ENVE 2061
Basic Fluid Mechanics

VISCOSITY

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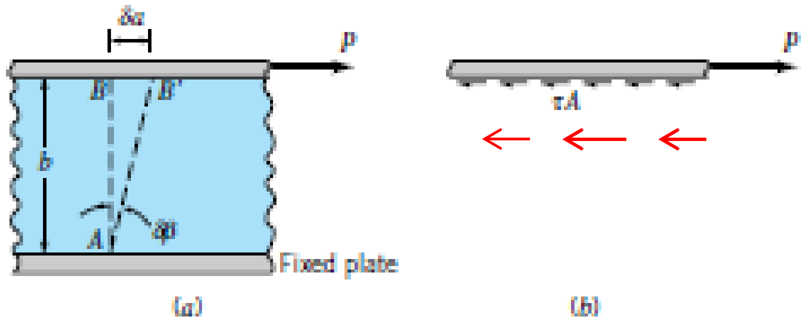

P = Force applied to the plate
τA = Friction force

Friction force develops ;

when a fluid moves relative to a solid (e.g. pipes, channels)

when two fluids move relative to each other

Viscocity is the property that represents the internal resistance of fluid to motion

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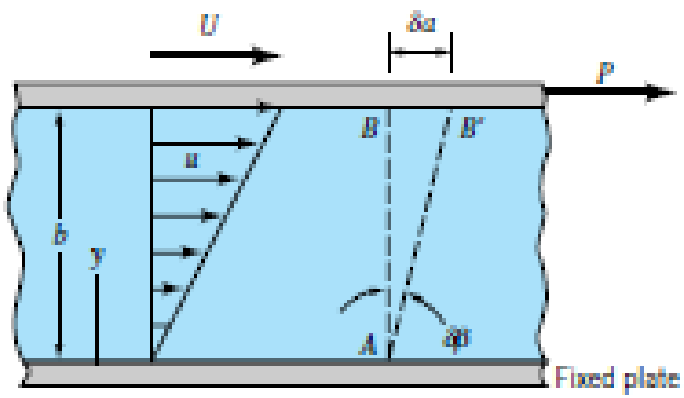

After the initial transients, upper plate moves continuously under the influence of the force (P) at a constant velocity, U

The fluid in contact with the upper plate stick to the plate surface and moves with it at the same velocity.

$$\tau = \frac{P}{A}$$

Shear stress

Contact area between the plate & fluid

The fluid in contact with the lower plate assumes the velocity of that plate, which is zero (no-slip condition)

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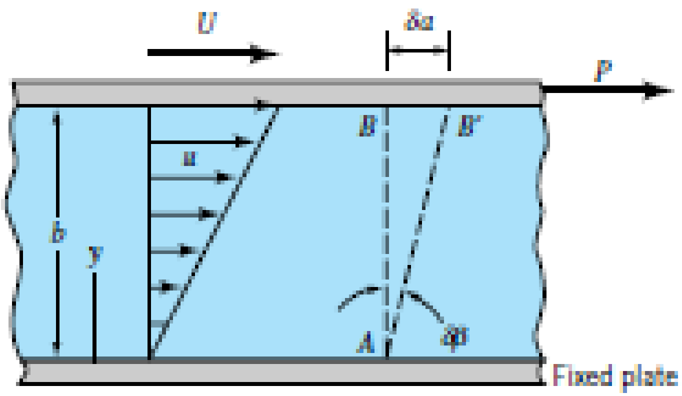


At steady operation:

$$\frac{U}{b} = \frac{du}{dy}$$

$\frac{du}{dy}$= velocity gradient (change of velocity with y)

y= vertical distance from the lower plate

During a differential time interval, dT, the fluid particles along a vertical line AB rotate through a differential angle dβ while the upper plate moves a differential distance da.

da=U.dt

dβ=tanβ=$\frac{da}{b}$=$\frac{U.dt}{b}$=$\frac{\left(\frac{du}{dy}xb\right)dt}{b}$ =$\frac{du}{dy}$ dt   the rate of deformation = rate of velocity gradient

For most fluids, the rate of deformation is directly proportional to the shear stress, τ

Units for Dynamic Viscosity

Many different unit systems are used to express viscosity. The systems used most frequently are described here for dynamic viscosity and in the next section for kinematic viscosity. Summary tables listing many conversion factors are included in Appendix K.

The definition of dynamic viscosity can be derived from Eq. (2–1) by solving for μ:

$$\mu = \frac{\tau}{\Delta v / \Delta y} = \tau\left(\frac{\Delta y}{\Delta v}\right) \tag{2–2}$$

The units for η can be derived by substituting the SI units into Eq. (2–2) as follows:

$$\mu = \frac{\mathrm{N}}{\mathrm{m}^2} \times \frac{\mathrm{m}}{\mathrm{m/s}} = \frac{\mathrm{N{\cdot}s}}{\mathrm{m}^2}$$

Because Pa is another name for $\mathrm{N/m^2}$, we can also express μ as

$$\mu = \mathrm{Pa{\cdot}s}$$

Sometimes, when units for μ are being combined with other terms—especially density—it is convenient to express μ in terms of kg rather than N. Because $1\ \mathrm{N} = 1\ \mathrm{kg{\cdot}m/s^2}$, μ can be expressed as

$$\mu = \mathrm{N} \times \frac{\mathrm{s}}{\mathrm{m}^2} = \frac{\mathrm{kg{\cdot}m}}{\mathrm{s}^2} \times \frac{\mathrm{s}}{\mathrm{m}^2} = \frac{\mathrm{kg}}{\mathrm{m{\cdot}s}}$$

Dynamic Viscosity Units in Different Unit Systems

Unit System	Dynamic Viscosity Units
International System (SI)	$N \cdot s/m^2$, $Pa \cdot s$, or $kg/(m \cdot s)$
U.S. Customary System	$lb \cdot s/ft^2$ or $slug/(ft \cdot s)$
cgs system (obsolete)	poise = $dyne \cdot s/cm^2$ = $g/(cm \cdot s)$ = 0.1 $Pa \cdot s$
	centipoise = poise/100 = 0.001 $Pa \cdot s$ = 1.0 $mPa \cdot s$

KINEMATIC & DYNAMIC VISCOSITY

$$\tau = \mu \frac{du}{dy} \ \left(\frac{N}{m^2}\right)$$

Shear stress

μ= Constant of proportionality is called the dynamic viscosity, kg.m/s or N.s/m^2

$$\boldsymbol{\upsilon} = \mu/\rho$$

Density

Kinematic viscosity

Dynamic viscosity

Units for Kinematic Viscosity

We can derive the SI units for kinematic viscosity by substituting the previously developed units for μ and ρ:

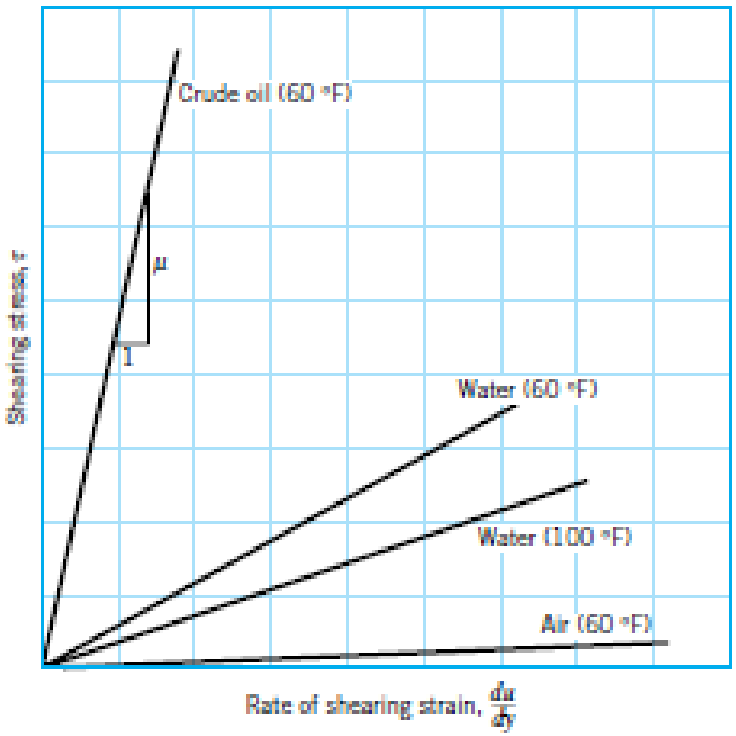
$$\nu = \frac{\mu}{\rho} = \mu\left(\frac{1}{\rho}\right)$$

$$\nu = \frac{\text{kg}}{\text{m}\cdot\text{s}} \times \frac{\text{m}^3}{\text{kg}}$$

$$\nu = \text{m}^2/\text{s}$$

Newtonian & Non-newtonian Fluids

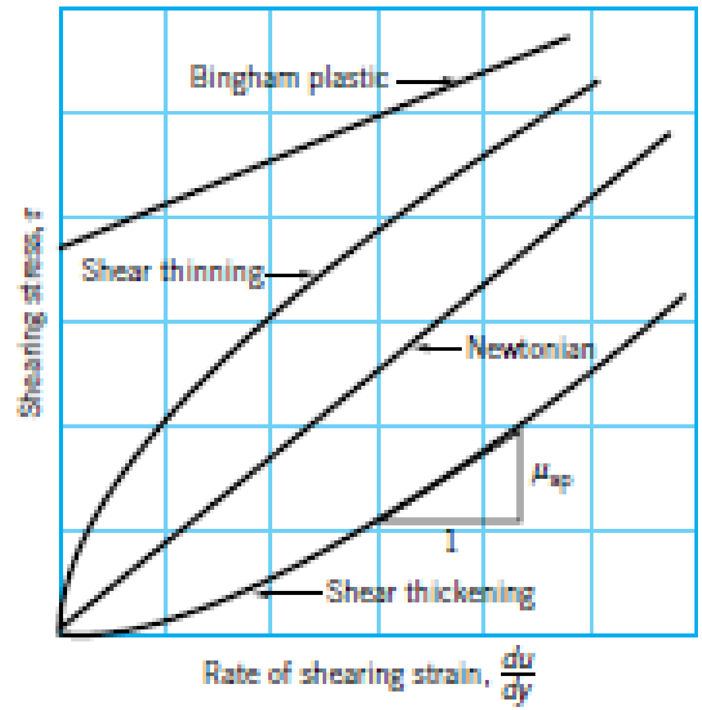
Newtonian Fluids



Rate of deformation is proportional to shear stress

e.g. water, air, gasoline

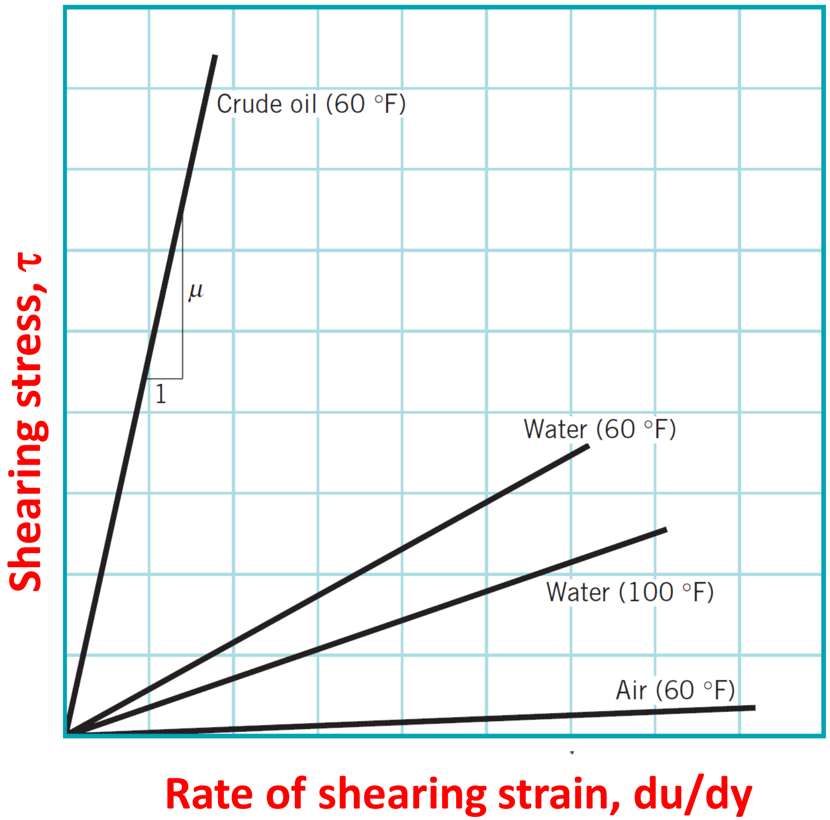
Non-newtonian Fluids



The relationship between shear stress and the rate of deformation is not linear.

Blood & liquid plastics

Newtonian Fluids



Plots of τ versus du/dy should be linear with the slope equal to the viscosity(μ).

Value of the viscosity depends on the particular fluid, and for a particular fluid the viscosity is also highly dependent on **temperature**

Fluids for which the shearing stress is *linearly* related to the rate of shearing strain are designated as ***Newtonian fluids.***

$\mu = \tau/(\mathrm{du}/\mathrm{dy}) \rightarrow \tau = \mu .\, (\mathrm{du}/\mathrm{dy})$

Rate of deformation is proportional to shear stress

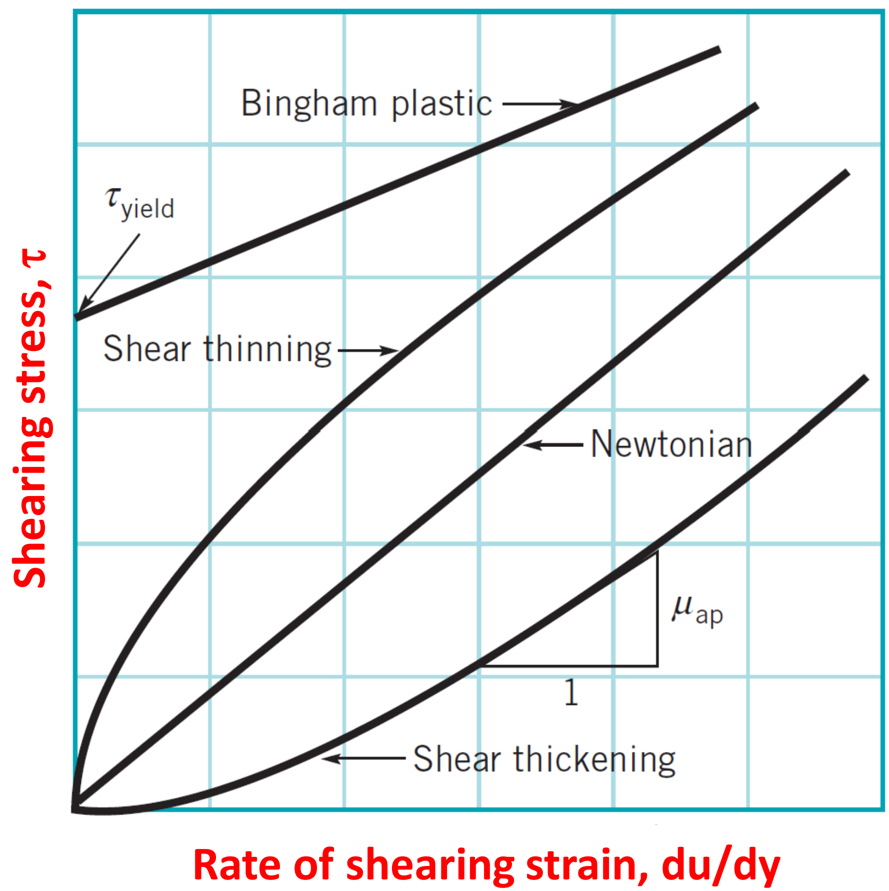
e.g. water, air, gasoline

Non-newtonian Fluids

Fluids for which the shearing stress is not linearly related to the rate of shearing strain are designated as ***non-Newtonian fluids.***

The slope of the shearing stress versus rate of shearing strain graph is denoted as the *apparent viscosity*(***μap***).

For Newtonian fluids the apparent viscosity is the same as the viscosity and is independent of shear rate.



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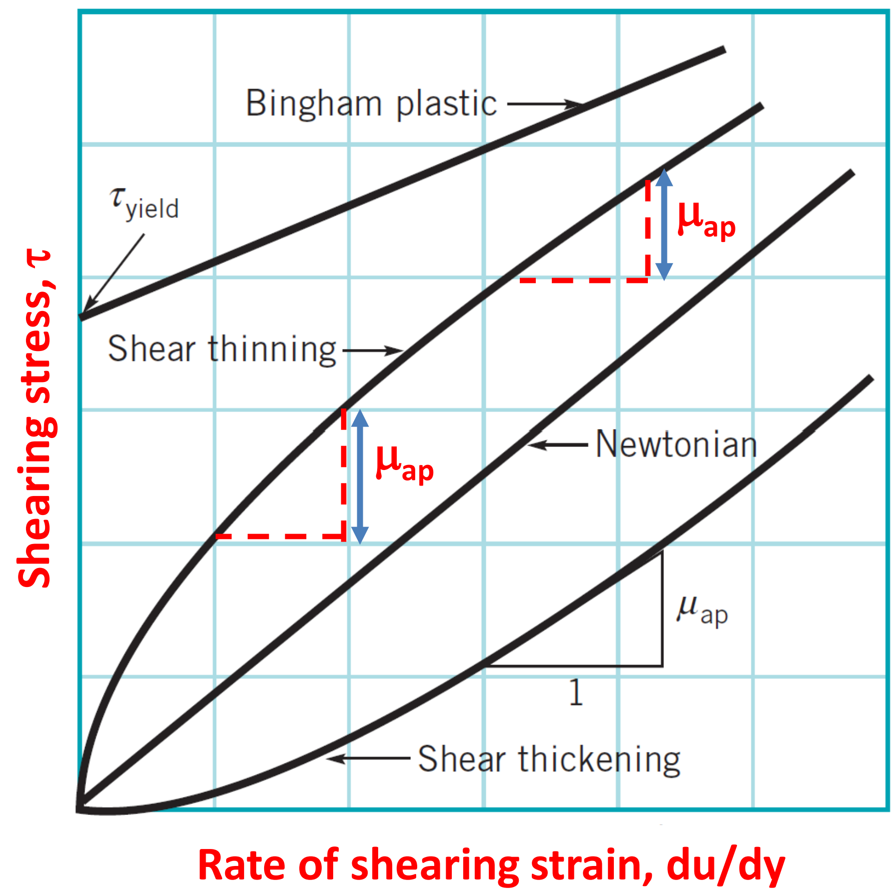
Non-newtonian Fluids

For *shear thinning fluids* the apparent viscosity decreases with increasing shear rate—the harder the fluid is sheared, the less viscous it becomes. Many colloidal suspensions and polymer solutions are shear thinning.

For example, latex paint does not drip from the brush because the shear rate is small and the apparent viscosity is large. However, it flows smoothly onto the wall because the thin layer of paint between the wall and the brush causes a large shear rate and a small apparent viscosity.

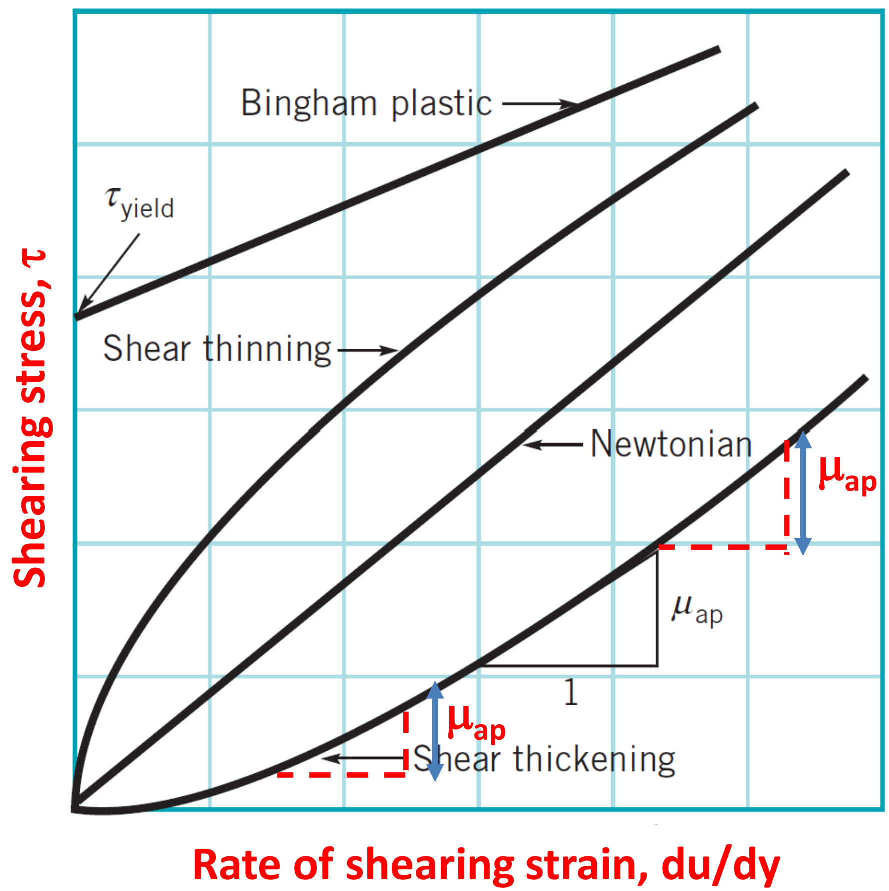


https://www.youtube.com/watch?v=kC6yJWcli60

Non-newtonian Fluids

For *shear thickening fluids*the apparent viscosity increases with increasing shear rate—the harder the fluid is sheared, the more viscous it becomes.

Common examples of this type of fluid include water–corn starch mixture and water–sand mixture(“quicksand”). Thus, the difficulty in removing an object from quicksand increases dramatically as the speed of removal increases.

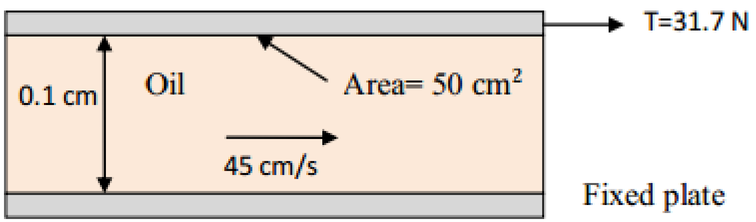


Viscosity & Temperature

TABLE 1.3 Viscosities of Water and Air

Temperature (°C)	Water: Viscosity (μ) $N \cdot sec/m^2$	Water: Kinematic Viscosity (ν) m^2/sec	Air: Viscosity (μ) $N \cdot sec/m^2$	Air: Kinematic Viscosity (ν) m^2/sec
0	1.781×10^{-3}	1.785×10^{-6}	1.717×10^{-5}	1.329×10^{-5}
5	1.518×10^{-3}	1.519×10^{-6}	1.741×10^{-5}	1.371×10^{-5}
10	1.307×10^{-3}	1.306×10^{-6}	1.767×10^{-5}	1.417×10^{-5}
15	1.139×10^{-3}	1.139×10^{-6}	1.793×10^{-5}	1.463×10^{-5}
20	1.002×10^{-3}	1.003×10^{-6}	1.817×10^{-5}	1.509×10^{-5}
25	0.890×10^{-3}	0.893×10^{-6}	1.840×10^{-5}	1.555×10^{-5}
30	0.798×10^{-3}	0.800×10^{-6}	1.864×10^{-5}	1.601×10^{-5}
40	0.653×10^{-3}	0.658×10^{-6}	1.910×10^{-5}	1.695×10^{-5}
50	0.547×10^{-3}	0.553×10^{-6}	1.954×10^{-5}	1.794×10^{-5}
60	0.466×10^{-3}	0.474×10^{-6}	2.001×10^{-5}	1.886×10^{-5}
70	0.404×10^{-3}	0.413×10^{-6}	2.044×10^{-5}	1.986×10^{-5}
80	0.354×10^{-3}	0.364×10^{-6}	2.088×10^{-5}	2.087×10^{-5}
90	0.315×10^{-3}	0.326×10^{-6}	2.131×10^{-5}	2.193×10^{-5}
100	0.282×10^{-3}	0.294×10^{-6}	2.174×10^{-5}	2.302×10^{-5}

Example 17.1(Example 1.2, Hwang, 4th Edition) A flat plate of 50 cm^2 is being pulled over a fixed flat surface at a constant velocity of 45 cm/s. An oil film of unknown viscosity separates the plate and the fixed surface by a distance of 0.1 cm. The force (T) required to pull the plate is measured to be 31.7 N, and the viscosity of the fluid is constant. Determine the viscosity (absolute).



$$\tau = \mu \times \frac{du}{dy} = \mu \times \frac{V}{l}$$

$$\text{Force} = \tau \times A$$

$$\text{Force} = (\mu \times \frac{V}{l}) \times (\text{Area})$$

$$31.7\ \text{N} = \mu \times \left(\frac{45\ \text{cm/sec}}{0.1\ \text{cm}}\right) \times (50\ \text{cm}^2)$$

$$\mu = \frac{31.7\ \text{N}}{\left(\frac{45\ \text{cm/sec}}{0.1\ \text{cm}}\right) \times (50\ \text{cm}^2) \times \frac{1\ \text{m}^2}{100\ \text{cm}^2}}$$

$$\mu = 14.1\ \text{N.sec/m}^2$$