

is usually the case, the products of pyrolysis are water and a complex of organic acids, gases, tars, and carbon. Insulation not consisting of cellulose may melt before decomposing.

Still a fourth source of excessive temperature lies in the condenser. If undersized in relation to the available or theoretical compressor capacity, the compressor head pressure and temperatures rise and a part of the compressor capacity is lost. Even a properly sized condenser in a location restricting the necessary air flow will cause the same effect. Possibly the most common cause of excessive compressor temperatures is dirty condensers. Undersized connecting lines can also result in higher compressor temperatures.

Restrictions and excessive pressure drops through driers due to undensating or accumulation of dirt are sources of high compressor temperatures.

Low Temperature

The low temperatures in a refrigeration cycle generally present no chemical problem of deterioration or interaction of the refrigerants and lubricants. Further, the rate of corrosion by contaminants such as water and acid is reduced roughly by half for each 18 F deg reduction of temperature. However, the lower the temperature in the evaporator the greater is the physical problem of precipitation and restriction. Expansion devices can be made inoperative or operate erratically when ice, oil, wax, or other contaminants exceed their solubility limits in the refrigerant as the temperature drops.¹⁴

There are substantial differences in the solvency of the various refrigerants for various materials. For instance, Refrigerant 22 can dissolve much more water than Refrigerant 12, but much smaller quantities of most oils. Refrigerant 22 also can extract more organic materials in general than Refrigerant 12. Consequently, low temperature problems will vary with the refrigerant. Also the restriction problems with any of the refrigerants will become quite pronounced as temperatures drop to -30 or -40 F or lower. At the lower temperatures, even evaporator passages can be blocked by congealed oil especially if charges of refrigerant are low. Oil return to the compressor is, perhaps, the primary problem at low temperatures.

Field Assembly

Proper field assembly and maintenance are prerequisites of contaminant control in refrigerant systems. To a high degree they depend on the ability and conscientiousness of the contractor and the serviceman, respectively.

Refrigeration components, entirely adequate for intended design limits can be misapplied or mismatched with consequent overloading, particularly, of compressor and controls. Connecting piping may be too large or too small to carry the necessary gas and yet circulate oil properly. Driers selected may be too small, or carelessly handled so that drying capacity is lost.

Tube-joint soldering unless carefully done is a major source of water, flux, and oxide scale contamination. Copper oxide scale from improper brazing is one of the most frequently found contaminants. The tube cutting and handling, if careless, can introduce excessive quantities of dirt and metal chips.

Dehydration of the assembled system is not easy in the field and for this reason *overdried* driers are recommended. Even though manufacturer's components are delivered sealed and bone-dry, the weather and the open-time during assembly can permit introduction of considerable quantities of moisture which must be removed.

Finally, wrong control settings, dirt-fouled air condensers, or water scaled and corroded heat exchangers will cause breakdown of any system—no matter how well designed.

MATERIALS IN SYSTEMS

Experimental Methods for Evaluation

System Tests. The evaluation of component materials in operating system tests is essential in order to obtain complete information about their performance. Other tests may give valuable evidence and serve for preliminary screening of materials or effect of additives. However, it is impossible to completely simulate the dynamic refrigeration system with static tests or with tests on isolated parts of the system. Performance is influenced by the interaction of all of the parts, by changes in temperature and pressure, by electrical effects and, perhaps, by other unrecognized factors.

The method of performing and evaluating system tests will depend somewhat on the purpose of the tests. These objectives may include: (1) life tests on standard equipment, (2) evaluation of mechanical design, (3) testing of non-metallic parts, (4) effect of contaminants, and (5) study of system characteristics.

System testing can be divided into two broad groups, (1) field tests and (2) laboratory tests. Since good performance in the field is the final goal, the best evaluation of any system or part is based on reports from the field. A limited amount of equipment with special features such as new insulation or a different oil may be placed in service. Careful records and search for the cause of failures, if any, can give the best possible answer to important questions. Although reliable, the field method is too slow and inflexible for most system testing.

Laboratory Tests. Any accelerated laboratory testing program of refrigerant systems should be planned for study of predetermined variables such as mechanical design changes, new insulation, change of oils or refrigerants, driers, moisture level, etc. All extraneous variables must be controlled as closely as possible, such variables being, for example, pump tolerances, degree of evacuation, and operating conditions. Not much faith can be placed in results obtained from a single unit; even duplicate tests are often inadequate.

Operating conditions must be carefully controlled while conducting system tests. Records should be kept of important factors such as motor winding temperature, input in watts, running time, cycling, etc.

Final analysis should be as complete as possible and may include any or all of the following:

1. Collect total refrigerant and noncondensables and compare with original charge.
2. Collect and measure total oil charge.
3. Determine amount and nature of noncondensable gases.^{15,16}
4. Analyze refrigerant for decomposition.¹⁷
5. Determine total moisture content and its distribution throughout the system.^{18,19,20}
6. Analyze oil for acidity, color, viscosity, pour point, floc point.
7. Analyze oil for structural changes by means of infrared spectrophotometer.
8. Test motor insulation for deterioration.
9. Inspect parts for bearing wear, copper plating, and formation of sludge or coke.
10. Analyze drier for sorbed products.
11. Sectioning of condenser, evaporator, capillary tube or expansion device.²

Very little work has been reported with regard to air and other noncondensables in refrigerant systems.¹¹ The refrigerant is usually sampled in the condenser vapor space because air tends to collect there. For equilibrium conditions, the concentration of air in the liquid phase of the condenser can be estimated from known solubility relationships.²¹ The

Contaminant Control in Refrigerant Systems

suction gas or compressor discharge gas could also be sampled for air analysis although it is likely that the concentration would be very low. Probably the best available method for analyzing refrigerant for air is gas chromatography.¹² The method is fast, accurate, and requires a sample of only a few cubic centimeters. Measurement of the gas not absorbed in perchloroethylene requires less expensive equipment. It is commonly used for the analysis of refrigerant¹⁷ and could be adapted for samples from systems. Some gas analysis has been done using a mass spectrometer.¹³

The analysis for water in refrigerant systems is especially difficult because it is present in many different locations. For methods of moisture analysis, refer to Chapters 47 and 49.

Sealed-Tube Tests and Their Limitations. Selecting materials for use in hermetic refrigeration systems requires great care and good judgment to insure long and trouble-free life. In the continuous search for new and better materials, extensive testing is required before units can be placed in the field. A well-planned series of sealed-tube tests at elevated temperatures provides a good basis for judging the effect of combinations of refrigerant, oil, metals, plastics, polymers and other materials under consideration. Such tests have been used for many years to study the suitability of materials for use in refrigerant systems.²²⁻²⁸

Methods of preparing the sealed tubes have been described in detail.²³ Considerable variation in testing procedure and evaluation of the results is possible to allow for differences in objective and interest. In general, the nonvolatile materials to be tested are placed first in the heavy-walled Pyrex glass tubes. Care must be used to prevent contact of oil or similar materials with the upper walls of the tubes during loading since decomposition may occur when the tubes are sealed. With the materials in place, the tubes are cooled to a low temperature (usually with liquid nitrogen) and evacuated. The refrigerant is introduced through an adequate measuring device and the tubes are sealed while still under vacuum. The tubes are then placed in individual metal protective containers and heated in an oven or by other means at the desired storage temperature. From time to time the tubes are cooled to room temperature and inspected. Two or more duplicate tubes are usually prepared to allow for possible breakage and to increase the reliability of the tests.

Methods of evaluating the results of the sealed-tube tests depend on the materials under test and the object of the work. Visual inspection of the contents is the simplest and at the same time one of the most important methods. Changes in color of liquids²⁹ or metals or other solids compared with those in control tubes should be noted. The appearance of metal test pieces and the deterioration of plastic and elastomer samples is significant. The formation of solids and other unusual developments will help in judging the results of the test. In order to help remove the subjective element from visual observations and to give results of a semiquantitative order, the following classification has been suggested:

Rating	Appearance of	
	Liquids	Metals
0	No change	No change
1	Slightly darker or cloudy	Slight discoloration or tarnish
2	Moderately darker or cloudy	Slight copper plating or corrosion
3	Very dark or cloudy	Moderate copper plating or corrosion
4	—	Heavy copper plating or corrosion

Such a rating system will not fit all tests but can be useful in many cases.

Nonmetallic and metallic test pieces are weighed and measured for changes in size and shape. Measurements immediately after removal and again after air drying may be significant. Refrigerant decomposition can be determined by analyzing the liquid contents of the tube for chloride ion. A coulometric titration method^{30,31} has given good results. If the refrigerant tested does not contain chlorine, other methods of analysis must be used.

In addition to the analytical methods mentioned above, the use of modern instruments such as infrared mass spectroscopy, gas chromatograph, etc., may be helpful in special cases.

Sealed-tube tests have been and will continue to be valuable in refrigeration testing. In many cases, good correlation has been found between tube tests and machine tests. However, they cannot entirely replace testing of complete systems. The tube tests are carried out with a limited number of components under static conditions. During the time of storage, there is no chance for impurities or decomposition products to escape or be removed by a strainer or drier. Temperature conditions are quite constant. On the other hand, in a commercial operating unit, there is a dynamic condition with a cyclic flow of some of the components. Temperatures fluctuate over wide ranges. Abnormal conditions may prevail for short periods of time. From a thermal point of view, tube tests are often designed to be more severe than unit tests. However, factors affected by dynamic conditions are not readily studied this way. For these reasons, some care must be used in judging the results of sealed-tube tests. To simulate field conditions, some investigators are testing a small glass loop tube in which the refrigerant circulates. This arrangement gives dynamic conditions closer to an actual refrigerant system.

Refrigerants

1. **Thermal Stability.** The ability of a material to withstand heat without decomposition or without other adverse effects is a measure of its thermal stability. It is difficult to assign a temperature that will define the stability of a material under all conditions because the presence of other materials may greatly affect the result. Studies of the ultimate thermal stability of refrigerants would be valuable and some work in this direction has been done.³² However, for practical purposes the refrigerant is usually in contact with metals and may also be exposed to oil, insulation, air, water, and perhaps, small amounts of contaminants, such as metal oxides, oil additives, etc. All of these may affect the thermal stability and usually will decrease it.^{33,34,35,36,37,38,39}

a. **Fluorinated Hydrocarbons.** The fluorinated refrigerants are derivatives of methane and ethane containing fluorine and usually chlorine. Although related in structure, each member of the series has different properties as well as a different degree of thermal stability.⁴⁰ The presence of fluorine atoms in the molecule is responsible for a high degree of stability and, as a general rule, the more fluorine present the greater the stability. For example, Refrigerant 14 is an extremely stable compound. In one test it was heated at a temperature of 750 F for a period of 500 hr with no evidence of decomposition. On the other hand, Refrigerant 11 is less stable although still in a stability class considerably higher than similar chlorinated products.

When heated in steel at 400 F, the initial decomposition rate for Refrigerant 11 was 27 percent per year while the final steady rate was 2 percent per year. At the same temperature, the initial decomposition rate for methylene chloride has been reported as 2400 percent per year.

Since the presence of other materials and the time and general nature of exposure have a definite effect, it is not possible to define the stability of the fluorinated refrigerants in a precise way which will include all possible applications. As general examples, some thermal stability data are shown in Table 2.

Columns 1 and 2 of Table 2 give the refrigerant number and