Fluid Mechanics CEE 3311

LECTURE 1

Properties of fluids

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Introduction

Mechanics

Mechanics is the science that describes and predicts the conditions of **rest** or **motion** of bodies under the action of forces.

Mechanics is divided into 3 categories:

(a) Mechanics of rigid bodies

(b) Mechanics of deformable bodies

(c) Fluid Mechanics or Mechanics of fluids is the science dealing with the action of forces on fluids.

Introduction

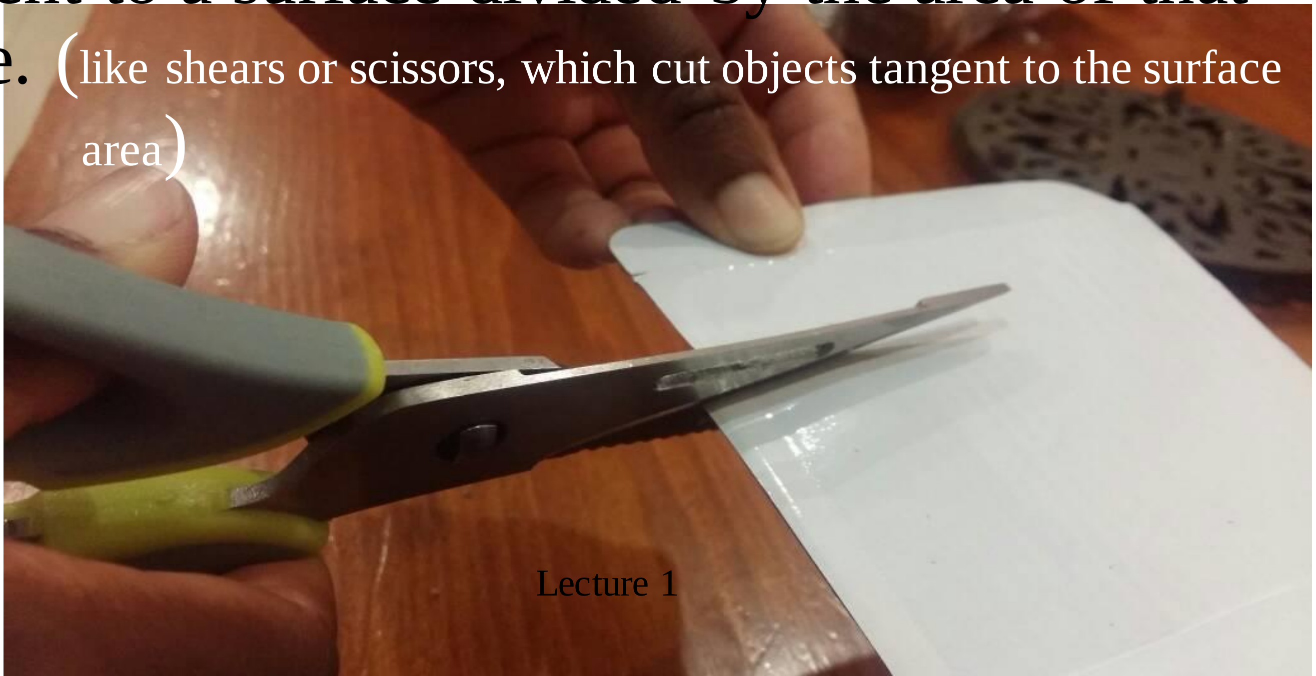
- A fluid: gas or liquid
  - Gas (compressible fluid)
  - Liquid (incompressible fluid-not always)

  In medicine: fluid usually used to mean liquid e.g. intravenous fluid
  Corona virus transported in fluids through coughing/sneezing and moves through another fluid, air

- A liquid is a state of matter in which the molecules are relatively free to change their positions with respect to each other but restricted by cohesive forces so as to maintain a relatively fixed volume
- A gas is a state of matter in which the molecules are practically unrestricted by cohesive forces. A gas has neither definite shape nor volume

Introduction

- In contrast to a solid, a fluid is a substance that deforms continuously when subjected to a shear stress, no matter how small that shear stress may be
- Shear stress is defined as the force component tangent to a surface divided by the area of that force. (like shears or scissors, which cut objects tangent to the surface area)



Introduction

- Principles of FM same as in solid particle motion:
  - Conservation of mass
  - Conservation of energy
  - Conservation of momentum

- The subject of FM will be divided into 3 broad categories:
  - Fluid statics (fluid at rest)
  - Classical fluid dynamics (mathematical approach of fluids in motion)
  - Fluid dynamics (real fluids in motion)

Introduction

- Actual fluid relationship is made up of a collection of discrete molecules.
- In most engineering applications, however, we are interested in the average conditions of velocity, pressure, temperature, density, etc.
- Therefore, a fluid will be regarded as a continuum: a continuous distribution of matter with no empty space (instead of the actual conglomeration of separate molecules). In FM, this assumption is normally justifiable because the no. of molecules is so enormous and the distance between them is very small.

Properties of fluids

Properties involving the mass or weight of the fluid

$$(a)\ Density \quad \rho = \frac{mass}{volume}$$

Water = 1000kg/m^3
Air = 1.23kg/m^3

$$(b)\ specific\ Volume \quad \forall = \frac{1}{\rho}$$

$$(c)\ Specific\ weight \quad \gamma = \rho g$$
$$= weight\ per\ unit\ volume.$$

$$(d)\ Specific\ gravity = \frac{weight\ of\ a\ fluid}{weight\ of\ an\ equal\ volume\ of\ water} = \frac{\gamma\ fluid}{\gamma\ water}$$

Properties of fluids

Viscosity

Definitions

1. Viscosity is that property of a fluid by virtue of which it offers resistance to shear stress
2. Viscosity of a fluid is a measure of its resistance to shear or angular deformation
3. Viscosity can be thought of as the internal stickiness of a fluid. (Proverbs 5:3 "… smoother than oil")

Note: stress is pressure like pressure of exams, stress due to social problems

e.g., motor oil has high viscosity and resistance to shear , whereas gasoline (petrol) has low viscosity. More energy required to pump a more viscous fluid

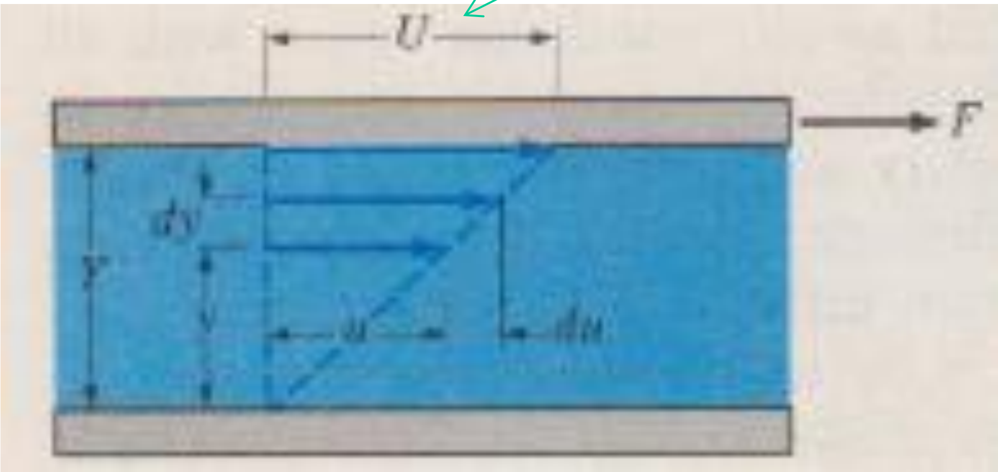
(A fluid is a substance which continuously deforms when subjected to a small amount of shear)

Properties of fluids

Viscosity

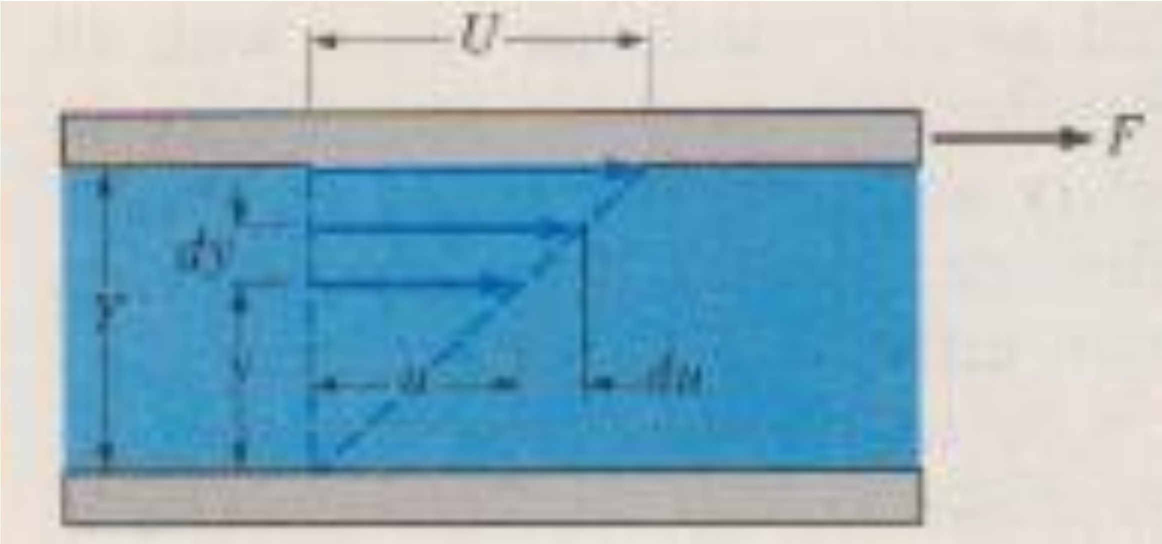
Consider the classic case of two parallel plates, sufficiently large that edge conditions may be neglected, placed a small distance Y apart, the space being filled with the fluid.

The lower surface is assumed to be stationary, while the upper one is moved parallel to it with a velocity U by the application of a force F corresponding to some area **A *of the moving plate***.



Properties of fluids

Viscosity

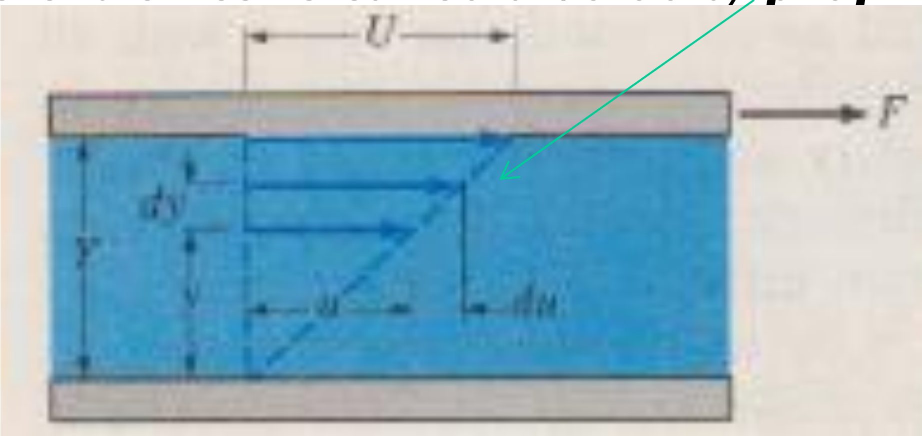


The lower plate is fixed, and a force F is applied to the upper plate, which exerts a shear stress on any substance between the plates

Properties of fluids

Viscosity

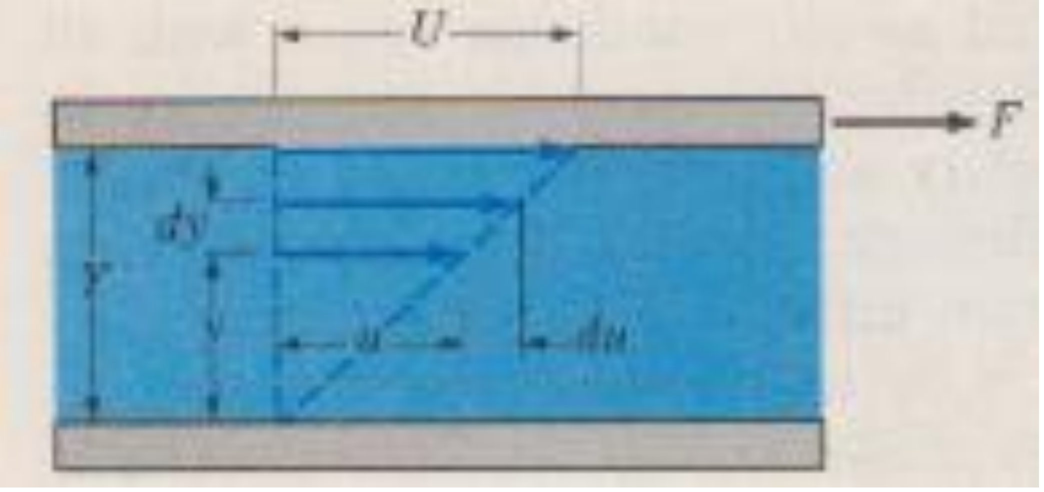
- At boundaries, particles of fluid adhere to the walls, and so their velocities are zero relative to the wall. This so-called ***no-slip condition*** occurs **with all *viscous* fluids**. Thus the fluid *velocities* must be ***zero*** where in contact with the plate at the lower boundary and ***U at the upper boundary***.
- The form of the *velocity variation* with distance between these two extremes is called a ***velocity profile***.



Properties of fluids

Viscosity

- If the separation distance *Y is not too great*, the velocity *U is not too high*, and if there is no net flow of fluid through the space, the velocity profile will be linear, as shown in Fig. The behaviour is much as if the fluid were composed of a *series of thin layers*, each of which slips a little relative to the next.



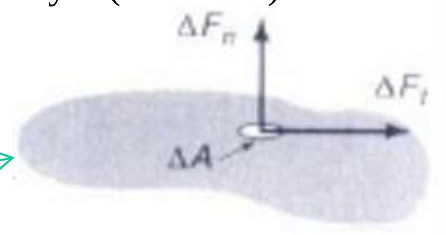
Properties of fluids

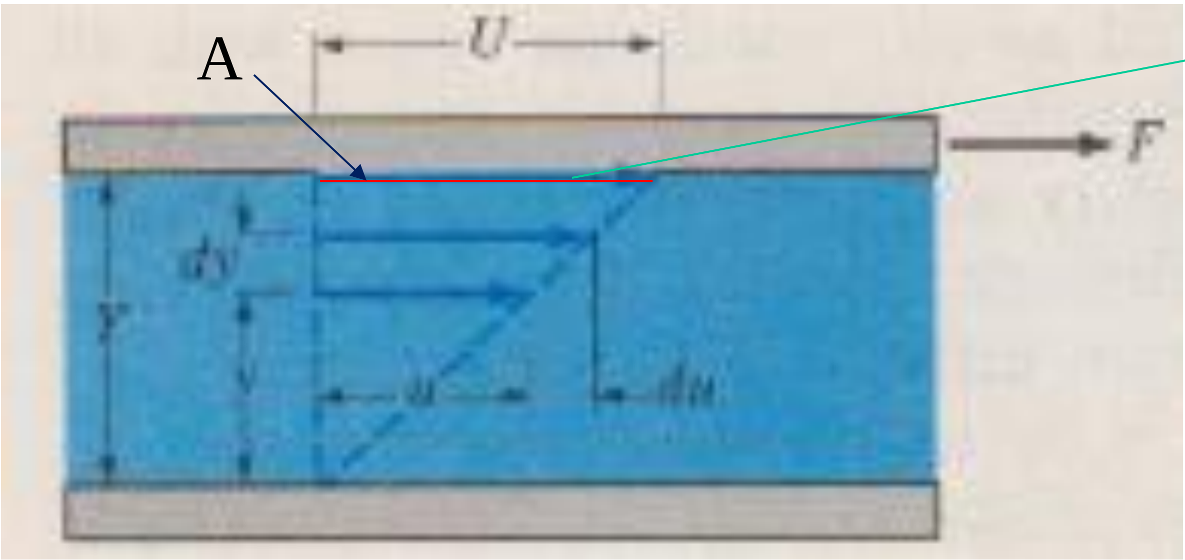
Viscosity

- Experiments have shown that for a large class of fluids under such conditions

$$F \alpha \frac{AU}{Y}$$

where A is the area over which shear is acting i.e., along the surface of the moving plate or for any depth y, the surface of the thin water layer (U x width) & not cross section of the water (Y x width)

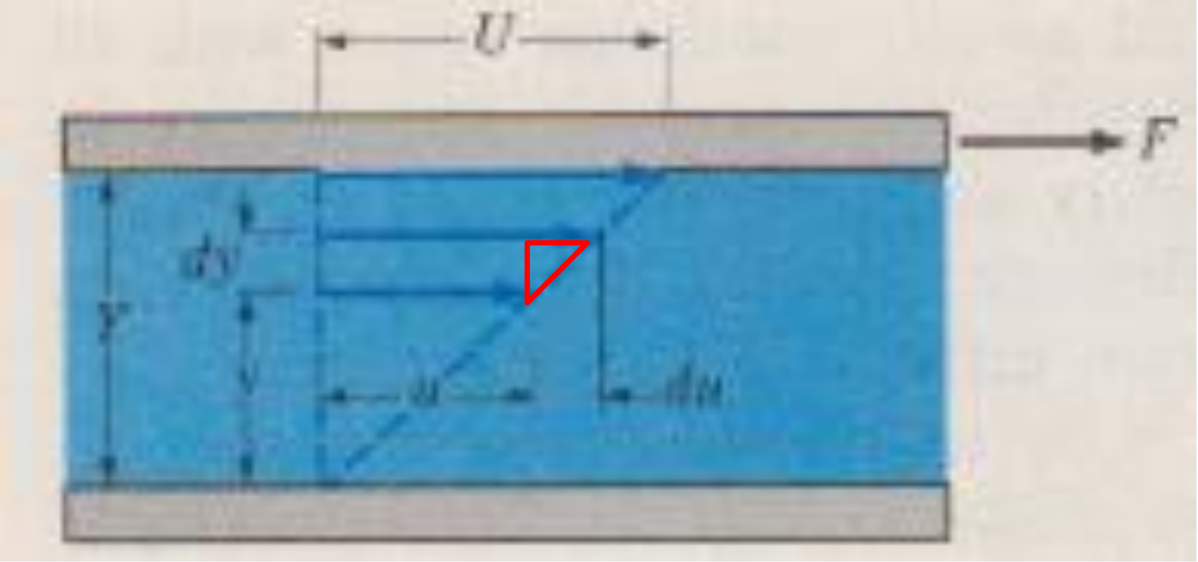




Properties of fluids

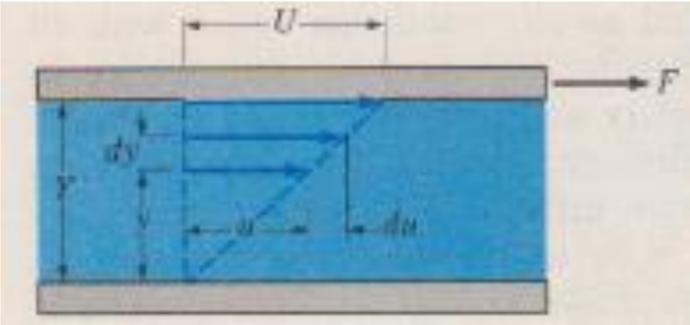
Viscosity

- From similar triangles in Fig, U/Y can be replaced by velocity gradient $\dfrac{du}{dy}$ (with v=0 at bottom and v=U at the top)



Properties of fluids

Viscosity



$$F \alpha \frac{AU}{Y} \Rightarrow \frac{F}{A} \alpha \frac{U}{Y}$$

If a constant of proportionality μ is now introduced, the shearing stress τ between any two thin sheets of fluid may be expressed by $\frac{F}{A} = \mu \frac{U}{Y}$ and $\frac{F}{A} = \tau$ therefore

$$\tau = \frac{F}{A} = \mu \frac{U}{Y} = \mu \frac{du}{dy}$$

Newton's Equation of Viscosity

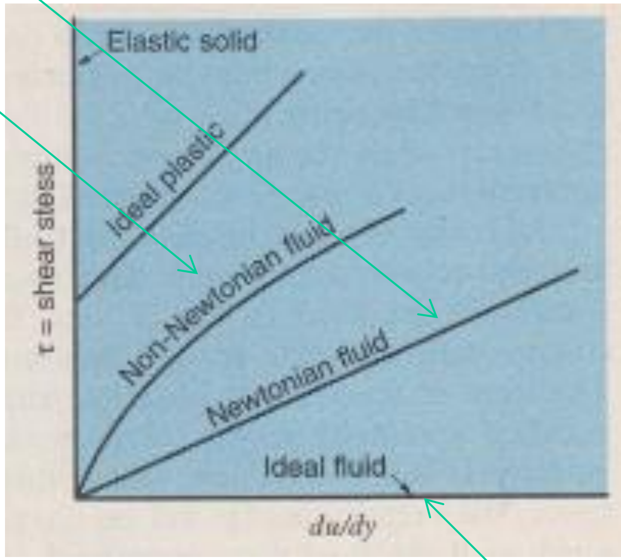
$\mu = \tau / \left(du/dy \right)$ is called absolute viscosity, dynamic viscosity, coefficient of viscosity or simply the viscosity of the fluid

Properties of fluids

Newtonian fluids - μ is constant for a given material and temperature.

Non Newtonian fluids - μ is not a constant for a given force.

Kinematic viscosity $\nu = \dfrac{\mu}{\rho}$



Slope is μ

$$\mu = \frac{\tau}{du/dy}$$

No viscosity for ideal fluid

Properties of fluids

Perfect gas

Molecules of a perfect gas:

- Would behave like tiny, perfectly elastic spheres in random motion
- Would influence each other only at collision
- Form a volume which would be negligible in comparison with the volume in which they moved

Properties of fluids

Perfect gas

In many circumstances gases may be ***assumed*** as perfect gases for which the equation below is valid

$$pV = mRT \text{ or } p = \rho RT \quad \text{eqn of state of a perfect gas}$$

where p = absolute pressure

V = volume

T = absolute temperature

R = gas constant

Properties of fluids

Compressibility

- All liquids compress if the pressure increases, resulting in an increase in density
- Compressibility is expressed by its bulk modulus of elasticity or coefficient of compressibility, K

$$K = \frac{dP}{-\frac{dV}{V}} \qquad or \qquad K = \frac{dP}{\frac{d\rho}{\rho}}$$

- Small density changes in liquids can be very significant when large pressure changes are present e.g. water hammer which can be heard shortly after sudden closing of a valve in a pipeline: when the valve is closed an internal pressure wave propagates down the pipe, producing a hammering sound due to pipe motion when the wave reflects from the closed valve

Properties of fluids

Surface tension

- Surface tension is the property of a fluid surface to behave *as if it were covered with a tight skin* (the meniscus), so that a needle or fine powder can be made to float on cold water without being wetted (dictionary of civil engineers).
- Surface tension is a property that results from the *attractive forces* between molecules.
- *As such* it manifests itself only in liquids *at an interface*, usually a liquid-gas interface.

Properties of fluids

Surface tension

- The forces between molecules in the bulk of a liquid are *equal* in all directions, and as a result *no net force* is exerted on the molecules.
- However, at an interface the molecules exert a force that has a *resultant* in the interface layer:

  - force holds drop of water suspended on a rod
  - force causes the small drops from a sprayer to assume spherical shapes
  - force plays significant role when two immiscible liquids (e.g., oil & water) are in contact with each other
  - May be important when water depth is very low when in contact with a solid boundary in hydraulic modelling

Properties of fluids

Surface tension

- In *most* cases of fluid mechanics and hydraulics, surface tension and its effects may be *neglected* in comparison with hydrostatic and dynamic forces

Properties of fluids

Vapour pressure

- Liquids evaporate because of molecules escaping from the liquid surface.
- Vaporisation will terminate when equilibrium is reached between the liquid & gaseous states of the substance in the container i.e., when the no. of molecules escaping from the water surface is equal to the no. of molecules striking the liquid surface and condensing (the conversion of a vapour or gas to a liquid).
- The pressure resulting from molecules in the gaseous state is the ***vapour pressure***.
- Boiling occurs when the pressure above a liquid equals the vapour pressure.

Properties of fluids

Vapour pressure

- In general, a transition from the *liquid state to the gaseous state occurs* if the local absolute pressure is less than the vapour pressure of the liquid.
- When this happens, bubbles are formed locally
- This phenomenon, called ***cavitation***, can be very damaging when these bubbles are transported by the flow to *higher pressure regions*.
- The bubbles collapse (*implosion*) upon entering the higher pressure regions, and this collapse produces *local pressure spikes* which have the potential to damage hydraulic pumps and turbines, ship's propeller, pipes, overflow spillway in dams (pitting, spongy appearance)

Properties of fluids

Vapour pressure

- damage hydraulic pumps

Properties of fluids

Vapour pressure

- overflow spillway in dams (pitting, spongy appearance)

- Ways are there to avoid cavitation-for later courses