CHAPTER 1. INTRODUCTION TO FLUID MECHANICS

1. Field of application of Fluid Mechanics
2. Brief history of Fluid Mechanics
3. Fluid as a continuum. Fluid definition
4. Dimensions and Units
5. Physical properties of fluids
6. Acting forces on a mass of fluid

1. Field of application of Fluid Mechanics

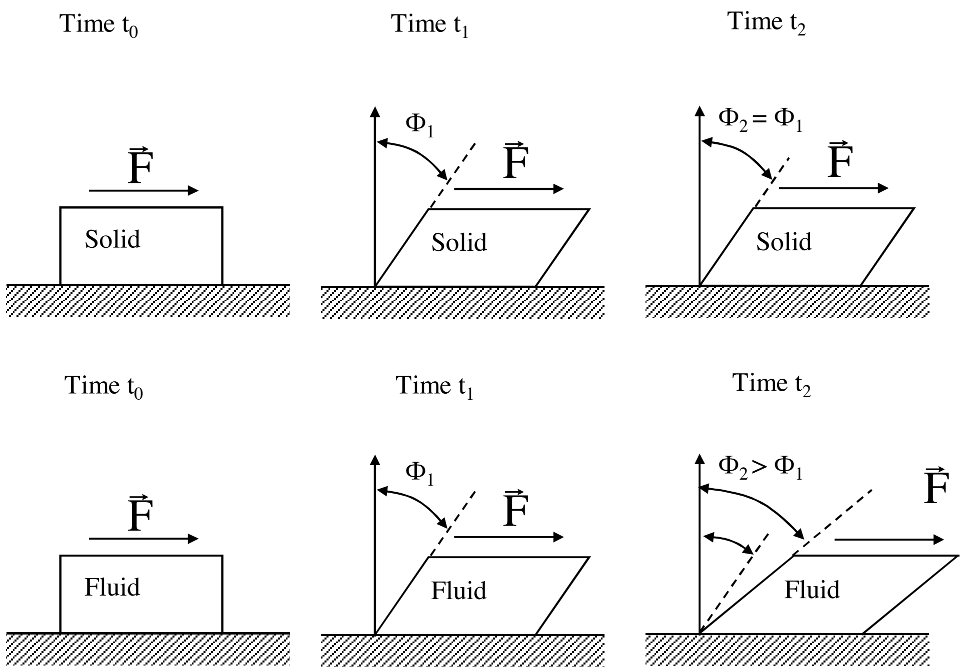
- ✓ "Fluid Mechanics" , definition
- ✓ Physical phenomena in nature
- ✓ Engineering
- ✓ Other aspects in common life
- ✓ Main branches:
  - Statics
  - Kinematics
  - Dynamics

3. Fluid as a continuum. Definition of fluid

- ✓ Definition of fluid
- ✓ Comparison to solid*
- ✓ States of matter (liquid and gas)
- ✓ Modelling the fluid as a continuum*

3. Fluid as a continuum. Definition of fluid

Comparison to solid

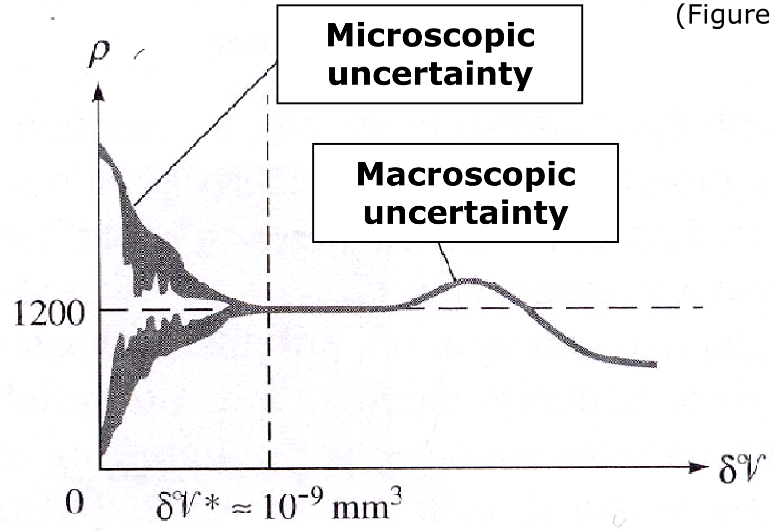


- Deformation of solid: invariable with time

- Deformation of fluid: continuous with time

3. Fluid as a continuum. Definition of fluid

The model of the continuum



(Figure from White)

- Differential volume range for analysing the fluid as a continuum

5. Physical properties of fluids

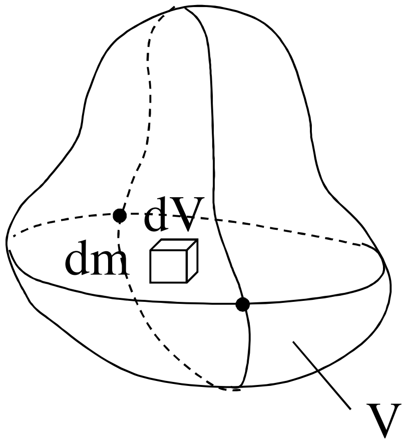
1. Density and specific weight
2. Pressure
3. Ideal gas equation of state
4. Process equation
5. Compressibility
6. Viscosity
7. Vapour pressure. Saturation pressure. Cavitation

5.1. Density and specific weight

- ✓ Density (definition, dimensions, units) *
- ✓ Specific weight (definition, dimensions, units)
- ✓ Relative density and specific weight (definition)

5.1. Density and specific weight

- **Density (definition)**



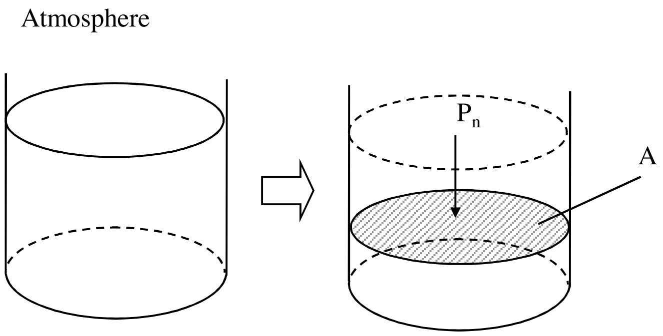
$$\rho = \frac{m}{V} \Rightarrow \rho = \frac{dm}{dV}$$

5.2. Pressure

- ✓ Definition (2 forms)*
- ✓ Dimensions. Units
- ✓ Pressure level with different references*

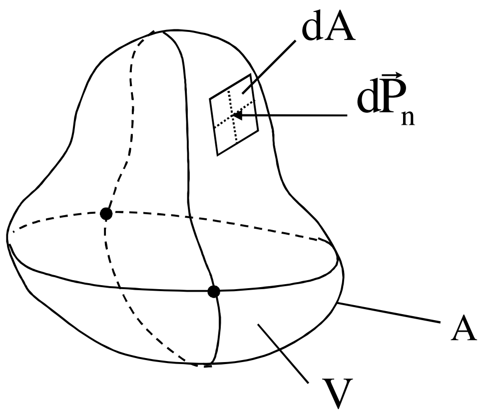
5.2. Pressure

- **Definition (2 forms)**



$$p = \frac{P_n}{A}$$

Figure 1.2. Pressure in plane A



$$p = \frac{dP_n}{dA}$$

Figure 1.3. General concept of pressure

5.2. Pressure

- **Pressure references**

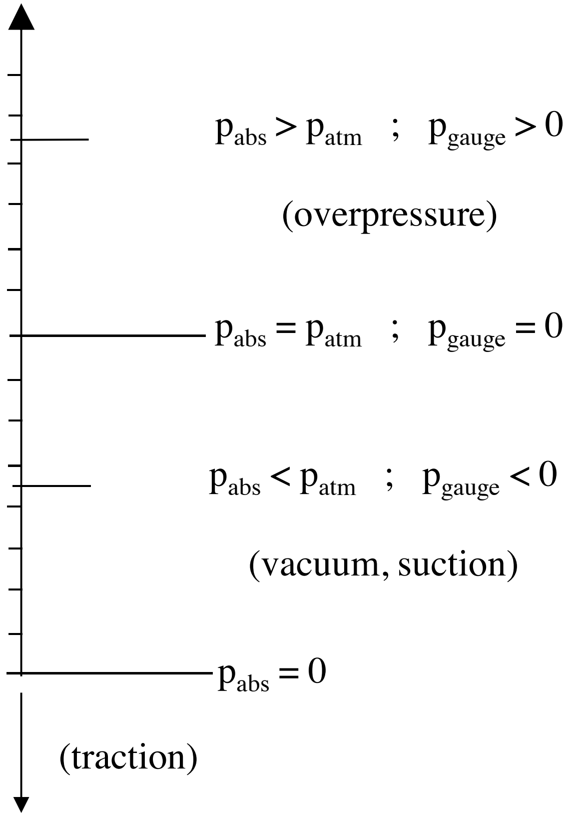


Figura 1.4. Pressure references

Absolute pressure (p_{abs}): pressure relative to absolute zero, absolute vacuum, p = 0 Pa.

Gauge pressure (p_{gauge}): pressure relative to the local atmospheric pressure.

$$p_{abs} = p_{gauge} + p_{atm}$$

5.3. Ideal gas equation of state

- **Definition of the equation of state**

- **Ideal gas equation of state. Forms of the equation**

$$\boxed{pV = nRT}$$ R = 8,314 J / K mol

$$\boxed{p = \gamma R'T} \qquad R' = \left[\frac{R}{(A \cdot 10^{-3})g}\right]$$ (m/K)

$$\boxed{p = \rho R''T} \qquad R'' = \left[\frac{R}{(A \cdot 10^{-3})}\right]$$ (J/K·kg)

5.4. Process equation

✓ Gases: $p = C\rho^k$

- Isothermal process: $k=1$
- Isentropic process: $k=c_p/c_v$
- Isobaric process: $k=0$
- Isochoric process: $k\rightarrow\infty$

5.5. Compressibility and elasticity

✓ Parameters:

- Bulk modulus E_V:

$$E_V = -\frac{dp}{(dV/V)} \qquad E_V = \frac{dp}{(d\rho/\rho)}$$

- Compressibility α:

$$\alpha = -\frac{(dV/V)}{dp} \qquad \alpha = \frac{(d\rho/\rho)}{dp}$$

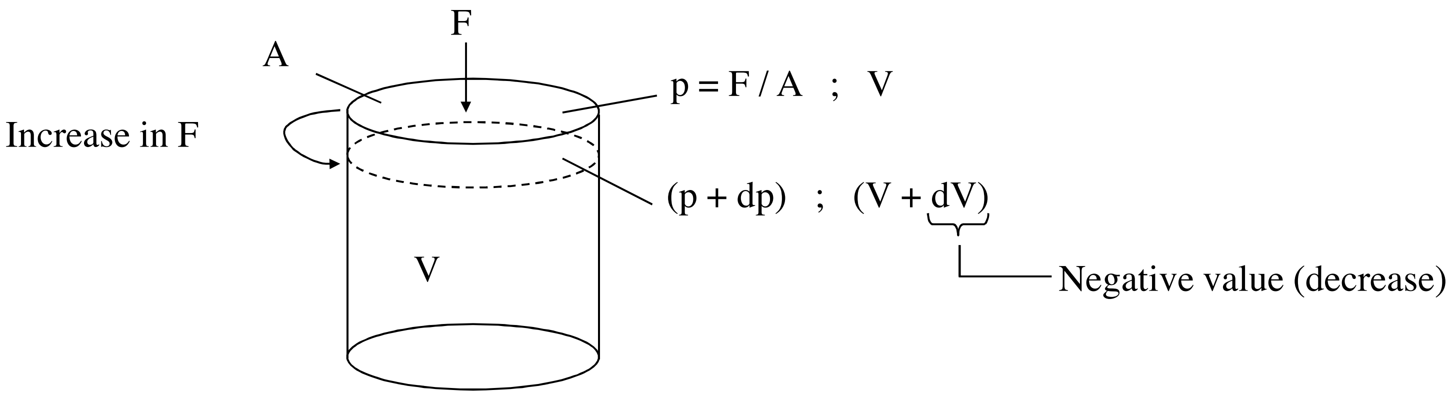


Figure 1.5. Decrease in volume by an increase in pressure

5.5. Compressibility and elasticity

TablE 1.2 Bulk modulus values for some liquids

Liquid	**E (GPa)**
Water	2,07
Ethanol	1,21
Benzene	1,03
Carbon tetrachloride	1,10
Mercury	26,20

✓ Ideal gases: $E_V = kp$

✓ Newton´s formula for speed of sound (Newton – Laplace equation): $c^2 = \frac{dp}{d\rho} = \frac{E_V}{\rho}$

5.6. Viscosity

1. Viscosity: Definition*
2. Newton´s law of viscosity*
3. Rheological diagram*
4. Dependence on pressure and temperature*

5.6. Viscosity: dynamic and kinematic

✓ Definition

✓ Physical phenomena causing viscosity:

- Intermolecular cohesion:

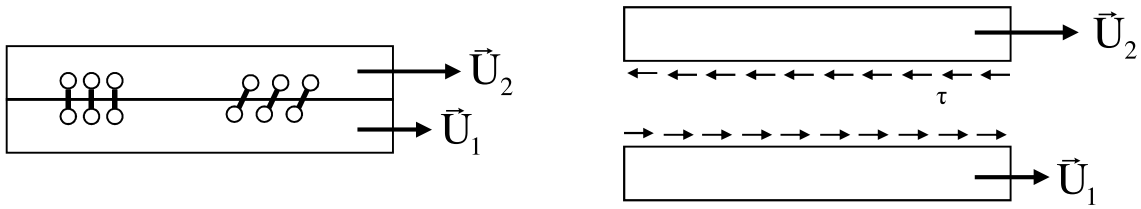


Figure 1.6. Influence of intermolecular cohesion on viscosity

- Collisional exchange of momentum:

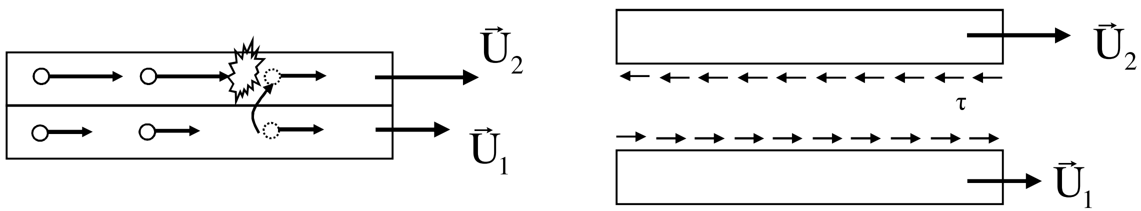


Figure 1.7. Influence of momentum exchange on viscosity

5.6. Newton´s law of viscosity

• **Velocity profile, shear stress, deformation:**

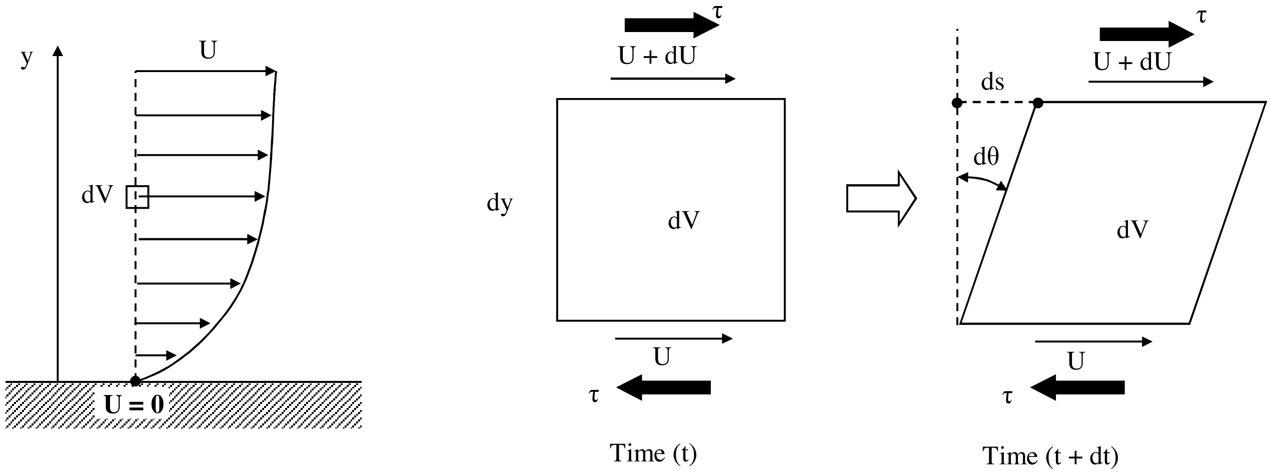


Figure 1.8 Deformation of a fluid element

• **Deformation rate:** $$\frac{d\theta}{dt} = \frac{dU}{dy}$$

•**Newton´s law of viscosity:** $$\tau = \mu \frac{d\theta}{dt} = \mu \frac{dU}{dy}$$

• **Inviscid flow hypothesis (ideal fluid)**

5.6. Rheological diagram

- ✓ Newtonian fluid
- ✓ Pseudo plastic fluid
- ✓ Dilatant fluid
- ✓ Ideal plastic
- ✓ Ideal fluid
- ✓ Elastic solid

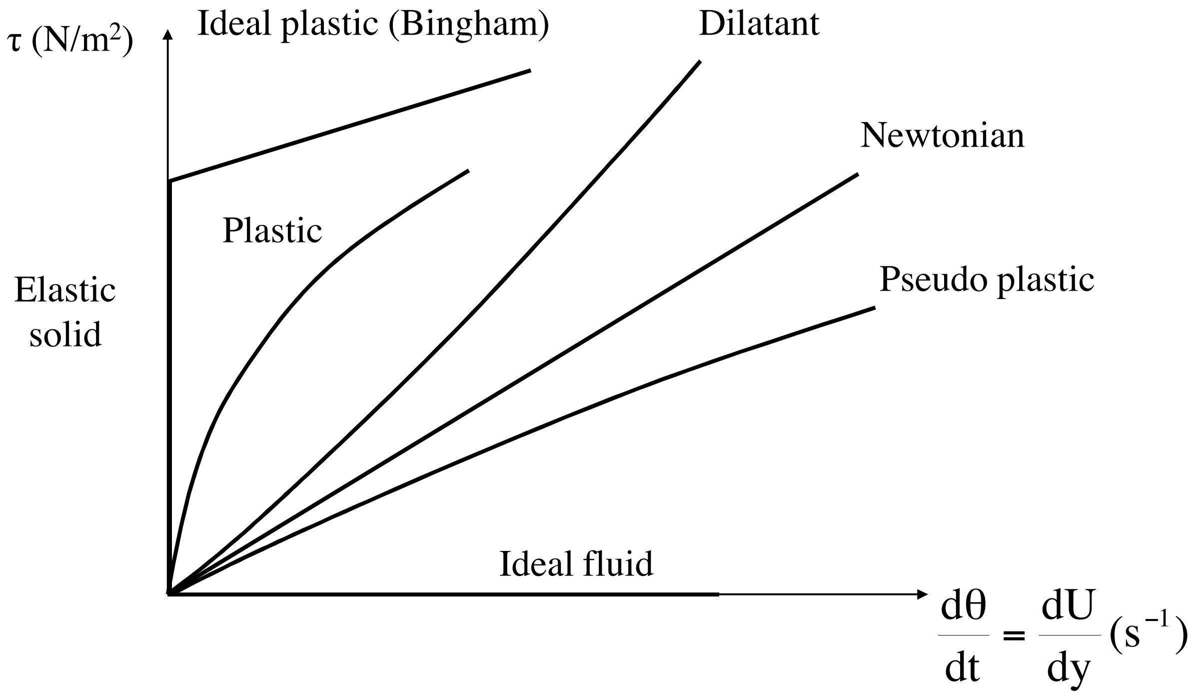


Figure 1.10 Rheological diagram

5.6. Dependence on pressure and temperature

✓ **Dynamic viscosity**

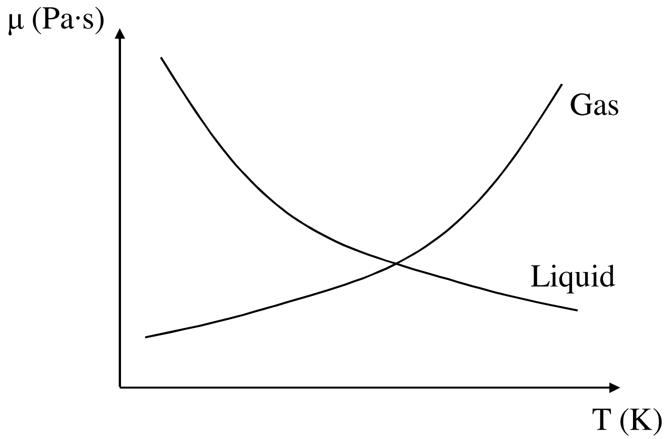


Figure 1.12 Dynamic viscosity of gases and liquids as a function of temperature

✓ **Kinematic viscosity:** $\nu = \dfrac{\mu}{\rho}$

- Effect of pressure

- Liquid: $\left\{\begin{array}{l} \mu \approx \text{Cst} \\ \rho \approx \text{Cst (incompressible)} \end{array}\right\} \nu \approx \text{Cte}$

- Gas: $\left\{\begin{array}{l} \mu \approx \text{Cst} \quad (\Delta p \text{ not excessive}) \\ \rho \uparrow \quad \text{as} \quad p\uparrow \end{array}\right\} \nu\downarrow \quad \text{decreases when} \quad p\uparrow$

- Effect of temperature

$\left\{\begin{array}{l} \mu\downarrow \quad \text{as} \quad T\uparrow \\ \rho \approx \text{Cst (incompressible)} \end{array}\right\} \nu\downarrow \quad \text{decreases when} \quad T\uparrow$

$\left\{\begin{array}{l} \mu\uparrow \quad \text{as} \quad T\uparrow \\ \rho\downarrow \quad \text{as} \quad T\uparrow \; (p = \gamma R' T) \end{array}\right\} \nu\uparrow\uparrow \quad \text{increases when} \quad T\uparrow$

5.6. Dependence on pressure and temperature

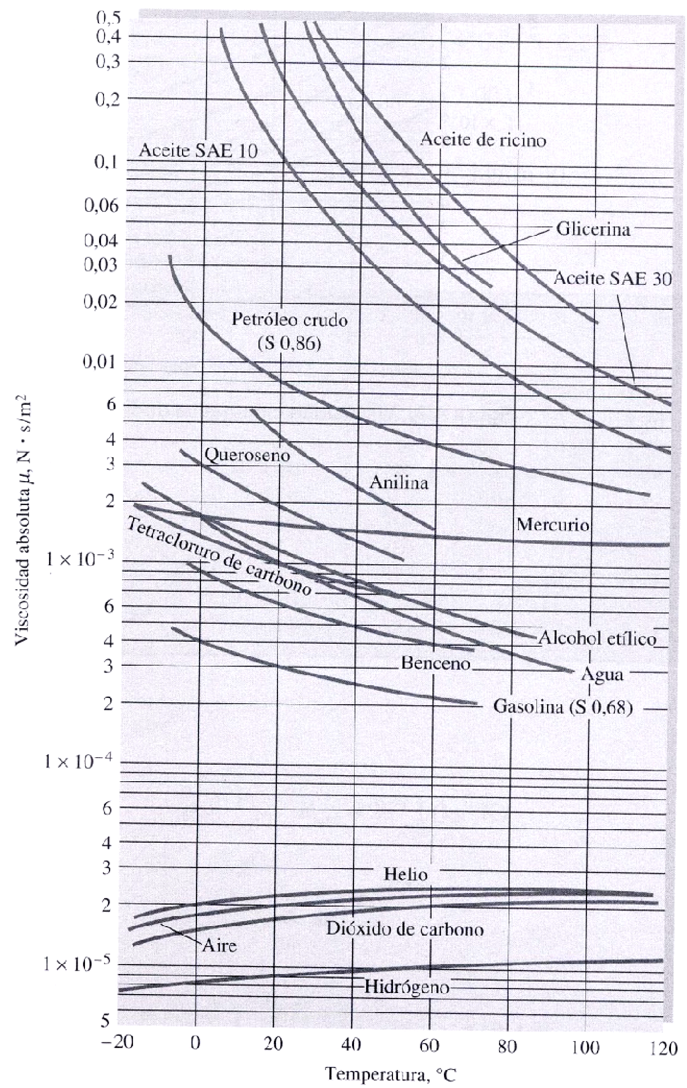


Figura A.1. Viscosidad absoluta de fluidos comunes a 1 atm.

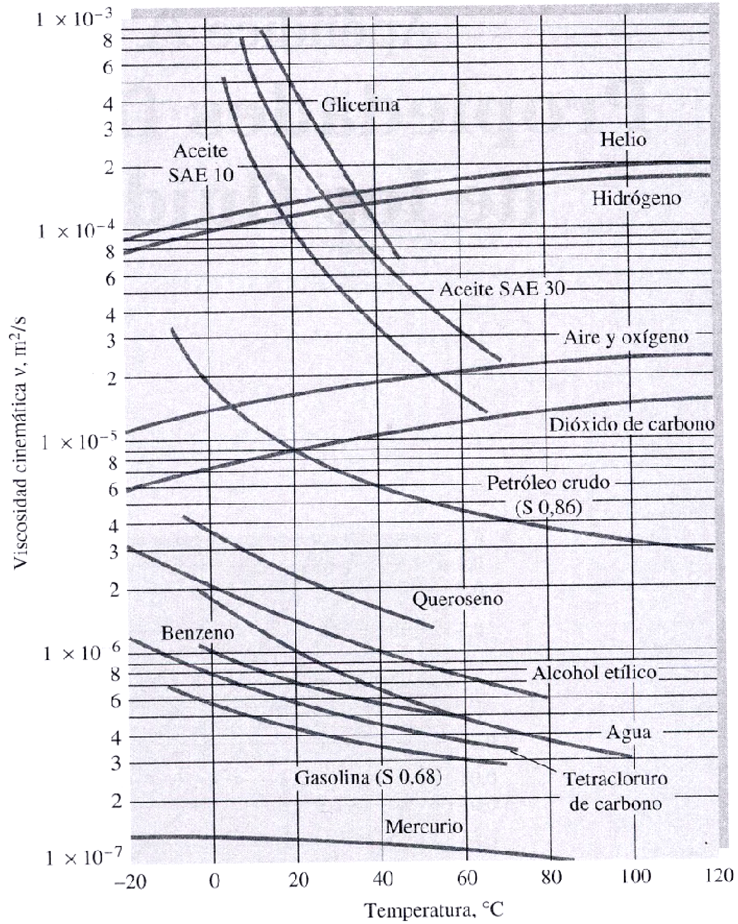


Figura A.2. Viscosidad cinemática de fluidos comunes a 1 atm.

(Figures from F. M. White)

5.8. Vapour pressure and saturation pressure

✓ Reviewing the concepts of vapour pressure and saturation pressure

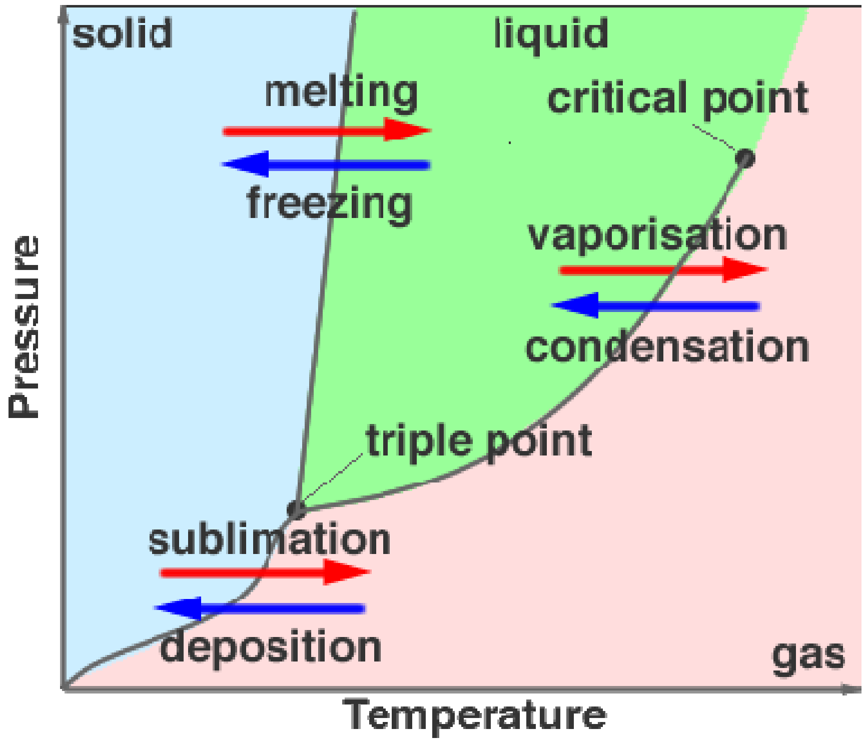


Figure. Phase diagram

5.8. Vapour pressure and saturation pressure

✓ Cavitation:

- Gaseous and vaporous
- Cavitation number:

$$Ca = \frac{p - p_{sat}}{\frac{1}{2}\rho U^2}$$

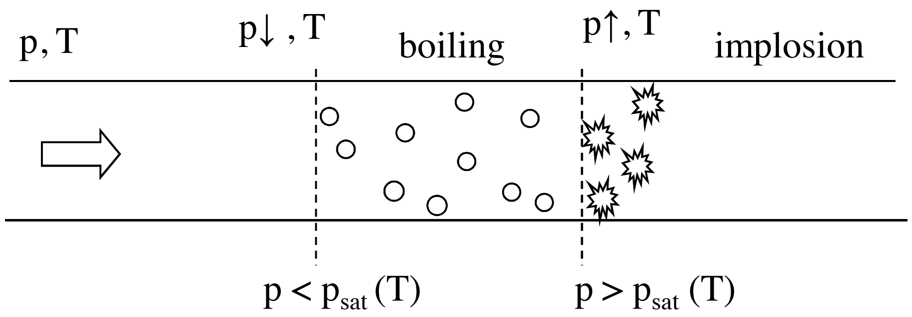


Figure 1.22. “Scheme of the cavitation process”

5.8. Vapour pressure and saturation pressure

Figure 1.23. Consequence of cavitation damage on an impeller of a pump

Figure 1.24. Consequence of cavitation damage on an impeller of a pump. Detail

Figure 1.25. Consequence of cavitation damage on an impeller of a pump. Profile view

Figure 1.26. Consequence of cavitation damage on an impeller of a pump. Profile view

6. Acting forces on a mass of fluid

✓ **Intrinsic forces:**

- **Normal component:** $p = \frac{dP_n}{dA}$
- **Shearing component:** $\tau = \frac{dP_t}{dA}$

$$\vec{P} = \iint_A \vec{T} dA$$

✓ **External field forces:**

$$\vec{G} = \iiint_V \rho \vec{F} dV$$

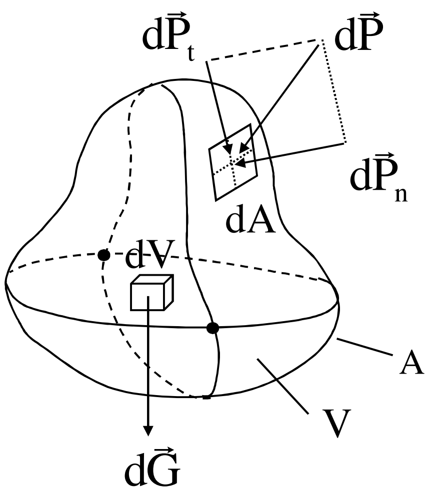


Figure 1.27 Actuating forces on a mass of fluid