

## ***FLASH POINT***

- **Flash point is the temperature at which the lubricant vapor will ignite.**
- **In order to determine the flash point, the lubricant is heated at standard pressure to a temperature which is just high enough to produce sufficient vapor to form an ignitable mixture with air.**

## ***THERMAL STABILITY***

- **Is the resistance of the lubricant to molecular breakdown or molecular rearrangement at elevated temperatures in the absence of oxygen.**
- **When heated mineral oils breakdown to methane, ethane and ethylene.**
- **Thermal stability can be improved by refining processes rather than addition of additives.**

## ***VISCOSITY TEMPERATURE RELATIONSHIP***

- **The viscosity of lubricants is extremely sensitive to the operating temperature.**
- **Oil viscosity reduces quite rapidly with increasing temperature.**
- **In some cases, the viscosity of lubricant can drop by 80% with a temperature increase of 25°C.**
- **Therefore, it is of critical importance to know operating temperature since it determines the lubricant film thickness separating the surface.**

# ***VISCOSITY TEMPERATURE MODELS***

## ***(Continued)***

- **Reynolds**

$$\mu = b e^{-aT}$$

- one of the first models
- accurate for limited temperature range

- **Slotte**

$$\mu = a/(b + T)^c$$

- useful in numerical analysis

# ***VISCOSITY TEMPERATURE MODELS***

## ***(Continued)***

- **Walther**

$$(\nu + a) = b d^{1/T^c}$$

- **used in ASTM**
- **viscosity - temperature chart**

- **Vogel**

$$\mu = a e^{b/(T-C)}$$

- **Most accurate**
- **Used in engineering calculations**
- **T ~ absolute temperature [K]**

## ***VISCOSITY PRESSURE RELATIONSHIP***

- **Lubricant viscosity increases significantly with pressure. This is particularly important in lubrication of heavily loaded concentrated contacts (i.e., rolling element bearings, gears, cams, etc.)**
- **The viscosity increase due to pressure in concentrated contacts is so large that the lubricant is thought to behave as a solid rather than a liquid.**

## ***VISCOSITY PRESSURE MODELS***

- **Barus**

$$\mu = \mu_0 e^{\alpha P}$$

$\mu_0$  - atmospheric viscosity [Pa.sec]

$\alpha$  - pressure viscosisty index [1/Pa]

P - pressure [Pa]

**This Equation is valid up to 0.7 GPa or 100 ksi.**

- **Chu et. al.**

$$\mu = \mu_0 (1 + CP)^n$$

where c and n are constants .

**This Equation is proposed for pressure slightly higher than 0.7 GPa.**

## ***VISCOSITY PRESSURE MODELS*** ***(Continued)***

- **Wooster**

$$\alpha = (0.6 + 0.965 \log_{10} \mu_o) \times 10^{-8}$$

$\alpha$  - pressure viscosity index [1/Pa]

$\mu_o$  - atmospheric pressure [Pa.sec]

- **Roelands**

$$\log_{10} \mu + 1.2 = (\log_{10} \mu_o + 1.2) \left(1 + \frac{P}{2000}\right)^{Z_1}$$

- $Z_1$  - viscosity pressure index

***SHEAR STRESS SHEAR STRAIN  
RELATIONSHIP  
(Continued)***

$$\frac{\mu_e}{\mu} = -\frac{\tau/\tau_L}{\ln(1 - \tau/\tau_L)}$$

**Bair & Winer (1979)**

$$\frac{\mu_e}{\mu} = \frac{\tau/\tau_L}{\tanh^{-1}(\tau/\tau_L)}$$

**Gecim & Winer (1980)**

$$\frac{\mu_e}{\mu} = \frac{\tau/\tau_E}{\sinh^{-1}(\tau/\tau_E)}$$

**Eyring (1936)**

**Where**

$$\tau_L = \tau_{\text{atm}} + \gamma^* p$$

$\tau_E$  is the shear stress at which the fluid first starts to behave nonlinearly.

## ***GREASE***

- Grease is an oil to which a thickener has been added usually a metallic soap.
- Metallic soaps are produced during grease manufacturing by neutralizing fats; the compounds most commonly used are the hydroxides of lithium, calcium, sodium, barium and aluminum.
- The neutralizable compounds include:
  - lard oil
  - hydrogenated fats
  - fish oil
  - vegetable oils
- Greases are manufactured by adding oil and fatty acids together and heated to 135 to 150 degrees C, at which time the alkaline compound is added and neutralizing occurs. The water resulting from chemical reaction is boiled off.

## ***USE OF GREASE OVER OIL***

- **Preferred when continuous supply of oil is not practical.**
- **When machine component being lubricated is not readily accessible.**
- **When the lubricant cannot be retained in the enclosure.**
- **Provides a seal between the shaft and the machine element, therefore excluding contaminants.**

# ***OIL VISCOSITY CLASSIFICATION***

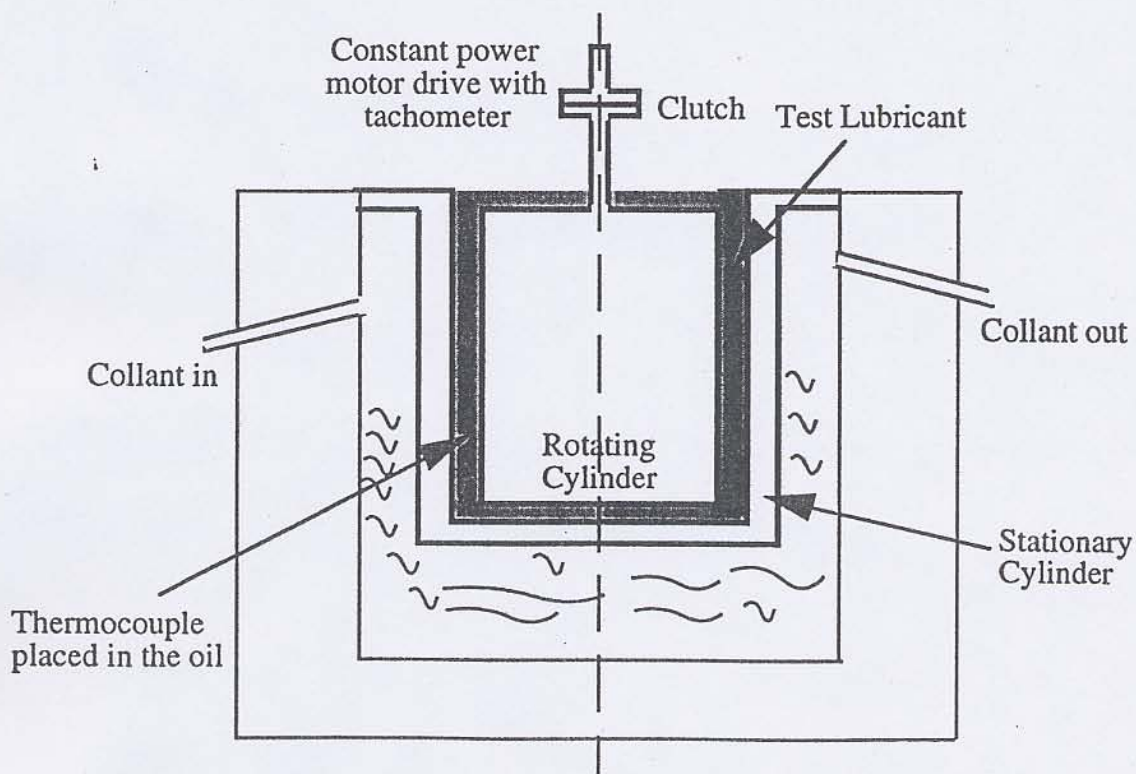
**There are several oil viscosity classifications**

- **SAE (Society of Automotive Engineers)**
- **ISO (International Organization for Standardization)**
- **Military Specification**

# SAE VISCOSITY CLASSIFICATION

## (Continued)

- The low temperature viscosity is measured using a “cold cranking simulator” and it is an indicator of cold weather starting ability.
- Oils without “W” suffix are monograde oils.
- Oils with “W” suffix are multigrade oils.
- “W” suffix stands for winter.

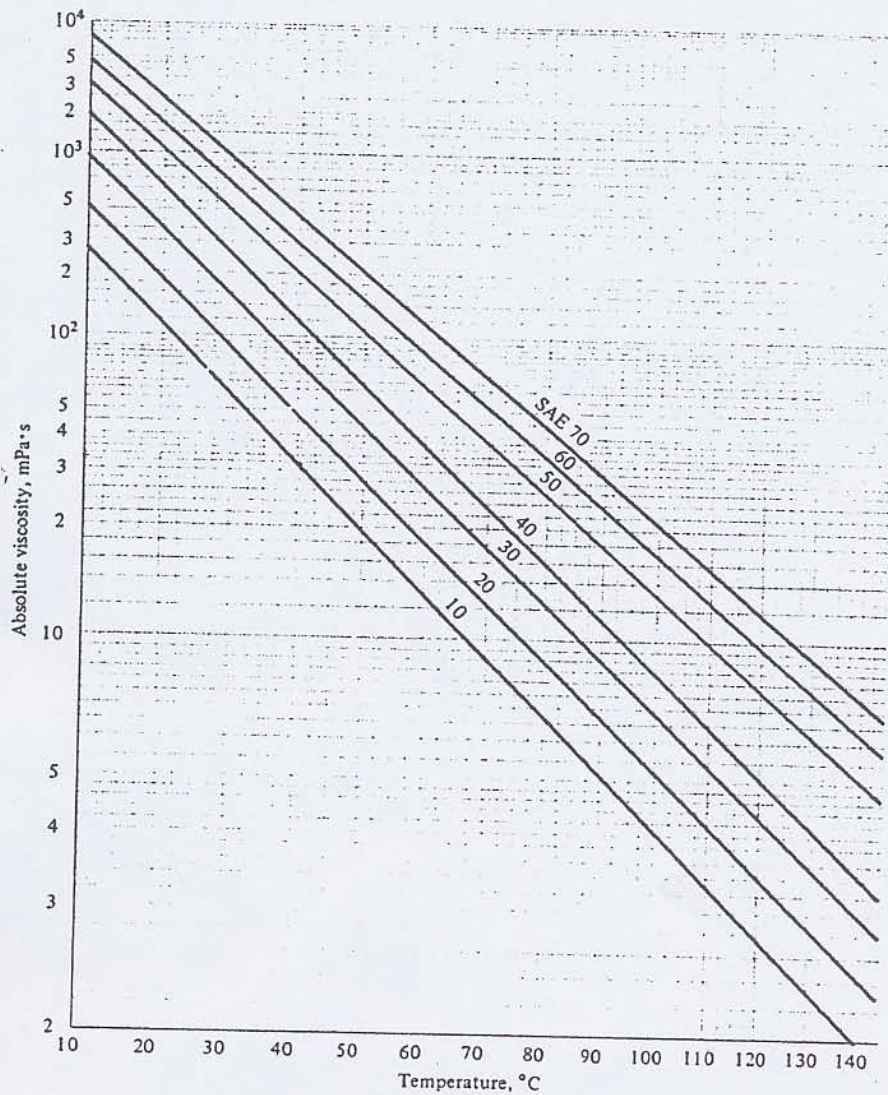


# SAE VISCOSITY CLASSIFICATION

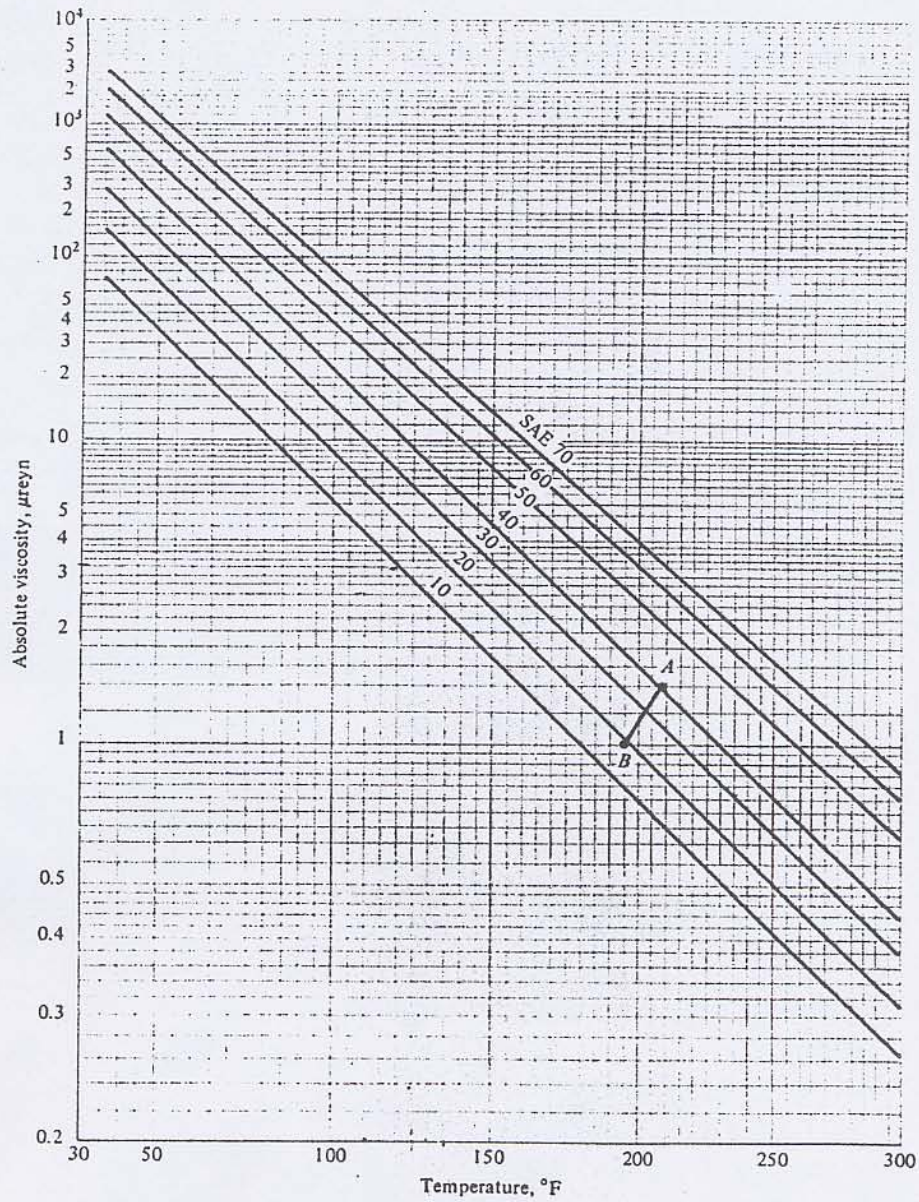
SAE engine oil classification.

SAE viscosity grade	Viscosity [cP] at temp [°C] max		Kinematic viscosity [cS] at 100°C	
	Cranking	Pumping	min	max
0W	3 250 at -30	30 000 at -35	3.8	-
5W	3 500 at -25	30 000 at -30	3.8	-
10W	3 500 at -20	30 000 at -25	4.1	-
15W	3 500 at -15	30 000 at -20	5.6	-
20W	4 500 at -10	30 000 at -15	5.6	-
25W	6 000 at -5	30 000 at -10	9.3	-
20	-	-	5.6	< 9.3
30	-	-	9.3	<12.5
40	-	-	12.5	<16.3
50	-	-	16.3	<21.9
60	-	-	21.9	<26.1

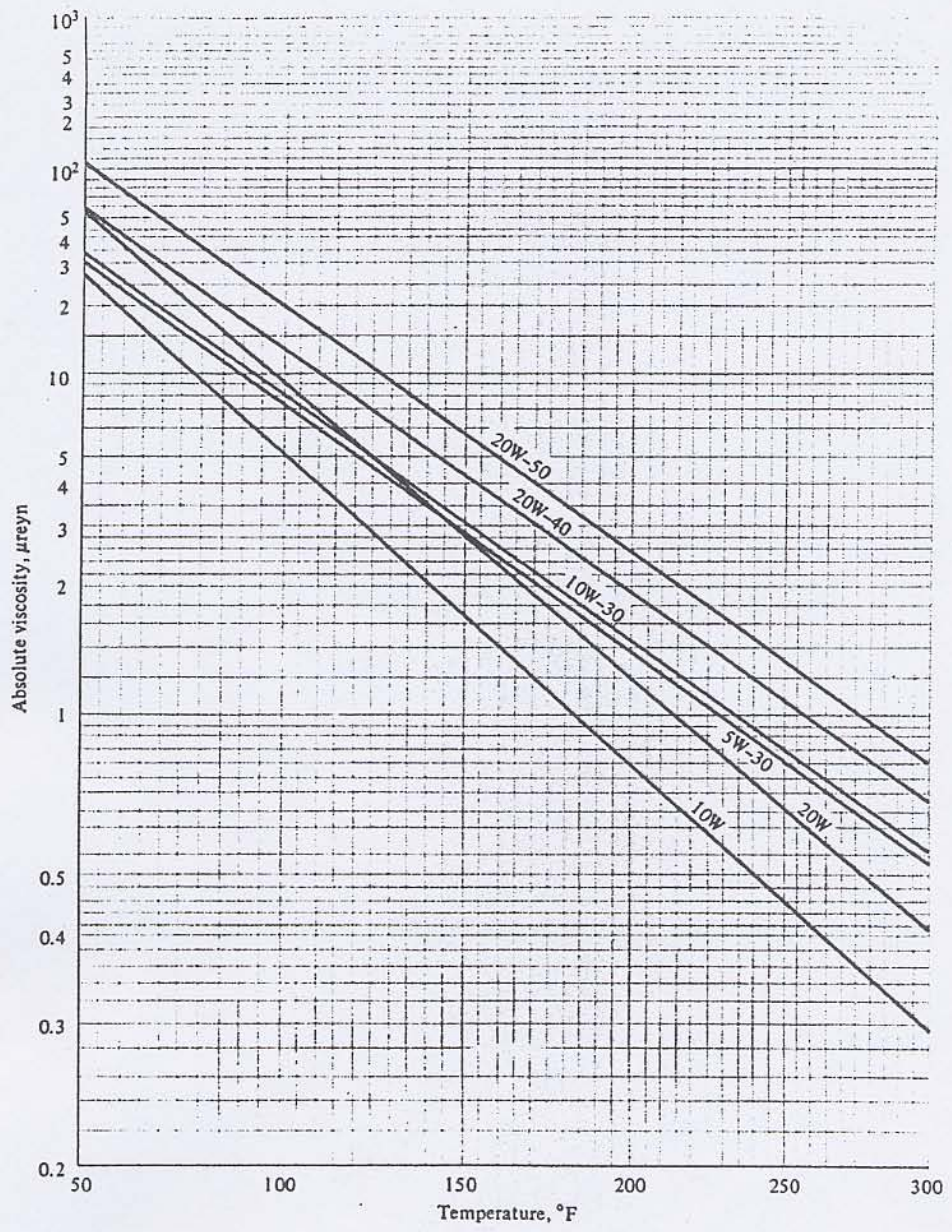
# VISCOSITY VARIATION WITH TEMPERATURE



# VISCOSITY VARIATION WITH TEMPERATURE



# VISCOSITY VARIATION WITH TEMPERATURE



# ***VISCOMETRY***

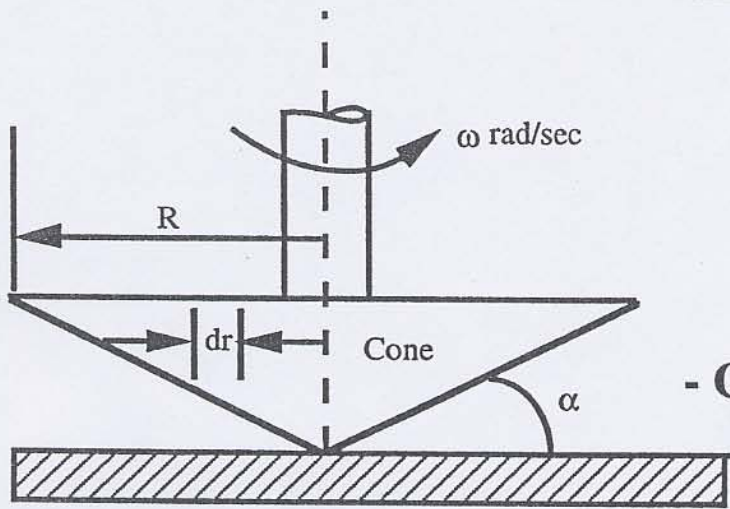
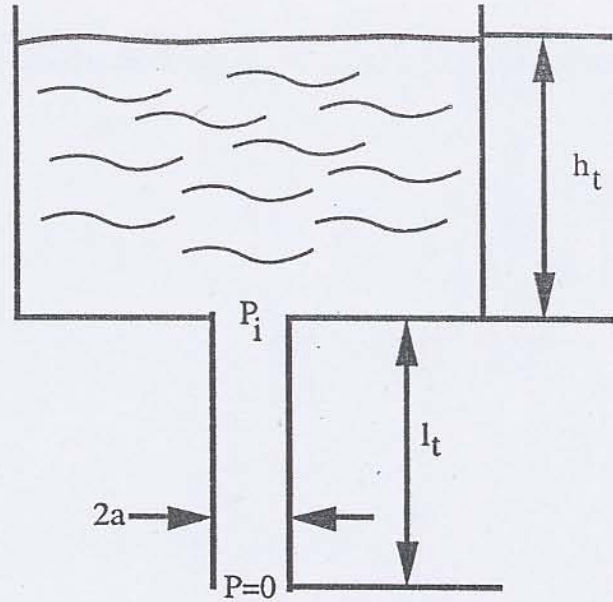
- **Viscosity of fluids can be measured by many methods based on different principles.**
- **Capillary Viscometer**
- **Rotational Viscometer**
  - **Rotational Cylindrical Viscometer**
  - **Cone & Plane Viscometer**
- **Falling Sphere (Ball) Viscometer**

## ***VISCOSITY MEASUREMENT***

- **Various viscometers have been developed to measure viscosity of lubricants**
  - **capillary**
  - **rotational**
  
- **Capillary viscometers are not commonly used for lubricants that don't behave in a non-Newtonian manner.**
  
- **Rotational viscometers are used for lubricants that are known to behave in a non-Newtonian manner.**
  - **Rotating cylinder viscometer**
  - **Cone on plate viscometer**

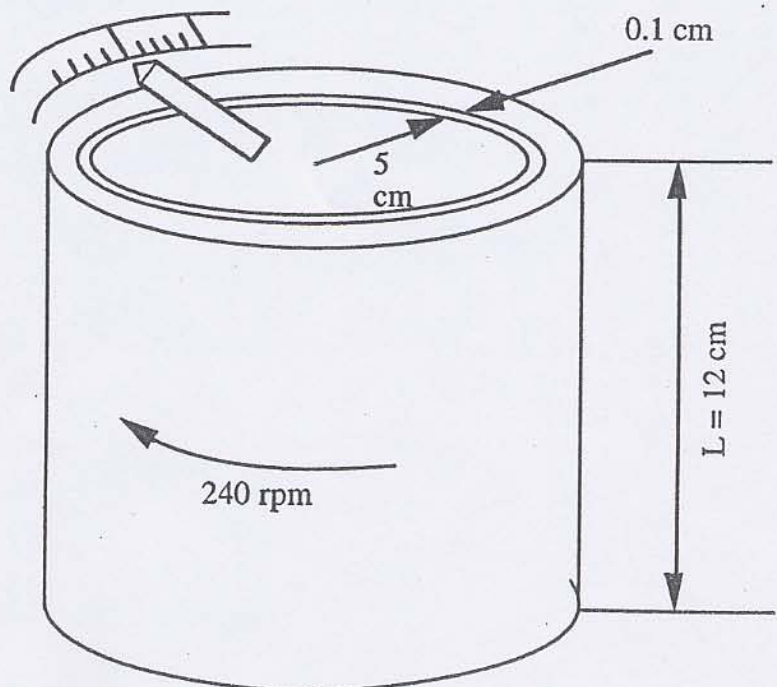
# VISCOSITY MEASUREMENT (continued)

- Capillary Viscometer



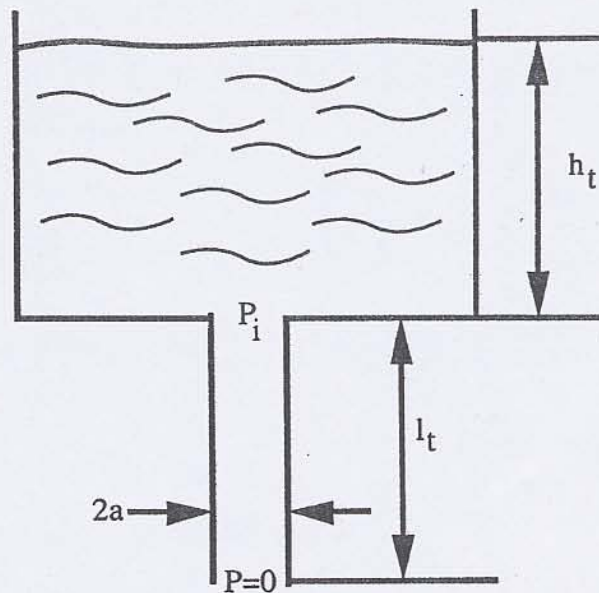
- Cone and Plane Viscometer

- Rotary Viscometer



## CAPILLARY VISCOMETER

is based on measuring the rate at which a fluid flows through a small diameter tube (i.e., the time it takes to discharge a specified quantity of fluid).



From Navier-Stokes Equation flow in a circular pipe is given by:

$$-\frac{dp}{dz} = \frac{8\mu_o q}{\pi a^4}$$

$$-\frac{dp}{dz} = \frac{P_i}{l_T}$$

# **CAPILLARY VISCOMETER**

## **(Continued)**

$$\therefore P_i = \frac{8 \mu_0 q \ell_t}{\pi a^4}$$

**Now recall**

$$P_i = \rho g h_t$$

**Substituting for  $P_i$  and evaluating  $h_t$**

$$h_t = \frac{8 \mu_0 q \ell_t}{\pi a^4 \rho_0 g}$$

**letting**

$$A = \frac{8 \ell_t}{\pi a^4 g}$$

**Note that  $\mu_0$  - is the dynamic viscosity**

**$\rho_0$  - is the density**

$$v_0 = \frac{\mu_0}{\rho_0}$$

**Note that  $v_0$  - is the kinematic viscosity**

$$\therefore h_t = A v_0 q$$

$$\therefore v_0 = \frac{h_t}{Aq}$$

# ROTATIONAL CYLINDRICAL VISCOMETER

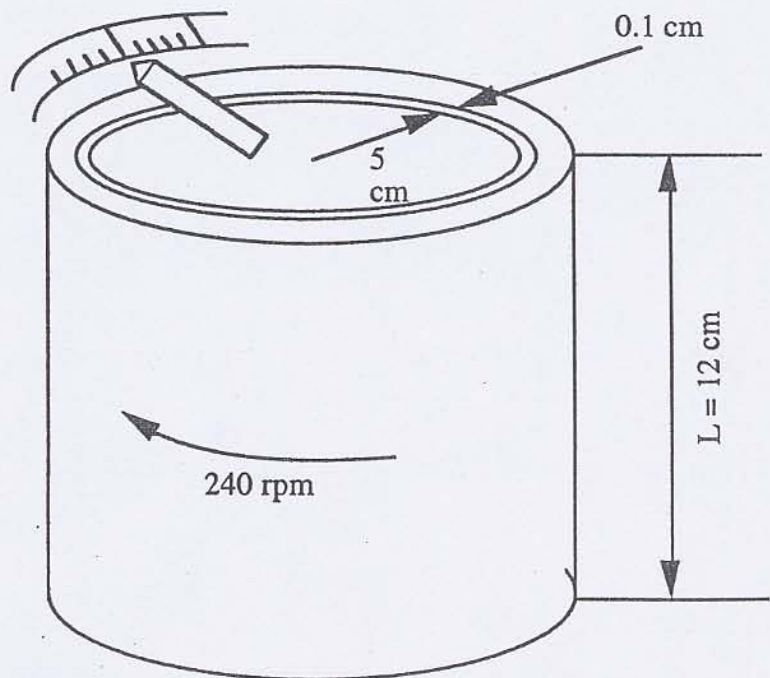
- Consist of two concentric cylinders with a fluid contained between them. As the outer cylinder rotates, it induces a torque on the inner cylinder which can be measured.

Based on Newton's Law

$$\tau = \mu_o \frac{\partial u}{\partial z}$$

$$\tau = \mu_o \frac{u}{r_o - r_i} = \mu_o \frac{u}{c}$$

$$T = (\tau A) r_i = \mu_o \frac{u}{c} A r_i$$



**ROTATIONAL CYLINDRICAL  
VISCOMETER  
(Continued)**

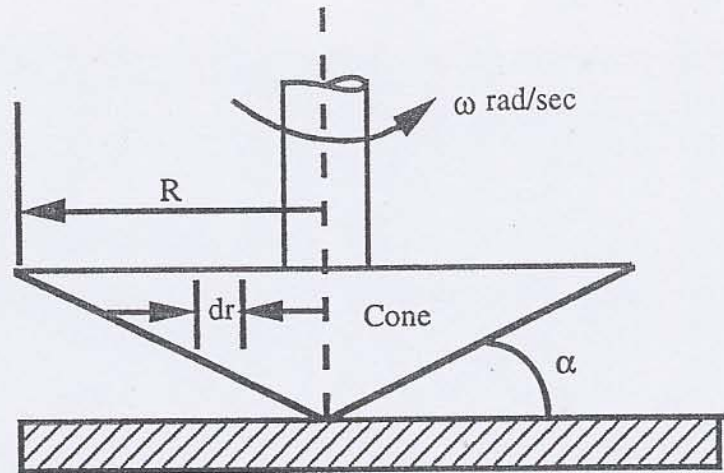
$$A = 2\pi r_o \ell$$

$$u = r_o \omega$$

$$T = \mu_o \frac{r_o \omega}{c} 2\pi r_o \ell r_i$$

$$\mu_o = \frac{T_o c}{2\pi \omega r_o^2 \ell r_i}$$

## CONE AND PLANE VISCOMETER



again

$$\tau = \mu_o \frac{u}{h} = \mu_o \frac{\omega r}{r \tan \alpha}$$

Note that the angle,  $\alpha$  is small, therefore

$$\tau = \mu_o \frac{\omega r}{r \alpha} = \mu_o \frac{\omega}{\alpha}$$

$$T = (\tau A) r = \int_0^R \mu_o 2\pi r dr \frac{\omega r}{r \alpha}$$

$$\mu_o = \frac{3 T \alpha}{2 \pi \omega R^3}$$

## ***FALLING BALL VISCOMETER***

**In this apparatus the viscosity of a fluid is determined by measuring the time it takes for a ball to fall through a tube. A ball falling freely under gravity in a liquid will be attaining a velocity as given by**

$$U_a = \frac{2 r^2 (\rho_S - \rho_f) g}{\mu_o} c_f$$

where

$$C_f = 1 - 2.104 \left( \frac{r}{R} \right) + 2.09 \left( \frac{r}{R} \right)^3 - 0.9 \left( \frac{r}{R} \right)^5$$

## ***FALLING BALL VISOMETER*** ***(Continued)***

**If the ball falls under constant velocity**

$$U_a = \frac{h_t}{t}$$

**Then**

$$\mu_o = \frac{2 r^2 (\rho_S - \rho_f) g t C_f}{h_t}$$

**Where**

$\rho$  - density (N Sec<sup>2</sup>/m<sup>4</sup>)

$r$  - ball radius (m)

$h_t$  - height from which the sphere falls (m)

$R$  - radius of the tube (m)

## ***SHEAR STRESS SHEAR STRAIN RELATIONSHIP***

- **Newton's Law of Fluids indicates that**

$$\mu_e = \frac{\tau}{S}$$

**where**

$$S = \frac{\partial u}{\partial z}$$

**The above equation indicates that as shear strain increases, shear stress increases.**

**However, many lubricants in concentrated contacts do not exhibit this behavior. Therefore, models have been developed to predict more closely the behavior of shear stress and shear strain.**

- 2. l  
c  
s  
d  
e
- 3. C  
a  
a

$q \sim$  Volume flow rate  
 $q \sim$  for pipe flow  
 is  $\int_0^a 2\pi r dr$

$$q = 2\pi \int_0^a v r dr$$

$\frac{a}{2} \quad \frac{r}{2}$

$q \sim$  vol. flow rate / unit time  
 $q \propto \frac{1}{E}$

or other foreign debris is and by the rotation of the bearing material, scoring this dirt determines the ll.

lity is a measure of the gnment between the shaft produced in manufactur-

- if the parts. Usually, bearing materials having a low modulus of elasticity (low E) are readily conformable.
- 4. **Corrosion resistance.** The bearing material should be resistant to attack by the lubricant or any of the oxidation products produced during lubricant degradation. For example, lubricating oils without oxidation inhibitors produce organic acids, which attack and corrode certain bearing materials. The selection of materials for use with water as the lubricant is of necessity limited to corrosion-resistant materials.
- 5. **Fatigue resistance.** High fatigue resistance is necessary in applications in which the load changes direction or in which the load intensity varies cyclically. Fatigue failures appear initially as cracks in the bearing surface. These cracks propagate throughout the bearing material, interconnecting with other cracks and resulting in loose pieces of bearing material. Fatigue strength is particularly important where cyclic loading is present.

TABLE 5.1 Properties and characteristics of various conformal bearing metals  
 [From Clauser (1948)]

Bearing metal	Brinell hardness number		Load-carrying capacity		Maximum operating temperature		Fatigue strength <sup>a</sup>	Antiseizure <sup>a</sup> property	Conformability and embeddability <sup>a</sup>
	Room temperature	149 °C (300 °F)	MPa	psi	°C	°F			
Tin-base babbitt	20-30	6-12	5.5-10.4	800-1500	149	300	3	1	1
Lead-base babbitt	15-20	6-12	5.5-8.3	800-1200	149	300	↓	↓	↓
Alkali-hardened lead	22-26	11-17	8.3-10.4	1200-1500	260	500	↓	2	2
Cadmium base	30-40	15	10.4-13.8	1500-2000	260	500	2	3	3
Copper lead	20-30	20-23	10.4-17.2	1500-2500	177	350	2	1	↓
Tin bronze	60-80	60-70	>27.6	>4000	260+	500+	1	3	↓
Lead bronze	40-70	40-60	20.7-31.1	3000-4500	232-260	450-500	1	3	↓
Phosphor bronze	75-100	65-100	>27.6	>4000	260+	500+	2	2	↓
Aluminum alloy	45-50	40-45	>27.6	>4000	107-149	225-300	2	2	↓
Silver (overplated)	25	25	>27.6	>4000	260+	500+	1	2	↓
Copper-nickel matrix	10	7	>27.6	>4000	177	350	2	1	↓
Trimetal and plated	(b)	(b)	>27.6	>4000	107-149	225-300	↓	↓	↓
Grid type									
Thin babbitt overlay, 0.051-0.178 mm (0.002-0.007 in.)			13.8	2000	149	300	↓	↓	↓
Conventional babbitt overlays, 0.51 mm (0.020 in.)			10.4	1500	149	300	↓	↓	↓

<sup>a</sup>This is an arbitrary scale with 1 being the highest rating.  
<sup>b</sup>Approximately the same as the babbitts.

biological elements  
 ial characteristics if  
 racteristics that will  
 ounterface materials;  
 ability to enable the  
 and deflection in the  
 re resistance.

ation depends on (1)  
 e of lubricant (grease,  
 is (temperature, pres-  
 at can satisfy all the  
 ection must be made  
 ary importance in the

dynamic bearing is one  
 a lubricant film, there  
 the bearing come into  
 rub, localized heating  
 welds can fracture. This  
 h the shaft and bearing  
 resist welding and

## ***BEARING TYPES***

- Bearings are used to support, load while allowing the relative motion inherent in the mechanism to take place.
- There are many different types of bearings. Some examples include:
- **Journal bearing**
  - dry rubbing
  - impregnated
  - lubricated
- **Rolling element bearing**
  - ball
  - roller (tapered, spherical, etc.)
- **Thrust bearing**
- However, bearings can be classified in general in two categories:
  - conformal
  - non-conformal

# REYNOLDS LUBRICATION EQUATION

- Reynolds equation describes the fluid pressure formation between bodies in relative motion

## Assumptions:

- Gravitational and inertial forces are negligible
- Pressure is constant across the film
- Lubricant flow is laminar
- No slip at the boundary surfaces
- Film thickness is small compared with the other dimensions
- Newtonian lubricant

$\mu_0 \sim$  dynamic viscosity

Surfaces although smooth in appearance

they are rough in nature

Peak.  
asperity



film thickness  $\frac{\lambda}{6}$

- Common surface roughnesses used in

lubrication .01 to 10  $\mu\text{m}$ .

Atomic Scales .0001 to .001  $\mu\text{m}$

## Geometric Characteristics of Surfaces.

