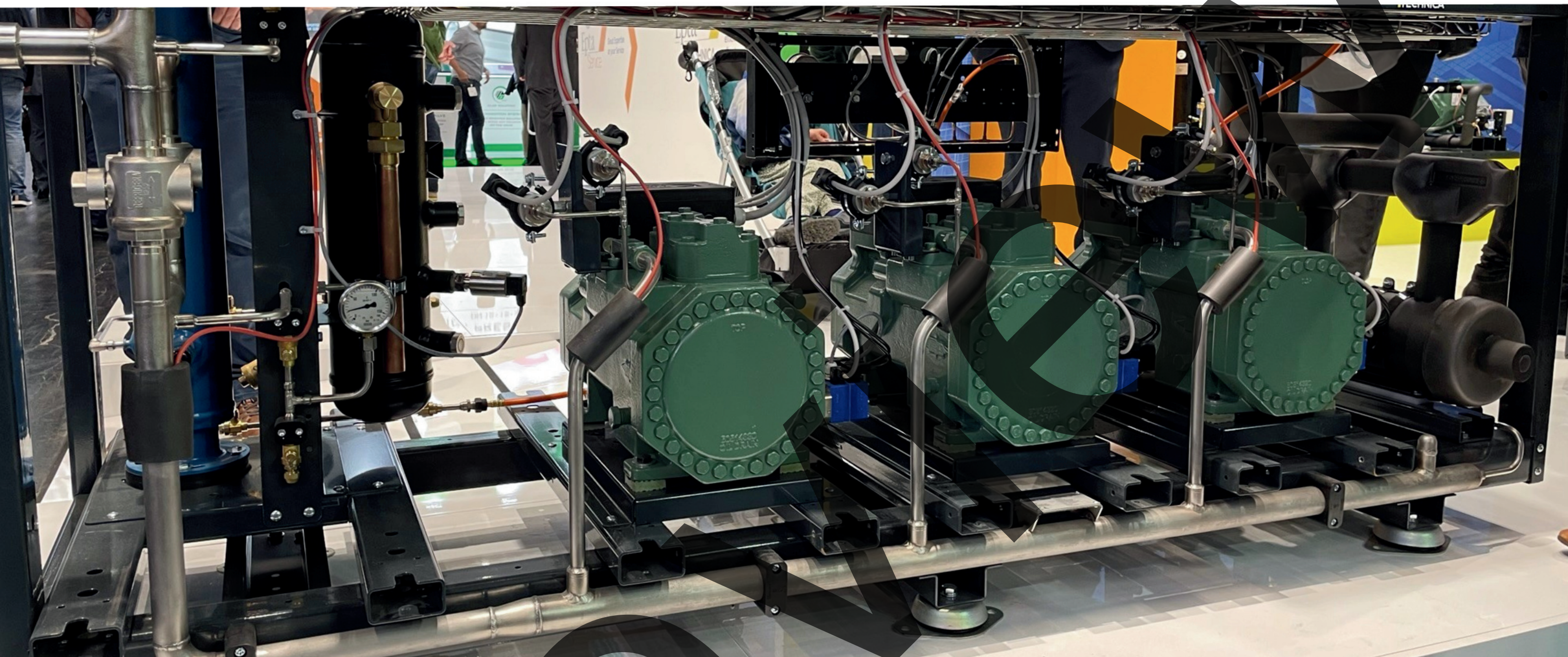
AN INTRODUCTION TO

R-744 (CO_2) REFRIGERATION



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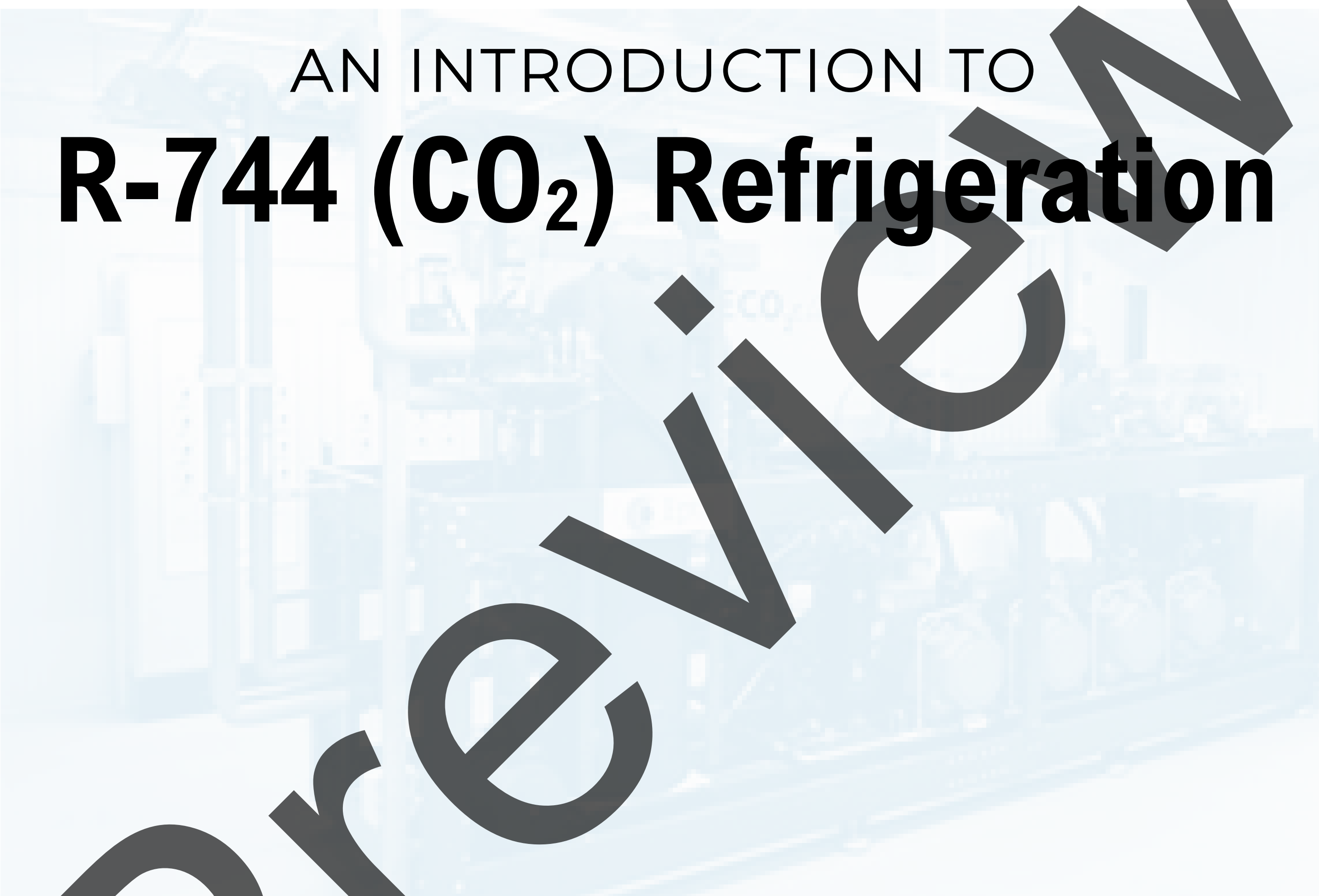

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Imagine a refrigerant that is natural, abundant, inexpensive, does not deplete our all-important ozone layer, and has a global warming potential of only 1. There is no need to imagine this refrigerant, as it's been around forever! Carbon dioxide, known to those in the refrigeration industry as R-744, is one of the oldest refrigerants ever and is now proving itself to be a viable solution to many of the challenges the refrigeration industry is currently facing.

When synthetic refrigerants were first introduced in the early 1900s, R-744 took a backseat to the promises and expectations that accompanied CFC, HFC, and HCFC refrigerants. From promises of lower system operating pressures to easier handling and less expensive equipment, the popularity of synthetic refrigerants grew at an alarming rate.

However, new advances in R-744 technologies, and the refrigeration industry as a whole, has resulted in a proverbial turning of the tides. The same refrigerants that replaced R-744 as a viable option over a century ago are now recognized by many organizations, including the Environmental Protection Agency (EPA) as some of the most harmful substances ever released into the atmosphere.

Today, R-744 stands at the center of the global transition toward sustainable refrigeration. Its thermodynamic properties make it uniquely suited for high-performance, high-efficiency applications. From supermarket display cases and heat pumps to ice rinks and industrial freezers, R-744 is being embraced as the go-to refrigerant, not just for its minimal environmental impact, but also for its ability to deliver cutting-edge system performance.

This book is about more than just valves, compressors, and piping. It's about rethinking refrigeration in a way that balances technology, safety, and sustainability. It's about understanding the unique challenges of high pressures, critical points, and transcritical cycles, and learning why these challenges are worth exploring and overcoming.

As you work through this book, you'll navigate the principles, practices, and procedures that define R-744 refrigeration. You'll also take the first step to learning how to safely and properly handle,, install, and maintain these systems with confidence.

This book is being brought to you by the ESCO Institute, a renowned provider of HVACR education and certification programs. With a commitment to delivering industry-leading training, the ESCO Institute equips industry professionals with the knowledge and skills necessary for success. The ESCO Institute offers a comprehensive range of training materials, certifications, and resources designed to support the professional development of students, technicians and instructors alike.

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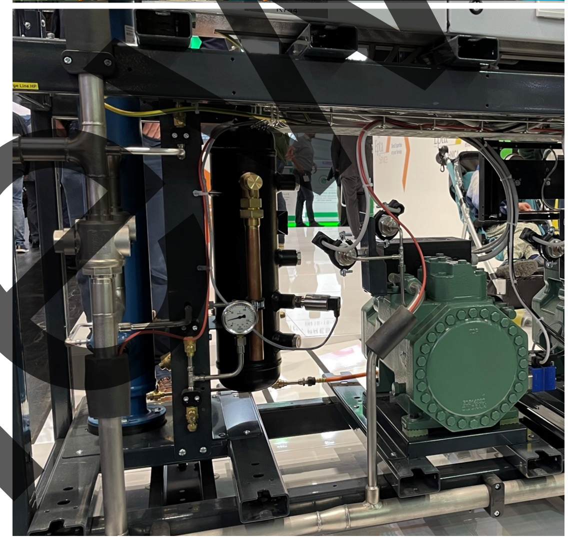
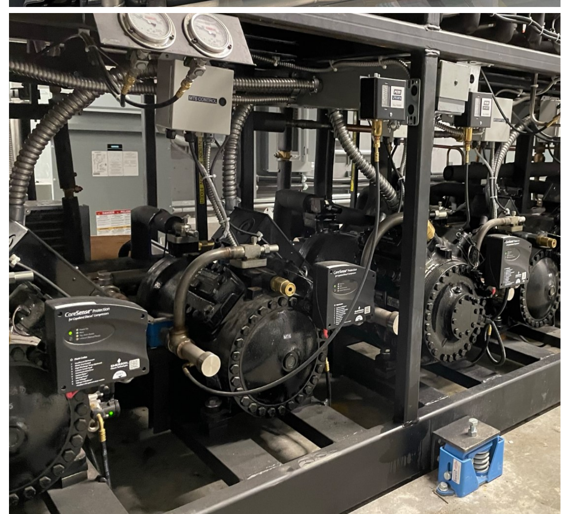
Chapter 1
Carbon Dioxide (R-744) Refrigeration Introduction





Objectives

After studying this chapter, you should be able to:

- explain how carbon dioxide is commonly found in nature.
- list the properties of carbon dioxide.
- explain why carbon dioxide is referred to as R-744.
- state the global worming potential (GWP) and ozone depletion potential (ODP) of R-744.
- compare the GWP and ODP of R-744 to those of CFC, HCFC, HFC and HFO refrigerants.
- compare the pressures of R-744 to other refrigerants, such as R-22 and R-410A.
- obtain information about R-744 from a temperature/pressure chart.
- define the term “boiling point” as it refers to refrigerants and refrigeration.
- define the term “freezing point” as it refers to refrigerants and refrigeration.
- define the term “triple point” as it refers to refrigerants and refrigeration.
- define the term “critical point” as it refers to refrigerants and refrigeration.
- define the term “critical pressure” as it refers to refrigerants and refrigeration.
- define the term “critical temperature” as it refers to refrigerants and refrigeration.

Carbon Dioxide in Nature

Carbon Dioxide (CO_2) is a naturally occurring chemical compound found in the atmosphere. In nature, CO_2 exists only as a gas. In its solid form, CO_2 is called dry ice, which does not form naturally. Dry ice can be created mechanically by compressing, cooling, and re-expanding carbon dioxide at temperatures below -109°F. Our discussion of carbon dioxide as a refrigerant in this manual does not include the use of dry ice as a means to temporarily store or preserve products or goods.

Why is CO_2 Referred to as R-744?

The American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) has assigned the number R-744 to CO_2 when it is used as a refrigerant. The “7” indicates that the substance is a natural substance, and the “44” refers to the molecular weight of an R-744 molecule. A carbon atom weighs 12 atomic mass units (amu) while an oxygen atom’s weight is16 amu. The sum of the weight of two oxygen atoms and one carbon atom (16 + 16 + 12) is 44. Two other examples of how natural substances are numbered are water and ammonia:

- Water (H_2O) is known as R-718. The “7” indicates that the substance is a natural substance, and the “18” refers to the molecular weight of an H_2O molecule. A hydrogen atom weighs 1 amu. The sum of the weight of two hydrogen atoms and one oxygen atom (1 + 1 + 16) is 18.

- Ammonia (NH_3) is known as R-717. The “7” indicates that the substance is a natural substance, and the “17” refers to the molecular weight of an NH_3 molecule. A hydrogen atom weighs 1 amu, while a nitrogen atom weighs 14 amu. The sum of the weight of three hydrogen atoms and one nitrogen atom (1 + 1 + 1 + 14) is 17.

Why are Some People Concerned About Using R-744 as a Refrigerant?

Advances in modern technologies have aided in the advancement of equipment using natural refrigerants. This has enabled a broader use of R-744 systems. One of the major challenges associated with systems operating with R-744 is the high system operating pressures associated with them. If you recall, the same pressure-related and safety concerns were present when R-410A was first introduced. The pressures of R-410A are about 30% to 70% higher than a conventional R-22 system, when evaluated within the normal operating ranges of the refrigerants. As R-410A training and education became more commonplace and, as technicians became more comfortable and confident working with and around R-410A and the systems that rely on it to operate, much of the hesitation and apprehension faded away. Such is very likely to be the case with R-744 systems and equipment. Figure 1-1 shows a brief comparison of the saturation pressures of R-744, R-22 and R-410A at four different temperatures. The complete temperature/pressure chart for R-744 is provided in Figure 1-2.

The operating pressures in R-744 systems are, in most cases, considerably higher when compared to other refrigerants. Because of the high working pressures and operational temperature ranges associated with R-744, early-generation systems were primarily used in northern, cooler climates. In cooler climates, the ambient temperatures are lower, resulting in lower high-side operating temperatures and pressures. With technological

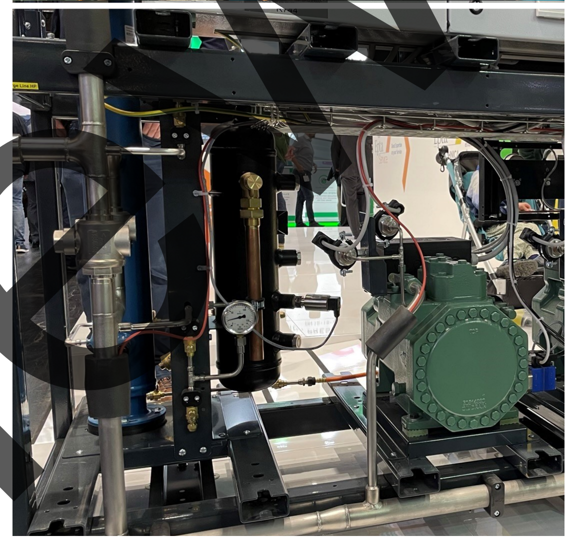
7. What is the Critical Point?
   A. The temperature and pressure at which refrigerant exists as either a liquid or gas.
   B. The temperature and pressure at which refrigerant exists as both a liquid and gas with boundary.
   C. The temperature and pressure at which refrigerant exists as both a liquid or gas without boundary.
   D. The temperature and pressure at which refrigerant coexists as a liquid, gas and solid.

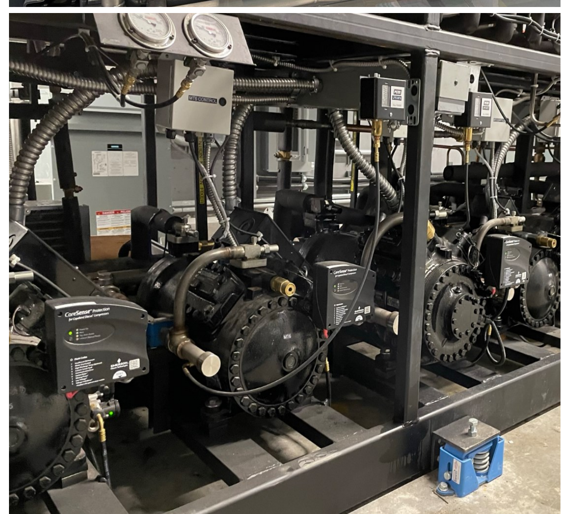
8. The critical point for R-744 is:
   A. 88°F at 1055 psia.
   B. 88°F at 1055 psig.
   C. 31°F at 73 psia.
   D. 31°F at 73 psig.

9. What is the Critical Temperature (Tc)?
   A. The highest temperature at which a gas can be turned into a liquid using pressure.
   B. The lowest temperature at which a gas can be turned into a liquid using pressure.
   C. The lowest temperature at which a gas can be turned into a liquid by extracting heat.
   D. The highest temperature at which a gas can be turned into a liquid by extracting heat.

10. What is the Critical Pressure (Pc)?
    A. The pressure below which it is not possible to condense gas to a liquid.
    B. The pressure above which it is not possible to condense gas to a liquid.
    C. The temperature above which it is not possible condense gas to a liquid.
    D. The temperature below which it is not possible condense gas to a liquid.

Chapter 2
R-744 Safety, Handling, and Storage





Objectives

After studying this chapter, you should be able to:

- explain the role carbon dioxide plays in the respiratory process.
- explain how carbon dioxide affects the pH level of blood.
- list R-744 exposure concentration levels and their associated health effects.
- explain the importance of monitoring CO_2 levels and concentrations.
- define the term asphyxiant.
- explain how organizations such as OSHA, NIOSH, and ACGIH have taken steps to protect individuals from the potential hazards of long-term CO_2 exposure.
- explain the importance of proper CO_2 sensor selection and installation.
- explain the importance of using the proper gauges, manifolds and hoses when working on R-744 equipment.
- define the terms standstill pressure as it applies to R-744 systems.
- describe the guidelines for proper installation of safety relief valve piping.
- describe proper procedures for installing relief valve piping when the possibility of solidifying R-744 exists.
- list refrigerants that are presently exempt from refrigerant management regulations.
- explain the importance of performing leak inspections on R-744 equipment.
- explain the guidelines for conducting leak inspections on R-744 equipment.

Keep in mind that there is no way to estimate the concentration of CO_2 in an air sample without measuring. CO_2 is odorless, colorless, and tasteless, making it impossible to detect without instrumentation. However, high CO_2 concentrations can cause a tingling sensation in the mucous membrane, eyes, and mouth. In most cases, you can be exposed to high concentrations of carbon dioxide without knowing it. This is very similar to the dangers posed by carbon monoxide, CO. For this reason, it cannot be stressed enough that CO_2 detectors are important and necessary to help ensure the safety of those working on and around carbon dioxide systems and equipment. It is a good idea for technicians to wear personal CO_2 gas detectors, Figure 2-2. These devices should be worn at chest level to ensure that samples are being taken within the breathing space. Improperly worn personal CO_2 detectors might not be sampling the air that is actually being inhaled.

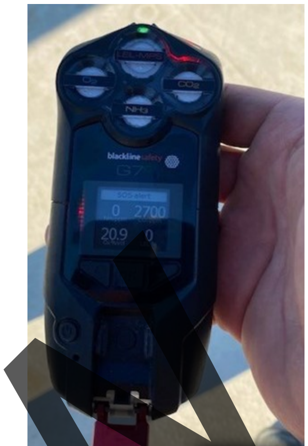


Figure 2-2. Personal CO_2 detector.

Refrigerants Displace Oxygen

Refrigerants are asphyxiants, meaning they displace oxygen. When oxygen is displaced at high enough rates, suffocation can result. In supermarket refrigeration applications, safety is a high priority due to the large number of people that may be affected if refrigerant leaks occur. It is crucial to implement safety protocols that respond quickly and accurately when unsafe refrigerant levels are detected. For this reason, individuals should be aware of the safety standards imposed by International Normative Documents, such as ASHRAE 34 and EN 378. These standards have been adopted by regulatory bodies as follows:

OSHA PEL (Occupational Safety and Health Administration – Permissible Exposure Limit)
5,000-ppm TWA (8-hour Time Weighted Average)
NIOSH REL (National Institute for Occupational Safety and Health – Recommended Exposure Limit)
5,000-ppm TWA (8-hour Time Weighted Average)
30,000-ppm STEL (Short Term Exposure Limit = 15 minutes time weighted average)
40,000 ppm IDLH (Immediately Dangerous to Life and Health)
ACGIH TLV (American Conference of Governmental Industrial Hygienists – Threshold Limit Value)
5,000-ppm TWA (8-hour Time Weighted Average)
30,000-ppm STEL (Short Term Exposure Limit = 15 minutes time weighted average)

R-744 Detection and Sensors

R-744 sensors are manufactured to function effectively within specific ranges. As such, they must be properly selected based on their intended function and the expected exposure levels. To ensure continued effective operation of the equipment, control sensors should be checked and calibrated periodically as required by the equipment manufacturer.

R-744 sensors typically range between 0 ppm and 300,000 ppm for short-term exposure, with specific warning setpoints of 5,000 ppm (0.5%) over an 8-hour time weighted average (TWA) and 10,000 ppm (1%) concentrations.

With these setpoints in place, alarms are triggered when a 5,000 ppm concentration of R-744 is detected, calling for an appropriate leakage investigation. The leakage investigation can be carried out with a hand-held

Name: ____ Date:_______________________

Read and answer the questions below.

1. The process of exchanging oxygen for carbon dioxide in the body is called;
   A. sublimation exchange.
   B. gas exchange.
   C. waste gas disposal.
   D. pH transfer disposal.

2. What is R-744's TEL for 8 hours?
   A. 420 ppm
   B. 1,500 ppm
   C. 2,000 ppm
   D. 5,000 ppm

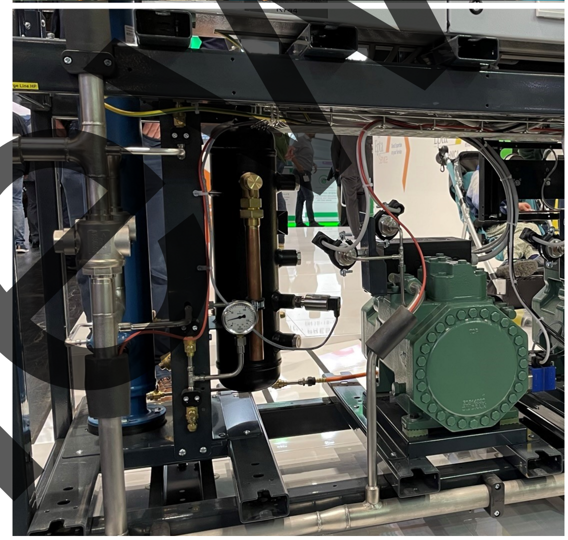
3. What is the best way to determine the concentration of R-744 in an air sample?
   A. Smell
   B. Order
   C. Taste
   D. Measure

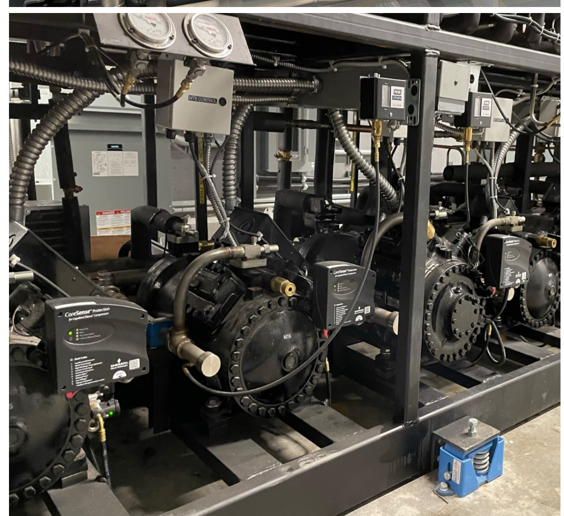
4. What minimum R-744 concentration level indicates that a refrigerant leak is likely present and needs to be investigated and repaired, if necessary?
   A. 1,000 ppm
   B. 2,000 ppm
   C. 5,000 ppm
   D. 10,000 ppm

5. What events must take place if the specified 10,000 PPM requirement of an R-744 alarm sensor concentration setpoint is exceeded?
   A. Visual and sound alarm, area evacuation, and systems be stopped.
   B. Visual alarm and sound alarm, area evacuation and mechanical exhausting of the area.
   C. System shut down, area evacuation and mechanical exhausting of the area.
   D. Mechanical exhausting of the area, visual and sound alarm, system shut down.

6. Industrial application R-744 sensors are generally mounted;
   A. no more than 12 inches above the floor.
   B. between 12 and 18 inches above the floor due to R-744 being heavier than air.
   C. Approximately 60 inches above the floor in the breathing zone.
   D. Only as required by code.

Chapter 3
The Vapor-Compression Refrigeration Cycle and the Pressure-Enthalpy Chart





Objectives

After studying this chapter, you should be able to:

- list the main system components that make up the vapor-compression refrigeration cycle.
- explain the four mini-processes that take place in the vapor-compression refrigeration cycle.
- describe the path refrigerant takes as it flows through a system's piping circuit.
- explain the three processes that take place in a refrigeration system's condenser.
- explain how the pressure, temperature and heat content of a refrigerant are affected as refrigerant passes through the metering device.
- explain why the compressor is represented by an upward-sloping line on a pressure enthalpy chart.
- explain how the pressure, temperature and heat content of a refrigerant are affected as it is compressed.
- describe the state of refrigerant under the saturation curve.
- describe the state of refrigerant on the left side of the saturation curve.
- describe the state of refrigerant on the right side of the saturation curve.
- explain why the metering device is represented by a vertical line on a pressure enthalpy chart.
- describe the function of a gas-cooler/condenser in an R-744 refrigeration system.
- describe the transcritical region on an R-744 pressure enthalpy chart.
- locate the triple point and critical points on an R-744 pressure enthalpy chart.
- describe a supercritical fluid as it applies to an R-744 refrigeration system.
- explain the difference between a transcritical R-744 refrigeration system and a subcritical R-744 refrigeration system.
- explain the importance of insulating the components on an R-744 refrigeration system.

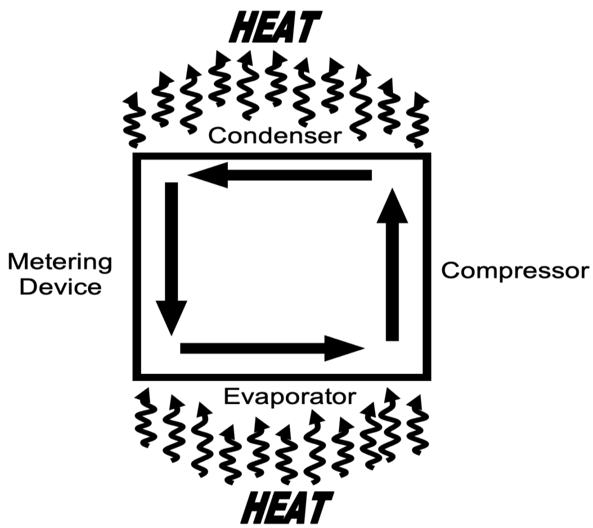


Figure 3-3. Diagram showing the four main system components, the direction of refrigerant flow through the system and the heat flow paths into the evaporator and out of the condenser.

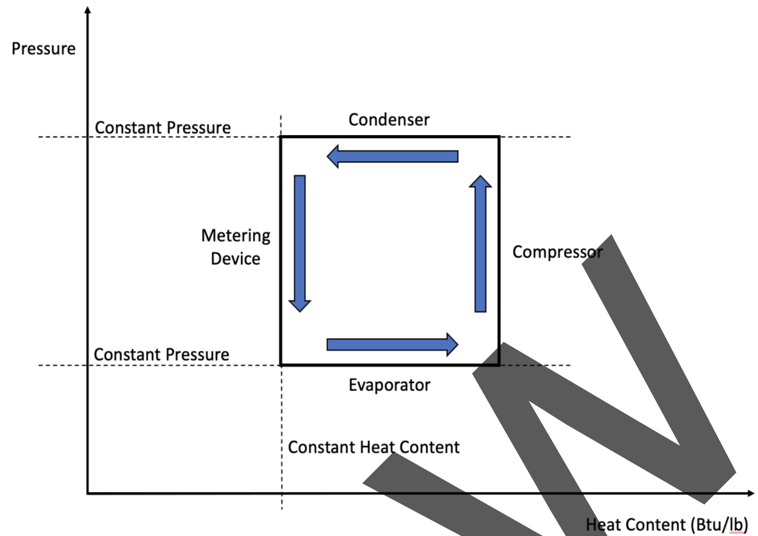


Figure 3-4. Basic refrigeration cycle "square" positioned on a coordinate system with heat content on the x-axis and pressure on the y-axis.

Vapor-Compression Refrigeration Cycle Observations

If we set this basic refrigeration cycle on an x-y coordinate system, where the x-axis represents heat content, in Btu/lb, and the y-axis represents pressure, looking at Figure 3-4, a few observations can be made:

- The high side pressure, which is the line at the top of square, remains constant from the point the refrigerant leaves the compressor to the point the refrigerant enters the metering device.
- The low side pressure, which is the line at the bottom of square, remains constant from the point the refrigerant leaves the metering device to the point the refrigerant enters the compressor.
- As the refrigerant flows through the metering device, there is no change in heat content. This is because the point at the top left of the square and the point at the bottom left of the square are located along a vertical line. *Note:* The expansion process is referred to as an *adiabatic expansion process*, where there are changes in pressure and temperature, but no change in heat content.

We cannot make an accurate observation about the compressor in this diagram without first making a very important modification. When vapor refrigerant is compressed, two important things happen:

- The pressure of the refrigerant increases as it is compressed. This was already represented in the square that was used to represent the vapor-compression refrigeration cycle.
- Heat is both concentrated and generated as the refrigerant is compressed. As refrigerant is compressed, the refrigerant molecules move closer together and often collide, generating new heat and concentrating existing heat. In addition, refrigerant absorbs heat from the compressor motor and the mating surfaces within the compressor shell. As a result, the heat content at the outlet of the compressor is greater than the heat content at the inlet of the compressor. So, the compressor is more accurately represented as a line that angles upwards and the right, Figure 3-5. In this figure it can be seen that, as refrigerant is compressed, both the pressure and heat content of the refrigerant increase.

6. The triple point is defined as the point on the saturation curve where a substance exists as a/an:
   A. gas, liquid, and plasma.
   B. gas, liquid, and solid.
   C. liquid, solid and plasma.
   D. gas, liquid, and plasma.

7. A supercritical fluid exists at conditions:
   A. exceeding the critical pressure and below the critical temperature.
   B. exceeding the critical temperature and below the critical pressure.
   C. below the critical pressure and critical temperature.
   D. exceeding the critical pressure and critical temperature.

8. In the transcritical state, R-744:
   A. is 100% liquid and cannot evaporate.
   B. is 100% vapor and cannot evaporate.
   C. is 100% liquid and cannot condense.
   D. is 100% vapor and cannot condense.

9. In the subcritical range, saturated R-744:
   A. can evaporate but cannot condense.
   B. can condense but cannot evaporate.
   C. does not follow a pressure/temperature relationship.
   D. can readily condense and evaporate.

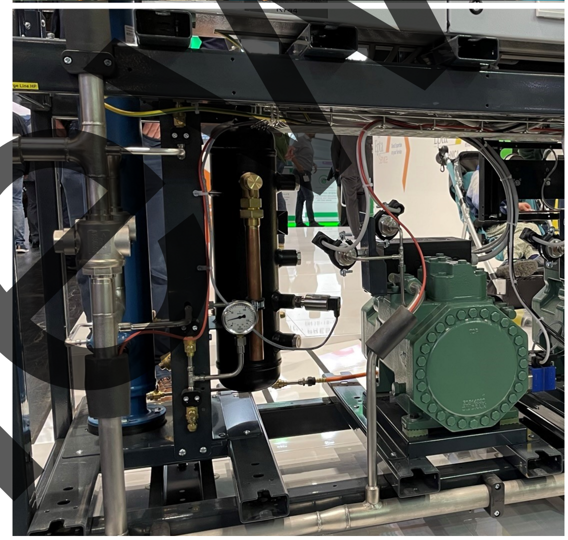
10. All R-744 system components should be insulated to prevent:
   A. condensation.
   B. rust.
   C. addition of unwanted heat to the system.
   D. all of the above.

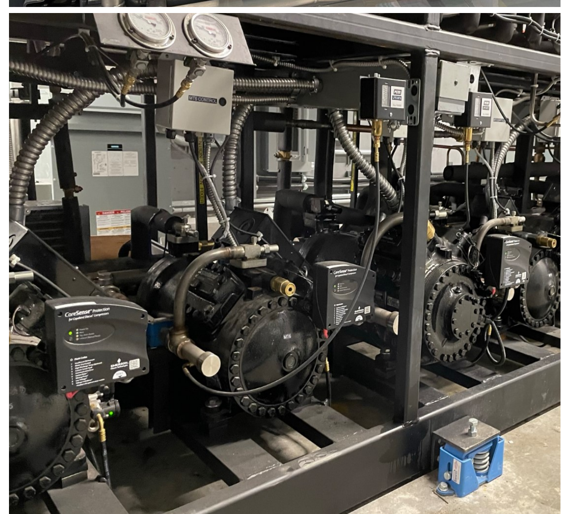
Chapter 4
R-744 System Types, Equipment Applications and High-Pressure Control

Objectives

After studying this chapter, you should be able to:

- define the term transcritical booster system as it applies to R-744 refrigeration systems.
- explain the difference between a booster/transcritical and a subcritical R-744 refrigeration system.
- describe an R-744 cascade refrigeration system.
- Describe the heat exchanger that links the two refrigeration circuits in a cascade system.
- describe a hybrid R-744 cascade refrigeration system.
- describe a pumped secondary R-744 refrigeration system.
- describe the term heat recovery as it applies to R-744 refrigeration systems.
- explain why plate-type heat exchangers are typically piped in counterflow or crossflow configuration.
- define the temperature boundaries for high, medium, and low temperature refrigeration.
- explain the function of parallel compressors on R-744 refrigeration systems operating with high ambient temperatures.
- explain the function and operation of a vapor ejector.
- explain the function and operation of a liquid ejector.
- describe the term adiabatic cooling as it applies to R-744 refrigeration systems.
- describe the term mechanical subcooling as it applies to R-744 refrigeration systems.
- explain what can be done to control the high side pressure of an R-744 refrigeration system.





R-744 Carbon Dioxide (CO_2) Systems

each group are piped in parallel with each other, while the compressor groups are connected in series with each other. The discharge of the low stage compressor group is connected to the inlet of the high stage compressor group, as shown on the right side of Figure 4-2. It is not always possible, or economical to compress refrigerant with a single compressor or a single group of compressors. In operation:

- the low temperature compressor or compressor group increases the pressure of the refrigerant at the outlet of the low temperature (LT) evaporator to the pressure at the outlet of the medium temperature (MT) evaporator. The pressure in the LT evaporator can often range between 200 psig (13.8 barg) and 250 psig (17 barg).
- The medium temperature compressor increases the pressure of the refrigerant at the outlet of the medium temperature evaporator to the pressure that is realized at the inlet of the gas cooler, which can be in the range of 1055 psig (73 barg) to 1450 psig (100 barg). If a single compressor or one compressor group was used for this type of application, the system's compression ratio would be over 5:1. By using two compressors or two compressor groups, the compression ratio for each compressor stage or group will typically be in the range of 2.1.

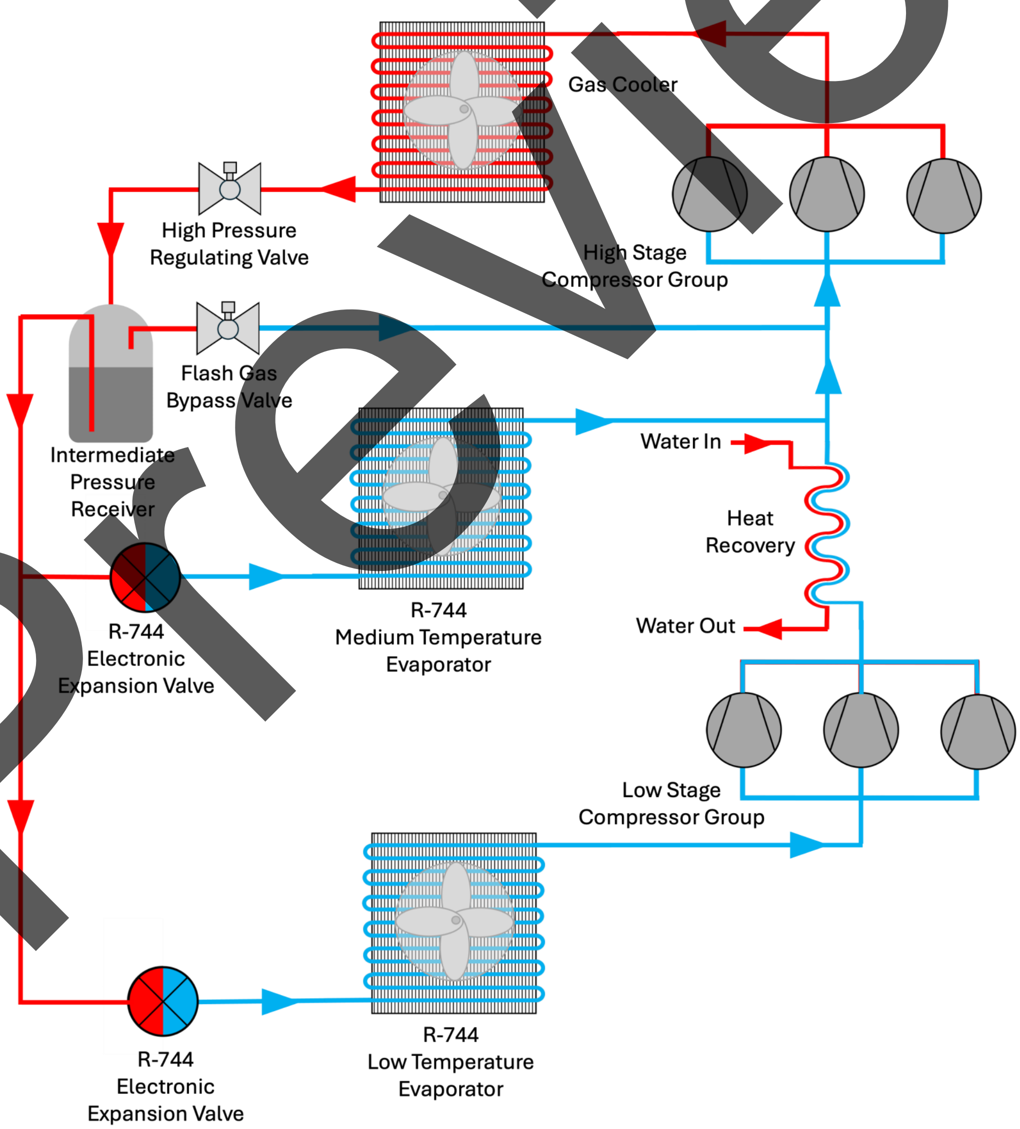


Figure 4-2. Piping diagram for an R-744 booster system. Figure based on images provided by Emerson.

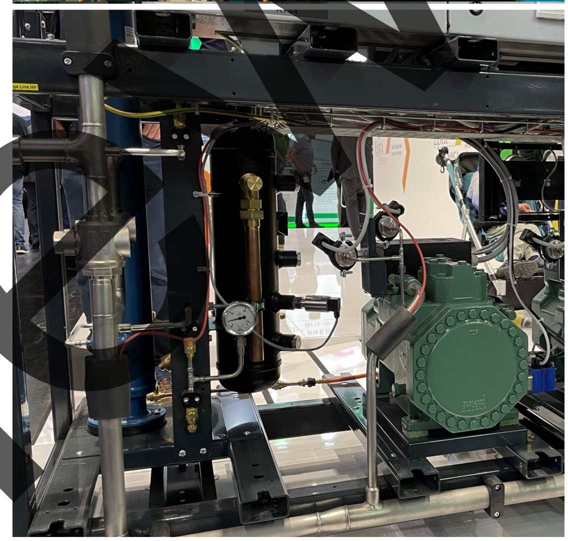
12. What is the flow rate and pressure effect at the exit of the nozzle, in an R-744 ejector?
    A. Low flow rate and low pressure.
    B. Low flow rate and high pressure.
    C. Very high flow rate and low pressure.
    D. Very high flow rate and high pressure.

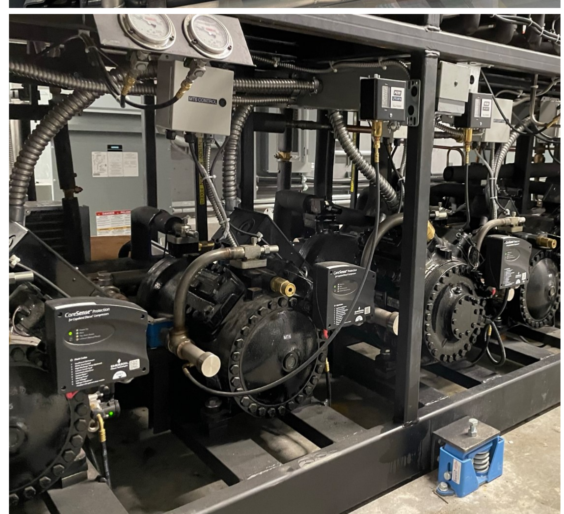
13. When in operation a vapor ejector, in a parallel compressor system;
    A. increases suction pressure resulting in the parallel compressor doing more work increasing efficiency.
    B. decreases suction pressure resulting in the medium temperature compressors doing more work than the parallel compressors.
    C. increases suction pressure resulting in the parallel compressors doing less work than the medium temperature compressors.
    D. decreases suction pressure resulting in the medium temperature compressors doing more work increasing system efficiency.

14. What is the purpose of the liquid ejector?
    A. Decrease superheat, increase latent heat transfer and increase efficiency.
    B. Decrease superheat, decrease latent heat transfer and increase efficiency.
    C. Increase superheat, increase latent heat transfer and increase efficiency.
    D. Increase superheat, decrease latent heat transfer and increase efficiency.

15. What is the purpose of mechanical subcooling in R-744 booster systems?
    A. Decrease entering gas cooler vapor temperature, reducing flash gas and enhancing efficiency.
    B. Decreasing gas cooler vapor temperature before entering the flash tank, reducing flash gas and increasing efficiency
    C. Decreasing high-pressure liquid temperature before entering the flash tank/receiver, reducing flash gas and increasing efficiency.
    D. Decreasing high-pressure fluid temperature leaving the gas cooler before the flash tank, reducing flash gas thus improving efficiency.

Chapter 5
R-744 Refrigeration System Components





Objectives

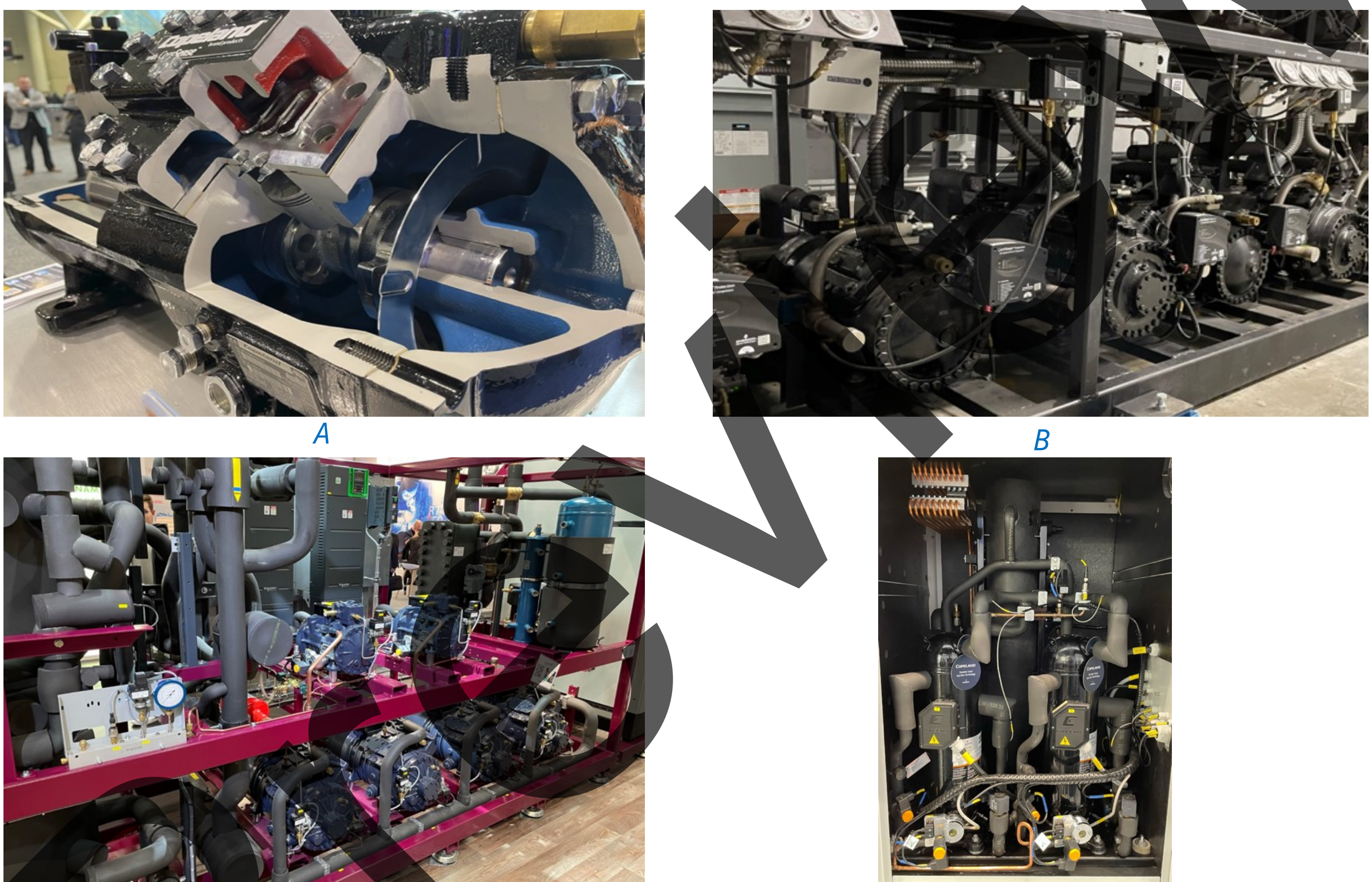
After studying this chapter, you should be able to:

- define the term transcritical booster system as it applies to R-744 refrigeration systems.
- explain the difference between a transcritical and a subcritical R-744 refrigeration system.
- describe a P&ID diagram.
- explain the purpose of P&ID diagrams.
- describe a compressor operation envelope.
- explain why it is important that compressor operating conditions and parameters remain within the compressor's operation envelope.
- list some of the possible conditions that can result if a compressor's operating conditions fall outside of the acceptable operation envelope.
- explain the function of an oil separator.
- explain the function of an oil reservoir/receiver.
- explain the function of an oil filter.
- explain the function of a gas cooler/condenser as it applies to R-744 refrigeration systems.
- explain the function of a high-pressure valve as it applies to R-744 refrigeration systems.
- explain the function of a flash tank/receiver as it applies to R-744 refrigeration systems.
- explain the function of a flash gas bypass valve as it applies to R-744 refrigeration systems.
- explain the function of a liquid line filter drier.
- explain the function of an electronic expansion valve.
- list two common types of electronic expansion valve.

When performing service or maintenance at a new location for the first time, it is recommended that the P&ID and the store layout legend are carefully reviewed to get a better understanding of the system components and where they are located. This will save time in the long run.

Compressors

The purpose of a refrigeration compressor, Figure 5-2, is to compress the refrigerant within the system to create a pressure difference between the high-and low-pressure sides of the system. Compression raises the pressure and temperature of the refrigerant, allowing it to eventually release heat and transfer energy to the surrounding environment. This process is essential for creating the desired cooling effect, as it enables the refrigerant to absorb heat from the space being cooled, and then release the heat elsewhere.



A B C D

Figure 5-2. (A) Copeland R-744 compressor cutaway. (B) Copeland Compressors Arneg Systèmes. (C) Dorin Compressors TEKO Rack. (D) Transcritical Copeland Scrolls. Images courtesy of Trevor Matthews.

In a typical subcritical refrigeration cycle, the compressor plays a central role in maintaining the continuous flow of refrigerant through the system. The compressor receives low-pressure, low-temperature refrigerant vapor from the evaporator, which is then compressed into a high-pressure, high-temperature vapor. This high-pressure, high-temperature vapor is then sent to the condenser.

Compressors for R-744 systems are similar to other refrigerant compressors, except for a few design differences. R-744 compressors are designed to withstand higher pressures, they may have external pressure relief valves, and the oil used will have a higher viscosity and, as a result, will be thicker. With HFC or HFO

7. Compressor operational envelopes are critical to ensuring that;
   A. compressors function properly over time reducing the compression ratio.
   B. compressors and systems operate properly over time.
   C. compressors and systems operate within to boundaries increasing compression ratio and efficiency.
   D. the system's compression ratios are reduced.

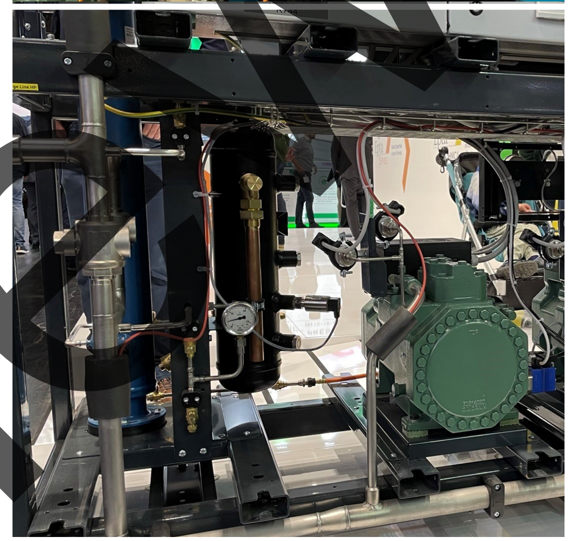
8. Oil separators are designed to collect;
   A. large droplets of oil, allowing gravity to return the oil to the compressor.
   B. droplets of oil and distribute throughout system to lubricated components.
   C. small drops of oil, combine them into larger drops and return directly to compressor.
   D. small drops of oil, combine them into larger drops to accumulate, dropping to bottom of oil separator and return to the compressor sump.

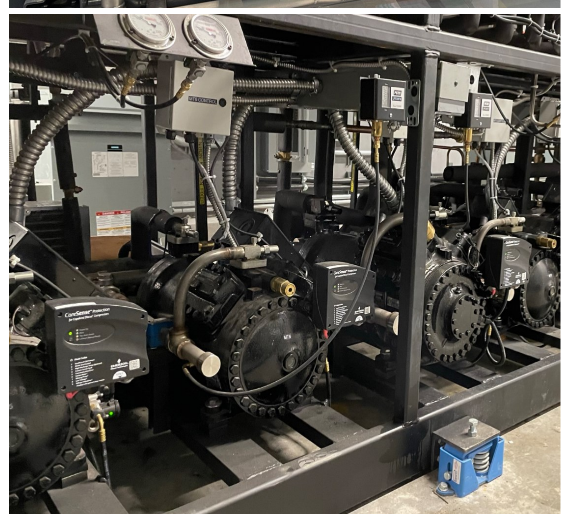
9. An oil separator is used to return oil;
   A. to the compressor after it has been collected to prevent excessive oil accumulation in the evaporator or gas cooler/condenser potentially leading to decreased capacity.
   B. to the compressor after it has been collected to prevent excessive oil accumulation in the evaporator or gas cooler/condenser potentially leading to increase capacity.
   C. directly to the compressor after it has been collected to prevent excessive oil accumulation in the evaporator or gas cooler/condenser potentially leading to decreased capacity.
   D. to the compressor after it has been collected to prevent increase oil accumulation in the evaporator or gas cooler/condenser potentially leading to decreased capacity.

10. An oil reservoir/receiver is a;
   A. storage container for previously collected separated oil until it is needed for compressor and system component lubrication.
   B. separator and storage container for previously collected separated oil until it is needed for compressor lubrication.
   C. storage container for previously collected separated oil until it is needed for compressor lubrication.
   D. storage container for small droplets collected in the oil separator until it is needed for lubrication.

11. The purpose of an oil filter is to remove contaminants and impurities, helping to maintain oil;
   A. quality and ensure effective system components protection.
   B. quantity and ensure effective system components protection.
   C. quantity and ensure effective system components lubrication.
   D. quality and ensure effective system components with proper viscosity.

Chapter 6
R-744 Refrigeration System Installation





Objectives

After studying this chapter, you should be able to:

- explain why site-specific installation drawings and protocols often take priority over an equipment manufacturer's documentation or literature.
- explain the importance of understanding the local codes and guidelines that are in place within the project's jurisdiction.
- explain the importance of reading all project documents and equipment literature before starting the installation process.
- explain the importance of being aware of all system component pressure ratings.
- describe the piping materials commonly used on R-744 refrigeration systems.
- explain how the piping materials commonly used on R-744 refrigeration systems differ from the piping materials commonly used on traditional air-conditioning and refrigeration systems.
- explain why long radius elbows are preferred over short radius elbows for refrigerant-carrying piping circuits.
- explain the importance of properly insulating the piping circuits of an R-744 refrigeration system.
- list five factors that should be considered when determining the proper thickness of pipe insulation to be used.
- use charts to properly select an insulation material and thickness based on ambient and project conditions.
- demonstrate how to properly insulate refrigerant lines on R-744 refrigeration systems.
- explain the importance of purging refrigerant lines with dry nitrogen while brazing refrigerant piping connections.
- explain what is meant by the term dry nitrogen.
- demonstrate how to properly braze refrigerant lines on R-744 refrigeration systems.
- demonstrate how to properly position and level refrigerated cases.

Continued on next page

Piping Insulation

In an R-744 installation, system pipes and components need to be insulated, Figure 6-3, with very few exceptions. One of these exceptions being the medium temperature compressor's discharge line. However, depending on the manufacturer, even this line may require insulation, so be sure to carefully review all installation specifications, guidelines, and literature as they apply to the specific system, equipment and application. The refrigeration legend specifies the type and thickness of insulation for each section of the system. For example, pipe insulation on the low-temperature suction side of the system is typically thicker than the insulation on the medium and high-temperature piping sections. Properly insulating the pipes is of utmost importance to help keep system efficiency and equipment reliability as high as possible.

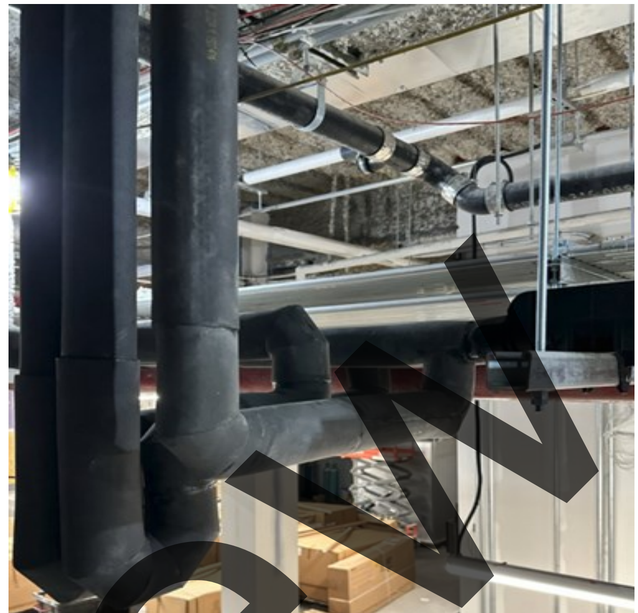


Figure 6-3. R-744 system piping insulation. Photo courtesy of Paul Binette.

Proper piping insulation is not only important to help ensure proper system operation, but also helps prevent damage to the customer's property. Without properly sized and installed piping insulation, ice and condensation can form on the piping. This can cause water damage and facilitate mold growth. The use of improper insulation materials, or the improper installation of piping insulation, for example, can cause additional heat to be added to the refrigerant in the suction line. This can cause the system to run improperly, possibly causing damage.

Insulation should be selected and installed in accordance with local building codes, the project engineer's specifications, and the manufacturer's recommendations. Figure 6-4, for example, provides an equipment manufacturer's recommendation chart to aid in the proper selection of refrigerant line insulation thickness. The thickness recommendations provided in this chart will differ depending on the size of the refrigerant line, the expected ambient temperature acting on the line, the state of the refrigerant in the line and, if used on a suction line, the temperature range of the compressor.

Recommended Insulation Thickness of Elastomeric and Rigid Insulation Materials

Pipe Size (OD)	Normal Conditions 85°F (29°C) Dry-Bulb 70% Relative Humidity, 0 fpm			Severe Conditions 90°F (32°C) Dry-Bulb 80% Relative Humidity, 0 fpm		
	Liquid	LT Suction Return	MT Suction Return	Liquid	LT Suction Return	MT Suction Return
3/8"	3/4"	3/4"	3/4"	1"	1-1/2"	1"
1/2"	3/4"	3/4"	3/4"	1"	1-1/2"	1"
5/8"	3/4"	1"	3/4"	1"	1-1/2"	1"
7/8"	3/4"	1"	3/4"	1"	1-1/2"	1"
1-1/8"	3/4"	1"	3/4"	1"	1-1/2"	1"
1-3/8"	N/A	1"	N/A	N/A	1-1/2"	N/A
1-5/8"	N/A	1"	N/A	N/A	1-1/2"	N/A
2-1/8"	N/A	1"	N/A	N/A	1-1/2"	N/A

Figure 6-4. Insulation thickness selection chart. Image based on data from Hillphoenix.

Name: ____ Date:________________________

Read and answer the questions below.

1. Which documents should be reviewed before the installation of an R-744 system begins?
   A. Refrigeration and piping schedules
   B. Piping and Instrumentation Diagram (P&ID)
   C. Piping legend, bill of materials, and the project parts list
   D. All of the above

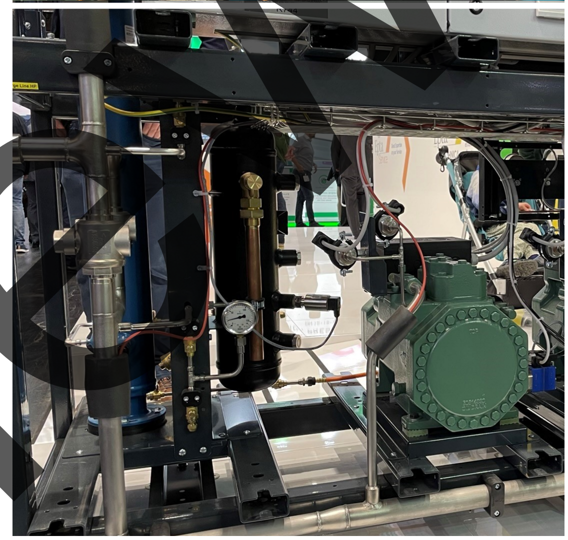
2. The subcritical pressure side of the system extends from;
   A. outlet of the high-pressure control valve to the medium temperature-temperature compressor's suction service valve.
   B. inlet of the high-pressure control valve to the medium temperature-temperature compressor's suction service valve.
   C. outlet of the high-pressure discharge service valve to the medium temperature-temperature compressor's suction service valve.
   D. outlet of the high-pressure control valve to the medium temperature-temperature compressor's discharge service valve.

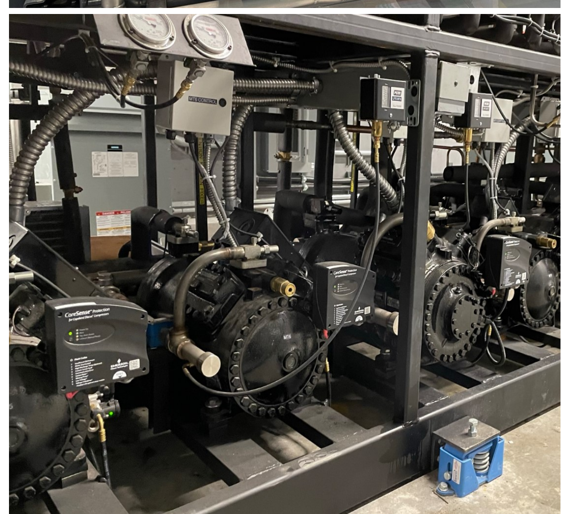
3. Where in the system's refrigerant piping is the high-pressure (transcritical) side?
   A. From the outlet of the high-pressure control valve to the medium-temperature compressor's suction service valve.
   B. From the inlet of the low-pressure control valve to the medium-temperature compressor's suction service valve.
   C. From the outlet of the high-pressure control valve to the suction service valve of the low-temperature discharge valve.
   D. From the inlet of the medium-temperature systems discharge service valve to the high-pressure systems discharge service valve.

4. What type of copper tubing is pressure rated for the low-pressure side of an R-744 System?
   A. DWV
   B. Type K
   C. Type L
   D. Type M

5. In the US and Europe, what type of tubing must be installed on the transcritical side of R-744 systems?
   A. Copper Type L
   B. Copper Type K
   C. Copper-Iron alloys
   D. Copper-Stainless Steel alloys

Chapter 7
R-744 Refrigeration System Leak Testing, Evacuation, and Start-Up





Objectives

After studying this chapter, you should be able to:

- explain why a system inspection is important before leak testing an R-744 refrigeration system.
- explain how to properly leak test an R-744 refrigeration system.
- explain the importance of properly evacuating an R-744 refrigeration system.
- explain how to properly perform a triple evacuation on an R-744 refrigeration system.
- explain what is meant by system start-up and commissioning.
- list the tools, instruments and materials required to properly commission an R-744 refrigeration system.
- explain the importance of preparing a commissioning report.
- properly start-up an R-744 refrigeration system.
- properly charge an R-744 refrigeration system.
- perform an inspection of a refrigeration system's control devices and sensors.

Introduction to R-744 Refrigeration System Leak Testing, Evacuation and Start-Up

Once an R-744 refrigeration system has been designed and installed, the system must then be put into operation. However, before the power switch is flipped and the humming of the compressors and fans can be heard, important steps must be taken first. These important pre-start-up steps include system leak testing and evacuation. Although leak testing and evacuation are processes commonly performed by most HVACR technicians, there are important differences between performing these procedures on R-744 systems and performing them on conventional refrigeration systems. Once the system has been properly leak tested and evacuated, the start-up or commissioning process can begin. System start-up and commissioning is the process of verifying that a newly installed system is operating according to the manufacturer's specifications and delivering the desired refrigeration performance.

R-744 System Leak Testing

Before any air conditioning or refrigeration system is put into service, it must be properly leak tested. Refrigerant leaks, if not found before a system is system is started up, can be costly and time consuming to repair, and often result in product loss due to a malfunctioning or underperforming refrigeration system. As such, the importance of the leak testing portions of a refrigeration system installation cannot be emphasized enough. The leak testing process should never be overlooked, sidestepped, rushed through, or otherwise avoided. It is also important to adhere to and follow any local codes or regulations that might be in place when performing any processes and procedures on an air conditioning or refrigeration system, including system pressurization and leak testing.

The first step in performing a system leak check is to inspect the system. This involves:

Inspect the System

- visually inspecting the refrigerant lines, connections, and fittings for proper assembly and installation.
- visually inspecting the support elements used to mount the refrigerant piping and other system components.
- visually inspecting for any metal-to-metal contact or rubbing.
- physically verifying that all mechanical joints and connections, such as flare fittings, are tight.
- opening all piping system and component valves to ensure that, when the system is pressurized, all portions of the system will be under test pressure. This includes branch circuits, heat reclaim components, refrigerant receivers, and any other system element that will ultimately contain refrigerant.

Inspecting the system prior to leak testing helps ensure that, once the system has been deemed to be leak-free, it remains leak-free. Deficiencies in the piping connections, mounting, and installation can result in the creation of system leaks after the system has been put into service, resulting in lost time and money. For this reason, any concerns identified during this pre leak test inspection should be addressed before proceeding with system leak test, evacuation and start-up.

6. What process should be followed between the second evacuation and the third?
   A. Pump R-744 grade oil into the oil reservoir.
   B. Draw R-744 grade oil into the oil reservoir maintaining the vacuum in the reservoir.
   C. Pump manufacturer recommended oil into the oil reservoir.
   D. Draw manufacturer recommended oil into the oil reservoir maintaining the vacuum in the reservoir.

7. The value of the start-up and commissioning report can be used to determine;
   A. where the commissioning technician missed a step.
   B. the original operational conditions to help identify future capacity deficiencies quickly.
   C. original operational conditions to set up the maintenance scheduling.
   D. operational conditions for making adjustments to match variable load changes.

8. Why should an R-744 system have the final evacuation broken using an R-744 tank without a dip tube?
   A. Breaking a vacuum to -14.69 psig preventing the formation of dry ice from liquid R-744
   B. Breaking a vacuum to 0 psig preventing the formation of dry ice from liquid R-744
   C. Breaking a vacuum to 61 psig preventing the formation of dry ice from liquid R-744
   D. Breaking a vacuum to 145 psig preventing the formation of dry ice from liquid R-744

9. Coleman grade carbon dioxide contains less than what percentage of impurities?
   A. 0.001
   B. 0.01
   C. 0.1
   D. 1.0

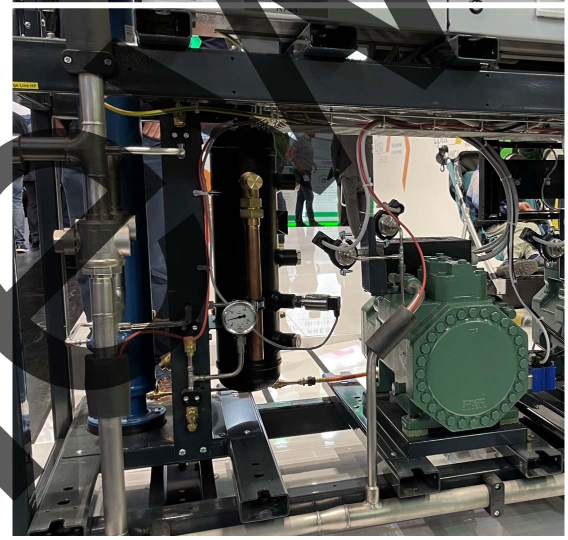
10. What are some of the items to be checked during an R-744 system start-up?
   A. Positive suction liquid return, proper oil supply to the compressor, high superheat indicating underfeeding
   B. Proper oil supply to the compressor, high superheat indicating underfeeding, simulated rack failure to check all detection devises operate as intended
   C. Compressor superheat indicating proper metering devise setting, simulated rack failure to check all detection devises operate as intended
   D. Positive suction liquid return, proper oil supply to the compressor, high superheat indicating underfeeding

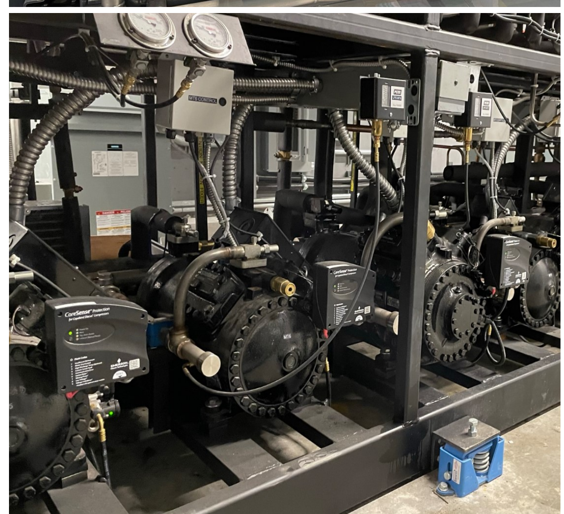
Chapter 8
R-744 Refrigeration System Service and Maintenance Procedures

Objectives

After studying this chapter, you should be able to:

- identify the items that should be checked when servicing the compressor on an R-744 refrigeration system.
- name the components that make up the typical oil management system on an R-744 refrigeration system.
- describe the items that should be checked when servicing the oil management system on an R-744 refrigeration system.
- list the tasks that should be performed as part of an R-744 refrigeration system's general evaluation.
- state some important refrigerant-related items that an R-744 refrigeration technician should be aware of when servicing an R-744 refrigeration system.
- recall the items that should be inspected when evaluating the electrical portions of an R-744 refrigeration system.
- replace a liquid line filter drier on an R-744 refrigeration system's semi-hermetic compressor.
- replace an electronic expansion valve (EEV) on an R-744 refrigeration system's semi-hermetic compressor.
- replace a valve plate on an R-744 refrigeration system's semi-hermetic compressor.





The oil management system can consist of oil separators, oil reservoirs, filter driers, level controls, sensors, solenoids, pressure reducing valves, and oil differential pressure valves. Be sure to refer to the system's piping schematic (P&ID) to get a full understanding of how the manufacture has designed the oil management system on the system being worked on.

Note: Oils chosen for specific systems must be highly soluble in the refrigerant, resistant to aging, and thermally and chemically stable within the system's operating temperature ranges. While using the proper oil is crucial for optimizing system performance, establishing and maintaining an effective oil management system is equally essential. It's imperative to consult with system or compressor manufacturers for their recommended oil, as their expertise is invaluable in ensuring the system's longevity and efficiency.

General System Inspection Items

When conducting maintenance on an R-744 system, make certain that you address the following items:

- Inspect the integrity of refrigerant and oil circuit piping. Address any piping circuit deficiencies, including leaks, corrosion and damage, to prevent or minimize refrigerant loss. Ensure all mechanical fittings are tight.
- Check integrity of pipe clamps. Tighten as needed to reduce/eliminate noise, vibrations, and potential pipe damage.
- Thoroughly inspect the gas cooler for fan operation, noise, damage, and cleanliness. Check electrical connections, sensors, and setpoints.
- Inspect the high-pressure valve strainer (if applicable) if the rack is running with high pressure in the discharge line and the HPV is fully open.
- Check and clean all system strainers when necessary.
- Inspect all system heat exchangers and vessels.
- Check system for signs of corrosion.
- Visually inspect all system gauges.
- Check integrity of heat exchanger and vessel insulation. Repair if necessary.
- Ensure that all valve caps are in place. Replace any missing or damaged caps.
- Inspect gaskets for cracks or other damage. Replace as needed.
- Check condition and integrity of any electronic expansion valve, or similar component, cables.
- Review valves controller trend graphs, valve opening percentages and superheats. Address any abnormalities in the trend graphs.
- Change refrigerant line filters when the pressure drop across them gets too high.
- Be sure to inspect any adiabatic cooling equipment for scale, mineral deposits, or slime. If found, take actions to alleviate the present conditions and prevent future occurrences.

Refrigerant Considerations

- Use R-744 with the required or recommended purity. If proper refrigerant purity is not available, use a filter drier during charging.
- When adding liquid refrigerant to the system, introduce it through the flash tank/ liquid receiver or liquid line filter drier. Adding liquid refrigerant at any other system location increases the risk of liquid returning to the compressors.
- Maintain proper liquid level in the refrigerant receiver by carefully monitoring the receiver's sight glass.
- Test for leaks with a leak detector capable of detecting R-744. If refrigerant needs to be added, it may indicate a system leak.
- Keep detailed records indicating how much refrigerant was added to, or removed from, the system.

Name: ____ Date:______________________

Read and answer the questions below.

1. Of the list below what is important when conducting compressor maintenance and inspections?
   A. Compressor oil level, lack of ice on compressor shell, and proper manufacturer specified superheat
   B. Change out oil, lack of ice on compressor shell, and proper manufacturer specified superheat
   C. Compressor oil level, full pack ice on compressor shell, and proper manufacturer specified superheat
   D. Compressor oil level, lack of ice on compressor shell, and proper EEV specified superheat

2. Of the list below, what is part of proper oil system maintenance?
   A. Inspect for leakage and repair, add refrigerant oil/identifying the cause of the deficiency, replace filters if necessary/including gaskets, re-torque all bolts and evacuate.
   B. Inspect for leakage and repair, add specified oil/identifying the cause of the deficiency, replace filters if necessary/including gaskets, re-torque all bolts.
   C. Inspect for leakage and repair, add specified oil/identifying the cause of the deficiency, replace filters if necessary, re-torque all bolts and evacuate.
   D. Inspect for leakage and repair, add specified oil/identifying the cause of the deficiency, replace filters if necessary/including gaskets, re-torque all bolts and evacuate.

3. Refrigerant line filters should be replaced;
   A. on a monthly basis depending on trend usage.
   B. during all quarterly inspections.
   C. on a yearly basis depending on manufacturers requirements.
   D. when pressure drop across the filter becomes too high.

4. Refrigerant requirements must be followed with special consideration for;
   A. proper grade (99.00% pure), testing for leaks, maintaining proper liquid level, and charging into the flash tank/receiver.
   B. proper grade (99,99% pure), testing for leaks, maintaining proper liquid level in compressor sight glass, and charging into the flash tank/receiver.
   C. proper grade (99.99% pure), testing for leaks, maintaining proper liquid level, and charging into the flash tank/receiver.
   D. proper grade (99,99% pure), maintaining proper liquid level, and charging into the flash tank/receiver.

5. Items to be inspected in an electrical system are;
   A. pressure switches, gas alarms, emergency stop signals, and system operation logs for alarms and alerts.
   B. pressure switches, safety valves, gas alarms, emergency stop signals, sensors coils and cables, and system operation logs for alarms and alerts.
   C. hand operated switches, safety valves, gas alarms, emergency stop signals, sensors coils and cables, and system operation logs for alarms and alerts.
   D. pressure switches, safety valves, gas alarms, sensors coils and cables, and system operation logs for alarms and alerts.

AN INTRODUCTION TO

R-744 (CO_2) REFRIGERATION

Today, R-744 stands at the center of the global transition toward sustainable refrigeration. Its thermodynamic properties make it uniquely suited for high-performance, high-efficiency applications. From supermarket display cases and heat pumps to ice rinks and industrial freezers, R-744 is being embraced as the go-to refrigerant, not just for its minimal environmental impact, but also for its ability to deliver cutting-edge system performance.

This book is about more than just valves, compressors, and piping. It's about rethinking refrigeration in a way that balances technology, safety, and sustainability. It's about understanding the unique challenges of high pressures, critical points, and transcritical cycles, and learning why these challenges are worth exploring and overcoming.

As you work through this book, you'll navigate the principles, practices, and procedures that define R-744 refrigeration. You'll also take the first step to learning how to safely and properly handle, install, and maintain these systems with confidence.

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