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Factors Affecting Reliability of Hermetic Compressors

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by

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ABSTRACT

Attaining long life and reliable performance of compressors for air conditioners and heat pumps requires a combination of well-designed equipment, proper installation procedures and systematic maintenance by the owner. This paper reviews the importance of the stability of critical materials and components in these systems, how stability limits can be determined and how they interrelate with compressor operating parameters. The contributions of well-designed, cost-effective manufacturing processes to production of reliable hermetic compressors is reviewed.

The compressor designer must specify the thermal capability of the hermetic motor and determine that the motor thermal protection system provides an adequate margin of safety for the selected motor insulation materials. The inadequacy of conventional thermal rating systems as a means of selecting hermetic motor insulation systems is noted.

The refrigerant-oil working fluid must meet specified requirements of lubricity and stability. The paper describes procedures for selecting lubricant or lubricant-additive combinations and provides examples of the range of properties that can be expected. Emphasis is placed on systems using Refrigerant 22 as working fluid and a comparison with other refrigerants is sometimes provided.

The paper concludes with observations concerning the interpretation and utility of field tests for acid in hermetic units. A critical review of system performance and operating history is highly recommended before an oil change is endorsed.

INTRODUCTION

Continuing improvements in compressor design offer future owners of refrigeration and air conditioning equipment potential benefits in terms of operating and maintenance costs. These advantages however, will be realized only if the chain of events from product inception to user application is considered in a systems context, where all elements are interrelated. Complexity of the compressor delivery system is illustrated in Figure 1, which defines work elements (left column), responsible parties (center column), and tasks or contributions (right column).

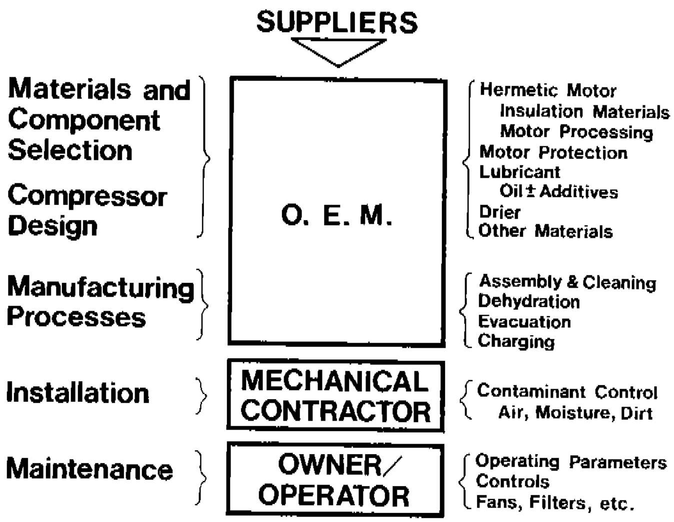

Figure 1. Factors Affecting Compressor Reliability

Although the task requirements are generally appreciated by specialists in those areas, the complexity of the total system in terms of technology disciplines, operational requirements and business considerations is unusually wide-ranging. The information displayed in Figure 1 illustrates that compressor quality and performance is not limited to the OEM who designs and manufactures the product, but that material and component suppliers, equipment installers and maintenance personnel play key roles. In the following discussion of total system requirements, opportunities for improvement and interfaces vulnerable to neglect will be noted.

MATERIAL AND COMPONENT SELECTION

Refrigeration and air conditioning compressors are designed for duty with a specific refrigerant and once the refrigerant has been fixed, other material and design criteria become, in a sense, dependent variables with fewer degrees of freedom. The material selection aspects of this situation are illustrated in Figure 2 where the refrigerant is depicted as playing a dominant role in the choice of lubricant, hermetic motor and drier. The areas of interaction (shaded I, II, III) are shown in decreasing size to illustrate varying degrees of significance.

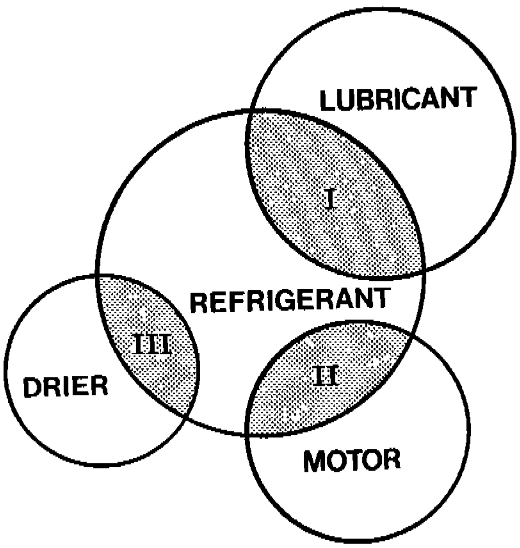

Figure 2. Refrigerant Interactions

Lubricant/refrigerant interactions are of primary importance and hence the selection of the type of oil or oil and additive combination is a major decision requiring the following considerations:

- chemical stability with the refrigerant and metals of construction
- lubrication properties (boundary and film)
- additive response
- additive (type and amount)
- lubricant-refrigerant solution properties
- uniformity of lubricant quality
- lubricant availability, short and long term
- cost

A wealth of information is available in the technical literature concerning refrigerant-oil chemical reactions. One attempt to reduce this widely distributed data base to manageable proportions is shown in Figure 3 which displays Refrigerant 12 and Refrigerant 22 decomposition in the presence of naphthenic oil and metals over a wide range of application temperatures. The upper curve for R12 is based on data reported by three different investigators. Comparison of the two curves underscores the significantly greater stability of the naphthenic oil with R22 and metals of construction. Refrigeration oils of widely varying properties are available commercially. Sealed tube tests of these oils with refrigerants reveals decomposition with R12 ranging from about 0.01% to several % when tested at 175°C, 14 days, metals present. In all instances, however, stability with R22 is greater than with R12, as illustrated in Figure 3.

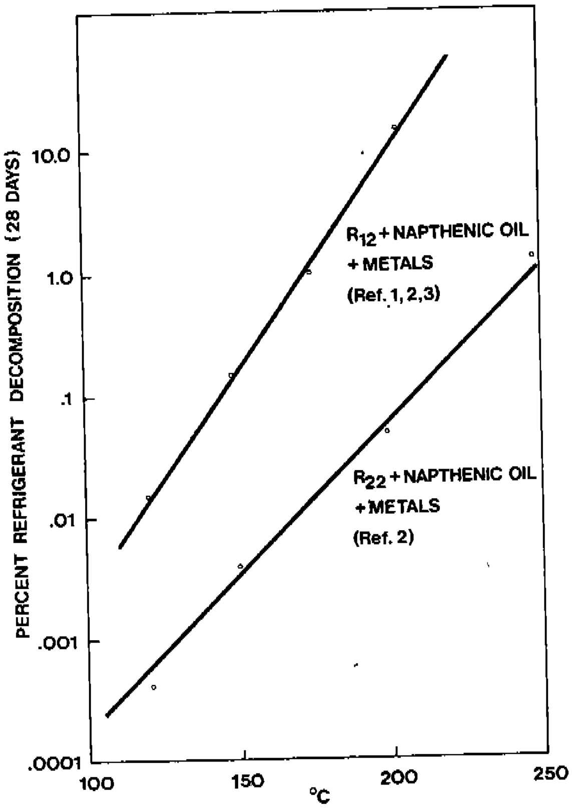

Figure 3. Stability of Oil-Refrigerant Combinations

Although this brief discussion has emphasized chemical stability, other factors such as lubricity and refrigerant solution properties are also important and must receive full consideration in choosing a compressor lubricant.

Motor insulation/refrigerant interactions deserve special attention in systems designed for Refrigerant 22. This refrigerant is a powerful solvent which may produce swelling and softening of electrical insulation materials that would be unaffected by Refrigerant 12. R22 is a polar molecule and, in the liquid state, is a much better conductor of electricity than is R12 (4), thereby imposing further requirements on the insulation materials to protect against shorting or grounding. Choice of hermetic motor insulation materials must consider these effects related to the refrigerant, as well as the motor application temperature and characteristics of the thermal protection system.

The importance of selecting the proper motor insulation is illustrated in Figure 4, showing dielectric loss as a function of temperature, all measurements in R22 vapor at 4.4 torr (5).

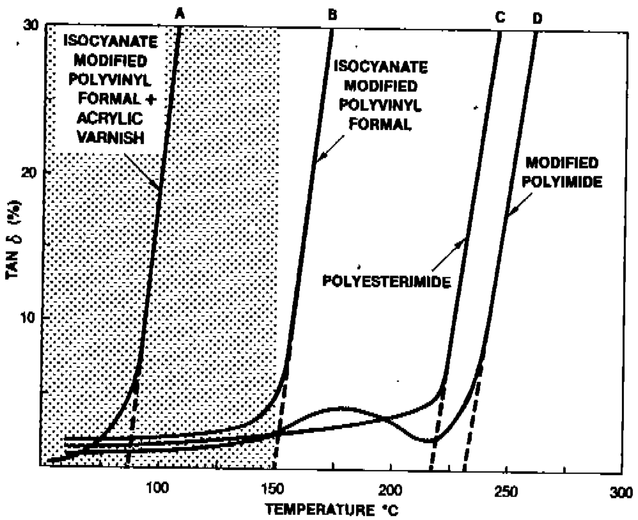

Figure 4. Temperature Limits for Hermetic Motor Insulation (Ref. 5)

If the set point of the motor protection system is 150°C, it is clear that Insulation A is inadequate, Insulation B is marginal and that higher temperature rated insulations such as C or D must be specified. Unfortunately, motor manufacturers are not always aware of nuances related to these complex requirements and thus may recommend insulation systems that are well adapted to their manufacturing processes but not optimum for meeting application requirements. To summarize, in addition to the basic electrical and mechanical performance requirements, the following factors should be considered in selecting a hermetic motor:

- type of refrigerant
- compressor design (high-side, low-side, cooling mode, etc.)
- electrical properties of the insulation materials at the use conditions
- chemical properties of the insulation materials at the use conditions
- system contaminants derived from the motor
- ease of motor dehydration and evacuation
- cost

Temperature classifications according to ratings established for open motors, where the insulation materials operate in an air environment, have limited value as a basis for selecting hermetic motors and can, in fact, lead to serious field problems.

Drier/refrigerant interactions, though not as significant as refrigerant interactions with the lubricant and with the hermetic motor insulation materials, nevertheless need to be evaluated. It is known (6), for example, that early forms of refrigerant-grade molecular sieve 4A reacted with Refrigerant 22 to produce carbon monoxide and halogen decomposition products. Thus careful screening of desiccants, and also of new drier materials, is highly recommended. Drier bodies contain inorganic binders and the nature of these can vary from one manufacturer to another.

In addition to detailed review of the desiccant or drier manufacturer's property sheets, the following questions need to be addressed by the potential user:

- composition, i.e. active ingredients
- water capacity as function of temperature and water content
- chemical reactivity in the refrigerant environment
- physical properties, such as hardness
- organic and inorganic acid capacity
- potential for system contamination resulting from "fines" in the product
- control of moisture in "as received" condition

Further discussion of the role of driers for clean-up of installed systems is presented later in this paper.

MANUFACTURING PROCESSES

In this discussion, attention is directed to hermetic system factory processing in order to highlight practices which will minimize energy requirements, reduce rework and ultimately lead to a general improvement of quality. To this end, the following areas are suggested for review by the manufacturer:

- analyzing factory work flow in operations related to cleaning and assembly
- assessing chemical effects of processing agents
- establishing tolerance of the sealed system for contaminants
- minimizing requirements for energy-intensive factory processes

The order in which component cleaning operations are carried out, prior to assembly, determines the nature of contaminants most likely to be found in the sealed unit. Furthermore, proper sequencing of operations can contribute to ease of removal of wash or cleaning agents. Clearly, the ideal assembly operation is one that deals with components free of residues and residual solvents. Since the ideal is rarely achieved, the presence of residual cleaning agents or metal forming aids can be checked for chemical compatibility using sealed tube tests of the oil, refrigerant and metals and comparing the results with similar tests where a small quantity of the expected contaminants are present. Evaluations of this kind for many different processing agents reveals substantial variations in their effect on system chemistry and provides guidance relative to their use.

Various methods of processing hermetic systems have been developed by different manufacturers. Common to all compressor assembly operations is a final evacuation and leak check, designed to achieve an acceptably low level of residual contaminants. Since this evacuation step often requires significant energy for compressor heating and evacuation, the effectiveness of the process should be studied in detail with a view of answering questions such as:

- what contaminants are being removed?
- how harmful are these contaminants?
- what level of residual contaminants is acceptable?
- is the evacuation schedule (time, temperature, pressure) optimum?
- what is the most likely source of these contaminants?
- is it cost and/or quality-effective to control more closely pre-cleaning or pre-conditioning of sub-assemblies?

It is unlikely that definitive answers to these questions are known for any process. However, through analysis of operations and the application of modern process technology, it is likely that substantial reductions in process energy and improvements in product reliability can be achieved.

CONTAMINANTS INTRODUCED DURING FIELD ASSEMBLY

Many of the observations reviewed in the previous sections related to packaged units that are processed and sealed in the OEM's factories. Split systems, however, are assembled and charged with refrigerant at the construction site and under these less favorable conditions the likelihood of introducing contaminants is significantly greater. Typical contaminants found in field assembled systems are air, moisture and dirt. While most larger systems can tolerate small quantities of these contaminants, larger amounts adversely affect system performance and life.

Introduction of air provides a source of oxygen which, with time, will oxidize organic materials or metal surfaces in the compressor or the system. If the quantities of oxygen are modest, the resulting effects on materials, though undesirable, are not likely to lead to early failure, as would large quantities of air.

The presence of non-condensable gases in vapor compression systems results in reduced efficiency because the compressor is doing non-productive work in circulating these gases along with the refrigerant. Furthermore, non-condensable gases can interfere with the heat transfer function of the halocarbon refrigerant. A recent study of the effects of non-condensable gases in a 250 ton centrifugal chiller (7) showed that the presence of 8% non-condensables caused a 6.4% increase in power at 50% load and 5.9% increase in power at 70% load. Smaller quantities of non-condensables produced similar, though correspondingly smaller, effects. Thus air, introduced inadvertently during field assembly, will result in parasitic energy losses, and these losses will persist until the air is purged from the system.

Moisture and dirt introduced during field assembly can be controlled to some extent by filter-driers that are normally incorporated into field assembled split systems. The quantity of these contaminants that the filter-drier can hold is, of course, limited. Effective performance of the filter-drier depends on the transport of moisture and dirt by means of the circulating refrigerant. Experiments have shown that significant elapsed time, equivalent to many circulations of the refrigerant charge is required to arrive at steady state conditions. There is some risk of damage to the compressor and the system during this contaminant collection period, and good practice dictates minimizing entry of all contaminants in assembly.

MAINTENANCE

Most larger refrigeration and air conditioning equipment requires some routine maintenance after installation. In the simplest case, this may amount to an annual lubrication of open motors, checking and replacing fan belts, replacement of air filters and the like. Larger systems may have provisions for operating information such as pressure and temperature readings. Proper note and interpretation of these readings requires a level of expertise that is not always available and consequently incipient problems may not be addressed or may be incorrectly diagnosed.

One example of such a problem has to do with the increasing popularity of oil changes in field units when the compressor has not failed. In this situation, oil samples are taken from installed equipment and subjected to acid analysis using the acid test kits that are available from all refrigeration supply houses. A visual indication of acidity in the oil sample often leads to a recommendation of an oil change, regardless of other indicators related to operation of the motor-compressor.

An unwarranted oil change violates good refrigeration system maintenance practices. Figure 5 is a reproduction of the original data presented by Wojtkowski (8) upon which all acid test kits are based. Note that the "accept/reject" decision band at an acid number of approximately 0.05 was chosen because it differentiated between acid found in units which had burned out motors (reject) and those that did not (accept).

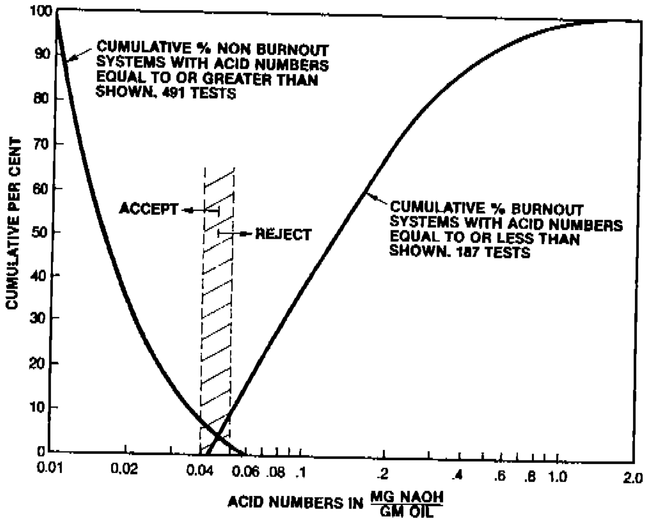

Figure 5. Oil Acid Number and Motor Burnouts (Ref. 8)

Changing oil in a refrigeration unit in the field, unless specifically required to correct a motor burnout, is likely to incur unneeded risk of impaired performance and shortened life for the following reasons:

- acid test kits vary in performance
- unused oils may test acid
- changing oil requires refrigerant transfer or purging; operations with attendant problems
- the new oil supplied in the field may not be that specified by the manufacturer
- effective evacuation in the field is difficult to achieve
- risk of improper recharging

A consideration of the factors listed above suggests a careful evaluation is in order before an oil change is approved. In fairness, however, it is recognized that refrigeration and air conditioning maintenance, system service and repair personnel are often required to make quick decisions based on very sparse information. Development of improved monitoring devices is underway and these should prove useful for identifying and diagnosing compressor field problems before reliability and performance are seriously impaired.

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