CHAPTER 6

CONTROL OF MOISTURE AND OTHER CONTAMINANTS IN REFRIGERANT SYSTEMS

THIS chapter covers the following topics: (1) control of moisture, which is an important and universal contaminant in refrigeration systems; (2) control of other contaminants in refrigeration systems; (3) recovery, recycling, and reclamation of refrigerants; (4) service procedures typically used in cleaning a refrigeration system following a hermetic motor burnout; and (5) control of contaminants during retrofit to alternative refrigerants.

MOISTURE

The amount of moisture in a refrigerant system must be kept below an allowable maximum to provide satisfactory operation. Moisture must be removed from components during manufacture and assembly to minimize the amount of moisture in the completed assembly. Any moisture that enters during installation or servicing should be removed promptly.

Sources of Moisture

Moisture in a refrigerant system results from

1. Inadequate equipment drying in factories and service operations
2. Introduction during installation or service operations in the field
3. Low-side leaks, resulting in entrance of moisture-laden air
4. Leakage of water-cooled heat exchangers
5. Oxidation of certain hydrocarbon lubricants that produce moisture
6. Wet lubricant, refrigerant, or desiccant
7. Moisture entering a nonhermetic refrigerant system through hoses and seals

Drying equipment in the factory is discussed in Chapter 43. Proper installation and service procedures as given in ASHRAE *Guideline* 3 minimize the sources listed in items 2, 3, and 4. Lubricants are discussed in Chapter 7. If purchased refrigerants and lubricants meet specifications and are properly handled, the moisture content generally remains satisfactory. See the section on Electrical Insulation under Compatibility of Materials in Chapter 5 and the section on Motor Burnouts in this chapter.

Effects of Moisture

Excess moisture in a refrigerating system can cause one or all of the following undesirable effects:

1. Ice formation in expansion valves, capillary tubes, or evaporators
2. Corrosion of metals
3. Copper plating
4. Chemical damage to motor insulation in hermetic compressors or other system materials
5. Hydrolysis of lubricants and other materials
6. Sludge formation

Ice or solid hydrate separates from refrigerants if the water concentration is high enough and the temperature low enough. Solid hydrate, a complex molecule of refrigerant and water, can form at temperatures higher than those required to separate ice. Liquid water forms at temperatures above those required to separate ice or solid hydrate. Ice forms during refrigerant evaporation when the relative saturation of vapor reaches 100% at temperatures of 32°F or below.

The separation of water as ice or liquid also is related to the solubility of water in a refrigerant. This solubility varies for different refrigerants and with temperature (see Table 1). Various investigators have obtained different results on water solubility in R-134a and R-123. The data presented here are the best available. The

Table 1 Solubility of Water in the Liquid Phase of Certain Refrigerants

Temp., °F	Solubility, ppm (by weight)								
	R-11	R-12	R-13	R-22	R-113	R-114	R-123	R-134a	R-502
160	460	700	—	4100	460	450	2600	4200	1780
150	400	560	—	3600	400	380	2300	3600	1580
140	340	440	—	3150	344	320	2000	3200	1400
130	290	350	—	2750	290	270	1800	2800	1220
120	240	270	—	2400	240	220	1600	2400	1080
110	200	210	—	2100	200	180	1400	2000	930
100	168	165	—	1800	168	148	1200	1800	810
90	140	128	—	1580	140	120	1000	1500	690
80	113	98	—	1350	113	95	900	1300	580
70	90	76	—	1140	90	74	770	1100	490
60	70	58	44	970	70	57	660	880	400
50	55	44	—	830	55	44	560	730	335
40	44	32	26	690	44	33	470	600	278
30	34	23.3	—	573	34	25	400	490	225
20	26	16.6	14	472	26	18	330	390	180
10	20	11.8	—	384	20	13	270	320	146
0	15	8.3	7	308	15	10	220	250	115
–10	11	5.7	—	244	11	7	180	200	90
–20	8	3.8	3	195	8	5	140	150	69
–30	6	2.5	—	152	6	3	110	120	53
–40	4	1.7	1	120	—	2	90	89	40
–50	3	1.1	—	91	—	1.5	70	66	30
–60	2	0.7	—	68	—	1	53	49	22
–70	1	0.4	—	50	—	0.6	40	35	16
–80	0.8	0.3	—	37	—	0.4	30	25	11
–90	0.5	0.1	—	27	—	0.2	22	18	8
–100	0.3	0.1	—	19	—	0.1	16	12	5

Data on R-134a adapted from Thrasher et al. (1993) and Allied-Signal Corporation. Data on R-123 adapted from Thrasher et al. (1993) and E.I. DuPont de Nemours & Company. Remaining data adapted from E.I. DuPont de Nemours & Company and Allied-Signal Corporation. Data used by permission.

The preparation of this chapter is assigned to TC 3.3, Refrigerant Contaminant Control.

Table 2 Distribution of Water Between the Vapor and Liquid Phases of Certain Refrigerants

Temp., °F	Water in Vapor/Water in Liquid, mass %/mass %						
	R-11	R-12	R-22	R-114	R-123	R-134a	R-502
100	30.1	5.5	0.400	13.3	4.25	0.542	0.63
90	—	6.1	0.397	14.4	4.57	0.571	0.64
80	34.8	6.3	0.405	16.0	4.53	0.573	0.65
70	—	7.5	0.404	17.6	4.69	0.585	0.66
60	43.1	8.2	0.401	19.7	4.82	0.625	0.66
50	—	9.0	0.391	21.7	4.97	0.637	0.66
40	50.5	9.9	0.390	24.7	5.16	0.650	0.66
30	—	11.2	0.378	26.9	5.17	0.654	0.65
20	57.9	11.9	0.351	29.5	5.09	0.639	0.61
0	62.4	13.1	0.301	32.1	4.91	0.584	0.53
–20	71.0	15.3	0.251	37.4	4.78	0.543	0.47
–40	—	17.1	0.203	52.2	4.43	0.484	0.40

Data adapted from E.I. DuPont de Nemours & Company, Inc. Used by permission.

greater the solubility of water in a refrigerant, the less the possibility that ice or liquid water will separate in a refrigerating system. The solubility of water in ammonia, carbon dioxide, and sulfur dioxide is so high that ice or liquid water separation does not occur.

It is recognized (Elsey and Flowers 1949) that the concentration of water by mass at equilibrium is greater in the gas phase than in the liquid phase of Refrigerant 12. The opposite is true for Refrigerants 22 and 502. The ratio of mass concentrations differs for each refrigerant; it also varies with temperature. Table 2 shows the distribution ratios of water in the vapor phase to water in the liquid phase for common refrigerants. It can be used to calculate the equilibrium water concentration of the liquid-phase refrigerant if the gas phase concentration is known, and vice versa. The water content in the vapor phase is determined by

$$W = \left[\frac{P_w}{(P_w)^0}\right]\left[\frac{(d_w)^0}{(d_R)^0}\right] \qquad (1)$$

where

W = mass water/mass refrigerant
P_w = partial pressure of water vapor
$(P_w)^0$ = partial pressure of water vapor at saturation
$(d_w)^0$ = density of water vapor at saturation
$(d_R)^0$ = density of refrigerant vapor at saturation

Freezing at expansion valves or capillary tubes can occur when excessive moisture is present in a refrigerating system. Formation of ice or hydrate in evaporators can partially insulate the evaporator and reduce efficiency or cause system failure. It has been shown that excess moisture can cause corrosion and enhance copper plating (Walker et al. 1962). Other factors affecting copper plating are discussed in Chapter 5.

The moisture required for freeze-up is a function of the amount of refrigerant vapor formed during expansion and the distribution of water between the liquid and gas phases downstream of the expansion device. For example, in an R-12 system with a 110°F liquid temperature and a –20°F evaporator temperature, the refrigerant after expansion is 41.3% vapor and 58.7% liquid (by mass). The percentage of vapor formed is determined by

$$\%\ \text{Vapor} = 100\frac{h_{L(liquid)} - h_{L(evap)}}{h_{fg(evap)}} \qquad (2)$$

where

$h_{L(liquid)}$ = saturated liquid enthalpy for refrigerant at liquid temperature
$h_{L(evap)}$ = saturated liquid enthalpy for refrigerant at evaporating temperature
$h_{fg(evap)}$ = latent heat of vaporization of refrigerant at evaporating temperature

Table 1 lists the saturated water content of the R-12 liquid phase at –20°F as 3.8 ppm. Table 2 is used to determine the saturated vapor phase water content as

$$3.8\ \text{ppm} \times 15.3 = 58\ \text{ppm}$$

When the vapor contains more than the saturation quantity (100% rh), free water will be present as a third phase. If the temperature is below 32°F, ice will form. Using the saturated moisture values and the liquid-vapor ratios, the critical water content of the circulating refrigerant can be calculated as:

$$\begin{aligned} 3.8 \times 0.587 &= 2.2 \\ 58.0 \times 0.413 &= \underline{24.0} \\ &\ 26.2\ \text{ppm} \end{aligned}$$

Maintaining moisture levels below critical value keeps free water from the low side of the system.

The previous analysis can be applied to all refrigerants and applications. An R-22 system with 110°F liquid and –20°F evaporating temperatures reaches saturation when the moisture circulating is 139 ppm. Note that this value is less than the liquid solubility, 195 ppm at –20°F.

Excess moisture causes paper or polyester motor insulation to become brittle, which can cause premature motor failure. However, not all motor insulations are affected adversely by moisture. The amount of water present in a refrigerant system must be small enough to avoid ice separation, corrosion, and insulation breakdown.

Polyol ester lubricants (POEs), which are used largely with hydrofluorocarbons (HFCs), absorb substantially more moisture than do mineral oils and do so very rapidly on exposure to the atmosphere. Once present, the moisture is difficult to remove. Hydrolysis of these POEs can lead to the formation of acids and alcohols that, in turn, can have a negative impact on system durability and performance (Griffith 1993). For these reasons, POEs should not be exposed to ambient air except for very brief periods required for compressor installation. Also, adequate driers are particularly important elements for equipment containing POEs.

Exact experimental data on the maximum permissible moisture level in refrigerant systems are not known because so many factors are involved.

Drying Methods

Equipment in the field is dried by decontamination, evacuation, and driers. Prior to opening the equipment for service, refrigerant must be isolated or recovered into an external storage container (see the section on Refrigerant Recovery, Recycling, and Reclamation). After installation or service, noncondensable gases (air) should be removed with a vacuum pump connected preferably to both suction and discharge service ports. The absolute pressure should be reduced to 1 mm of mercury or less, which is below the vapor pressure of water at ambient temperature. External or internal heat may be required to vaporize water in the system. Care should be taken not to overheat the equipment. Even with these procedures, small amounts of moisture trapped under a lubricant film, adsorbed by the motor windings, or located far from the vacuum pump are difficult to remove. Evacuation will not remove any significant amount of water from polyol ester lubricants used in HFC systems.

It is good practice to install a drier. On larger systems a drier with a replaceable core is frequently used. The core may need to be changed several times before the proper degree of dryness is obtained. A moisture indicator in the liquid line can indicate when the system has been dried satisfactorily.

Special techniques are required to remove free water in a refrigeration or air-conditioning system due to a burst tube or water chiller leak. The refrigerant should be transferred to a pumpdown receiver or recovered in a separate storage tank. Parts of the system may have to be disassembled and the water drained from system low points. In some large systems, the semihermetic or open-drive compressor may need to be cleaned by disassembling and hand-wiping the various parts. Decontamination work should be performed prior to reinstallation of compressors, particularly hermetic units. After reassembly, the compressor should be dried further by passing dry nitrogen through the system and by heating and evacuation. Use of internal heat, by circulating warmed water on the water side of water-cooled equipment, is preferred. Drying may take an extended period and require frequent changes of the vacuum pump lubricant. The liquid line driers should be replaced and temporary suction line driers installed. During the initial operating period, driers will need to be changed often. Decontamination procedures use large temporary driers. A properly performed decontamination will eliminate the need for frequent on-board liquid line drier changes.

If the refrigerant in the pumpdown receiver is to be reused, it must be thoroughly dried before being reintroduced into the system. One method begins by drawing a liquid refrigerant sample and recording the ambient temperature. If a chemical analysis of the sample by a qualified laboratory reveals a moisture content at or near the water solubility in Table 1 at the recorded temperature, then free water is probably present. In that case, a recovery unit with a suction filter-drier and/or a moisture/lubricant trap must be used to transfer the bulk of the refrigerant from the receiver liquid port to a separate tank. When the free water reaches the tank liquid port, most of the remaining refrigerant can be recovered through the receiver vapor port. The water can then be drained from the pumpdown receiver.

Moisture Indicators

Moisture-sensitive elements that change color according to moisture content can gage the moisture level in the system; the color changes at a low enough level to be safe. Manufacturers' instructions must be followed since the color change point is also affected by the liquid line temperature and the refrigerant used.

Moisture Measurement

Techniques for measuring the amount of moisture in a compressor, or in an entire system, are discussed in Chapter 45. The following methods are used to measure the moisture content of various halocarbon refrigerants. The moisture content to be measured is generally in the parts-per-million range, and the procedures require special laboratory equipment and techniques.

The **Karl Fischer Method** is suitable for measuring the moisture content of a refrigerant, even if it contains mineral oil. Although different firms have slightly different ways of performing this test and get somewhat varying results, the method remains the common industry practice for determining moisture content in refrigerants. The refrigerant sample is bubbled through predried methyl alcohol in a special sealed glass flask; any water present remains with the alcohol. In the **volumetric titration method**, Karl Fischer reagent is added, and the solution is immediately titrated to a "dead stop" electrometric end point. The reagent reacts with any moisture present so that the amount of water in the sample can be calculated from a previous calibration of the Karl Fischer reagent.

In the **coulometric titration method** (ARI *Standard* 700, Appendix Part 2) water is titrated with iodine that is generated electrochemically. The instrument measures the quantity of electric charge used to produce the iodine and titrate the water and calculates the amount of water present.

These titration methods, considered among the most accurate, are also suitable for measuring the moisture content of unused lubricant or other liquids. Special instruments designed for this particular analysis are available from laboratory supply companies. Haagen-Smit et al. (1970) describe improvements in the equipment and technique that significantly reduce analysis time.

The **gravimetric method** for measuring moisture content of refrigerants is described in ASHRAE *Standards* 63.1 and 35. It is not widely used in the industry. In this method, a measured amount of refrigerant vapor is passed through two tubes in series, each containing phosphorous pentoxide (P_2O_5). Moisture present in the refrigerant reacts chemically with the P_2O_5 and appears as an increase in mass in the first tube. The second tube is used as a tare. This method is satisfactory when the refrigerant is pure, but the presence of lubricant produces inaccurate results, because the lubricant is weighed as moisture. Approximately 200 g of refrigerant are required for accurate results. Because the refrigerant must pass slowly through the tube, analysis requires many hours to complete.

DeGeiso and Stalzer (1969) discuss the **electrolytic moisture analyzer**, which is suitable for high-purity refrigerants. Other electronic hygrometers are available that sense moisture by the adsorption of water on an anodized aluminum strip with a gold foil overlay (Dunne and Clancy 1984). Calibration of such instruments is critical to obtain maximum accuracy. These hygrometers give a continuous moisture reading and respond rapidly enough to monitor changes. Data showing drydown rates can be gathered with these instruments (Cohen 1994). Brisken (1955) used this method in a study of moisture migration in hermetic equipment.

Thrasher et al. (1993) used nuclear magnetic resonance spectroscopy to determine the moisture solubilities in R-134a and R-123. Another method, infrared spectroscopy, is used for moisture analysis, but requires a large sample for precise results and is subject to interference if lubricant is present in the refrigerant.

Desiccants

Desiccants used in refrigeration systems adsorb or react chemically with the moisture contained in a liquid or gaseous refrigerant-lubricant mixture. Solid desiccants, used widely as dehydrating agents in refrigerant systems, remove moisture from both new and field-installed equipment. The desiccant is contained in a device called a drier (also spelled dryer) or filter-drier and can be installed in either the liquid or the suction line of a refrigeration system.

Desiccants must remove most of the moisture and not react unfavorably with any other materials in the system. Activated alumina, silica gel, and molecular sieves are the most widely used desiccants acceptable for refrigerant drying. Water is physically adsorbed on the internal surfaces of these highly porous desiccant materials.

Activated alumina and silica gel have a wide range of pore sizes. The pores are large enough to adsorb refrigerant, lubricant, additives, and water molecules. The pore sizes of molecular sieves, however, are uniform, with an aperture of approximately 0.3 nm for a type 3A molecular sieve or 0.4 nm for a type 4A molecular sieve. The uniform openings exclude lubricant molecules from the adsorption surfaces. Molecular sieves can be selected to exclude refrigerant molecules as well. This property gives the molecular sieve the advantage of increasing the water capacity and improving the chemical compatibility between refrigerant and desiccant (Cohen 1993, 1994; Cohen and Blackwell 1995). The drier or desiccant manufacturer can provide information about which desiccant adsorbs or excludes a particular refrigerant.

Drier manufacturers offer combinations of desiccants that can be used in a single drier and may have certain advantages over a single desiccant because they can adsorb a greater variety of refrigeration contaminants. Two combinations are activated alumina with molecular sieves and silica gel with molecular sieves. Activated carbon is also used in some mixtures.

Table 3 Reactivation of Desiccants

Desiccant	Temperature, °F
Activated alumina	400 to 600
Silica gel	350 to 600
Molecular sieves	500 to 660

Desiccants are available in granular, bead, and block forms. Solid core desiccants, or block forms, consist of desiccant beads, granules, or both held together by a binder (Walker 1963). The binder is usually a nondesiccant material. Suitable filtering action, adequate contact of the desiccant with the refrigerant, and low pressure drop are obtained by properly sizing the desiccant particles used to make up the core, and by the proper geometry of the core with respect to the flowing refrigerant. Beaded molecular sieve desiccants offer higher water capacity per unit mass than solid core desiccants. The composition and form of the desiccant is varied by drier manufacturers to achieve the desired properties.

Desiccants that take up water by chemical reaction are not recommended. Calcium chloride reacts with water to form a corrosive liquid. Barium oxide is known to cause explosions. Magnesium perchlorate and barium perchlorate are powerful oxidizing agents, which are potential explosion hazards in the presence of lubricant. Phosphorous pentoxide is an excellent desiccant, but its fine powdery form makes it difficult to handle and produces a high resistance to gas and liquid flow. A mixture of calcium oxide and sodium hydroxide, which has limited use as an acid scavenger, should not be used as a desiccant.

Desiccants readily adsorb moisture and must be protected against it until ready for use. If a desiccant has picked up moisture, it can be reactivated under laboratory conditions by heating for about 4 h at a suitable temperature, preferably with a dry air purge or in a vacuum oven (Table 3). Only adsorbed water is driven off at the temperatures listed, and the desiccant is returned to its initial activated state. Care must be taken against repeated reactivation and excessive temperatures during reactivation, as this may damage the desiccant. The desiccant in a refrigerating equipment drier should not be reactivated for reuse, because of lubricant and other contaminants in the drier as well as possible damage caused by overheating the drier shell.

Equilibrium Conditions of Desiccants. Desiccants in refrigeration and air-conditioning systems function on the equilibrium principle. If an activated desiccant contacts a moisture-laden refrigerant, the water is adsorbed from the refrigerant-water mixture onto the desiccant surface until the vapor pressures of the adsorbed water (i.e., at the desiccant surface) and the water remaining in the refrigerant are equal. Conversely, if the vapor pressure of the water on the desiccant surface is higher than that in the refrigerant, water is released into the refrigerant-water mixture, and equilibrium is reestablished.

Adsorbent desiccants function by holding (adsorbing) moisture on their internal surfaces. The amount of water adsorbed from a refrigerant by an adsorbent at equilibrium is influenced (1) by the pore volume, pore size, and surface characteristics of the adsorbent; (2) by the temperature and moisture content of the refrigerant; and (3) by the solubility of water in the refrigerant.

Figures 1, 2, and 3 are equilibrium curves (known as **adsorption isotherms**) for various adsorbent desiccants with R-12 and R-22. These curves are representative of commercially available materials. The adsorption isotherms are based on the technique developed by Gully et al. (1954), as modified by ASHRAE *Standard* 35. ASHRAE *Standards* 35 and 63.1 define the moisture content of the refrigerant as Equilibrium Point Dryness (EPD), and the moisture held by the desiccant as water capacity. The curves show that for any specified amount of water in a particular refrigerant, the desiccant holds a corresponding specific quantity of water.

Figures 1 and 2 show moisture equilibrium curves for three common adsorbent desiccants in drying R-12 and R-22 at 75°F. As shown, the capacity of a desiccant can vary widely for different refrigerants when the same EPD is required. Generally, a refrigerant in which moisture is more soluble requires more desiccant for adequate drying than one that has less solubility.

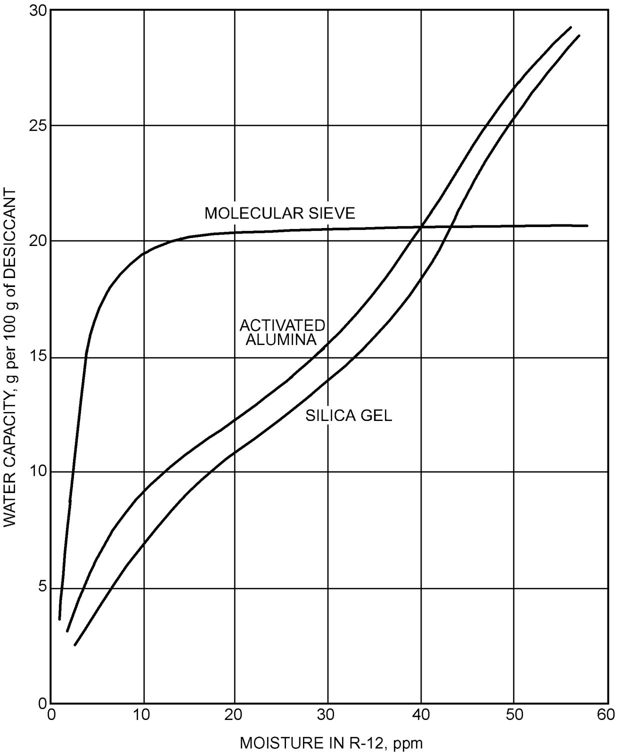

Fig. 1 Moisture Equilibrium Curves for R-12 and Three Common Desiccants at 75°F

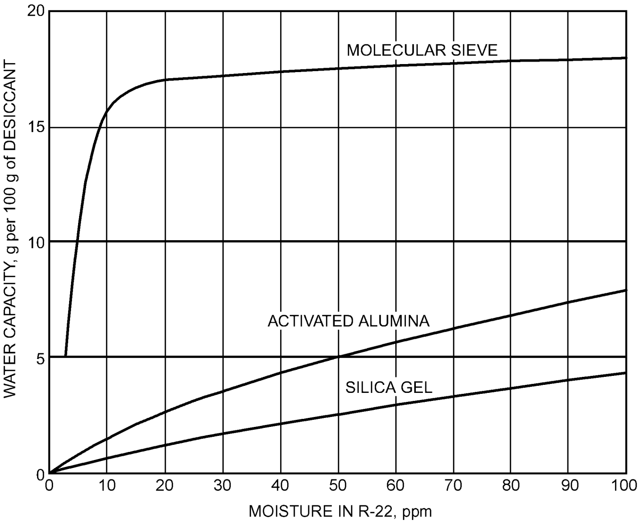

Fig. 2 Moisture Equilibrium Curves for R-22 and Three Common Desiccants at 75°F

Figure 3 shows the effect of temperature on moisture equilibrium capacities of activated alumina and R-12. Much higher water capacities are obtained at lower temperatures, demonstrating the advantage of locating the alumina driers at relatively cool spots in the system. When using molecular sieves, the effect of temperature on water capacity is much smaller. ARI *Standard* 710 requires determining the water capacity for R-12 at an EPD of 15 ppm, and for

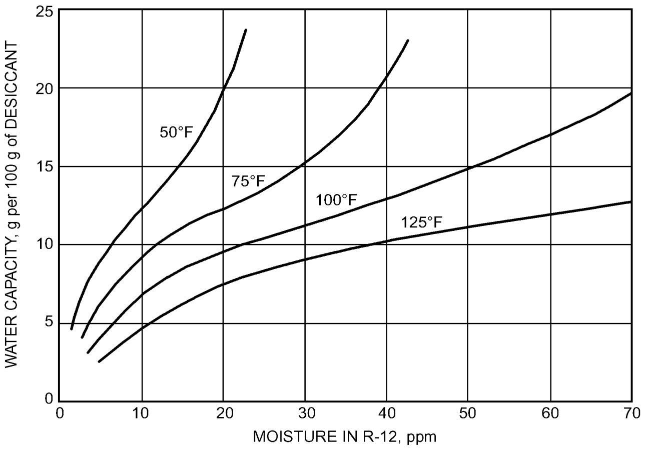

Fig. 3 Moisture Equilibrium Curves for Activated Alumina at Various Temperatures in R-12

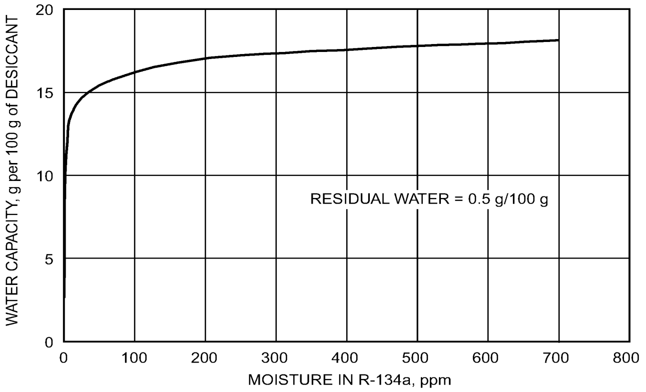

Fig. 4 Moisture Equilibrium Curve for Molecular Sieve in R-134a at 125°F

(Courtesy UOP, Reprinted with permission.)

R-22 at 60 ppm. Each determination must be made at 75°F (see Figures 1 and 2) and 125°F.

Figure 4 shows water capacity of a molecular sieve in liquid R-134a at 125°F. These data were obtained using the Karl Fischer method similar to that described in Dunne and Clancy (1984). Cavestri and Schafer (1999) determined water capacities for three common desiccants in R-134a when POE lubricant was added to the refrigerant. Figures 5 and 6 show water capacity for type 3A molecular sieves, activated alumina beads, and bonded activated alumina cores in R-134a and 2% POE lubricant at 75°F and 125°F.

Although the figures show that molecular sieves have greater water capacities than activated alumina or silica gel at the indicated EPD, all three desiccants are suitable if sufficient quantities are used. Cost, operating temperature, other contaminants present, and equilibrium capacity at the desired EPD must be considered when choosing a desiccant for refrigerant drying. The desiccant manufacturer has information and equilibrium curves for specific desiccant-refrigerant systems.

Activated carbon technically is not a desiccant, but it is often used in filter-driers to scavenge waxes and insoluble resins. The other common desiccants do not remove these contaminants, which can plug expansion devices and reduce system capacity and efficiency. The activated carbon is typically incorporated into bound desiccant blocks along with molecular sieve and activated alumina.

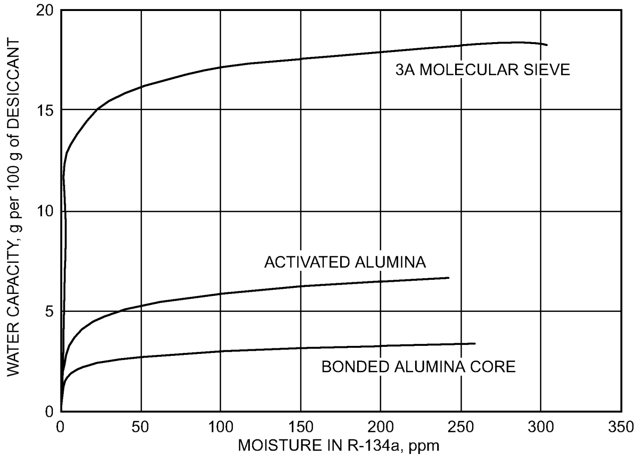

Fig. 5 Moisture Equilibrium Curves for Three Common Desiccants in R-134a and 2% POE Lubricant at 75°F

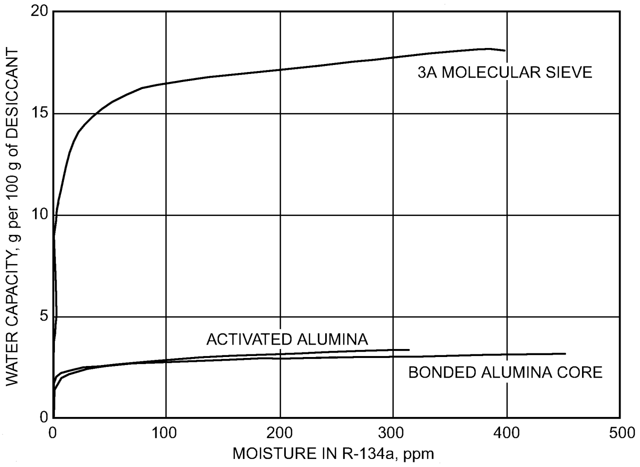

Fig. 6 Moisture Equilibrium Curves for Three Common Desiccants in R-134a and 2% POE Lubricant at 125°F

Desiccant Applications

In addition to removing water, desiccants may be capable of adsorbing or reacting with acids, dyes, chemical additives, and refrigerant lubricant reaction products.

Acids. Generally, acids can harm refrigerant systems. The quantity of acid that a refrigerant system tolerates depends in part on the size, the mechanical design and construction of the system, the type of motor insulation, the type of acid, and the amount of water in the system.

The acid removal capacity of desiccants is difficult to determine because the environment is complex. Hoffman and Lange (1962) and Mays (1962) showed that desiccants remove acids from refrigerants and lubricants by adsorption and/or chemical reaction. Hoffman also showed that the concentration of water in the desiccant, the type of desiccant, and the type of acid play a major role in a desiccant's ability to remove acids from refrigerant systems. In addition, acids formed in these systems can be inorganic, such as HCl and HF, or a mixture of organic acids. Cavestri and Schooley (1998) determined the inorganic acid capacity of desiccants. All factors must be considered to establish acid capacities of desiccants.

Colors. Colored materials frequently are adsorbed by activated alumina and silica gel and occasionally by calcium sulfate and molecular sieves. Leak detector dyes may lose their effectiveness when used in systems containing desiccants. The interaction of the dye and drier should be evaluated before putting a dye in the system.

Lubricant Deterioration Products. Lubricants can react chemically to produce substances that are adsorbed by desiccants. Some of these are hydrophobic and, when adsorbed by the desiccant, may reduce the rate at which it can adsorb liquid water. However, the rate and capacity of the desiccant to remove water dissolved in the refrigerant are not significantly impaired (Walker et al. 1955). Often the reaction products are sludges or powders that can be filtered out mechanically by the drier.

Chemicals. Refrigerants that can be adsorbed by desiccants cause the drier temperature to rise considerably when the refrigerant is first admitted. This temperature rise is not the result of moisture in the refrigerant, but the adsorption heat of the refrigerant. Lubricant additives may be adsorbed by silica gel and activated alumina. Because of small pore size, molecular sieves generally do not adsorb additives or the lubricant.

Driers

A drier is a device containing a desiccant. It collects and holds moisture, but it also acts as a filter and adsorber of acids and other contaminants.

To prevent moisture from freezing in the expansion valve or capillary tube, a drier is installed in the liquid line close to these devices. Hot locations should be avoided. Driers can function on the low-pressure side of expansion devices, but this is not the preferred location (Jones 1969).

Moisture is reduced as liquid refrigerant passes through a drier. However, Krause et al. (1960) showed that considerable time is required before moisture equilibrium is reached in a refrigeration unit. The moisture is usually distributed throughout the entire system, and time is required for the circulating refrigerant-lubricant mixture to carry the moisture to the drier. Cohen and Dunne (1987) and Cohen (1994) treat the kinetics of drying refrigerants in circulating systems.

Loose-filled driers should be mounted vertically with the refrigerant flow direction downward. With vertical orientation and downward flow, both gravity and drag forces act in the downward direction on the beads. Settling of the beads creates a void space at the top, which is not a problem.

Vertical orientation with upward flow, where gravity and drag act in opposite directions, should be avoided because the flow will likely fluidize the desiccant beads, causing the beads to move relative to one another. This promotes attrition or abrasion of the beads, producing fine particles that can contaminate the system. Settling will create a void space between the retention screens, promoting fluidization.

Horizontal mounting should also be avoided with a loose-filled drier because settling of the beads will create a void space that promotes fluidization. Such a void may also produce a channel around the beads that reduces drying effectiveness.

Driers are also used effectively to clean up systems severely contaminated due to hermetic motor burnouts and mechanical failures (see the section on System Cleanup Procedure after Hermetic Motor Burnout).

Drier Selection

The drier manufacturer selection chart lists the amount of desiccants, flow capacity, filter area, water capacity, and a specific recommendation covering the type and refrigeration capacity of the drier for various applications.

The equipment manufacturer must consider the following factors when selecting a drier:

1. The **desiccant** is the heart of the drier and its selection is most important. The section on Desiccants has further information.
2. The drier's **water capacity** is measured by methods described in ARI *Standard* 710. The reference points are set arbitrarily to prevent confusion arising from determinations made at other points. The specific refrigerant, the amount of desiccant, and the effect of temperature are all considered in the statement of water capacity.
3. The **liquid line** flow capacity is listed at 1 psi pressure drop across the drier by the official procedures of ASHRAE *Standard* 63.1 and ARI *Standard* 710. Rosen et al. (1965) described a closed-loop method for evaluating filtration and flow characteristics of liquid line refrigerant driers. The flow capacity of suction line filters and filter-driers is determined according to ASHRAE *Standard* 78 and ARI *Standard* 730. The latter standard gives recommended pressure drops for selecting suction line filter-driers for permanent and temporary installations. Flow capacity may be reduced quickly when critical quantities of solids and semisolids are filtered out by the drier. Whenever flow capacity drops below the machine's requirements, the drier should be replaced.
4. Although limits for particle size vary with refrigerant system size and design, and with the geometry and hardness of the particles, manufacturers publish **filtration capabilities** for comparison.

Testing and Rating

Desiccants and driers are tested according to the procedures of ASHRAE *Standards* 35 and 63. Driers are rated under ARI *Standard* 710. Minimum standards for listing of refrigerant driers can be found in UL *Standard* 207. ASHRAE *Standard* 63.2 specifies a test method for filtration testing of filter-driers. No ARI Standard has been developed to give rating conditions for publication of filtration capacity.

OTHER CONTAMINANTS

Refrigerant filter-driers are the principal devices used to remove contaminants from refrigeration systems. The filter-drier is not a substitute for good workmanship or design, but a maintenance tool necessary for continued and proper system performance. Contaminants removed by filter-driers include moisture, acids, hydrocarbons with a high molecular weight, oil decomposition products, and insoluble material, such as metallic particles and copper oxide.

Metallic Contaminants and Dirt

Small contaminant particles frequently left in refrigerating systems during manufacture or servicing include chips of copper, steel, or aluminum; copper or iron oxide; copper or iron chloride; welding scale; brazing or soldering flux; sand; and other dirt. Some of these contaminants, such as copper chloride, develop from normal wear or chemical breakdown during system operation. Solid contaminants vary widely in size, shape, and density. Solid contaminants create problems by

- Scoring cylinder walls and bearings
- Lodging in the motor insulation of a hermetic system, where they act as conductors between individual motor windings or abrade the wire coating when flexing of the windings occurs
- Depositing on terminal blocks and serving as a conductor
- Plugging expansion valve screen or capillary tubing
- Depositing on suction or discharge valve seats, significantly reducing compressor efficiency
- Plugging oil holes in compressor parts, leading to improper lubrication
- Increasing the rate of chemical breakdown. At elevated temperatures, R-22, for example, decomposes more readily when in contact with iron powder, iron oxide, or copper oxide (Norton 1957)
- Plugging driers

Liquid line filter-driers, suction filters, and strainers isolate contaminants from the compressor and expansion valve. Filters minimize the return of particulate matter to the compressor and expansion valve, but the capacity of permanently installed liquid and/or suction filters must accommodate this particulate matter without causing excessive, energy-consuming pressure losses. Equipment manufacturers should consider the following procedures to ensure proper operation during the design life:

1. Develop cleanliness specifications that include a reasonable value for maximum residual matter. Some manufacturers specify allowable quantities in terms of internal surface area. ASTM *Standard* B 280 allows a maximum of 0.0035 g of contaminants per square foot of internal surface.
2. Multiply the factory contaminant level by a factor of five to allow for solid contaminants that will be added during installation. This factor depends on the type of system and the previous experience of the installers, among other considerations.
3. Determine a value for maximum pressure drop to be incurred by the suction or liquid filter when loaded with the quantity of solid matter calculated in Step 2.
4. Conduct pressure drop tests according to ASHRAE *Standard* 63.2.
5. Select driers for each system according to its capacity requirements and test data. In addition to contaminant removal capacity, tests can evaluate filter efficiency, maximum escaped particle size, and average escaped particle size.

Very small particles passing through filters tend to accumulate in the crankcase. Most compressors tolerate a small quantity of these particles without allowing them into the oil pump inlet, where they can damage running surfaces.

Organic Contaminants—Sludge, Wax, and Tars

Organic contaminants in a refrigerating system with a mineral oil lubricant can appear when organic materials such as oil, insulation, varnish, gaskets, and adhesives decompose. As opposed to inorganic contaminants, these materials are mostly carbon, hydrogen, and oxygen. Organic materials may be partially soluble in the refrigerant-lubricant mixture or may become so through the action of heat. They then circulate in the refrigerating system and can plug small orifices. Organic contaminants in a refrigerating system using a synthetic polyol ester lubricant may also generate sludge. The following contaminants should be avoided:

Paraffin—typically found in mineral oil lubricants
Silicone—found in some machine lubricants
Phthalate—found in some machine lubricants

Whether mineral oil or synthetic lubricants are used, some organic contaminants remain in a new refrigerating system during manufacture or assembly. For example, excessive brazing paste introduces a wax-like contaminant into the refrigerant stream. Certain cutting lubricants, corrosion inhibitors, or drawing compounds frequently contain paraffin-based compounds. These lubricants can leave a layer of paraffin on a component that may be removed by the refrigerant-lubricant combination and generate insoluble material in the refrigerant stream. Organic contamination also results during the normal method of fabricating return bends. The die used during forming is lubricated with these organic materials, and afterwards the return bend is brazed to the tubes to form the evaporator and/or condenser. During brazing, residual lubricant inside the tubing and bends can be baked to a resinous deposit.

If organic materials are handled improperly, certain contaminants remain. Resins used in varnishes, wire coating, or casting sealers may not be cured properly and can dissolve in the refrigerant-lubricant mixture. Solvents used in washing stators may be adsorbed by the wire film and later, during compressor operation, carry chemically reactive organic extractables. Chips of varnish, insulation, or fibers can detach and circulate in the system. Portions of improperly selected or cured rubber parts or gaskets can dissolve in the refrigerant.

Refrigeration-grade mineral oil decomposes under adverse conditions to form a resinous liquid or a solid frequently found on refrigeration filter-driers. These mineral oils decompose noticeably when exposed for as little as 2 h to temperatures as low as 250°F in an atmosphere of air or oxygen. The compressor manufacturer should perform all high-temperature dehydrating operations on the machines prior to adding the lubricant charge. In addition, equipment manufacturers should not expose compressors to processes requiring high temperatures unless the compressors contain refrigerant or inert gas.

The result of organic contamination is frequently noticed at the expansion device. Materials dissolved in the refrigerant-lubricant mixture, under liquid line conditions, may precipitate at the lower temperature in the expansion device, resulting in restricted or plugged capillary tubes or sticky expansion valves. A few milligrams of these contaminants can render a system inoperative. These materials have physical properties that range from a fluffy powder to a solid resin entraining inorganic debris. If the contaminant is dissolved in the refrigerant-lubricant mixture in the liquid line, it will not be removed by a filter-drier.

Chemical identification of these organic contaminants is very difficult. Infrared spectroscopy can characterize the type of organic groups present in contaminants. Materials found in actual systems vary from wax-like aliphatic hydrocarbons to resin-like materials containing double bonds, carbonyl groups, and carboxyl groups. In some cases, organic compounds of copper and/or iron have been identified.

These contaminants can be eliminated by carefully selecting materials and strictly controlling cleanliness during manufacture and assembly of the components as well as the final system. Because heat degrades most organic materials and enhances chemical reactions, operating conditions with excessively high discharge or bearing surface temperatures must be avoided to prevent formation of degradation products.

Residual Cleaning Agents for Mineral Oil Systems

Solvents used for cleaning compressor parts are likely contaminants if left in refrigerating equipment. Solvents in this category are considered pure liquids without additives. If additives are present, they are reactive materials and should not be in a refrigerating system. Some solvents are relatively harmless to the chemical stability of the refrigerating system, while others initiate or accelerate degradation reactions. For example, the common mineral spirits solvents are considered harmless. Other common compounds react rapidly with hydrocarbon lubricants (Elsey et al. 1952).

Residual Cleaning Agents for Polyol Ester Lubricated Systems

Typical solvents used in cleaning mineral oil systems are not compatible with polyol ester lubricants. Several chemicals must be avoided to reduce or eliminate possible contamination and sludge generation. In addition to paraffin, silicone, and phthalate contaminants, a small amount of the following contaminants can cause system failure:

Chlorides—typically found in chlorinated solvents
Acid or alkali—found in some water-based cleaning fluids
Water—a component of water-based cleaning fluids

Noncondensable Gases

Gases, other than the refrigerant, are another contaminant frequently found in refrigerating systems. These gases result (1) from incomplete evacuation, (2) when functional materials release sorbed gases or decompose to form gases at an elevated temperature during system operation, (3) through low-side leaks, and (4) from chemical reactions during system operation. Chemically reactive gases, such as hydrogen chloride, attack other components, and, in extreme cases, the refrigerating unit fails.

Chemically inert gases, which do not liquefy in the condenser, reduce cooling efficiency. The quantity of inert, noncondensable gas that is harmful depends on the design and size of the refrigerating unit and on the nature of the refrigerant. Its presence contributes to higher-than-normal head pressures and resultant higher discharge temperatures, which speed up undesirable chemical reactions.

Gases found in hermetic refrigeration units include nitrogen, oxygen, carbon dioxide, carbon monoxide, methane, and hydrogen. The first three gases originate from incomplete air evacuation or a low-side leak. Carbon dioxide and carbon monoxide usually form when organic insulation is overheated. Hydrogen has been detected when a compressor is experiencing serious bearing wear. These gases are also found where a significant refrigerant-lubricant reaction has occurred. Only trace amounts of these gases are present in well-designed, properly functioning equipment.

Spauschus and Olsen (1959), Doderer and Spauschus (1966), and Gustafsson (1977) developed sampling and analytical techniques for establishing the quantities of contaminant gases present in refrigerating systems. Parmelee (1965), Spauschus and Doderer (1961, 1964), and Kvalnes (1965) applied gas analysis techniques to sealed tube tests to yield information on stability limitations of refrigerants, in conjunction with other materials used in hermetic systems.

Motor Burnouts

Motor burnout is the final result of hermetic motor insulation failure. During burnout, high temperatures and arc discharges can severely deteriorate the insulation, producing large amounts of carbonaceous sludge, acid, water, and other contaminants. In addition, a burnout can chemically alter the compressor lubricant, and/or thermally decompose refrigerant in the vicinity of the burn. The products of burnout escape into the system, causing severe cleanup problems. If decomposition products are not removed, replacement motors fail with increasing frequency.

While RSES (1988) has chosen to differentiate between mild and severe burnouts, many compressor manufacturers' service bulletins treat all burnouts alike. A rapid burn from a spot failure in the motor winding results in a mild burnout with little lubricant discoloration and no carbon deposits. A severe burnout occurs when the compressor remains on line and burns over a longer period, resulting in highly discolored lubricant, carbon deposits, and acid formation.

Because the condition of the lubricant can be used to indicate the amount of contamination, the lubricant should be examined during the cleanup process. Wojtkowski (1964) stated that acid in R-22/mineral oil systems should not exceed 0.05 total acid number (mg KOH per g oil). Commercial acid test kits can be used for this analysis. An acceptable acid number for other lubricants has not been established.

Various methods are recommended for cleaning a system after hermetic motor burnout (RSES 1988). However, the suction line filter-drier method is commonly used (see the section on System Cleanup Procedure after Hermetic Motor Burnout).

Field Assembly

Proper field assembly and maintenance are essential for contaminant control in refrigerating systems and to prevent undesirable refrigerant emissions to the atmosphere. Driers may be too small or carelessly handled so that drying capacity is lost. Improper tube-joint soldering is a major source of water, flux, and oxide scale contamination. Copper oxide scale from improper brazing is one of the most frequently observed contaminants. Careless tube cutting and handling can introduce excessive quantities of dirt and metal chips. Care should be taken to minimize these sources of internal contamination. In addition, because an assembled system cannot be dehydrated easily, oversized driers should be installed. Even if components are delivered sealed and dry, weather and the amount of time the unit is open during assembly can introduce large amounts of moisture.

In addition to internal sources, external factors can cause a unit to fail. Too small or too large transport tubing, mismatched or misapplied components, fouled air condensers, scaled heat exchangers, inaccurate control settings, failed controls, and improper evacuation are some of these factors.

REFRIGERANT RECOVERY, RECYCLING, AND RECLAMATION

Studies have shown that chlorofluorocarbon (CFC) and hydrochlorofluorocarbon (HCFC) refrigerants deplete ozone in the stratosphere when released to the atmosphere. Various international and federal regulations require actions to contain and properly handle refrigerants. The procedures involved in removing contaminants when recycling refrigerants are similar to those discussed earlier in this chapter. Service techniques, proper handling and storage, and possible mixing of refrigerants are of concern. Building owners, equipment manufacturers, and contractors are concerned about reintroducing refrigerants with unacceptable levels of contaminants into refrigeration equipment.

Installation and Service Practices

Proper installation and service procedures, including proper evacuation and leak checking, are essential to minimize major equipment repairs. Service lines should be made of hose material with low permeability and should include shutoff valves. Larger systems should include isolation valves and pumpdown receivers. ASHRAE *Guideline* 3 gives further detail on equipment, installation, and service requirements.

Recovering refrigerant to an external storage container and then returning the refrigerant for cleanup inside the refrigeration system is similar to the procedure described in item C in the section on System Cleanup Procedure after Hermetic Motor Burnout. Some additional air and moisture contamination may be introduced in the service procedure. In general, the refrigeration system must be cleaned whether the refrigerant is isolated in the receiver, recovered into a storage container, recycled, reclaimed, or replaced with new refrigerant. This cleanup is necessary because contaminants are distributed throughout the system. The advantage of new, reclaimed, or recycled refrigerant is that a properly cleaned system is not recontaminated by the addition of impure refrigerant.

Contaminants

The contaminants encountered in recovered refrigerants are covered in previous sections of this chapter. The main contaminants are moisture, acid, noncondensables, particulates, high boiling residue (lubricant and sludge), and other condensable gases (Manz 1995). The characteristics of these contaminants are as follows:

1. Moisture is normally dissolved in the refrigerant or lubricant, but sometimes free water is present. Moisture is removed by passing the refrigerant through a filter-drier. Some moisture is also removed by lubricant separation.
2. Acid consists of organic and inorganic types. Organic acids are normally contained in the lubricant and are removed in the oil separator and in the filter-drier. Inorganic acids, like hydrochloric acid, are removed by the noncondensable purge process, reaction with metal surfaces, and by the filter-drier.
3. Noncondensable gases consist primarily of air. These gases can come from the refrigeration equipment or can be introduced during servicing procedures. The control method consists of minimizing infiltration through proper equipment construction and installation (ASHRAE *Guideline* 3). Proper service equip-

ment construction, connection techniques, and maintenance procedures (such as during filter-drier change) also reduce air contamination. Typically, a vapor purge is used to remove air.

4. Particulates are removed by suction filters, oil separators, and filter-driers.
5. High boiling residues consist primarily of refrigerant lubricant and sludge. Because different refrigeration systems use different lubricants and because it is a collection point for other contaminants, the lubricant is considered a contaminant. High boiling residues are removed by separators designed to extract the lubricant from the vapor-phase refrigerant, or by a distillation process.
6. Other condensable gases consist mainly of other refrigerants. They can be generated in small quantities by high-temperature operation or during a burnout. In rare cases, refrigerants may be mixed intentionally for performance or to top off with substitutes. Refrigerants should not be mixed in order to maintain the purity of the used refrigerant supply as well as the performance and durability of the particular system. In general, separation of other condensable gases, if possible, can only be done at a fully equipped reclamation center.
7. Mixed refrigerants are a special case of other condensable gases in that the refrigerant would not meet product specifications even if all moisture, acids, particulates, lubricant, and noncondensables were removed. Inadvertent mixing may occur because of a failure to

- Dedicate and clearly mark containers for specific refrigerants
- Clear hoses or recovery equipment before switching to a different refrigerant
- Test the suspect refrigerant before consolidating it into large batches, or
- Use proper retrofit procedures

Refrigerant Recovery

To **recover** means to remove refrigerant in any condition from a system and to store it in an external container. Recovery reduces refrigerant emissions to the atmosphere and is a necessary first or concurrent step to either recycling or reclamation. The largest potential for service-related emissions of refrigerant occurs during recovery. These emissions consist of refrigerant left in the system (recovery efficiency) and losses due to service connections (Manz 1995).

The key to reducing emissions is proper recovery equipment and techniques. The recovery equipment manufacturer and the technician must share this responsibility to minimize refrigerant loss to the atmosphere. Training in handling halocarbon refrigerants is required to learn the proper techniques (RSES 1991).

Important: *Recover refrigerants into an approved container and keep containers for different refrigerants separate. Do not fill containers over 80% of capacity as liquid expansion with rising temperature could cause loss of refrigerant through the pressure relief valve or even rupture of the container.*

Medium- and high-pressure refrigerants are commonly recovered using a compressor-based recovery unit to pump the refrigerant directly into a storage container (Manz 1995). Such a system is shown in Figure 7. Minimum functions include the processes of evaporating, compressing, condensing, storing, and controlling. Where possible, the recovery unit should be connected to both the high and low side ports to speed up the process (Manz 1995). Removal of the refrigerant as a liquid, especially where the refrigerant is to be reclaimed, greatly speeds the process (Clodic and Sauer 1994). As a variation, a refrigeration unit may be used to cool the storage container to transfer the refrigerant directly. For low-pressure refrigerants (e.g., R-11), a compressor or vacuum pump may be used to lower the pressure in the storage container and raise the pressure in the vapor space of the refrigeration system so that the liquid refrigerant will flow without evaporation. An alternative is to use a liquid pump to transfer the refrigerant (Manz 1995). A pump-down unit such as a condensing unit will be required to remove the remaining vapor refrigerant after liquid removal is complete. Recovery systems for use at a factory for charging or leak testing operations will probably be larger in size and of specialized construction to meet the specific needs of the manufacturer (Parker 1988).

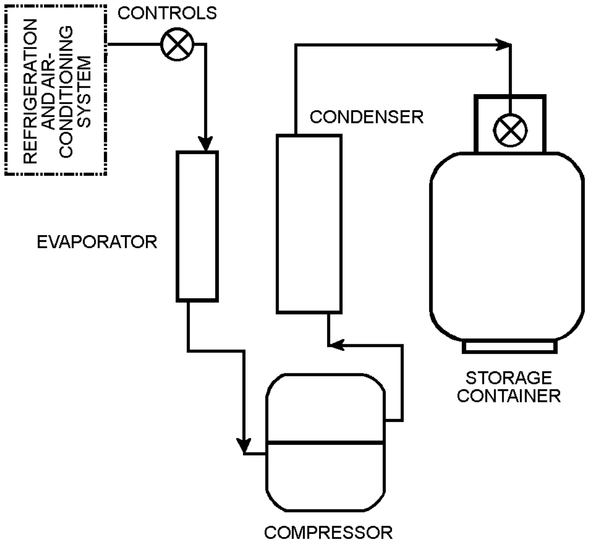

Fig. 7 Recovery Functions

Components in which liquid could be trapped, such as an accumulator, may need to be gently heated (with a thermostatically controlled heating blanket or a warm air gun) to remove all the refrigerant. Good practice requires watching for a pressure rise after recovery is completed to determine if the recovery unit needs to be restarted to remove all refrigerant. Where visual inspection is possible, such components would be identified by frosting on external surfaces to the level of the liquid refrigerant inside.

For fast refrigerant transfer, the entire liquid phase must be recovered without evaporating it or evaporating only a very small fraction. Depending on the particular refrigeration circuit, special methods must be developed, access may have to be created, and components may need to be modified; these modifications must be simple and fast (Clodic and Sauer 1994). Lubricant separation is essential in systems where used refrigerant is to be introduced without reclaiming. It may take longer to pump out vapor and separate lubricant, but clean recovery units, clean storage containers, and clean refrigeration systems are usually worth the extra time (Manz 1995).

Refrigerant Recycling

To **recycle** means to reduce contaminants in used refrigerants by separating lubricant, removing noncondensables, and using devices such as filter-driers to reduce moisture, acidity, and particulate matter. The term usually applies to procedures implemented at the field job site or at a local service shop. Industry guidelines (ARI [IRG-2] 1994) and federal regulations (EPA 1996) specify maximum contaminant levels in recycled refrigerant for certified recycling equipment under ARI *Standard* 740.

Recycling conserves limited supplies of regulated refrigerants (e.g., R-12). A single-pass recycling schematic is shown in Figure 8 (Manz 1995). In the single-pass recycling unit, refrigerant is processed by oil separation and filter-drying in the recovery path. Typically, air and noncondensables are not removed during the recovery process and are handled at a later time.

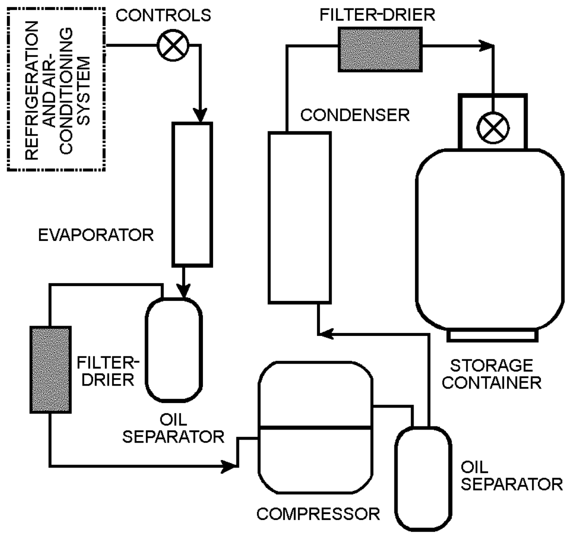

Fig. 8 Single-Pass Recycling

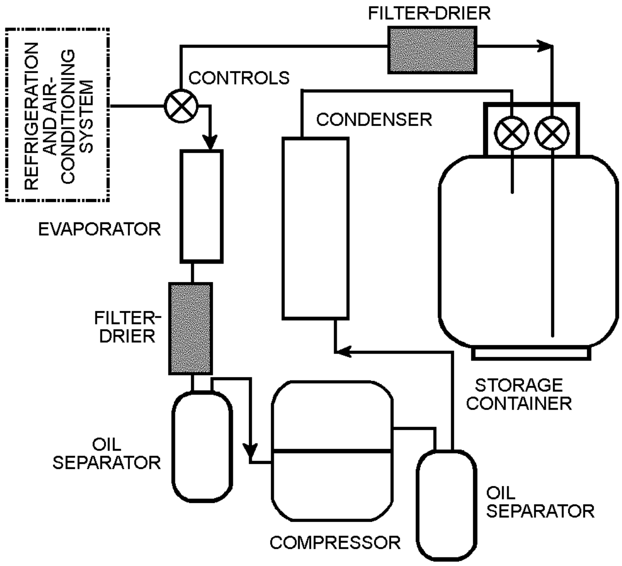

Fig. 9 Multiple-Pass Recycling

In a multiple-pass recycling unit, as shown in Figure 9, the refrigerant is typically processed through an oil separator during recovery. The filter-drier may be placed in the compressor suction line or in a bypass recycling loop or both. During a continuous recycling loop, refrigerant is withdrawn from the storage tank, processed through filter-driers, and returned to the storage container. Noncondensable purge is accomplished during this recycling loop.

The primary function of the filter-drier is to remove moisture, and its the secondary function is to remove acid, particulate, and sludge (Manz 1995). The capability of the filter-drier to remove moisture and acid from used refrigerants is improved if the lubricant is separated prior to passing through the filter-drier (Kauffman 1992). Moisture indicators are typically used to indicate when a filter-drier change is required. For some refrigerants, these devices cannot indicate a moisture level as low as the purity level required by ARI *Standard* 700. Devices such as an in-situ mass flowmeter can be used to accurately determine when to change the filter-drier and still meet the purity requirements (Manz 1995).

Important: *The service technician must change recovery/recycle unit filter-driers at frequent intervals as directed by the indicators and manufacturer's instructions.*

The primary advantage of recycling is performing this operation at the job site or at a local service shop and avoiding transportation costs. The likelihood of mixing refrigerants is reduced if recycling is done at the service shop compared to consolidating refrigerant batches for shipment to a reclamation facility. Recycling equipment cannot separate mixed refrigerants to bring them back to product specifications.

A preliminary investigation of recycling refrigerants R-404A, R-410A, and R-507 showed that the refrigerant blend compositions changed less than 1% after 23 repetitions (Manz 1996). The study showed similar moisture removal capabilities as for R-22 under the test conditions. The most difficult contaminants to remove were noncondensable gases (air).

Industry Guidelines

An industry recycling guide (IRG-2), "Handling and Reuse of Refrigerants in the United States" (ARI 1994), includes a flow chart that outlines the following options:

Option 1: Put refrigerant back into the system without recycling it.
Option 2: Recycle refrigerant and put it back into the system from which it was removed or back into a system with the same owner.
Option 3: Recycle the refrigerant, test to verify conformance to ARI *Standard* 700 prior to reuse in a different owner's equipment provided that the refrigerant remains in the contractor's custody and control at all times from recovery through recycling to reuse.
Option 4: Send refrigerant to a certified reclaimer.

IRG-2 states, "Used refrigerants shall not be sold, or used in a different owner's equipment, unless the refrigerant has been analyzed and found to meet requirements of ARI *Standard* 700 (latest edition), 'Specifications for Fluorocarbon and Other Refrigerants.' "

IRG-2 provides maximum contaminant levels of recycled refrigerants in same owner's equipment and lists the following reasons for concern for mixed refrigerant:

- Effect on performance and operating characteristics that may affect the capacity and efficiency of the equipment
- Effect on materials compatibility, lubrication, equipment life, and warranty costs
- Increased service and repair requirements and higher operating costs
- High cost or inability to separate refrigerants
- High cost of disposal and loss of refrigerant for future service

Equipment Standards

Recovery and recycling equipment comes in a variety of sizes, shapes, and functions (Manz 1995). ARI *Standard* 740 establishes methods of testing for rating performance of equipment for type of equipment, designated refrigerants, liquid recovery rate, vapor recovery rate, final recovery vacuum, recycle rate, and trapped refrigerant. The standard requires that refrigerant emissions due to lubricant draining, noncondensable purging, and clearing between refrigerant types not exceed 3% by mass.

In the test method, contaminated refrigerant (sometimes called "dirty cocktail") is processed to determine the contaminant levels of the recycled refrigerant. Measured contaminant levels of recycled refrigerant include moisture content, chloride ions, acidity, high boiling residue, particulates/solids, and noncondensables. Each refrigerant is sampled at the time of the first filter-drier change when levels are expected to be highest. U.S. regulations (EPA 1996) require that recycling equipment meet the maximum contaminant levels in IRG-2 for recycled refrigerant (Option 2).

The basic distinction between recycling and reclamation is best illustrated by associating recycling with certification (ARI 740) and reclamation with analysis (ARI 700). ARI *Standard* 740 covers certification testing of the recycling equipment using a "standard contaminated refrigerant sample" in lieu of chemical analysis of each batch. It provides a means of comparing equipment performance under controlled conditions. By contrast, as described later, ARI *Standard* 700 is based on chemical analysis of a refrigerant sample from each batch after contaminant removal. ARI 700 provides a means of analyzing refrigerant and comparing the contaminant levels to product specifications.

ARI *Standard* 740 applies to single-refrigerant systems and their normal contaminants. It does not apply to refrigerant systems or storage containers with mixed refrigerants. No attempt is made to rate the equipment's ability to remove different refrigerants and other condensable gases from recovered refrigerant. The standard places responsibility on the equipment operator to identify those situations and to treat them accordingly. One of the uncertainties associated with recycled refrigerants is describing the purity levels when offering the refrigerant for resale. The purity of recycled refrigerant is uncertain because appropriate field measurement techniques do not exist for all contaminants listed in ARI 700. The *Industry Recycling Guide* (IRG-2) discusses possible options.

The Society of Automotive Engineers (SAE) has developed standards for mobile air-conditioning equipment.

Special Considerations and Equipment for Handling Multiple Refrigerants

Different refrigerants must be kept separate. Storage containers should meet applicable standards for transportation and use with that refrigerant as specified in ARI *Guideline* K. Disposable cylinders must not be used (RSES 1991). Containers should be filled per ARI *Guideline* K and marked with the refrigerant type. Container colors for recovered refrigerants and for new and reclaimed refrigerants are specified in ARI *Guidelines* K and N, respectively.

Recovery/recycling (R/R) equipment capable of handling more than one refrigerant is readily available and often preferred. The R/R equipment should only be used for labeled refrigerants. At the time the technician desires to switch refrigerants, a significant amount of the previous refrigerant will be contained in the R/R equipment, particularly in the condenser section (Manz 1991). This trapped refrigerant must be removed, preferably by using isolation/bypass valves to connect the condenser section to the compressor suction and by connecting the compressor discharge directly to the storage container (Manz 1995). After the bulk of the refrigerant has been removed, the system should be evacuated before changing to the appropriate storage container for the new refrigerant. This procedure should also include all lines and connecting hoses and may include replacement of the filter-driers.

The need for purging noncondensables is determined by comparing the refrigerant pressure to the saturation pressure of pure refrigerant at the same temperature. Circulation to achieve thermal equilibrium may be required to eliminate the effect of the temperature difference on pressures. A sealed bulb is often used to determine the saturation pressure for a single refrigerant system. When purging air from R/R equipment capable of handling multiple refrigerants, the difference in saturation pressures between refrigerants far exceeds any allowable partial pressure due to noncondensables. Special equipment and/or techniques are required (Manz 1991, 1995).

Refrigerant to be recovered may be in vapor or liquid states. To optimize the recovery, R/R equipment must be able to handle each of these states. For some equipment, this may involve one hookup or piece of R/R equipment for liquid and a separate hookup or second piece of R/R equipment to recover vapor. In general, a single hookup is desired. When handling multiple refrigerants, traditional liquid flow control devices such as capillary tubes or expansion valves either compromise performance or simply do not work. Possible solutions include (1) the operator watching a sight glass for liquid flow and switching a valve; (2) multiple flow control devices with a refrigerant selection switch; and (3) a two-bulb expansion valve, which controls temperature differential across the evaporator (Manz 1991).

Refrigerant Reclamation

To **reclaim** means to process used refrigerant to new product specifications. This term usually implies the use of processes or procedures available only at a reprocessing or manufacturing facility. Chemical analysis of the refrigerant is required to determine that appropriate product specifications have been met. U.S. regulations (EPA 1996) require that refrigerants must meet ARI *Standard* 700 contaminant levels in order to be sold using one of the following options discussed in IRG-2 (ARI 1994):

Option 3: Recycle the refrigerant; test to verify conformance to ARI *Standard* 700 prior to reuse in a different owner's equipment provided that the refrigerant remains in the contractor's custody and control at all times from recovery through recycling to reuse.

Option 4: Send refrigerant to a certified reclaimer.

U.S. regulations (EPA 1996) call for use of third-party certified laboratories for option 3 and third-party certified reclaimers for option 4, both based on ARI *Standard* 700.

Some equipment warranties, especially those for smaller consumer appliances, may not permit the use of refrigerants reclaimed to purity levels specified in ARI 700. For small appliances (refrigerators and freezers), the manufacturer's literature should be consulted before charging with reclaimed refrigerants.

Reclamation has traditionally been used for systems containing more than 100 lb refrigerant (O'Meara 1988). Assistance is often provided by the reclaimer in furnishing shipping containers and labeling instructions. Many reclaimers use air-conditioning and refrigeration wholesalers as collection points for refrigerant. Mixing of refrigerants at the consolidation points is possible. If the refrigerant is contaminated beyond limits, the price paid for the refrigerant may be reduced or the shipment may be refused. One of the advantages associated with reclaimed refrigerants is in describing the purity levels when offering the refrigerant for resale.

Purity Standards

ARI *Standard* 700 covers halocarbon refrigerants, regardless of source, and defines acceptable levels of contaminants, which are the same as Federal Specifications for Fluorocarbon Refrigerants BB-F-1421B. It specifies laboratory analysis methods for each contaminant. Only fully equipped laboratories with trained personnel are presently capable of performing the analysis.

Because ARI 700 is based on chemical analysis of a sample from each batch after contaminant removal, it is not concerned with the level of contaminants before contaminant removal (Manz 1995). This disassociation from the "standard contaminated refrigerant sample" required in ARI 740 is the basic distinction between analysis/reclamation and certification/recycling.

SAE *Standards* J1991 and J2099 contain recycled refrigerant purity levels for mobile air-conditioning systems using R-12 and R-134a, respectively.

SYSTEM CLEANUP PROCEDURE AFTER HERMETIC MOTOR BURNOUT

Introduction

This procedure is limited to positive-displacement hermetic compressors. Centrifugal compressor systems are highly specialized and are frequently designed for a particular application. A centrifugal system should be cleaned according to the manufacturer's recommendations. All or part of the procedure can be used depending on such factors as severity of the burnout and size of the refrigeration system.

After a hermetic motor burnout, the system must be cleaned thoroughly to remove all contaminants. Otherwise a repeat burnout will *likely* occur. Failure to follow these minimum cleanup recommendations as quickly as possible increases the potential for repeat burnout.

Procedure

A. **Make sure a burnout has occurred.** Although a motor that will not start appears to be a motor failure, the problem may be improper voltage, starter malfunction, or a compressor mechanical fault (RSES 1988). Investigation should include the following steps:

   1. Check for proper voltage.
   2. Check that the compressor is cool to the touch. An open internal overload could prevent the compressor from starting.
   3. Check the compressor motor for improper grounding using a megohmmeter or a precision ohmmeter.
   4. Check the external leads and starter components.
   5. Obtain a small sample of oil from the compressor, examine it for discoloration, and analyze it for acidity.

B. **Safety.** In addition to electrical hazards, service personnel should be aware of the hazard of acid burns. If the lubricant or sludge in a burned-out compressor must be touched, wear rubber gloves to avoid a possible acid burn.

C. **Cleanup after a burnout.** Just as proper installation and service procedures are essential to prevent compressor and system failures, proper system cleanup and installation procedures when installing the replacement compressor are also essential to prevent repeat failures. Key elements of the recommended procedures are:

   1. In the United States, federal regulations require that the refrigerant be isolated in the system or recovered into an external storage container to avoid discharge into the atmosphere. Prior to opening any portion of the system for inspection or repairs, refrigerant should be recovered from that portion until the vapor pressure has been reduced to less than 12.7 psia (4 in. Hg vacuum) for R-22 or 9.8 psia (10 in. Hg vacuum) for CFC or other HCFC systems.
   2. Remove the burned-out compressor and install the replacement. Save a sample of the new compressor lubricant that has not been exposed to refrigerant and store in a sealed glass bottle. This will be used later for comparison.
   3. Inspect all system controls such as expansion valves, solenoid valves, check valves, etc. Clean or replace if necessary.
   4. Install an oversized drier in the suction line to protect the replacement compressor from any contaminants remaining in the system. Install a pressure tap upstream of the filter-drier. This tap permits measuring the pressure drop from the tap to the service valve during the first hours of operation to determine if the suction line drier needs to be replaced.
   5. Remove the old liquid line drier, if one exists, and install a replacement drier of the next larger capacity than is normal for this system. Install a moisture indicator in the liquid line if the system does not have one.
   6. Evacuate and leak check the system or portion opened to the atmosphere according to the manufacturer's recommendations.
   7. Recharge the system and begin operations according to the manufacturer's startup instructions, typically as follows:

      a. Observe pressure drop across the suction line drier for the first 4 h. Follow the manufacturer's guide; otherwise compare to pressure drop curve in Figure 10 and replace driers as required.

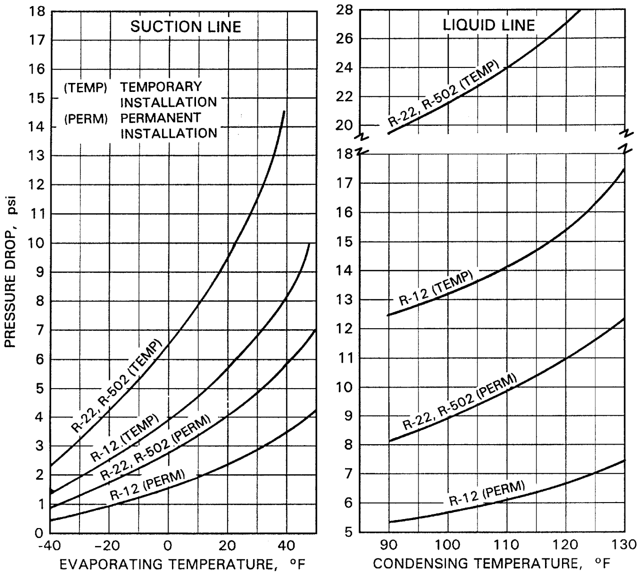

Fig. 10 Maximum Recommended Filter-Drier Pressure Drop

      b. After 24 to 48 h, check pressure drop and replace driers as required. Take a lubricant sample and check with an acid test kit. Compare the lubricant sample to the initial sample saved at the time the replacement compressor was installed. Cautiously smell the lubricant sample. Replace lubricant if acidity persists or if color or odor indicates.

      c. After 7 to 10 days or as required, repeat step b.

D. **Additional suggestions**

   1. If sludge or carbon has backed up into the suction line, swab it out or replace that section of the line.
   2. If a change in the suction line drier is required, change the lubricant in the compressor each time the cores are changed, if the compressor design permits.
   3. Remove the suction line drier after several weeks of system operation to avoid excessive pressure drop in the suction line. This problem is particularly significant on commercial refrigeration systems.
   4. In some cases, noncondensable gases are produced during the burnout. With the system off, compare the head pressure to the saturation pressure after stabilization at ambient temperature. Adequate time must be allowed to ensure stabilization. If required, purge the charge by recycling it or submit the purged material for reclamation.

Special System Characteristics and Procedures

Because of unique system characteristics, the procedures described here may require adaptations.

A. If a lubricant sample cannot be obtained from the new compressor, determine another method to get a sample from the system.

   1. Install a tee and a trap in the suction line. An access valve at the bottom of the trap permits easy lubricant drainage. Only 0.5 oz of lubricant is required for an acid analysis. Be certain the lubricant sample represents lubricant circulating in the system. It may be necessary to drain the trap and discard the first amount of lubricant collected, before collecting the sample to be analyzed.
   2. Make a trap from 1 3/8 in. copper tubing and valves. Attach this trap to the suction and discharge gage port connections with a charging hose. By blowing discharge gas through the trap and into the suction valve, enough lubricant will be

collected in the trap for analysis. This trap becomes a tool that can be used repeatedly on any system that has suction and discharge service valves. Be sure to clean the trap after every use to avoid cross contamination.

B. On semihermetic compressors, remove the cylinder head to determine the severity of burnout. Dismantle the compressor for solvent cleaning and hand wiping to remove contaminants. Consult the manufacturer's recommendations on compressor rebuilding and motor replacement.
C. In rare instances on a close-coupled system, where it is not feasible to install a suction line drier, the system can be cleaned by repeated changes of the cores in the liquid line drier and repeated lubricant changes.
D. On heat pump systems, the four-way valve and the compressor should be carefully inspected after a burnout. In cleaning a heat pump after a motor burnout, it is essential to remove any drier originally installed in the liquid line. These driers may be replaced for cleanup, or a biflow drier may be installed in the common reversing liquid line.
E. Systems with a critical charge require a particular effort for proper operation after cleanup. If an oversized liquid line drier is installed, an additional charge must be added. Check with the drier manufacturer for specifications. However, no additional charge is required for the suction line drier that may be added.
F. The new compressor should not be used to pull a vacuum. Refer to the manufacturer's recommendations for evacuation. Normally, the following method is used, after determining that there are no refrigerant leaks in the system:

    a. Pull a high vacuum to an absolute pressure of less than 500 μm Hg for several hours.
    b. Allow the system to stand several hours to be sure the vacuum is maintained. This requires a good vacuum pump and an accurate high-vacuum gage.

CONTAMINANT CONTROL DURING RETROFIT

Because of the phase-out of CFCs, existing refrigeration and air-conditioning systems are commonly retrofitted to alternative refrigerants. The term "refrigerant" in this section refers to a fluorocarbon working fluid offered as a possible replacement for a CFC, whether that replacement consists of one chemical, an azeotrope of two chemicals, or a blend of two or more chemicals. The terms "retrofitting" and "conversion" are used interchangeably to mean the modification of an existing refrigeration or air-conditioning system designed to operate on a CFC so that it can safely and effectively operate on an HCFC or HFC refrigerant. This section only covers the contaminant control aspects of such conversions. Equipment manufacturers should be consulted for guidance regarding the specifics of actual conversion. Industry standards and manufacturers' literature are also available that contain supporting information (UL 1993a, UL 1993b, UL 1993c).

Contaminant control concerns for retrofitting a CFC system to an alternative refrigerant fall into the following categories:

- **Cross-contamination of old and new refrigerants.** This should be avoided even though there are usually no chemical compatibility problems between the CFCs and their replacement refrigerants. One problem with mixing refrigerants is that it is difficult to determine system performance after retrofit. Pressure-temperature relationships are different for a blend of two refrigerants than for each refrigerant individually. A second concern with mixing refrigerants is that if the new refrigerant charge must be removed in the future, the mixture may not be reclaimable (DuPont 1992).
- **Cross-contamination of old and new lubricant.** Equipment manufacturers generally specify that the existing lubricant be replaced with the lubricant they consider suitable for use with a given HFC refrigerant. In some cases, the new lubricant is incompatible with the old one or with chlorinated residues present. In other cases, the old lubricant is insoluble with the new refrigerant and tends to collect in the evaporator, interfering with heat transfer. For example, when mineral oil is replaced by a polyol ester lubricant during retrofit to an HFC refrigerant, a typical recommendation is to reduce the old oil content to 5% or less of the nominal oil charge (Castrol 1992). Some retrofit recommendations specify lower levels of acceptable contamination in the case of polyol ester lubricant/HFC retrofits, so original equipment manufacturers recommendations should be obtained before attempting a conversion.
- **Chemical compatibility of old system components with new fluids.** One of the preparatory steps in a retrofit is to confirm that either the existing materials in the system are acceptable or that replacement materials are on hand to be installed in the system during the retrofit. Fluorocarbon refrigerants generally have solvent properties, and some are very aggressive. This characteristic can lead to swelling and extrusion of polymer O rings, undermining their sealing capabilities. Material can also be extracted from polymers, varnishes, and resins used in hermetic motor windings. These extracts can then collect in expansion devices, interfering with system operation. Residual manufacturing fluids such as those used to draw wire for compressor motors can be extracted from components and deposited in areas where they can interfere with operation. Suitable materials of construction have been identified by equipment manufacturers for use with HFC refrigerant systems.

  Drier media must also be chemically compatible with the new refrigerant and effective in removing moisture, acid, and particulate in the presence of the new refrigerant. Drier media commonly used with CFC refrigerants tend to accept small HFC refrigerant molecules and lose moisture retention capability (Cohen and Blackwell 1995). Drier media have been developed that minimize this tendency.

CHILLER DECONTAMINATION

Chiller decontamination is a process used to clean reciprocating, rotary screw, and centrifugal machines. Large volumes of refrigerant are circulated through a contaminated chiller while continuously being reclaimed. It has been used successfully to restore many chillers to operating specifications. Some chillers have been saved from early retirement by decontamination procedures. Variations of the procedure are myriad and have been used for burnouts, water- flooded barrels, particulate incursions, chemical contamination events, brine leaks, and oil strips. One frequently used technique is to perform numerous batch cycles, thus increasing the velocity- based cleansing component. Excess oil is stripped out to improve chiller heat transfer efficiency. The full oil charge can be removed in preparation for a refrigerant conversion.

Low-pressure units require different machinery than high-pressure units. It is best to integrate the decontamination and mechanical services early into one overall procedure. On machines that require compressor rebuild, it is best to perform decontamination work while the compressor is removed or before compressor rebuild, particularly for reciprocating units. Larger diameter or relocated access ports may be requested. The oil sump will be drained. For chillers that cannot be shut down, special on-line techniques have been developed using reclamation. The overall plan is coordinated with operations personnel to prevent service interruptions. For some decontamination projects it is advantageous to have the water boxes open; in other cases, closed. Intercoolers offer special challenges.

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