Viscosity

Tuesday, August 22, 2017 14:22

For the glory of God

What is viscosity? cf. The word 'viscosity' is derived from the Latin 'viscum' meaning a viscous glue

a) By definition

- Viscosity is defined as the resistance to flow.
- For liquids, it implies the informal concept of thickness
  - e.g. Honey is more thicker than water

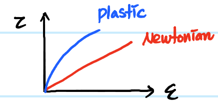
(First of all, Newton suggested that $\tau \propto \varepsilon$) → It's linear → called as Newtonian (with μ = const)

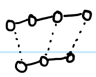
cf. when an experiment was performed, it was found that $\tau \propto \frac{du}{dy}$

↳ It implies we need a proportional constant $\tau \simeq \mu \frac{du}{dy}$

b) At a molecular level

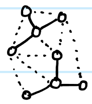
- It is the property of the fluid due to momentum exchange between molecules.
- Transport of molecular momentum : viscosity
- For example, for liquid,





water (weak intermolecular force)

vs.



Honey (strong intermolecular force)

; More viscous

dominant ↓ $\mu \frac{du}{dy}$

For water, (usually, $\mu_{air} \lll \mu_{water}$)

$\nu \downarrow$ as $T \uparrow$ ($\because$ less intermolecular force)

: For gas, $\mu \frac{du}{dy}$ (small)

$\nu \uparrow$ as $T \uparrow$

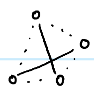
($\because$ high temperature = more momentum exchange)

↳ more vigorous ($T\uparrow$, more moving)

What if we're heating up the honey?

- It will become less viscous but more flow. This is because;

→ Heat → more energy



→ weak intermolecular force → Less momentum exchange

(weak molecules bonding)

c) For Newtonian fluid,

- viscosity can be used as a coefficient that specifies the relationship between the shear stress and the local deformation of the fluid. e.g. $\tau \propto \mu \frac{du}{dy}$; where μ = const. of the fluid

Then, what is the difference between Newtonian and Non-Newtonian fluid?

{ Newtonian fluid : It is a fluid in which τ (deviatoric part of; see momentum eq. note) is linearly proportional to the local strain rate.
(viscosity remains constant) e.g. water, oil, gasoline, ...

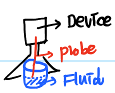
Non-newtonian fluid : when shear is applied to this flow, the viscosity of the flow changes.

Dynamic viscosity vs. Kinematic viscosity

- Dynamic viscosity (or just viscosity) is the quantitative expression of fluid's resistance to flow. (μ)
- Kinematic viscosity is the ratio of the viscous force to the inertia force. ($\nu = \frac{\mu}{\rho}$)

Resistance against gravity ↳ It is characterized by fluid density.

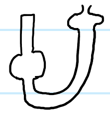
How to measure viscosity



- Measuring dynamic viscosity
  - Rotational viscometers are one of the more popular types of instruments used to measure μ.
  - These instruments rotate a probe in the liquid sample.

- Viscosity is determined by measuring the force needed to turn the probe.

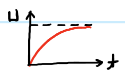
- Measuring Kinematic viscosity
  - The most used method is determining the time.
  - It takes a fluid to flow through a tube.
  - The time is converted directly to kinematic viscosity using a calibration constant provided for the tube.



- SAE 30
  - This means that 60 ml of this oil at a specific temperature takes 30 sec to run out of a 1.76 cm hole in the bottom of cup
  - The higher SAE number, the more viscosity effects.

- Drop a small sphere into it (valid only for liquids of relatively high μ) ↳ It may not work for gas.

  - Let's say we know the mass ↳ It will be a combination of $F_p + F_s$
  - At some point, gravity force = resistance force
    → we will get terminal velocity ↳ Then, sphere starts to drop at a constant speed.



  - Finally, $\tau = \mu \frac{du}{dy}$; known τ (Resistance F), Δy, Δu ⇒ Estimate μ

Then, why should we measure viscosity for different fluids?

→ The data will give us the ability to predict how the material will behave in the real world.

Units of viscosity

- Dynamic viscosity

$$Re = \frac{\rho u L}{\mu} \Leftrightarrow \frac{kg/m^3 \cdot m/s \cdot m}{\mu} = \text{Dimensionless}, \quad \therefore kg/(m \cdot s)$$

- Kinematic viscosity

$$\nu = \frac{\mu}{\rho} \Leftrightarrow \frac{kg/(m \cdot s)}{kg/m^3} = m^2/s$$

Basically, prof. P.K. Yeung claimed that ;
$\nu = f(T)$ but
$\mu = f(T, p)$ because $\mu = \rho \cdot \nu$
↳ we need to consider the density effect

cf. In fact, μ varies with both temperature and pressure.

↳ In Aerodynamics, we usually neglect the pressure dependency of gas viscosity ; thus only $f(T)$

- Viscous flow can be defined as the flow where transport phenomena is actively happened.

To be more specific,

- For most circumstances near the conditions we live in, pressure doesn't have much effect on viscosity.

- For gas {
  - viscosity depends only on temperature for ideal gas.
  - In Sutherland's law for viscosity of gases, there is no input for pressure.
  - That's still a very good approximation for real gas.

- For liquids {
  - The pressure has very little effect on viscosity rather than temperature.
  - Temperature is by far the dominant factor in viscosity.
  - For most liquids, a considerable change in pressure from 0.1 to 30 MPa causes about the same change in viscosity

as a temperature change of about 1 K.