how the system itself influences these factors.

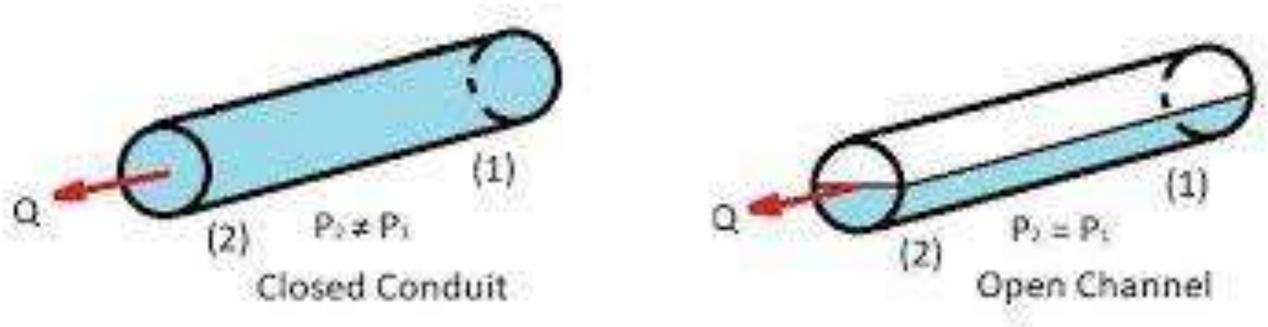


Fig III.2 Conduit and channel

III.4 Head Loss in Fluid Flow

Head loss in fluid flow refers to the loss of energy (or pressure) in a fluid as it flows through a pipe, duct, or other conduit. This loss occurs due to various factors, including friction, turbulence, changes in direction, and obstructions in the flow path.

III.4.1 Types of Head Loss

a. **Major Head Loss**: Caused by friction between the fluid and the inner surface of the pipe. Depends on factors such as:

- Flow velocity.
- Pipe diameter.
- Length of the pipe.
- Fluid properties (e.g., viscosity).
- Pipe roughness.

Governed by the Darcy-Weisbach Equation:

$$h_f = f.\frac{L}{D}.\frac{v^2}{g}$$

Where :

- h_f = friction head loss (meters or feet).
- f = Darcy friction factor (dimensionless).
- L = pipe length (meters or feet).
- D = pipe diameter (meters or feet).
- V = flow velocity (meters per second or feet per second).
- g = gravitational acceleration (9.81 m/s^2)

b. **Minor Head Loss**: Results from fittings, bends, valves, and other components in the system.

Calculated using the formula:

$$h_m = K.\frac{v^2}{2g}$$

Where:

- h_m = minor head loss (meters or feet).
- K = loss coefficient (dimensionless), depends on the fitting or obstruction.
- v and g are the same as above.

c. Total Head Loss: The total head loss in a system is the sum of major and minor losses:

$$h_{total}=h_f+h_m$$

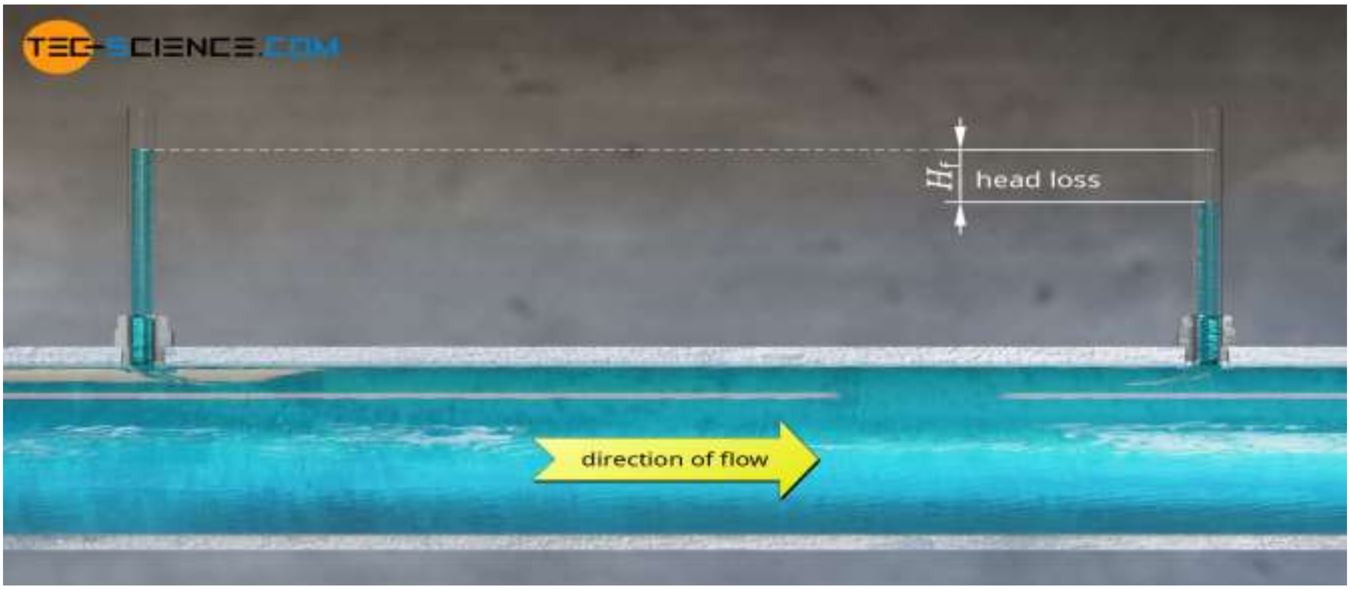


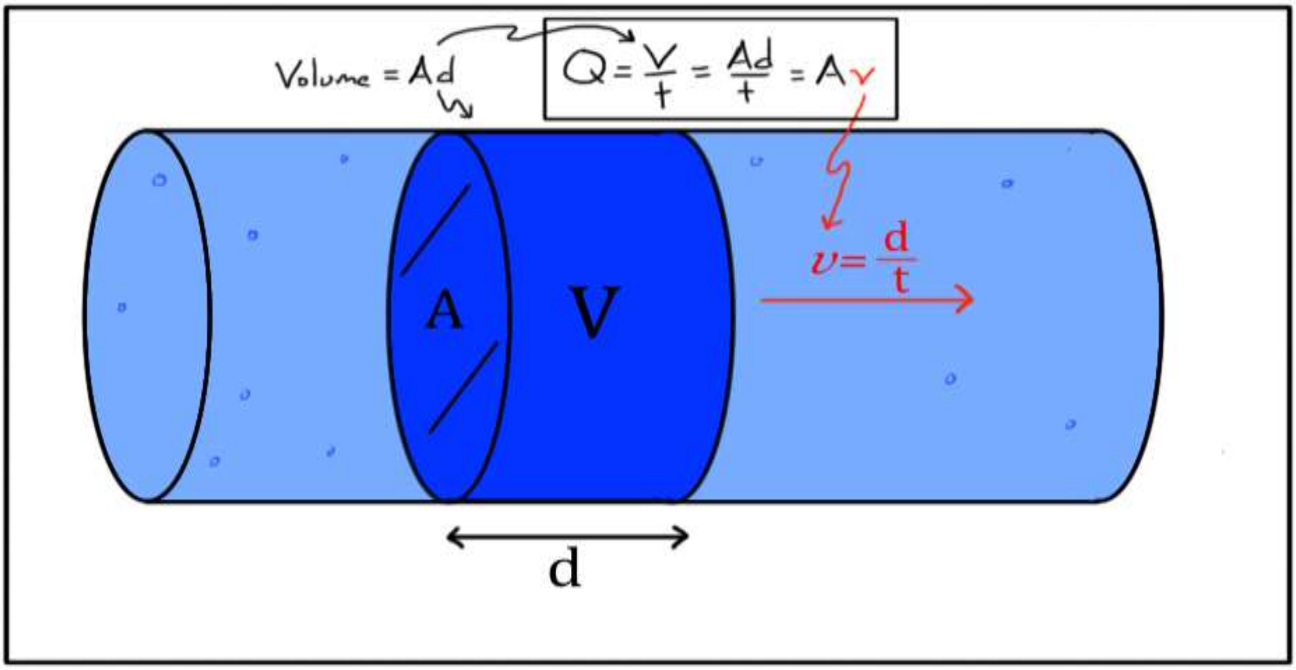
Fig III.3 Head loss

III.4.2 Factors Affecting Head Loss

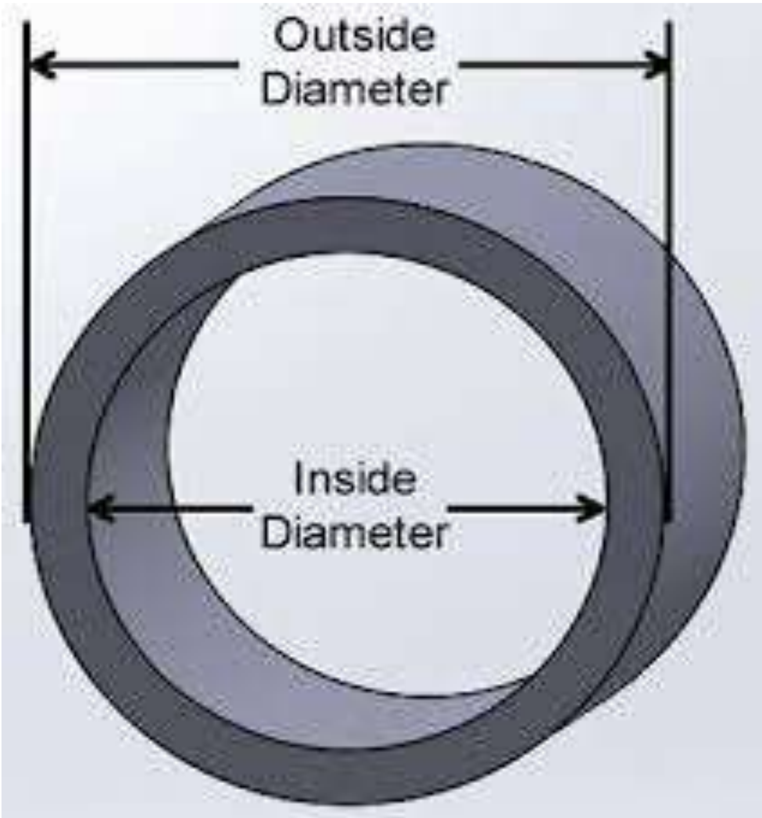
- **Pipe Material and Roughness**: Rougher materials increase friction, leading to higher head loss.
- **Flow Rate and Velocity**: Higher velocities lead to increased turbulence and head loss.
- **Pipe Diameter**: Smaller diameters result in higher head loss for the same flow rate.
- **Fittings and Valves**: Each component adds resistance and increases head loss.

Material	Hazen-williams C	Darcy-Weisbach ε	Manning's n
Cast Iron	130-140	0.85	0.012-0.015
Concrete or concrete lined	120-140	1.0-10	0.012-0.017
Galvanized Iron	120	0.5	0.015-0.017
Plastic	140-150	0.005	0.011-0.015
Steel	140-150	0.15	0.015-0.017
Vitrified Clay	110		0.013

(a)


Volume = Ad
Q = V/t = Ad/t = Av
A
V
v = d/t
d

(b)


Outside Diameter
Inside Diameter

(c)

(d)

Fig III.4 Factors influent on Head Loss

Exercice 01

Water flows through a 20-m-long pipe of 5 cm diameter with a velocity of 3 m/s. If the Darcy-Weisbach friction factor is 0.02, calculate the head loss due to friction.

Solution

$$\boldsymbol{h_f = f.\frac{L}{D}.\frac{v^2}{g}}$$

Given:

f=0.02, L=20, D=0.05, V=3 m/s, g=9.81 m/s²

$$\boldsymbol{h_f} = (0{,}02).\frac{(20)}{0.05}.\frac{(3)^2}{2(9.81)}$$

$$\boldsymbol{h_f} = \frac{(0{,}4)}{0.05}.\frac{9}{(19{,}62)} = 8*0{,}4588 = \mathbf{3{,}67\ m}$$

Chapter IV

Calculation of pressure losses using the MANNING equation

Chapter IV═══Calculation of pressure losses using the MANNING equation

IV.1 Flow Regimes laminar flow and turbulent Flow

In fluid mechanics, a flow regime describes how fluid particles move through a pipe. Identifying the regime is essential for calculating energy loss and hydraulic resistance. The state of the flow depends on the balance between velocity, pipe diameter, and viscosity:

IV.1.1 Laminar Flow (Orderly)

Occurs at low velocities. Fluid moves in smooth, parallel layers (laminae) with no mixing. Viscous forces dominate, resulting in a parabolic velocity profile.

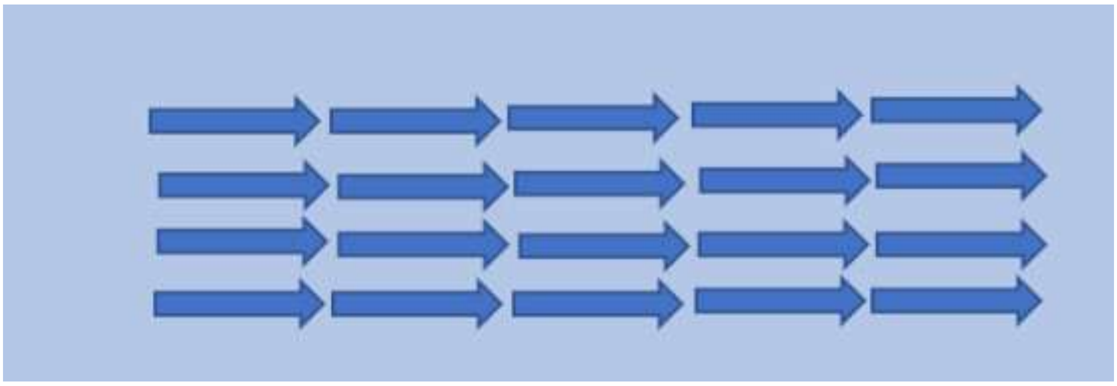


Fig. IV.1 Scheme of laminar water flow

IV.1.2Turbulent Flow (Chaotic)

Occurs at high velocities. Orderly layers break down into eddies and vortices. Inertial forces dominate, causing intense mixing, higher energy dissipation, and a flatter velocity profile.

Fig. IV.2 Scheme of Turbulent water flow

IV.1.3 The Transition from laminar flow to turbulent Flow

The Transition Zone occurs when the flow is no longer strictly laminar but has not yet become fully turbulent. It is a state of instability where the fluid's behavior is unpredictable.

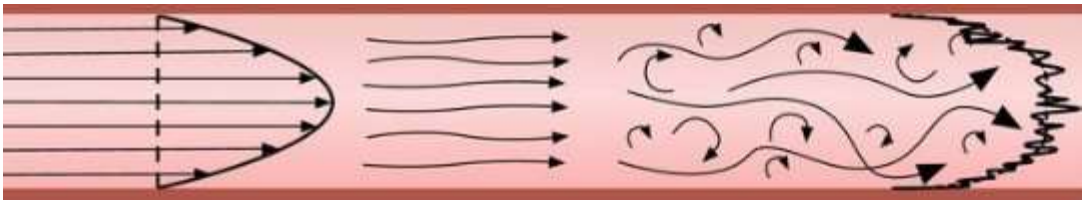


Fig. IV.3 Scheme of transition water flow

IV.2 Reynolds number

The Reynolds number is a dimensionless parameter used in fluid mechanics to determine the nature of flow inside pipes or channels (laminar, transitional, or turbulent). Which is expressed as follows:

$$Re = \frac{\rho v D}{\mu}$$

Where :

- ρ = Density of the liquid
- v = Velocity
- D = Diameter of the pipe
- μ = Viscosity

a. **Laminar flow**: This occurs at low velocities where the fluid flows smoothly in layers with little or no mixing between them. The flow is orderly, and the fluid moves in parallel layers. Laminar flow generally occurs when Re<2000

b. **Turbulent flow:** At higher velocities, the flow becomes chaotic and irregular, with eddies and vortices forming in the fluid. This is known as turbulent flow. Turbulent Flow typically occurs when Re>4000

- c. **Transition flow:** This occurs between laminar and turbulent flow, where the flow can fluctuate between the two, ie 2000<Re<4000

IV.3 Calculation of pressure losses using the Manning equation

The Manning equation is widely used to calculate pressure losses (or head losses) due to friction in open channels. It is typically used in hydraulics for open channel flow but can also approximate pressure losses in partially full pipes.

The Manning equation is as follows:

$$\boldsymbol{Q = \frac{1}{n} R^{\frac{2}{3}} S^{\frac{1}{2}}}$$

Where :

- Q: Flow rate (m3/s)
- n: Manning's roughness coefficient (dimensionless)
- A: Cross-sectional flow area (m^2)
- R: Hydraulic radius (m), R=$\frac{P(perimtre)}{A(area)}$
- S: Slope of the energy grade line (dimensionless) or channel slope

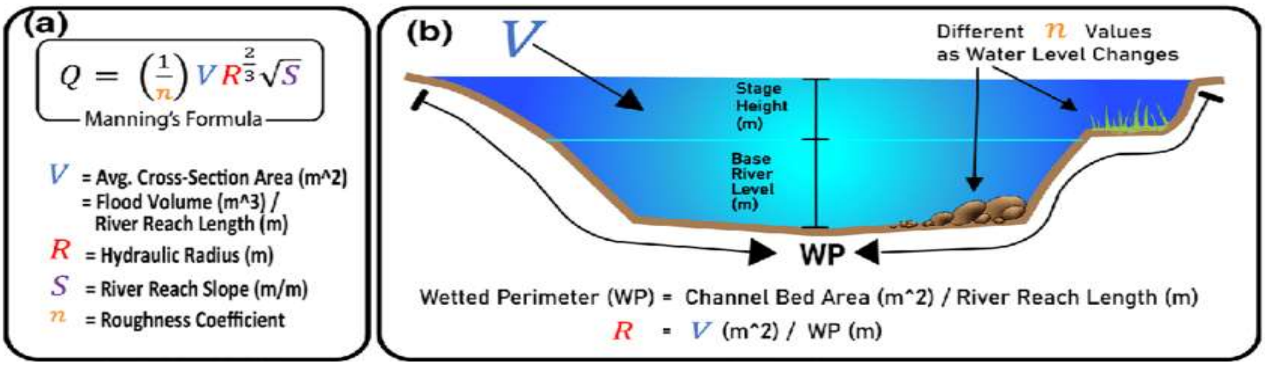
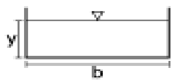
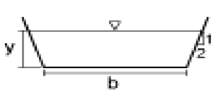
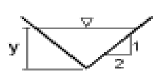
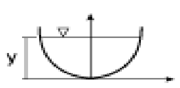


Fig IV.5 MANNING equation' description

Channel type	Area A	Wetted permiter P	Hydraulic radius R	Top width T	Hydraulic depth D
	by	b+2y	$\frac{by}{b+2y}$	b	y
	b+2y	$b+2y\sqrt{1+z^2}$	$\frac{(b+zy)y}{b+2y\sqrt{1+z^2}}$	b+2zy	$\frac{(b+zy)y}{b+2zy}$
	zy^2	$2y\sqrt{1+z^2}$	$\frac{zy}{2\sqrt{1+z^2}}$	2zy	$\frac{1}{2}y$
	$\frac{2}{3}Ty$	$T+\frac{8}{3}\frac{y^2}{T}$	$\frac{2T^2y}{3T^2+8y^2}$	$\frac{3}{2}\frac{A}{y}$	$\frac{2}{3}y$
	$\frac{1}{8}(\theta - \sin\theta)$	$\frac{1}{2}\theta d_0$	$\frac{1}{4}\left[1-\frac{\sin\theta}{\theta}\right]d_0$	$2\sqrt{y(d_0-y)}$	$\frac{1}{8}\left(\frac{\theta - \sin\theta}{\sin\frac{\theta}{2}}\right)d_0$

Tab IV.1 Hydraulic radius

Chapter IV═Calculation of pressure losses using the MANNING equation

Exercice 01

A rectangular channel has :

- Width b=3 m
- Water depth y=1 m
- Slope S=0.001
- Manning coefficient n=0.015

Find the discharge Q

Solution

$A=b\times y=3\times 1=3m^2$
$P=b+2y=3+2=5m^2$
$R_h=A/P=3/5=0.6m$
$Q= 66.67\times 3\times 0.711\times 0.0316$
$Q= 4.5$ m3/s

Exercice 02

A trapezoidal channel has:

- Bottom width b=4 m
- Side slope z=1 (1H:1V)
- Depth y=1.5 m
- n=0.02, S=0.0005

Find the mean velocity V

Solution

$A=y(b+zy) =1.5(4+1\times 1.5) =1.5\times 5.5=8.25m^2$

$P=b+2y\sqrt{1+z^2} = 4+3\sqrt{2}=8.24$

$R_h=8.25/8.24\approx 1$

$V=\frac{1}{n}\times R^{\frac{2}{3}}\times S^{\frac{1}{2}}$

$V=50\times 0.02236\approx 1.12$ m/s

Chapter V
Flow through the orifices

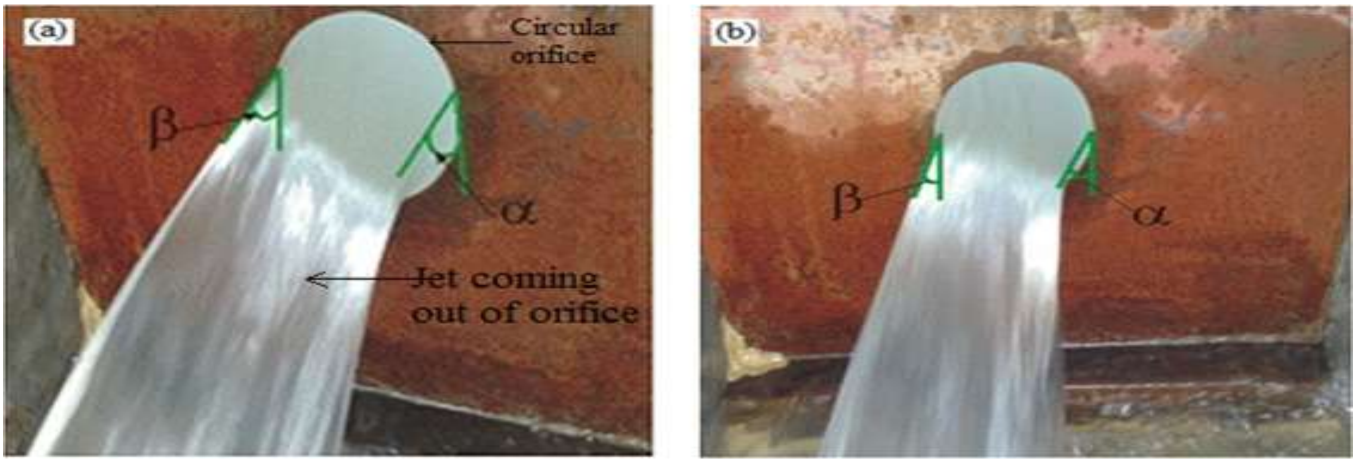
Introduction

Orifices are openings in the walls of a container or a conduit through which fluid can flow. These openings can be circular, rectangular, or of any other shape. The study of flow through orifices is essential in various fields, including civil engineering, fluid mechanics, and process engineering, as it helps in understanding discharge rates, energy losses, and flow characteristics.

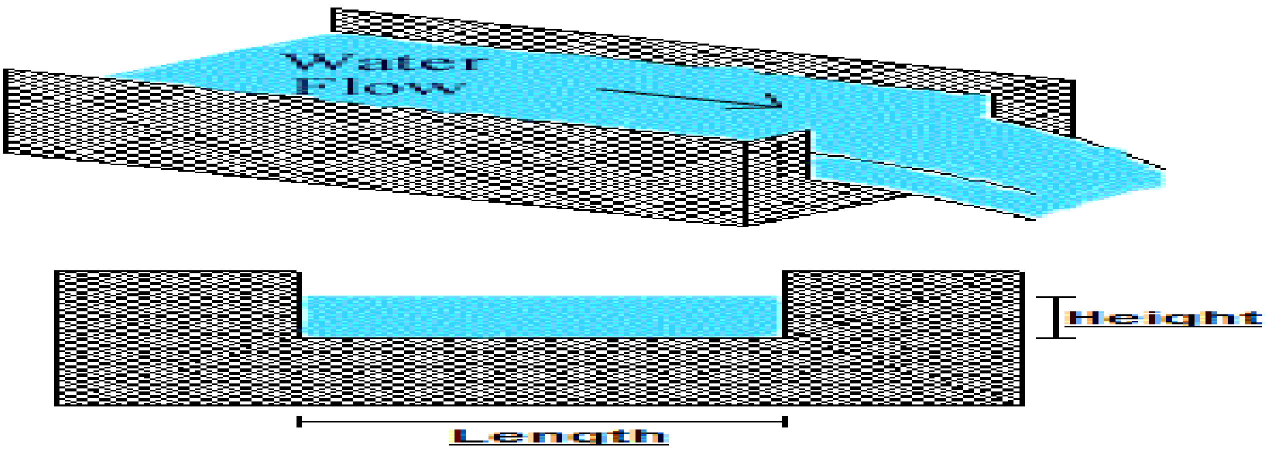
V.1 Types of Orifices

a. **Based on Shape :**

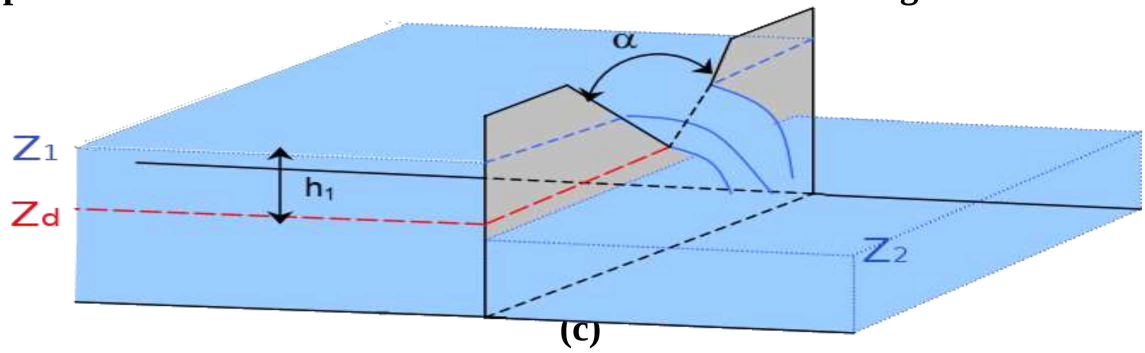
- Circular orifice
- Rectangular orifice
- Triangular orifice



(a)



(b)



(c)

Fig IV.1 Types of Orifices

b. **Based on Size :**

- Small orifice: Where the jet contraction and flow characteristics are clearly noticeable.
- Large orifice: Where the flow area cannot be considered small compared to the container dimensions.

c. **Based on Edge :**

- Sharp-edged orifice
- Bell-mouthed orifice

d. **Based on Flow Conditions :**

- Submerged orifice: When both sides of the orifice are submerged in the fluid.
- Free orifice: When one side of the orifice opens to the atmosphere.

V.2 Fundamental Principles

The flow through an orifice can be analyzed using basic fluid mechanics principles:

- **Continuity Equation:** The rate of flow is conserved, and the mass flow rate can be expressed as: where is the discharge, is the cross-sectional area of the orifice, and is the velocity of the fluid.
- **Bernoulli's Theorem:** Bernoulli's equation relates the velocity, pressure, and potential energy of the fluid along a streamline:
- **Torricelli's Law:** The velocity of the fluid jet exiting the orifice under the influence of gravity can be calculated as: where is the height of the fluid above the center of the orifice and is the acceleration due to gravity.
- **Coefficient of Discharge (Cd):** The discharge coefficient accounts for energy losses and is expressed as: where typically ranges between 0.6 and 0.7 for sharp-edged orifices.

V.3 Jet Contraction

When fluid exits an orifice, the jet tends to contract due to the convergence of streamlines. This phenomenon is known as **vena contracta**. The area of the contracted jet is smaller than the orifice area, and the contraction coefficient is defined as: where is the cross-sectional area of the vena contracta.

V.4 Applications

- **Measurement of Flow:** Orifices are widely used in flow meters for determining the discharge of fluids in pipelines.
- **Hydraulic Structures:** Used in dams, spillways, and reservoirs to regulate water flow.
- **Industrial Processes:** Utilized in various industrial processes for metering and controlling the flow of liquids and gases.

V.5 Experimental Setup

To study the flow through orifices, a typical experimental setup consists of:

- A tank with an adjustable water level.
- A sharp-edged orifice mounted on one side.
- A measuring device for jet velocity and discharge.

V.5 Factors Affecting Flow Through Orifices

- **Shape and Size of the Orifice:** Larger orifices allow higher discharge rates.
- **Head of Fluid:** Higher fluid levels increase the flow velocity and discharge.
- **Viscosity of Fluid:** Higher viscosity reduces flow rates due to increased resistance.
- **Edge Condition:** Sharp-edged orifices exhibit more pronounced vena contracta compared to rounded or bell-mouthed orifices.

Conclusion

Understanding the flow through orifices is essential for designing efficient hydraulic systems and measuring devices. By applying principles like Bernoulli's theorem, Torricelli's law, and continuity equations, engineers can accurately predict discharge rates and optimize fluid flow in various applications.

Exercice 01

A tank contains water with a constant head of H=2 m above a small sharp-edged orifice.

- Area of orifice $A=5\times10^{-4}$ m2
- Coefficient of discharge Cd=0.62

Find the discharge Q

Solution

$Q=C_dA\sqrt{2gh}$

$\sqrt{2gh}=\sqrt{2}\times 9.81\times 2=6.26$

$Q=0.62\times5\times10^{-4}\times6.26$

$Q=0.00194\ m^3/s$

Exercice 02

A cylindrical tank has :

- Cross-sectional area At=1 m^2
- Orifice area $A=2\times10^{-4}\ m^2$
- Initial water height H_1=2 m
- Final height H_2=0.5
- Cd=0.6

Find the time required to lower the water level.

Solution

$t=\frac{2A_t}{C_dA\sqrt{2g}}(\sqrt{H1\_\sqrt{H2}})$

$\sqrt{2g}$=4.43

$\sqrt{H1}$=1.414

$\sqrt{H2}$=0.707

t=CdA2g2At(H1−H2)

$t=\frac{2\times1}{0.6\times2\times10^{-4}\times4.43}(1.414-0.707)$

t= 2660s≈44.3minutes

Chapter VI

Free surface flow and spillways

VI.1 Free surface flow

Free surface flow is a type of fluid motion in which the upper surface of the fluid is exposed to the atmosphere and is not confined by a solid boundary. It is governed by gravity and pressure forces, making it significantly different from pressurized flow. Examples of free surface flow include rivers, canals, and spillways.

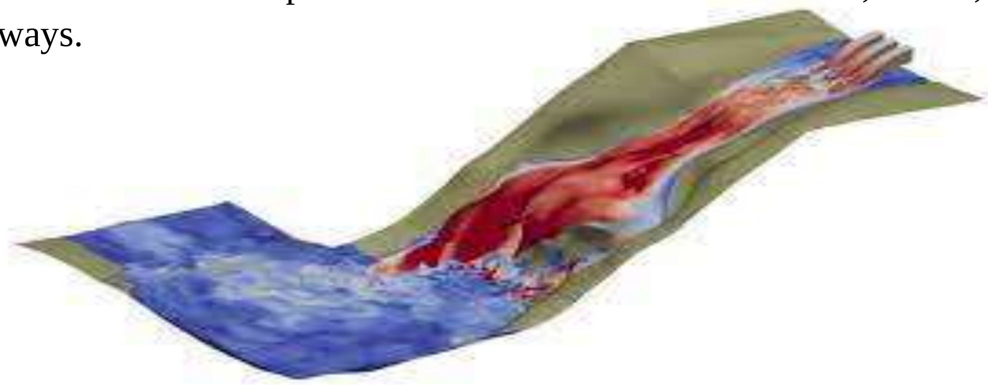


Fig V.1 Free surface flow

VI.1.1 Characteristics of Free Surface Flow

- The pressure at the free surface is equal to atmospheric pressure.
- Flow depth varies along the length of the channel.
- Gravity plays a dominant role in flow behavior.
- Can be classified into uniform and non-uniform flow.

VI.1.2 Governing Equations

- Continuity Equation
- Energy Equation (Bernoulli's Principle for Open Channel Flow)
- Momentum Equation

VI.2 Spillways

Spillways are hydraulic structures designed to safely pass excess water from a reservoir to a downstream area, preventing dam overtopping and potential failure.

VI.2.1 Functions of Spillways

- **Flood control**: Prevents water from exceeding dam capacity.
- **Reservoir regulation**: Maintains optimal water levels.
- **Erosion prevention**: Protects downstream areas from uncontrolled water flow.
- **Energy dissipation**: Reduces the destructive force of water.

VI.2.1 Types of Spillways

a. Free Overflow Spillway

- Allows water to flow over a crest freely.
- Common in concrete dams.

(a)

b. Ogee Spillway

- Curved profile that enhances flow efficiency.
- Often used in gravity and arch dams.

(b)

c. Chute Spillway

- A steep channel that conveys water downstream at high speed.
- Used when there is ample space.

(c)

d. Side Channel Spillway

- Water flows into a side channel parallel to the dam before being discharged.
- Useful in narrow valleys.

(d)

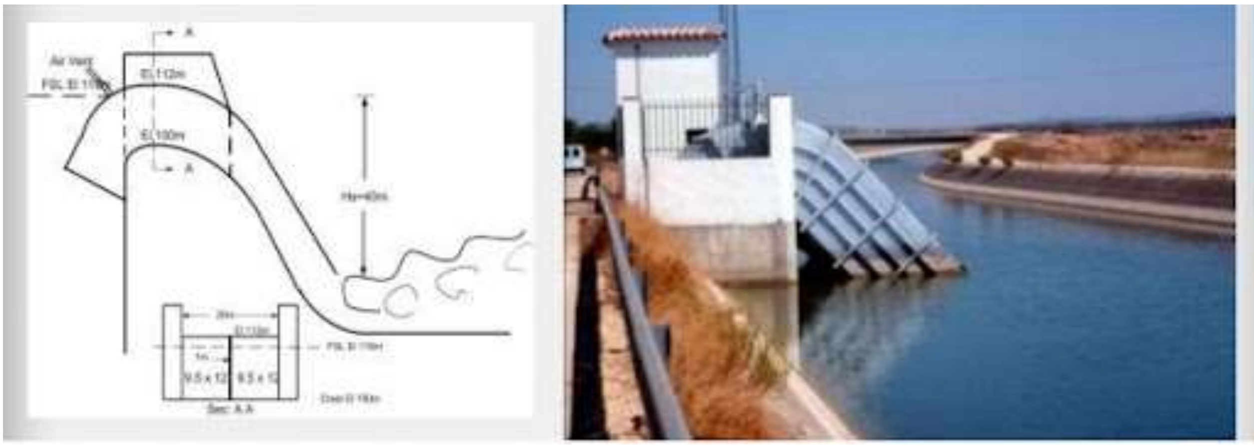
e. Shaft (Morning Glory) Spillway

- A vertical shaft that funnels water downward like a drain.
- Used where space is limited.

(e)

f. Siphon Spillway

- Uses siphon action to regulate outflow automatically.
- Starts discharging only when the water level reaches a certain height.



(f)

g. Labyrinth Spillway

- A zigzag crest design increases the discharge capacity.
- Useful in dams with space constraints.

(g)

h. Fuse Plug Spillway

- A temporary embankment that erodes when water reaches a critical level.
- Used as an emergency overflow mechanism.

(h)

Fig V.2: Types of Spillway a,b,c,d,e,f,gand h.

VI.3 Froude number (F_r)

The Froude number (Fr) is a dimensionless number used in fluid dynamics and open-channel flow to compare inertial forces to gravitational forces. It helps determine the flow regime and characterizes the influence of gravity on the motion of a fluid. The Froude number is given by the equation:

$$F_r = \frac{V}{\sqrt{gL}}$$

where :

- V= characteristic velocity of the fluid (m/s),
- g= acceleration due to gravity (m/s²),
- L= characteristic length (m) (such as water depth in open-channel flow).

VI.4 Flow Regimes

- **Fr < 1 (Subcritical Flow)**: Gravity dominates, and waves can propagate upstream.

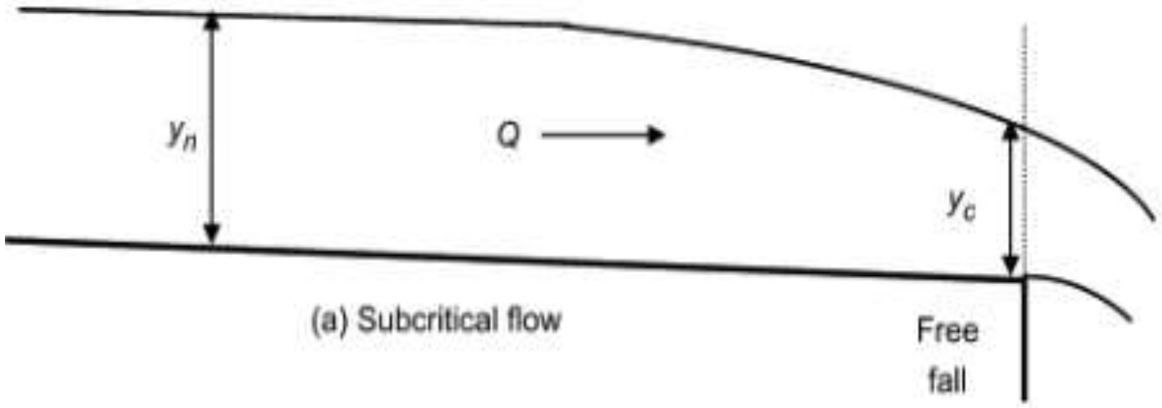


Fig V.3 Subcritical Flow

- **Fr = 1 (Critical Flow)**: The flow velocity is equal to the wave propagation speed.

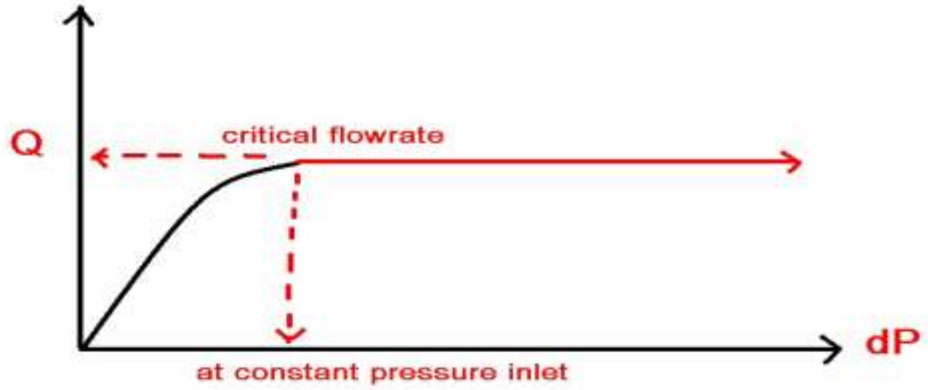


Fig V.4 Critical Flow

- **Fr > 1 (Supercritical Flow)**: Inertia dominates, and disturbances cannot propagate upstream.

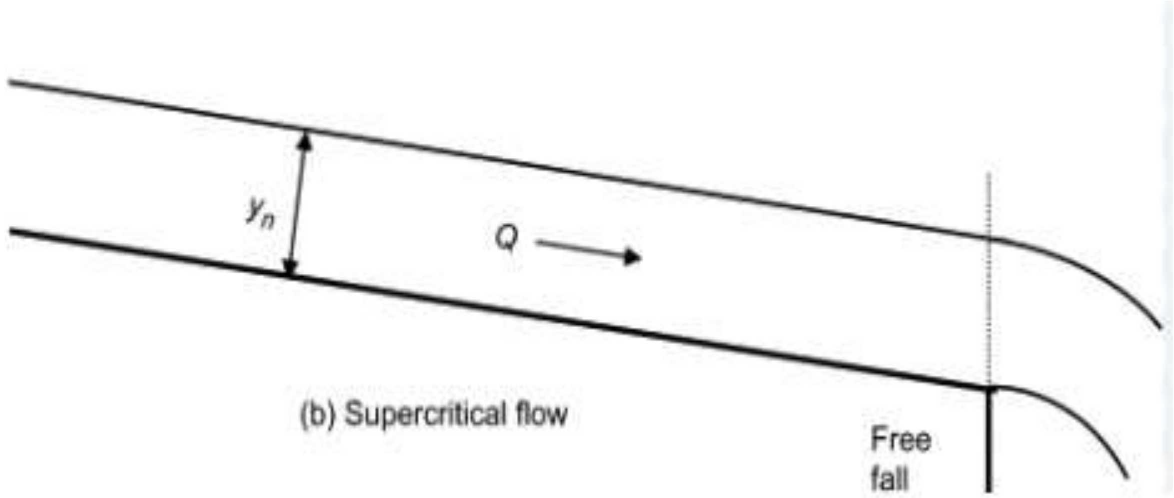


Fig V.5 Supercritical Flow

VI.4 Discharge Formula for Spillways

The general equation for the discharge over a spillway is:

$Q=C_d*L*H^n$

where:

- Q = discharge (m³/s),
- C_d = discharge coefficient (dimensionless),
- L = effective length of the spillway crest (m),
- H = total head over the crest (m), including velocity head,
- n = exponent depending on the spillway shape (usually n=1.5n)

VI.4.1 Discharge Formula for Ogee Spillways

The ogee spillway is the most commonly used type, found in gravity and arch dams. Its shape follows the natural flow profile of water. The discharge equation for an ogee spillway is:

$Q=C_d*L*H^{1.5}$

where:

- C = discharge coefficient, which depends on the upstream head and crest shape,

- L = crest length of the spillway (m),
- H = total head over the crest (m).

Correction for Submergence: When the downstream tailwater level is high, reducing effective discharge, a submergence correction factor (K_s) is introduced:

$$Q = C_d * L * H^{1.5} * k_s$$

where : K_s is determined experimentally.

VI.4.2 Discharge Formula for Broad-Crested Spillways

A broad-crested spillway has a flat crest that allows flow to develop critical depth. The discharge formula is:

$$Q = C_d * L * H^{1.5}$$

where the discharge coefficient C is often given as:

$$C = \frac{2}{3}\sqrt{2g}$$

which simplifies to:

$$C \approx 1.705$$

for SI units ($g = 9.81\ m/s^2 g$)

Exercice 01

Water flows over a rectangular sharp-crested weir:

- Width b=2 m
- Head over the crest H=0.5 m
- Coefficient Cd=0.62

Find the discharge Q

Solution

$Q=C_d \times b \times \sqrt{2g} \times H^{1.5}$

$Q \approx 0.667 \times 0.62 \times 2 \times 4.43 \times 0.353$

$Q \approx 1.30 m^3/s$

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22. Khazari, A. (2025). *Application of Potential Flow Theory to Free Surface Problems* (Master's thesis). University of M'sila, Algeria. ([Référentiel Université MSILA][6])

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24. Delestre, O., Lucas, C., Ksinant, P.-A., et al. (2011). *SWASHES: A Compilation of Shallow Water Analytic Solutions for Hydraulic and Environmental Studies*. arXiv. ([arXiv][7])

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