

CHAPTER 6

CONTROL OF MOISTURE AND OTHER CONTAMINANTS IN REFRIGERANT SYSTEMS

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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 as quickly as is feasible.

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 to produce moisture
6. Wet lubricant, refrigerant, or desiccant
7. Decomposing cellulose insulation in hermetically sealed units
8. Moisture entering a nonhermetic refrigerant system via permeation of nonmetallic 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 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

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 0°C 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 greater the solubility of water in a refrigerant, the less the possibility

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

Temp., °C	Solubility, mg/kg								
	R-11	R-12	R-13	R-22	R-113	R-114	R-123	R-134a	R-502
71.1	460	700	—	4100	460	450	2600	4200	1780
65.5	400	560	—	3600	400	380	2300	3600	1580
60.0	340	440	—	3150	344	320	2000	3200	1400
54.4	290	350	—	2750	290	270	1800	2800	1220
48.9	240	270	—	2400	240	220	1600	2400	1080
43.3	200	210	—	2100	200	180	1400	2000	930
37.8	168	165	—	1800	168	148	1200	1800	810
32.2	140	128	—	1580	140	120	1000	1500	690
26.7	113	98	—	1350	113	95	900	1300	580
21.1	90	76	—	1140	90	74	770	1100	490
15.6	70	58	44	970	70	57	660	880	400
10.0	55	44	—	830	55	44	560	730	335
4.4	44	32	26	690	44	33	470	600	278
−1.1	34	23.3	—	573	34	25	400	490	225
−6.7	26	16.6	14	472	26	18	330	390	180
−12.2	20	11.8	—	384	20	13	270	320	146
−17.8	15	8.3	7	308	15	10	220	250	115
−23.3	11	5.7	—	244	11	7	180	200	90
−28.9	8	3.8	3	195	8	5	140	150	69
−34.4	6	2.5	—	152	6	3	110	120	53
−40	4	1.7	1	120	—	2	90	89	40
−45.6	3	1.1	—	91	—	1.5	70	66	30
−51.1	2	0.7	—	68	—	1	53	49	22
−56.7	1	0.4	—	50	—	0.6	40	35	16
−62.2	0.8	0.3	—	37	—	0.4	30	25	11
−67.8	0.5	0.1	—	27	—	0.2	22	18	8
−73.3	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.

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

Temperature, °C	Water in Vapor/Water in Liquid, mass %/mass %						
	R-11	R-12	R-22	R-114	R-123	R-134a	R-502
37.8	30.1	5.5	0.400	13.3	4.25	0.542	0.63
32.2	—	6.1	0.397	14.4	4.57	0.571	0.64
26.7	34.8	6.3	0.405	16.0	4.53	0.573	0.65
21.1	—	7.5	0.404	17.6	4.69	0.585	0.66
15.6	43.1	8.2	0.401	19.7	4.82	0.625	0.66
10.0	—	9.0	0.391	21.7	4.97	0.637	0.66
4.4	50.5	9.9	0.390	24.7	5.16	0.650	0.66
−1.1	—	11.2	0.378	26.9	5.17	0.654	0.65
−6.7	57.9	11.9	0.351	29.5	5.09	0.639	0.61
−17.8	62.4	13.1	0.301	32.1	4.91	0.584	0.53
−28.9	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.

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 is not a problem.

Elsey and Flowers (1949) recognized 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:

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

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. Walker et al. (1962) showed that excess moisture can cause corrosion and enhance copper plating. Other factors affecting copper plating are discussed in Chapter 5.

The moisture required for freeze-up is a function of the amount of flash gas 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 43.3°C liquid temperature and a −28.9°C evaporator temperature, the refrigerant after expansion is 41.3% vapor and 58.7% liquid (by mass). The percentage of vapor formed is determined by:

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

where

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

Table 1 lists the saturated water content of the R-12 liquid phase at −28.9°C as 3.8 mg/kg. Table 2 is used to determine the saturated vapor phase water content as:

$$3.8 \text{ mg/kg} \propto 15.3 = 58 \text{ mg/kg}$$

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 0°C, 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:

$$\begin{aligned} 3.8 \propto 0.587 &= 2.2 \\ 58.0 \propto 0.413 &= 24.0 \\ \hline &26.2 \text{ mg/kg} \end{aligned}$$

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 43.3°C liquid and −28.9°C evaporating temperatures reaches saturation when the moisture circulating is 139 mg/kg. Note that this value is less than the liquid solubility, 195 mg/kg at −28.9°C.

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 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. Table 3 shows the results of moisture analysis of refrigerants taken from equipment in normal service from 1 to 16 years (ARI 1991a).

Table 3 Data on Moisture in Refrigeration Systems

Application	Range of Moisture Content Observed in Refrigerant, mg/kg			
	R-11	R-12	R-22	R-502
Centrifugal chillers	0 – 30	0 – 25	—	—
Reciprocating and screw chillers	—	—	0 – 56	—
Refrigeration systems	—	0 – 2	1 – 122	3 – 33
Large unitary systems 35 kW	—	—	0 – 75	—
Small unitary systems < 35 kW	—	—	3 – 127	—

Drying Methods

Equipment in the field is dried by evacuation and driers. Prior to opening the equipment for service, refrigerant must be isolated or recovered into an external storage container. After installation or service, noncondensables (air) should be removed with a vacuum pump connected preferably to both suction and discharge service ports. The absolute pressure should be reduced to 130 Pa or less, which is below the vapor pressure of water at ambient temperature. External 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 an oil film,

adsorbed by the motor windings, or located far from the vacuum pump are difficult to remove.

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. After reassembly, it should be dried further by passing dry nitrogen through the system and by heating and evacuation. Drying may take an extended period and require frequent changes of the vacuum pump oil. 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.

If the refrigerant in the pumpdown receiver is to be reused, it must be thoroughly dried before being reintroduced into the system. One way to dry it is to draw a liquid refrigerant sample and record the ambient temperature. If a chemical analysis of the sample by a qualified laboratory reveals a moisture content at or near the water solubility of 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/oil 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. Manufacturer's 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 milligram per kilogram, 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 pure oil 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 oil produces inaccurate results, because it 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). Briskin (1955) used this method in a study of moisture migration in hermetic equipment.

Thrasher (1993) used nuclear magnetic resonance spectroscopy to determine the moisture solubilities in R-134a and R-123. Another method, the infrared spectrophotometer, is used for moisture analysis, but requires a large sample for precise results and is subject to interference if oil 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-oil mixture. Solid desiccants, used widely as dehydrating agents in refrigerant systems, remove moisture from both new or 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 water 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.

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

Table 4 Reactivation of Desiccants

Desiccant	Temperature, °C
Activated alumina	200 to 310
Silica gel	180 to 310
Molecular sieves	260 to 350

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 oil. 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 has limited use, and 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 (see Table 4). 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 oil 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 a new equilibrium point is established.

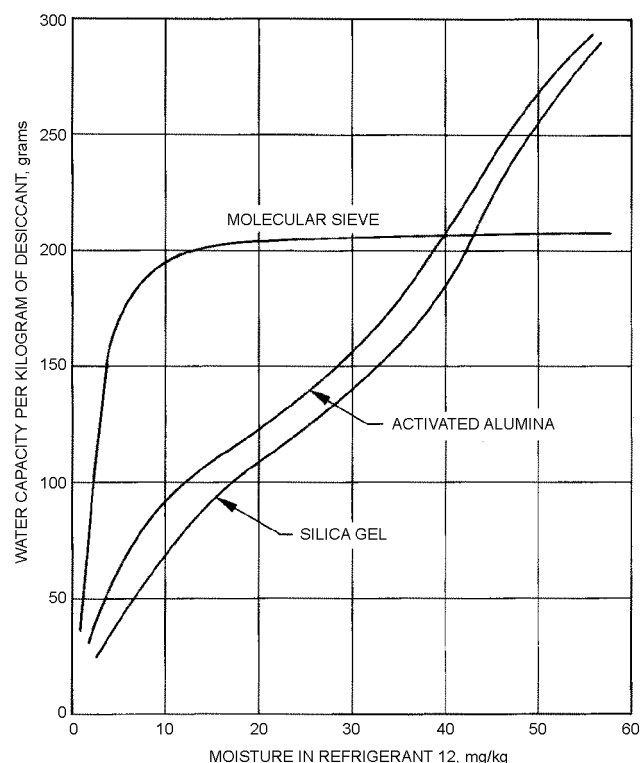
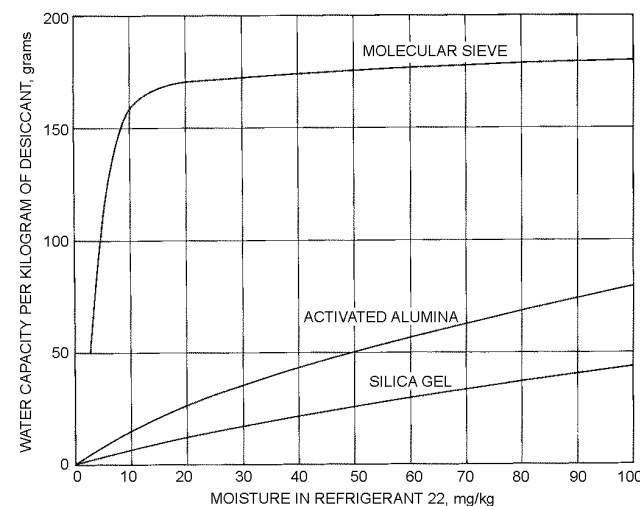
Adsorbent desiccants function by holding (adsorbing) moisture on their internal surfaces. The amount of water adsorbed from a refrigerant by an adsorbent at equilibrium is influenced (1) by the pore volume, pore size, and surface characteristics of the adsorbent; (2) by the temperature and moisture content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

Figures 1, 2, and 3 are equilibrium curves for various adsorbent desiccants with R-12 and R-22. These curves are representative of commercially available materials. They (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.

Figure 1 and Figure 2 show moisture equilibrium curves for three common adsorbent desiccants in drying R-12 and R-22 at 24°C. 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.

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 less. ARI *Standard 710* requires determining the water capacity for R-12 at an EPD of 15 mg/kg, and for R-22 at 60 mg/kg. Each determination must be made at 24°C (see Figures 1 and 2) and 52°C.

**Fig. 1 Moisture Equilibrium Curves for R-12 and Three Common Desiccants at 24°C****Fig. 2 Moisture Equilibrium Curves for R-22 and Three Common Desiccants at 24°C**

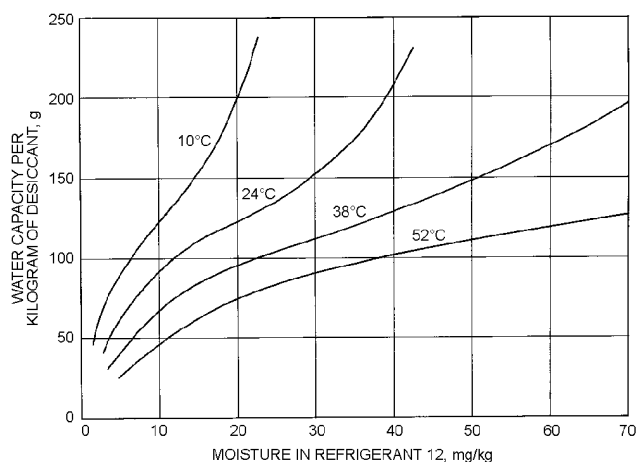


Fig. 3 Moisture Equilibrium Curves for Activated Alumina at Various Temperatures in R-12

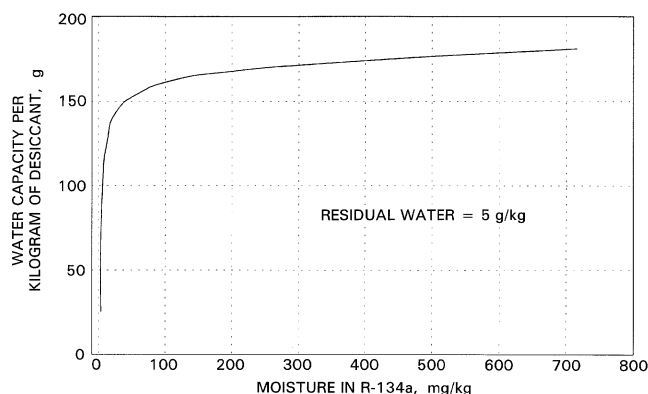


Fig. 4 Moisture Equilibrium Curves for Molecular Sieve in R-134a at 52°C

(Courtesy UOP, Reprinted with permission.)

Figure 4 shows water capacity of a molecular sieve in liquid R-134a at 52°C. This data was obtained using the Karl Fischer method similar to that described in Dunne and Clancy (1984).

Although the figures show that molecular sieves have higher 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.

Desiccant Applications

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

Oil Deterioration Products. Oils can react chemically to produce substances that are adsorbed by desiccants. Some of these are hydrophobic and, when adsorbed by the desiccant, reduce the rate at which it can adsorb liquid water. The rate and capacity of the desiccant to remove water dissolved in the refrigerant are not significantly impaired, however (Walker et al. 1955). Frequently, 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. Oil additives may be adsorbed by silica gel and activated alumina. Methanol is coadsorbed with moisture and competes with it for adsorption capacity in desiccants. Because of small pore size, molecular sieves generally do not adsorb additives or the oil.

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 oil-refrigerant mixture to carry the moisture to the drier. Cohen and Dunne (1987) and Cohen (1994) treat the kinetics of drying refrigerants in circulating systems.

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

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 14kPa pressure drop across the drier by the official procedures of *ASHRAE Standard 63.1* and *ARI Standard 710*. Jones (1964) developed a gravity flow method for determining flow capacities that uses R-113 and

converts the results to R-12 and R-22. 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* 78-1985 and ARI *Standard* 730-86. 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 63.1, respectively. Driers are rated under ARI *Standard* 710. Minimum standards for listing of refrigerant driers can be found in UL *Standard* 207. Filtration ratings and test standards have not been developed.

OTHER CONTAMINANTS

Refrigerant filter-driers are the principal devices used to remove contaminants from refrigeration systems. The filter-drier is not a substitute for poor 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 mass, 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 37 mg of contaminants per square metre 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 staters 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 oil decomposes under adverse conditions to form a resinous liquid or a solid frequently found on refrigeration filter-driers. These oils decompose noticeably when exposed for as little as 2 h to temperatures as low as 120°C in an atmosphere of air or oxygen. The compressor manufacturer should perform all high-temperature dehydrating operations on the machines prior to adding the oil charge. In addition, equipment manufacturers should not

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