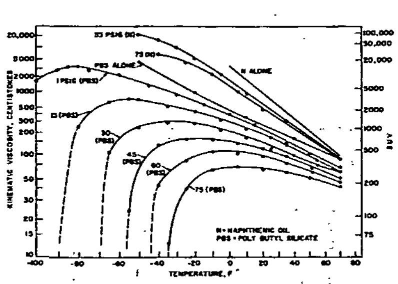

Fig. 37 .... Viscosity of Refrigerant 13-Oil Solutions at Low-Side Conditions[8]

parts approaches zero. Such low speeds may occur during start-up, or upon reversal of reciprocating motion. Bearing pressures and oil viscosities are also involved, and the boundary condition may prevail at relatively high speeds when bearings carry heavy loads and/or viscosities are so low that the lubricating fluid tends to be squeezed out of the bearing clearance. It is generally accepted that adequate lubrication under these circumstances depends on existence of a nonfluid film which adheres strongly and permanently to bearing surface despite squeezing-out of the oil.

Boundary lubrication has not been a serious problem in most refrigerant systems. As a rule, fluid lubrication can be depended on during operation, except under some starting conditions.[34] Commercial brands of refrigeration oils apparently possess a natural film-forming ability which is adequate to meet the service conditions.

The *natural film-forming property* is believed to depend on slightly reactive constituents left in the oil after refining. These reactive substances supposedly act on bearing metal surfaces to form tenacious films which, although invisible to the eye, are sufficient to prevent metal to metal contact.

The oils which are most stable against attack by hot refrigerant gases are not necessarily the best lubricants. Tests have shown that removal of the colored, more reactive constituents from a pale yellow refrigeration oil leaves a white oil which then resists attack for longer periods of time when heated with metals and Refrigerant 12. However, the reactive constituents, by chemically changing and combining with the metal in the bearing surfaces, may actually provide a good boundary lubrication film. The experiments of Thorpe and Larsen,[35] for example, have shown that with a white oil, boundary lubrication is readily driven to the dry friction state, but not with a less refined 10 W mineral oil.

The refrigerant itself may sometimes aid in boundary lubrication as indicated by recent studies with gaseous refrigerants at high temperatures.[36] When run very hot in the absence of any other lubricant, Refrigerant 12 apparently reacts with steel surfaces and forms a lubricating film. However, Refrigerant 22 does not form such a film.

Some compressor designers use *special processes* and *oil additives*, or both, as a supplement to the natural film-forming property of the oil. Steel pistons, shafts and wrist pins have been treated by phosphating processes (Parkerizing or Granodizing) which form iron phosphate films on the metallic surfaces, and thus provide an initial base for a boundary lubrication film. In some instances a phosphate ester (tricresyl phosphate) which has been found to improve boundary lubrication of heavily loaded bearings in an air environment, has also been injected into the bearings of refrigeration compressors and added to the refrigeration oil itself.

At present, there is no simple test for boundary lubrication in the presence of refrigerants. Divers[30] has reported the use of a *Falex machine* to evaluate refrigeration oils by comparing wear rates, but this machine operates in air and, as Divers points out, the data obtained may not be too significant when applied to reciprocating refrigeration compressors. Elaborate tests using *radioactive tracers* in refrigerant systems have been reported as giving useful results.[37,38]

## Oxidation Resistance

In the early days of refrigeration oil development, the chemical stability of lubricating oils was usually judged by an oxidation resistance test. In addition, it was assumed that an oil which resisted air oxidation would show less tendency toward copper plating in a refrigerating system.[39]

In recent years the value of oxidation tests as a measure of the chemical stability of refrigeration oils has been seriously questioned.[40] Oxygen, at least so far as significant quantities are concerned, is normally excluded from sealed refrigerant systems. Refrigerant systems must be rid of air and all other noncondensable gases if they are to function properly (see Chapter 47).

None of the standard oxidation resistance tests have won universal approval for qualifying refrigeration oils. However, tests of this type are still included in many refrigeration oil specifications.[30] Oxidation resistance provides another clue to oil quality although first consideration in this respect is generally directed toward specific procedures (refrigerant resistance tests) which more closely duplicate the service environment.

Moreover, air oxidizing conditions may actually be encountered during some manufacturing operations. A small amount of oil must be used during assembly and test of pumps and compressors, and it is not always practicable to completely remove this oil before the system is dehydrated.

If the subsequent dehydration process is one in which compressors or systems are heated in a stream of hot, dry air, as is frequently the case, the hot oxidizing conditions may change the residual oil to a gummy, varnish-like coating on bearings and valves. This gummy film may then lead to stuck pumps, overloaded motors, and other operating difficulties. For this reason, a high resistance to oxidation may be a valuable attribute of any oil which must pass through an air dehydration oven.

Much work has been done in refining and treating base oils as well as in attempting to develop chemical additives (*oxidation inhibitors*) which will minimize or possibly prevent gum and varnish formation. Refrigeration oils containing oxidation inhibitors, i.e., antioxidants, are commercially available. Under the extreme conditions imposed by high temperature dehydration processes, the usual oxidation inhibitor may not be wholly effective and the compressor manufacturer can discover only by trial if benefit is obtained.

Once a refrigerant system is sealed and oxygen excluded, no further beneficial effect of oxidation inhibitors is to be expected. Refrigerant resistance, rather than oxidation resistance, is then important. Some commercially used antioxidants have been found to decrease the chemical stability in a refrigerant environment, while others seem to have no effect one way or the other. Rizzuti, Staffin, and Jenkins[40] have described a series of tests in which the refrigerant resistance of four naphthene base oils, with and without a certain unspecified additive, was measured. According to their laboratory data, the use of the additive improved the chemical stability of the oil-refrigerant mixture, particularly if the oil had been severely refined. A number of claims for chemical additives which are said to improve the stability of oil-refrigerant systems in service have appeared in patents from time to time.[41] However, the extent to which such inhibitors may be in actual use is unknown.

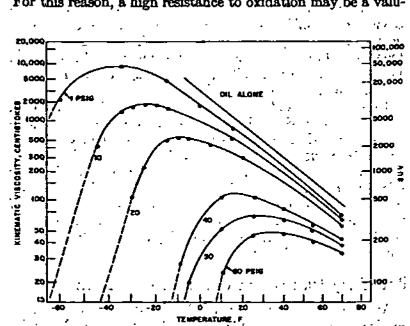

Fig. 38 .... Viscosity of Refrigerant 13B1-Oil Solutions at Low-Side Conditions[8]



## Refrigerant Resistance

Refrigerant resistance tests are sometimes referred to as *oil stability tests*. All published tests have been relatively simple, at least in a physical sense. In a typical test[42] a small predetermined quantity of oil is put into a strong glass tube or a pressure vessel (bomb) which is then dehydrated thoroughly, charged with a specified amount of refrigerant, and sealed. The ratio of oil and liquid refrigerant used is usually 1:1, but this ratio does not appear to be critical. Quite often, the tubes or bombs will also contain one or more of the common metals, iron, copper and aluminum, usually in the form of small strips of metal or wire coils which are so placed as to be partially or completely covered by the liquid during the test. After sealing, the tubes or bombs are heated at some specified temperature for a time long enough to produce observable results.

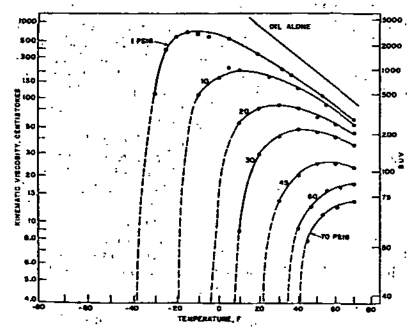

Fig. 39 .... Viscosity of Refrigerant 22-Naphthenic Oil Solutions at Low-Side Conditions[8]

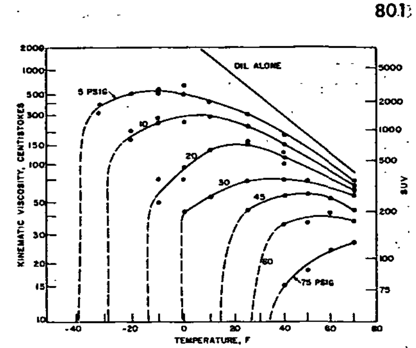

Fig. 40 .... Viscosity of Refrigerant 502-Naphthenic-Oil Solutions at Low-Side Conditions[8]

In making such a test the observer usually looks for symptoms of the same type found in operating systems which have given trouble in the field. Various developments, such as sludge formation, carbon deposits on valves and pistons, gumming and copper plating of bearing surfaces, acid formation, corrosion and damage to electrical insulation have been well publicized in the literature; and at one time or another have been attributed to oil decomposition (see Chapter 48). For this reason, refrigerant resistance tests are frequently evaluated by noting such effects as the degree of discoloration or carbonization of the oil; the time required for acid decomposition products to appear; and if metals have been included in the tests, to observe the extent of copper and steel corrosion and whether copper plating is seen on the steel.

## Chemical Reactions in Oil-Refrigerant Systems

It has been known for many years that destructive chemical changes can occur inside refrigerating systems if the refrigerant, the lubricating oil, and all other materials used in constructing the systems are not carefully selected and controlled. Visible evidence of such chemical reactivity has appeared in several forms, one early sign being the so-called *copper plating* that is sometimes observed on iron or steel parts inside compressors when a tear-down examination is made after laboratory or field service tests. These copper films, even though light and without apparent effect on the operation of the compressor at the time of examination, are symptoms of chemical changes that have taken place within the system and should not be ignored. Severe cases of copper plating can frequently be traced to contaminated systems (see Chapter 48); however, the lubricating oil may sometimes be involved, as was first recognized by McGovern[39] in 1939.

The mechanism through which copper is dissolved from parts containing that metal and transferred to steel surfaces in refrigerant-oil systems has been studied by Shaw and Brandon,[43] Steinle and Seeman,[44,45] and Spauschus.[46] According to Steinle and Seeman, copper plating should not be produced with Refrigerant 12-oil systems at test temperatures up to about 212 F if the lubricating oil satisfies the following requirements: (a) oil resin content, maximum 0.3 percent, (b) sulfur content, maximum 0.2 percent, (c) aniline point, minimum 212 F; (d) refrigerant resistance test (in low pressure vapor at 482 F), minimum 96 hr. Spauschus measured the copper plating that occurred when a highly refined water-