temperatures to avoid the possibility of oil-sludge formation. With operating temperature continually creeping upward it is necessary to carefully select the type of lubricant used in these systems. Combinations of variables—refrigerants, oils, water content, air, temperature, and metals—studied by Walker, Rosen, and Levy[38] show the bad effects of air and high temperature.

2. *Oil Additives.* Among the additives investigated for use are: (a) pour point depressants, (b) floc point depressants, (c) viscosity index improvers, (d) thermal stability improvers, (e) extreme pressure additives, (f) rust inhibitors, (g) anti-foaming agents, (h) copper plating inhibitors, and (i) oxidation inhibitors.[37]

Oils which contain certain additives have given highly satisfactory service, and in many cases their use is completely justifiable. Not all additives continue to be effective in the system, since they may eventually be retained in the drier, or elsewhere in the system. Additives may also be soluble in refrigerant and be removed from the oil, and deposited elsewhere. Extreme pressure additives have been known to contribute to the clogging of capillary tubes. Pour point and floc point depressants and anti-foam agents are generally regarded with suspicion because of questionable permanency. Selected additives, used judiciously, are beneficial and significantly improve certain properties. On the other hand, the user must be alert to the possibility that additives may react unfavorably with other components in the system.[38]

Hermetic Motor Insulation

In motors the magnet wire covering, used in windings, is the primary electrical insulation; it may be a continuous film of an organic resin, die coated on the wire and baked to cure it, a composite of organic resin film and fiber wrapping, or a fiber wrapping over the bare conductor.

With the continuous film coatings, which account for the major volume of magnet wire used in hermetic motor construction, many different types of resins and polymers have been investigated, with polyvinyl formal formulations having had the greatest acceptance. Carefully prepared, these coatings have proven satisfactory with Refrigerant 12 and even with Refrigerant 22 within limitations discussed below. Recently, continuous film coatings based on a polyacrylic system and on an isocyanate modified polyvinyl formal system have accounted for a considerable volume of the continuous film coated magnet wire utilized in hermetic motors.

The advent of large sized hermetic reciprocating systems utilizing random wound motors and hermetic centrifugal systems utilizing form wound motors has renewed interest in composite (organic film and fiber wrapping) and fiber wrapped conductors. The most utilized seems to be a polyester glass fiber wrapping over a polyvinyl formal film coated conductor.

The major volume of sheet insulating material, involved in slot liners, wedges, phase insulation, and tie point insulation, is at present divided between a high quality electrical insulation grade paper and polyethylene terephthalate film.

Miscellaneous insulation materials also involved in the construction of the motor include the tie cord, which may be either a specially treated cotton or synthetic fiber; the lead wire insulation which is generally a composite system; sheet insulation in tape or sheet form used in wrapped coil construction; and the final impregnating varnish which must be carefully selected for compatibility with the other insulating materials in addition to its performance capability in the refrigeration system environment. Of these the lead wire insulation system exhibits the greatest variety in commercial utilization including: heavy multiple layer cotton or synthetic fiber braid; cotton or synthetic fiber braid over an extruded elastomer jacket; woven glass fiber varnish impregnated; and synthetic fiber braid over a polyethylene terephthalate film.

All of the organic electrical insulating materials should be given careful scrutiny on two points.[39,40]

1. What is the effect of the refrigeration system environment on their performance capability? Of secondary importance to this chapter, but worthy of note due to the fact that failure of the electrical insulation does contribute to a contaminated refrigeration system environment, the following factors must be considered in selection of electrical insulating materials:
   a. *Physical.* Do they soften, dissolve, disintegrate?
   b. *Electrical.* Does the refrigeration system environment degrade their dielectric properties without any other apparent effects?
   c. *Chemical.* Do they react chemically with the refrigeration system environment to the detriment of their physical and electrical properties?

2. What is their effect on the refrigeration system environment? The following factors are important, from a contaminants viewpoint, in the selection of an electrical insulation material:
   a. Does the material contribute *extractables* to the refrigeration system environment? If it does, what are the nature of these *extractables?* Are they subject to temperature dependent solubility? Will they deposit an adhesive-cohesive mass somewhere else in the system? Are they apt to enter into degrading chemical reactions with other elements of the system?
   b. Does the material enter into degrading chemical reactions deleterious to the refrigeration system? If it does, within the anticipated operating limits, what are the nature of these reactions and what are the degradation products?
   c. Does the material serve as a nonreacting catalyst to degradation reactions between other elements of the refrigeration system environment?

Despite the promise inherent in newer materials, cellulose is still a major factor in the ground and phase insulation of both large and small random wound motors due to its economy and serviceability if properly utilized. When cellulose is employed under conditions where its performance capability limits are apt to be exceeded, its effect on the refrigeration system environment must be given consideration. As is well known, thermal degradation of even properly dehydrated cellulose will yield large amounts of moisture, noncondensable gases, tars and other objectionable contaminants. It should be kept in mind that cellulose and substantially all of the newer synthetic insulating materials are of organic origin and, therefore, less thermally stable than metallic or inorganic materials used in other parts of the system.

Excessive overheating causes chemical changes (depolymerization and actual decomposition) which degrades the physical properties of the resins used for wire coating and as varnishes. Failure through embrittlement is the most frequent result although the softening of enamels and varnishes by Refrigerant 22 certainly is often a cause of conductor shorts and hence failure. However, thermal degradation is always associated with an insulation failure even though it may not be apparent at the time of inspection.

The acid which may develop in an operating system has a very deleterious effect on cellulose motor insulation. Acid causes loss of strength, embrittlement, and eventual charring of cellulose. For example, it has been found that electrical insulating paper exposed to 0.026 percent hydrogen chloride dissolved in an anhydrous organic liquid for three hours at 150 F was not charred but had lost more than 90 percent of its strength.[37] In this regard experimental work by Elsey and Flowers[37] has indicated that Refrigerant 22 reacts at 257 F to form hydrochloric acid when an *acid acceptor* is present. This reaction proceeds at lower temperatures but at progressively slower rates. Electrical insulation paper was the *acid acceptor* in their work. These tests, conducted in glass tubes containing Refrigerant 22 and electrical insulation paper held at 257 F produced a darkening and loss of strength in the insulating paper. At the end of four weeks at 257 F the insulating paper would crumble to powder when removed. Elsey and Flowers believe that the reaction between cellulose and Refrigerant 22 is the factor which limits the temperatures applied to the motor windings in hermetic refrigerating systems.

The nonhygroscopic character of polyethylene terephthalate films, relative to paper, results in shorter and more effective dehydration cycles and the absence of a tendency to contribute moisture to the refrigeration system under abnormal operating conditions. However, a thermoplastic deformation point is a definite disadvantage in use of this film.

These films, like most polyesters, tend to suffer degradation of their properties by hydrolysis degradation reactions if water is present in sufficient amounts but the quantity of water required to effect serious degradation has been shown to be in excess of that tolerable in the average refrigeration system.[41,42] A recent paper by Bushouse[43] presents data to show that polyethylene terephthalate films tend to suffer an accelerated degradation in the presence of certain alcohols and particularly with methanol at elevated temperatures within the range of operating hermetic motors. The practice of relying upon even small amounts of ordinary antifreeze alcohols for correction of excessive moisture conditions thus becomes subject to criticism when the prevalence of polyethylene terephthalate in the modern hermetic motor is considered.

Care should also be observed that the polyethylene terephthalate film selected contains a minimum of the lower molecular weight polymer molecules which exhibit a temperature-dependent solubility in mineral lubricating oils and tend to precipitate as non-cohesive granules at temperatures lower than those experienced in the motor.

A corona discharge due to ionization of the gas surrounding an electrical conductor also causes insulation breakdown. It has been found that Refrigerant 12 decomposes in the presence of an electrical discharge to form chlorine. Refrigerant 22, Refrigerant 14, Refrigerant 114, and tetrafluoroethylene.[44] The chlorine is a highly reactive material and attacks the insulation or reacts with other materials such as oil or metals that may be present in the system. The corona effect depends upon the voltage gradient which exists between the motor winding and ground. It has been determined that it does not normally occur below 1000 volts RMS. Surge voltages in this range and higher have been reported to occur momentarily during start-up of a motor. Therefore during start-up and perhaps under certain abnormal conditions corona can be a factor in insulation breakdown.

With certain combinations of wire coating and refrigerant, excessive softening of the wire coating can occur due entirely to the effect of the refrigerant. Wire coatings are permeable to both Refrigerant 12 and Refrigerant 22 and most wire coatings, as well as impregnating varnishes, are softened by Refrigerant 22. The extent of softening varies greatly from one material to another and the extent of the damage is a function, not only of the chemical nature, but of the degree of curve. This softening is frequently a contributing factor in the failure of the insulation. The details of this effect on a specific polyvinyl formal wire coating formulation are given in Table 4.

Unfortunately, the phase-to-ground resistance of systems using Refrigerant 22 is not an indication of the presence of moisture. By measurements on actual refrigerant systems, Beacham and Divers[45] have found that in air or under vacuum the phase-to-ground resistance for a particular compressor motor was about 20,000 megohms. When Refrigerant 22 was added the phase-to-ground resistance dropped within seconds and in five minutes was only 68 megohms, eventually leveling off to 1.0 to 1.5 megohms. On the other hand, a similar experiment involving Refrigerant 12 indicated a sharp phase-to-ground resistance drop to 2000 megohms and within five minutes a recovery to a plateau of about 10,000 megohms. These experiments revealed that the polyvinyl formal is permeable to both refrigerants and that the final phase-to-ground resistance illustrated that the two refrigerant saturated wire coatings involved had distinctly different volume resistivities. The higher conductivity of wire coatings saturated with Refrigerant 22 impose limitations on the motor designer, particularly for larger sizes and higher voltages.

Table 4 .... Effect of Liquids on Polyvinyl Formal Type Wire Coating*,[46]

No Effect	Slight Softening	Peels With Difficulty	Peels Spontaneously
Carbontetrachloride	Toluene	Refrigerant 21	Chloroform
Refrigerant 11	Methyl ether	Refrigerant 22	Trichlorethylene
Refrigerant 12	Ethyl Alcohol	Methylene chloride	
Refrigerant 13		Methyl chloride	
Refrigerant 114		Acetone	
Benzene		Chlorobenzene	
Kerosine		Methyl Alcohol	
Refrigeration Oil			
Petroleum ether			
Ethyl ether			

* At room temperature.

Motor Burnouts

The final result of hermetic motor insulation failure is a motor burnout. During burnout high temperatures and arc discharges contribute to severe deterioration of the insulation, producing large amounts of carbonaceous sludge, acid, water, and other contaminants and severe deterioration of the refrigerant and oil, producing highly corrosive inorganic acids, organic acids and carbonaceous sludges. In many cases the products of the burnout escape into the system and cause considerable difficulty in clean-up. If these decomposition products are not removed from the system, additional failures of replacement motors can be expected with increasing frequency.

There is no universally accepted method for cleaning systems following a motor burnout. Many of those in use are modifications or combinations of two general procedures—flushing with liquid Refrigerant 11 (or Refrigerant 113) or temporary installation of a suction line filter-drier or suction line filter. Flushing with the cleaning Refrigerant is most effective if the solvent is recirculated through the system by means of a mechanical pump until the acids and sludge are removed. In the *one-pass* methods, the cleaning Refrigerant is forced through the lines using compressed air, nitrogen or other sources of pressure. This method may be adequate for mildly contaminated systems. However, in cases of extensive contamination, the *one-pass* method may require excessive amounts of the cleaning refrigerant or not provide sufficient cleaning.

The installation of a temporary suction line filter-drier protects the new compressor from acid, sludge, and finely divided carbon that may be in the system after burnout. Normal circulation of the refrigerant brings these contaminants to the filter-drier during the first few days of operation. When the contaminants have been collected, the suction filter-drier is removed and normal operation is continued. This procedure is applicable to most units and permits the re-use of the refrigerant in some cases.

In large systems an effective method of removing contaminants consists of frequent oil changes combined with the use of a high-side filter-drier.

In all cases of motor burnout, the cleaning procedure recommended by the manufacturer of the equipment should be followed and the oil charge replaced if it is dark or acidic.