CHAPTER 8

REFRIGERANT CONTAINMENT, RECOVERY, RECYCLING, AND RECLAMATION

CONTAINMENT of refrigerant is an important consideration during service and maintenance of refrigeration systems. The potential environmental effect of chlorofluorocarbon (CFC) and hydrochlorofluorocarbon (HCFC) refrigerants on ozone depletion, and of these and hydrofluorocarbon (HFC) refrigerants on global warming, make it imperative that refrigerants are confined to closed systems and recovered during service and at the end of life. Containment must be considered in all phases of a system's life, including (1) design and construction of leaktight and easily serviced systems, (2) leak detection and repair, (3) recovery during service, and (4) recovery system disposal. Additional reference can be found in ASHRAE *Standard* 147-2002.

EMISSIONS TYPES

Refrigerant emissions to the atmosphere are often generically called *losses*, without distinguishing the causes. However, emission types are very different, and their causes must be identified before they can be controlled. Clodic (1997) identified six types:

- Sources of **fugitive emissions** cannot be precisely located.
- **Tightness degradation** is caused by temperature variations, pressure cycling, and vibrations that can lead to unexpected and significant increases of refrigerant emission rates.
- **Component failures** mostly originate from poor construction or faulty assembly.
- **Losses during refrigerant handling** occur mainly when charging the system, and opening the system without previously recovering the refrigerant.
- **Accidental losses** are unpredictable and are caused by fires, explosions, sabotage, theft, etc.
- **Losses at equipment disposal** are caused by intentionally venting, rather than recovering, refrigerant at the end of system life.

DESIGN

The potential for leakage is first affected by system design. Every attempt must be made to design systems that are leaktight for the length of their useful service lives, and reliable, to minimize the need for service. Selection of materials, joining techniques, and design for easy installation and service access are critical factors in designing leaktight systems.

For example, leaktight service valves should be installed to allow removal of replaceable components from the cooling system, and located for efficient liquid refrigerant recovery.

Design should minimize charge, to reduce the amount of released refrigerant in case of catastrophic loss. There are many opportunities for refrigerant charge reduction in initial design. Heat exchangers, piping, and components should be selected to reduce the amount of refrigerant in the system (but not at the expense of energy efficiency).

INSTALLATION

Proper installation is critical to proper operation and containment during the useful life of refrigerating systems. Tight joints and proper piping materials are required. Later service requirements are minimized by proper cleaning of joints before brazing, purging the system with an inert gas (e.g., nitrogen) during brazing, and evacuation to remove noncondensables. Use an inert gas purge to prevent oxides, which can contaminate the system. Proper charging and careful system performance and leak checks should be performed. At installation, systems should be carefully charged per design specifications to prevent overcharging, which can potentially lead to a serious release of excess refrigerant, and make it impossible to transfer the entire charge into the receiver for service. The installer also has the opportunity to find manufacturing defects before the system begins operation.

SERVICING AND DECOMMISSIONING

Proper service is critical in reducing emissions. Refrigerating systems must be monitored to ensure that they are well sealed, properly charged, and operating properly. The service technician must study service records to determine any history of leakage or malfunction. The equipment should be checked to detect leaks before significant charge is lost. During system maintenance, refrigerant should not be released; instead, it should be isolated in the system or recovered by equipment capable of handling the specific refrigerant.

A maintenance document allows the user to monitor additions and removals of refrigerant, and whether recharging operations are actually associated with repairs of leaks. Maintenance documents are mandatory in a number of countries, because they enable authorities to check the actual consumption of refrigerants. In a retrofit, the new refrigerant must be noted in the service record and clearly marked on equipment. Technicians must follow manufacturers' retrofit procedures, because some system components may be incompatible with different refrigerants. Failure to perform proper retrofits may result in system failure and subsequent loss of refrigerant.

When a system is decommissioned, recover the refrigerant for recycling, reuse, or disposal (usually by incineration). Special care is required to properly clean or reclaim used refrigerants to industry-recognized standards (see ARI *Standard* 700).

The preparation of this chapter is assigned to TC 3.8, Refrigerant Containment.

TRAINING

Technician training is essential for proper handling and containment of refrigerants. Training must provide a basic understanding of the environmental effects of refrigerants; recovery, recycling, and reclamation of refrigerants; leak checks and repairs; and introduction to new refrigerants. The service operator requires continuous training to understand new designs, new refrigerants and their compatibility with lubricants, new low-emission purge units, retrofitting requirements, and service practices.

Some countries have mandatory training and certification for refrigerant technicians. In other countries, private groups provide voluntary certification and training programs for service technicians.

LEAK DETECTION

Leak detection is a basic element for manufacturing, installing, and servicing systems, because it makes it possible to measure and improve containment of refrigerant. Leak detection must be performed as the final step after the system is completed in the factory or in the field. It is good practice (and mandatory in some countries) to regularly leak test the equipment.

There are three general types of leak detection: global, local, and automated performance monitoring.

Global Detection

These methods indicate whether a leak exists, but do not identify its location. They are useful at the end of construction, and when the system is opened for repair or retrofit.

System Checking. These approaches are applicable to a system that has been emptied of its charge.

- Pressurize the system with a tracer gas and isolate it. A pressure drop within a specified time indicates leakage.
- Evacuate the system and measure the vacuum level over a specified time. A pressure rise indicates leakage.
- Place the system in a chamber and charge with a tracer gas. Then evacuate the chamber and monitor it for leaks with a mass spectrometer or residual gas analyzer.
- Evacuate the system and place it in an atmosphere with a tracer gas. Monitor for leaks with a mass spectrometer or residual gas analyzer.

Many of these tests use a tracer gas, often nitrogen or helium. It is not good practice to use a refrigerant as the tracer gas.

Continuous Monitoring During Operation. Electronic leak detectors in machinery rooms may be efficient if (1) they are sensitive enough to refrigerant dilution in the air, and (2) air is circulated properly in the room.

Local Detection

These methods pinpoint locations of leaks, and are usually used during servicing. Sensitivity varies widely; it is usually stated as ppm/volume but, for clarity, mass flow rates (oz/year) are often used.

- **Visual checks** locate large leaks (≥2 oz/year) by seeking telltale traces of oil at joints.
- **Soapy water detection (bubble testing)** is simple and inexpensive; a trained operator can pinpoint leaks of 1 oz/year or more.
- **Tracer color** added to the oil/refrigerant mixture shows the leak's location. The tracer must be compatible with the various materials used in the refrigeration circuit.
- **Electronic detectors** of different techniques can detect leaks as low as 0.25 to 2 oz/year, according to their sensitivity. They must be used with proper care and training.
- **Ultrasonic detectors** register noise generated by the flow of gas exiting through the leak, and are less sensitive than electronic detectors; they are easily disturbed by air circulation.
- **Helium and HFC mass spectrometers** with probes or hoods can detect leaks at very low levels (less than 0.1 oz/year).

Automated Performance Monitoring Systems

Monitoring parameters such as temperatures and pressures helps identify any change in the equipment. It also provides data useful for performing diagnostics on the condition of heat exchanger surfaces, proper refrigerant pumping, and shortage of refrigerant charge. Automated diagnostic programs are now being developed to produce pre-alarm messages as soon as a drift is observed. These developments are in their early stages, but their general adoption would give better control over refrigerant leaks. Equipment room monitors are currently used. On low-pressure systems, it is also possible to monitor equipment tightness by monitoring purge unit run time, which can indicate leaks.

RECOVERY, RECYCLING, AND RECLAMATION

The procedures involved in removing contaminants when recycling refrigerants are similar to those discussed in Chapter 6. Service techniques, proper handling and storage, and possible mixing or cross contamination of refrigerants are of concern. Building owners, equipment manufacturers, and contractors are concerned about reintroducing refrigerants with unacceptable levels of contaminants into refrigeration equipment. Contaminated refrigerant can negatively affect system performance, and may lead to equipment failure and release of refrigerant into the atmosphere.

Installation and Service Practices

Proper installation and service procedures, including proper evacuation and leak checking, are essential to minimize major repairs. Service lines should be made of low-permeability hose material and should include shutoff valves. Larger systems should include isolation valves and pumpdown receivers. ASHRAE *Standard* 147 describes equipment, installation, and service requirements.

Recovering refrigerant to an external storage container and then returning the refrigerant for cleanup inside the refrigeration system is similar to the procedure described in Chapter 6. Some additional air and moisture contamination may be introduced in the service procedure. In general, because contaminants are distributed throughout the system, the refrigeration system must be cleaned regardless of whether the refrigerant is isolated in the receiver, recovered into a storage container, recycled, reclaimed, or replaced with new refrigerant. The advantage of new, reclaimed, or recycled refrigerant is that a properly cleaned system is not recontaminated by impure refrigerant.

Contaminants

Contaminants found in recovered refrigerants are discussed in detail in Chapter 6. The main contaminants are moisture, acid, noncondensables, particulates, high-boiling residue (lubricant and sludge), and other condensable gases (Manz 1995).

Moisture is normally dissolved in the refrigerant or lubricant, but sometimes free water is present. Moisture is removed by passing the refrigerant through a filter-drier. Some moisture is also removed by lubricant separation.

Acid consists of organic and inorganic types. Organic acids are normally contained in the lubricant and are removed in the oil separator and in the filter-drier. Inorganic acids, such as hydrochloric acid, are removed by noncondensable purging, reaction with metal surfaces, and the filter-drier.

Noncondensable gases consist primarily of air. These gases can come from refrigeration equipment or can be introduced during servicing. Control consists of minimizing infiltration through proper equipment construction and installation (ASHRAE *Standard* 147). Proper service equipment construction, connection techniques, and maintenance procedures (e.g., during filter-drier change) also reduce air contamination. Typically, a vapor purge is used to remove air.

Suction filters, oil separators, and filter-driers remove **particulates**.

High-boiling residues consist primarily of refrigerant lubricant and sludge. Because different refrigeration systems use different lubricants and because it is a collection point for other contaminants, the lubricant is considered a contaminant. High-boiling residues are removed by separators designed to extract lubricant from vapor-phase refrigerant, or by distillation.

Other **condensable gases** consist mainly of other refrigerants. They can be generated in small quantities by high-temperature operation or during a burnout. In rare cases, refrigerants may be mixed intentionally for performance or to top off with substitutes. To maintain purity of the used refrigerant supply as well as the performance and durability of the particular system, refrigerants should not be mixed. In general, separation of other condensable gases, if possible, can only be done at a fully equipped reclamation center.

Mixed refrigerants are a special case of other condensable gases in that the refrigerant would not meet product specifications even if all moisture, acids, particulates, lubricant, and noncondensables were removed. Inadvertent mixing may occur because of a failure to

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

Recovery

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

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

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

Medium- and high-pressure refrigerants are commonly recovered using a compressor-based recovery unit to pump the refrigerant directly into a storage container (Manz 1995). Such a system is shown in Figure 1. Minimum functions include evaporation, compression, condensation, storage, and control. Where possible, the recovery unit should be connected to both the high- and low-side ports to hasten the process. Removal of the refrigerant as a liquid, especially where the refrigerant is to be reclaimed, greatly speeds the process (Clodic and Sauer 1994). As a variation, a refrigeration unit may be used to cool the storage container to transfer the refrigerant directly. For low-pressure refrigerants (e.g., R-11), a compressor or vacuum pump may be used to lower pressure in the storage container and raise pressure in the vapor space of the refrigeration system so that the liquid refrigerant will flow without evaporation. An alternative is to use a liquid pump to transfer the refrigerant (Manz 1995). A pumpdown unit (e.g., a condensing unit) is required to remove vaporized refrigerant remaining after liquid removal is complete. Recovery systems for use at a factory for charging or leak-testing operations are likely to be larger and of specialized construction to meet the manufacturer's specific needs (Parker 1988).

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

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

Recycling

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

Recycling conserves limited supplies of regulated refrigerants (e.g., R-12). A single-pass recycling schematic is shown in Figure 2 (Manz 1995). In the single-pass recycling unit, refrigerant is processed by oil separation and filter-drying in the recovery path. Typically, air and noncondensables are not removed during recovery, and are handled at a later time.

In a multiple-pass recycling unit (Figure 3) the refrigerant is typically processed through an oil separator during recovery. The filter-drier may be placed in the compressor suction line, a bypass recycling loop, or both. During a continuous recycling loop, refrigerant is withdrawn from the storage tank, processed through filter-

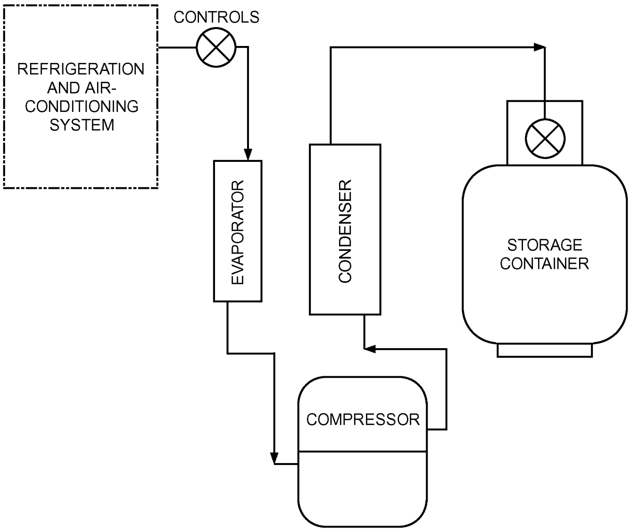

Fig. 1 Recovery Functions

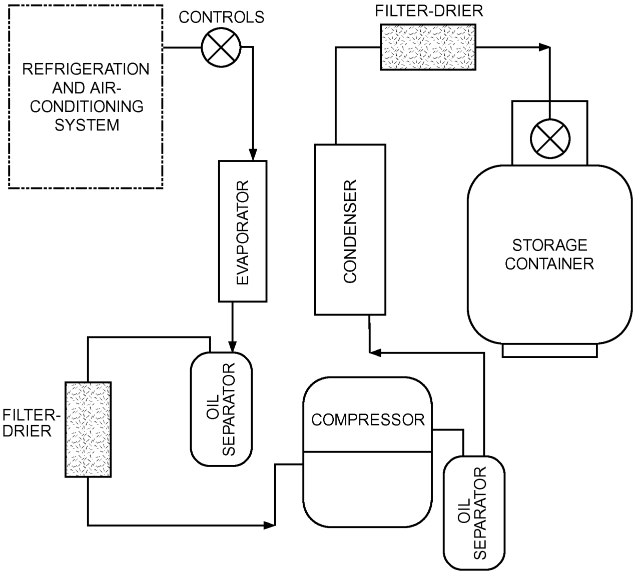

Fig. 2 Single-Pass Recycling

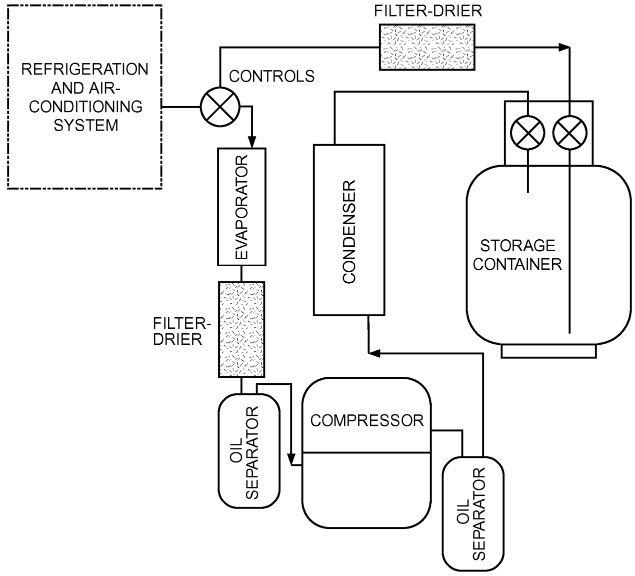

Fig. 3 Multiple-Pass Recycling

driers, and returned to the storage container. Noncondensable purge is accomplished during this recycling loop.

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

Important: *The service technician must change recovery/recycling unit filter-driers frequently, as directed by the indicators and manufacturer's instructions.*

The primary advantage of recycling is that this operation can be performed at the job site or at a local service shop, thus avoiding transportation costs. The chance of mixing refrigerants is reduced if recycling is done at the service shop instead of consolidating refrigerant batches for shipment to a reclamation facility. Recycling equipment cannot separate mixed refrigerants to bring them back to product specifications.

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

Industry Guidelines. ARI's (1994) *Industry Recycling Guide* 2 (IRG-2), Handling and Reuse of Refrigerants in the United States, includes a flowchart that outlines the following options:

Option 1: Return refrigerant to the system without recycling.

Option 2: Recycle refrigerant and return it to the original system or one with the same owner.

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

Option 4: Send refrigerant to a certified reclaimer.

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

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

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

Equipment Standards

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

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

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

ARI *Standard* 740 applies to single-refrigerant systems and their normal contaminants. It does not apply to refrigerant systems or storage containers with mixed refrigerants, and does not attempt to rate equipment's ability to remove different refrigerants and other condensable gases from recovered refrigerant. Responsibility is placed on the equipment operator to identify those situations and to treat them accordingly. One uncertainty associated with recycled refrigerants is describing purity levels when offering the refrigerant for resale; appropriate field measurement techniques do not exist for all contaminants listed in ARI *Standard* 700. IRG-2 discusses possible options.

The Society of Automotive Engineers (SAE) has Standards for refrigerant recovery equipment used to service motor vehicle air-conditioners.

Special Considerations and Equipment for Handling Multiple Refrigerants

Different refrigerants must be kept separate. Storage containers should meet applicable standards for transportation and use with that refrigerant, as specified in ARI *Guideline* K. Disposable cylinders are not recommended (RSES 1991); if they are used, the remaining refrigerant heels should be recovered before cylinder disposal.

Containers should be filled per ARI *Guideline* K and marked with the refrigerant type. Container colors for recovered refrigerants and for new and reclaimed refrigerants are specified in ARI *Guidelines* K and N, respectively.

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

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

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

Reclamation

To **reclaim** means to process used refrigerant to new product specifications. It usually implies use of processes or procedures available only at a reprocessing or manufacturing facility. Chemical analysis is required to determine that appropriate product specifications have been met. U.S. regulations (EPA 1996) require that refrigerants must meet ARI *Standard* 700 contaminant levels in order to be sold, using option 4 discussed in IRG-2 (ARI 1994) (see Industry Guidelines in the section on Refrigerant Recycling). The EPA (1996) requires use of certified reclaimers for option 4 (reclamation), based on ARI *Standard* 700.

Some equipment warranties, especially those for smaller consumer appliances, may not allow use of refrigerants reclaimed to purity levels specified in ARI *Standard* 700. For small appliances (e.g., refrigerators and freezers), consult the manufacturer's literature before charging with reclaimed refrigerants.

Reclamation has traditionally been used for systems containing more than 100 lb refrigerant (O'Meara 1988). The reclaimer often provides help in furnishing shipping containers and labeling instructions. Many reclaimers use air-conditioning and refrigeration wholesalers as collection points for refrigerant. Refrigerant mixing at the consolidation points is possible. If the refrigerant is contaminated beyond limits, the price paid for the refrigerant may be reduced or the shipment may be refused. One advantage of reclaimed refrigerants is in the availability of purity level data when offering the refrigerant for resale; this information is generally not available for recycled refrigerant.

Purity Standards

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

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

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

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Related Commercial Resources