ENVE2061
Basic Fluid Mechanics

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Analysis of Fluid Behavior

Measures of Fluid Mass & Weight: Density, Specific Weight, Specific Gravity

Ideal Gas Law

Viscosity

Analysis of Fluid Behavior

The study of fluid mechanics involves the same fundamental laws encountered in physics
and other mechanics courses.

These laws include

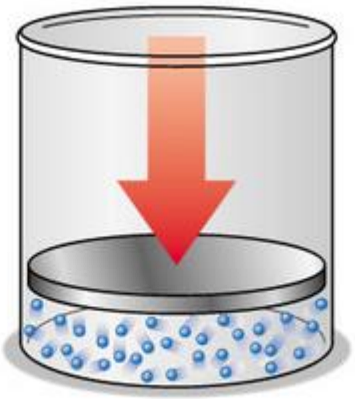
Newton’s laws of motion,
conservation of mass, and
the first and second laws of thermodynamics.

Analysis of Fluid Behavior

FLUID MECHANICS

- Fluid Statics: The fluid is at rest (not moving)
- Fluid Dynamics: The fluid is moving

Analysis of Fluid Behavior



It is important to define and discuss certain fluid *properties* that are intimately related to fluid behavior.

Different fluids can have grossly different characteristics:

Gases are light and compressible, whereas liquids are heavy by comparison and relatively incompressible.

A syrup flows slowly from a container, but water flows rapidly when poured from the same container.

To quantify these differences, certain fluid properties are used.

Measures of Fluid MASS & WEIGHT:

DENSITY (ρ)

The density of a fluid:
Its mass per unit volume. Typically used to characterize the mass of a fluid system.

Symbol used: ρ (rho)

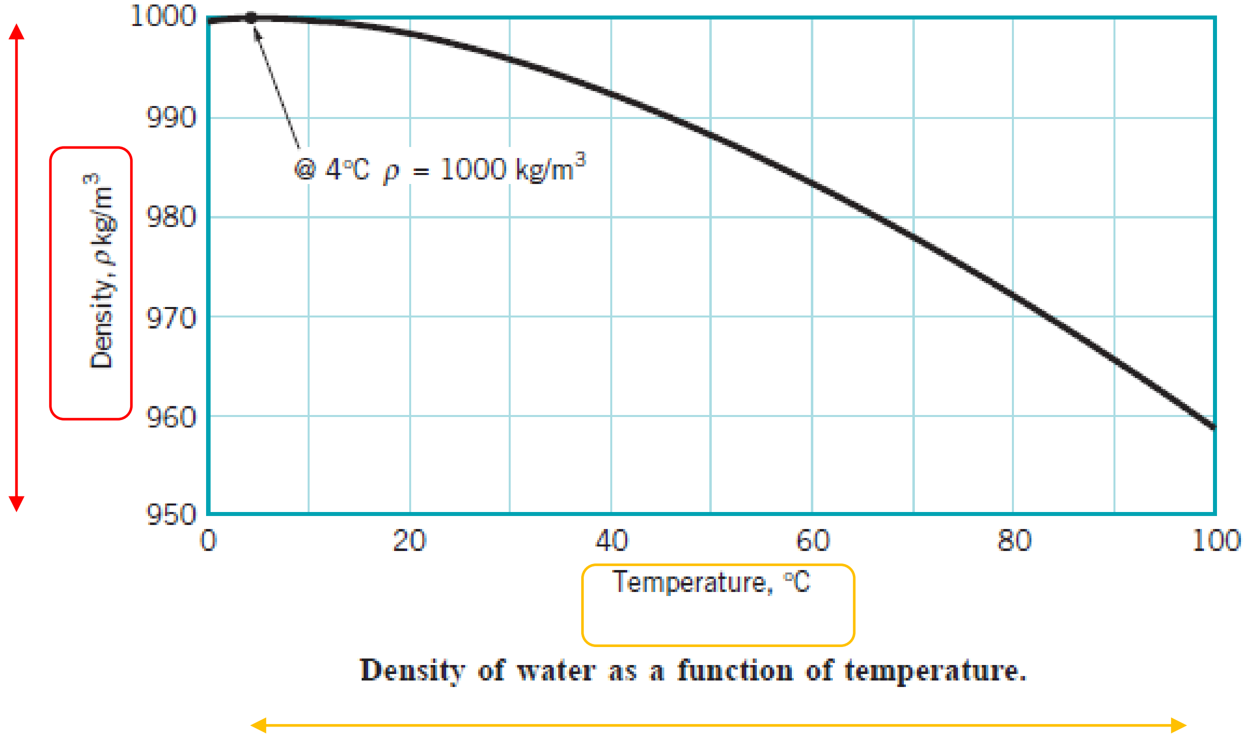
$$Density = \frac{mass}{volume} = \rho = \frac{m}{\forall}$$

Units:
In the BG system: **slugs/ft³**
In SI: **kg/m³**

$$\frac{mass}{volume} = \frac{M}{L^3}$$

Measures of Fluid MASS & WEIGHT:

DENSITY (ρ)



Density of water as a function of temperature.

for LIQUIDS:
Variations in pressure and temperature generally have only a small effect on the value of ρ.

Density of a gas is strongly influenced by both pressure and temperature.

Measures of Fluid MASS & WEIGHT:

DENSITY (ρ)

Specific volume (ϑ):

Volume per unit mass → reciprocal of density

$$v = \frac{1}{\rho}$$

Specific volume is not commonly used in fluid mechanics. It is used in thermodynamics.

Measures of Fluid MASS & WEIGHT:

SPECIFIC WEIGHT (γ)

The specific weight of a fluid:
Its weight per unit volume. Typically used to characterize the weight of a fluid system.

Symbol used: γ (gamma)

Measures of Fluid MASS & WEIGHT:

SPECIFIC WEIGHT $\gamma = \rho g$

weight per unit volume

$$\gamma = \frac{Weight}{Volume} = \frac{W}{\forall} = \frac{mg}{\forall} = \rho g$$

$$\left[Density = \frac{mass}{volume} = \rho = \frac{m}{\forall}\right]$$

Units:
In the BG system: **lb/ft^3**
In SI: **N/m^3**

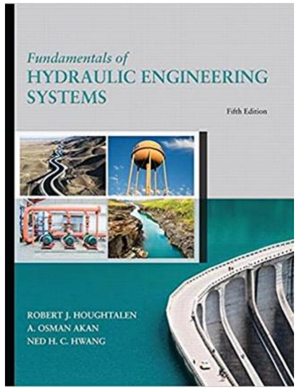
$$\frac{weight}{volume} = \frac{F}{L^3}$$

Under conditions of standard gravity (g = 9.807 m/s^2 = 32.174 ft/s^2)

Water at 60 ^{o}F (15.5 ^{o}C) has a specific weight of 9.80 kN/m^3 and 62.4 lb/ft^3

TABLE 1.2 Density and Specific Weight of Water

Temperature (°C)	Density (ρ, kg/m^3)	Specific Weight (γ, N/m^3)
0° (ice)	917	8,996
0° (water)	999	9,800
4°	1,000	9,810
10°	999	9,800
20°	998	9,790
30°	996	9,771
40°	992	9,732
50°	988	9,692
60°	983	9,643
70°	978	9,594
80°	972	9,535
90°	965	9,467
100°	958	9,398



Measures of Fluid MASS & WEIGHT:

SPECIFIC GRAVITY (SG)

The specific gravity of a fluid:
Ratio of the density of the fluid to the density of water at specified temperature.

Usually taken as
4 ^{o}C (39.2 ^{o}F)

Symbol used: SG

$$SG_{fluid} = \frac{\rho_{fluid}}{\rho_{H_2O\ at\ 4^oC}}$$

$$\rho_{H_2O\ at\ 4^oC} = 1000\ \mathrm{kg/m^3}$$
$$\rho_{H_2O\ at\ 4^oC} = 1.94\ slugs/ft^3$$

Units:
In the BG system: **-**
In SI: **-**
(ratio of densities → dimensionless)

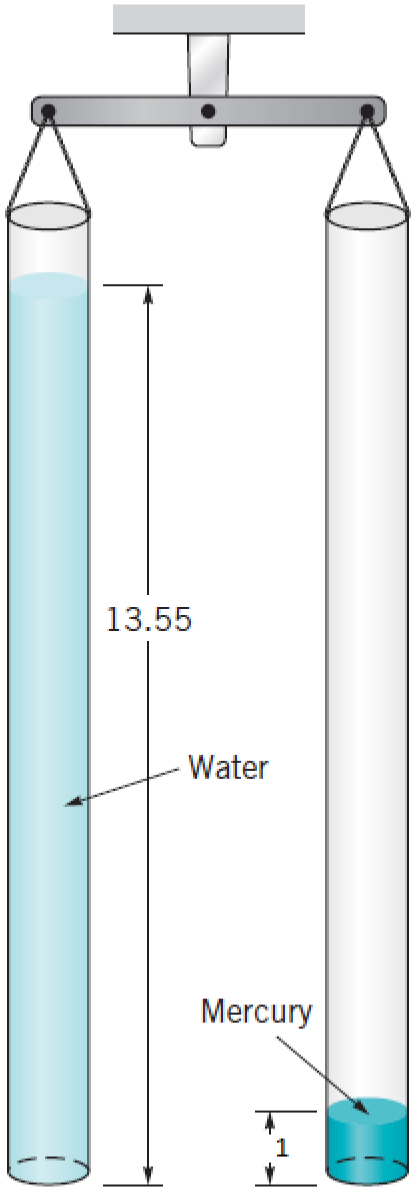
Measures of Fluid MASS & WEIGHT:

SPECIFIC GRAVITY (SG)

$$\rho_{fluid} = (SG_{fluid})(\rho_{H_2O\ at\ 4^oC})$$

$$\rho_{Hg} = (13.55)(1000\ \mathrm{kg/m^3}) = 13.6\ x\ 103\ \mathrm{kg/m^3}$$

$$\rho_{Hg} = (13.55)(1.94\ \mathrm{slugs/ft^3}) = 26.3\ \mathrm{slugs/ft^3}$$



Measures of Fluid MASS & WEIGHT

DENSITY (ρ)

$$Density = \frac{mass}{volume} = \rho = \frac{m}{\forall}$$

SPECIFIC GRAVITY (SG)

$$SG_{fluid} = \frac{\rho_{fluid}}{\rho_{H_2O\ at\ 4^oC}}$$

SPECIFIC WEIGHT (γ)

$$\gamma = \frac{Weight}{Volume} = \frac{W}{\forall} = \frac{\boldsymbol{m}g}{\forall} = \boldsymbol{\rho}g$$

- Density, specific weight, and specific gravity are all interrelated
- Knowing any one of the three, the others can be calculated.

Ideal Gas Law

Gases are highly compressible in comparison to liquids, with changes in gas density directly related to changes in pressure and temperature through the equation

$$\rho = \frac{p}{RT}$$

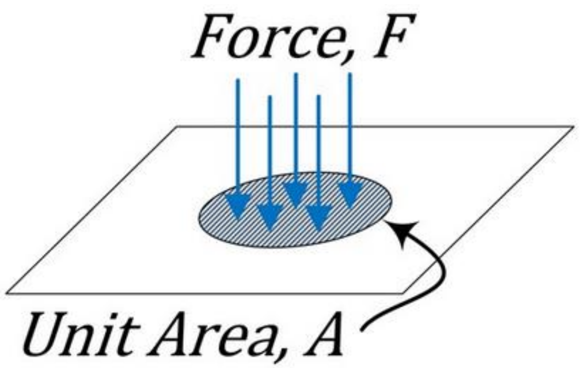
Ideal gas law ("perfect gas law" or "equation of state for an ideal gas")

p: **absolute** pressure
ρ : density
T: **absolute** temperature
R: gas constant

depends on the particular gas and is related to the molecular weight of the gas.

Ideal Gas Law

$$\rho = \frac{p}{RT}$$



Pressure in a fluid at rest is defined as the **normal force per unit area** exerted on a plane surface real or imaginary immersed in a fluid and is created by the bombardment of the surface with the fluid molecules.

$$\frac{F}{L^2}$$

in BG: $\frac{lb}{ft^2}$ (psf: pounds per square feet), $\frac{lb}{in^2}$ (psi: pounds per square inches)

in SI: $\frac{N}{m^2}$ (Pa: pascal)

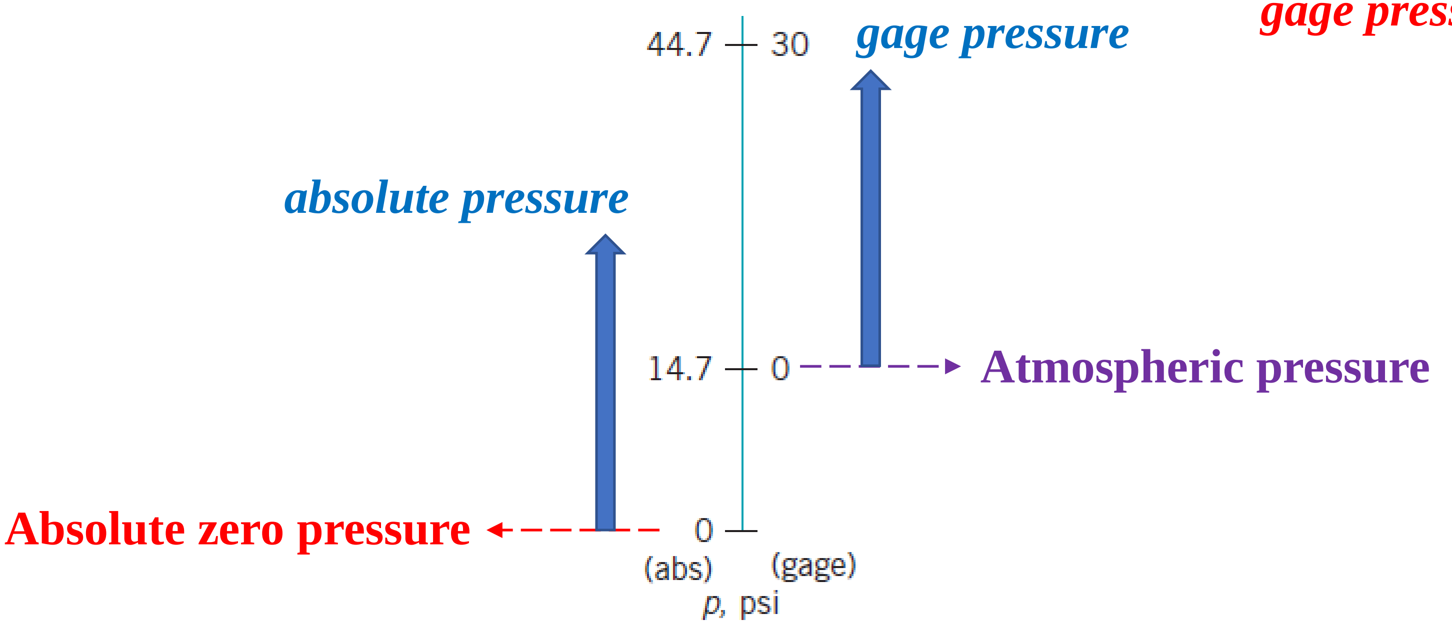
Ideal Gas Law

$$\rho = \frac{p}{RT}$$

The pressure in the ideal gas law must be expressed as an ***absolute pressure***, denoted (abs).
Means that it is measured relative to absolute zero pressure (a pressure that would only occur in a perfect vacuum).

In engineering it is common practice to measure pressure relative to the local atmospheric pressure, and when measured in this fashion it is called ***gage pressure*****.**

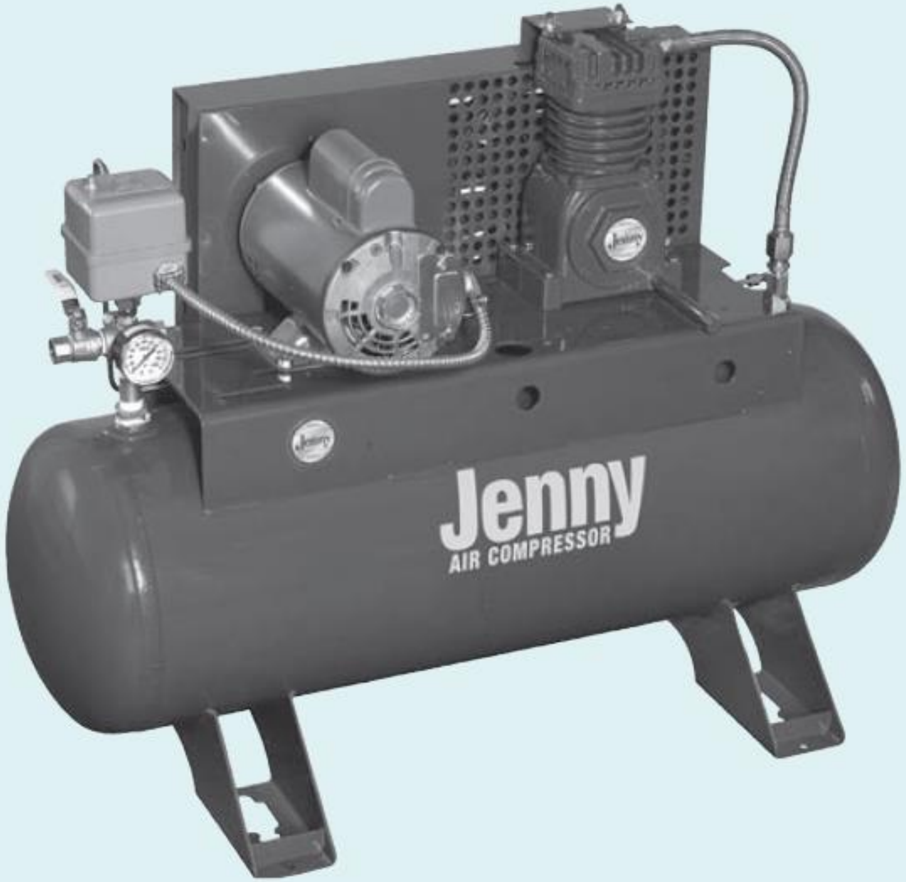
Standard sea-level atmospheric pressure (by international agreement) is **14.696 psi (abs)** or **101.33 kPa (abs)**. For most calculations these pressures can be rounded to <u>14.7 psi</u> and <u>101 kPa</u>, respectively.



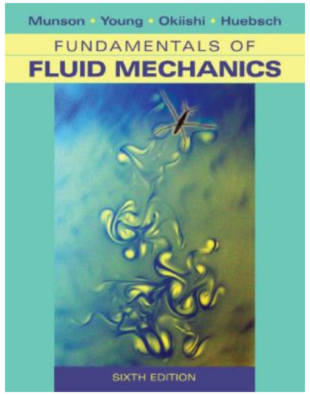
EXAMPLE 1.3 Ideal Gas Law

GIVEN The compressed air tank shown in Fig. E1.3*a* has a volume of 0.84 ft^3. The temperature is 70 °F and the atmospheric pressure is 14.7 psi (abs).

FIND When the tank is filled with air at a gage pressure of 50 psi, determine the density of the air and the weight of air in the tank.



■ FIGURE E1.3*a* (Photograph courtesy of Jenny Products, Inc.)



Viscosity

The properties of **density** and **specific weight** are measures of the "heaviness" of a fluid. ρ γ

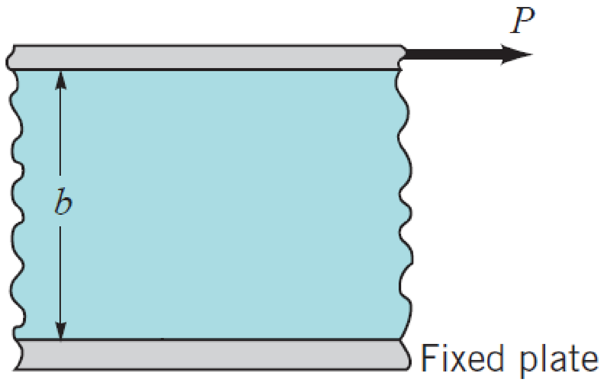
These properties are not sufficient to uniquely characterize how fluids behave since two fluids (such as water and oil) can have approximately the same value of density but behave quite differently when flowing.

There is apparently some additional property that is needed to describe the **"fluidity" of the fluid**.

Viscosity

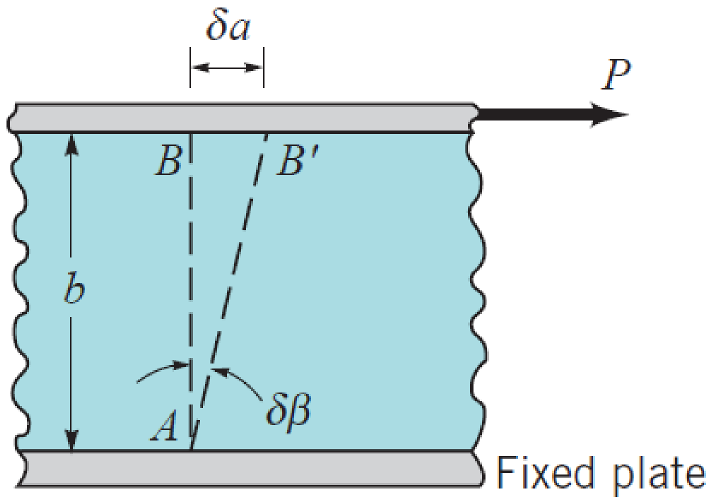
To determine this property, consider a hypothetical experiment:

A material is placed between two very wide parallel plates.
The bottom plate is rigidly fixed, but the upper plate is free to move.



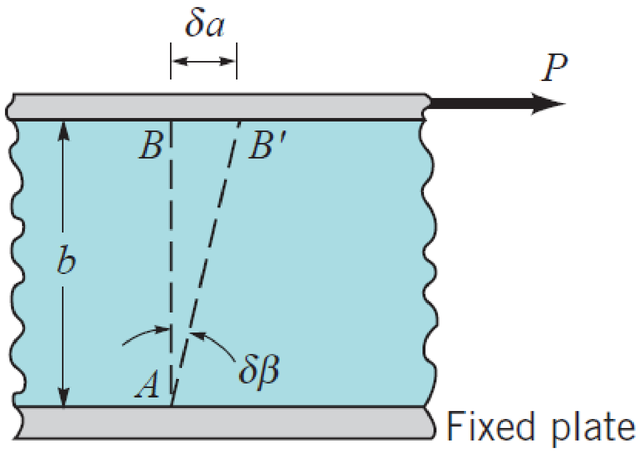
If a solid, such as steel, were placed between the two plates and loaded with the force ***P***, the top plate would be displaced through some small distance, ***δa*** (assuming the solid was mechanically attached to the plates).

The vertical line ***AB*** would be rotated through the small angle, ***δβ***, to the new position ***AB′***



Viscosity

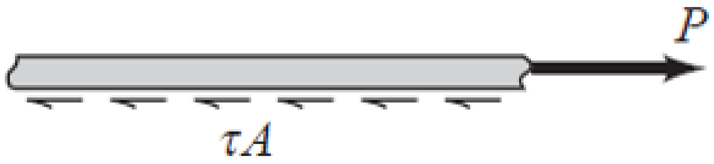
shearing stress, τ (**N/m²**) * upper plate area, A (**m²**) = applied force, P (**N**)



Deformation of material placed between two parallel plates.

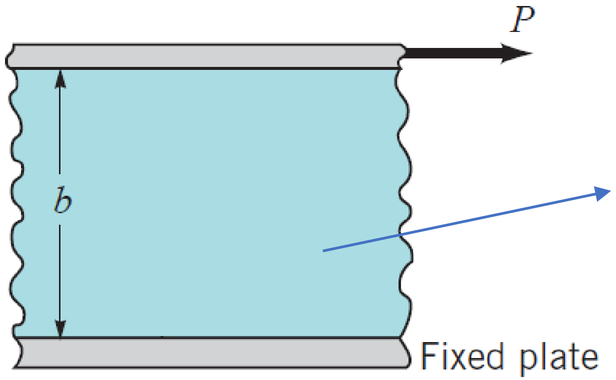
To resist the applied force, P, a shearing stress, τ, would be developed at the plate–material interface, and for equilibrium to occur, $\boldsymbol{P = \tau A}$ where A is the effective upper plate area.

It is well known that for elastic solids, such as steel, the small **angular displacement, $\delta\beta$** (called the shearing strain), **is proportional** to the **shearing stress, τ**, that is developed in the material.



Forces acting on upper plate.

Viscosity



What happens if the solid is replaced with a fluid such as water?

A major difference:

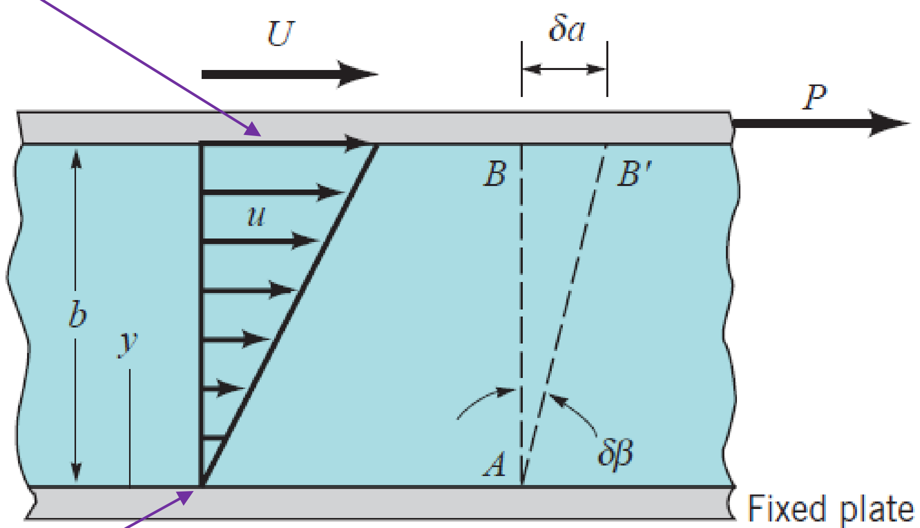
When the force P is applied to the upper plate, it will move continuously with a velocity, U.

This behavior is consistent with the definition of a fluid—that is, if a shearing stress is applied to a fluid, it will deform continuously.

- Fluid in contact with the upper plate moves with the plate velocity, U.
- Fluid in contact with the bottom fixed plate has a zero velocity.

Viscosity

Fluid in contact with the upper plate moves with the **plate velocity, *U***.



Fluid in contact with the bottom fixed plate has a **zero velocity**.

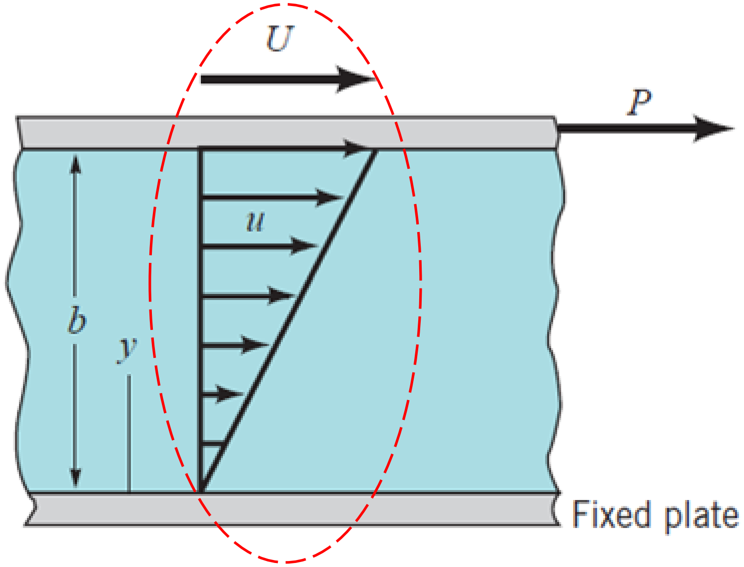
The experimental observation that the fluid "sticks" to the solid boundaries is a very important one in fluid mechanics and is usually referred to as the ***no-slip condition.***

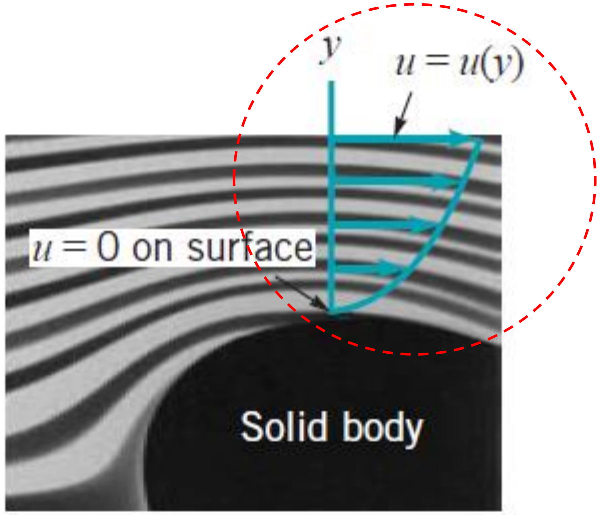
All fluids, both liquids and gases, satisfy this condition.

Viscosity

A velocity gradient (du/dy) is developed in the fluid between the plates

$$u = u(y)$$



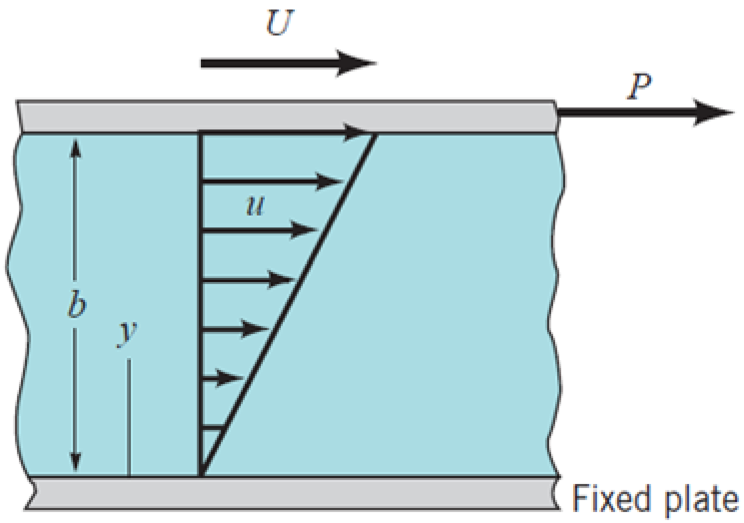


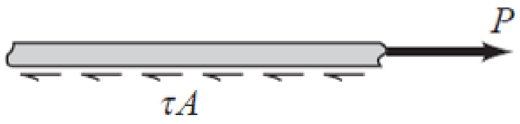
du/dy is more complex in situations as above

In this case velocity changes linearly, $u = U\frac{y}{b}$

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

Viscosity





As the **shearing stress** (τ), is increased by increasing P ($P = \tau A$) the rate of shearing strain is increased in direct proportion

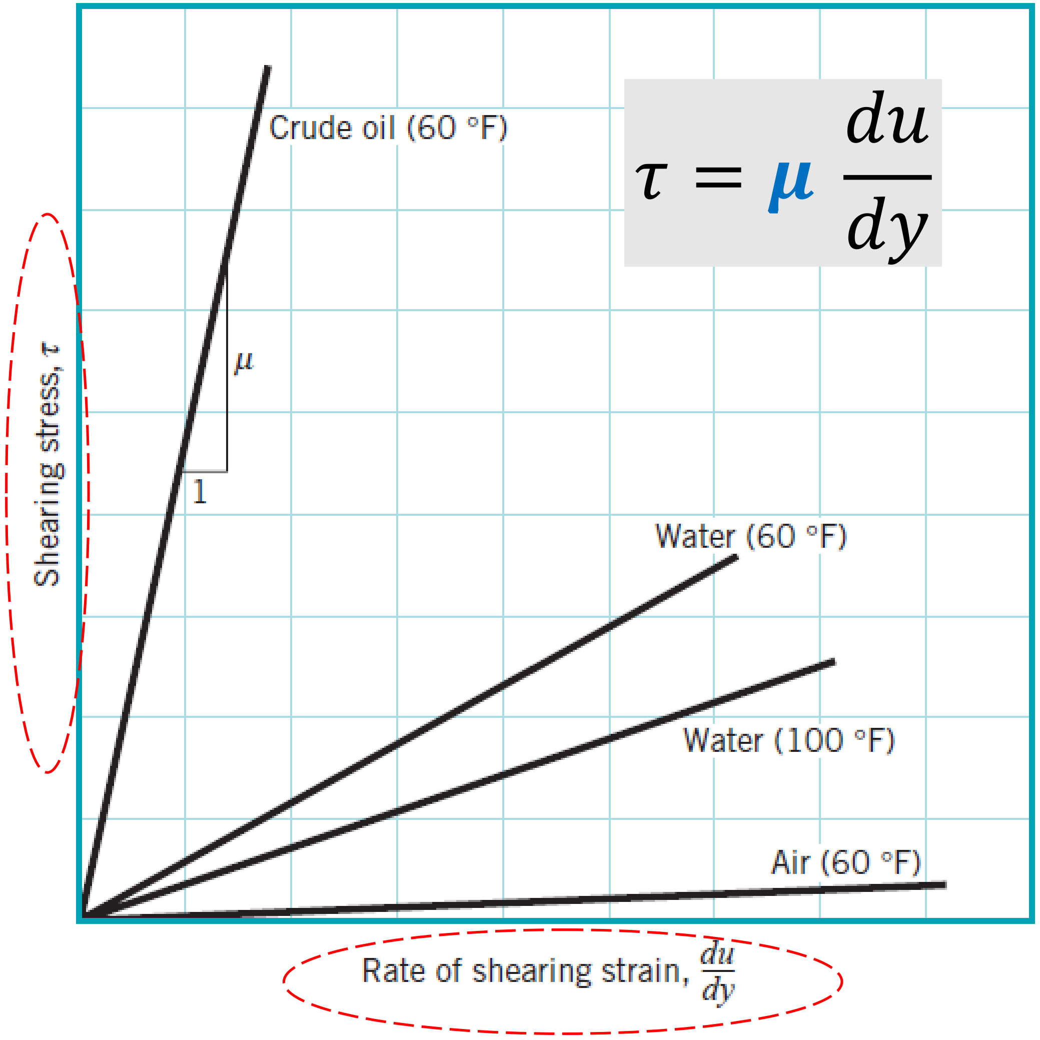
$$\tau \propto \frac{du}{dy}$$

This result indicates that for common fluids such as water, oil, gasoline, and air the shearing stress and rate of shearing strain (velocity gradient) can be related with a relationship of the form

Constant of proportionality, μ, (mu) is called the ***absolute viscosity***, ***dynamic viscosity***, or simply the ***viscosity*** of the fluid

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

Viscosity



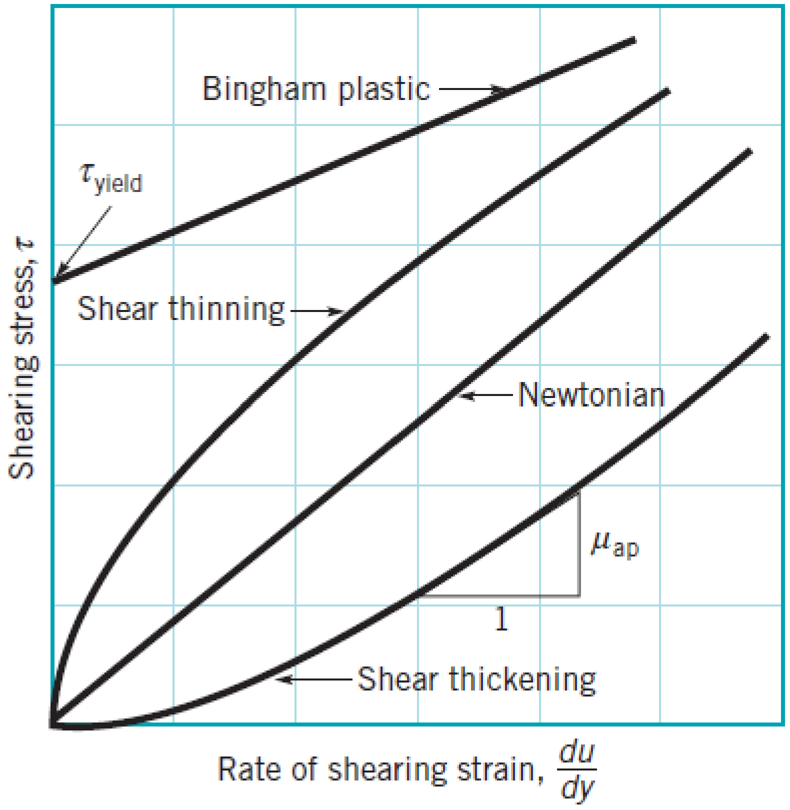
Linear variation of shearing stress with rate of shearing strain for common fluids.

Plots of τ versus $\dfrac{du}{dy}$ 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 (see the 2 curves for water).

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

Viscosity



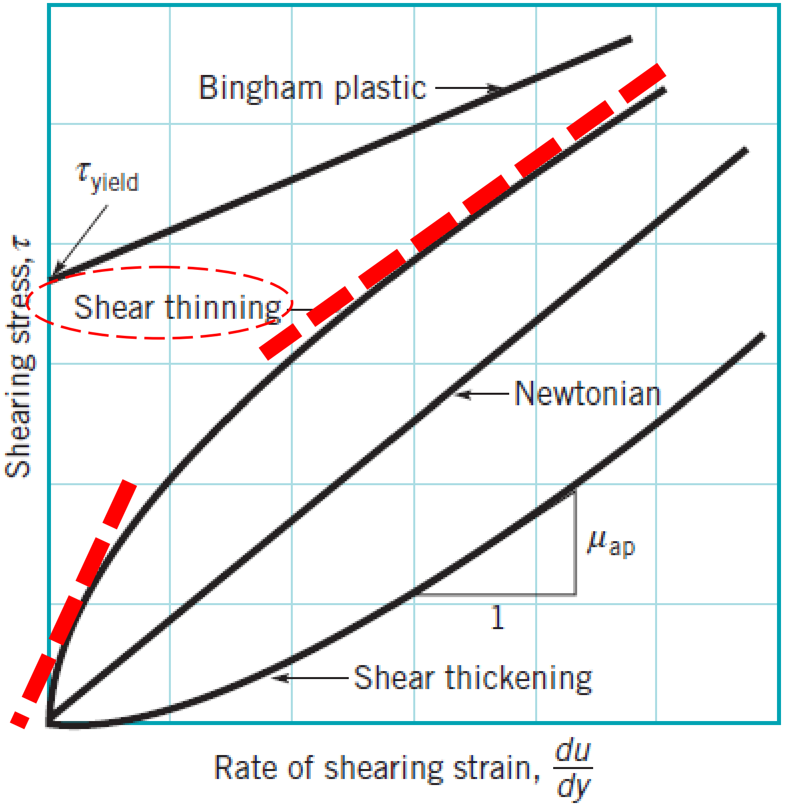
Variation of shearing stress with rate of shearing strain for several types of fluids, including common non-Newtonian fluids.

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* (μ_{ap}).

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

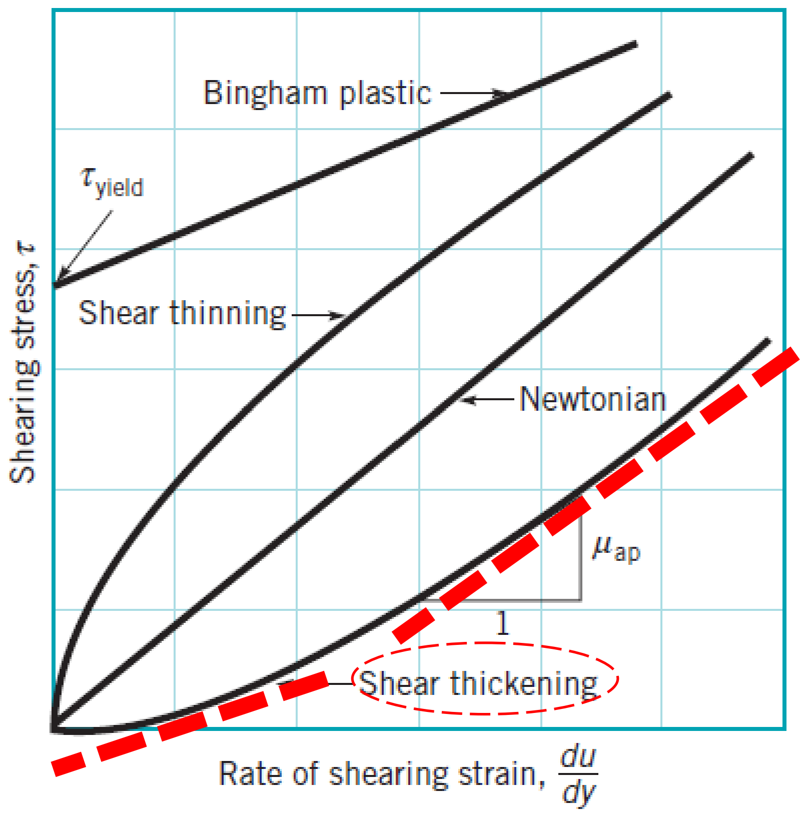
Viscosity



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.

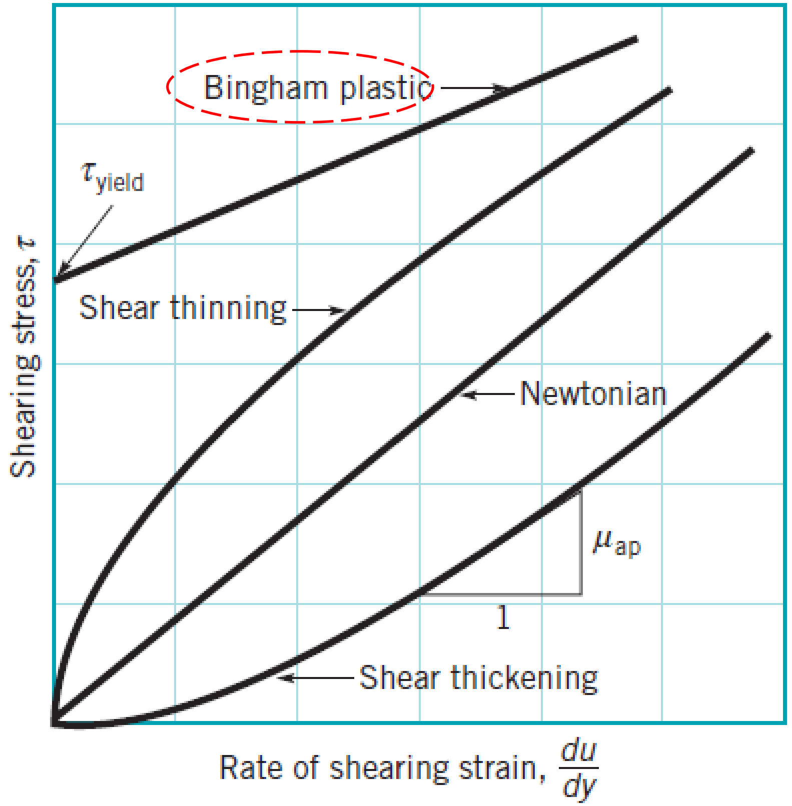
Viscosity



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

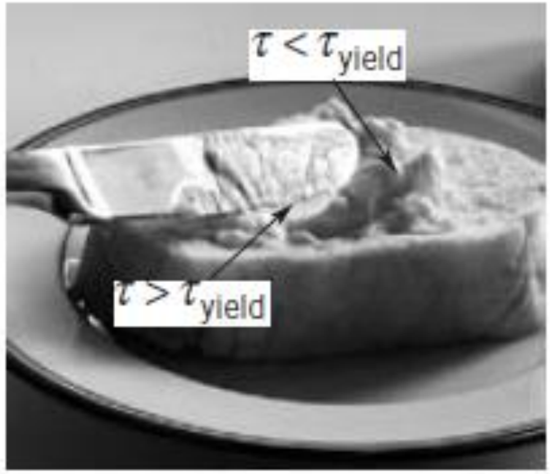
Common examples of this type of fluid include water–corn starch mixture and water–sand mixture (“quicksand”). Thus, the difficulty in removing an object from quicksand increases dramatically as the speed of removal increases.

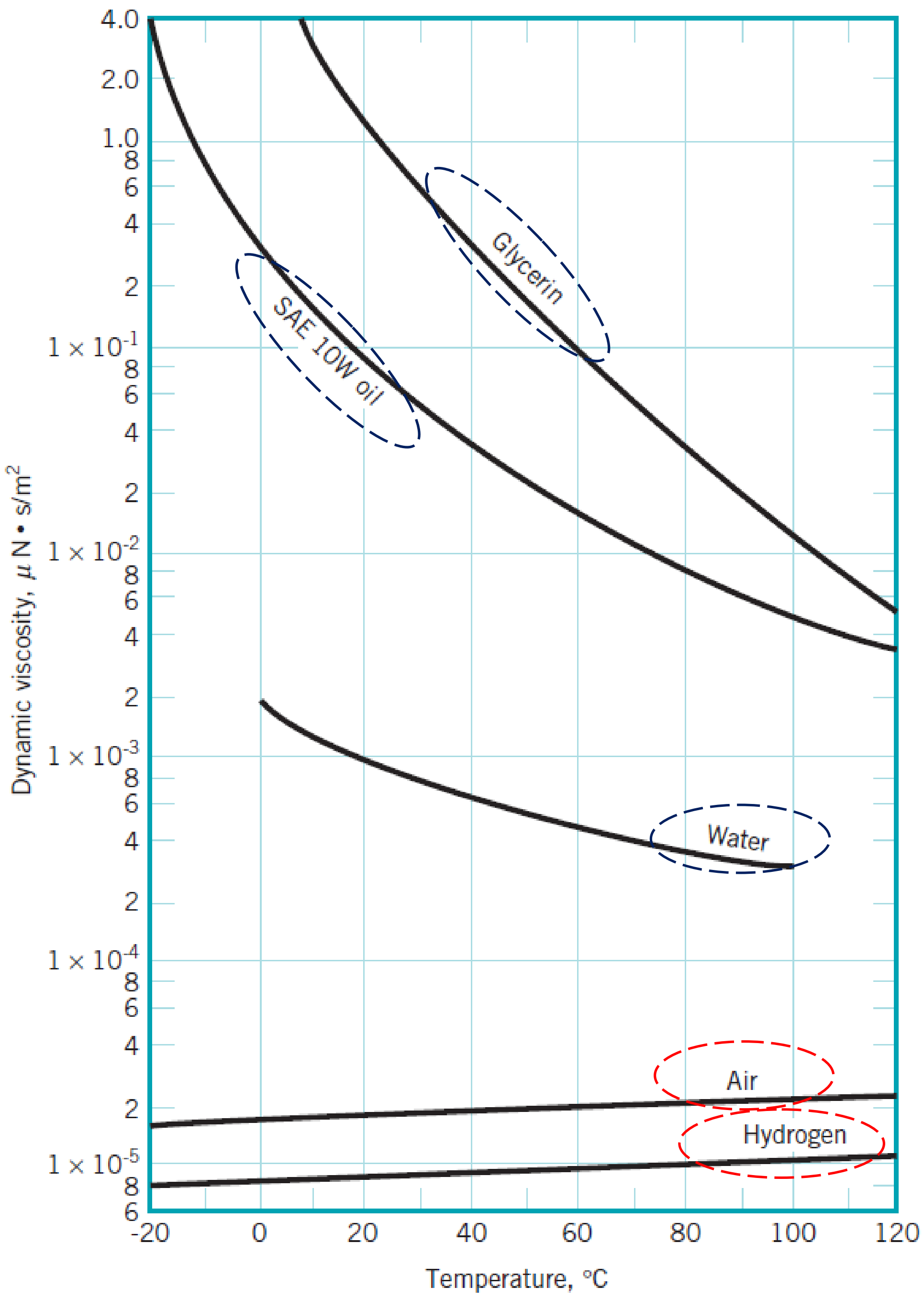
Viscosity



Bingham plastic is neither a fluid nor a solid. Such material can withstand a finite, nonzero shear stress ($\boldsymbol{\tau_{yield}}$: the yield stress) without motion (therefore, it is not a fluid), but once the yield stress is exceeded it flows like a fluid (hence, it is not a solid).

<u>Toothpaste</u> and <u>mayonnaise</u> are common examples of Bingham plastic materials. Mayonnaise can sit in a pile on a slice of bread (the shear stress less than the yield stress), but it flows smoothly into a thin layer when the knife increases the stress above the yield stress.



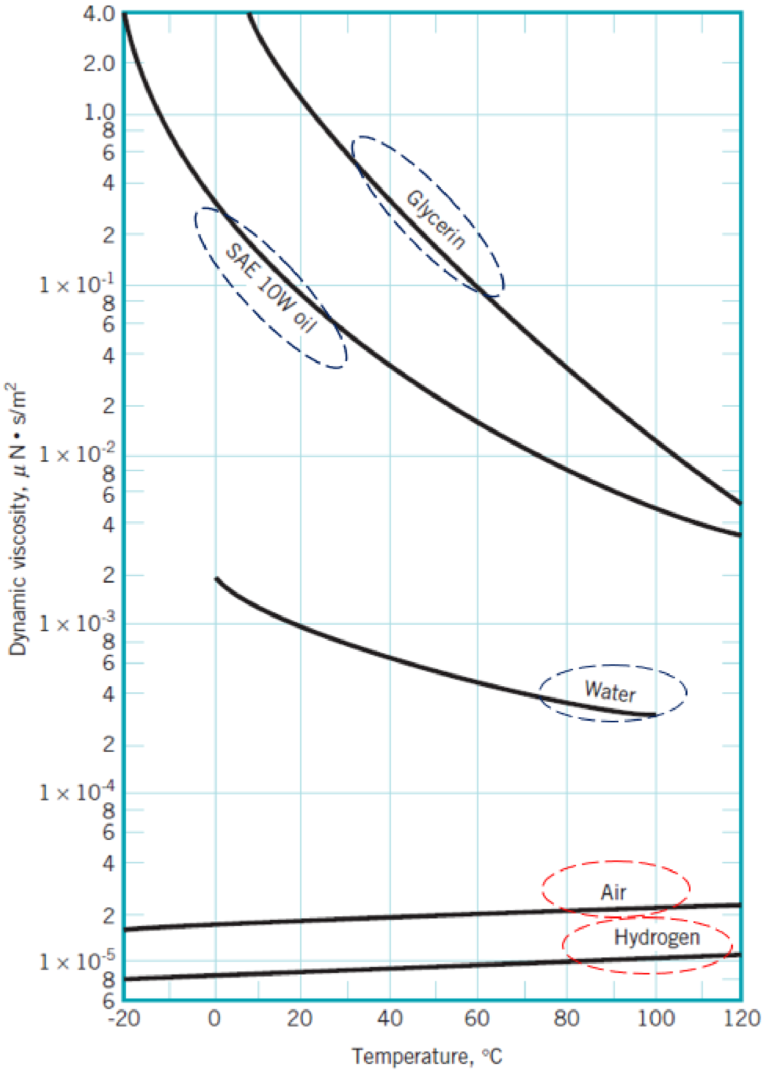


Viscosity
Effect of Temperature

Figure shows in more detail how the viscosity varies from fluid to fluid and how for a given fluid it varies with temperature.

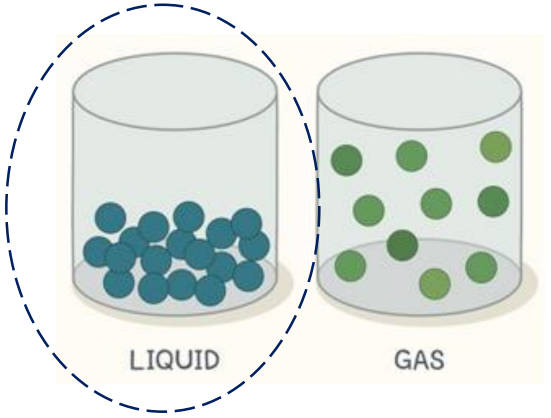
Viscosity of liquids decreases with an increase in temperature.

For gases an increase in temperature causes an increase in viscosity.



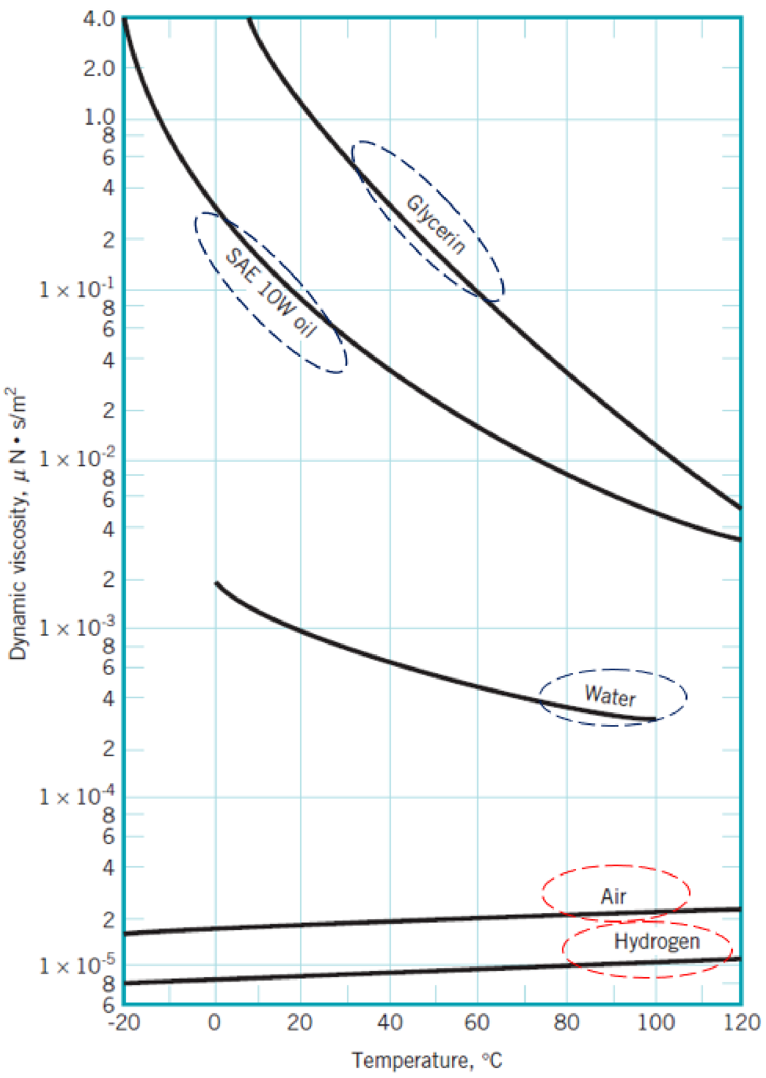
Viscosity of Liquids - Effect of Temperature

This difference in the effect of temperature on the viscosity of liquids and gases can again be traced back to the difference in molecular structure.

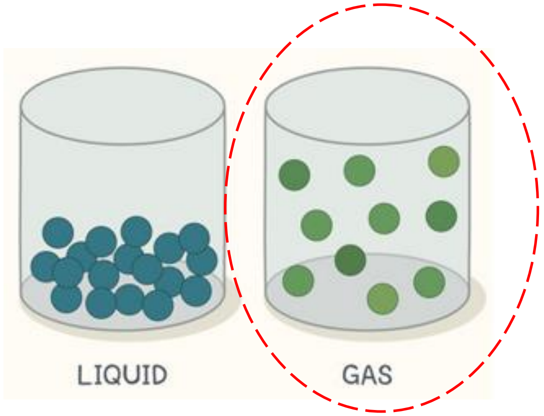


The liquid molecules are closely spaced, with strong cohesive forces between molecules, and the resistance to relative motion between adjacent layers of fluid is related to these intermolecular forces. As the temperature increases, these cohesive forces are reduced with a corresponding reduction in resistance to motion.

Since viscosity is an index of this resistance, it follows that the viscosity is reduced by an increase in temperature.



Viscosity of Gases - Effect of Temperature



<u>In gases</u>, however, the <u>molecules are widely spaced</u> and <u>intermolecular forces negligible</u>. In this case, <u>resistance to relative motion arises due to the exchange of momentum of gas molecules</u> between adjacent layers.

<u>As the temperature of the gas increases</u>, the <u>random molecular activity increases</u> with a corresponding <u>increase in viscosity</u>.

Viscosity - Effect of Temperature

The effect of temperature on viscosity can be closely approximated using two empirical formulas.

For gases the *Sutherland equation* can be expressed as

$$\mu = \frac{CT^{3/2}}{T + S}$$

C and S are empirical constants
T is absolute temperature

Thus, if the viscosity is known at two temperatures, C and S can be determined.

For liquids an empirical equation that has been used is

$$\mu = De^{B/T}$$

D and B are constants
T is absolute temperature

This equation is often referred to as *Andrade's equation*. As was the case for gases, the viscosity must be known at least for two temperatures so the two constants can be determined.

Viscosity - Units

Absolute viscosity (dynamic viscosity) μ

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

$$\mu = \frac{\overbrace{\frac{F}{L^2}}^{\tau}}{\underbrace{\frac{L}{T}/L}_{du/dy}}$$

$$F = ma \qquad \boldsymbol{N} = kg.\frac{m}{s^2}$$

$$\mu = \frac{FT}{L^2}$$

in BG: **lb.s/ft²**

in SI: **N.s/m²**

Pa.s

$$kg.\frac{m}{s^2}.s.\frac{1}{m^2} = \frac{\boldsymbol{kg}}{\boldsymbol{m.s}} \qquad \left(\frac{\boldsymbol{M}}{\boldsymbol{L.T}}\right)$$

Viscosity - Units

Poise: viscosity unit (named after French engineer – physiologist J.L.M. Poiseuille)

$$\mu_{water\ at\ room\ temp.\ 20.2\ ^oC} = 1\ cP\ (centipoise) = \frac{1}{100} poise$$

1 poise = 100 cP = 0.1 N.sec/m^2

1 N.sec/m^2 = 1000 cP

$\mu_{air} = 0.018\ cP$ (~ 2% of water)

Viscosity - Units

Kinematic viscosity ϑ

In engineering practices, kinematic viscosity is often used.

$$\vartheta = \frac{absolute\ viscosity}{density\ of\ the\ fluid} = \frac{\mu}{\rho}$$

$$\vartheta = \frac{\frac{M}{L.T}}{\frac{M}{L^3}} = \frac{L^2}{T}$$

in BG: **ft²/s**

in SI: **m²/s**

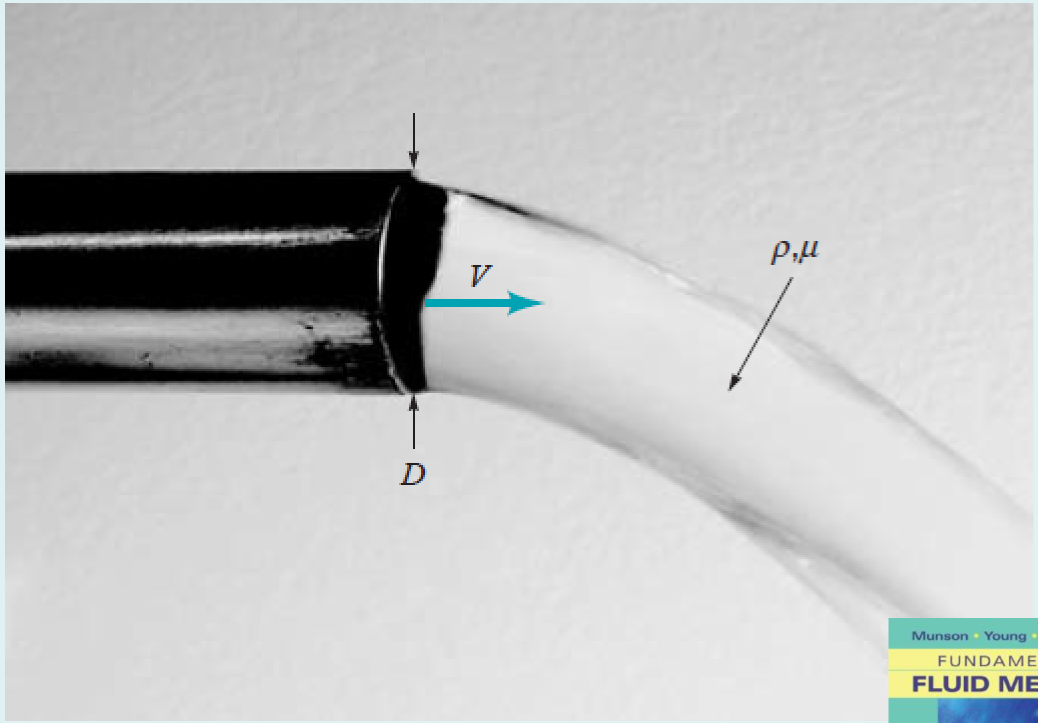
Stokes: viscosity unit (named after British mathematician G.G. Stoke)

cm²/s

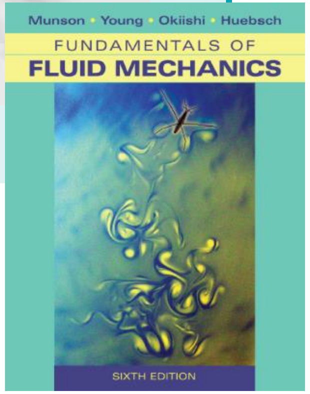
EXAMPLE 1.4 Viscosity and Dimensionless Quantities

GIVEN A dimensionless combination of variables that is important in the study of viscous flow through pipes is called the *Reynolds number,* Re, defined as $\rho VD/\mu$ where, as indicated in Fig. E1.4, ρ is the fluid density, V the mean fluid velocity, D the pipe diameter, and μ the fluid viscosity. A Newtonian fluid having a viscosity of $0.38\ \text{N}\cdot\text{s/m}^2$ and a specific gravity of 0.91 flows through a 25-mm-diameter pipe with a velocity of 2.6 m/s.

FIND Determine the value of the Reynolds number using (a) SI units, and (b) BG units.



■ FIGURE E1.4



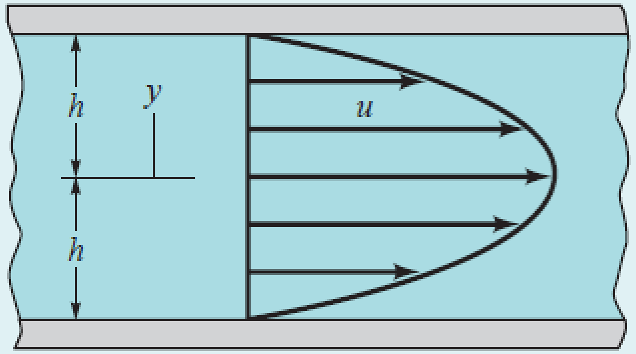
EXAMPLE 1.5 Newtonian Fluid Shear Stress

GIVEN The velocity distribution for the flow of a Newtonian fluid between two wide, parallel plates (see Fig. E1.5*a*) is given by the equation

$$u = \frac{3V}{2}\left[1 - \left(\frac{y}{h}\right)^2\right]$$

where V is the mean velocity. The fluid has a viscosity of $0.04\ \text{lb}\cdot\text{s/ft}^2$. Also, $V = 2\ \text{ft/s}$ and $h = 0.2$ in.

FIND Determine: (a) the shearing stress acting on the bottom wall, and (b) the shearing stress acting on a plane parallel to the walls and passing through the centerline (midplane).



■ FIGURE E1.5*a*

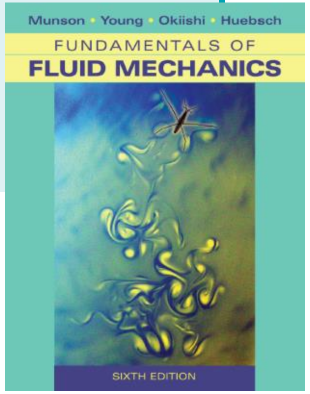


TABLE 1.5

Approximate Physical Properties of Some Common Liquids (BG Units)

Liquid	Temperature (°F)	Density, ρ (slugs/ft^3)	Specific Weight, γ (lb/ft^3)	Dynamic Viscosity, μ (lb · s/ft^2)	Kinematic Viscosity, ν (ft^2/s)	Surface Tension,[a] σ (lb/ft)	Vapor Pressure, p_v [lb/in.^{2} (abs)]	Bulk Modulus,[b] E_v (lb/in.^{2})
Carbon tetrachloride	68	3.09	99.5	2.00 E − 5	6.47 E − 6	1.84 E − 3	1.9 E + 0	1.91 E + 5
Ethyl alcohol	68	1.53	49.3	2.49 E − 5	1.63 E − 5	1.56 E − 3	8.5 E − 1	1.54 E + 5
Gasoline[c]	60	1.32	42.5	6.5 E − 6	4.9 E − 6	1.5 E − 3	8.0 E + 0	1.9 E + 5
Glycerin	68	2.44	78.6	3.13 E − 2	1.28 E − 2	4.34 E − 3	2.0 E − 6	6.56 E + 5
Mercury	68	26.3	847	3.28 E − 5	1.25 E − 6	3.19 E − 2	2.3 E − 5	4.14 E + 6
SAE 30 oil[c]	60	1.77	57.0	8.0 E − 3	4.5 E − 3	2.5 E − 3	—	2.2 E + 5
Seawater	60	1.99	64.0	2.51 E − 5	1.26 E − 5	5.03 E − 3	2.56 E − 1	3.39 E + 5
Water	60	1.94	62.4	2.34 E − 5	1.21 E − 5	5.03 E − 3	2.56 E − 1	3.12 E + 5

[a]In contact with air.

[b]Isentropic bulk modulus calculated from speed of sound.

[c]Typical values. Properties of petroleum products vary.

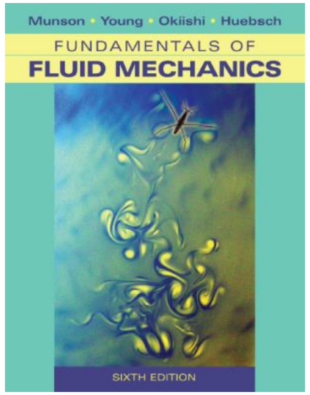


TABLE 1.6

Approximate Physical Properties of Some Common Liquids (SI Units)

Liquid	Temperature (°C)	Density, ρ (kg/m^3)	Specific Weight, γ (kN/m^3)	Dynamic Viscosity, μ (N · s/m^2)	Kinematic Viscosity, ν (m^2/s)	Surface Tension,[a] σ (N/m)	Vapor Pressure, p_v [N/m^2 (abs)]	Bulk Modulus,[b] E_v (N/m^2)
Carbon tetrachloride	20	1,590	15.6	9.58 E − 4	6.03 E − 7	2.69 E − 2	1.3 E + 4	1.31 E + 9
Ethyl alcohol	20	789	7.74	1.19 E − 3	1.51 E − 6	2.28 E − 2	5.9 E + 3	1.06 E + 9
Gasoline[c]	15.6	680	6.67	3.1 E − 4	4.6 E − 7	2.2 E − 2	5.5 E + 4	1.3 E + 9
Glycerin	20	1,260	12.4	1.50 E + 0	1.19 E − 3	6.33 E − 2	1.4 E − 2	4.52 E + 9
Mercury	20	13,600	133	1.57 E − 3	1.15 E − 7	4.66 E − 1	1.6 E − 1	2.85 E + 10
SAE 30 oil[c]	15.6	912	8.95	3.8 E − 1	4.2 E − 4	3.6 E − 2	—	1.5 E + 9
Seawater	15.6	1,030	10.1	1.20 E − 3	1.17 E − 6	7.34 E − 2	1.77 E + 3	2.34 E + 9
Water	15.6	999	9.80	1.12 E − 3	1.12 E − 6	7.34 E − 2	1.77 E + 3	2.15 E + 9

[a]In contact with air.

[b]Isentropic bulk modulus calculated from speed of sound.

[c]Typical values. Properties of petroleum products vary.

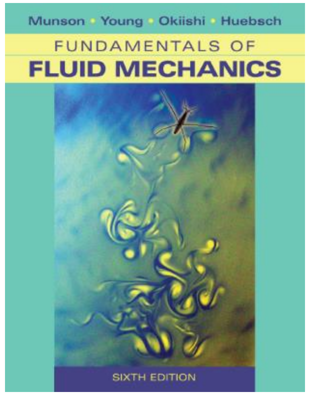


TABLE 1.7

Approximate Physical Properties of Some Common Gases at Standard Atmospheric Pressure (BG Units)

Gas	Temperature (°F)	Density, ρ (slugs/ft^3)	Specific Weight, γ (lb/ft^3)	Dynamic Viscosity, μ (lb · s/ft^2)	Kinematic Viscosity, ν (ft^2/s)	Gas Constant,[a] R (ft · lb/slug · °R)	Specific Heat Ratio,[b] k
Air (standard)	59	2.38 E − 3	7.65 E − 2	3.74 E − 7	1.57 E − 4	1.716 E + 3	1.40
Carbon dioxide	68	3.55 E − 3	1.14 E − 1	3.07 E − 7	8.65 E − 5	1.130 E + 3	1.30
Helium	68	3.23 E − 4	1.04 E − 2	4.09 E − 7	1.27 E − 3	1.242 E + 4	1.66
Hydrogen	68	1.63 E − 4	5.25 E − 3	1.85 E − 7	1.13 E − 3	2.466 E + 4	1.41
Methane (natural gas)	68	1.29 E − 3	4.15 E − 2	2.29 E − 7	1.78 E − 4	3.099 E + 3	1.31
Nitrogen	68	2.26 E − 3	7.28 E − 2	3.68 E − 7	1.63 E − 4	1.775 E + 3	1.40
Oxygen	68	2.58 E − 3	8.31 E − 2	4.25 E − 7	1.65 E − 4	1.554 E + 3	1.40

[a]Values of the gas constant are independent of temperature.

[b]Values of the specific heat ratio depend only slightly on temperature.

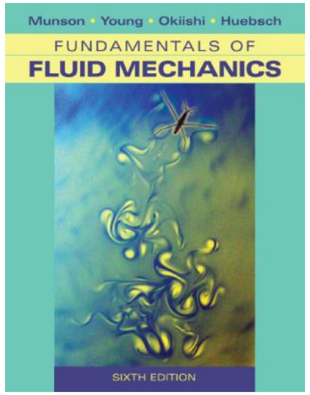


TABLE 1.8

Approximate Physical Properties of Some Common Gases at Standard Atmospheric Pressure (SI Units)

Gas	Temperature (°C)	Density, ρ (kg/m^3)	Specific Weight, γ (N/m^3)	Dynamic Viscosity, μ ($N \cdot s/m^2$)	Kinematic Viscosity, ν (m^2/s)	Gas Constant,[a] R ($J/kg \cdot K$)	Specific Heat Ratio,[b] k
Air (standard)	15	1.23 E + 0	1.20 E + 1	1.79 E − 5	1.46 E − 5	2.869 E + 2	1.40
Carbon dioxide	20	1.83 E + 0	1.80 E + 1	1.47 E − 5	8.03 E − 6	1.889 E + 2	1.30
Helium	20	1.66 E − 1	1.63 E + 0	1.94 E − 5	1.15 E − 4	2.077 E + 3	1.66
Hydrogen	20	8.38 E − 2	8.22 E − 1	8.84 E − 6	1.05 E − 4	4.124 E + 3	1.41
Methane (natural gas)	20	6.67 E − 1	6.54 E + 0	1.10 E − 5	1.65 E − 5	5.183 E + 2	1.31
Nitrogen	20	1.16 E + 0	1.14 E + 1	1.76 E − 5	1.52 E − 5	2.968 E + 2	1.40
Oxygen	20	1.33 E + 0	1.30 E + 1	2.04 E − 5	1.53 E − 5	2.598 E + 2	1.40

[a]Values of the gas constant are independent of temperature.

[b]Values of the specific heat ratio depend only slightly on temperature.