Table 1 .... Factors Affecting Copper Plating

Step 1. Solution of Copper in Oil	
Factors Which Cause Increased Solubility	1. Poor quality oil 2. Oxygen 3. High temperatures
Factors With Little Effect on Solubility	1. Water 2. Methanol 3. Acidity 4. Refrigerant
Step 2. Precipitation or Plating of Copper	
Factors Which Cause Increased Plating	1. Chlorinated refrigerant 2. High temperatures 3. Water (and probably methanol) 4. Acids 5. Other contaminants

copper solution. If a good quality oil is used and air is excluded, the solution of copper in the oil will be low at temperatures ordinarily found in operating equipment.

Over the years, copper plating has been attributed to many different factors. It seems clear now that, contrary to earlier assumptions, the solubility of copper in oil is not appreciably affected by the presence of water, methanol, acidity, or by the nature of the refrigerant. Although these materials have little effect on the solubility, they are important in causing precipitation or plating of the copper.[8]

The exact mechanism of the second step in copper plating is not clear. The presence of a chlorinated refrigerant is apparently necessary. The probable course of the reaction is, at first, a breakdown of the refrigerant either through hydrolysis, thermal decomposition, or direct reaction with the oil to form hydrochloric acid. This acid then reacts with the soluble organic copper compound to form copper chloride. By a metallic exchange reaction with iron or other metal surfaces present, copper is displaced from its chloride salt and is deposited as metallic copper.

When a chlorinated refrigerant is used, the other factors shown in Table 1 under Step 2 apparently contribute to copper plating by aiding in the decomposition of the refrigerant. The amount of copper plating can be directly related to the general stability of the refrigerant. High temperatures not only contribute to refrigerant decomposition but probably increase the reaction rate of the organic copper compound with hydrochloric acid. When copper plating develops it is often found at places where high temperatures are produced, such as bearing surfaces and flapper valves.

The mechanism of copper plating outlined above involves two separate steps. Conditions causing both steps must be present in order for copper plating to occur. It is possible for copper to dissolve in the oil without plating. This situation has been observed when sulfur dioxide is the refrigerant. On the other hand, copper plating never occurs if the copper does not dissolve in the oil.

The previous discussion of copper plating is an oversimplification of a complex subject. Although the factors mentioned in the discussion and listed in Table 1 undoubtedly affect copper plating, there may be other responsible factors which as yet are not completely understood. Nevertheless, the following practical conclusions can be drawn:

Properties of the lubricating oil are an important factor in copper plating. Variations in oil quality, resulting from changes in refining techniques or source of the crude, can substantially alter the degree of copper plating with a given refrigerant.

The stability of the halogenated refrigerant also has a direct bearing on copper plating. These materials are essentially pure compounds, but each different refrigerant has a different level of stability. It is probable that copper plating may also result from the direct action of hydrochloric acid (formed by the breakdown of the refrigerant) and an oxidizing agent on copper to form copper chloride salts, followed by reaction with iron and redeposition of the copper as outlined by Divers.[9] The chemical reactions involved are certainly valid, but the mechanism has not been thoroughly studied. Therefore, selection of a stable halogenated refrigerant and a good quality oil, removal of air and water, and operation of the system at moderate temperatures, will greatly reduce the possibility of copper plating.

Residual Solvent

Carbon tetrachloride is extremely reactive with oils and moisture.[7,9] Frequently, chlorinated hydrocarbons are used as cleaning solvents for refrigerant systems. Obviously, such solvents should not be used unless they can be thoroughly removed from the system. For field use, many manufacturers recommend that only refrigerant be used as a solvent

Metallic Contaminants, Flux, and Dirt

It has been found[10] that at elevated temperatures Refrigerants 12 and 22 decomposed more readily when in contact with iron powder, iron oxide or copper oxides. These materials are frequently found in refrigerant systems where they originate as cast iron dust, rust, or scale from soldering operations. Besides the possibility that these materials are abrasive enough to score cylinder walls and bearings and plug up driers and expansion valve screens, they may aggravate the effect that temperature alone may have on the refrigerant. Other solid particles such as flux residues, steel, copper and brass chips, or iron filings are sometimes present and can be the cause of restrictions, abrasive action, and corrosion. Sludge from oil decomposition is an even more common cause for partially plugged or, in extreme cases, fully plugged driers. (See section on Lubricants.)

Noncondensable Gases

Gases are another type of contaminant frequently found inside refrigerating systems. These gases can come from several sources: (1) they may be the result of incomplete evacuation, (2) they may concentrate in the system if functional materials release adsorbed gases or decompose to form gases at elevated temperature during operation, (3) they may enter the system through low side leaks, and (4) they may be formed as the result of chemical reactions occurring during the operation of the system. Whether or not such gases are harmful to the operation of a refrigeration unit depends on the nature of the gas and the amount which is present. Chemically reactive gases, such as hydrogen chloride, will attack other components in the refrigerating system. When these reaction rates are sufficiently high, they lead to failure of the refrigerating unit.

Chemically inert gases in the system, which do not liquefy in the condenser, reduce the cooling efficiency. The quantity of inert, noncondensable gas which is harmful depends on the design and size of the refrigerating system and the nature of the refrigerant. A discussion of the distribution of these noncondensable gases throughout a refrigeration system has been presented by D. D. Wile.[11] Their presence contributes to higher than normal head pressures and therefore higher discharge temperatures. These higher temperatures speed up undesirable chemical reactions.

Gases which have been found in various hermetic refrigeration units are nitrogen and oxygen and carbon dioxide from air, hydrogen, carbon monoxide, and methane. It should be emphasized that the gases listed are not present in quantities larger than traces in well-designed, properly functioning equipment. This requires use of chemically compatible materials which must be properly assembled.[12] Furthermore, proper installation and maintenance is required to assure trouble-free operation.

Aside from affecting the operating life of a refrigerant system, the presence of foreign gases, even in trace quantities, can be used as a measure of the chemical stability of the system. Spauschus and Olsen[13] used the mass spectrometer and gas chromatograph to study rates of gas formation in units operated at various controlled conditions.

Anti-Freeze Agents (Methyl Alcohol)

Anti-freeze agents are added to refrigerant systems to act as co-solvents for the small quantities of water present. They prevent ice formation at the expansion device but add to the contaminants already present in the system.

There are few published data available concerning the corrosion effect of small quantities of methyl alcohol in either Refrigerant 12 or 22 systems. However, tests have shown no significant adverse effects where methyl alcohol is used in the proportion of 3 cc per pound of Refrigerant 12. Also, many refrigerant systems do contain up to 1 percent methyl alcohol by weight.[14] Corrosion problems may result in systems containing more than 3 cc of methyl alcohol per pound of refrigerant, especially where aluminum is present, because the aluminum will be attacked and hydrogen gas will be formed.

If similar systems are test-run side by side, one *dry* and one with ½ to 1 percent methyl alcohol, the alcohol system can always be picked out as having more stain, corrosion, copper plating and debris on fine filter screens than the *dry* system. However, there is no evidence that these *alcohol systems* give inferior performance to those which do not contain methyl alcohol.

DESIGN AND OPERATING CONDITIONS

Both the design and the operating conditions, internal and external, determine the performance and life of a refrigeration system. Which factor is paramount for the system can only be found by specific evaluation of that particular system. It must be remembered that design alone cannot solve all the problems. On the one hand, design is limited by the materials available; on the other hand by their cost. Every design is a compromise between these two. In the total task to be performed, operating conditions must be matched to the machine or else trouble becomes inevitable.

High Temperature

Heat is one of the main operating problems. Excessive heat can thermally decompose or pyrolyze materials and it also can increase the rate of interaction of these materials with each other. Both of these modes of deterioration are roughly doubled for every 18 F deg of temperature rise. Thus the excessive heat not only deteriorates the material, but also forms by-products which interfere with operation and act as catalytic agents to speed further deterioration. The commonly used halocarbon refrigerants and oils appear very stable when pure and tested in glass. Yet in a refrigeration compressor, the refrigerant and oil combination, in contact with catalysing metals and further catalyzed by remaining contaminants can show reasonable operating life only at temperatures substantially below theoretical oil and refrigerant breakdown.

Both the thermal degradation and the interaction process will release or form water, acids, metal salts, noncondensable gases, and many other complex organic chemicals ranging from formaldehyde through heavy tars and carbon. These products, in addition to acting as catalytic agents, also give rise to excessive metal wear, restrictions of capillaries or expansion valves or lubricant passages, weakening of high-stress, parts such as valve reeds, copper plating, varnishing, sludging, and general corrosion.

The heat in any hermetic compressor originates from the electrical input. The percentage of this energy that is not converted to useful work reappears partly as heat of friction in the bearings, as heat of compression of the refrigerant, and as gas frictional effects of the refrigerant flowing through valves and connections. Consequently, an incorrectly selected, too much diluted, or a poor lubricant, or insufficient lubricant film pressure as well as insufficient bearing surface or improper sliding surface clearances will give rise to excess friction and therefore become a considerable source of heat. See Chapter 50.

Another critical location within the compressor is at the discharge valve. Here part of the electrical input that was converted to the useful work of compressing reappears as heat of compression and as heat of gas friction through the discharge valve and immediate fittings. Whether or not this temperature is excessive will depend on the amount of work (heat) performed in the piston-cylinder-head volume in relation to the possible heat transfer that the design permits. The amount of heat released will depend on the refrigerant used, the compression ratio, and the speed of compressing plus the cylinder-piston friction effects.

Except for inadequate bearing operation and for improper motor performance, the discharge point will be the hottest point within most refrigerant systems. High compression ratios and high speeds result in excessive temperatures. In the discharge area, the refrigerant and small amount of oil, which is carried as a mist, react to form HCl and HF, simultaneously transforming portions of the oil into a tarry and even carbon-like product. The acid gases corrode and erode valve seats and break valve reeds. The tar and carbon may form varnish and prevent discharge valve closure and thus cause even greater heat because of inefficient re-expansion. This vicious cycle will cause rapid failure of the system at excessive temperatures. On the basis of theoretical calculations and confirmed by tests, it is estimated that discharge temperatures frequently reach 300 F on Refrigerant 12 and 350 F on Refrigerant 22 systems.

A third area of possible excessive temperature lies in the hermetic stator and rotor of the compressor. Not all of the electrical input to the motor is converted to useful work even under ideal conditions; some appears as heat in the stator due to magnetic hysteresis; some as heat due to wire resistances and the induced currents in the stator-rotor iron. Under unfavorable conditions the temperature can rise very quickly to excessive levels. If the motor is undersized or overloaded the efficiency drops and greater proportions of the electrical input appear as heat.

Excessive heat at the stator deteriorates and decomposes not only the refrigerant and lubricant but also the motor insulation. Initially the high heat can soften the wire insulation, and the running vibration plus the movement due to alternating magnetic attraction and repulsion effects then may easily lead to a short circuit between wires or even between coils. Any current discharge or arc is a very potent destroyer of refrigerant and a factor in formation of hydrochloric and hydrofluoric acids. As this occurs, the slot insulation is also heated and pyrolized. If the insulation consists of cellulose, as