absorbed by the $CaSO_4$, and thus desired limits can be set up and monitored. In an article describing the use of this detector, the manufacturer reports that he has checked coils in ten seconds. This method can be applied for moisture limits between 2 and 60 milligrams. Corrections must be made for variations in the desiccant grain size, quantity of air passed through the desiccant, and difference in instrument and component temperatures.

Karl Fischer Method. In systems containing refrigerant and oil, moisture may be determined by measuring the dielectric strength, or by the Karl Fischer Method.[18] In this method a sample from the unit under test is condensed and cooled in a mixture of chloroform, methyl alcohol, and Karl Fischer reagent. Then the refrigerant is allowed to evaporate as the solution warms up 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 sample of 50 to 60 g, and takes about one hour to perform. It is generally felt that it is not accurate below 15 ppm; however, as the method does not require that oil be boiled off the refrigerant, it can be used for checking complete systems. Reed[13] points out that additions to the oil must be checked in order to make make sure 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.[13–15]

Infrared Spectrometer. Another method reported in the literature is the use of the infrared spectrometer.[16] This method utilizes infrared light passed through chemicals that show selective absorption. The energy of light transmitted through a sample, when compared to the energy at the source, is a measure of the moisture content. Oil is likely to be a problem, because the hydrogen absorbs infrared light at nearly the same wave length as the hydroxyl band in water, thus decreasing the sensitivity of the instrument to moisture. A fairly large sample of refrigerant is required for accuracy, although Gray[17] reports making the test instrument part of a system to test desiccants, thus securing an infinite sample. Gray also reports that this method is entirely suitable for Refrigerant 12, but that it cannot be used for Refrigerant 22.

Instrument described by Taylor.[13] Taylor described an instrument specifically designed for moisture analysis and based on the principle of Faraday's Law. Refrigerant and direct current applied to the electrodes causes the water to break down into H and O_2. The current flowing due to electrolysis is directly proportional to the amount of water present, in accordance with Faraday's Law. Taylor used the instrument for a pure refrigerant, but he believes that oil interfers with accurate measurement. In tests on desiccants, Gray found this method quick and accurate with Refrigerant 22.

Method described by Brisken.[19] A method utilizing a very small sample, which can be used on a unit charged with oil, is described by Brisken. A modified Aminco-Weaver Water Vapor indicator was used in order to study the migration of moisture in a hermetically sealed cycle. The Aminco-Weaver instrument uses the electric conductance of a thin hygroscopic film to measure moisture content, and the use of a gas of known moisture content for comparison purpose avoids the necessity of securing absolute conductance measurements. The instrument requires as little as five cubic centimeters of vapor to secure a test. Although it is objectionable if oil coats the detector, a small oil trap reduces this hazard, and cleaning the detector is a quick and relatively easy task. Although this instrument has been used effectively, gives fast results, and requires only insignificant amounts of refrigerant, its operation and the interpretation of the data require a careful and intelligent operator.

A point of interest for any method of moisture determination can be found in Reference 19 where a report on migration in a hermetic system is given. In his tests, Brisken found that the true moisture levels could be found only after the system had been running long enough to establish equilibrium between the moisture content of the vapor and the liquid, and where the cellulose of the motor had given up to the system the amount of water that it could not hold at operating temperature. It is well to remember in this connection that each refrigerant has its own moisture equilibrium curve between liquid and vapor phases, and that where the moisture content is determined in a static system, these curves must be utilized.

Weaver[20] *originally developed the method* in which the electrical conductivity of a film in equilibrium with the moisture contained in a gaseous refrigerant is measured.

Sight Glass Indicator. In fully charged systems, a sight glass indicator can be utilized in the refrigerant lines. This device consists of a colored chemical button visible through the sight glass, which indicates excessive moisture by a change in color. This method requires that the system be run for a reasonable length of time in order to allow moisture to circulate over the button. Obviously, this method compares moisture only qualitatively to a fixed standard. It has been used on factory-dehydrated split systems, in order to make sure that they are dry after field installation and charging.

Special Considerations. Although all methods described in this section can be used effectively to 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 as to weighing of the sample, time during cycle, and location of sample part, should be clearly defined and carefully followed. Checks and calibration of equipment must be made on a regular basis, if consistent readings are to be secured.

CHARGING

The accuracy needed when charging refrigerant or oil into a unit depends on its size and application. Charging equipment must also be adapted to the particular conditions of the plant. Either manual or automatic charging devices are used.

Manual Charging. Most manual devices require the operator to fill a cylinder to a given point, and then discharge that volume into the system. To minimize operator error, the liquid column is magnified. If the accuracy required is plus or minus a quarter of an ounce, for example, the column should be so thin that one inch of column length equals a quarter of an ounce. Since this device is primarily volume-charging, the temperature of the liquid must be kept constant when charging, or the necessary corrections for temperature variations must be made. Heat lamps can be used to keep the temperature constant and avoid the necessity of correction.

The dissdvantages of manual charging are obvious. It is time consuming and subject to operator error.

Automatic Charging. This method combines both speed and accuracy. Automatic charging boards charge by weight, and fully automatic boards check the vacuum in the unit, evacuate the charging line, and meter the desired amount of oil and refrigerant into the system.

Automatic charging boards are rather complex and must be carefully maintained to avoid malfunctioning. A visual metering device for flow observations or direct measurement of the quantity charged into the system is therefore recommended.

Special Considerations

As a general rule, refrigerant and oil must be carefully handled during charging. Also, the decision, of where to charge and in what order, may have a great deal of bearing on the life of a system. If a complete unit is charged prior to performance testing, the presence of liquid refrigerant in the crankcase port may cause damage due to slugging. If the oil is added after the refrigerant is already in the crankcase, excessive foaming and oil vapor lock may occur with possible bearing damage.

Obviously, refrigerant lines must be dry and clean, and all charging lines must carefully be kept free of moisture and noncondensable gases. Also, new containers must be connected with proper purging devices. Carelessness in observing these precautions may result in excessive moisture in the refrigeration system.

Oil drums must be stored lying on their sides to prevent accumulation of dirt and water on top which might get into the oil as soon as a drum is opened. Drums of oil should be opened in the last moment before charging, even when the oil must be degasified. Regular checks for moisture or contamination must be made at the charging station, and samples for analysis must be taken from each lot of refrigerant and oil after delivery.

TESTING FOR LEAKS

Loss of refrigerant by leakage has always been a serious problem to industry and, consequently, testing for leakage is extremely important. Extended warrantees and critical refrigerant charges add to the importance of proper testing.

Basically, *allowable leakage rate* depends entirely upon the system or component characteristics. Any leak on the low-pressure side of a system operating below atmospheric pressure is dangerous, no matter how large the refrigerant charge. A system having four to six ounces of refrigerant and a five-year warranty must have virtually no leak, whereas in a system having ten to twenty pounds of refrigerant the loss of an ounce of refrigerant in a year is not critical. It must be recognized that there is a certain element of risk in establishing any leak sensitivity, because a small hole could conceivably open up in time or even during shipment. It is also entirely possible that small leaks will vanish later due to impurities in the system which may close the openings.

Leak Detection Methods

Water Submersion Test. The most popular method of leak detection in use in the refrigeration industry today is the water submersion test. In this method a component or unit under positive pressure of dry gas is placed in a water bath and observed for bubbles that indicate a leak. This method is simple and reliable, and requires a minimum of operator training. Some precautions must be taken, however, to avoid errors.

The tank in which the item under test is submerged should be clean and well lighted. The water should be filtered and heated to free it of all trapped air. Carriers should permit observation of all portions of the tested unit, and should be designed to carry as little air into the tank as possible, because bubbles released by the carrier tend to distract the observer or may cause errors. The pressure used should be as high as possible, dependent on safety requirements. A pressure of 250 lb seems to be generally used.

The sensitivity of the water submersion test cannot be clearly defined, since pressures and time in the tank may vary considerably, but the minimum leak rate that can be consistently determined, is 1/1000 standard cc per sec. This is roughly equivalent to one ounce of refrigerant per year. However, a considerably higher leak rate per year must be expected because a number of individual leaks smaller than the minimum observable could possibly exist and add to the leakage found by test.

To establish the length of time that the unit should be under water, a calibrated leak should be used to establish the bubble frequency. If the desired rate results in a bubble per minute, then the unit should be in the water a minimum of three minutes, to allow the observer a chance to confirm a leak. The sensitivity of all the systems discussed in this chapter is at a maximum, if the leak checking can be accomplished before painting, since a fine opening can be temporarily sealed by paint. It is also to be noted that water can seal small leaks. Units should, therefore, be thoroughly dried before further leak testing is done.

A modification of the submersion method is application of soap suds to a component or unit under pressure. This system has fundamentally the same sensitivity as the submersion method, but it is considerably slower, and is used only on very large systems, or as a method of finding a leak for repair purposes.

Pressure Testing. Another leak detection method that falls into the same sensitivity range is the pressure method. The unit or part is either pressurized or evacuated, and then the pressure decrease or rise is measured against time. It is important to maintain constant temperatures in order to eliminate pressure variations.

Pressure testing is simple and reliable, takes very little plant investment, and determines total leakage. Disadvantages are that the time required to measure a significant change is fairly long, and that the location of the leaks cannot be determined.

Halide Leak Testing. Units or components charged with refrigerant containing a halogen may be leak tested with a halide torch or an electronic leak detector. Halide torches normally produce an almost colorless flame or flame of faintly blue color, but its color will change to a greenish blue in the presence of a halogen, varying in intensity with the size of the leak.

The sensitivity of the halide torch is about the same as that of the preceding methods, although sensitivity depends on the pressure in the unit and on the color perception of the operator. To test a unit at ambient temperatures, a small charge of refrigerant gas is backed up with air or nitrogen pressure to insure a driving force of reasonable magnitude.

Halide torches are influenced by refrigerant contamination, and become ineffective in locating small leaks when the unit has a large leak. If the torch is used, each joint must be probed carefully for small leaks; therefore the unit or part must be leak tested while all joints are exposed.

Electronic Leak Testing. The electronic type leak detector consists of a probe that draws air over a platinum diode whose positive ion emission 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, but it has some marked advantages. The main advantage is increased sensitivity. With a well maintained detector it is possible to identify leakage at a rate of 1×10^{-6} standard cc per sec which is roughly equivalent to the loss of one ounce of refrigerant in 100 years. Another advantage is that the detector can be calibrated in a number of ways, so that a leak can be quantitatively measured. The instrument also can be desensitized to the point that leaks below a pre-