

definite amount of the substance that can be present in a stated amount of solution when the solution is in equilibrium with its environment. The environmental conditions of temperature and pressure are essential to the definition and are either stated explicitly, or, if no ambiguity is possible, are implied when numerical values are expressed. The effect of the environmental variables of refrigerant pressure and mixture temperature is generally reported in the form of pressure-temperature-solubility curves. Solubilities are commonly stated in terms of percent by weight but volume percent and mol percent have also been used. When weight percents are used, these are more properly based on the weight of the whole solution and not on the weight of the oil alone.

The high degree of solubility illustrated by the foregoing example has two consequences with respect to a refrigerant system. First, an oil which contains 25 or 26 percent refrigerant will show a much lower viscosity than would be predicted from standard viscosity curves such as Fig. 1. Second, the Refrigerant 12 pressure of 59 psia in the example is substantially lower than the saturation pressure (94.5 psia) which would have been obtained if the system had been charged without oil. These effects are characteristic of most halogenated refrigerant systems.

Table 4 provides a convenient index to the pressure-temperature-solubility curves (and the viscosity-temperature charts) included in this chapter. Units for these charts are in psia, degrees F, and weight percent of dissolved refrigerant. Although in some, but not all instances, the pressure, temperature, and solubility units given by the original authors have been converted in order to minimize inconvenience in applying the data; a cross index to the original work is listed in the last column of the tabulation. Additional information on the solubility of refrigerants in commercial oils may be obtained from the oil suppliers.

#### Effect of Oil Type on Refrigerant Solubility

The solubility of a given refrigerant is not greatly affected by the type of mineral oil in which it dissolves. Some differences exist, however. A low viscosity oil will usually absorb more of a particular refrigerant than a high viscosity oil under equivalent conditions. Naphthene base oils, at least on a weight basis, are usually better solvents than paraffin base oils. As an illustration of the solubility differences, several of the charts contain curves for naphthene base oils and paraffin base oils plotted on the same diagram. See Fig. 13 (Refrigerant 13 solubility), or Fig. 22 (Refrigerant 22 solubility). In each case the naphthene and paraffin curves plotted at the same temperature are not far apart.

Sometimes it is necessary to know the solubility of a given refrigerant in an unknown oil; an oil for which actual solubility data have not been determined. If the solubility of the given refrigerant has been determined in any oil, these data will provide a reasonable approximation for the unknown oil. This assumption, however, does not apply to synthetic lubricants and should be limited to mineral oils that are customarily employed in refrigerant systems.

#### Effect of Dissolved Refrigerant on Viscosity

Refrigerants differ in their viscosity reducing effects when the solution concentration is measured in weight percent. However, when the solubility is plotted in terms of mol percent it has been shown that the reduction in viscosity at a given mol percent is approximately the same for the halogenated Refrigerants 13, 13B1, 22, and 115.<sup>14,15</sup> In comparison with paraffin base oils, naphthene base oils show a somewhat greater reduction in viscosity for the same weight percent dilution. (See Figs. 24 and 26.)

An index to the viscosity-temperature charts reproduced in this chapter is found in the fourth column of Table 4. The weight percent parameter, or in some instances, the pressure parameter may be used to correlate the corresponding solubility curves listed in the third column of the table.

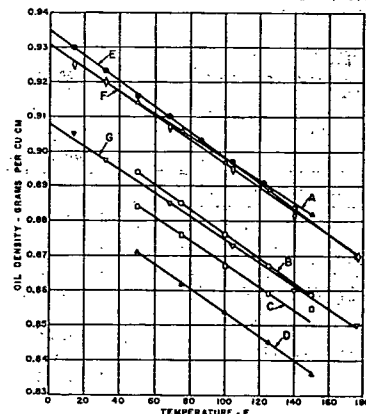
**Example #1:** A certain paraffin base oil of 150 SUV has a specific gravity of 0.86 and a viscosity of 37 centipoises at 90 F in air. Determine viscosity in contact with Refrigerant 22 at 105 psia and an oil temperature of 90 F.

**Solution:** Find on Fig. 23, weight percent Refrigerant 22 = 14 percent at 90 F and 105 psia. Then locate on Fig. 24, viscosity of oil-refrigerant mixture = 12.5 centipoises at 14 percent Refrigerant 22 and 90 F.

A general method for estimating the viscosity reduction of any mineral oil for refrigerant dilution up to 25 weight percent has been developed for solutions of oils containing Refrigerants 12, 13, 21, 22, 113, 114, 115, and 12-22 mixtures.<sup>16,17</sup> This method is based on the use of specialized viscosity plotting paper of German origin and is said to give results which agree within 2 or 3 percent of experimental values.

#### Effect of Viscosity Reduction on Lubricating and Sealing Functions

A large reduction in viscosity may affect the lubricating function, or more likely, the sealing function of the lubricant, and this possibility must be taken into account when the initial choice of oil viscosity is made.



| Oil | Base      | Viscosity SUV<br>seconds 100 F | Ref. |
|-----|-----------|--------------------------------|------|
| A   | Naphthene | 300                            | 14   |
| B   | Naphthene | 80                             | 14   |
| C   | Paraffin  | 300                            | 14   |
| D   | Paraffin  | 150                            | 14   |
| E   | Paraffin  | 240*                           | 10   |
| F   | Naphthene | 155*                           | 9a   |
| G   | Naphthene | 210*                           | 9a   |

\* Certain oils, base as stated by the author; viscosities converted to SUV and interpolated at 100 F.

Fig. 2 . . . . Variation of Refrigeration Oil Densities With Temperature

#### Lubricants in Refrigerant Systems

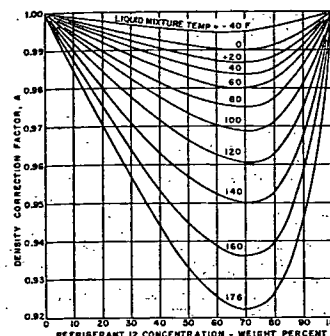


Fig. 3 . . . . Density Correction Factors for Mineral Oil-Refrigerant 12 Solutions\*

Bearing loads in most compressors are not high and the lubrication function is relatively easy to perform. The problem of sealing is not always so easy to accomplish. The design of some types of hermetically-sealed units, such as the single-vane rotary type, requires the lubricating fluid to act as a highly efficient sealing agent. In reciprocating compressors, the lubricant film is spread over the entire area of contact between the piston and the cylinder wall, and there is a very large area to resist leakage from the high- to the low-pressure side. In the single-vane rotary type, however, the only sealing area is a line contact between the vane and a roller. Viscosity reduction may then be a serious matter.

Normally, an oil should be chosen with a viscosity which is low enough to give the necessary sealing properties with the refrigerant used for the entire range of temperatures and pressures encountered. A practical method for determining the minimum safe viscosity is to determine the total volumetric efficiency of a given compressor system, using several oils of widely varying viscosity. The oil of lowest viscosity that gives satisfactory volumetric efficiency should be selected. These tests should be run at a number of ambient temperatures; for example, 70, 90 and 110 F.

#### Density of Oil-Refrigerant Solutions

For converting viscosity units (e.g., from centistokes or SUV seconds to centipoises or vice-versa) and for other purposes, it is necessary to know the density of the lubricating fluid. For a rough estimate of the density or specific gravity of an oil-refrigerant solution, one may assume that the solution is ideal and hence the specific volumes of the components are additive. The formula for calculating the ideal density ( $D_{id}$ ), in grams per cu cm or pounds per cu ft, is:

$$D_{id} = \frac{d}{1 + W(d/d_s - 1)} \quad (1)$$

where

$d$  = density of pure oil at the solution temperature.  
 $d_s$  = density of refrigerant liquid at the solution temperature.  
 $W$  = weight fraction of refrigerant in solution.

Fig. 2 shows published values for pure oil densities over a range of temperatures. These density-temperature curves all have approximately the same slope and appear merely to be

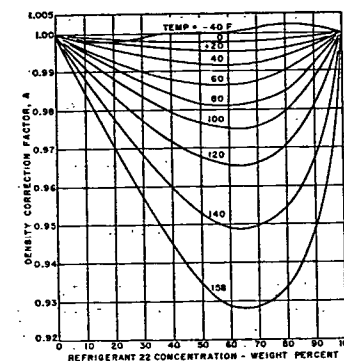


Fig. 4 . . . . Density Correction Factors for Mineral Oil-Refrigerant 22 Solutions\*

displaced from one another according to base type and viscosity. Hence, if the density of a particular oil is known at one temperature but not over a range of temperatures, a reasonable estimate at other temperatures may be obtained by constructing a line paralleling those in Fig. 2.

The actual density of an oil-refrigerant solution may deviate from the ideal by as much as 8 percent. The solutions are usually more, but sometimes less, dense than calculated.<sup>18,19</sup> Density correction factors for Refrigerant 12 and Refrigerant 22 solutions have been published by Löffler<sup>4</sup> and are redrawn in Figs. 3 and 4, respectively. The corrected densities may be obtained from the relation:

$$\text{Mixture density} = D_m = \frac{D_{id}}{A} \quad (2)$$

where  $A$  is the density correction factor read from Fig. 3 or 4 at the desired temperature and refrigerant concentration.

#### Thermodynamics of Refrigerant-Oil Solutions

The dissolving of oil in liquid refrigerant will affect the thermodynamic properties of the working fluid. The vapor

Table 5 . . . . Mutual Solubility of Refrigerants and Mineral Oil

(Ammonia and carbon dioxide are practically immiscible with oil.)

| High Miscibility                                                                          | Intermediate Miscibility           | Low Miscibility                                                                                                                      |
|-------------------------------------------------------------------------------------------|------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------|
| Refrigerant 11<br>Refrigerant 12<br>Refrigerant 13B1<br>Refrigerant 21<br>Refrigerant 113 | Refrigerant 22*<br>Refrigerant 114 | Sulfur Dioxide<br>Refrigerant 13<br>Refrigerant 14<br>Refrigerant 115<br>Refrigerant 152a<br><br>Refrigerant C318<br>Refrigerant 502 |
| Refrigerant 500<br>Methyl Chloride<br>Methylene Chloride<br>Hydrocarbons                  |                                    |                                                                                                                                      |

\* Under normal operating conditions Refrigerant 22 is completely miscible with oil in the high temperature side of the system, but at the lower temperatures which exist in the evaporator two liquid layers are formed. Each layer contains both oil and refrigerant, but the uppermost layer is much richer in oil and the bottom layer is much richer in Refrigerant 22.