

Table 6 .... Physical Properties of Antifreeze Solutions\*

| Fluid                            | Freezing<br>Protection<br>Temp. F | Item               | Fluid Temperature—Fahrenheit |       |       |       |       |       |       |
|----------------------------------|-----------------------------------|--------------------|------------------------------|-------|-------|-------|-------|-------|-------|
|                                  |                                   |                    | -20                          | 0     | 20    | 40    | 120   | 140   | 160   |
| Ethylene Glycol<br>15.3% by vol. | +20                               | $\rho \times 10^3$ | —                            | —     | —     | 2.64  | 0.840 | 0.687 | 0.577 |
|                                  |                                   | $c$                | —                            | —     | —     | 0.935 | 0.956 | 0.960 | 0.962 |
|                                  |                                   | $w$                | —                            | —     | —     | 64.0  | 62.8  | 62.5  | 62.1  |
| Ethylene Glycol<br>31.4% by vol. | 0                                 | $\rho \times 10^3$ | —                            | —     | 6.86  | 4.18  | 1.19  | 0.955 | 0.784 |
|                                  |                                   | $c$                | —                            | —     | 0.833 | 0.850 | 0.895 | 0.905 | 0.910 |
|                                  |                                   | $w$                | —                            | —     | 65.7  | 65.4  | 64.1  | 63.7  | 63.3  |
| Ethylene Glycol<br>42.7% by vol. | -20                               | $\rho \times 10^3$ | —                            | 16.1  | 9.47  | 5.75  | 1.46  | 1.20  | 0.950 |
|                                  |                                   | $c$                | —                            | 0.764 | 0.775 | 0.783 | 0.832 | 0.845 | 0.856 |
|                                  |                                   | $w$                | —                            | 66.8  | 66.7  | 66.3  | 65.3  | 64.9  | 64.4  |
| Ethylene Glycol<br>51.2% by vol. | -40                               | $\rho \times 10^3$ | 46.3                         | 21.3  | 12.13 | 7.54  | 1.77  | 1.46  | 1.14  |
|                                  |                                   | $c$                | 0.682                        | 0.717 | 0.726 | 0.745 | 0.809 | 0.823 | 0.835 |
|                                  |                                   | $w$                | 68.2                         | 67.6  | 67.4  | 67.2  | 65.9  | 65.4  | 65.0  |
| Heat Transfer Oil                | -40                               | $\rho \times 10^3$ | 105                          | 43.1  | 29.7  | 14.0  | 3.13  | 2.51  | 2.06  |
|                                  |                                   | $c$                | 0.382                        | 0.390 | 0.400 | 0.408 | 0.444 | 0.452 | 0.462 |
|                                  |                                   | $w$                | 62.9                         | 62.5  | 62.0  | 61.6  | 59.1  | 58.6  | 57.6  |
| Water                            | +32                               | $\rho \times 10^3$ | —                            | —     | —     | 1.71  | 0.603 | 0.494 | 0.413 |
|                                  |                                   | $c$                | —                            | —     | —     | 1.005 | 0.999 | 0.999 | 1.001 |
|                                  |                                   | $w$                | —                            | —     | —     | 62.4  | 61.7  | 61.4  | 61.0  |

\* Based on data given in Reference 6.

\* Kinematic viscosity, (feet squared per second) (e.g. for oil at 60 F,  $\nu = 0.000140$  ft<sup>2</sup>/sec). $c$  = specific heat, Btu per (pound) (Fahrenheit degree). $w$  = specific weight, pounds per cubic foot.

$l$  = the length of the pipe, in feet.  
 $V$  = the velocity, in feet per second.  
 $g$  = the acceleration due to gravity = 32.174 ft per (second)  
(second).  
 $D$  = the internal diameter of the pipe in feet.  
 $f$  = a dimensionless friction coefficient which can be determined from Fig. 19, Chapter 7 of the 1961 Guide And Data Book. The Reynolds number can be computed from data in Table 6 of this chapter.

Solutions for the pipe friction should be plotted for temperatures at the starting condition (probably 0 F) and at the operating condition (use either 120 or 160 F). Then on the same graph, the operating curve of the pump should be plotted (see Reference 4 for such a graph). The intersection of the fluid friction curve and pump operating curve will give the operating point for the system. Table 8 can be used to allow for the viscosity effect on the pump.

The designer must decide on the tolerable viscosity limit. Generally it is between 300 and 500 SSU, although for commercial or private systems (where  $A$ , is 0.5 or 0) it may go to 750 SSU.

Efficiency loss is not important, but head and capacity losses are. Reduced flow means a longer period of time for the system to become operative from a cold start.

The viscosity limit is controlled by means of a low-limit thermostat. For example, if it is desired to hold the viscosity of the solution to less than 200 SSU ( $46.3 \times 10^{-4}$  ft<sup>2</sup>/sec), then for the oil shown in Table 6, the low-limit control would be set at about 10 F.

For small installations, a quick method of determining the fluid friction for a 1-in. IPS pipe circuit is given in Fig. 2.

The required pump capacity, in pounds of fluid per hour is given by the equation:

$$C = \frac{A_p q_t}{c_m \Delta t} \quad (11)$$

where

 $C$  = pump capacity, pounds per hour. $A_p$  = area of slab, square feet. $q_t$  = total heat requirement (slab output,  $q_s$ , plus back and edge losses) Btu per (hour) (square foot). $c_m$  = specific heat at temperature  $t_m$ , Btu per (pound) (Fahrenheit degree). $\Delta t$  = temperature drop through circuit, Fahrenheit degrees.For a temperature drop of  $\Delta t = 20$  F, Equation 11 becomes

$$G = \frac{A_p q_t}{160 w_m c_m} \quad (12)$$

where

 $G$  = gallons per minute. $w_m$  = mean specific weight at temperature  $t_m$ , pounds per cubic foot.

An approximate solution for systems using pipe sizes other than 1-in. IPS can be obtained by using Table 9 or Fig. 3. Table 9 is for use when the flow is in the laminar zone. Fig. 3

Table 7 .... Conversion of Kinematic Viscosity Units\*

| Centistokes | (Ft/Sec) $\times 10^4$ | SSU <sup>a</sup> | Centistokes | (Ft/Sec) $\times 10^4$ | SSU <sup>a</sup> |
|-------------|------------------------|------------------|-------------|------------------------|------------------|
| 1           | 2.15                   | 32.6             | 31          | 33.4                   | 145.7            |
| 2.5         | 2.69                   | 36.0             | 32          | 34.4                   | 150.2            |
| 3           | 3.23                   | 36.0             | 33          | 35.5                   | 154.7            |
| 3.5         | 3.77                   | 37.6             | 34          | 36.6                   | 159.2            |
| 4           | 4.30                   | 39.1             | 35          | 37.7                   | 163.7            |
| 4.5         | 4.84                   | 40.8             |             |                        |                  |
| 5           | 5.38                   | 42.4             |             |                        |                  |
| 6           | 6.46                   | 45.6             | 36          | 38.7                   | 168.2            |
| 7           | 7.53                   | 48.8             | 37          | 39.8                   | 172.7            |
| 8           | 8.61                   | 52.1             | 38          | 40.9                   | 177.3            |
| 9           | 9.68                   | 55.5             | 39          | 42.0                   | 181.8            |
| 10          | 10.8                   | 58.9             | 40          | 43.0                   | 186.3            |
| 11          | 11.8                   | 62.4             | 41          | 44.1                   | 190.8            |
| 12          | 12.9                   | 66.0             | 42          | 45.2                   | 195.3            |
| 13          | 14.0                   | 69.8             | 43          | 46.3                   | 199.8            |
| 14          | 15.1                   | 73.6             | 44          | 47.3                   | 204.4            |
| 15          | 16.1                   | 77.4             | 45          | 48.4                   | 209.1            |
| 16          | 17.2                   | 81.3             | 46          | 49.5                   | 213.7            |
| 17          | 18.3                   | 85.3             | 47          | 50.6                   | 218.3            |
| 18          | 19.4                   | 89.4             | 48          | 51.6                   | 222.9            |
| 19          | 20.4                   | 93.6             | 49          | 52.7                   | 227.5            |
| 20          | 21.5                   | 97.8             | 50          | 53.8                   | 232.1            |
| 21          | 22.6                   | 102.0            | 55          | 59.2                   | 255.2            |
| 22          | 23.7                   | 106.4            | 60          | 64.6                   | 278.3            |
| 23          | 24.7                   | 110.7            | 65          | 69.9                   | 301.4            |
| 24          | 25.8                   | 115.0            | 70          | 75.3                   | 324.4            |
| 25          | 26.9                   | 119.3            |             |                        |                  |
| 26          | 28.0                   | 123.7            |             |                        |                  |
| 27          | 29.1                   | 128.1            |             |                        |                  |
| 28          | 30.1                   | 132.5            |             |                        |                  |
| 29          | 31.2                   | 136.9            |             |                        |                  |
| 30          | 32.3                   | 141.3            |             |                        |                  |

Over 70.0 centistokes, SSU = 4.633  $\times$  centistokes.\* Kinematic viscosity in ft<sup>2</sup>/sec =  $1.076 \times 10^{-4} \times$  centistokes.

\* Values listed for SSU (Saybolt Seconds—Universal) are for fluid temperatures of 100 F. To obtain the Saybolt Universal viscosity equivalent to a kinematic viscosity determined at a Fahrenheit temperature  $t$ , multiply the equivalent Saybolt Universal viscosity at 100 F by  $1 + (t - 100) 0.000264$ ; for example, 10 centistokes at 210 F are equivalent to 58.9  $\times$  1.070 or 63.0 sec Saybolt Universal at 210 F. (Taken from ASTM D 445 - 52.)

is for flow in the turbulent zone. For flows where Reynolds number falls between 2000 and 3000, no reliable prediction for pressure loss can be made. It is generally safe to assume the flow to be increased to a Reynolds number of 3000 with the pressure loss estimated at that flow rate.

Fig. 2 is based on a pipe size of 1 in. IPS. If another pipe size is used and the flow is laminar, the correction factor  $K$  from Table 8 can be used. For example, assume a viscosity of 300 SSU, a flow of 5 gpm, and a  $\frac{3}{4}$ -in. IPS pipe. Fig. 2 shows that for 1-in. IPS, friction loss would be 15.50 ft/100 ft. Table 9 gives  $K = 2.62$  for  $\frac{3}{4}$ -in. pipe; therefore, friction loss would be  $15.5 \times 2.62 = 40.6$  ft/100 ft.

If the flow is in the transition zone or is turbulent, then Fig. 5 of Chapter 8 can be used in conjunction with Fig. 3.

Table 8 .... Viscosity Effect on Centrifugal Pump Characteristics

| Kinematic Viscosity<br>SSU <sup>a</sup> | Correction Factors |               |                 |
|-----------------------------------------|--------------------|---------------|-----------------|
|                                         | Pump Head          | Pump Capacity | Pump Efficiency |
| 0 to 30                                 | 1.00               | 1.00          | 1.00            |
| 50                                      | 1.00               | 1.00          | 0.94            |
| 100                                     | 0.98               | 1.00          | 0.88            |
| 200                                     | 0.96               | 0.98          | 0.79            |
| 300                                     | 0.95               | 0.97          | 0.73            |
| 400                                     | 0.93               | 0.96          | 0.68            |
| 500                                     | 0.92               | 0.96          | 0.65            |
| 600                                     | 0.91               | 0.95          | 0.62            |
| 700                                     | 0.90               | 0.94          | 0.59            |
| 800                                     | 0.89               | 0.94          | 0.57            |
| 900                                     | 0.88               | 0.93          | 0.55            |
| 1000                                    | 0.87               | 0.92          | 0.53            |

\* SSU = Saybolt Seconds—Universal.

For example, assume a viscosity of 0.0001 sq ft/sec (56.5 SSU), a flow rate of 14 gpm and a  $\frac{1}{2}$ -in. IPS pipe size. Fig. 5, Chapter 8, shows a head loss for water to be 190 milinches per foot or 1.58 ft/100 ft. Fig. 3 gives a correction factor  $K$  of 1.75 for a viscosity of 0.0001 sq ft/sec; hence, the pressure loss is  $1.58 \times 1.75 = 2.77$  ft/100 ft.

## INSTALLATION

There are certain precautions that must be taken during installation. They concern internal corrosion, flammability, toxicity, cleaning, joints, and hookup. A comprehensive discussion of these precautions may be found in Reference 5.

## Safety

Since ethylene glycol and petroleum distillates are slightly toxic, the system should be installed and maintained independently. There should be no permanent connection

Table 9 .... Correction Factors for Pipe Size (For Laminar Flow  $N_{Re} < 2000$ )

| Pipe Size      | Inside Diameter |        | $D_v^4$<br>Ft <sup>4</sup> | $K = \frac{5.84 \times 10^{-4}}{D_v^4}$<br>(See Figure 2) |
|----------------|-----------------|--------|----------------------------|-----------------------------------------------------------|
|                | Inches          | Feet   |                            |                                                           |
| $\frac{1}{8}$  | 0.622           | 0.0518 | $7.18 \times 10^{-4}$      | 8.13                                                      |
| $\frac{1}{4}$  | 0.824           | 0.0687 | $2.23 \times 10^{-3}$      | 2.62                                                      |
| 1              | 1.049           | 0.0874 | $5.84 \times 10^{-3}$      | 1.00                                                      |
| $1\frac{1}{4}$ | 1.380           | 0.115  | $1.75 \times 10^{-2}$      | 0.334                                                     |
| $1\frac{1}{2}$ | 1.610           | 0.134  | $3.26 \times 10^{-2}$      | 0.179                                                     |
| 2              | 2.067           | 0.172  | $8.75 \times 10^{-2}$      | 0.0667                                                    |
| $2\frac{1}{2}$ | 2.469           | 0.206  | $1.81 \times 10^{-1}$      | 0.0322                                                    |
| 3              | 3.068           | 0.256  | $4.30 \times 10^{-1}$      | 0.0136                                                    |
| $3\frac{1}{2}$ | 3.548           | 0.296  | $7.68 \times 10^{-1}$      | 0.00760                                                   |
| 4              | 4.026           | 0.335  | $1.26 \times 10^{-1}$      | 0.00462                                                   |
| 5              | 5.047           | 0.421  | $3.14 \times 10^{-1}$      | 0.00186                                                   |
| 6              | 6.065           | 0.505  | $6.50 \times 10^{-1}$      | 0.000898                                                  |