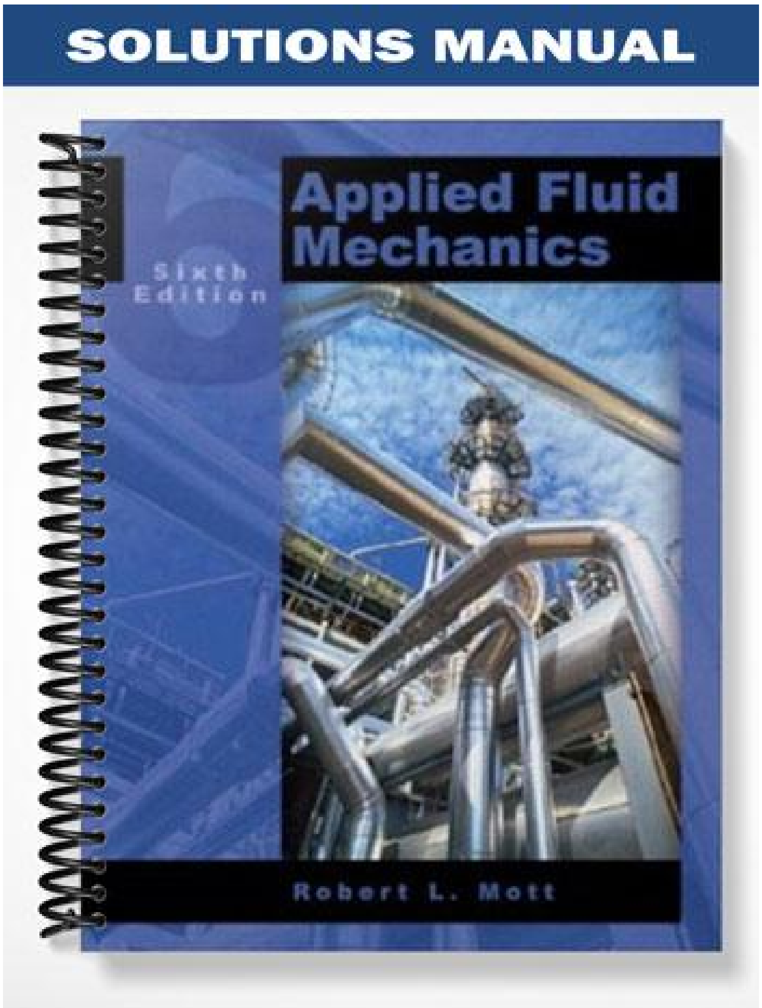
SOLUTIONS MANUAL
Applied Fluid Mechanics
Sixth Edition
Robert L. Mott

CHAPTER TWO

VISCOSITY OF FLUIDS

2.1 Shearing stress is the force required to slide one unit area layer of a substance over another.

2.2 Velocity gradient is a measure of the velocity change with position within a fluid.

2.3 Dynamic viscosity = shearing stress/velocity gradient.

2.4 Oil. It pours very slowly compared with water. It takes a greater force to stir the oil, indicating a higher shearing stress for a given velocity gradient.

2.5 $N \cdot s/m^2$ or $Pa \cdot s$

2.6 $lb \cdot s/ft^2$

2.7 1 poise = 1 $dyne \cdot s/cm^2$ = 1 $g/(cm \cdot s)$

2.8 It does not conform to the standard SI system. It uses obsolete basic units of dynes and cm.

2.9 Kinematic viscosity = dynamic viscosity/density of the fluid.

2.10 m^2/s

2.11 ft^2/s

2.12 1 stoke = 1 cm^2/s

2.13 It does not conform to the standard SI system. It uses obsolete basic unit of cm.

2.14 A newtonian fluid is one for which the dynamic viscosity is independent of the velocity gradient.

2.15 A nonnewtonian fluid is one for which the dynamic viscosity **is** dependent on the velocity gradient.

2.16 Water, oil, gasoline, alcohol, kerosene, benzene, and others.

2.17 Blood plasma, molten plastics, catsup, paint, and others.

2.18 6.5×10^{-4} $Pa \cdot s$

2.19 1.5×10^{-3} $Pa \cdot s$

2.20 2.0×10^{-5} $Pa \cdot s$

2.21 1.1×10^{-5} Pa·s

2.22 3.0×10^{-1} Pa·s

2.23 1.90 Pa·s

2.24 3.2×10^{-5} lb·s/ft^2

2.25 8.9×10^{-6} lb·s/ft^2

2.26 3.6×10^{-7} lb·s/ft^2

2.27 1.9×10^{-7} lb·s/ft^2

2.28 5.0×10^{-2} lb·s/ft^2

2.29 4.1×10^{-3} lb·s/ft^2

2.30 3.3×10^{-5} lb·s/ft^2

2.31 2.8×10^{-5} lb·s/ft^2

2.32 2.1×10^{-3} lb·s/ft^2

2.33 9.5×10^{-5} lb·s/ft^2

2.34 1.3×10^{-2} lb·s/ft^2

2.35 2.2×10^{-4} lb·s/ft^2

2.36 Viscosity index is a measure of how greatly the viscosity of a fluid changes with temperature.

2.37 High viscosity index (VI).

2.38 Rotating drum viscometer.

2.39 The fluid occupies the small radial space between the stationary cup and the rotating drum. Therefore, the fluid in contact with the cup has a zero velocity while that in contact with the drum has a velocity equal to the surface speed of the drum.

2.40 A meter measures the torque required to drive the rotating drum. The torque is a function of the drag force on the surface of the drum which is a function of the shear stress in the fluid. Knowing the shear stress and the velocity gradient, Equation 2-2 is used to compute the dynamic viscosity.

2.41 The inside diameter of the capillary tube; the velocity of fluid flow; the length between pressure taps; the pressure difference between the two points a distance L apart.
See Eq. (2-4).

2.42 Terminal velocity is that velocity achieved by the sphere when falling through the fluid when the downward force due to gravity is exactly balanced by the buoyant force and the drag force on the sphere. The drag force is a function of the dynamic viscosity.

2.43 The diameter of the ball; the terminal velocity (usually by noting distance traveled in a given time); the specific weight of the fluid; the specific weight of the ball.

2.44 The Saybolt viscometer employs a container in which the fluid can be brought to a known, controlled temperature, a small standard orifice in the bottom of the container and a calibrated vessel for collecting a 60 mL sample of the fluid. A stopwatch or timer is required to measure the time required to collect the 60 mL sample.

2.45 No. The time is reported as Saybolt Universal Seconds and is a relative measure of viscosity.

2.46 Kinematic viscosity.

2.47 Standard calibrated glass capillary viscometer.

2.48 See Table 2.4. The kinematic viscosity of SAE 20 oil must be between 5.6 and 9.3 cSt at 100°C using ASTM D 445. Its dynamic viscosity must be over 2.6 cP at 150°C using ASTM D 4683, D 4741, or D 5481. The kinematic viscosity of SAE 20W oil must be over 5.6 cSt at 100°C using ASTM D 445. Its dynamic viscosity for cranking must be below 9500 cP at −15°C using ASTM D 5293. For pumping it must be below 60,000 cP at −20°C using ASTM D 4684.

2.49 SAE 0W through SAE 250 depending on the operating environment. See Table 2.4.

2.50 SAE 70W through SAE 60 depending on the operating environment and loads. See Table 2.5.

2.51 100°C using ASTM D 445 testing method and at 150° C using ASTM D 4683, D 4741, or D 5481.

2.52 At −25°C using ASTM D 5293; at −30°C using ASTM D 4684; at 100°C using ASTM D 445.

2.53 See Table 2.4. The kinematic viscosity of SAE 5W-40 oil must be between 12.5 and 16.3 cSt at 100°C using ASTM D 445. Its dynamic viscosity must be over 2.9 cP at 150°C using ASTM D 4683, D 4741, or D 5481. The kinematic viscosity must be over 3.8 cSt at 100°C using ASTM D 445. Its dynamic viscosity for cranking must be below 6600 cP at −30°C using ASTM D 5293. For pumping it must be below 60 000 cP at −35°C using ASTM D 4684.

2.54 $\nu = \text{SUS}/4.632 = 500/4.632 = 107.9\ \text{mm}^2/\text{s} = 107.9 \times 10^{-6}\ \text{m}^2/\text{s}$
$\nu = 107.9 \times 10^{-6}\ \text{m}^2/\text{s}\ [(10.764\ \text{ft}^2/\text{s})/(\text{m}^2/\text{s})] = 1.162 \times 10^{-3}\ \text{ft}^2/\text{s}$

2.55 SAE 10W-30 engine oil:

Low temperature cranking viscosity at −25°C: 7000 cP = 7000 mPa s = **7.0 Pa·s maximum**
Low temperature pumping viscosity at −30°C: 60 000 cP = 60 000 mPa s = **60 Pa·s maximum**
Low shear rate kinematic viscosity at 100°C: 9.3 cSt = 9.3 mm^2/s = **$9.3 \times 10^{-6}\ \text{m}^2/2$ minimum**
Low shear rate kinematic viscosity at 100°C: 12.5 cSt = 12.5 mm^2/s = **$12.5 \times 10^{-6}\ \text{m}^2/2$ maximum**
High shear rate dynamic viscosity at 150°C: 2.9 cP = 2.9 mPa s = **0.0029 Pa·s minimum**

2.56 η = 4500 cP [(1 Pa·s)/(1000 cP)] = **4.50 Pa·s**
η = 4.50 Pa·s [(1 lb·s/ft^2)/(47.88 Pa·s)] = **0.0940 lb·s/ft^2**

2.57 v = 5.6 cSt [(1 m^2/s)/(10^6 cSt)] = **5.60 × 10^{-6} m^2/s**
v = 5.60 × 10^{-6} m^2/s [(10.764 ft^2/s)/(m^2/s)] = **6.03 × 10^{-5} ft^2/s**

2.58 From Figure 2.12: v = 15.5 mm^2/s = 15.5 × 10^{-6} m^2/s

2.59 η = 6.5 × 10^{-3} Pa·s [(1 lb·s/ft^2)/(47.88 Pa·s)] = **1.36 × 10^{-4} lb·s/ft^2**

2.60 η = 0.12 poise [(1 Pa·s)/(10 poise)] = 0.012 Pa·s = 1.2 × 10^{-2} Pa·s. **SAE 10 oil**

2.61

$$\eta = \frac{(\gamma_s - \gamma_f)D^2}{18\upsilon} \quad \text{(Eq. 2-10)}$$

γ_f = 0.94(9.81 kN/m^3) = 9.22 kN/m^3
D = 1.6 mm = 1.6 × 10^{-3} m

$v = s/t$ = .250 m/10.4 s = 2.40 × 10^{-2} m/s

$$\mu = \frac{(77.0 - 9.22)\,\text{kN}(1.6\times10^{-3}\,\text{m})^2}{18\ \text{m}^3(2.40\times10^{-2}\ \text{m/s})} \times \frac{10^3\ \text{N}}{\text{kN}} = 0.402\frac{\text{N}\cdot\text{s}}{\text{m}^2} \quad = \mathbf{0.402\ Pa\cdot s}$$

2.62

$$\eta = \frac{(p_1 - p_2)D^2}{32\upsilon L} \quad \text{(Eq. 2-5)}$$

Use $\gamma_{Mercury}$ = 132.8 kN/m^3 (App. B)
γ_o = 0.90(9.81 kN/m^3) = 8.83 kN/m^3

Manometer Eq. using principles of Chapter 3:

$$p_1 + \gamma_o y + \gamma_o h - \gamma_m h - \gamma_o y = p_2$$

$$p_1 - p_2 = \gamma_m h - \gamma_o h = h(\gamma_m - \gamma_o) = 0.177\ \text{m}(132.8 - 8.83)\frac{\text{kN}}{\text{m}^3} = 21.94\frac{\text{kN}}{\text{m}^2}$$

$$\eta = \frac{(21.94\ \text{kN/m}^2)(0.0025\ \text{m})^2}{32(1.58\ \text{m/s})(0.300\ \text{m})} = 9.04\times10^{-6}\frac{\text{kN}\cdot\text{s}}{\text{m}^2}\times\frac{10^3\ \text{N}}{\text{kN}} \quad = \mathbf{9.04\times10^{-3}\ Pa\cdot s}$$

2.63 See Prob. 2.61. γ_f = 0.94(62.4 lb/ft^3) = 58.7 lb/ft^3: D = (0.063 in)(1 ft/12 in) = 0.00525 ft
$v = s/t$ = (10.0 in/10.4 s)(1 ft/12 in) = 0.0801 ft/s: γ_s = (0.283 lb/in^3)(1728 in^3/ft^3) = 489 lb/ft^3

$$\eta = \frac{(\gamma_s - \gamma_f)D^2}{18v} = \frac{(489 - 58.7)\text{lb/ft}^3(0.00525\ \text{ft})^2}{18(0.0801\ \text{ft/s})} = 0.00823\ \text{lb s/ft}^2 = 8.23\times10^{-3}\ \text{lb·s/ft}^2$$

2.64 See Problem 2.62. Use γ_m = 844.9 lb/ft^3 (App. B): γ_o = (0.90)(62.4 lb/ft^3) = 56.16 lb/ft^3
h = (7.00 in)(1 ft/12 in) = 0.5833 ft: D = (0.100 in)(1 ft/12 in) = 0.00833 ft
$p_1 - p_2 = h(\gamma_m - \gamma_o)$ = (0.5833 ft)(844.9 – 56.16) lb/ft^3 = 460.1 lb/ft^2

$$\eta = \frac{(p_1 - p_2)D^2}{32vL} = \frac{(460.1\ \text{lb/ft}^2)(0.00833\ \text{ft})^2}{32(4.82\ \text{ft/s})(1.0\ \ \text{ft})} = 0.000207\ \text{lb s/ft}^2 = 2.07\times10^{-4}\ \text{lb·s/ft}^2$$

2.65 From Fig. 2.12, kinematic viscosity = 78.0 SUS

2.66 From Fig 2.12, kinematic viscosity = 257 SUS

2.67 ν = 4.632(188) = 871 SUS

2.68 ν = 4.632(244) = 1130 SUS

2.69 From Fig. 2.13, A = 0.996. At 100°F, ν = 4.632(153) = 708.7 SUS.
At 40°F, ν = 0.996(708.7) = 706 SUS

2.70 From Fig. 2.13, A = 1.006. At 100°F, ν = 4.632(205) = 949.6 SUS.
At 190°F, ν = 1.006(949.6) = 955 SUS

2.71 ν = 6250/4.632 = 1349 mm^2/s

2.72 ν = 438/4.632 = 94.6 mm^2/s

2.73 From Fig. 2.12, ν = 12.5 mm^2/s

2.74 From Fig 2.12, ν = 37.5 mm^2/s

2.75 t = 80°C = 176°F. From Fig. 2.13, A = 1.005. At 100°F, ν = 4690/4.632 = 1012.5 mm^2/s.
At 176°F (80°C): ν = 1.005(1012.5) = 1018 mm^2/s.

2.76 t = 40°C = 104°F. From Fig. 2.13, A = 1.00. At 100°F, ν = 526/4.632 = 113.6 mm^2/s.
At 176°F (80°C): ν = 1.000(113.6) = 113.6 mm^2/s.

Kinematic Viscosity Conversions

Problem 2.77

SAE Viscosity Grades - Engine Oils				
	Kinematic Viscosity at 100 deg C			
	(mm^2/s)		SUS	
SAE No.	Min	Max	Min	Max
0W	3.8	---	38.9	---
5W	3.8	---	38.9	---
10W	4.1	---	39.8	---
15W	5.6	---	44.6	---
20W	5.6	---	44.6	---
25W	9.3	---	56.8	---
20	5.6	9.3	44.6	56.8
30	9.3	12.5	56.8	68.3
40	12.5	16.3	68.3	83.2
50	16.3	21.9	83.2	106.6
60	21.9	26.1	106.6	125.1

Conversion method for both Problem 2.77 and 2.78:
Used method from Section 2.7.5 in the text.
1: 100 deg C = 212 deg F.
S: From Fig. 2.13, A = 1.007
3: Read SUS for 100 deg F from Fig. 2.12.
4: Multiply *A* times SUS at 100 deg F to get SUS at 100 deg C (212 deg F)

Example: Given minimum kinematic viscosity = 21.9 mm^2/s for SAE 60
Read SUS at 100 deg F = 105.9 from Fig. 2.12
SUS at 100 deg C (212 deg F) = 1.007(105.9) = 106.6 SUS

NOTE: Results reported here used tabular values from ASTM 2161. Values read from Fig. 2.12 may vary because of precision of graph or reading of values from scale.

Problem 2.78 **(See Problem 2.77 for method.)**

SAE Viscosity Grades - Automotive Gear Lubricants				
	Kinematic Viscosity at 100 deg C			
	(mm^2/s)		SUS	
SAE No.	Min	Max	Min	Max
70W	4.1	---	39.8	---
75W	4.1	---	39.8	---
80W	7.0	---	49.1	---
85W	11.0	---	62.8	---
80	7.0	11.0	49.1	62.8
85	11.0	13.5	62.8	72.1
90	13.5	24.0	72.1	115.8
140	24.0	41.0	115.8	192.6
250	41.0	---	192.6	---

Kinematic Viscosity Conversions

Problem 2.79

ISO Viscosity Grades						
	Kinematic Viscosity at 40 deg C					
	(mm^2/s)			SUS		
ISO VG	Min	Nom	Max	Min	Nom	Max
2	1.98	2.2	2.40	32.5	33.3	34.0
3	2.88	3.2	3.52	35.6	36.6	37.6
5	4.14	4.6	5.06	39.6	41.1	42.6
7	6.12	6.8	7.48	46.0	48.1	50.3
10	9.00	10	11.0	55.4	58.8	62.4
15	13.5	15	16.5	71.6	77.4	83.4
22	19.8	22	24.2	97.0	106.3	115.9
32	28.8	32	35.2	136.2	150.5	164.9
46	41.4	46	50.6	193.1	214	235
68	61.2	68	74.8	284	315	347
100	90.0	100	110	417	463	510
150	135	150	165	625	695	764
220	198	220	242	917	1019	1121
320	288	320	352	1334	1482	1630
460	414	460	506	1918	2131	2344
680	612	680	748	2835	3150	3465
1000	900	1000	1100	4169	4632	5095
1500	1350	1500	1650	6253	6948	7643
2200	1980	2200	2420	9171	10190	11209
3200	2880	3200	3520	13340	14822	16305

Note: Method used is same as for Problem 2.77.
Temperature: t = 40 deg C = 104 deg F
From Fig. 2.13, A = 1.000
Therefore, SUS values are read directly from Fig. 2.12.