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Fluid Mechanics

Class Notes

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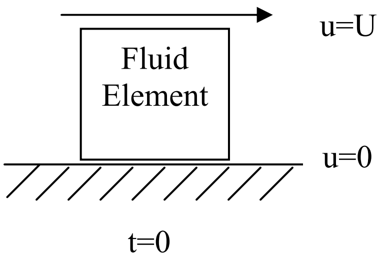
Chapter 1: Introduction and basic concepts

1.1 Fluids and the no-slip condition

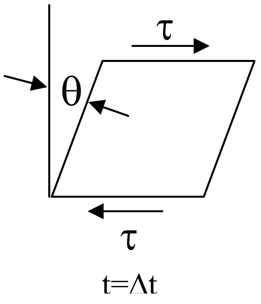
Fluid mechanics is the science of fluids either at rest (fluid statics) or in motion (fluid dynamics) and their effects on boundaries such as solid surfaces or interfaces with other fluids.

Definition of a fluid: a substance that deforms continuously when subjected to a shear stress

Consider a fluid between two parallel plates, which is subjected to a shear stress due to the impulsive motion of the upper plate



No slip condition: no relative motion between fluid and boundary, i.e., fluid in contact with lower plate is stationary, whereas fluid in contact with upper plate moves at speed U.



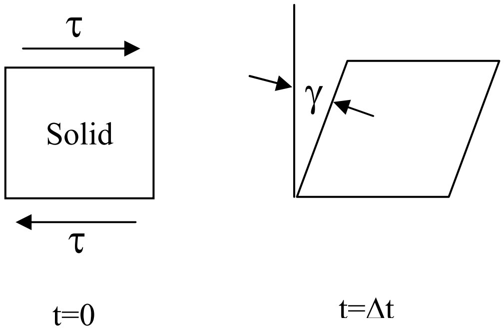
Fluid deforms, i.e., undergoes strain θ due to shear stress τ

Newtonian fluid: $\tau \propto \dot{\theta}$ = rate of strain

$\tau = \mu \dot{\theta}$

μ = coefficient of viscosity

Such behavior is different from solids, which resist shear by static deformation (up to elastic limit of material)



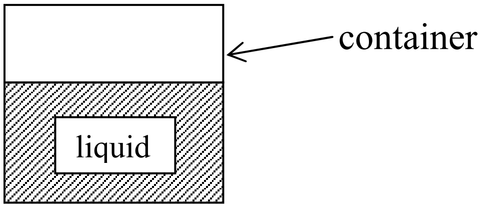
Elastic solid: $\tau \propto \gamma$ = strain

$\tau = G \gamma$

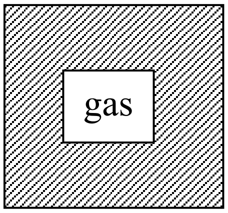
G = shear modulus

<u>Both liquids and gases behave as fluids</u>

Liquids:
Closely spaced molecules with large intermolecular forces
Retain volume and take shape of container

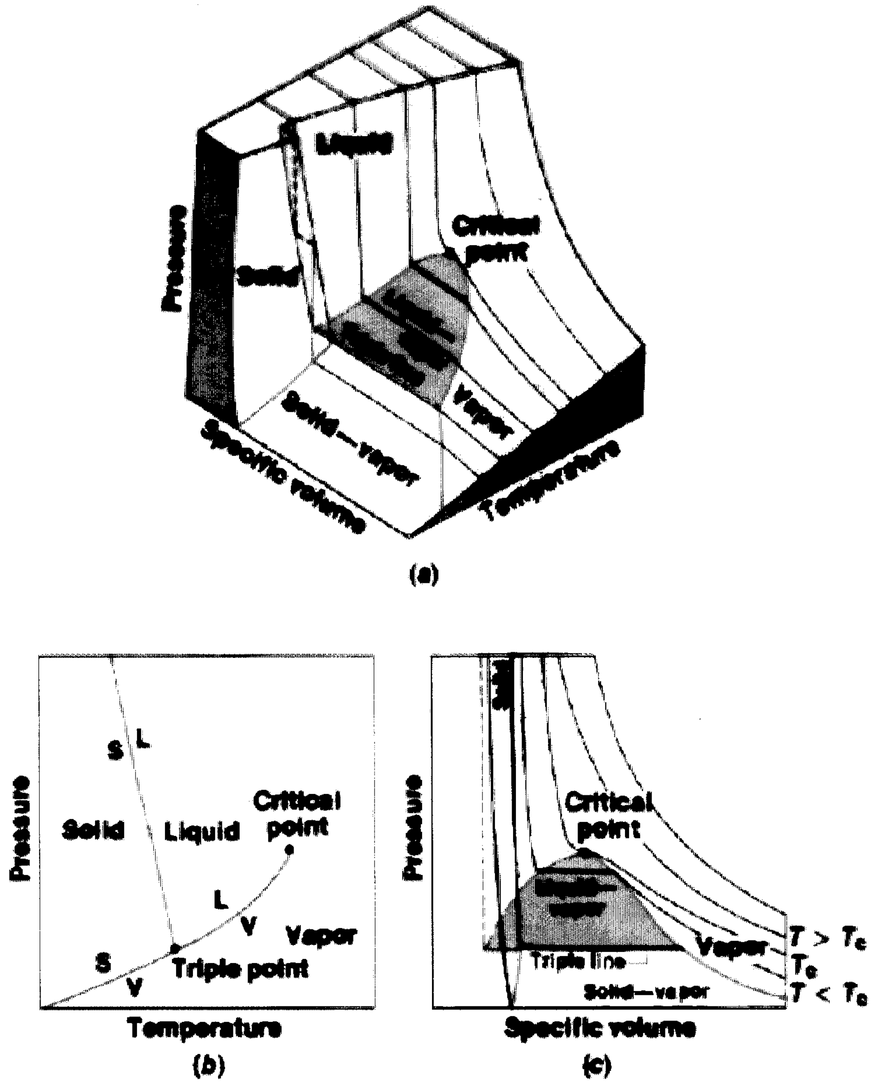


Gases:
Widely spaced molecules with small intermolecular forces
Take volume and shape of container



Recall p-v-T diagram from thermodynamics:
single phase, two phase, triple point (point at which solid, liquid, and vapor are all in equilibrium), critical point (maximum pressure at which liquid and vapor are both in equilibrium).

Liquids, gases, and two-phase liquid-vapor behave as fluids.



1.2 Fluid Mechanics and Flow Classification

Hydrodynamics: flow of fluids for which density is constant such as liquids and low-speed gases. If in addition fluid properties are constant, temperature and heat transfer effects are uncoupled such that they can be treated separately.

Examples: hydraulics, low-speed aerodynamics, ship hydrodynamics, liquid and low-speed gas pipe systems

Gas Dynamics: flow of fluids for which density is variable such as high-speed gases. Temperature and heat transfer effects are coupled and must be treated concurrently.

Examples: high-speed aerodynamics, gas turbines, high-speed gas pipe systems, upper atmosphere

1.3 Continuum Hypothesis

In this course, the assumption is made that the fluid behaves as a continuum, i.e., the number of molecules within the smallest region of interest (a point) are sufficient that all fluid properties are point functions (single valued at a point).

For example:
Consider definition of density ρ of a fluid

$$\rho(\underline{x},t)=\frac{\lim}{\delta V \to \delta V^{*}}\frac{\delta M}{\delta V}$$

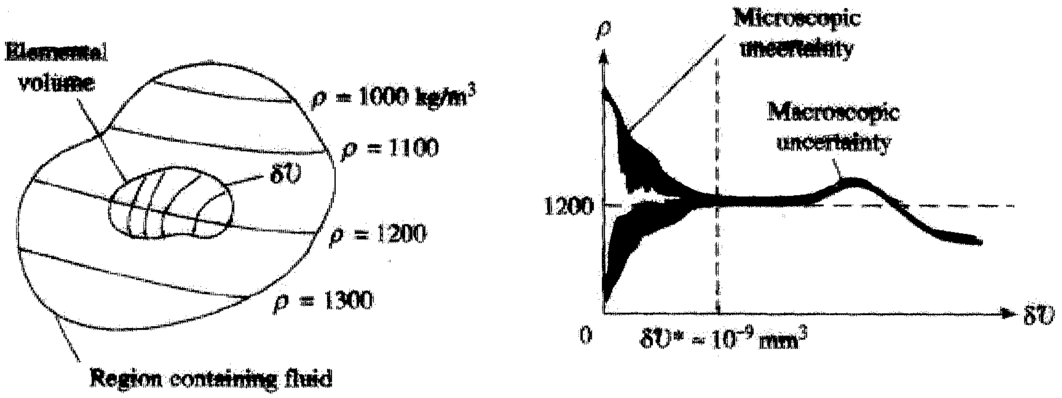
$\underline{x}$ = position vector $= x\mathbf{i}+y\mathbf{j}+z\mathbf{k}$
t = time

δV^* = limiting volume below which molecular variations may be important and above which macroscopic variations may be important

$\delta V^* \approx 10^{-9}$ mm^3 for all liquids and for gases at atmospheric pressure

10^{-9} mm^3 air (at standard conditions, 20°C and 1 atm) contains $3\text{x}10^7$ molecules such that $\delta M/\delta V$ = constant = ρ

Note that typical "smallest" measurement volumes are about $10^{-3} - 10^0$ mm^3 >> δV^* and that the "scale" of macroscopic variations are very problem dependent



(a) (b)

[2] One atmosphere equals 2116 lbf/ft^2 = 101,300 Pa.

Exception: rarefied gas flow

1.4 A brief history of fluid mechanics

1.5 System and control volume

1.6 Mathematical modeling of engineering problem

1.7 Problem-solving technique and accuracy, precision, and significant digits

See text and as per following discussion