Volume 1, Issue 1 July 2015 ISSN NO:

North Asian International Research Journal Consortium

North Asian International Research Journal

Of

Science, Engineering and Information Technology

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Publisher
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ISSN NO:

North Asian International Research Journal of Science, Engineering and Information Technology is a research journal, published monthly in English, Hindi, Urdu all research papers submitted to the journal will be double-blind peer reviewed referred by members of the editorial board. Readers will include investigator in Universities, Research Institutes Government and Industry with research interest in the general subjects

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Email: nairjc5@gmail.com Website: www.nairjc.com

FLUIDS MECHANICS AND FLUID PROPERTIES

Bilal Ahmad Malik

Department of Mechanical Engineering,

Techno Global University, Meghalaya.

Email: bilalmalik15@gmail.com

Introduction

What is fluid mechanics? As its name suggests it's the branch of applied mechanics involved with the statics and dynamics of fluids – each liquids and gases. The analysis of the behavior of fluids relies on the basic law of mechanics that relate continuity of mass and energy with force and momentum in conjunction with the acquainted solid mechanics properties.

Objectives

- Outline the character of a fluid.
- Show wherever mechanics ideas area unit common with those of solid mechanics and indicate some elementary areas of distinction.
- Introduce viciousness and show what Newtonian and non-Newtonian fluids area unit.
- Outline the suitable physical properties and show however these permit differentiation between solid and fluid further as between liquids and gases.

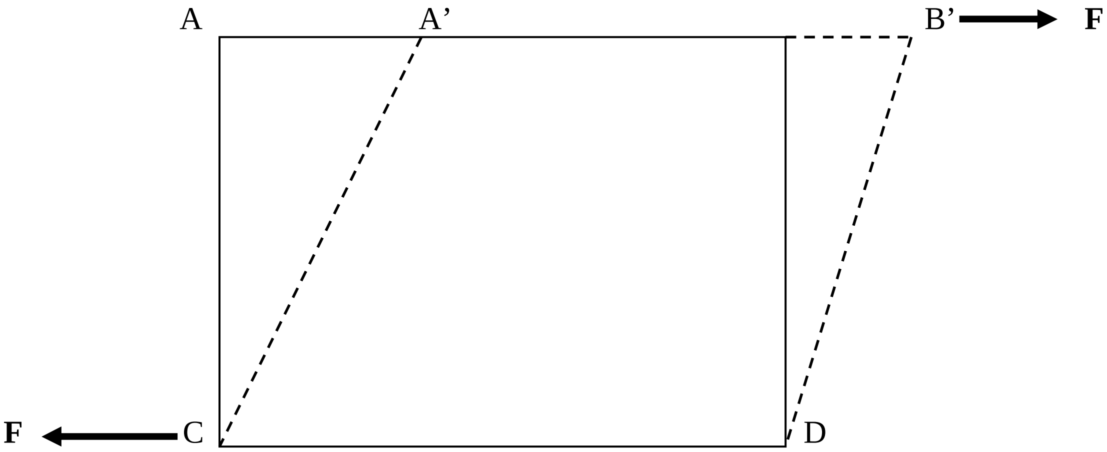
Fluids

There are unit 2 aspects of mechanics that create it totally different to solid mechanics:

1. The character of a fluid is way totally different to it of a solid.
2. In fluid we have a tendency to sometimes agitate continuous streams of fluid while not a starting or finish. In solids we have a tendency to solely contemplate individual components.

We unremarkable acknowledge 3 states of matter: solid; liquid; and gas. However, liquid and gas area unit each fluid: in distinction to solids they lack the flexibility to resist deformation. As a result of a fluid cannot resist the deformation force, it moves, it flows below the action of the force. It's from cans modification incessantly as long as force is applied. A solid will resist a deformation force whereas at rest, this force might cause some displacement however the solid doesn't still move indefinitely.

The deformation is caused by cutting off forces that acts tangentially to a surface. Pertaining to the figure below, we have a tendency to see the force F acting tangentially on an oblong (solid lined) part ABCD. This is often a cutting off force and produces the (dashed lined) rhombus part A'B'DC.



Cutting off force, F, working on a fluid part.

We are able to then say:

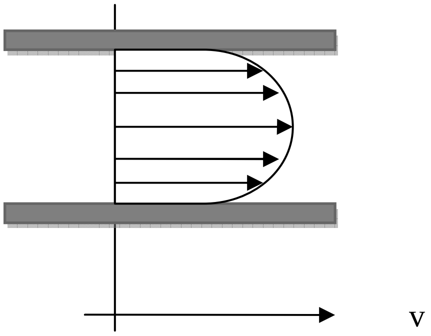
A fluid is a substance which deforms continuously,
or flows, when subjected to shearing forces.

And conversely this definition implies the vital purpose that:

If a fluid is at rest there are no shearing forces acting.
All forces must be perpendicular to the planes which the arc acting.

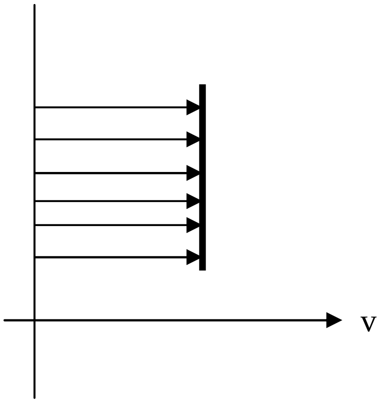
When a fluid is in motion shear stresses area unit developed if the particles of the fluid move relative to at least one another. When this happens adjacent particles have totally different velocities. If fluid speed is that the same at each purpose then there's no shear stress produced: the particles have zero relative speed.

Consider the flow in a very pipe during which water is flowing. At the pipe wall the rate of the water are going to be zero. The rate can increase as we have a tendency to move towards the middle of the pipe. This modification in speed across the direction of flow is understood as speed profile and shown diagrammatically within the figure below:



Speed profile in a very pipe.

Because particles of fluid next to every alternative area unit moving with totally different velocities there are a unit shear forces within the moving fluid i.e. shear force area unit unremarkable gift in a very moving fluid. On the opposite hand, if a fluid could be a good distance from the boundary and every one the particles area unit travel with an equivalent speed, the rate profile would look one thing like this:

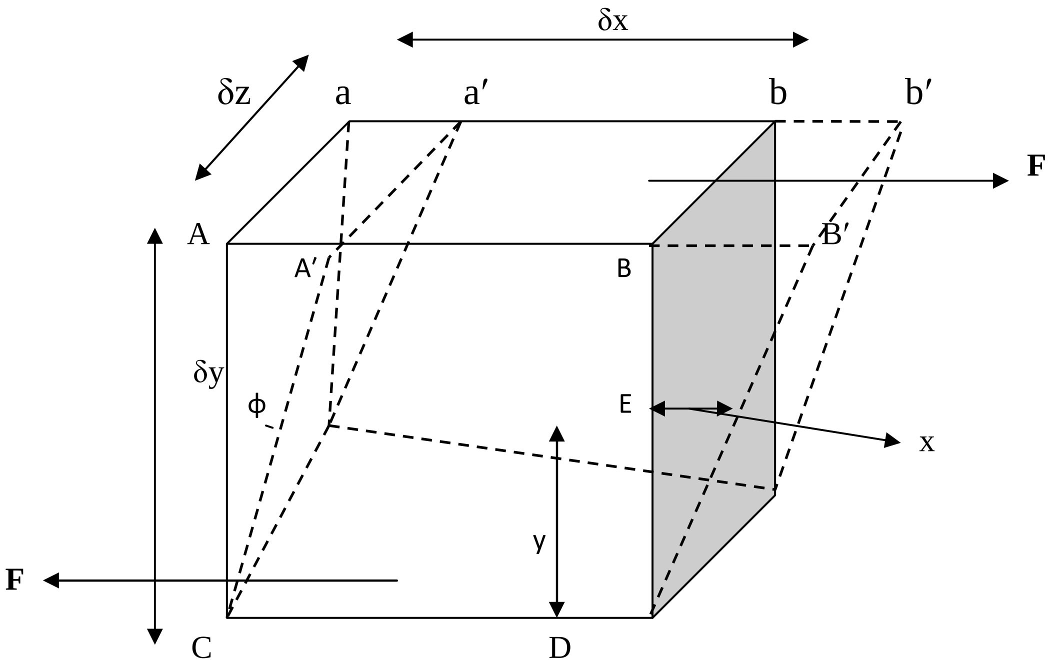


Speed profile in uniform flow

And there'll be no shear force gifts as all particles have zero relative speed. In observe we have a tendency to area unit involved with flow past solid boundaries; aeroplanes, cars, pipe walls, watercourse channels etc. and shear forces are going to be gift.

Newton’s Law of viciousness

How will we have a tendency to create use of those observations? We are able to begin by considering a 3D rectangular part of fluid, like that within the figure below:



Fluid part below a shear force

The cutting off force F acts on the realm on the highest of the part. This space is given by A = δs × δx. We are able to so calculate the shear stress that is adequate to force per unit space i.e.

$$\text{Shear stress,}\quad \tau = \frac{F}{A}$$

The deformation that this shear stress causes is measured by the scale of the angle ϕ and is understood as shear strain.

In a solid shear strain, ϕ is constant for a fixed shear stress τ.
In fluid ϕ increases for as long as τ is applied – the fluid flow.

It has been found through an experiment that the speed of shear stress (shear stress per unit time, τ / time) is directly proportional to the shear stress. If the particle at purpose E (in the figure above) move below the shear stress to purpose E′ and it takes time t to induce there, it's touched the space x. for little deformation we are able to write:

$$\text{Shear strain}\quad \phi = \frac{x}{y}$$

Rate of shear strain = ϕ/y

$$= \frac{x}{ty} = \frac{x}{t}\frac{1}{y}$$

$$= \frac{u}{y}$$

Where $\frac{x}{t} = u$ is that the speed of the particle at E.

Using the experiment result that shear stress is proportional to rate of shear strain then;

$$\tau = constant \times \frac{u}{y}$$

The term $\frac{u}{y}$ is that the modification in speed with y, or the rate gradient, and should be written within the differential type $\frac{du}{dy}$. The constant of quotient is understood because the coefficient of viscosity, μ of the fluid, giving

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

This is known as **Newton's law of Viscosity**

Fluids vs. solids

In the higher than we've got mentioned the variations between the behaviour of solids and fluids below an applied force. Summarizing, we have;

1. For a solid the strain is a function of the applied stress (providing that the elastic limit has been reached).for a fluid, the rate of strain is proportional to the applied stress.
2. The strain in a solid is independent of the time over which the force is applied and (if the elastic limit is not reached) the deformation disappears when the force is removed. A fluid continues to flow for as long as the force is applied and will not recover its original form when the force is removed.

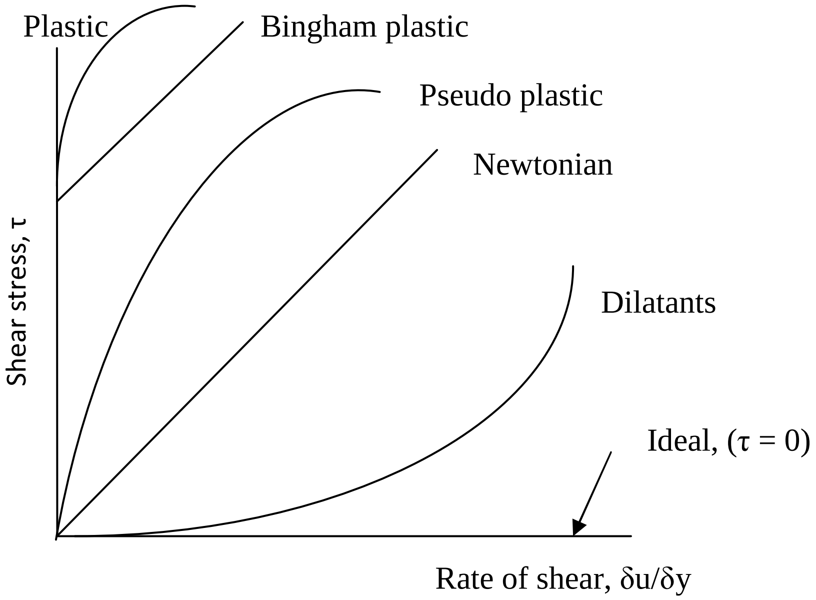
It is sometimes quite easy to classify substances as either solid or liquid. Some substances, however, (e.g. pitch or glass) seem solid below their weight. Pitch will, though showing solid at temperature, deform and detached over days-rather than the fraction of a second it might go in.

As you may have seen once staring at properties of solids, once the elastic limit is reached they appear to flow. They become plastic. They still don't meet the definition of true fluids as they're going to solely flow when a particular minimum shear stress is earned.

Newtonian /Non- Newtonian Fluids

Even among fluids that area unit accepted as fluids there may be wide variations in behaviour below stress. Fluids obeying Newton's law wherever the worth of μ is constant area unit famed Newtonian fluids. If μ is constant the shear stress is linearly keen about speed gradient. This is often true for many common fluids. Fluids during which the worth of μ isn't constant area unit referred to as Non-Newtonian fluids. There is a unit many classes of those and that they area unit printed in short below.

These classes area unit supported the link between shear stress and the speed gradient (rate of shear strain) within the fluid. Their relationships may be seen within the graph below for many classes.



Shear stress vs. shear strain δu/δy

Each of those lines may be represented by the equation

$$\tau = A + B\left(\frac{\delta u}{\delta y}\right)^n$$

Where A, B and n area unit constants. For Newtonian fluids A = zero, B = μ , and n = 1

Below are unit temporary descriptions of the physical properties of the many categories:

- *Plastic:* Shear stress should reach a particular minimum before flow commences.
- *Bingham plastic:* Like the plastic higher than a minimum shear stress should be achieved. With this classification n = one. An example is waste material sludge.
- *Pseudo*-plastic: No minimum shear stress necessary and the viciousness decreases with rate of shear, e.g. mixture substances like clay, milk and cement.
- *Dilatant substances:* viciousness will increase with rate of shear e.g. quicksand.
- *Thixotropic substances:* A viciousness decrease with length of shear force is applied e.g. thixotropic jelly paints.
- Rheopectic substances: viciousness is will increase with length of your time shear force is applied.
- *Elastic materials:* like Newtonian however if there's an explosive giant modification in shear they behave like plastic.

There is conjointly a new – that isn't real, it doesn't exist – referred to as the best fluid. This is often a fluid that is assumed to own no viciousness. This is often a helpful idea once theoretical solutions area unit being thought of – it will facilitate accomplish some much helpful solutions.

Liquids vs. Gasses

Though liquids and gasses behave in a lot of an equivalent means and share several similar characteristics, they conjointly possess distinct characteristics of their own. Specifically,

- A liquid is troublesome to compress and infrequently considered being incompressible. A gas is well to compress and typically treated in and of it – it changes volume with pressure.

- A given mass of liquid occupies a given volume and can occupy the instrumentality it's in and type a free surface (if the instrumentality is of an oversized volume). A gas has no fastened volume; it changes volume to expand to fill the containing vessel. It'll utterly fill the vessel therefore no free surface is created.

Causes of Consistency in Fluids

Viscosity in Gasses: - The molecules of gasses square measure solely debile unbroken in position by molecular cohesion (as they're up to now apart). As adjacent layers move by one another there's an eternal exchange of molecules. Molecules of a slower layer move to quicker layers inflicting a tangle, whereas molecules moving the opposite means exert associate degree acceleration force. Mathematical issues of this momentum exchange will cause Newton law of consistency.

If the temperature of gas will increase the momentum exchange between layers can increase so increasing consistency.

Viscosities also will amendment with pressure – however below traditional conditions this modification is negligible in gasses.

Viscosity in Liquids

There is some molecular interchange between adjacent layers in liquids – however because the molecules square measure most nearer than in gases the cohesive forces hold the molecules in its original place way more bolt. This cohesion plays a very important role within the consistency of liquids.

Increasing the temperature of the fluid reduces the cohesive forces and increasing the molecular interchange. Reducing cohesive forces reduces shear stress, whereas increasing molecular interchange will increase shear stress. As a result of this complicated relation the impact of temperature on consistency has one thing of the form:

$$\mu_r = \mu_0 \, (\mathrm{AT} + \mathrm{BT})$$

Where μ_r is that the consistency at temperature $T^O C$, and μ_0 is that the consistency at temperature $0^O C$, A and B square measure constants for a specific fluid.

High pressures can even amendment the consistency of a liquid. As pressure will increase the relative movement of molecules needs additional energy thence consistency will increase.

Properties of Fluids

The property outlines below square measure general properties of fluids that square measure of interest in engineering. The image sometimes wont to represent the property is specified along some typical values in SI units for common fluids. Values below specific conditions (temperature, pressure etc.) may be promptly found in several references books. The scales of every unit also are giving within the MLT system.

Density

The density of a substance is that the amount of matter contained in an exceedingly unit volume of the substance. It may be expressed in 3 other ways. They're as under:

1. **Mass Density: -** Mass Density, ρ, is outlined because the mass of substance per unit volume.
   Units: kg per kilolitre, metric weight unit, $kg \,/\, m^3$ (or $kg \; m^{-3}$)
   Dimension: ML^{-3}
   Typical Values:
   Water = 1000$kg \; m^{-3}$, Mercury = 13547$kg \; m^{-3}$, Air = 1.23$kg \; m^{-3}$, Lamp oil = 800$kg \; m^{-3}$.
   (At pressure = $1.013 \times 10^{-5} \, Nm^{-2}$ and Temperture = 288.15 K.

2. **Specific Weight: -** Specific Weight ω, (sometimes ϒ, and typically referred to as specific gravity) is outlined because the weight per unit volume.
   Or
   the force exerted by gravity, g, upon a unit volume of the substance.

   The Relationship g and ω may be determined by Newton's Second Law, since

   Weight per unit volume = mass per unit volume ×g

   ω = ρg

   Units: Newton's per kilolitre, $N/m^3(orNm^{-3})$
   Dimensions:$ML^{-2}\ \ T^{-2}$
   Typical values:
   Water = 9814Nm^{-3}, Mercury = 132943Nm^{-3}, Air = 12.07Nm^{-3}, Lamp oil = 7851Nm^{-3}

3. **Relative Density**
   Relative Density, σ, is outlined because the magnitude relation of mass density of a substance to some customary mass density. For solids and liquids this customary mass density is that the most mass density for water (which happens at 4°C) at atmosphere pressure.
   σ=σ (substance/ σ (H2O at 4℃))

$$\sigma = \sigma_{substance}/\ \sigma_{H2o\ at\ 4℃}$$

   Units: None, since a magnitude relation may be a pure variety.
   Dimensions: one
   Typical Values: Water = one, Mercury = 13.5, Lamp oil = .8.

Viscosity

Viscosity, μ, is that the property of a fluid, attributable to cohesion and interaction between molecules, that offers resistance to sheer deformation. Totally different completely different} fluids deform at different rates below constant shear stress. Fluids with a high consistency like sirup, deforms additional slowly than fluid with an occasional consistency like water.
All fluids square measure vicious, 'Newtonian Fluids'' adapt the linear relationship given by Newton's law of consistency.

$\tau = \mu\frac{du}{dy}$, wherever τ is that the shear stress,

Units: $N\ m^{-2};\ kg\ m^{-1}\ s^{-2}$

Dimensions: $ML^{-1}T^{-2}$

$\frac{du}{dy}$ Is that the speed gradient or rate of shear strain, and has, Units: $radians\ \ s^{-2}$, $Dimensions\ t^{-1}$

μ is that the 'coefficient of dynamic viscosity''

Coefficient of Dynamics Viscosity

The constant of coefficient of viscosity, μ, is outlined because the shear force, per unit space, (or shear stress τ), needed to pull one layer of fluid with unit speed past another layer a unit distance away.

$$\mu = \tau \frac{du}{dy} = \frac{Force}{Area} / \frac{Velocity}{Distance} = \frac{Force \times Time}{Area} = \frac{Mass}{Length \times Area}$$

Units: Newton second per square meter, $N\ s\ m^{-2}$ or Kilograms per meter per second.

(Although note that μ is usually expressed in Poise, P, wherever Ten Poise = 1 metric weight unit m).

Typical Values:

$Water = 1.4 \times 10^{-3}\ kg\ m^{-1}\ s^{-1}, Air = 1.78 \times 10^{-5}\ kg\ m^{-1} s^{-1}, Mercury$

$= 1.552\ kg\ m^{-1} s^{-1}, Paraffin\ Oil = 1.9\ kg\ m^{-1} s^{-1}$,

Kinematic Consistency

Kinematic consistency, v, is outlined because the magnitude relation of coefficient of viscosity to mass density.

$$\mathrm{v} = \frac{\mu}{\rho}$$

Units: sq. meters per second, $m^2\ s^{-1}$

(Although note that v is usually expressed in Stokes, St, wherever $10^4\ St = 1\ m^2\ s^{-1}$.)

Dimensions: $L^2 T^{-1}$.

Typical Values:

$Water = 1.14 \times 10^{-6}\ m^2 s^{-1}, Air = 1.46 \times 10^{-5}\ m^2 s^{-1}, Mercury = 1.145 \times 10^{-4}\ m^2 s^{-1}$,

$Lamp\ oil = 2.375 \times 10^{-3}\ m^2 s^{-1}$.

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