CHAPTER 45

FACTORY DEHYDRATING, CHARGING, AND TESTING

PROPER dehydration, charging, and testing of packaged refrigeration systems and components (compressors, evaporators, and condensing coils) help ensure proper performance and extend the life of refrigeration systems. This chapter covers the methods used to perform these functions. It does not address criteria such as allowable moisture content, refrigerant quantity, and performance, which are specific to each machine.

DEHYDRATION (MOISTURE REMOVAL)

Factory dehydration may be feasible only for certain sizes of equipment. On large equipment, which is open to the atmosphere when connected in the field, factory treatment is usually limited to purge and backfill, with an inert holding charge of nitrogen. In most instances, this equipment is stored for short periods only, so this method suffices until total system evacuation and charging can be done at the time of installation.

Excess moisture in refrigeration systems may lead to freeze-up of the capillary tube or expansion valve. It also has a negative effect on thermal stability of certain refrigeration oils [e.g., polyol ester (POE)]. Contaminants can cause valve breakage, motor burnout, and bearing and seal failure. Chapter 6 has more information on moisture and other contaminants in refrigerant systems.

Except for freeze-up, these effects are not normally detected by a standard factory test. Therefore, it is important to use a dehydration technique that yields a safe moisture level without adding foreign elements or solvents. In conjunction with dehydration, an accurate method of moisture measurement must be established. Many factors, such as the size of the unit, its application, and type of refrigerant, determine acceptable moisture content. Table 1 shows moisture limits recommended by various manufacturers for particular refrigeration system components.

Sources of Moisture

Moisture in refrigerant systems can be (1) retained on the surfaces of metals; (2) produced by combustion of a gas flame; (3) contained in liquid fluxes, oil, and refrigerant; (4) absorbed in the hermetic motor insulating materials; (5) derived from the factory ambient at the point of unit assembly; and (6) provided by free water. Moisture contained in the refrigerant has no effect on dehydration of the component or unit at the factory. However, because the refrigerant is added after dehydration, it must be considered in determining the overall moisture content of the completed unit. Moisture in oil may or may not be removed during dehydration, depending on when the oil is added to the component or system.

Bulk mineral oils, as received, have 20 to 30 ppm of moisture. Synthetic POE lubricants have 50 to 85 ppm; they are highly hygroscopic, so they must be handled appropriately to prevent moisture contamination. Refrigerants have an accepted commercial tolerance of 10 to 15 ppm on bulk shipments. Controls at the factory are needed to ensure these moisture levels in the oils and refrigerant are maintained.

Newer insulating materials in hermetic motors retain much less moisture compared to the old rag paper and cotton-insulated motors. However, tests by several manufacturers have shown that the stator, with its insulation, is still the major source of moisture in compressors.

Dehydration by Heat, Vacuum, or Dry Air

Heat may be applied by placing components in an oven or by using infrared heaters. Oven temperatures of 180 to 340°F are usually maintained. The oven temperature should be selected carefully to prevent damage to the synthetics used and to avoid breakdown of any residual run-in oil that may be present in compressors. Air in the oven must be maintained at low humidity. When dehydrating by heat alone, the time and escape area are critical; therefore, the size of parts that can be economically dehydrated by this method is restricted.

The **vacuum** method reduces the boiling point of water below the ambient temperature. The moisture then changes to vapor, which is pumped out by the vacuum pump. Table 3 in Chapter 6 of the 2005 *ASHRAE Handbook—Fundamentals* shows the relationship of temperature and pressure for water at saturation.

Vacuum is classified according to the following absolute pressure ranges:

Low Vacuum	29.92 to 1.0 in. Hg
Medium Vacuum	1.0 in. Hg to 1 μm Hg
High Vacuum	1 to 10^{-3} μm Hg
Very High Vacuum	10^{-3} to 10^{-6} μm Hg
Ultrahigh Vacuum	10^{-6} μm Hg and below

The degree of vacuum achieved and the time required to obtain the specified moisture level are a function of the (1) type and size of vacuum pump used, (2) internal volume of the component or system, (3) size and composition of water-holding materials in the system, (4) initial amount of moisture in the volume, (5) piping and fitting sizes, (6) shape of the gas passages, and (7) external temperatures maintained. The pumping rate of the vacuum pump is critical only if the unit is not evacuated through a conductance-limiting orifice such as a purge valve. Excessive moisture content, such as a pocket of puddled water, takes a long time to remove because of the volume expansion to vapor.

Vacuum measurements should be taken directly at the equipment (or as close to it as possible) rather than at the vacuum pump. Small tubing diameters or long tubing runs between the pump and the equipment should be avoided because line/orifice pressure drops reduce the actual evacuation level at the equipment.

If **dry air** or **nitrogen** is drawn or blown through the equipment for dehydration, it removes moisture by becoming totally or partially saturated. In systems with several passages or blind passages, flow may not be sufficient to dehydrate. The flow rate should obtain

The preparation of this chapter is assigned to TC 8.1, Positive Displacement Compressors.

Table 1 Typical Factory Dehydration and Moisture-Measuring Methods for Refrigeration Systems

Component	Dehydration Method	Moisture Audit	Moisture Limit
Coils and tubing	250°F oven, –70°F dry-air sweep	Dew point recorder	10 mg
Evaporator coils			
Small	–70°F dew point dry-air sweep, 240 s	P_2O_5	25 mg
Large	–70°F dew point dry-air sweep, 240 s	P_2O_5	65 mg
Evaporators/condensers	300°F oven, 1 h, dry-air sweep	Cold trap	200 mg
	Dry-air sweep	Nesbitt tube	8.5 mg/ft^2 surf. area
Condensing unit (0.25 to 7.5 ton)	Purchase dry	P_2O_5	25 to 85 mg
	Dry-air sweep	Nesbitt tube	8.5 mg/ft^2 surf. area
Air-conditioning unit	Evacuate to 240 μm Hg	P_2O_5	35 ppm
	3 h winding heat, 0.5 h vacuum	Refrigerant moisture check	25 ppm
Refrigerator	250°F oven, dc winding heat, vacuum	Cold trap	200 mg
Freezer	–70°F dew point dry-air ambient, –40°F dew point air sweep	P_2O_5	10 ppm
Compressors			
	dc Winding Heat		
	0.5 h dc winding heat 350°F, 0.25 h vacuum/repeat	Cold trap	200 mg
	dc winding heat 190°F, 0.5 h vacuum	Cold trap	1200 mg
2 to 60 ton semihermetic	dc winding heat, 30 min, evacuation, N_2 charge	Cold trap	1000 to 3500 mg
	Oven Heat		
	250°F oven, 4 h vacuum	Cold trap	180 mg
	250°F oven, 5.5 h at –60°F dew point air	Cold trap	200 mg
0.5 to 12 ton hermetic	300°F oven 4 h, –70°F dew point air 3.5 min	Cold trap	150 to 400 mg
50 to 100 ton	Oven at 270°F, 4 h evacuate to 1000 μm Hg	Cold trap	750 mg
1.5 to 5 ton hermetic	340°F oven, –100°F dew point dry air, 1.5 h	Cold trap	100 to 500 mg
2 to 40 ton semihermetic	250°F oven, –100°F dew point dry air, 3.5 h	Cold trap	100 to 1100 mg
5 to 150 ton open	175°F oven, evacuate to 1 mm Hg	Cold trap	400 to 2700 mg
Scroll 2 to 10 ton hermetic	300°F oven 4 h, 50 s evacuation and 10 s –70°F dew point air charge/repeat 7 times	Cold trap	300 to 475 mg
	Hot Dry Air, N_2		
3 to 5 ton	Dry air at 275°F, 3 h	Cold trap	250 mg
7.5 to 15 ton	Dry air at 275°F, 0.5 h vacuum	Cold trap	750 mg
20 to 40 ton	Dry N_2 sweep at 275°F, 3.5 h evacuate to 200 μm Hg	Cold trap	750 mg
	Dry N_2 Flush		
Reciprocating, semihermetic	N_2 run, dry N_2 flush, N_2 charge	—	—
Screw, hermetic/semihermetic	R-22 run, dry N_2 flush, N_2 charge	—	—
Screw, open	N_2 run, dry N_2 flush, N_2 charge	—	—
	Evacuation Only		
Screw, open, 50 to 1500 ton	Evacuate <1500 μm Hg, N_2 charge	—	—
Refrigerants	As purchased	Electronic analyzer	Typically 10 ppm
Lubricants			
Mineral oil	As purchased	Karl Fischer method	25 to 35 ppm
	As purchased and evacuation	Hygrometer	10 ppm
Synthetic polyol ester	As purchased	Karl Fischer method	50 to 85 ppm

optimum moisture removal, and its success depends on the overall system design and temperature.

Combination Methods

Each of the following methods can be effective if controlled carefully, but a combination of methods is preferred because of the shorter drying time and more uniform dryness of the treated system.

Heat and Vacuum Method. Heat drives deeply sorbed moisture to the surfaces of materials and removes it from walls; the vacuum lowers the boiling point, making the pumping rate more effective. The heat source can be an oven, infrared lamps, or an ac or dc current circulating through the internal motor windings of semihermetic and hermetic compressors. Combinations of vacuum, heat, and then vacuum again can also be used.

Heat and Dry-Air Method. Heat drives moisture from the materials. The dry air picks up this moisture and removes it from the system or component. The dry air used should have a dew point between –40 and –100°F. Heat sources are the same as those mentioned previously. Heat can be combined with a vacuum to accelerate the process. The heat and dry-air method is effective with open, hermetic, and semihermetic compressors. The heating temperature should be selected carefully to prevent damage to compressor parts or breakdown of any residual oil that may be present.

Advantages and limitations of the various methods depend greatly on the system or component design and the results expected. Goddard (1945) considers double evacuation with an air sweep between vacuum applications the most effective method, whereas Larsen and Elliot (1953) believe the dry-air method, if controlled carefully, is just as effective as the vacuum method and much less expensive, although it incorporates a 1.5 h evacuation after the hot-air purge. Tests by manufacturers show that a 280°F oven bake for 1.5 h, followed by a 20 min evacuation, effectively dehydrates compressors that use newer insulating materials.

MOISTURE MEASUREMENT

Measuring the correct moisture level in a dehydrated system or part is important but not always easy. Table 1 lists measuring methods used by various manufacturers, and others are described in the literature. Few standards are available, however, and acceptable moisture limits vary by manufacturer.

Cold-Trap Method. This common method of determining residual moisture monitors the production dehydration system to ensure that it produces equipment that meets the required moisture specifications. An equipment sample is selected after completion of the dehydration process, placed in an oven, and heated at 150 to 275°F (depending on the limitations of the sample) for 4 to 6 h. During this time, a vacuum is drawn through a cold-trap bottle immersed in an acetone and dry-ice solution (or an equivalent), which is generally held at about –100°F. Vacuum levels are between 10 and 100 µm Hg, with lower levels preferred. Important factors are leaktightness of the vacuum system and cleanliness and dryness of the cold-trap bottle.

Vacuum Leakback. Measuring the rate of vacuum leakback is another means of checking components or systems to ensure that no water vapor is present. This method is used primarily in conjunction with a unit or system evacuation that removes the noncondensables before final charging. This test allows a check of each unit, but too rapid a pressure build-up may signify a leak, as well as incomplete dehydration. The time factor may be critical in this method and must be examined carefully. Blair and Calhoun (1946) show that a small surface area in connection with a relatively large volume of water may only build up vapor pressure slowly. This method also does not give the actual condition of the charged system.

Dew Point. When dry air is used, a reasonably satisfactory check for dryness is a dew-point reading of the air as it leaves the part being dried. If airflow is relatively slow, there should be a marked difference in dew point between air entering and leaving the part, followed by a decrease in dew point of the leaving air until it eventually equals the dew point of the entering air. As is the case with all systems and methods described in this chapter, acceptable values depend on the size, usage, and moisture limits desired. Different manufacturers use different limits.

Gravimetric Method. In this method, described by ASHRAE *Standard* 35, a controlled amount of refrigerant is passed through a train of flasks containing phosphorous pentoxide (P_2O_5), and the weight increase of the chemical (caused by the addition of moisture) is measured. Although this method is satisfactory when the refrigerant is pure, any oil contamination produces inaccurate results. This method must be used only in a laboratory or under carefully controlled conditions. Also, it is time-consuming and cannot be used when production quantities are high. Furthermore, the method is not effective in systems containing only small charges of refrigerant because it requires 200 to 300 g of refrigerant for accurate results. If it is used on systems where withdrawal of any amount of refrigerant changes the performance, recharging is required.

Aluminum Oxide Hygrometer. This sensor consists of an aluminum strip that is anodized by a special process to provide a porous oxide layer. A very thin coating of gold is evaporated over this structure. The aluminum base and gold layer form two electrodes that essentially form an aluminum oxide capacitor.

In the sensor, water vapor passes through the gold layer and comes to equilibrium on the pore walls of the aluminum oxide in direct relation to the vapor pressure of water in the ambient surrounding the sensor. The number of water molecules absorbed in the oxide structure determines the sensor's electrical impedance, which modulates an electrical current output that is directly proportional to the water vapor pressure. This device is suitable for both gases and liquids over a temperature range of 158 to –166°F and a pressure range of about 10 µm Hg to 5000 psig. The **Henry's Law constant** (saturation parts per million by mass of water for the fluid divided by the saturated vapor pressure of water at a constant temperature) for each fluid must be determined. For many fluids, this constant must be corrected for the operating temperature at the sensor.

Christensen Moisture Detector. The Christensen moisture detector is used for a quick check of uncharged components or units on the production line. In this method, dry air is blown first through the dehydrated part and then over a measured amount of calcium sulfate ($CaSO_4$). The temperature of the $CaSO_4$ rises in proportion to the quantity of water it absorbs, and desired limits can be set and monitored. One manufacturer reports that coils were checked in 10 s with this method. Moisture limits for this detector are 2 to 60 mg. Corrections must be made for variations in desiccant grain size, the quantity of air passed through the desiccant, and the difference in instrument and component temperatures.

Karl Fischer Method. In systems containing refrigerant and oil, moisture may be determined by (1) measurement of the dielectric strength or (2) the Karl Fischer method (Reed 1954). In this method, a sample is condensed and cooled in a mixture of chloroform, methyl alcohol, and Karl Fischer reagent. The refrigerant is then allowed to evaporate as the solution warms to room temperature. When the refrigerant has evaporated, the remaining solution is titrated immediately to a dead stop electrometric end point, and the amount of moisture is determined. This method requires a 15 g sample of refrigerant and takes about 20 min. Multiple checks are run to confirm results. This method is generally considered inaccurate below 15 ppm; however, it can be used for checking complete systems because this method does not require that oil be boiled off the refrigerant. Reed points out that additives in the oil, if any, must be checked to ensure that they do not interfere with the reactions of the method. The Karl Fischer method may also be used for determining moisture in oil alone (ASTM *Standard* D117; Morton and Fuchs 1960; Reed 1954).

An alternative method is available. A 5 to 10 g refrigerant sample is injected directly into Karl Fischer reagents at a constant flow rate using a pressure-reducing device such as a capillary tube. After the refrigerant is completely passed through the reagent, the moisture content is determined by automatic titration of a dead stop electrometric end point. This alternative method takes about 1 h to perform and is typically considered to be accurate to 5 ppm.

Electrolytic Water Analyzer. Taylor (1956) describes an electrolytic water analyzer designed specifically to analyze moisture levels in a continuous process, as well as in discrete samples. The device passes the refrigerant sample, in vapor form, through a sensitive element consisting of a phosphoric acid film surrounding two platinum electrodes; the acid film absorbs moisture. When a dc voltage is applied across the electrodes, water absorbed in the film is electrolyzed into hydrogen and oxygen, and the resulting dc current, in accordance with Faraday's first law of electrolysis, flows in proportion to the weight of the products electrolyzed. Liquids and vapor may be analyzed because the device has an internal vaporizer. This device handles the popular halocarbon refrigerants, but samples must be free of oils and other contaminants. In tests on desiccants, this method is quick and accurate with R-22.

Sight-Glass Indicator. In fully charged halocarbon systems, a sight-glass indicator can be used in the refrigerant lines. This device consists of a colored chemical button, visible through the sight glass, that indicates excessive moisture by a change in color. This method requires that the system be run for a reasonable length of time to allow moisture to circulate over the button. This method compares moisture only qualitatively to a fixed standard. Sight-glass indicators have been used on factory-dehydrated split systems to ensure that they are dry after field installation and charging, and are commonly used in conjunction with filter driers to monitor moisture in operating systems.

Special Considerations. Although all methods described in this section can effectively measure moisture, their use in the factory requires certain precautions. Operators must be trained in the use of

the equipment or, if the analysis is made in the laboratory, the proper method of securing samples must be understood. Sample flasks must be dry and free of contaminants; lines must be clean, dry, and properly purged. Procedures for weighing the sample, time during the cycle, and location of the sample part should be clearly defined and followed carefully. Checks and calibrations of the equipment must be made on a regular basis if consistent readings are to be obtained.

CHARGING

The accuracy required when charging refrigerant or oil into a unit depends on the size and application of the unit. Charging equipment must also be adapted to the particular conditions of the plant; equipment may be manual or automatic. Standard charging is used where extreme accuracy is not necessary or the production rate is not high. Fully automatic charging boards check the vacuum in the units, evacuate the charging line, and meter the desired amount of oil and refrigerant into the system. These devices are accurate and suitable for high production.

Refrigerant and oil must be handled carefully during charging; the place and time of oil and refrigerant charging greatly affect the life of a system. To avoid unnecessary complications (foaming, oil slugging, improper oil distribution, etc.), the unit should be charged with oil before the refrigerant. Charging with refrigerant should avoid liquid slugging during initial start-up; the best way to do this is to charge the unit at the high-pressure side. Refrigerant lines must be dry and clean, and all charging lines must be kept free of moisture and noncondensable gases. Also, new containers must be connected with proper purging devices. Carelessness in observing these precautions may lead to excess moisture and noncondensables in the refrigeration system.

Oil storage and charging systems should be designed and maintained to avoid contamination and direct contact between oil and air. Regular checks for moisture or contamination must be made at the charging station to ensure that oil and refrigerant delivered to the unit meet specifications. Compressors charged with oil for storage or shipment must be charged with dry nitrogen. Compressors without oil may be charged with dry air.

TESTING FOR LEAKS

Extended warranties and critical refrigerant charges add to the importance of proper leak detection before charging.

The U.S. Environmental Protection Agency (EPA) established an allowable leakage rate for certain refrigerants (e.g., no more than 0.1 oz per year of R-22 at 150 psig). A system that has 4 to 6 oz of refrigerant and a 5 year warranty must have virtually no leak, whereas in a system that has 10 to 20 lb of refrigerant, the loss of 1 oz of refrigerant in 1 year would not have much affect on system performance. Any leak on the low-pressure side of a system operating below atmospheric pressure is dangerous regardless of the size of the refrigerant charge.

Before any leak testing is done, the component or system should be strength tested at a pressure considerably higher than the leak test pressure. This test ensures safety when the unit is being tested under pressure in an exposed condition. Applicable design test pressures for high- and low-side components have been established by Underwriters Laboratories (UL), the American Society of Mechanical Engineers (ASME), the American National Standards Institute (ANSI), and ASHRAE. Units or components using composition gaskets as joint seals should have the final leak test after dehydration. Retorquing bolts after dehydration helps to reduce leaks past gaskets.

Leak Detection Methods

Water Submersion Testing. A water submersion test is a method of leak and strength testing. The test article is pressurized to the specified positive pressure and submerged in a well-lighted tank filled with clean water. It may take a few minutes for development of a small bubbles trace to visualize a small leak. Note that bubbles can develop on the surface as a result of outgassing, and development of a trace is a key factor. This method of leak testing is not as sensitive as the mass spectrometer or electronic leak detection methods, but is suitable for high-volume production.

Soap Bubble Leak Detection. High-rate leaks from a pressurized system can be found by applying a soapy liquid solution to the suspected leak areas. Bubbles that form in the solution indicate refrigerant leakage.

Fluorescent Leak Detection. This system involves infusing a small quantity of a fluorescent additive into the oil/refrigerant charge of an operating system. Leakage is observed as a yellow-green glow under an ultraviolet (UV) lamp. This method is suitable for halocarbon systems. Because the additive is in the oil, thorough cleanup is needed after the leak is fixed to avoid a false positive caused by leftover oil residue. It may also be a problem to identify fluorescent glow in daylight.

Pressure Testing. The test article is sealed off under pressure or vacuum, and any decrease or rise in pressure noted over time indicates leakage. Dry nitrogen is often used as the medium for pressure testing. The limitations of this method are the time required to conduct the test, the lack of sensitivity, and the inability to determine the location of any leak that may exist.

Electronic Leak Testing. The electronic leak detector consists of a probe that draws air over a platinum diode, the positive ion emission of which is greatly increased in the presence of a halogen gas. This increased emission is translated into a visible or audible signal. Electronic leak testing shares with halide torches the disadvantages that every suspect area must be explored and that contamination makes the instrument less sensitive; however, it does have some advantages: mainly, increased sensitivity. With a well-maintained detector, it is possible to identify leakage at a rate of 10^{-3} mm^3/s (standard), which is roughly equivalent to the loss of 1 oz of refrigerant in 100 years. The instrument also can be desensitized to the point that leaks below a predetermined rate are not found. Some models have an automatic compensating feature to accomplish this.

The problem of contamination is more critical with improved sensitivity, so the unit under test is placed in a chamber slightly pressurized with outside air, which keeps contaminants out of the production area and carries contaminating gas from leaky units. An audible signal allows the probe operator to concentrate on probing, without having to watch a flame or dial. Equipment maintenance presents a problem because the sensitivity of the probe must be checked at short intervals. Any exposure to a large amount of refrigerant causes loss of probe sensitivity. A rough check (e.g., air underwater testing) is frequently used to find large leaks prior to use of the electronic device.

Mass Spectrometer. In this method, the unit to be tested is evacuated and then surrounded by a helium-and-air mixture. The vacuum is sampled through a mass spectrometer; any trace of helium indicates one or more leaks. Many equipment manufacturers use the mass spectrometer leak detection method because of its high sensitivities: mass spectrometers can detect leaks of 10^{-7} mm^3/s. Test levels for production equipment are typically set near 10^{-2} mm^3/s. This method is normally used to measure the total leakage rate from all joints simultaneously. The main limitation for this method is that the costs for test equipment and consumables are higher than for other leak detection methods.

The required concentration of helium depends on the maximum leak permissible, the configuration of the system under test, the time the system can be left in the helium atmosphere, and the vacuum level in the system; the lower the vacuum level, the higher the helium readings. The longer a unit is exposed to the helium atmosphere, the lower the concentration necessary to maintain the required sensitivity. If, because of the shape of the test unit, a leak is

distant from the point of sampling, a good vacuum must be drawn, and sufficient time must be allowed for traces of helium to appear on the mass spectrometer.

As with other methods described in this chapter, the best testing procedure in using the spectrometer is to locate and characterize calibrated leaks at extreme points of the test unit and then to adjust exposure time and helium concentration to allow cost-effective testing. One manufacturer reportedly found leaks of 0.05 oz of refrigerant per year by using a 10% concentration of helium and exposing the tested system for 10 min.

The sensitivity of the mass spectrometer method can be limited by the characteristics of the tested system. Because only the total leakage rate is found, it is impossible to tell whether a leakage rate of, for example, 1 oz per year is caused by one fairly large leak or several small leaks. If the desired sensitivity rejects units outside the sensitivity range of tests listed earlier in this chapter, it is necessary to use a **helium probe** to locate leaks. In this method, the component or system to be probed is fully evacuated to clear it of helium; then, while the system is connected to the mass spectrometer, a fine jet of helium is sprayed over each joint or suspect area. With large systems, a waiting period is necessary because some time is required for the helium to pass from the leak point to the mass spectrometer. To save time, isolated areas (e.g., return bends on one end of a coil) may be hooded and sprayed with helium to determine whether the leak is in the region.

Special Considerations

There are two general categories of leak detection: those that allow a leak check before refrigerant is introduced into the system, and those that require refrigerant. Methods that do not use refrigerant have the advantage that heat applied to repair a joint has no harmful effects. On units containing refrigerant, the refrigerant must be removed and the unit vented before any welding, brazing, or soldering is attempted. This practice avoids refrigerant breakdown and pressure build-up, which would prevent the successful completion of a sound joint.

All leak-testing equipment must be calibrated frequently to ensure maximum sensitivity. The electronic leak detector and the mass spectrometer are usually calibrated with equipment furnished by the manufacturer. Mass spectrometers are usually checked using a flask containing helium. A glass orifice in the flask allows helium to escape at a known rate; the operator calibrates the spectrometer by comparing the measured escape rate with the standard.

The effectiveness of the detection system can best be checked with calibrated leaks made of glass, which can be bought commercially. These leaks can be built into a test unit and sent through the normal leak detection cycles to evaluate the detection method's effectiveness. Ensure that the test leak site does not become closed; the leakage rate of the test leak must be determined before and after each system audit.

From a manufacturing standpoint, use of any leak detection method should be secondary to leak prevention. Improper brazing and welding techniques, unclean parts, untested sealing compounds or improper fluxes and brazing materials, and poor workmanship result in leaks that occur in transit or later. Careful control and analysis of each joint or leak point make it possible to concentrate tests on areas where leaks are most likely to occur. If operators must scan hundreds of joints on each unit, the probability of finding all leaks is rather small, whereas concentration on a few suspect areas reduces field failures considerably.

PERFORMANCE TESTING

Because there are many types and designs of refrigeration systems, this section only presents specific information on reciprocating compressor testing and covers some important aspects of performance testing of other components and complete systems.

Compressor Testing

The two prime considerations in compressor testing are power and capacity. Secondary considerations are leakback rate, low-voltage starting, noise, and vibration.

Testing Without Refrigerant. A number of tests measure compressor power and capacity before the unit is exposed to refrigerant. In cases where excessive power is caused by friction of running gear, **low-voltage tests** spot defective units early in assembly. In these tests, voltage is increased from a low or zero value to the value that causes the compressor to break away, and this value is compared with an established standard. When valve plates are accessible, performance can be tested by using an air pump for **leakback tests**. Air at fixed pressure is put through the unit to determine the flow rate at which valves open properly. The air pressure exerted against the closing side of the valve indicates its efficiency. This method is effective only when the valves are reasonably tight, and is difficult to use on valves that must be run in before seating properly.

Extreme care should be taken when a compressor is used to pump air because the combination of oil, air, and high temperatures caused by compression can result in a diesel effect or an explosion.

In a common test using the compressor as an air pump, the discharge airflow is measured through a flowmeter, orifice, or other flow-measuring device. When the volumetric efficiency of the compressor with refrigerant is known, the flow rate that can be expected with air at a given pressure may be calculated. Because this test adiabatically compresses the air, the discharge pressure must be low to prevent overheating of discharge lines and oil oxidation if the test lasts longer than a few minutes. (The temperature of adiabatic compression is 280°F at 35 psig, but 540°F at 125 psig.) When the compressor is run long enough to stabilize temperatures, both power and flow can be compared with established limits. Discharge temperature readings and speed measurements aid in analyzing defective units. If a considerable amount of air is discharged or trapped, the air used in the test must be dry enough to prevent condensation from causing rust or corrosion on the discharge side.

Another method of determining compressor performance requires the compressor to pump from a free air inlet into a fixed volume. The time required to reach a given pressure is compared against a maximum standard acceptable value. The pressure used in this test is approximately 125 psig, so that a reasonable time spread can be obtained. The time needed for measuring the capacity of the compressor must be sufficient for accurate readings but short enough to prevent overheating. Power readings can be recorded at any time in the cycle. By shutting off the compressor, the leakback rate can be measured as an additional check. In addition to the pump-up and leakback tests noted above, a vacuum test should also be performed.

The **vacuum test** should be performed by closing off the suction side with the discharge open to the atmosphere. The normal vacuum obtained under these conditions is 1 to 1.5 psia. Abrupt closing of the suction side also allows the oil to serve as a check on the priming capabilities of the pump because of the suppression of the oil and attempt to deaerate. This test also checks for porosity and leaking gaskets. To establish reasonable pump-up times, leakback rates, and suctions, a large number of production units must be tested to determine the range of production variation.

In any capacity test using air, only clean, dry air should be used in order to prevent compressor contamination.

Observing performance while testing compressors of known capacity and power best establishes the acceptance test limits described. Take precautions to prevent oil that has been used repeatedly to lubricate many compressors from becoming acidic or contaminated.

Testing with Refrigerant. Calorimeter and flow meter testing methods for rating positive-displacement compressors are described in ASHRAE *Standard* 23. This type of testing is typically conducted

on an audit basis. If the purpose of the testing is not an accurate determination of the unit's capacity and efficiency, alternative methods can be used, such as testing on vapor or desuperheating stands. The vapor stand requires an expansion device (TXV) and a heat exchanger (or condenser) large enough to handle the heat equivalent to the motor power. The gas compressed by the compressor is cooled until its enthalpy is the same as that at suction conditions. It is then adiabatically expanded back to the suction state. This method eliminates the need for an evaporator and uses a smaller heat exchanger (condenser). On small-capacity compressors, a piece of tubing that connects discharge to suction and has a hand expansion valve can be used effectively. The measure of performance is usually the relationship of suction and discharge pressures to power. When a water-cooled heat exchanger (condenser) is used, the discharge pressure is usually known, and the water temperature rise and flow are used as capacity indicators. Operation of the desuperheating stand is similar, but in addition to a condenser and TXV, it also requires a hot-gas bypass valve (HGBV). Liquid refrigerant from a condenser and hot discharge gas are mixed by the HGBV to provide adequate suction pressure and temperature to the compressor: the HGBV controls suction pressure and the TXV, acting as a quench valve, controls superheating. Note that higher range and stability during operation are achieved by using a desuperheating stand instead of a vapor stand.

As a further refinement, flow-measuring devices can be installed in the refrigerant lines. This system is charge-sensitive if predetermined discharge and suction pressures and temperatures are to be obtained. This is satisfactory when all units have the same capacity and one test point is acceptable, because the charge desired can be determined with little experimentation. When various sizes are to be tested, however, or more than one test point is desired, a liquid receiver after the condenser can be used for full-liquid expansion.

The refrigerant must be free of contamination, inert gases, and moisture; the tubing and all other components should be clean and sealed when they are not in use. In the case of hermetic and semihermetic systems, a motor burnout on the test stand makes it imperative not to use the stand until it has been thoroughly flushed and is absolutely acid-free. In all tests, oil migration must be observed carefully, and the oil must be returned to the crankcase.

The length of a compressor performance test depends on various factors. Stable conditions are required for accuracy. If oil pump or oil charging problems are inherent, the compressor should be run long enough to ensure that all defects are detected.

Testing Complete Systems

In a factory, testing of any system may be done at a controlled ambient temperature or at an existing shop ambient temperature. In both cases, tests must be run carefully, and any necessary corrections must be made. Because measuring air temperature and flow is difficult, production-line tests are usually more reliable when secondary conditions are used as capacity indicators. Measurements of water temperature and flow, power, cycle time, refrigerant pressures, and refrigerant temperatures are reliable capacity indicators.

When testing self-contained air conditioners, for example, a fixed load may be applied to the evaporator using any air source and either a controlled ambient or shop ambient temperature. As long as the load is relatively constant, its absolute value is not important. For water-cooled units, in which water flow can be absolutely controlled, capacity is best measured by the heat rejected from the condenser. Suction and discharge pressures can be measured for the analysis.

Suction and discharge pressures and temperatures can be used as an indirect measure of capacity in units with air-cooled condensers. As long as the load is relatively constant, the absolute value is not important. Air distribution, velocity, or temperature over the test unit's coil must be kept constant during the test, and the performance of the test unit must then be correlated with the performance of a standard unit. Power measurements supplement the suction and discharge parameter readings.

The primary function of the factory performance test is to ensure that a unit is constructed and assembled properly. Therefore, all equipment must be compared to a standard unit, which should be typical of the unit used to pass the Air-Conditioning and Refrigeration Institute (ARI) and Association of Home Appliance Manufacturers (AHAM) certification programs for compressors and other units. ARI and AHAM provide rating standards with applicable maximum and minimum tolerances. Several ASHRAE and International Organization for Standardization (ISO) standards specify applicable rating tests.

Normal causes of malfunction in a complete refrigeration system are overcharging, undercharging, presence of noncondensable gases in the system, blocked capillaries or tubes, and low compressor efficiency. To determine the validity and sensitivity of any test procedure, it is best to use a unit with known characteristics and then establish limits for deviations from the test standard. If the established limits for charging are ±1 oz of refrigerant, for example, the test unit is charged first with the correct amount of refrigerant and then with 1 oz more and 1 oz less. If this procedure does not establish clearly defined limits, it cannot be considered satisfactory and new values must be established. This same procedure should be followed regarding all variables that influence performance and cause deviations from established limits. All equipment must be maintained carefully and calibrated if tests are to have any significance. Gages must be checked at regular intervals and protected from vibration. Capillary test lines must be kept clean and free of contamination. Power leads must be kept in good repair to eliminate high-resistance connection, and electrical meters must be calibrated and protected to yield consistent data.

In plants where component testing and manufacturing control have been so well managed that the average unit performs satisfactorily, units are tested only long enough to find major flaws. Sample lot testing is sufficient to ensure product reliability. This approach is sound and economical because complete testing taxes power and plant capacity and is not necessary.

When the evaporator load is static (e.g., for refrigerators or freezers), time, temperature, and power measurements are used to measure performance. Performance is determined by the time elapsed between start and first compressor shutoff or by the average on-and-off period during a predetermined number of cycles in a controlled or known ambient temperature. Also, concurrent suction and discharge temperatures in connection with power readings are used to establish conformity to standards. On units where the necessary connections are available, pressure readings may be taken. Such readings are usually possible only on units where refrigerant loss is not critical because some loss is caused by gages.

Units with complicated control circuits usually undergo an operational test to ensure that controls function within design specifications and operate in the proper sequence.

Testing of Components

Component testing must be based on a thorough understanding of the use and purpose of the component. Pressure switches may be calibrated and adjusted with air in a bench test and need not be checked again if there is no danger of blocked passages or pulldown tripout during the operation of the switch. However, if the switch is brazed into the final assembly, precautions are needed to prevent blocking the switch capillary.

Capillaries for refrigeration systems are checked by air testing. When the capillary limits are known, it is relatively easy to establish a flow rate and pressure drop test for eliminating crimped or improperly sized tubing. When several capillaries are used in a distributor, a series of water manometers check for unbalanced flow and can find damaged or incorrectly sized tubes.

In plants with good manufacturing control, only sample testing of evaporators and condensers is necessary. Close control of coils during manufacture leads to the detection of improper expansion,

poor bonding, split fins, or uneven spacing. Proper inspection eliminates the need for costly test equipment. In testing the sample, either a complete evaporator or condenser or a section of the heat transfer surface is tested. Because liquid-to-liquid is the most easily and accurately measurable method of heat transfer, a tube or coil can be tested by flowing water through it while it is immersed in a bath of water. The temperature of the bath is kept constant, and the capacity is calculated by measuring the coil flow rate and the temperature differential between water entering and leaving the coil.

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