●●● POWER ENGINEERING

Fourth Class

Edition 3.5

Basic Concepts of Compression and Absorption Refrigeration

Part B

Unit B-9

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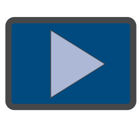
MEDIA 	Media icons show that some form of supporting medium is available. These media may include videos, animations, 2D and 3D models, multi-views of cutaways, simulations, and more. Media elements are available to registered textbook purchasers online via MyPower Study.
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4th Class Edition 3.5 • Part B

UNIT B-9

BASIC CONCEPTS OF COMPRESSION AND ABSORPTION REFRIGERATION

Unit Introduction

Those studying Power Engineering learn about systems that generate and utilize steam, and other thermal fluids. They are often surprised when refrigeration arises as a topic of discussion. After all, refrigeration is the artificial production of cold, with the use of mechanical means. Is the production of cold relevant to those that manage the production of heat? How, then, does a Power Engineer factor into this field?

Although Power Engineers do not produce energy, they do manage its transfer from one form to another form; and from one location to another location. Energy can be converted and transferred; however, it cannot be created or destroyed. Heat transfer may raise or lower the temperature of a substance. The direction of temperature change is relative.

Consider a fuel-fired boiler. Does the furnace add heat to water, causing it to boil, or does water withdraw heat from the furnace, keeping it cool? If it is true that water cools the furnace, then think of water boiling in a steam drum as "refrigeration!" This unit discusses how steam production and refrigeration both involve "boiling."

Across Canada, the provincial and territorial jurisdictions agree that refrigeration plants present potential public safety hazards that Power Engineers are best suited to handle. So, Power Engineers follow various regulations to operate large building cooling systems, arena ice-making machinery, and industrial refrigeration plants. Refrigeration is an important element to a variety of industrial sectors. These include:

- Sterilization and preservation of food products in the food-processing sector
- Cryogenic storage and operating processes in the health sector
- Process refrigeration in the industrial and energy sectors

CAUTION

A number of refrigerants have been shown to have negative effects on the environment. Those with the greatest environmental effect are chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs). Both of these have been implicated in the earth's ozone layer depletion.

Worldwide reductions in the production and use of CFCs and HCFCs have taken place since the **Montreal Protocol on Substances that Deplete the Ozone Layer** went into force in 1989. Since then, this treaty (intended to protect the ozone layer) has been ratified by over 160 countries.

Both Canada and the USA have instituted progressive measures to meet the requirements for phasing out the production, import, and use of CFCs and HCFC.

This unit emphasizes the use of "natural refrigerants," such as ammonia and CO_2. These natural refrigerants do not have the same impact on the environment as CFCs and HCFCs; therefore, they are not subject to be phased out under the **Montreal Protocol.**

Unit Rationale

Power Engineers across Canada need to be skilled in safe and efficient refrigeration plant operation. Many Power Engineers actively maintain, troubleshoot, and repair refrigeration equipment. They must be aware of the environmental impact of refrigerants, and must try to prevent fugitive refrigerant emissions.

This unit provides a basic understanding of refrigeration systems. This is an important element to operate, troubleshoot, and maintain refrigeration systems. It will also assist those who plan to continue on to 3rd Class Power Engineering.

Note: The material in this Unit does not qualify a Power Engineer as a Journeyperson Interprovincial Refrigeration and Air Conditioning Mechanic.

CHAPTER 1

Refrigeration Basics

Learning Outcome

When you complete this chapter you should be able to:

Explain the basic concept of refrigeration and refrigerants.

Learning Objectives

Here is what you should be able to do when you complete each objective:

1. *Explain the fundamentals of refrigeration.*
2. *Describe the cycle of operations in a vapour compression refrigeration system.*
3. *Explain how the operating temperatures and pressures are selected and related for a vapour compression refrigeration system.*
4. *State how the capacity of a refrigeration system is described and how refrigeration tables are used to calculate system performance.*
5. *Describe how refrigerants are classified.*
6. *Describe the thermodynamic properties of refrigerants.*
7. *Describe the properties of refrigerants relating to miscibility, leakage tendency, odour, moisture reaction, toxicity, and flammability.*

Chapter Introduction

Refrigeration is the thermodynamic process that moves heat from one location to another by circulating refrigerant in a closed cycle. This reduces and maintains the temperature of a material below the temperature of its surroundings.

This chapter deals with the science and theory of refrigeration. It introduces the principle components of a refrigeration system and describes their roles and interactions.

Objective 1

Explain the fundamentals of refrigeration.

Evaporation

From thermodynamics, recall that one kilogram of pure boiling water, at 101.3 kPa absolute pressure, absorbs 2257 kJ of latent heat. This is the amount of energy needed, per kilogram, to change water from its liquid form to a gaseous state. For water to evaporate, it must have heat transferred to it. When giving off heat energy, the heat source may do one of the following:

- Undergo a temperature drop (sensible heat)

  or

- Undergo a change of state (latent heat)

On Track

Another word for *state* is *phase. Change of state* is also called *phase change.* This chapter uses the terms *phase change* and *change of state* interchangeably.

Consider the first point. Most everyone has stepped out of a shower, pool, or bathtub and shivered vigorously. While shivering, every kilogram of surface water that evaporates withdraws 2257 kJ of heat, which results in a cold feeling. The evaporating water removes sensible heat from the body and lowers its temperature.

This leads to the first fundamental principle of refrigeration: **A substance must absorb or reject latent heat in order to change state.** Adding latent heat to a liquid makes it evaporate. Removing latent heat from a gas makes it condense. The evaporative process removes heat (as in the sensible heat removed from a shivering body) and causes a cooling effect.

Consider the second point. It is possible for liquids to boil below the freezing point of water. Such liquids are called *refrigerants.* If a refrigerant continually draws heat away from a body of water, the water's temperature drops and then its state changes from liquid to solid. First, the refrigerant removes sensible heat from the water and then it removes the latent heat of fusion. This is what happens when an ice-cube tray full of water goes in the freezer.

In summary, evaporation of a liquid can lower the temperature of a body by the extraction of sensible heat. Evaporation can cause a change in state if the liquid evaporates below the freezing point of the heat source.

Now consider the effect of pressure on a boiling liquid. Pure water, at 101.3 kPa absolute pressure (zero gauge pressure), boils at 100°C. However, in a boiler, boiling occurs at a higher temperature because of the higher pressure exerted on the surface of the water. For example, at 200 kPa absolute, pure water boils at 120.21°C. At higher altitudes, where the atmospheric pressure is lower, pure water boils at temperatures below 100°C.

In Lake Louise, AB, the elevation is 1731 m above sea level. Here, the air pressure is around 83 kPa absolute, and water boils at 94.48°C. This leads to the second fundamental principle of refrigeration: **The pressure exerted on the surface of a boiling liquid affects the temperature at which the liquid boils.**

When a pure liquid is heated, its temperature increases until the substance is heat-saturated. Additional heat will cause a change in state but no change in temperature. This state-change occurs at the temperature where heat saturation occurs. This temperature is called the **saturation temperature.**

The pressure applied to the boiling liquid surface when saturation temperature is reached is called the **saturation pressure.** When saturation pressure increases, saturation temperature increases. The opposite is also true. Therefore, with regard to pure liquids, a third principle of refrigeration can be stated: **For every saturation pressure, there is one corresponding saturation temperature.**

Lithium bromide (LiBr) refrigeration systems use water as a refrigerant. The **American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE)** identifies all refrigerants with the capital letter *R* followed by a number. The designation for water is Refrigerant 718 (or simply, R-718). To work as a refrigerant, water must be boiled in a deep vacuum. For example, the saturation pressure of pure water boiling at 4°C is 0.814 kPa (absolute).

Many commonly used refrigerants, though, boil at pressures well above atmospheric pressure. The common refrigerant **ammonia** (R-717), at atmospheric pressure, boils at −33.3°C. Carbon dioxide (CO_2) (R-744), at atmospheric pressure, boils at −93.7°C. Suva 134a, (R-134a), at atmospheric pressure, boils at −26.2°C. This leads to the fourth principle of refrigeration: **One of the physical properties of every pure liquid is a characteristic set of saturation pressures and temperatures.**

Table 1 compares saturation temperatures of a variety of refrigerants at a saturation pressure of 101.3 kPa (normal atmospheric pressure at sea level). Note the wide range of saturation temperatures. A refrigerant will boil if the temperature of its surroundings exceeds the saturation temperature (in the far right column). Below the saturation temperature, a refrigerant will remain liquid. Note that R-123 remains a liquid at normal room temperature

Side Track

Propane, which is also used to fuel forklifts and other machinery, does not evaporate below −41°C. So, if a propane-powered vehicle is left outside on a cold winter night, the vehicle may not start until the propane warms up.

Table 1 – Saturation Temperature of Various Refrigerants

Common or trade name	Chemical name and formula	ASHRAE designation	Saturation temperature (°C) at 101.3 kPa
Suva 123	2,2-Dichloro-1,1,1-trifluoroethane, $CHCl_2CF_3$	R-123	27.7
Suva 134a	1,1,1,2-Tetrafluoroethane, CH_2FCF_3	R-134a	−26.2
Ammonia	Ammonia, NH_3	R-717	−33.3
Freon 22	Chlorodifluoromethane, $CHClF_2$	R-22	−40.8
Propane	Propane, $CH_3CH_2CH_3$	R-290	−41.9

Table 2 shows the saturation pressures of these same refrigerants, at a saturation temperature of 0°C. Note that each of these refrigerants, except R-123, boils well above 103 kPag (204.3 kPa) at 0°C. Therefore, refrigeration systems are designed with high-pressure components, according to ASME BPVC VIII **Rules for Construction of Pressure Vessels** and ASME B31.5 **Refrigeration Piping and Heat Transfer Components**.

Table 2 – Saturation Pressure of Various Refrigerants

Common or trade name	Chemical name and formula	ASHRAE designation	Saturation pressure (kPa absolute) at 0°C
Suva 123	2,2-Dichloro-1,1,1-trifluoroethane, $CHCl_2CF_3$	R-123	32.9
Suva 134a	1,1,1,2-Tetrafluoroethane, CH_2FCF_3	R-134a	292.8
Ammonia	Ammonia, NH_3	R-717	429.4
Propane	Propane, $CH_3CH_2CH_3$	R-290	471.0
Freon 22	Chlorodifluoromethane, $CHClF_2$	R-22	497.6

To summarize, the main principles involved in refrigeration are:

1. A substance must absorb or reject latent heat in order to change state.
2. The pressure exerted on the surface of a boiling liquid affects the temperature at which the liquid boils.
3. For every saturation pressure, there is one corresponding saturation temperature.
4. A physical property of every pure liquid is a characteristic set of saturation pressures and temperatures.

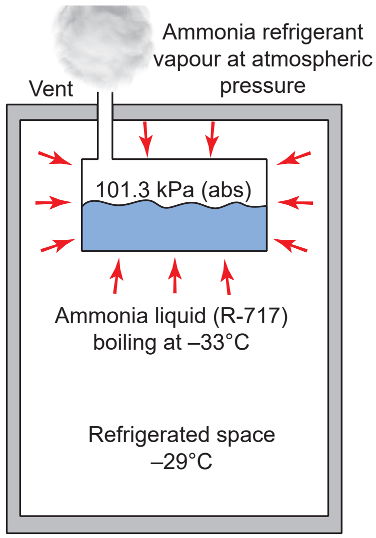
Basic Refrigeration System

A refrigerant is a liquid that is capable of boiling at a low temperature. Consider a refrigerant liquid, at saturation temperature and pressure, contained inside a vessel. According to principle 2 (above), the temperature of this refrigerant can be controlled by varying the pressure in the vessel.

Figure 1 shows such a vessel, containing liquid ammonia (R-717), located inside an insulated room (the **refrigerated space**). The air in the refrigerated space is the **refrigerated medium**. In other words, air is the substance being cooled.

The vessel in Figure 1 is called the **evaporator**; it is within this vessel that the liquid boils. The evaporator in a refrigeration system is in physical contact with the refrigerated medium so that heat may transfer to the refrigerant. The small arrows show the direction of heat transfer, from the refrigerated medium to the boiling liquid ammonia. Note that the refrigerated space is about four degrees warmer than the boiling ammonia. Even though both the ammonia and the air in the room are cold, heat continues to transfer from the warmer material to the colder material in accordance with the second law of thermodynamics.

Figure 1 – A Simple Refrigerator Operating at Atmospheric Pressure



Most refrigeration systems are used for freezing food products or preserving food freshness. This simple refrigerator is impractical for several reasons:

a) The temperature of the refrigerated space (–29°C) is appropriate for freezing food but not for preserving fresh produce.

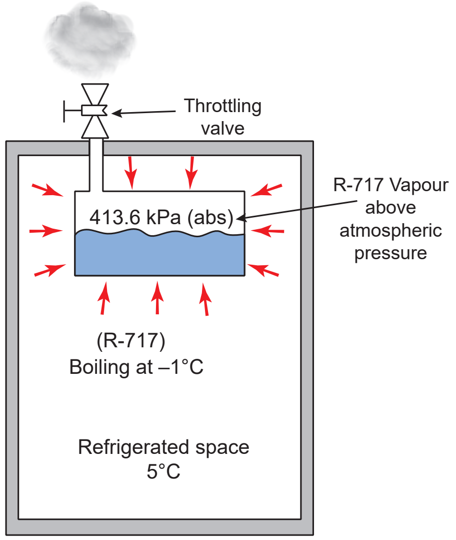
b) There is no means of controlling the temperature of the refrigerated space because the refrigerant can only boil at atmospheric pressure.

c) The refrigerant vapour vents directly to the atmosphere.

Such a refrigerator would waste costly refrigerant and, in the case of ammonia, contaminate the natural environment. Other refrigerants could contaminate more or less depending on their toxicity.

Figure 2 addresses the issue of temperature control. A **backpressure regulator**, in the form of a throttling valve, is installed at the evaporator outlet. By adjusting the valve, refrigerant vapour flow can be adjusted, which in turn changes the saturation pressure and saturation temperature in the vessel. In the case of Figure 2, the valve is partially closed, which raises the saturation pressure to 413.6 kPa and causes the ammonia to boil at –1°C. Now the refrigerated space can be kept at a temperature suitable for fresh produce (5°C).

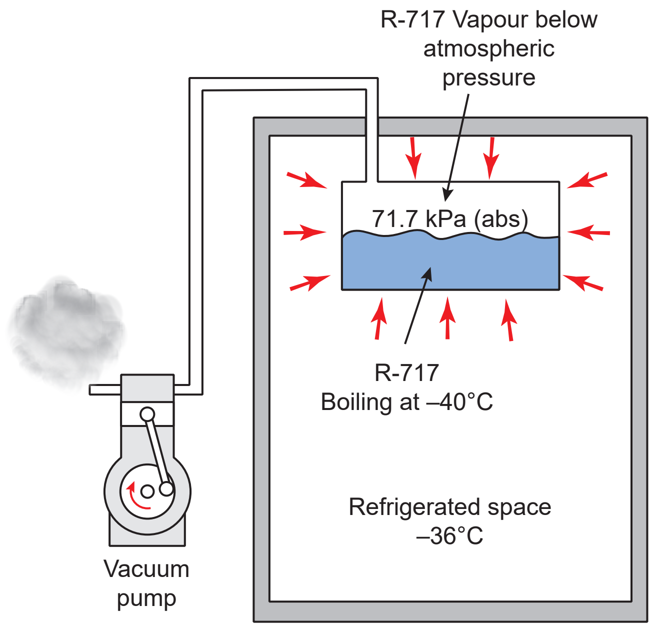
Figure 2 – A Simple Refrigerator Operating Above Atmospheric Pressure



With the vent valve closed, vapour cannot escape the evaporator. This will increase the evaporator pressure until the corresponding saturation temperature equals the temperature of the refrigerated space. This causes heat transfer to cease and boiling to stop. In the case of Figure 2, if the throttling valve is shut and the refrigerated space remains at 5°C, the evaporator pressure will increase to 515.8 kPa.

Sometimes, an evaporator must operate below atmospheric pressure in order to develop a low enough temperature. Figure 3 addresses this situation. For ammonia to boil at –40°C, the evaporator pressure must be 71.7 kPa absolute, which is approximately 30 kPa below atmospheric pressure. This low pressure can be achieved by installing a vacuum pump at the evaporator outlet. The vacuum pump can withdraw refrigerant vapour faster than the rate at which it boils. In this way, the vacuum pump can lower the evaporator pressure to below atmospheric pressure.

Figure 3 – A Simple Refrigerator Operating Below Atmospheric Pressure



Relying on the four principles of refrigeration discussed above, the simple refrigerators in Figures 1 to 3 show how to use refrigerant evaporation to artificially create various cold temperatures. The next objective examines the components needed to create an actual, practical refrigeration system.

Objective 2

Describe the cycle of operations in a vapour compression refrigeration system.

Actual Refrigeration Systems

Actual refrigeration systems are not like those described in Objective 1. Additional equipment is required to address the significant shortcomings of those simple systems. First, in order for the system to run continuously, there must be a continual feed of vaporized refrigerant to replace the refrigerant boiled in the evaporator. The rate of replacement must be the same as the rate of evaporation. Larger systems have a reservoir of refrigerant (the **liquid receiver**) to supply liquid to the evaporator.

To control the refrigerant flow, a **metering device** (such as an adjustable valve or nonadjustable restriction) must be installed between the liquid receiver and the evaporator. If too much refrigerant enters the evaporator, both the vapour and unboiled liquid will leave the evaporator. This liquid will cause damage to the **compressor** (this is discussed later). If there is not enough refrigerant, the evaporator will starve or run dry. With insufficient boiling liquid, heat flow to the evaporator is reduced, which reduces the refrigerating effect.

Second, refrigerant vapour must be recovered and reused. In actual systems, the refrigerant vapour that leaves the evaporator is compressed and then cooled in a heat exchanger called the *condenser.* In this exchanger, the vapour gives off latent heat to a coolant (or **cooling medium**) and returns to its liquid state. The liquefied refrigerant then flows from the condenser to the liquid receiver, where it resides until it is reused in the evaporator.

Finally, a refrigeration system needs a compressor. In order for the refrigerant vapour to release its latent heat, the vapour must be hotter than the cooling medium. Consider Figure 1. The refrigerant vapour leaving the evaporator is at its saturation temperature of –33.3°C. To condense, the vapour needs to be exposed to a cooling medium that is colder than –33.3°C. However, most condensers use relatively warm cooling media (between 0 and 40°C, depending on the source). Therefore:

1. The temperature of the refrigerant vapour must be made higher than the temperature of the cooling media (typically, higher than 40°C).

   and

2. The pressure of the refrigerant vapour must be raised to a point where the condensed liquid refrigerant – now at high temperature – will remain a liquid. In other words, the saturation pressure in the condenser must correspond with the high saturation temperature of the condensed liquid.

The compressor accomplishes both of these tasks.

The compressor in a refrigeration system takes the place of the vacuum pump shown in Figure 3. A compressor draws refrigerant vapour at a low pressure and discharges it at a higher pressure. Compression is work, and requires the expenditure of mechanical energy ($W = F \times d$). The mechanical energy of compression is converted to potential energy (pressure) and internal energy (vapour temperature). Therefore, in compressing the low-pressure refrigerant vapour, the compressor also raises the refrigerant vapour temperature. The pressurized, high-temperature vapour then enters the condenser. It transfers heat to the surrounding coolant, and condenses. The refrigerant liquid drains to the receiver and eventually returns to the evaporator, where the cycle repeats.

Figure 4 shows an actual refrigeration system with the following mandatory components:

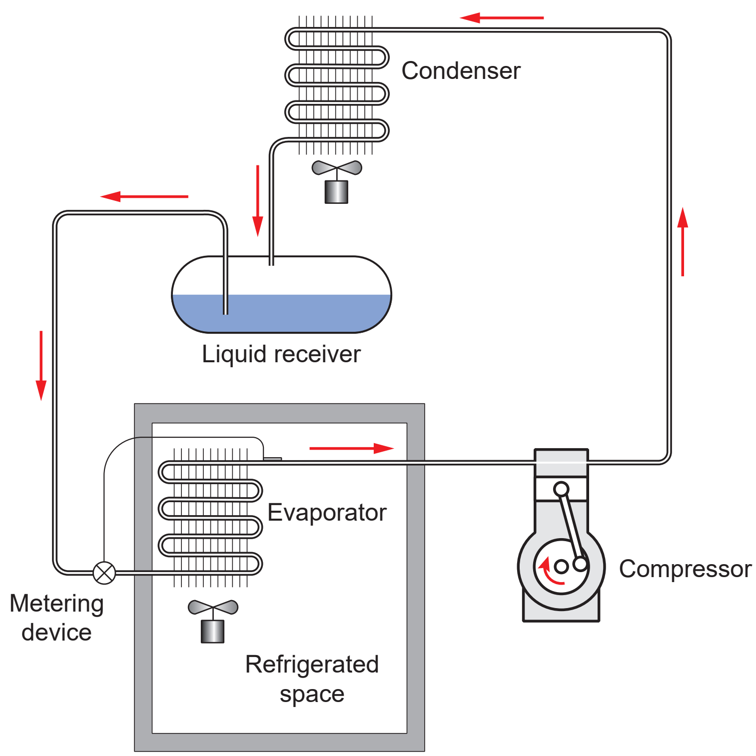
- An evaporator
- A refrigerant metering device (control valve, orifice, or capillary tube)
- A condenser
- A compressor

Optional components shown in Figure 4 include:

- A liquid receiver
- A condenser cooling fan
- An evaporator fan

This simple but complete system is typical of a household refrigerator, freezer, or air-conditioning unit. This type of system transfers heat from a low-temperature region (such as the inside of a refrigerator) to a higher temperature condensing medium (such as air or water). This is called a *vapour compression refrigeration system.* The evaporator and condenser pressures, maintained by the compressor and metering device, are essential for achieving proper system temperatures.

Figure 4 – Vapour Compression Refrigeration System



Fundamental Cycle of Operation and Operating Principles

The following is a theoretical description of a refrigeration system cycle of operations. It is presented here as a starting point on which to develop an understanding of real-life refrigeration systems.

Refer to the arrows on Figure 4. The liquid receiver contains warm liquid refrigerant under high pressure. The liquid is at the saturation temperature associated with the saturation pressure inside the liquid receiver (refer to refrigeration principles 2 and 3). The refrigerant, then, is saturated liquid that is, ready to evaporate if given additional heat. The refrigerant liquid flows from the liquid receiver, which is at a higher pressure, through a metering device to an evaporator, which is at a lower pressure. It is the difference in pressure between the liquid receiver and the evaporator that causes the refrigerant liquid to flow. The metering device controls the flow rate.

In the evaporator (which has low internal pressure), the liquid immediately boils and becomes vapour. Because the evaporator saturation pressure is low, the saturation temperature is also low (again, refer to refrigeration principles 2 and 3). The boiling low-pressure refrigerant absorbs heat from the interior of the refrigerated space because the evaporator saturation temperature is less than the temperature of the refrigerated space.

In order to maintain a constant evaporator pressure, and therefore a constant evaporator temperature, refrigerant vapour must be drawn from the evaporator at the same rate at which it develops. This is one of several functions of the compressor. The compressor also raises the pressure of the vapour high enough that its saturation temperature is higher than the temperature of the condenser cooling medium. In Figure 4, the condenser cooling medium is air, supplied by a fan.

The vapour discharging from the compressor and entering the condenser is at high temperature and pressure. In the condenser, the vapour gives off latent heat and returns to its liquid state. The liquid refrigerant flows by gravity to the receiver, where it will again flow to the evaporator in a continuous cycle.

A **pressure-enthalpy (p-h) diagram** can represent a refrigeration cycle. The p-h diagram for refrigeration is similar to the p-h diagram of the steam water cycle that was introduced earlier in this course.

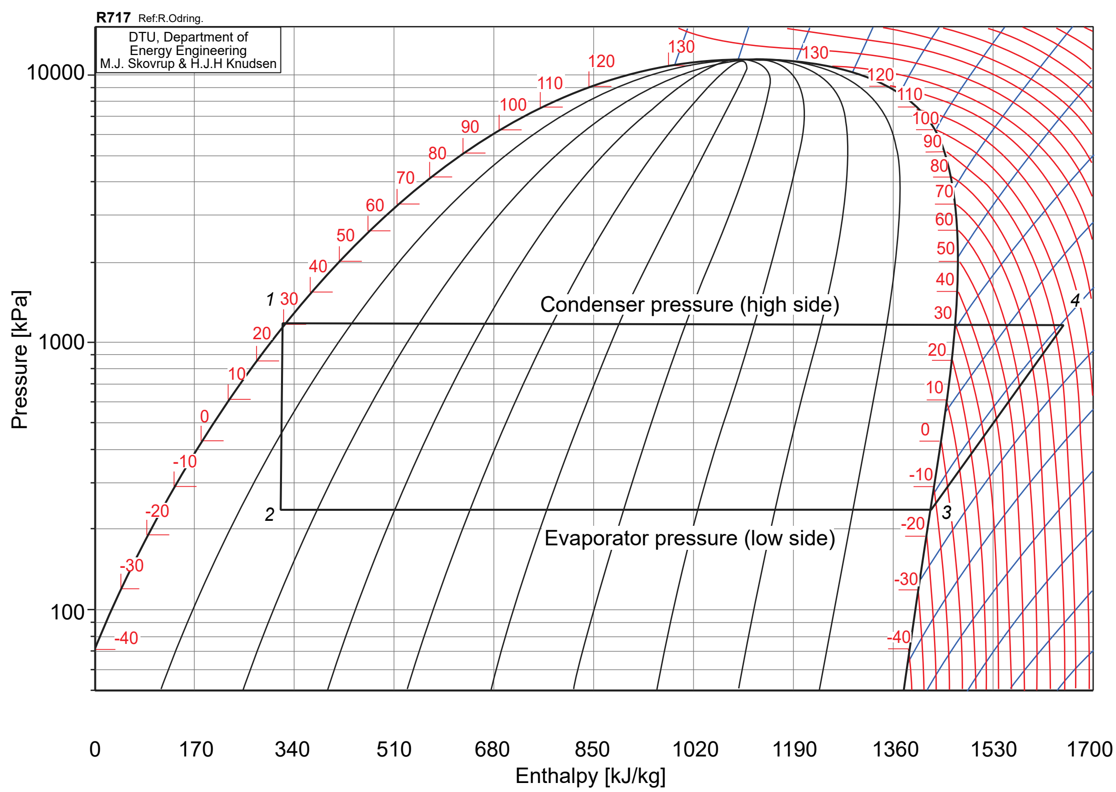
Figure 5 shows a p-h diagram for R-717 (ammonia refrigerant).

On Track

Review the thermodynamics of steam to help understand the concepts related to refrigeration. The **PanGlobal Academic Supplement** has additional refrigeration p-h diagrams and tables for reference.

The y-axis (or ordinate) of the p-h diagram represents pressure, in kPa. Lines may be drawn perpendicular to the ordinate to connect points with the same pressure. In other words, a horizontal line on the diagram is a line of constant pressure. Note that condenser pressure is higher than the evaporator pressure, and therefore condenser temperature is higher than evaporator temperature. Because the condenser pressure is higher than the evaporator pressure, the condenser, and any part of the refrigeration system that is under high pressure, are said to be on the **high side** of the system. Any part of the system that is not under condenser pressure, then, is said to be part of the system's **low side.**

Figure 5 – Pressure-Enthalpy Diagram for Ammonia at Standard Conditions



The high side and low side are shown as opposite sides of a trapezoid drawn on the p-h diagram. At each corner of the trapezoid are points labelled 1 through 4. Each point represents a different component of a compression refrigeration system:

Point 1	Metering device inlet (or condenser outlet)
Point 2	Evaporator inlet (or metering device outlet)
Point 3	Compressor inlet (or evaporator outlet)
Point 4	Condenser inlet (or compressor outlet)

Note that the refrigeration cycle in Figure 6 also shows the points discussed above. As well, it indicates the pressures and temperatures of an ammonia refrigeration system operating at an evaporator temperature of –15°C and a condenser temperature of 30°C.

Side Track

Refrigerant cycles are compared using a set of standard conditions: an evaporator temperature of −15°C and a condenser temperature of 30°C. However, few refrigeration plants actually operate under these conditions.

Therefore, Figure 5 is a graphical representation of the refrigeration cycle shown in Figure 6. This chapter will continue to use the p-h diagram to illustrate various refrigeration system operating conditions.

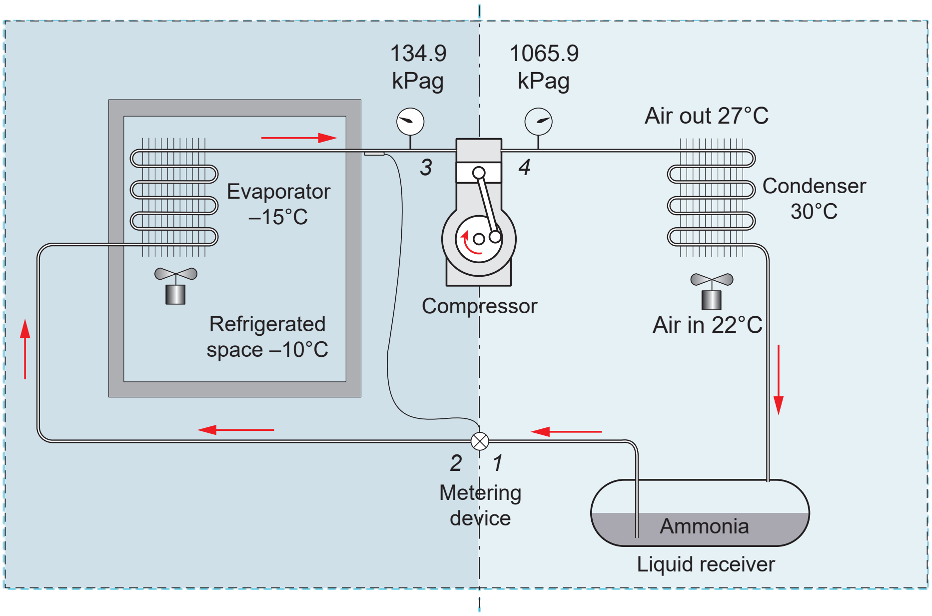
On Track

Note that the evaporator and condenser pressure readings in Figure 6 are in kPag. These are the pressures that standard pressure gauges show, assuming an atmospheric pressure of 101.3 kPa.

The p-h diagram (Figure 5) shows the same pressures in kPa absolute (kPa). Be aware the refrigeration tables and p-h diagrams in the **PanGlobal Academic Supplement** use absolute pressure, not gauge pressure.

Other publishers may show pressures in kPag in their tables and diagrams. Therefore, to know the thermodynamic properties of a refrigerant in a system, the learner MUST know the units of pressure measurement.

Figure 6 – Diagram of Ammonia Refrigeration Cycle at Standard Conditions



Point 1 to Point 2

Consider the four points on the p-h diagram (Figure 5) and on Figure 6. From point 1 to point 2, liquid refrigerant at its saturation pressure and temperature passes through the metering device from the high side to the low side. The p-h diagram shows this process with a vertical straight line. This vertical line (perpendicular to the x-axis, or *abscissa*) connects points with the same enthalpy. Therefore, the enthalpy of the high-pressure liquid is the same as the enthalpy of the boiling, low-pressure two-phase refrigerant just as it passes through the metering device.

Point 2 to Point 3

From point 2 to point 3, the liquid refrigerant boils at low temperature and pressure in the evaporator. Though the temperature and pressure remain constant, the enthalpy of the refrigerant increases as it gains latent heat from the refrigerated space. At point 3, the refrigerant is completely vapourized and is 100% dry and saturated.

Point 3 to Point 4

At point 3, the dry, low-pressure vapour enters the compressor. Compression takes place between points 3 and 4. Note that during compression, the vapour increases in the following properties:

a) Enthalpy

b) Pressure

c) Temperature

Energy is consumed in order to compress the refrigerant. The energy consumed by the compressor results in increased enthalpy, pressure, and temperature.

Point 4 to Point 1

After compression, the refrigerant vapour enters the condenser. Here, the refrigerant gives off the energy added by the compressor. Then, the saturated refrigerant vapour gives off the latent heat it absorbed in the evaporator, thus condensing back to saturated liquid.

The cycle described is not a *batch* process (in which a discrete mass of refrigerant circulates through the system and repeatedly undergoes thermodynamic processes). Rather, each part of the system is simultaneously filled with refrigerant in various states of expansion, evaporation, compression, and condensation. Whenever the compressor is operating, heat is constantly absorbed from the refrigerated space and rejected to the condenser cooling medium. Because the heat transfer is continuous, the refrigeration cycle is called a *constant flow* cycle.

Heat Absorbed by the Evaporator

Notice that the enthalpy of the refrigerant at point 1 is the same as the enthalpy at point 2. The heat absorbed by the evaporator from the refrigerated space is the difference between the enthalpy at point 3 minus the enthalpy at point 2. Because point 2 equals point 1, it can also be said that the heat absorbed by the evaporator is the enthalpy at point 3 minus the enthalpy at point 1:

$$Q_e = h_3 - h_1$$

Energy Added by The Compressor

The compressor takes refrigerant from the evaporator at point 3 and compresses it to point 4. Therefore, the energy added by the compressor is as follows:

$$Q_{compressor} = h_4 - h_3$$

Heat Rejected by the Condenser

The condenser rejects the heat absorbed by the evaporator, plus the energy added by the compressor. Therefore, the energy rejected by the condenser is as follows:

$$\begin{aligned} Q_c &= (h_3 - h_1) + (h_4 - h_3) \\ &= h_4 - h_1 \end{aligned}$$

A More Accurate System Model

To complete the analysis of the compression refrigeration cycle, and in order to develop a more accurate model, it is necessary to add to the information above. Observe Figures 7 and 8. These show an ammonia refrigeration system operating at standard evaporator and condenser conditions. The model shows the following:

- 10 degrees of evaporator **superheat**
- 10 degrees of condenser **subcooling**

Figure 7 – Diagram of Ammonia Refrigeration Cycle at Standard Conditions with Subcooling and Superheat

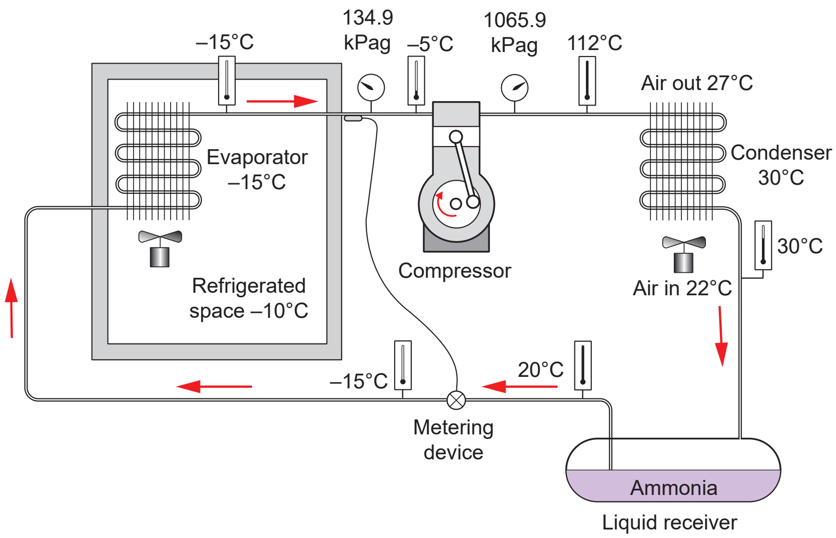
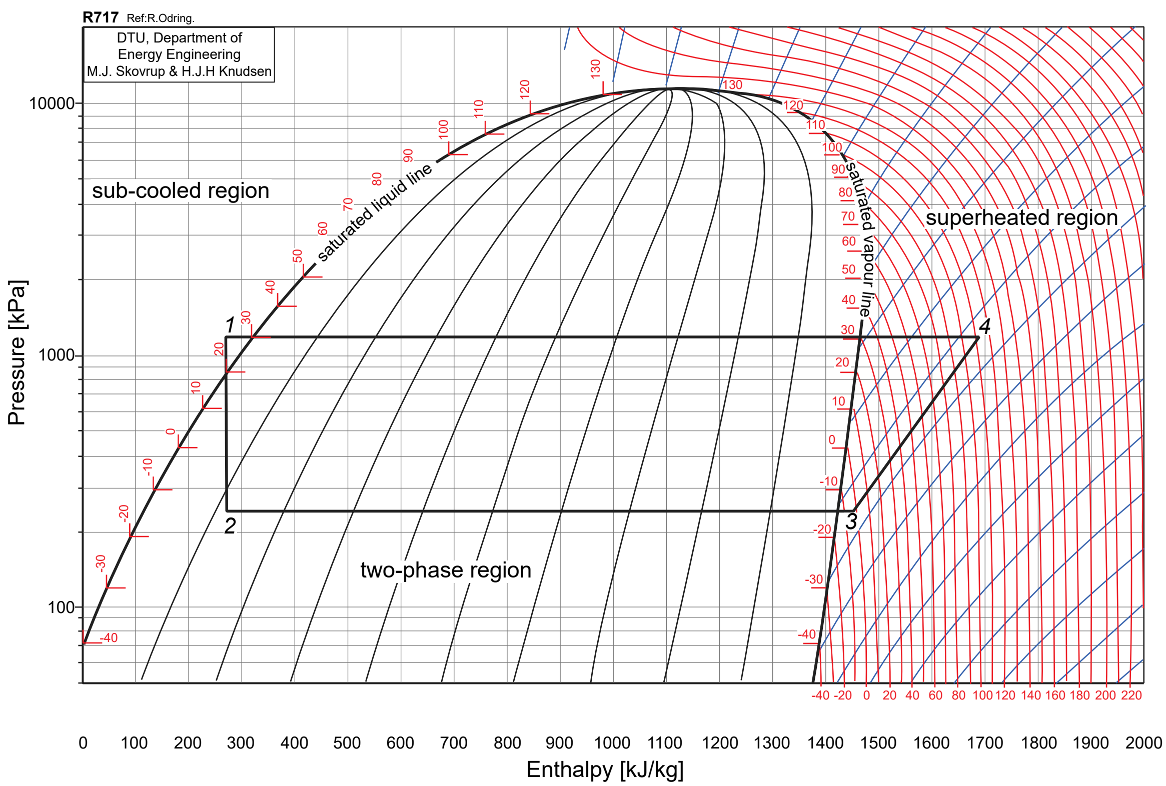


Figure 8 – Pressure-Enthalpy Diagram for Ammonia at Standard Conditions with Subcooling and Superheat



Note that, in Figures 7 and 8, the refrigerant entering the metering device is not saturated liquid. In reality, the liquid piped to the receiver and metering device, and the liquid stored in the receiver, continue to lose sensible heat to the surrounding environment. For the examples in Figures 7 and 8, this sensible heat loss produces a 10°C temperature drop in the liquid refrigerant. Thus, the refrigerant became subcooled (cooled to below its saturation temperature). Note that point 1 on Figure 8 is to the left of the saturated liquid line and is located in the subcooled liquid region of the chart. Subcooling can also occur in the condenser if the cooling medium is quite cool.

Figures 7 and 8 also show evaporator superheat. It is unsafe for the refrigerant to be saturated at the compressor inlet. If the cooling load on the evaporator was to decrease, unboiled liquid would enter the compressor and cause considerable damage (liquids are incompressible). Therefore, refrigeration systems must be able to accommodate evaporator loads that are either decreasing or increasing by regulating the evaporator's cooling capacity (**evaporator capacity** control).

A metering device can continuously monitor the evaporator superheat and regulate the refrigerant flow to the evaporator to keep the superheat constant. This will prevent the compressor from ingesting slugs of liquid. Other systems may use low-pressure receivers (accumulators) in the suction line of the compressor to separate liquid and vapour if evaporator loads change suddenly.

On Track

The metering device in Figure 7 has a small bulb located at the evaporator outlet. This bulb monitors evaporator superheat, and controls the opening of the metering device. These types of metering devices are called **thermostatic expansion valves**.

System Pressure Drops

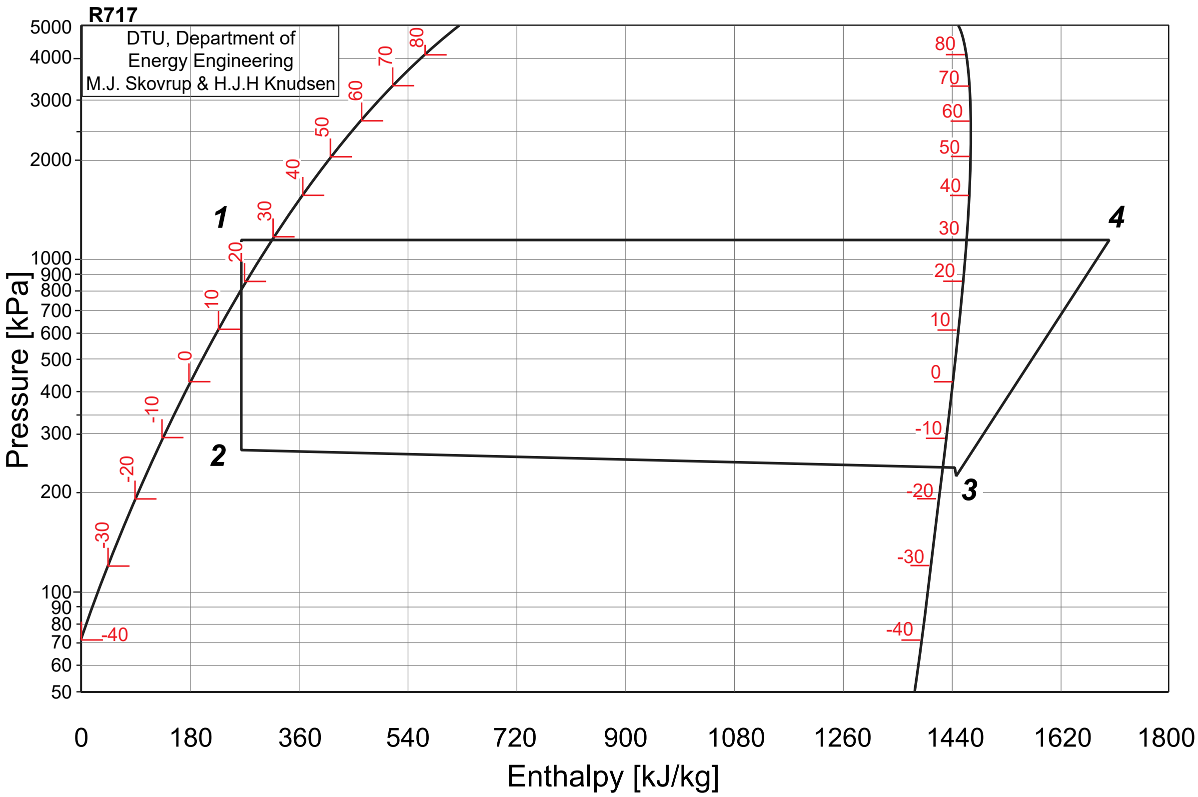
Figures 5 and 8 assume that, in the low side of the system, the pressure of the refrigerant remains constant from the moment it enters the evaporator until it passes through the suction inlet of the compressor as vapour. In a realistic system, this will not be true.

Figures 5 and 8 also assume that the pressure of the refrigerant in the high side remains constant from the time it leaves the compressor until the time it leaves the high side as liquid. Again, in a realistic system, this will not be true.

In actual refrigeration systems, the refrigerant pressure drops from the metering device outlet to the compressor inlet and from the condenser inlet to the metering device inlet. This is due to the length of the piping, internal roughness of the pipe, and the numerous bends in the evaporator and condenser.

Figure 9 shows how refrigerant pressure drops in an actual refrigeration system. In both the high and low sides of the system, pressures drop in the direction of refrigerant flow. The evaporator pressure drop reduces the compressor suction pressure. This causes the **pressure ratio** to increase and makes the compressor work harder for every kilogram of refrigerant circulated.

Figure 9 – p-h Diagram with Subcooling, Superheat, and System Pressure Drops



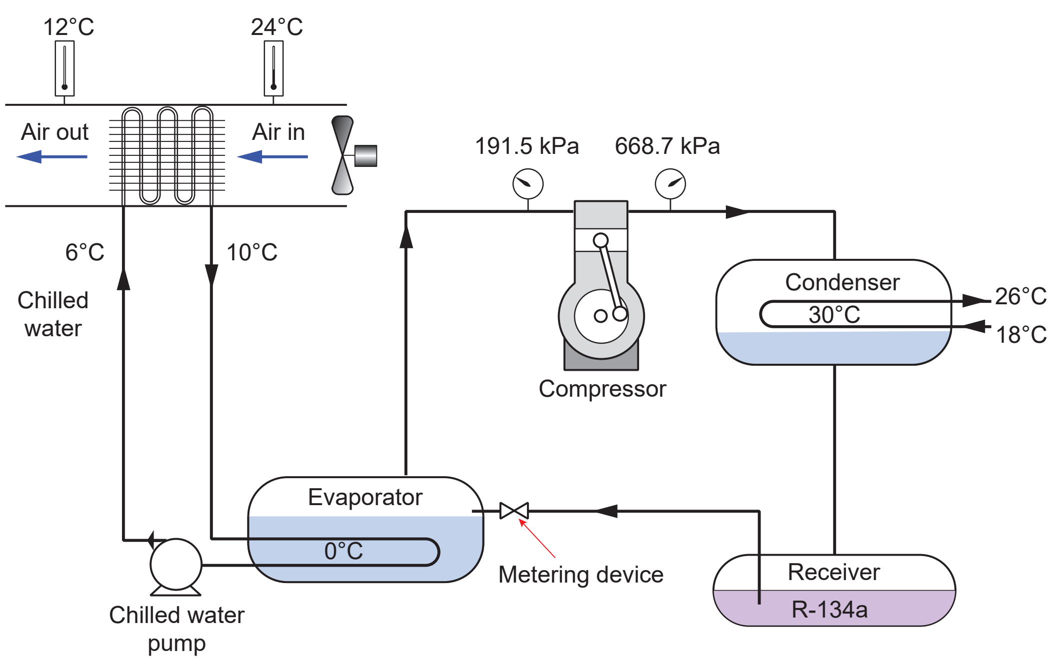
Objective 3

Explain how the operating temperatures and pressures are selected and related for a vapour compression refrigeration system.

Operating Temperatures and Pressures For Vapour Compression Refrigeration Systems

Figure 10 shows an indirect compression refrigeration system using R-134a as the refrigerant. This system chills water to cool the air in a central air conditioning system. The evaporator is a shell-and-tube heat exchanger. The **chilled water** flows through the tubes, and the liquid refrigerant surrounds the tubes. The condenser is water-cooled.

Figure 10 – Indirect Refrigeration System (R-134a)



The pressures and temperatures in this refrigeration system are determined by the temperature required for the air leaving the cooling coil in the air duct – in this case 12°C. The average temperature of the air passing through the condenser coil is approximately 18°C. Assume that the cooling coil is designed for a temperature difference of 10°C between the average air temperature and the average chilled water temperature. The average temperature of the chilled water must be 8°C. Since the water leaves the cooling coil at 10°C, it should be therefore be supplied at 6°C to provide an average temperature of 8°C.

From the above, it follows that the water enters the evaporator at 10°C, and it is cooled to 6°C. Again, assume that the evaporator is designed for a temperature difference of 10°C between the average chilled water temperature (8°C) and the temperature of the boiling refrigerant. It is not practical to operate the evaporator below freezing, so 0°C is the lowest temperature at which the evaporator can operate. This requires an evaporator pressure of 292.8 kPa absolute pressure (191.5 kPag).

The cooling water enters the condenser at 18°C and leaves at 26°C, giving an average cooling water temperature of 22°C. Assuming the condenser is designed for a temperature drop of 8°C, the condensing temperature of the refrigerant vapour must be 8°C higher than the average cooling water temperature. Therefore, the condensing temperature will be 30°C. This requires a condenser pressure of 770 kPa absolute (668.7 kPag).

On Track

It is important to know that converting temperatures between units is done differently than converting temperature changes. To convert a given temperature from °C to °F, use the following equation:

$$°F = \frac{9}{5} \times °C + 32$$

For example:

$$18.5°C = \frac{9}{5} \times 18.5 + 32 = 65.3°F$$

However, when considering a temperature change or a temperature difference, an increment of 1°C equals an increment of 1.8°F. Therefore, to convert a temperature difference from °C to °F, use the equation:

$$°F = 1.8 \times °C$$

For example, a temperature difference of 10°C equals a temperature difference of:

$$1.8 \times 10°C = 18°F$$

Objective 4

State how the capacity of a refrigeration system is described and how refrigeration tables are used to calculate system performance.

Refrigerant Tables

Certain properties of refrigerants, such as the saturation temperatures and pressures, volume, density, and enthalpy, are called *thermodynamic properties* of refrigerants. These values must be known in order to solve capacity and performance problems. These thermodynamic properties have been obtained by careful experiments. The resulting values have been tabulated in the refrigerant tables.

Refer to Table 1 – Refrigerant R-717 (Ammonia): Saturation Properties (Temperature) in the **PanGlobal Academic Supplement**. This table lists the thermodynamic properties of ammonia at various saturation temperatures. Part of this table is shown below in Table 3.

Table 3 – Refrigerant R-717 (Ammonia): Saturation Properties (Temperature)

Saturation temperature	Saturation pressure	Volume vapour V_g	Density liquid $1/V_f$	Enthalpy, kJ/kg		
1	2	3	4	5	6	7
°C	kPa	m^3/kg	kg/m^3	h_f	h_{fg}	h_g
−5	354.76	0.34664	645.37	157.77	1279.73	1437.5
−4	368.80	0.33414	644.02	162.37	1276.23	1438.6
−3	383.27	0.32218	642.66	166.98	1272.82	1439.8
−2	398.19	0.31074	641.30	171.59	1269.31	1440.9
−1	413.56	0.29979	639.94	176.21	1265.79	1442.0

Column 1 lists the saturation temperature in °C for each absolute pressure.

Column 2 lists the corresponding saturation pressure in kPa (absolute).

It is obvious, by examining the values in columns 1 and 2 that the temperature increases as the pressure increases.

Column 3 lists the specific volume (V_g) in m^3/kg of refrigerant vapour. Note that the specific volume of the vapour decreases as the pressure increases.

Column 4 lists the density ($1/V_f$) in kg/m^3 of refrigerant liquid.

Column 5 lists the enthalpy (h_f) in kJ/kg of saturated liquid refrigerant, for each temperature.

Column 6 lists the enthalpy of evaporation (h_{fg}) in kJ/kg of refrigerant.

Column 7 lists the enthalpy (h_g) in kJ/kg of saturated refrigerant gas, for each temperature.

Refrigeration System Capacity

Internal combustion engines are compared according to kilowatt output. Boilers are compared according to boiler horsepower. Refrigeration plants are compared according to tonnes of refrigeration (or in United States Customary System (USCS) units, tons of refrigeration).

On Track

This text abbreviates the SI unit tonne of refrigeration with the letters *TR*. This must not be confused with the USCS ton of refrigeration, which, if used in the learning materials, will not be abbreviated.

A boiler horsepower is the amount of heat required to produce 15.68 kg (34.5 lb) of dry and saturated steam at 100°C (212°F) from pure feedwater at 100°C (212°F), over a period of one hour. This calculates to a heat output rate of 35 394 kJ per hour (33 475 Btu/h). However, no boilers actually produce steam under such conditions. Despite this, the concept of boiler horsepower remains a useful way to compare the heat output of various boilers.

A similar situation applies to the concept of tonnes of refrigeration. A tonne of refrigeration is the amount of heat required to produce 1 tonne of ice at 0°C from pure water at 0°C, over a 24-hour period. In other words, one tonne of refrigeration is the amount of latent heat of fusion that must be extracted from 1 tonne of water at 0°C to turn it into ice at 0°C. No refrigeration systems operate under such conditions; however, the concept of tonnes of refrigeration is a useful way to compare the heat transfer rate of various refrigeration plants.

SI Tonne of Refrigeration (TR)

A tonne of refrigeration is a heat rate based on the latent heat of fusion of pure water, which is 335 kJ/kg. Consequently, to produce 1 tonne of ice at 0°C from water at 0°C would require the following:

$$1\ \text{TR} = \frac{1\ \text{tonne}}{\text{d}} \times \frac{1000\ \text{kg}}{\text{tonne}} \times \frac{335\ \text{kJ}}{\text{kg}} = \mathbf{335\ 000\ kJ/d}$$

As a heat rate, a tonne of refrigeration can be expressed over different time spans. So, one TR can also be expressed as a heat rate per hour, a heat rate per minute, or a heat rate per second:

$$1\ \text{TR} = \frac{335\ 000\ \text{kJ}}{\text{d}} \times \frac{1\ \text{d}}{24\ \text{h}} = \mathbf{13\ 958\ kJ/hour}$$

$$1\ \text{TR} = \frac{335\ 000\ \text{kJ}}{\text{d}} \times \frac{1\ \text{d}}{24\ \text{h}} \times \frac{1\text{h}}{60\ \text{min}} = \mathbf{232.6\ kJ/min}$$

$$1\ \text{TR} = \frac{335\ 000\ \text{kJ}}{\text{d}} \times \frac{1\ \text{d}}{24\text{h}} \times \frac{1\ \text{h}}{60\ \text{min}} \times \frac{1\ \text{min}}{60\ \text{s}} = \mathbf{3.877\ kJ/s}$$

Note that the last conversion to kJ/s can be expressed as kW. So, **one TR is equal to 3.877 kW**.

United States Customary System (USCS) Ton of Refrigeration

USCS units are still commonly used in Canada. It is helpful, then, to review the USCS definition for *ton of refrigeration.*

A weight of one ton equals 2000 pounds (lb.). The latent heat of fusion of water, in USCS, is 144 Btu/lb (British thermal units [BTU] per pound). Therefore, to produce one ton of ice at 32°F from water at 32°F would require:

$$1 \text{ ton of refrigeration} = \frac{1 \text{ ton}}{\text{d}} \times \frac{2000 \text{ lb.}}{\text{ton}} \times \text{lb.} = \mathbf{288\,000 \text{ Btu/d}}$$

One ton of refrigeration can also be expressed as a heat rate per hour, a heat rate per minute, or a heat rate per second.

$$1 \text{ ton of refrigeration} = \frac{288\,000 \text{ Btu}}{\text{d}} \times \frac{1 \text{ d}}{24 \text{ h}} = \mathbf{12\,000 \text{ Btu/h}}$$

$$1 \text{ ton of refrigeration} = \frac{288\,000 \text{ Btu}}{\text{d}} \times \frac{1 \text{ d}}{24 \text{ h}} \times \frac{1 \text{ h}}{60 \text{ min}} = \mathbf{200 \text{ Btu/min}}$$

$$1 \text{ ton of refrigeration} = \frac{288\,000 \text{ Btu}}{\text{d}} \times \frac{1 \text{ d}}{24 \text{ h}} \times \frac{1 \text{ h}}{60 \text{ min}} \times \frac{1 \text{ min}}{60 \text{ s}} = \mathbf{3\frac{1}{3} \text{ Btu/s}}$$

Because one Btu equals 1.055 kJ, a direct comparison can be made between one tonne of refrigeration and one ton of refrigeration:

$$1 \text{ ton of refrigeration} = \frac{3\frac{1}{3} \text{ Btu}}{\text{s}} \times \frac{1.055 \text{ kJ}}{\text{Btu}} = \mathbf{3.517 \text{ kJ/s}} \text{ or } \mathbf{3.517 \text{ kW}}$$

It can be seen, then, that a USCS ton of refrigeration is a slightly smaller heat transfer rate than an SI tonne of refrigeration. **To convert directly from ton of refrigeration to TR, the conversion factor is 0.907**, as shown below:

$$1 \text{ ton of refrigeration} \times \frac{3.517 \text{ kW}}{\text{ton of refrigeration}} \times \frac{\text{TR}}{3.877 \text{ kW}} = \mathbf{0.907 \text{ TR}}$$

To convert directly from TR to ton of refrigeration, the conversion factor is 1.1:

$$1 \text{ TR} \times \frac{3.877 \text{ kW}}{\text{TR}} \times \frac{\text{ton of refrigeration}}{3.517 \text{ kW}} = \mathbf{1.1 \text{ ton of refrigeration}}$$

Example 1

A household air conditioning system is rated at 1.5 TR. Calculate its heat transfer rate in the following:

a) kJ/min

b) kW

Solution 1

a) $1.5 \text{ TR} \times \frac{233 \text{ kJ/min}}{\text{TR}} = \mathbf{349.5 \text{ kJ/min (Ans.)}}$

b) $1.5 \text{ TR} \times \frac{3.877 \text{ kW}}{\text{TR}} = \mathbf{5.816 \text{ kW (Ans.)}}$

Note that this kW rating is not the energy consumed by the compressor. Rather, it is the amount of heat a system can transfer from one location to another, in a given time period.

Example 2

Calculate the heat transfer rate of a 2-ton commercial icemaker in:

a) Btu/hr

b) kW

Solution 2

a) $2 \text{ tons of refrigeration} \times \dfrac{12\ 000 \text{ Btu/h}}{\text{ton of refrigeration}} = \mathbf{24\ 000 \text{ Btu/h (Ans.)}}$

b) $2 \text{ tons of refrigeration} \times \dfrac{3.517 \text{ kW}}{\text{ton of refrigeration}} = \mathbf{7.03 \text{ kW (Ans.)}}$

Example 3

a) Convert the capacity of the refrigeration system in Example 1 to USCS units.

b) Convert the capacity of the refrigeration system in Example 2 to SI units.

Solution 3

a) $1.5 \text{ TR} \times \dfrac{1.1 \text{ tons of refrigeration}}{\text{TR}} = \mathbf{1.65 \text{ tons of refrigeration (Ans.)}}$

b) $2 \text{ tons of refrigeration} \times \dfrac{0.907 \text{ TR}}{\text{ton of refrigeration}} = \mathbf{1.814 \text{ TR (Ans.)}}$

Self-Test 1

An industrial refrigeration plant is rated at 800 tons of refrigeration. How many kilograms of ice at 0°C can it make from pure water at 0°C over one week?

5 079 200 kg (Ans.)

Evaporator Capacity

Evaporator capacity refers to the cooling capacity of the evaporator. This capacity is expressed in tonnes of refrigeration (or simply **evaporator tonnage**). As in the previous section, referring to the capacity of a system in TR is the same as referring to the evaporator capacity.

The evaporator transfers less heat than the condenser, because it does not need to handle the energy added to the refrigerant by the compressor. Therefore, evaporators often have smaller capacities than condensers.

Condenser Capacity

Condenser capacity refers to the heat rejection capability of the condenser. Once again, this can be expressed in TR. A system's condenser must have a greater heat transfer capability than the system evaporator.

Net Refrigerating Effect

The **net refrigerating effect (NRE)** is the heat absorbed per kilogram of refrigerant circulated through the evaporator, expressed in kJ/kg. This was described earlier in the chapter as the heat absorbed by the evaporator.

Consider a boiler. Feedwater enters the boiler, removes heat from the furnace, then leaves as vapour. The entering feedwater has some amount of heat. The boiler adds heat to the water and produces steam. The steam leaves the boiler with more heat per kilogram than when it entered as feedwater. The heat added by the boiler, per kilogram of water, is the difference between the specific enthalpy of the steam minus the specific enthalpy of the feedwater. This is a fundamental part of the boiler efficiency calculation.

In an evaporator, the same is true. Like the boiler feedwater, the refrigerant enters the evaporator with heat (h_f at the high-side pressure). The evaporator adds heat to the refrigerant, and turns it into vapour. The vapour then leaves the evaporator with more heat (h_g at the low side pressure) than when it entered as liquid. The NRE is the difference between the enthalpy of the vapour leaving the evaporator at low pressure and the liquid entering the evaporator at high pressure.

Calculating NRE

Figure 5 shows the refrigeration cycle at **standard operating conditions**, with no superheat or subcooling. The heat absorbed by the evaporator from the refrigerated space, per kilogram of refrigerant, is the difference between the enthalpy at point 3 minus the enthalpy at point 1. This is also called the net refrigeration effect (NRE), which is calculated as follows:

$$\text{NRE} = Q_e = h_3 - h_1$$

The enthalpy at points 3 and 1 can be found in two ways: using a p-h diagram or refrigerant tables. Both are in the **PanGlobal Academic Supplement**.

Using the p-h Diagram

1. Draw a horizontal line at the −15°C isotherm. Draw another horizontal line at the 30°C isotherm. These lines also represent the high side and low side pressures.
2. Draw a vertical line from the intersection of the high-side line and the saturated liquid line, until it intersects the x-axis. Read the enthalpy where this line intersects the x-axis. This, then, is the enthalpy at points 1 and 2 (the liquid enthalpy entering the evaporator). From Figure 5, the enthalpy is approximately 320 kJ/kg.
3. Finally, draw a vertical line from the intersection of the low-side line and the saturated liquid line, so it intersects the x-axis. From this intersection, read the enthalpy at point 3. From Figure 5, the enthalpy of the saturated refrigerant vapour at point 3, leaving the evaporator, is approximately 1425 kJ/kg.
4. Subtract the value of the enthalpy at point 1 from the enthalpy at point 3: 1425 − 320 = 1105 kJ/kg.

Using the Refrigeration Tables

It is far more accurate to use refrigeration tables for refrigeration calculations. The **PanGlobal Academic Supplement** has tables for four refrigerants. It is important to use the correct tables. Also, recall that pressures in the **Academic Supplement** refrigeration tables are absolute. Each set of tables are like steam tables and have data organized according to temperature or pressure. Depending on the given data, it may be easier to use the temperature table or the pressure table. The following example refers once again to the ammonia refrigeration system shown in Figure 5.

1. Locate h_f at 30°C (enthalpy of saturated liquid), from the ammonia refrigerant temperature tables, Table 1 in the **Academic Supplement**. The value of the specific enthalpy is shown as 322.59 kJ/kg. This is the specific enthalpy at points 1 and 2. In other words, each kilogram of refrigerant liquid enters the evaporator with an enthalpy of 322.59 kJ.
2. Locate h_g (enthalpy of saturated vapour) at –15°C. The value of the specific enthalpy is shown as 1425.2 kJ/kg. This is the specific enthalpy at point 3. Each kilogram of refrigerant liquid leaves the evaporator with an enthalpy of 1425.2 kJ.
3. Subtract the value of the enthalpy at point 1 from the enthalpy at point 3.

Now the NRE can be calculated. The NRE of the system shown in Figures 5 and 6 is as follows:

$$\begin{aligned} \text{NRE} &= h_3 - h_1 \\ &= 1425.2 \text{ kJ/kg} - 322.59 \text{ kJ/kg} \\ &= \mathbf{1102.61 \text{ kJ/kg (Ans.)}} \end{aligned}$$

Self-Test 2

An ammonia refrigeration plant operates with a 35°C condenser temperature and a −35°C evaporator temperature. Using the ammonia refrigeration tables, determine the following:

a) The specific enthalpy of the refrigerant entering the evaporator

b) The specific enthalpy of the refrigerant leaving the evaporator

c) The NRE

346.9 kJ/kg (Ans. a)
1396.5 kJ/kg (Ans. b)
1049.6 kJ/kg (Ans. c)

Flash Gas

In actual refrigerating systems, the pressure and temperature of the liquid refrigerant supplied from the high side of the system to the metering device are considerably higher than the pressure and temperature in the evaporator. Consequently, part of the liquid entering the evaporator will immediately become vapour, as soon as its pressure drops in the evaporator. The portion of the refrigerant that evaporates is called *flash gas.* Flashing occurs because the liquid has higher enthalpy on the high side than it can have on the low side. This excess enthalpy converts to latent heat in the evaporator and produces flash gas. Subcooling reduces the amount of flash gas produced.

The refrigerant that flashes into vapour will not take part in the actual refrigerating process. Only the remaining liquid will absorb heat from the surrounding medium for evaporation. This means that the NRE is considerably less when the liquid refrigerant entering the evaporator is at a temperature higher than the boiling point in the evaporator. The larger the difference between the temperature of the liquid refrigerant entering the evaporator and the actual evaporator temperature, the smaller the NRE will be. In other words, the refrigerating effect will be less than the latent heat of vaporization of the refrigerant.

The amount of liquid that may flash into vapour can be as high as 30%, depending on the difference between the temperature of the liquid refrigerant supplied and the evaporator temperature.

Coefficient of Performance (COP)

The **coefficient of performance (COP)** is the ratio of the amount of heat absorbed from the refrigerated medium by the evaporator, to the amount of energy used to drive the compressor. A higher COP means a more effective refrigeration system.

To find the COP, calculate the net refrigerating effect of the evaporator per second. Then, divide the NRE by the compressor power in kW.

Compressor Capacity

Refrigerant vaporized at a temperature corresponding to the pressure in the evaporator has a definite volume. A compressor must remove this vapour as fast as it is formed; otherwise, a rise in vapour pressure will cause an increase in the boiling point of the liquid refrigerant, which will have an adverse effect on the entire cooling system. At the same time, the compressor must increase the pressure of the vapour so its saturation temperature is above that of the cooling medium in the condenser. A refrigeration system must also be designed so that the compressor has adequate capacity to meet peak load demands.

Piston Displacement

Piston displacement is the volume of refrigerant that can be circulated through all the cylinders in a reciprocating compressor, per unit of time. Most manufacturers rate the displacement of compressors in terms of cubic metres per minute or hour.

The volume displaced per minute or hour depends on the following:

- Cylinder bore
- Length of stroke
- Number of cylinders
- Number of revolutions per minute
- Volumetric efficiency

As a compressor completes one revolution, each cylinder is permitted to fill with low-pressure refrigerant on the intake stroke. Then the vapour is compressed to the condenser pressure when each piston completes its upward or compression stroke. The size of compressor required for a particular application will depend on the volume to be compressed.

Piston displacement can be calculated by the following formula:

$$V = A \times L \times N \times R$$

Where:

V = Volume, m^3/ min (ft^3/min)

A = Cross-sectional area of cylinder, m^2 (ft^2)

L = Length of stroke, m (ft)

N = Number of cylinders

R = Revolutions per minute or per hour (r/min)

Example 4

A two-cylinder compressor has a 100 mm (3.94 in) bore and a stroke of 120 mm (4.7 in). Calculate the volume compressed per minute and per hour if the compressor operates at 400 rpm.

Solution 4

Diameter = 100 mm

= 0.10 m

Radius = 0.05 m

$$A = \pi r^2$$
$$= 3.14 \times (0.05)^2 \text{ m}^2$$
$$= 3.14 \times 0.0025 \text{ m}^2$$
$$= 0.00785 \text{ m}^2$$
$$L = 120 \text{ mm}$$
$$= 0.12 \text{ m}$$
$$V = A \times L \times N \times R$$
$$= (0.00785 \text{ m}^2 \times 0.12 \text{ m}) \times 2 \times 400 \text{ rev/min}$$
$$= (0.000942 \text{ m}^3) \times 2 \times 400\text{/min}$$
$$= 0.001884 \times 400 \text{ m}^3\text{/min}$$
$$= \mathbf{0.754\ m^3/min\ (Ans.)}$$
$$\text{Volume/h} = 0.754 \text{ m}^3 \times 60 \text{ min/h}$$
$$= \mathbf{45.24\ m^3/h\ (Ans.)}$$

If we extend Example 4 by assuming that the refrigerant is R-717 (ammonia) and that the evaporator operates at −15°C (standard conditions), then the specific volume of the vapour is 0.50868 m^3/kg (from Refrigerant tables). Thus, the compressor in Example 4 will circulate the following mass of refrigerant per minute:

$$\text{Mass/min} = \text{volume/min/specific volume}$$
$$= 0.754 \text{ m}^3\text{/min}/0.50868 \text{ m}^3\text{/kg}$$
$$= \mathbf{1.48\ kg/min\ (Ans.)}$$

Volumetric Efficiency

In the preceding discussion, it was assumed that at each stroke of the piston, the cylinder would fill completely with vapour at exactly the same pressure and temperature at which it left the evaporator. This result is not true of actual compressors.

The volume, and therefore the mass, of refrigerant that flows into a cylinder is always less than this theoretical amount for several reasons.

One reason is that the walls of the compressor cylinder are considerably warmer than the vapour entering the suction valve from the evaporator. The hot cylinder walls raise the temperature of the vapour that flows into the cylinder. The heated vapour in the cylinder expands and prevents additional cold vapour from entering.

Another reason is that the vapour entering the cylinder must first flow through the suction valves. In doing so, there is a pressure drop due to the friction of the vapour flowing through the small valve openings. As a result, the vapour inside the cylinder will expand because it is at lower pressure than the vapour in the suction valve. In other words, there is a smaller mass of refrigerant in each cubic metre of cylinder space.

Still another reason is that all reciprocating compressors are built with a slight clearance between the top of the piston and the cylinder. If the piston could just touch the top of the cylinder at the end of each stroke, all of the vapour left in the cylinder would be forced out through the discharge valve. However, due to the clearance space, a small amount of gas will remain in the cylinder after the piston reaches the top. As the piston starts its downward stroke, this trapped vapour expands. Thus, instead of having an empty cylinder that can fill completely with vapour from the evaporator, the cylinder is already partially filled with vapour. As this trapped vapour always remains in the cylinder, it decreases the mass of vapour that can flow into the cylinder from the evaporator.

For these reasons, the compressor cylinder cannot be filled with a volume of vapour equal to its piston displacement plus the clearance volume. However, in practice, the clearance volume remains constant during suction and compression strokes. This does not affect the net work done by the compressor, but it does affect the volumetric efficiency. The total effect of the various factors that contribute to decrease the mass of refrigerant vapour that flows into a cylinder cannot be computed exactly. It is necessary to run tests on compressors to determine the actual flow rate of vapour into a cylinder under operating conditions. From such tests, it is possible to measure the actual mass of vapour that can flow into the cylinder and compare it to the theoretical mass flow rate:

$$\text{Volumetric efficiency} = (\text{actual mass}/\text{theoretical mass}) \times 100\%$$

Example 5

The theoretical mass of refrigerant moved in the compressor in Example 4 was 1.48 kg/min. If the compressor has a volumetric efficiency of 75%, then what is the actual mass moved?

Solution 5

Transposing:

$$\begin{aligned} \text{Volumetric efficiency} &= (\text{actual mass}/\text{theoretical mass}) \times 100\% \\ \text{Actual mass} &= \text{volumetric efficiency} \times \text{theoretical mass} \\ &= 0.75 \times 1.48 \text{ kg/min} \\ &= \mathbf{1.11\ kg/min\ (Ans.)} \text{ or } \mathbf{2.44\ lb./min} \end{aligned}$$

Thus, the actual refrigerating effect of this system will be considerably less (25% less) than its theoretical refrigerating effect.

Pressure Ratio

Compression ratio is defined as the clearance volume plus the piston displacement (between top and bottom dead centres) divided by the clearance volume.

Pressure ratio is defined as the compressor cylinder discharge pressure divided by the suction pressure. Absolute pressures must be used.

Note that a pressure gauge mounted on a compressor will indicate zero pressure when connected to a system under only atmospheric pressure. To find the absolute pressure in a system, add approximately 101 kPa (more precisely, the local atmospheric pressure at the time of observation) to the gauge pressure.

Example 6

What is the pressure ratio if the gauge pressure at a compressor discharge indicates 1120 kPa (162 psi) and the suction pressure gauge indicates 70 kPa (10 psi)?

Solution 6

$$\text{Pressure ratio} = \frac{\text{discharge pressure + atmospheric pressure}}{\text{suction pressure + atmospheric pressure}}$$

$$= \frac{1120\ kPa + 101\ kPa}{70\ kPa + 101\ kPa}$$

$$= \frac{1221\ kPa}{171\ kPa}$$

$$= \mathbf{7.14\ (Ans.)}$$

Note that the compression ratio is **not** equal to the ratio of the discharge gauge pressure to suction gauge pressure.

In everyday plant use, *compression ratio* is often used interchangeably with *pressure ratio,* but they are different. In more advanced compression calculations, beyond the scope of this course, they cannot be interchanged.

A compressor should be operated at its designed pressure ratio for highest operating efficiency. An increase in the pressure ratio will result in higher discharge temperatures and larger power consumption. Higher temperatures will also accelerate the chemical reaction of materials such as lubricating oil and oxygen, resulting in higher maintenance costs.

Objective 5

Describe how refrigerants are classified.

Refrigerant Identification and Classification

There are hundreds of refrigerants available; however, only a few are widely used in modern residential, commercial, industrial, and institutional refrigerating and air conditioning systems. It is important to know the chemical and physical properties of refrigerants in order to compare them. The appropriate refrigerant must be used for particular applications. Therefore, it is important to refer to refrigerants consistently so they are properly identified.

Refrigerants are categorized according to flammability and toxicity, then placed in a safety group. Refrigerants are also classified according to their:

a) Impact on the environment

b) Chemical origins

c) Operating temperature suitability

ASHRAE Designation

Table 4 shows the various ways to identify refrigerants, including the following:

- ASHRAE designation
- Chemical formula
- Chemical name
- Trade name

Table 4 lists common refrigerants designated by ASHRAE. ASHRAE denotes refrigerants with the capital letter *R* followed by a dash and a number. There are well over 300 ASHRAE-designated refrigerants and refrigerant blends. Many of these refrigerants are used only in very small amounts, in special laboratory equipment.

Table 4 – Common Refrigerants and Their Use

Common or trade name	ASHRAE number	Chemical name Chemical formula	Temperature class	Common uses
Suva 123	R-123	2,2-Dichloro-1,1,1-trifluoroethane $CHCl_2CF_3$	High temperature (evaporator temperature above 0°C)	Large-scale low-pressure chillers (HVAC)
Suva 134a	R-134a	1,1,1,2-Tetrafluoroethane CH_2FCF_3	High temperature (evaporator temperature above 0°C) to medium temperature (0°C to −25°C)	Domestic, automotive, large-scale, high-pressure chillers (HVAC)
Ammonia	R-717	Ammonia NH_3	Low temperature (evaporator temperature −25°C to −50°C) to very low temperature (below −50°C)	Cold storage, icemaking, flash-freezing
Freon 22	R-22	Chlorodifluoromethane $CHClF_2$	High temperature (evaporator temperature above 0°C) to medium temperature (0°C to −25°C)	Domestic, automotive, large-scale, high-pressure chillers (HVAC), icemaking
Carbon Dioxide	R-744	Carbon dioxide CO_2	High temperature (evaporator temperature above 0°C) to very low temperature (below −50°C)	Industrial, commercial, automotive

Safety Group

The **Canadian Standards Association (CSA) B52 Mechanical Refrigeration Code** classifies refrigerants into six groups, according to their toxicity and flammability. This designation is based upon **ASHRAE Standard 34**.

Table 5 shows the **ASHRAE Standard 34** eight-group designation. **CSA-B52** combines A2L with A2, and B2L with B2.

Table 5 – Refrigerant Safety Classification, according to ASHRAE 34

	Safety group (example)	
Higher flammability	**A3** (R-290 propane)	**B3** (R-1140 vinyl chloride)
Lower flammability	**A2** (R-406a)	**B2** (R-40 chloromethane)
Lower flammability, with a maximum burning velocity of ≤ 10 cm/s	**A2L** (R-32 difluoromethane)	**B2L** (R-717 ammonia)
No flame propagation	**A1** (R-134a)	**B1** (R-123)
	Lower toxicity	**Higher toxicity**

Group A1 refrigerants are refrigerants that are nontoxic and nonflammable. Other examples for this group are R-22 (chlorodifluoromethane) and R-744 (carbon dioxide).

ASHRAE separates Group A2 refrigerants into two categories: A2 and A2L. Both categories are considered lower flammability refrigerants. However, A2L refrigerants have a lower burning velocity, and so present a somewhat lower flammability hazard. Both A2 and A2L refrigerants have low toxicity. Other examples for A2 are R-142b (1-chloro-1,1-difluoroethane) and R-152a (1,1-difluoroethane). Other examples for A2L are R-1234ze (1,3,3,3-tetrafluoropropene) and R-1234yf (2,3,3,3-tetrafluoropropene).

Group A3 refrigerants are highly flammable with low toxicity. Other examples for this group are R-600 (butane) and R-170 (ethane).

Group B1 refrigerants are nonflammable and highly toxic. Other examples for this group are R-764 (sulfur dioxide) and R-245fa (1,1,1,3,3-pentafluoropropane).

Group B2 is separated into two categories: B2 and B2L. Both categories are considered lower flammability refrigerants. However, like A2L refrigerants, B2L refrigerants have a lower burning velocity and present a somewhat lower flammability hazard. Both B2 and B2L refrigerants are highly toxic. Examples for this group are R-717 (ammonia) and R-611 (methyl formate).

Group B3 refrigerants are highly flammable and highly toxic. R-1140 (vinyl chloride) is the example given in Table 5.

Environmental Impact

Perfectly sealed refrigeration systems should allow no ingress of air into the system, and (more importantly) no leakage of refrigerant from the system. However, leaks are inevitable. Leaking refrigerant may have considerable environmental impact on the Earth's ozone layer, and on global warming.

Ozone Depleting Potential (ODP)

A number of refrigerants have been shown to have negative effects on the environment. Those with the greatest environmental impact are chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs). Both of these have been implicated in the depletion of the earth's ozone layer. The ozone layer protects the natural environment from the harmful effects of ultraviolet light.

Worldwide reduction in the production and use of CFCs and HCFCs has taken place since the **Montreal Protocol on Substances that Deplete the Ozone Layer** went into force in 1989. Since then, this treaty (intended to protect the ozone layer) has been ratified by over 160 countries.

Both Canada and the USA have instituted progressive measures to meet the requirements for phasing out the production, import, and use of CFCs and HCFCs. Certain ASHRAE-designated refrigerants are no longer in production, due to their high **ODP**. Phased-out refrigerants include R-11 and R-12 (commonly called by their trade names: Freon 11 and Freon 12).

Refrigerants are ranked according to their **ozone depleting potential**. Some refrigerants with medium ozone-depleting potential, such as R-22, are still being produced but will eventually be phased out.

Global Warming Potential (GWP)

Some refrigerants have been shown to be greenhouse gases. They are rated according to their global warming potential. Refrigerants with a high GWP, such as R-12, are being phased out. Oddly enough, CO_2 (R-744) is considered to have zero GWP. This is because, unlike combustion equipment, refrigeration systems do not produce CO_2. They merely store CO_2 that originated in the atmosphere. Releases of CO_2 refrigerant to the environment are therefore neutral in their effect on global warming.

Natural Refrigerants

Natural refrigerants occur naturally in the environment. They include R-717 (ammonia), R-744 (CO_2), and R-718 (water). These refrigerants are popular because they have less impact on the environment. Ammonia is particularly desirable from an environmental standpoint because it is an energy efficient refrigerant, with zero ODP and zero GWP.

Chemical Origins

Some hydrocarbon compounds are excellent refrigerants, although they are highly flammable. An example is R-290 (propane). Propane, butane, ethane, and other hydrocarbons are called *hydrocarbon refrigerants.* Therefore, propane is also called HC-290.

Many refrigerants begin as hydrocarbon compounds, but they are chemically modified to achieve certain physical properties. Some refrigerants are based on the methane molecule (CH_4). Others are based on ethane (C_2H_6). These methane and ethane molecules are chlorinated or fluorinated, or may contain both. The resulting refrigerants are called CFCs, HFCs, and HCFCs.

CFCs are chlorinated fluorocarbons and include the phased-out refrigerants R-11 and R-12. Because they are chlorinated, they have high ODP.

HCFCs are hydrochlorofluorocarbons. They have less environmental impact than CFCs. HCFCs include R-22 and R-123, which are both designated for phase-out due to their ODP.

HFCs are hydrofluorocarbons. They are not chlorinated, so they have no ODP. However, they may still have GWP. An example of an HFC in common use is R-134a.

The elements chlorine and fluorine are in an elemental group called **halogens**. Collectively, CFCs, HFCs, and HCFCs are called **halocarbons**.

Operating Temperature

Due to their physical properties, refrigerants may be more suited to one application than another. One consideration may involve how easily a refrigerant will achieve the desired system evaporator temperature. Some refrigerants, such as R-717, can easily achieve the low temperatures required for a deep-freeze. Others, such as R-123, cannot, even when operating at a deep vacuum. However, R-123 is well suited for chilling water to a few degrees Celsius, for use cooling commercial buildings.

Table 4 above shows typical temperature ranges and applications for the listed refrigerants.

Physical and Chemical Properties of Refrigerants

Refrigerants vary widely in physical and chemical properties. In order to be suitable for use in a refrigerating system, the ideal refrigerant should possess certain properties. These include the following:

a) A low boiling point at atmospheric pressure
b) A high latent heat capacity; it should require a large amount of heat to convert it from a liquid to a gas after its saturation temperature has been reached
c) A fairly low condensing (high-side) pressure
d) An inoffensive odour, but still be easy to detect
e) A non-toxic nature
f) A noncorrosive action on metals
g) A non-flammable and nonexplosive nature when mixed with air
h) A low vapour specific volume
i) A low liquid density
j) Low environmental impact

As well, the refrigerant should be inexpensive to purchase. However, no single refrigerant meets all these criteria. Any refrigerant selection, therefore, involves compromise.

Objective 6

Describe the thermodynamic properties of refrigerants.

Thermodynamic Properties of Refrigerants

Thermodynamic properties are the physical properties that directly affect the movement of heat. These properties are pressure, temperature, volume, density, enthalpy, and entropy.

There are tables and charts for the thermodynamic properties of R-717, R-134a, R-123, and R-744 in the **PanGlobal Academic Supplement.** Refer to these tables while studying this objective.

A S

A discussion of the various refrigerant properties follows. Comparisons between properties are provided. It will become obvious how much refrigerants differ from one another and that no single refrigerant is ideal for all purposes. Differences in thermodynamic properties is what makes one refrigerant more suitable for an application than the other ones.

Refrigerant Properties at Standard Operating Conditions

Table 6 shows the boiling point, at atmospheric pressure (101.3 kPa), of the refrigerants listed in Table 1. Note that some refrigerants boil well below 0°C, the freezing point of water, while others boil above 0°C.

Table 6 also compares the thermodynamic properties of these common refrigerants at standard operating conditions of −15°C evaporator temperature, and 30°C condenser temperature.

Careful review of Table 6 reveals significant differences in the properties of these refrigerants.

Table 6 – Comparison of Thermodynamic Properties of Common Refrigerants at Standard Conditions

	R-134a (Suva 134a)	R-123 (Suva 123)	R-717 (ammonia)
Boiling point at 101.3 kPa absolute	−26.1	27.7	−33.3
Evaporating pressure (kPa abs.) at −15°C	163.9	15.7	236.2
Condensing Pressure (kPa abs.) at 30°C	770	110	1167
NRE at standard conditions (kJ/kg)	147.9	142.2	1102.6
Specific volume of vapour (m^3/kg) at −15°C	0.1207	0.8848	0.5087
Density of liquid (kg/m^3) at 30°C	1187.5	1451	595.2

Pressure-Temperature Relationship

Note that R-123 boils at 27.7°C at atmospheric pressure. An R-123 chiller, then, must operate with its evaporator well below atmospheric pressure. In fact, at −15°C, the evaporator is at 15.7 kPa absolute pressure. This is the reason R-123 is termed a high-temperature refrigerant. It is suitable for HVAC use, but not well suited for industrial cold storage freezers or ice making. Because of the low evaporator pressure, air may leak into the refrigeration circuit; therefore, air purgers are installed, so that air is continuously removed from these systems.

Also, note the condensing pressures. R-123 has a low pressure at 30°C. The refrigeration equipment is considered low pressure by many jurisdictions. Therefore, it may not require a Power Engineer. Both R-717 and R-134a have a high condensing pressure at 30°C. Large plants using these refrigerants generally require full-time operation by Power Engineers. Note also that R-717 has the highest condensing pressure of the three listed. The high-side equipment of R-717 systems (and R-134a systems) must be rugged and built according to **ASME BPVC VIII** and **ASME-B31.5.**

Table 6 compares how the operating pressures of different refrigerants vary with temperature. This is important since the operating pressure determines the strength of the equipment required, cost of construction, and operator staffing requirements for a particular refrigerant. A consideration when choosing a refrigerant is that it should have a low condensing pressure. As well, evaporators should preferably operate above atmospheric pressure to prevent air and moisture infiltration, which causes operational problems.

Specific Volume

Table 6 gives the specific volumes (in m^3/kg) of refrigerant vapour at −15°C. The R-717 vapour has the lowest specific volume. This means that a refrigeration compressor in an R-717 system can have a smaller displacement than a compressor for R-123 or R-134a in a system of similar capacity. As well, suction lines for an R-717 system can be made smaller in diameter, for a given mass of refrigerant circulated, than an R-123 or R-134a system.

Density

Refrigerant liquid density (in kg/m^3) indicates how heavy the liquid lines will be, which is important for the design. The density is also used to calculate the required size of control valves and piping. Table 5 shows that R-717 is not a very dense liquid in comparison to R-123 and R-134a. In fact, liquid ammonia is less dense than water.

Refrigerating Effect

Finally, examine the NRE of each refrigerant listed in Table 6. The NRE is the heat absorbed in the evaporator under standard operating conditions. R-717 is the most effective at transferring heat in the evaporator. In fact, R-717 removes over seven times the heat, per kilogram of refrigerant, than R-123 or R-134a.

Table 7 – Comparison of Thermodynamic Properties of Common Refrigerants at Standard Conditions

SI units				USCS units			
Temp.	Pressure (kPa absolute)			Temp.	Pressure (psia)		
(°C)	R-134a	R-123	R-717	(°F)	R-134a	R-123	R-717
−15	163.9	15.7	236.2	5	23.8	2.3	34.3
−10	200.6	20.2	290.7	15	29.7	3.0	43.1
−5	243.3	25.8	354.8	25	36.8	4.0	53.7
0	292.8	32.6	429.4	35	45.1	5.1	66.3
5	349.7	40.8	515.8	45	54.7	6.5	81.0
10	414.6	50.6	615.1	55	65.9	8.2	98.1
15	488.4	62.1	728.5	65	78.7	10.3	117.9
20	571.7	75.6	857.5	75	93.4	12.7	140.6
25	665.4	91.4	1003.2	85	109.9	15.6	166.5
30	770.2	109.6	1167.2	95	128.7	18.9	195.9

Enthalpy

The refrigeration tables and steam tables in the **PanGlobal Academic Supplement** use the same abbreviations for enthalpy at various states.

- h_f: is the enthalpy of saturated liquid
- h_g: is the enthalpy of saturated vapour
- h_{fg}: is the latent heat of evaporation of the refrigerant, which is equal to h_g minus h_f

Remember that these three properties are thermodynamic characteristics that are specific to every refrigerant, and that vary with the pressure and temperature of that refrigerant.

The values in the refrigeration tables are used to determine net refrigerating effect, pressure ratio, and COP. As well, the tables provide the information necessary to calculate the following:

- Work done in compression
- Heat rejected by the condenser
- Mass of refrigerant circulated per tonne of refrigeration
- Compressor displacement

There are many other advanced calculations that can be performed; however, these are beyond the scope of this resource.

Objective 7

Describe the properties of refrigerants relating to miscibility, leakage tendency, odour, moisture reaction, toxicity, and flammability.

Physical properties of refrigerants

The important physical properties of a refrigerant are as follows:

- **Miscibility**
- Leakage tendency
- Odour
- Toxicity
- Flammability/explosiveness
- Moisture reaction

Table 8 – Comparison of Physical Properties of Common Refrigerants

	R-134a (Suva 134a)	R-123 (Suva 123)	R-717 (ammonia)
Flammable	No	No	Slightly
Explosive when mixed with air	No	No	Yes
Toxic	No	Yes	Yes
Corrosive to metals in the presence of water	No	No	Corrosive to copper and copper alloys.
Effect of contact with food	None	None	Spoils taste, may cause toxicity.
Effect on lubricating oil	Incompatible with mineral oil. miscible with polyo ester oil.	Moderately miscible with mineral oils.	Nonmiscible. compatible with mineral oil.
Odour	Slightly sweet odour	Slight, ether-like odour.	Strong and offensive.

Miscibility

Miscibility refers to how soluble two or more liquids are when mixed together in all proportions. Some refrigerants are entirely miscible with lube oil. Some are partially miscible. Some are not miscible at all.

Refrigerants come in contact with lube oil in the compressor crankcase, cylinder walls, and screws. The refrigerants then carry some of this oil into other parts of the system. Miscibility is dependent on the type of refrigerant and the type of lube oil. Lube oils are categorized as conventional mineral-based oils and synthetic polyolester oils. Most halocarbon refrigerants are miscible with one or the other. Ammonia, however, is not miscible with any lube oil.

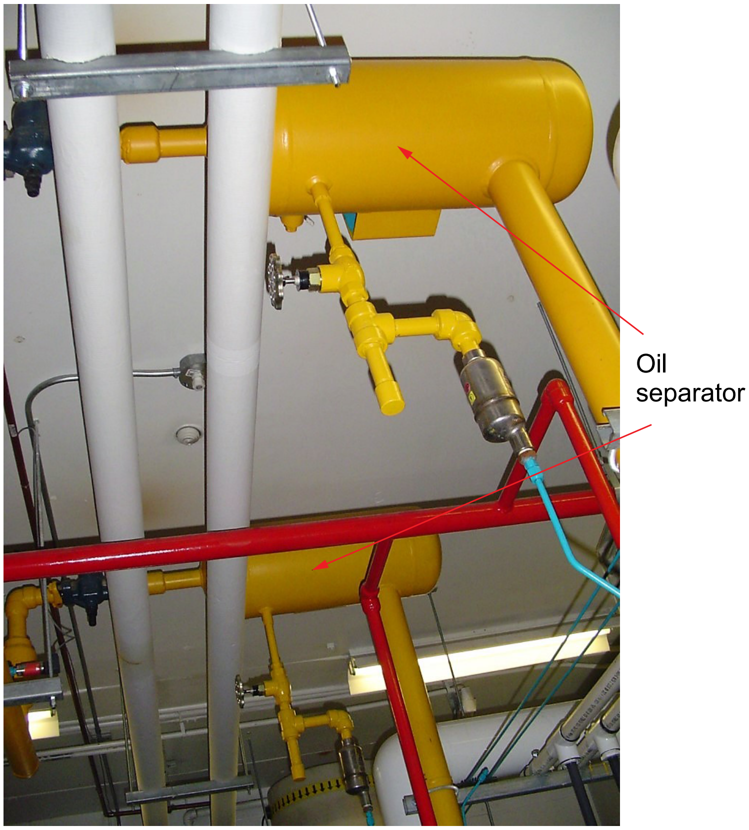
Oil-miscible refrigerants dilute compressor crankcase oil. This lowers the viscosity and lubricating ability of the oil. There needs to be an allowance for this when selecting a lubricating oil.

The oil carried into the condenser and evaporator coats the heat transfer surfaces. This tends to be an insulating coating, which reduces evaporator and condenser capacity.

When oil-miscible refrigerants are used, the refrigerant will dissolve most of the oil in the system components and return it to the compressor. This avoids problems with heat exchange or oil blockage.

When non-miscible refrigerants are used, the oil tends to build up in the evaporator and the condenser. This reduces system capacity, and eventually blocks the evaporator tubing. Therefore, ammonia systems require oil separators and oil return systems. These remove oil from the piping and other low points in the system, and return the oil to the compressor. Figure 11 shows oil separators installed on the compressor discharge piping in an ammonia refrigeration plant.

Figure 11 – Oil Separators



Due to the possible need for oil separators and oil return lines, the miscibility of the refrigerant used is an important design consideration for refrigeration systems. Miscibility also affects the size of the piping. In order to prevent oil from settling in the evaporator tubing, the pipe size must be able to maintain a sufficiently high refrigerant velocity.

Odour

In large concentrations, refrigerants in the halocarbon group have a slight odour that resembles ether. In low concentrations, they are practically odourless. Other refrigerants, such as ammonia, have a strong, pungent smell.

A slight odour is advantageous, because it makes small leaks easier and quicker to detect. Repairs can then take place before all refrigerant is lost. A strong, pungent odour is quickly noticeable, even when escaping from a minor leak. If detected in a place of public assembly, such as an arena, even a small ammonia leak may cause panic.

Flammability/Explosiveness

Flammable and explosive refrigerants require special consideration as to how and where to use them. Typically, flammable and explosive refrigerants, such as R-290 (propane), are limited by **CSA B52** code to industrial sites. These locations are likely to employ full-time system supervision. They also have specialized explosion-proof electrical equipment (including explosion-proof light switches, lamps, heaters, transformers, and motors).

Of the refrigerants listed in Table 8, only ammonia supports combustion. It is explosive in concentrations between 15% and 28% by volume in air.

Toxicity

As previously mentioned, refrigerants are divided into groups according to toxicity. Although refrigerants in the chlorofluorocarbon group are not toxic except in high concentrations, when exposed to a flame, they react and decompose, producing highly toxic products. When a halide torch is used for leak detection, ample ventilation should be provided.

CAUTION

Even non-toxic refrigerants can kill. If a substantial leak occurs, the refrigerant vapour displaces air. Cold refrigerant vapour is usually denser than air, so pockets of refrigerant gas may accumulate in low-lying areas. These areas must be properly ventilated; otherwise, anyone entering these areas could die of asphyxiation. Therefore, all refrigeration plants must have appropriate leak detection systems, ventilation systems, and breathing apparatus.

Leakage Tendency

Many factors determine the leakage tendency of a refrigerant. These factors include operating pressure, viscosity, density, and the chemical's effects on seals and gaskets. Leakage tendency also depends on the molecular mass of the refrigerant. The greater the molecular mass, the larger the molecule, and the less able it is to escape through tiny openings.

Moisture Reaction

Moisture will combine in varying degrees with most of the commonly used refrigerants. CFCs, HFCs, and HCFCs absorb only small amounts of moisture. Ammonia, however, readily absorbs moisture.

At high temperatures, refrigerants are able to absorb a greater percentage of moisture than at low temperatures. This means that when a warm moisture-saturated refrigerant is cooled to a lower temperature (e.g., in the evaporator), it will produce free water.

Moisture in the refrigerant should be avoided for three reasons:

1. When present in the liquid refrigerant, moisture may cause ice to form between the valve and valve seat of the metering device when the liquid is reduced in pressure and temperature as it enters the evaporator. This causes improper operation of the metering device.
2. When present in the system, moisture may also cause acid to form. Acid can result in corrosion, sludge forming in the compressor crankcase, and deterioration of the electric motor insulation in hermetic compressors.
3. In ammonia refrigeration systems, ammonia combines with water to form ammonium hydroxide, which is highly corrosive to copper and its alloys. For this reason, ammonia systems must **NEVER** use components made of copper or copper alloys.

Chapter Summary

This chapter introduced basic refrigeration terminology. Refrigeration was discussed from its fundamental principles. From these principles, vapour compression refrigeration processes were explained.

Refrigeration processes – both theoretical and actual – were illustrated with simple schematics and p-h diagrams. As well, refrigeration system capacity was discussed and calculated using both SI and USCS units.

Refrigeration tables and p-h diagrams were used to find information for calculations, including NRE. The concepts of coefficient of performance and pressure ratio were also introduced.

The last three objectives examined refrigerants in detail, including the following topics:

- How to identify them
- Their thermal properties
- Their physical properties
- Their behaviour

CHAPTER 2

Compression Refrigeration Systems

Learning Outcome

When you complete this chapter you should be able to:

Describe the operating principles of compression refrigeration systems.

Learning Objectives

Here is what you should be able to do when you complete each objective:

1. *Describe the basic layout of compression refrigeration systems.*
2. *Distinguish between direct and indirect refrigeration systems.*
3. *Describe the layout of packaged refrigeration systems and the role of a refrigeration economizer.*
4. *Describe the special types of refrigeration compressors, including how they are similar to and different from air compressors.*
5. *Describe the special designs of refrigeration system evaporators and condensers.*

Chapter Introduction

As previously defined, refrigeration may be broadly described as:

> The controlled process of cooling or removing heat from a substance. It then maintains the temperature of that substance below the temperature of the surrounding atmosphere.

In order to evaporate a liquid, there must be a supply of latent heat to bring about the change of state from liquid to a gas. One of the earliest methods of refrigeration made use of this process. It was found that water could be cooled by placing it in porous jars. The moisture seeping through the jars evaporated. This cooled the water that remained inside the jar.

Another early method of refrigeration involved the use of ice, which was kept in insulated storehouses. When placed in an ice chest, the melting ice absorbed heat from the substances placed inside of it, and lowered the temperature in the chest to near 0°C. Ice is still used to some extent for refrigeration; however, the disadvantages are that ice cannot cool below 0°C, and it must be replenished after it melts.

Modern refrigeration systems make use of thermodynamic principles:

- Heat moves naturally from hot to cold.
- There is a direct relationship between pressure and boiling point.

By decreasing the pressure exerted on a refrigerant, its boiling point decreases, and it will absorb latent heat of evaporation from its surroundings. After evaporating, the refrigerant is pressurized, and returns to its liquid state by discarding latent heat. Because this process involves the use of machinery, it is called mechanical refrigeration.

Most refrigeration systems work on the closed cycle principle. In the closed cycle system, the vapour from the evaporator is collected continuously. This vapour is then compressed, condensed, and returned to the evaporator so that the same refrigerant is used over and over again.

Closed cycle refrigerating systems are divided into two classes, based on the method used to raise the pressure of the refrigerant after it leaves the evaporator. The two classes are:

- Compression system
- Absorption system

This chapter will cover only the compression system.

Before starting this chapter, review the **4th Class** unit on **Pumps and Compressors (Part B, Unit 2)**, especially **Chapter 3 – Introduction to Compressors.**

Objective 1

Describe the basic layout of compression refrigeration systems.

Operators must know the components of the refrigeration systems they run. For the plant to meet performance expectations, the manufacturer design operating parameters must be observed and followed. This objective introduces the equipment common to most mechanical compression systems.

Closed Cycle Compression Refrigeration System

A closed-cycle compression refrigeration system, such as that shown in Figure 1, consists of the following principal parts:

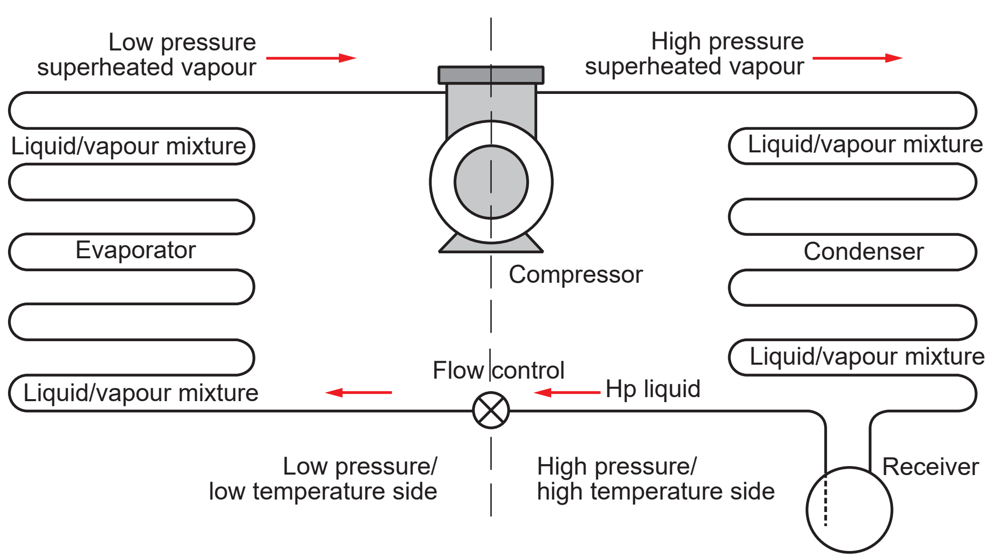
- Evaporator
- Compressor
- Condenser
- Metering device (Liquid refrigerant control or regulating valve)
- Liquid receiver

The centre line divides the system into two sections: a high side and a low side.

The high side contains refrigerant at high pressure and high temperature. The refrigerant leaving the compressor is high-pressure superheated gas. The refrigerant in the condenser is in both states: liquid and gas. In the condenser, the refrigerant is at saturation temperature and pressure. The refrigerant leaving the condenser is high pressure, high temperature liquid. The refrigerant entering the metering device is high pressure and high temperature, but subcooled a few degrees.

The low side contains refrigerant at low pressure and low temperature. The refrigerant leaving the metering device is low pressure saturated liquid and flash gas. The refrigerant in the evaporator is in both states: liquid and gas, at saturation temperature and pressure. The refrigerant leaving the evaporator is low pressure, low temperature gas. The refrigerant entering the compressor device is low pressure and low temperature, but superheated to a certain extent.

Figure 1 – Simple Compression Refrigeration System



Therefore, the low side of the system includes all equipment downstream of the metering device:

- The evaporator
- The suction side of the compressor
- All interconnected tubing and piping

The design pressure of the low side is determined by the temperature requirements for the cooled medium. For example, a deep-freeze would be designed for relatively low refrigerant gas pressure.

The high side consists of:

- The compressor discharge
- The condenser
- The liquid receiver
- The piping on the upstream side of the metering device
- Connected tubing and piping

The high side design pressure is determined by the required condensing temperature of the refrigerant vapour, which depends on the temperature of the available condensing medium.

It is also important to remember that the heat removed from the refrigerant by the condensing medium is equal to the heat added to the refrigerant in the evaporator plus the work done on the refrigerant by the compressor. This is the basic energy flow in the compression refrigeration system.

Industrial refrigeration systems are expanded versions of this simple system. Additional equipment found in industrial systems may include all or some of the following:

Multiple evaporators. Some plants have more than one cooling requirement. For example, one room may flash-freeze product to –40°C. Another room may be used for long-term storage at –10°C. Another room may store fresh produce at 3°C. Each of these rooms will have its own evaporator, operating at different pressures than the other two.

Multiple compressors. Many plants have multiple compressors, for the same reason that many plants have multiple boilers. Plants need redundant compressors, in case one compressor fails. As well, multiple compressors may be required to meet the entire load range of the plant. For example, at the beginning of the skating season, additional compressor capacity is required to make ice. In fall and spring, the required refrigerating capacity is greater, due to the warmer weather. In mid-January, most ice plants have adequate cooling capacity running a single compressor. Other plants use booster compressors to achieve the low temperatures and pressures for the coldest evaporators in the system.

Multiple condensers. Many plants have multiple condensers for redundancy. If one condenser fails, the plant can continue to operate. Depending on the required condenser tonnage, the plant may need to operate at a lower capacity, though.

Isolation and servicing valves. Refrigeration plants need valves to isolate evaporators, condensers, receivers, and compressors to service and repair system components. Emergency discharge valves release all the refrigerant from the system in the event of an emergency. Other valves are used for adding or reclaiming refrigerant from a system.

Safety valves and safety limit controls. Refrigerant systems are comprised of pressure piping and pressure vessels. As such, they require overpressure protection.

Operating temperature and temperature limit controls. Temperature controls may be used to control the temperature of a refrigerated space, a cooled medium, or compressor discharge pressure. Temperature limit controls may be used to prevent the freezing of cooled medium, such as chilled water.

Pressure regulating valves. In systems with multiple evaporators, pressure-regulating valves can be installed to maintain an evaporator temperature set point.

Compressor protective devices. The devices that fall under this category include oil pressure cut-off switches; cooling water temperature controls; high discharge temperature and pressure cut-off switches; and safety valves. Also, for systems with oil-miscible refrigerants, compressors are equipped with crankcase heaters. These heaters drive dissolved refrigerant from the oil, to keep the oil from foaming. Otherwise, the foam will starve the lube oil pump in the compressor, and cause bearing failure.

Heat exchangers, intercoolers, and economizers: These pieces of equipment are used to improve cycle efficiency.

Objective 2

Distinguish between direct and indirect refrigeration systems.

Mechanical refrigeration systems are categorizes as direct and indirect. Each of these systems is in common use. The **CSA B52 Mechanical Refrigeration Code** describes these systems and their variations.

Direct Systems

The **direct system** is one in which the evaporator surface is in direct contact with the material or space being refrigerated. Household refrigerators and air conditioners are examples of direct systems. These have evaporators that transfer heat directly from the cooled medium or refrigerated space. If an evaporator, piping joint, or fitting developed a leak, refrigerant could enter the occupied space. If the refrigerant was toxic or flammable, an unsafe situation would arise.

Direct refrigeration systems are often called direct expansion (or DX) systems. Evaporators used in DX systems are often called DX coils.

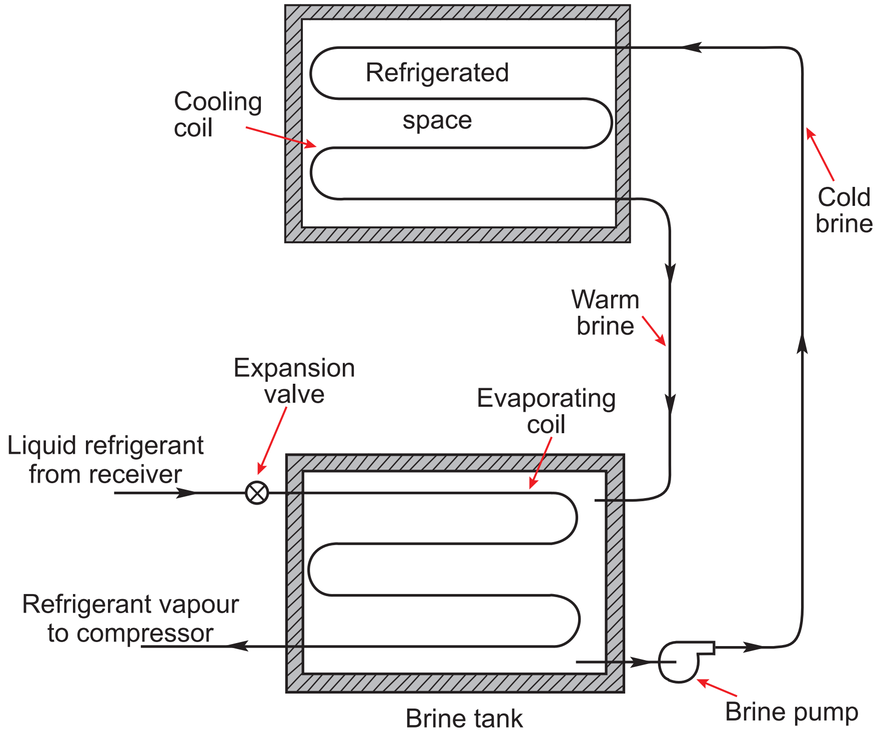
Indirect Systems

An **indirect system** is one in which a liquid, such as **brine**, glycol, or water, is cooled by the refrigerant and then circulated by means of a pump to the material or space being refrigerated. One advantage of this type of system is that hazardous refrigerants can be used to cool the brine. The parts that contain refrigerant are located in a machinery room, separate from the occupied space. If a refrigerant leak occurs, it cannot readily proceed from the machinery room into the occupied space.

Indirect systems are also cost-saving designs. Rather than filling the entire cooling system with expensive refrigerant, most of the system is filled with chilled water or brine, which is far less costly. The chilled water or brine transfers heat from the occupied space, and reduces the amount of refrigerant required for an initial charge

Figure 2 shows the arrangement of an indirect system. The evaporator coils are located within a tank of brine. The refrigerant evaporates within the coils, cooling the brine. The cold brine is then pumped through coils located within the refrigerated space. The brine absorbs the heat from this space, and then circulates back to the brine tank to be cooled once again.

Figure 2 – Indirect Refrigeration System



On Track

Evaporators, used to cool water or brine, are called chillers.

This method is commonly used for ice rinks. Chillers cool the brine (a salt or glycol solution) to about –11°C (12°F) to freeze the ice surface. The most common brine used for this service is a solution of calcium chloride. Depending on the concentration, calcium chloride brine can be cooled as low as –51°C (–60°F) without freezing.

Indirect refrigeration systems are frequently used in larger air conditioning systems. Water is often used instead of brine as the heat transfer medium in these applications.

The water is cooled in a chiller. The water then circulates through cooling coils, over which air passes. Since the air is not cooled any lower than 13°C (55°F), the temperature of the chilled water can be kept high enough to prevent freezing. Normally, the chilled water temperature is kept at or above 5°C.

Objective 3

Describe the layout of packaged refrigeration systems and the role of a refrigeration economizer.

Packaged Ice Rink Plant

Except for the externally mounted condenser, all the ice rink equipment for the packaged rink plant is on a skid.

Figure 3 – Ice Rink Packaged Plant

(Courtesy of Whitelaw Agricultural Society, Curling Club)

The plant shown in Figure 3 has the compressor, evaporator, liquid receiver, and necessary controls mounted on a skid. The compressor and its electric drive motor are in the foreground. A control panel is on the left hand side of the skid. The control panel contains the motor starter for the compressor, the start and stop pressure controls, the high pressure cut out, and the compressor low oil pressure cut-off.

The two large tanks at the rear of the skid contain brine, which is pumped through the concrete slab beneath the ice surface, by the brine pump. The uninsulated pressure vessel at the rear of the skid is the liquid receiver. An uninsulated pipe carries refrigerant liquid through a solenoid liquid shut-off valve and a metering device (a thermostatic expansion valve), and into the chiller. The chiller (evaporator) is the black insulated vessel behind the compressor, and below the receiver.

The brine pump keeps the brine in constant circulation. When the return brine temperature exceeds the brine set point temperature, the solenoid valve opens. This allows liquid refrigerant to enter the evaporator to cool off the brine.

When the evaporator pressure rises, the compressor starts. The compressor draws the refrigerant vapour off the top of the evaporator through the suction line (the black insulated pipe that leads to the compressor). The compressor discharges high pressure, high-temperature vapour to the condenser, which is located outside. The condenser converts the vapour to liquid. The liquid refrigerant then flows to the liquid receiver.

Different activities require different ice temperatures. Table 1 shows the required ice surface temperatures.

Table 1 – Ideal Ice Rink Temperatures

Activity	Ideal Temperature °C
Hockey	−6 to −4
Public Skating	−4 to −3
Figure Skating	−4 to −3
Ice Maintenance	−3 to −2
Curling	−4 to −3

Packaged Centrifugal Water Chillers

The main components of a refrigerating plant can be ordered and installed separately. These components include the compressor, evaporator, condenser, and liquid receiver. However, it is common practice to use factory assembled packaged units. These units come packaged on a single skid, with many components of the refrigerating system. This is especially true for chilled water systems with water-cooled condensers used for air conditioning systems.

There are many advantages to a packaged refrigeration unit. In order to obtain the greatest operating efficiency, the components of this system match each other. The unit is very compact, with all the components mounted on a single frame, which keeps space requirements to a minimum. Units are equipped with all the required auxiliary equipment, such as gauges and controls. This makes them easy and quick to install. The unit is factory tested and the manufacturer takes full responsibility for design and performance, provided it is installed according to their recommendations.

Figure 4 shows a diagram of the basic flow of a centrifugal unit. The economizer, installed between the condenser and chiller (evaporator), is of particular interest. The economizer has several functions:

- It produces flash gas to cool the compressor motor.
- It increases the net refrigerating effect (NRE) of the evaporator.
- It reduces the power consumption of the compressor.

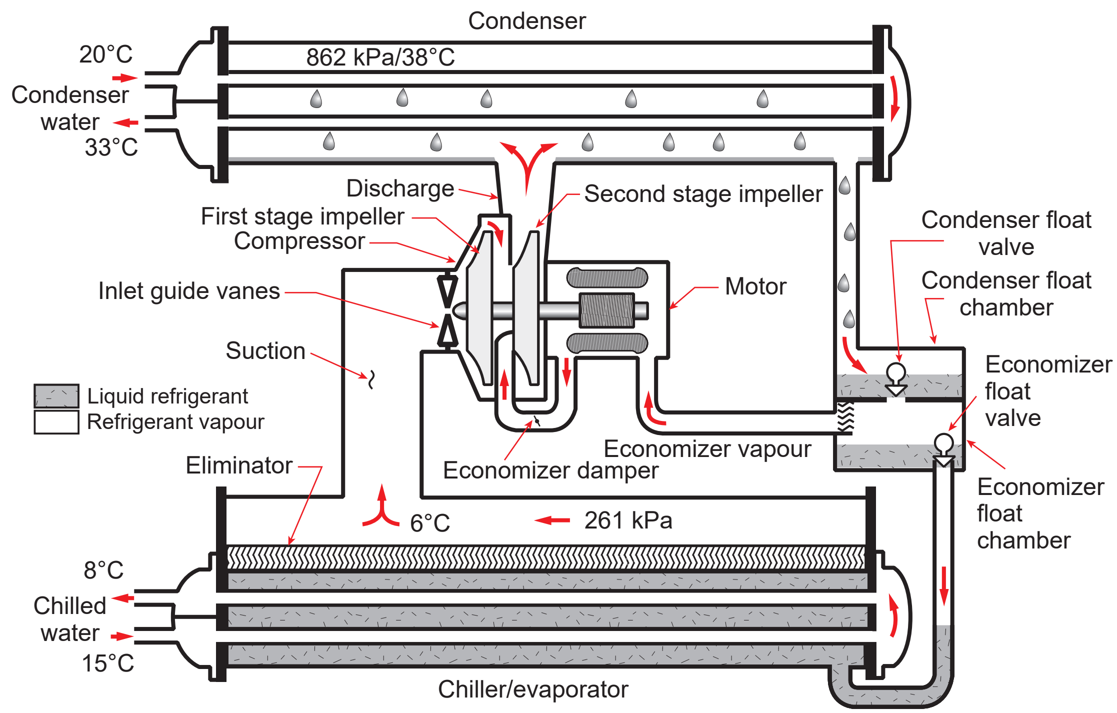
Liquid/vapour refrigerant flows from the condenser, through the economizer, and into the chiller. The economizer is a chamber with two float valves in series. Pressure and temperature drop across each valve.

The flash gas produced after the first float valve is at the pressure and temperature of the refrigerant at the second stage compressor inlet. The flash gas flows through the compressor motor windings, and cools the motor. The flash gas is recompressed, and it enters the condenser. Here it converts to liquid, with the rest of the circulating refrigerant. This mass of flash gas takes less power to recompress, because it is compressed from an intermediate pressure (not low side pressure) to high side pressure.

After the first pressure drop, the liquid that remains in the economizer flows to the evaporator. Some of this refrigerant flashes in the evaporator. However, the pressure drop from the economizer to the evaporator is relatively small. The amount of flash gas produced is considerably less than in similar refrigeration systems, where the reduction in pressure from condenser to evaporator takes place in a single step. When evaporator flash gas is reduced, the net refrigerating effect (kJ per kg of liquid entering the evaporator) increases. This increases the cooling capacity of the system.

Only the refrigerant vapour produced by the evaporator goes through two compression stages. Some refrigerant is diverted directly to the second compression stage through the motor windings, which requires less compressor work.

Figure 4 – Water Chiller with Economizer Using R-134a Refrigerant



(Courtesy of Carrier Corporation)

The economizer also provides an intercooling effect for the compressor. The cool vapour from the intermediate chamber cools the first stage compressor discharge gas, which reduces the power required for compression in the second stage.

Objective 4

Describe the special types of refrigeration compressors, including how they are similar to and different from air compressors.

The **4th Class** chapter, **Introduction to Compressors (Part B, Unit 2, Chapter 3),** covered the general types of compressors and their applications. Refrigeration compressors, though, have some unique features. Construction materials and strength of components vary with the type of refrigerant used. These compressors are cooled without fins, and they are specially designed to prevent or inhibit refrigerant leakage.

Refrigeration Compressors

Refrigeration compressors have three main functions:

1. They draw refrigerant gas from the evaporator as it is produced. This prevents the evaporator pressure (and therefore temperature) from varying from the desired set point.
2. They raise the refrigerant gas pressure, so that refrigerant can flow from the high side to the low side.
3. They raise the saturation temperature of the gas to above the temperature of the condensing medium (usually air, water, or both). This is done by adding work (kJ) to the gas, which converts to heat and pressure. When exposed to the condensing medium, the refrigerant returns to its original liquid state, so it can recycle in the refrigerant circuit.

Refrigeration compressors can be classified as:

Reciprocating compressors, in which a piston travels back and forth in a cylinder. This action draws in and compresses the vapour.

Rotary compressors, which use helical rotors (screws) or an eccentric rotor with vanes, to compress the vapour.

Centrifugal compressors, which use rapidly revolving impellers to draw in the vapour, and discharge it at high velocity by centrifugal force. The high velocity, low-pressure vapour then converts to low velocity, high-pressure vapour, before it leaves the compressor.

Reciprocating Compressor Types

Compressor housings for reciprocating compressors are divided into three types according to their design:

1. Open
2. Hermetic
3. Serviceable or semi-hermetic

These are discussed in the **4th Class** chapter, **Introduction to Compressors (Part B, Unit 2, Chapter 3)**.

Safety Head

If a drop in refrigeration load occurs, it may be possible for liquid refrigerant to enter the compressor through the suction line. When cooling requirements decrease, some refrigerant in the evaporator may not evaporate. So, it is possible for an evaporator to contain more refrigerant than necessary for the load. Therefore, reciprocating compressors are often fitted with safety heads, to prevent damage to the compressor by the hydraulic pressure that results from trapped liquid at the end of the compression stroke.

During normal operation, safety heads are kept firmly in place with a heavy spring, as shown in Figure 5. The entire head lifts when the pressure in the cylinder becomes too high, due to liquid refrigerant in the cylinder. This lifting action allows the liquid to pass into the discharge line without doing serious damage.

The same principle of construction is often applied in compressors equipped with ring plate valves. Only the valve assembly, instead of the entire cylinder head, is held down by the spring. The valve assembly lifts when excessive pressure occurs in the cylinder.

Figure 5 – Compressor Showing Valve Assembly with Safety Spring

Compressor Bearings

Compressor bearings are identical in type and function to those used in air compressors and pumps. Bearing materials must be compatible with the type of refrigerant used. Bearings with copper or copper alloys are not used in ammonia compressors, because ammonia attacks these materials.

Rotary Compressors

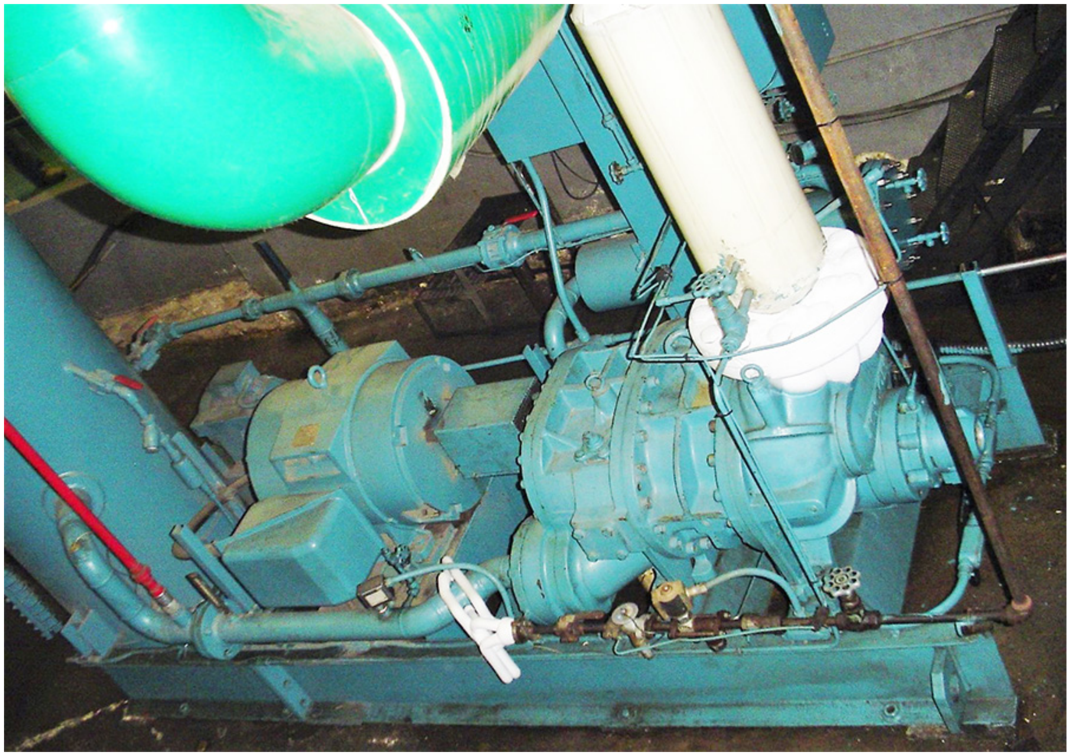
Rotary compressors compress refrigerant vapour with rotary motion instead of reciprocating motion. Rotary compressors have several different designs, including:

- Stationary single-blade
- Rotating sliding vane
- Helical rotor or screw
- Scroll

Rotary compressors are often used in compound refrigeration systems. In this type of plant, the compressor is called a booster. The rotary compressor produces very low evaporator pressure for deep freeze applications. It discharges intermediate pressure refrigerant into the suction of the main compressor. An intercooler lowers the density of the intermediate pressure refrigerant, which reduces the work and power requirements of the main compressor. A reciprocating or other high-pressure compressor then raises the intermediate pressure of the refrigerant vapour to condensing pressure and temperature.

Figure 6 shows a rotary style of booster compressor, equipped with an intercooler. Frost can be seen on the large-diameter compressor suction line. Several smaller frosted lines appear at the bottom of the picture. These are the distributor pipes of the intercooler. They feed liquid ammonia into the booster compressor discharge, to lower the discharge temperature of the intermediate pressure refrigerant.

Figure 6 – Booster Compressor and Intercooler



Centrifugal Compressors

In both the reciprocating and rotary compressors, the vapour is compressed by the direct action of pistons, vanes, rollers, or gears. These components force the vapour into a decreasing space, thus compressing it. Which means that these compressors use positive displacement to force the vapour into a smaller volume.

Centrifugal compressors are dynamic compressors. They increase the velocity of the refrigerant with a rapidly rotating impeller. This high velocity vapour travels through specially shaped passages of increasing cross-sectional area. Here, the high velocity is converted to high pressure. In terms of energy transformation, the kinetic energy of the low pressure, high velocity vapour is transformed into potential energy in the high pressure, low velocity vapour.

Helical Rotor (or Screw) Design

The primary application of the helical rotor design is in medium and high-capacity refrigeration compressors. This rotor is identical to those used for air compression.

Scroll Compressors

Due to their efficiency and relatively quiet, vibration free operation, the application of scroll compressors to commercial chillers is increasing. Figure 7 shows four hermetic scroll compressors as part of a packaged water chiller used for HVAC purposes. Each compressor operates successively, with changes in cooling load. The black insulated lines are refrigerant suction lines. These compressors are also well insulated.

Figure 7 – Scroll Compressors for a Packaged Water Chiller

Developments in Compressors

With the advent of new refrigerants and refrigerant blends, the refrigeration industry requires new compressor designs. These units may be designed to overcome higher discharge pressures more efficiently, such as when CO_2 (R-744) is used as a refrigerant. They may be compressors designed to handle refrigerant blends better. These blends evaporate over a range of temperatures rather than at a single temperature. New compressors must be able to operate efficiently over a pressure range, rather than at a single evaporator or condenser pressure.

One compressor design that is proving quite capable of handling refrigerant blends is the scroll compressor. This compressor is becoming more commonplace.

Objective 5

Describe the special designs of refrigeration system evaporators and condensers.

Heat exchangers transfer heat from one fluid to another, without mixing the fluids. This means that one process fluid gains heat, and the other one loses heat.

In a refrigeration system, there are two main heat exchangers: the evaporator and the condenser. This objective explains the principle functions, varieties, and applications of evaporators and condensers.

Evaporators

In a refrigerating system, the evaporator is where the liquid refrigerant absorbs the heat from the medium to be cooled, and vaporizes.

Operating Classification

Evaporators can be divided into three basic types, based on how they operate:

1. Direct expansion (or "dry") evaporator
2. Flooded evaporator
3. Liquid Recirculating (or liquid overfeed) evaporator

The three types differ in their method of circulating refrigerant.

Dry Evaporator

In a dry evaporator, the expansion valve admits only enough liquid refrigerant to maintain the desired temperature. As the liquid enters and flows through the evaporator, it absorbs heat, evaporates, and leaves again as a vapour.

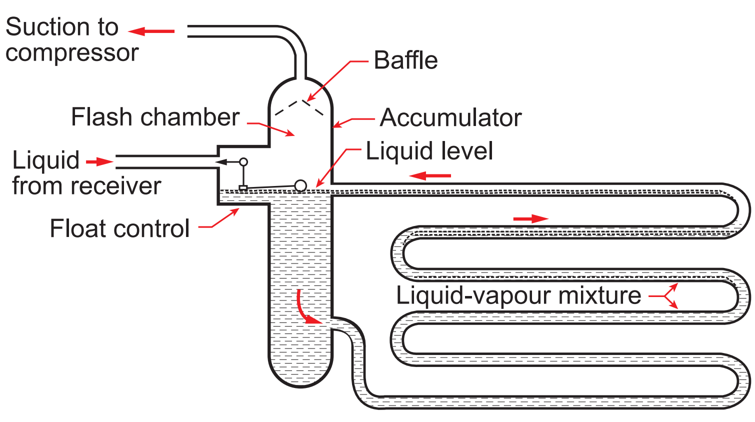
The amount of liquid refrigerant entering the evaporator balances the amount of refrigerant leaving the evaporator as a vapour, with no recirculation of liquid or gas taking place. The evaporator contains only a small amount of liquid refrigerant at any time. The percentage of liquid in the evaporator varies with the load demand.

Flooded Evaporator

A flooded evaporator is kept almost completely filled (or flooded) with liquid refrigerant, regardless of load demand. The compressor draws off the vapour formed by the boiling of the liquid. Then, fresh liquid is automatically supplied, to maintain the level.

Because the heat exchange surface of the flooded evaporator is always completely wetted with liquid, it has a higher heat transfer rate than the dry evaporator. It also responds rapidly to changes in load, since refrigerant has already gone through a pressure reduction and is awaiting exposure to heat. This makes the flooded evaporator favourable for pasteurization processes where, on start-up, fluid must not pass through without being cooled. The disadvantages of this evaporator, however, are that it requires a relatively large refrigerant charge, and is often quite bulky.

Figure 8 – Flooded Bare Tube Evaporator



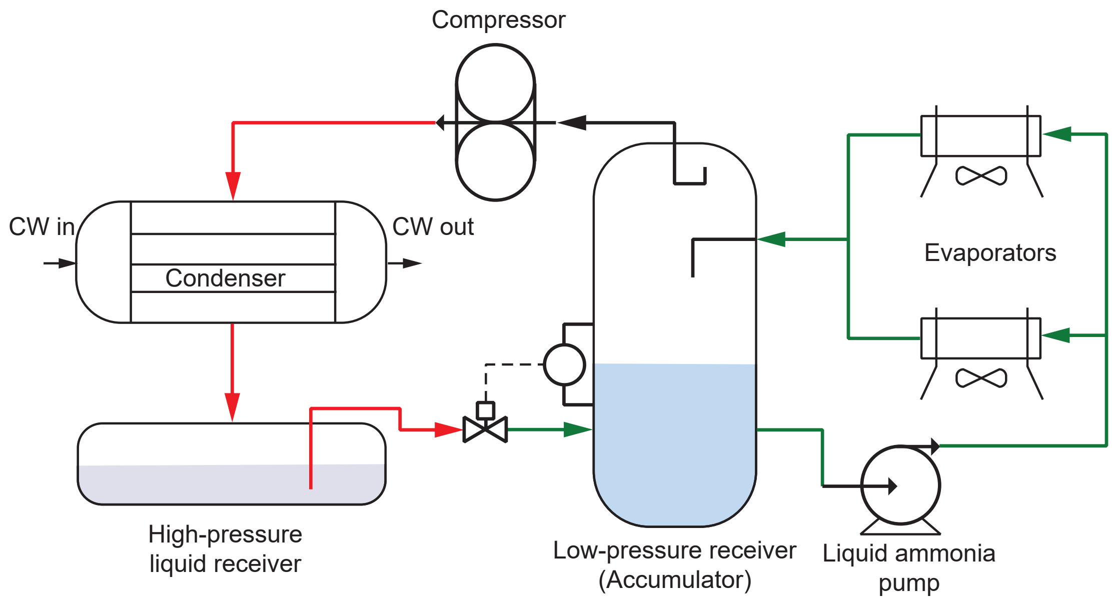
Liquid Recirculating Evaporator

The liquid recirculating evaporator is used in liquid overfeed refrigeration systems. These evaporators have a constant flow of liquid refrigerant, regardless of load demand. The refrigerant is supplied to the evaporators with a liquid ammonia pump that draws from a low-pressure liquid receiver. The pump feeds around three times the amount of liquid to the evaporators than they require. The evaporators return a mixture of liquid and vapour to a low-pressure receiver (also called a surge drum or an accumulator). This mixture is then pumped back again through the evaporators. The compressor draws off the vapour, formed by the boiling of the liquid, from the low-pressure receiver. Fresh liquid is automatically supplied to maintain the level.

The low-pressure receiver is a critical element of the system. It separates the liquid and vapour returning from the evaporators, so that the vapour can be recompressed and condensed. Without the low-pressure receiver, liquid would enter and damage the compressor.

Figure 9 shows a simplified liquid overfeed system. Low-pressure liquid piping is shown in green. Low-pressure vapour piping is blue. High-pressure vapour and liquid is shown in red.

Figure 9 – Simple Liquid Overfeed System with Liquid Recirculating Evaporators



Because the heat exchange surface of the liquid recirculating evaporator is completely wetted with liquid, it has a higher heat transfer rate than the dry evaporator. It also responds rapidly to changes in load, since refrigerant has already gone through a pressure reduction and is awaiting exposure to heat. This makes the liquid recirculating evaporator favourable for quick freeze. Also, for loads that quickly swing from almost no load to full load. This evaporator, however, has a couple of disadvantages:

- The system requires a relatively large and costly refrigerant charge.
- Additional equipment (surge drum, pumps, and level controller) adds to the initial cost of the system.

Construction Classification

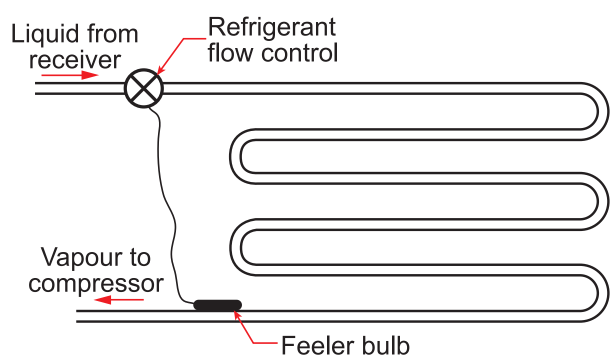
Based on their construction, evaporators fall into the following classes:

- Bare tube
- Plate surface
- Finned tube
- Shell-and-tube

Bare Tube Evaporator

The bare tube evaporator consists of either a single coil bent in various shapes, such as the flat serpentine coil illustrated in Figure 10, or a number of coils placed in parallel and connected to common headers. The tubes are constructed of either steel pipe or copper tubing. This evaporator can be used as a direct expansion evaporator (Figure 10), a flooded evaporator (Figure 8), or a liquid recirculation evaporator. If in flooded or liquid recirculation service, the outlet of the coil goes to an **accumulator.**

Figure 10 – Direct Expansion Bare Tube Evaporator



Bare tube evaporators are used where the space temperature is maintained below 1°C and frost accumulation cannot be readily prevented, such as in coolers and freezers. They can also be submerged in liquids that are to be cooled.

Figure 11 shows heavily frosted, bare-tube, liquid recirculation evaporator piping on the ceiling and walls of a cold-storage facility.

Figure 11 – Bare Tube Evaporator

Defrost Processes for Bare Tube Evaporators

The accumulation of ice on evaporator surfaces results in an insulation effect, which reduces the efficiency of the evaporator. There are several different methods that combat the accumulation of ice and defrost the system, such as:

- On/off cycle
- Electric defrost
- Hot gas bypass
- Water or Brine Spray

For each of these methods, there must be an adequate means of removing the melted ice from the cooled space.

On/Off Cycle

The on/off cycle is used for refrigeration systems that operate close to 0°C. In this case, the flow of refrigerant to the evaporator may be stopped for a short time. To stop the flow of refrigerant, either close the refrigerant flow control valve, or shut down the compressor, or both. The compressor may shut down without evacuating the refrigerant from the evaporator, which further aids the defrosting process. Alternatively, the compressor may pump down the low-pressure side before shutting down. The temperature of the cooled space rises above 0°C, allowing the frost to melt. The system will restart at the end of the defrost cycle. The cycle may be controlled by a timer, by evaporator pressure, or by evaporator temperature.

Electric Defrost

Electric defrost may be used for refrigeration systems that operate well below 0°C, or where the cooled space must not exceed 0°C. Electric heaters are attached to the bare evaporator tubes. A defrost timer shuts down the compressor and turns on the electric heaters to melt the accumulated frost. The cycle may be controlled by a timer or by evaporator temperature.

Hot Gas Bypass

The hot gas bypass stops the flow of refrigerant to the evaporator while it opens a small bypass line from the compressor. The hot refrigerant from the compressor feeds directly to the evaporator to melt the frost. The hot gas bypass may be controlled by a timer or by temperature.

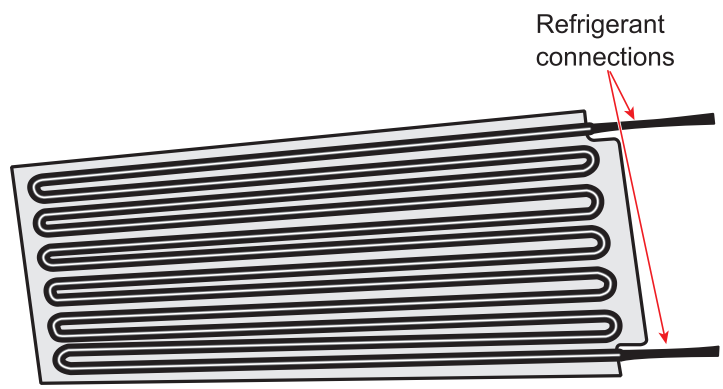
Water or Brine Spray

Water or brine spray is used on large commercial systems. Once the flow of refrigerant stops, the outside of the evaporator tubes are sprayed with water or brine to melt the accumulated frost. This system may also be controlled by a timer or by temperature.

Plate Surface Evaporator

The plate surface evaporator is manufactured in a variety of ways. One method is to use two flat steel plates embossed or stamped so that a serpentine coil for the refrigerant is formed when the plates are fused together (Figure 12). Another method uses a regular coil, attached between two plates.

Figure 12 – Plate Surface Evaporator

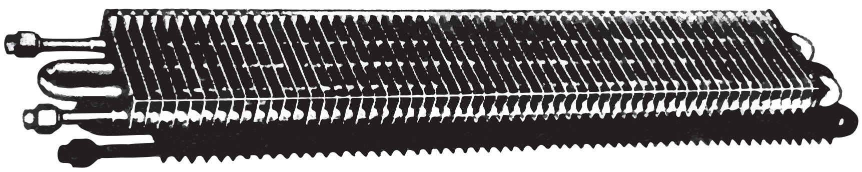


This evaporator can be formed into various shapes, and is used individually or in banks. It is easy to clean and defrost by manual scraping, without interrupting the cooling process. Therefore, it is widely used in refrigerators, freezers, display cases, and locker plants. It is usually used as a direct-expansion evaporator.

Finned Tube Evaporator

The finned tube evaporator (Figure 13) is basically a bare tube coil with fins attached to it, by crimping or bonding, to form a large surface area for heat exchange. The most common way of attaching the fins is to place them over the tubing, and run a mandrel or expander down the tube, which causes it to expand. This is sometimes called a "pressed fin" design, because of the method of manufacturing.

Figure 13 – Finned Tube Evaporator



This evaporator is used as a direct-expansion evaporator in many applications. These include walk-in coolers and display cases.

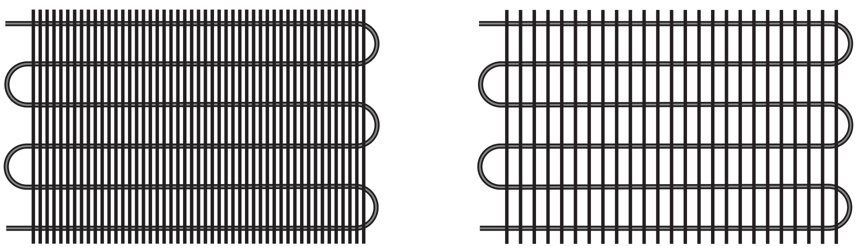
The finned tube evaporator with forced air circulation is the most widely used in air conditioning applications. Air is forced between the fins, and gives up its heat to the vaporizing refrigerant inside the coils.

In applications where low air velocities and minimum dehydration are required, the air flows over the evaporator by natural convection. In other applications, to increase the airflow and cooling capacity, the evaporator is equipped with one or more fans.

Figure 14 shows the different fin spacing requirements for use in medium and low temperature applications. The lower the temperature of the space (and coil), the greater the rate of frost buildup. At low temperatures, frost accumulates faster and becomes thicker. For this reason, the lower the temperature, the greater the fin spacing.

Finned evaporators have a large number of finned serpentine coils mounted in a frame. One end of each coil connects to a liquid refrigerant distributor. The other end connects to a common compressor suction header.

Figure 14 – Finned Evaporator Spacing



(a) Medium temperature (b) Low temperature

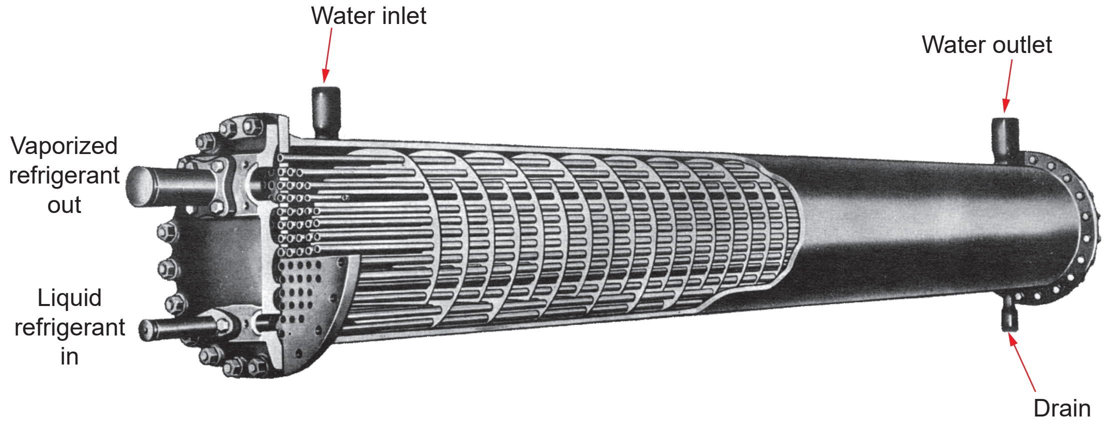
Shell-and-Tube Evaporator

A shell-and-tube (also called a chiller) is used for almost any type of liquid cooling application. It consists of a cylindrical steel shell in which a number of straight bare tubes are arranged in parallel. The tubes are held in place at the ends by tube sheets, which close the shell. In the case of the chiller shown in Figure 15, each head has baffles to redirect the flow of refrigerant through multiple passes. Other designs admit the liquid refrigerant to the shell side of the heat exchanger. Chillers may be direct-expansion or flooded.

In the direct-expansion evaporator, the liquid refrigerant enters the lower tubes. While traveling back and forth through a number of passes, it evaporates by absorbing heat from the liquid surrounding the tubes.

The compressor draws the vapour from the evaporator through the suction connection, after it leaves the final, upper pass. The liquid to be chilled is admitted to one end of the shell. The baffles then force it to follow a serpentine course, across the tubes, to the outlet at the other end of the shell, where it leaves at a reduced temperature. Figure 15 shows a direct-expansion shell-and-tube evaporator, used as a water chiller.

Figure 15 – Direct-Expansion Shell-and-Tube Chiller



In the flooded type evaporator, the tubes are arranged in a single or multi-pass configuration. The liquid to be chilled passes through these tubes. The shell is filled with liquid refrigerant, which surrounds the tubes. A float-controlled valve maintains the level of the liquid in the shell so that at least seventy-five percent of the tubes remain submerged at all times. The vapour, boiled off by the heat of the liquid circulating through the tubes, is then drawn off through nozzles in the upper part of the shell.

At high loads, the refrigerant in a flooded chiller may boil quite violently. This will cause some liquid refrigerant to carry over with the vapour leaving the evaporator. The liquid carried over will damage the compressors. There are two methods to separate this liquid from the vapour before it enters the compressor suction line.

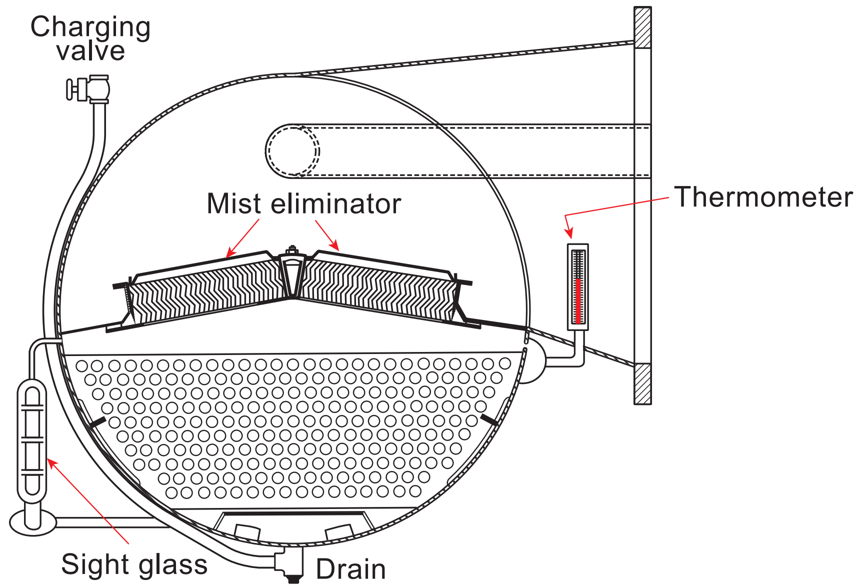
In the first method, shown in Figure 16, a surge drum is mounted on top of the evaporator. Two or more large diameter pipes connect the surge drum to the evaporator. The diameter of the evaporator is relatively small, and the tubes fill nearly all of the shell, thus the liquid level has to be kept quite high. Due to the change of direction, and the length of the gas travel, any liquid refrigerant carried over with the vapour into the surge drum will drop out of the gas flow before it reaches the suction line on top of the surge drum. This liquid will run back into the evaporator.

Figure 16 – Flooded Chiller with Surge Drum Mounted on Top

In the second method, the liquid is separated from the vapour before it leaves the evaporator. The same number of tubes are used for a given heat exchange capacity as are used in an evaporator with a surge drum. However, a large diameter shell is used, and all the tubes are mounted in the lower half of the shell.

The tubes are submerged in the liquid refrigerant. The space above the tubes (the upper half of the shell) is used to separate the liquid from the vapour. To aid in this process, most evaporators are also equipped with a bank of chevron shaped mist eliminator plates, as shown in Figure 17.

Figure 17 – Flooded Chiller with Eliminators



Condensers

The refrigeration condenser removes the heat from compressed refrigerant vapour, until the vapour changes state and becomes a liquid. The condenser must remove both:

1. The heat the vapour absorbed in the evaporator.
2. The heat of compression added to the vapour in the compressor.

The function of the refrigeration condenser is to remove heat from compressed refrigerant vapour until it changes state and becomes a liquid. To do this, the condenser must remove both the heat absorbed in the evaporator by the vapour, and the heat of compression added to it in the compressor.

Three General Types of Condensers

1. Air-cooled
2. Water-cooled
3. Evaporative

Air-Cooled Condensers

The air-cooled condenser uses air to remove heat from the refrigerant vapour. The hot refrigerant vapour flows through finned tubes. Fans or blowers circulate cooling air around the outside of the tubes.

Units with larger capacities are usually equipped with a remotely mounted condenser, which is installed either indoors or outdoors.

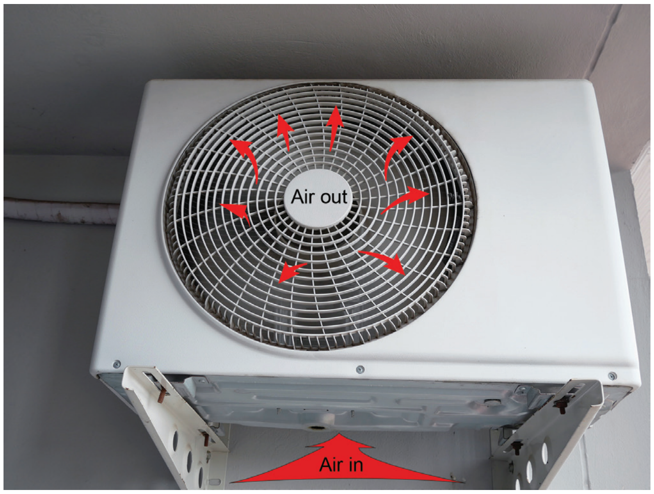
An indoor mounted remote air-cooled condenser needs to be placed in a relatively warm location. There must be provisions for an adequate supply of outdoor air to reach the condenser. For small units, opening a window may suffice. For larger units, it is necessary to use ducts to carry outdoor air to the condenser, and then back to the outside.

Usually mounted outdoors, large condensers are frequently located on a roof. If mounted indoors, they would require extensive space-consuming ductwork; therefore, this is not a common practice.

One disadvantage of the air-cooled condenser is that as the cooling load increases in hot weather, the condenser capacity decreases as the temperature difference between the cooling medium and the refrigerant decreases. However, this condenser does not require cooling water or water treatment chemicals, and it does not breed harmful bacteria. Therefore, an air-cooled condenser is preferred when environmental considerations are of primary importance.

Figure 18 shows a horizontal air-cooled condenser for outdoor use. A belt-driven propeller fan draws cooling air through the condenser. There are also vertical units manufactured for this type of condenser. In either case, fans are used to force or draw air through the condenser.

Figure 18 – Outdoor Air-Cooled Condenser



Water-Cooled Condensers

This type of condenser uses cooling water to remove heat from the refrigerant vapour. Three basic designs of water-cooled condensers are commonly used:

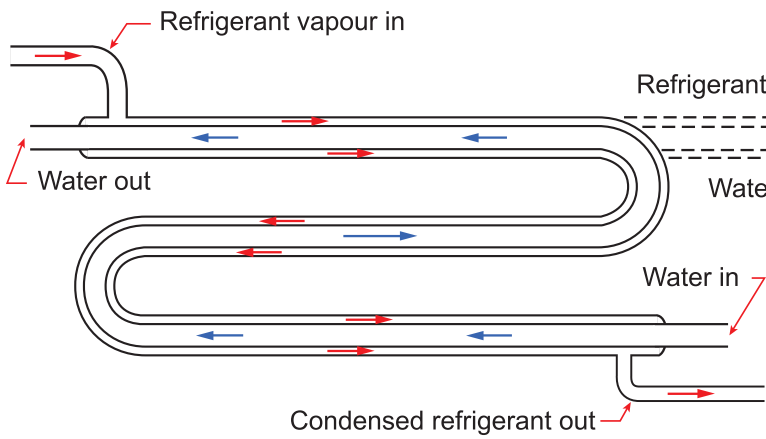
1. Double-tube
2. Shell-and-coil
3. Shell-and-tube

Double-Tube Condenser

A double-tube condenser consists of a small tube contained concentrically within a larger tube, as shown in Figure 19. Cooling water flows through the inner tube of the double-tube condenser. At the same time, refrigerant flows in the opposite direction, in the annular space between the inner and outer tubes.

This type has the lowest efficiency of the three designs, which results in a need for a larger condenser for a given capacity. During periods of peak loading, this type is sometimes used with air-cooled condensers as a booster. Notice that this is a counter-flow design. The water flows through the inside tube, to keep cooling water from absorbing heat from the surroundings. All absorbed heat should be directly from the refrigerant gas.

Figure 19 – Double-Tube Condenser



Shell-and-Coil Condenser

The shell-and-coil condenser consists of a horizontal or vertical steel shell that contains a coiled bare or finned tube, through which cooling water circulates. The hot refrigerant vapour enters near the top of the shell, gives up its heat to the cool surface of the coil, and collects in the bottom of the shell as a liquid. The bottom portion of the shell often serves as a receiver. A cross-sectional view of a horizontal shell-and-coil condenser is shown in Figure 20.

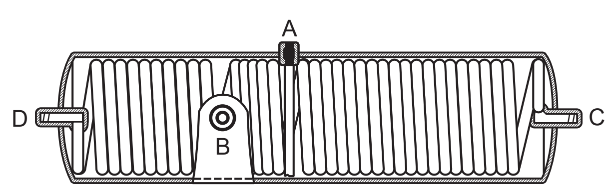
This condenser is very efficient and compact, which makes it easily adaptable to packaged refrigeration units. The tubes can be cleaned with an acid solution and then neutralized. Its main disadvantages are:

a) It is difficult to clean.

b) When leaks develop, the repair costs may exceed the cost of a new condenser.

Figure 20 – Shell-and-Coil Condenser

A - Refrigerant vapour in
B - Liquid refrigerant out
C - Water in
D - Water out

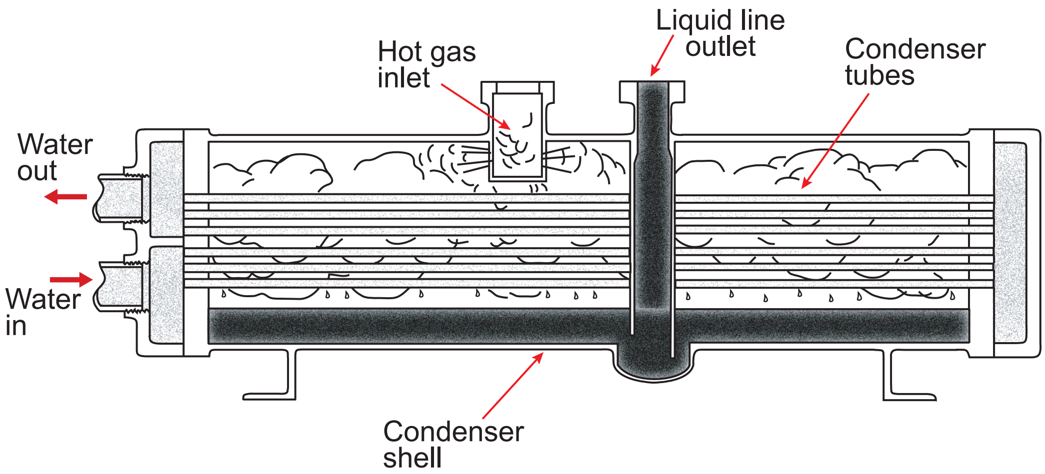


Shell-and-Tube Condenser

The shell-and-tube condenser consists of a welded steel shell that contains a number of straight tubes fastened in the tube sheets, which close the shell. The condenser is fitted with water boxes to which the cooling water supply and return pipes are connected. The water boxes direct the cooling water through two or more passes. The hot refrigerant vapour enters at the top of the shell and condenses by coming in contact with the cool outer surface of the tubes. As the vapour condenses, the refrigerant drains and collects in the bottom of the shell as a liquid. Figure 21 shows a cross-sectional view of a shell-and-tube condenser with two-pass cooling water flow.

This type of condenser is used extensively in ammonia installations of all sizes. It is also used in medium and large sized air conditioning installations that use other types of refrigerants. The horizontal shell-and-tube condenser provides high cooling efficiency at reasonable cost. It is easy to clean, so routine maintenance costs are low, as well.

Figure 21 – Shell-and-Tube Condenser

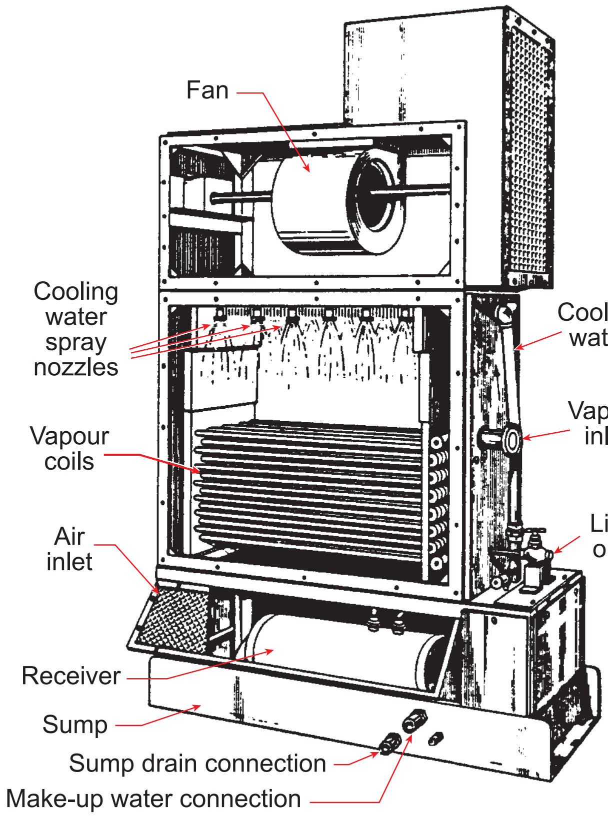


Evaporative Condensers

Evaporative condensers use both air and water to provide cooling, in order to condense the refrigerant vapour. Figure 22 shows a cross-sectional view of a typical evaporative condenser. Figure 23 is a basic schematic diagram of a similar unit.

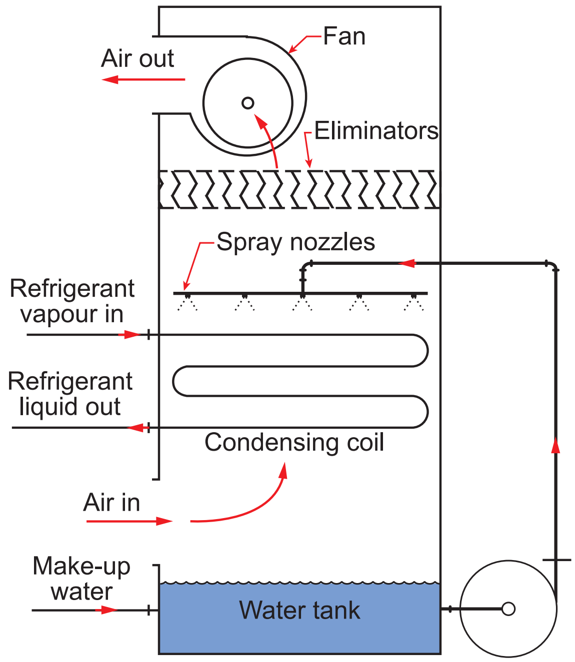
The evaporative condenser contains condensing coils mounted in a cabinet. The hot refrigerant vapour from the compressor enters at the top of the condenser. The refrigerant liquid leaves at the bottom, and flows to a receiver.

Figure 22 – Evaporative Condenser



The refrigerant vapour flows through a set of coils, over which water is sprayed from nozzles. Air is drawn counter flow to the water. A portion of the water evaporates, which produces a cooling effect on the remaining water and on the refrigerant in the tubes. A sump pump, located at the bottom of the condenser, continuously circulates the water back to the spray nozzles (Figure 23). The fan may be the induced or forced draft type. The air flows through drift eliminators as it exits the condenser. This traps the entrained water droplets, and they fall back over the cooling coil.

Figure 23 – Schematic Diagram of an Evaporative Condenser



The amount of heat absorbed by the evaporating water is quite large (approximately 2257 kJ per kg of water evaporated). Therefore, the amount of water used by an evaporative condenser is only a small percentage of that required in a water-cooled condenser of the same capacity. The amount of air circulated through this condenser is also only a small percentage of that required in an air-cooled condenser of the same capacity.

Evaporative condensers are favoured in locations where it is necessary to conserve water. A saving of 80 to 90 percent in water consumption may be achieved over a conventional water-cooled condenser that discharges the water to waste.

Since part of the spray water evaporates and is carried off by the air leaving at the top, it is necessary to supply make-up water to the condenser sump. A float valve is used to maintain the water at a constant level.

These condensers may be located either indoors or outdoors. When placed indoors, the air inlet and discharge are connected to the outside of the building by ducts, which are closed by louvres when the condenser is not in operation.

When placed outdoors, it is important to prevent the water from freezing during cold weather. A heating coil placed in the sump of the condenser usually takes care of the problem. The coil keeps the temperature of the water above the freezing point when the condenser is not in operation. Alternatively, the condenser sump drains to an indoor tank. The spray water pump (also placed indoors) takes its suction from this tank, so no water stays in the sump at any time.

As can be seen in Figure 22, the liquid refrigerant receiver is sometimes placed in the sump of the evaporative condenser. This subcools the liquid refrigerant before it enters the evaporator. This reduces flash gas and increases the net refrigerating effect. The exterior of the tank, however, should be protected against the corrosive action of the sump water and the air.

The air intake requires a filter, to prevent dust or sludge formation in the sump or water tank.

Because of the continual evaporation of water, and its replenishment from the make-up supply, the concentration of dissolved solids steadily increases in the water. If uncontrolled, these solids eventually precipitate out as scale. Therefore, sumps usually have a bleed valve, which continuously bleeds off some of the water. The make-up water has a low solids concentration, which reduces the dissolved solids concentration of the condenser water.

Figure 24 shows a large evaporative condenser used in an industrial refrigeration plant. It has four condensers combined in a single large block. Each cell has two cooling fans. High-pressure refrigerant vapour enters the top of each condenser, through the orange coloured pipes. High-pressure liquid refrigerant leaves the condenser coils at the bottom of each cell, where it is collected and returned to the liquid receiver. The large black pipes deliver condenser water that sprays above each condenser coil.

Figure 24 – Large Industrial Evaporative Condenser

If discharging coolant to waste, water-cooled condensers waste a tremendous amount of water. Local water-use regulations may prohibit the installation or limit the capacity of such open-loop cooling systems. Therefore, a cooling tower is often used with this condenser to limit water consumption. This type of condenser uses the same evaporative principles as an evaporative condenser to cool condenser water. A condenser water pump circulates cooled water from the tower through the water-cooled condenser. The warm water flows from the condenser to the cooling tower, where evaporation again cools the condenser water.

Chapter Summary

This chapter examined many of the main components of direct and indirect compression refrigeration systems. This included a description of high and low side components, such as compressors, metering devices, evaporators, and condensers. Reciprocating, rotary, and centrifugal types of compressors were described, as well as their hermetic, semi-hermetic, and open frame variants.

Packaged refrigeration systems are commonly used for ice arenas and HVAC service. These indirect systems were examined, and their characteristics noted. These systems may use direct expansion evaporators or flooded evaporators. Most of these systems use water-cooled or evaporative condensers. However, larger air-cooled condensers are becoming more common because they have less environmental impact. If water-cooled condensers are used, they are usually coupled with cooling towers to conserve water.

Liquid overfeed systems use a type of flooded evaporator supplied with refrigerant by a circulating pump. A low-pressure receiver prevents liquid refrigerant from damaging compressors. These systems are commonly used in industry, in large direct systems.

Chapter 3

Refrigeration System Control and Operation

Learning Outcome

When you complete this chapter you should be able to:

Describe the purposes and operating principles of refrigeration system operational and safety controls.

Learning Objectives

Here is what you should be able to do when you complete each objective:

1. *Describe refrigeration system controls.*
2. *List the safety shutdown devices specific to centrifugal compressor water chillers.*
3. *Describe typical refrigeration system safety shutdown devices.*
4. *Describe the construction and operation of refrigerant metering devices.*
5. *Describe the different methods used to control evaporator capacity.*
6. *Describe the different methods used to control the capacity of refrigeration compressors.*

Chapter Introduction

This chapter will discuss the controls used to help refrigeration plants operate safely and efficiently. Refrigeration systems operate under varying conditions. Though designed to operate at particular high side and low side temperatures, load changes and atmospheric conditions influence system operation.

For example, in a cold storage facility, when a load of fresh goods is brought in to be frozen, the cooling load increases. In ice arenas, each time the ice is flooded, the cooling load increases. In HVAC systems, the cooling load increases during the day and decreases at night.

All refrigeration systems carry greater load during hot summer months than in the dead of winter. Refrigeration systems therefore need controls to automate the response to load changes, which may vary from no-load to full-load.

Refrigeration system controls are classified into three types:

Operating (system capacity) controls: When process conditions (temperature, pressure, or humidity) approach or deviate from their set points, these controls start or stop the compressor, or they regulate its capacity.

Actuating and secondary controls: These controls either indirectly control the changes in operation called for by the primary controls, or they regulate the cycle during operation.

Limiting and safety controls: This group of controls protects the system against operation beyond the limits for which it was designed.

Many of the controls used in refrigerating systems are quite similar in design and operation to those used on boilers and in heating systems. Many large stand-alone refrigeration systems have human machine interface (HMI) panels. Some systems may have controls linked to the plant supervisory control and data acquisition (SCADA) systems.

Every operator should review the manufacturer manuals. Operators must also be familiar with plant data for site-specific practices and procedures.

Objective 1

Describe refrigeration system controls.

In HVAC systems, refrigeration system controls maintain set points and safe operating conditions for the comfort and safety of the occupants. In cold storage and process plants, it is critical to adhere to set points, to maintain process conditions, and prevent damage to goods or equipment. Millions of production dollars can be lost if refrigeration systems do not perform according to design.

As new technologies arise, controls become more complex, and they also become better able to efficiently and accurately control processes. Refrigeration plant controls are no exception. For example, controls can now sense the ice surface temperature of arenas for optimum hockey or figure skating conditions. They can also check buildings for occupancy, and adjust HVAC set points accordingly.

Human Machine Interfaces (HMIs)

Usually, an HMI is either mounted on a packaged refrigeration unit (supplied by the manufacturer), or it is mounted on a wall in the machine area, close to the unit. HMIs send operational data and alarms to a screen or a series of screens. The operator can then make changes to set points or operational expectations right on the screen. This is a "stand alone" unit, it does not report to a central control system or hook up to the SCADA system. However, it can be interlinked to the master control system reporting to a control room.

Figure 1 – Human Machine Interface for HVAC Chiller

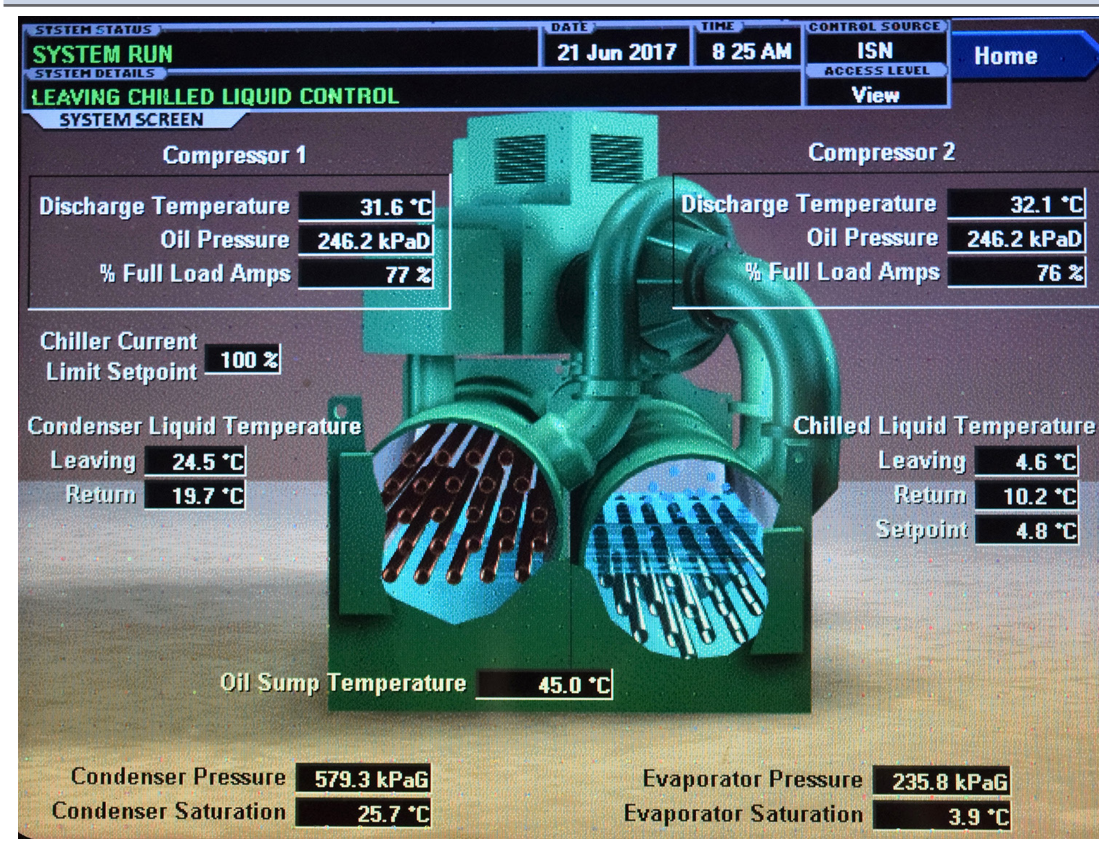


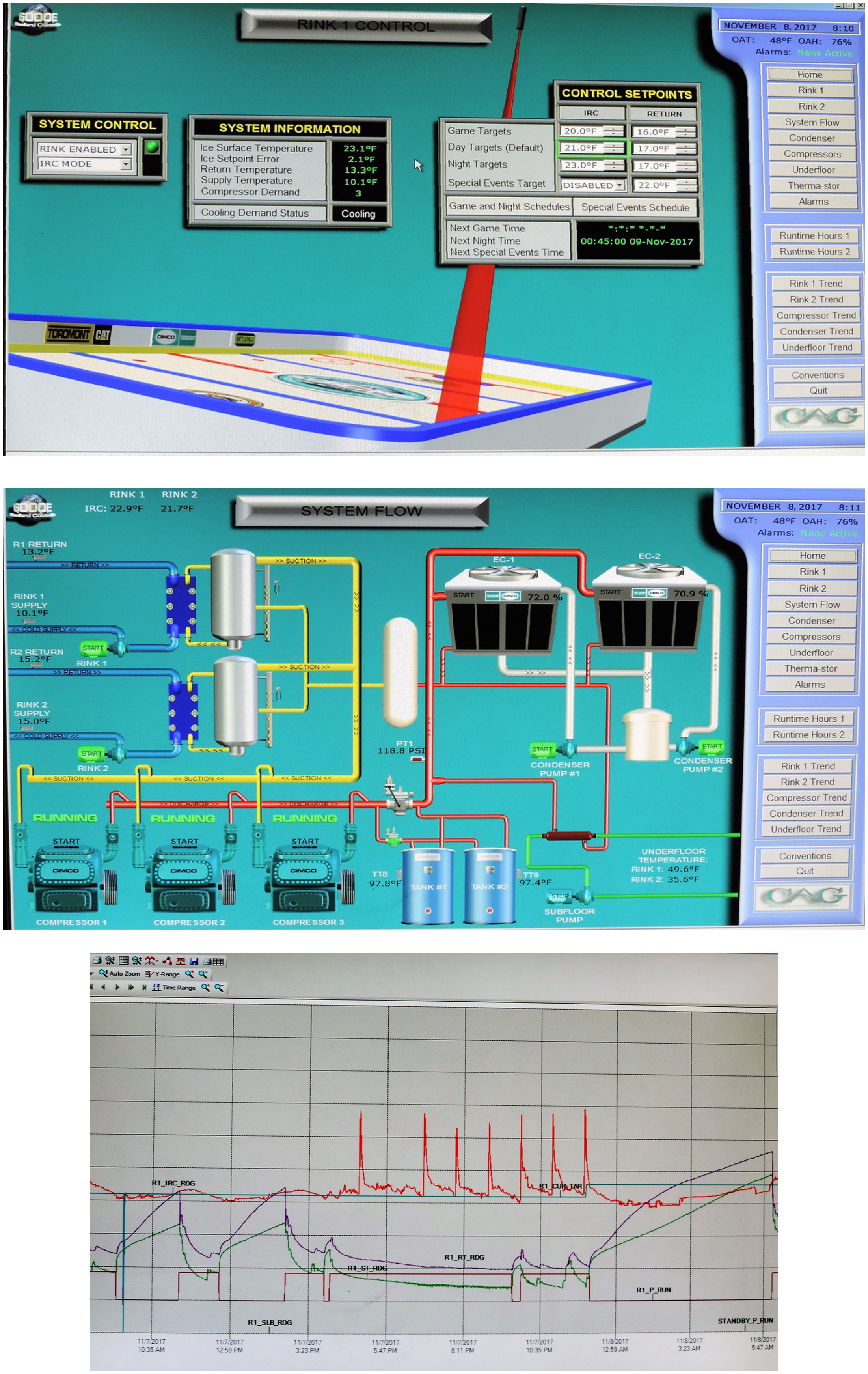
Figure 1 shows the status screen of an HMI system which provides the operator with overall system operating conditions. HMIs may have several different control screens. The operators are able to:

- View and change operating set points
- Change system operating schedules
- View and change alarm set points
- View critical operating parameters
- View historical and current operating trends
- Print system status reports
- View, acknowledge, and reset alarms

Figure 2 shows a series of screen shots from an ice arena control room operator interface. The operator can scroll through several screens to:

- Start and stop equipment
- Change set points
- Observe trends
- Set occupancy schedules
- Respond to alarms
- Check equipment runtimes
- Review all pertinent operating parameters

Figure 2 – Arena Ice-Making Equipment Control Screens



Operating Controls

Refrigeration plant cooling capacity must always equal the cooling load. If the plant operates at full capacity when the load is low, the temperature of the refrigerated medium will drop below set point. If the system operates at low capacity when the cooling load is high, then the temperature of the refrigerated medium will rise above set point.

System capacity (kW or TR) is controlled by adjusting the mass of refrigerant circulated per unit time (kg of refrigerant circulated per hour). The compressor circulates the refrigerant. The system capacity control must influence the amount of refrigerant the compressor circulates (the compressor capacity); this may be done directly or indirectly. A control system can either directly adjust compressor capacity; or it can directly regulate evaporator capacity. In the second situation, the compressor responds to changing evaporator capacity, which means the compressor is controlled indirectly.

Compressor capacity, like the output of small boilers, can be adjusted by cycling it on and off (two-position control). The capacity can also be regulated with multi-stage control (cylinder unloading) and full modulation (variable speed control). These control systems respond to:

- Temperature
- Pressure
- Humidity

Temperature-Actuated Control (Thermostat)

Electric controls can start and stop compressors. A thermostat with a bimetal or filled system thermal sensing element is used to detect the temperature of the refrigerated medium. Deviations from the set point operate electrical contacts that start or stop the compressor.

Thermostats can be used as contact closures; they signal inputs to a computerized control system used to start or stop compressors. These thermostats enable or disable a compressor when its capacity cannot be controlled any other way. A compressor running at minimum capacity may still circulate too much refrigerant. In this case, the thermostat signals the control system to disable the compressor. When disabled, the compressor stops. When enabled, the compressor starts, and its capacity varies from low to high.

Other thermostats may have electrical resistance elements or electronic temperature sensors. These thermostats can be used to produce variable resistance, variable voltage, or variable current. They can also send digital signals to electrical or computerized control systems.

Bimetal Thermostat

A bimetal element can directly control the power supply to small compressor motors. A thermostat that actuates a magnetic motor starter (contactor) can indirectly control larger motors that have a high current draw. When the compressor is equipped with an unloader, a thermostat can control the operation of the unloader actuator.

Filled System Remote Bulb Thermometer

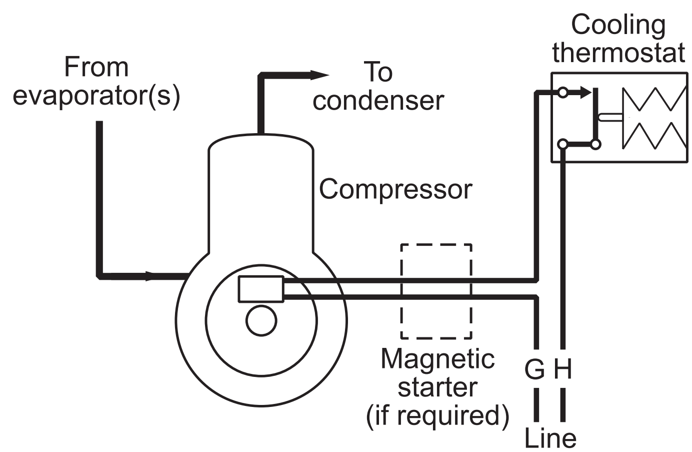
When equipped with a switch, a filled system thermometer can also directly control the compressor motor power supply. If the temperature of the refrigerated medium increases above set point, the fluid within the thermometer expands, and causes the bellows to expand, as well. The bellows closes the thermostat switch, which energizes the magnetic motor starter to start the compressor. The opposite occurs when the temperature of the refrigerated medium drops below set point.

To keep the compressor from **short-cycling**, the thermostat has a differential setting. The temperature must drop a few degrees below the set point for the switch to open, and then the temperature must rise a few degrees above the set point for the switch to close. These are referred to as the cut-in and cut-out points. The cut-out point is always at a lower temperature than the cut-in. The difference in temperature between these two points is called the temperature differential.

Thermostats often have adjustable differential settings. The range refers to the span of temperatures over which the compressor operates. The differential setting controls the size of the range. For example, suppose the range of thermostat "A" is from 8°C to 3°C, and that of thermostat "B" is from 15°C to 10°C. Though they operate over different ranges, in each case, the differential is 5 degrees. If the range of thermostat "C" was between 3°C and 10°C, its differential would be 7 degrees.

Figure 3 shows the location of a filled system remote bulb thermostat in a compressor electrical control circuit.

Figure 3 – Thermostatic Control of Compressor



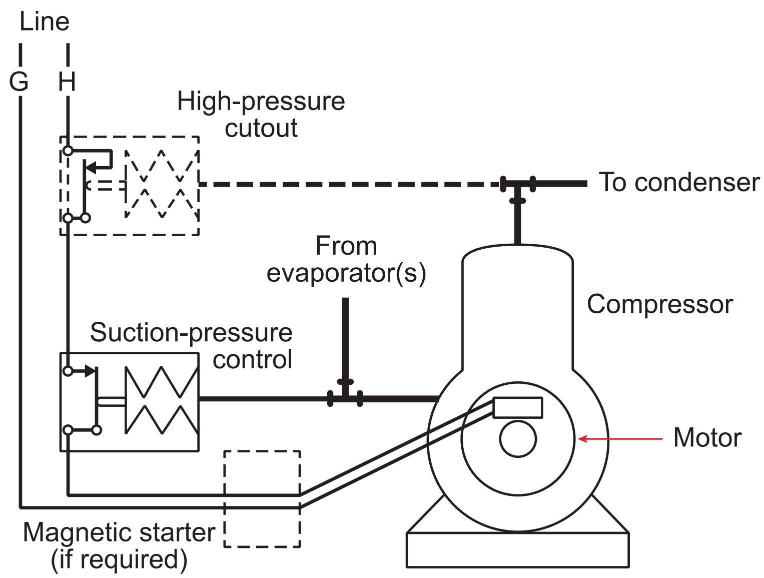
Temperature-actuating devices that control compressor operation are used in conjunction with refrigerant flow controls. These controls are typically solenoid valves that stop the flow of refrigerant when the compressor stops.

Pressure-Actuated Control (Pressurestat)

The suction pressure of the refrigeration compressor is directly related to the boiling temperature of the liquid refrigerant in the evaporator. Therefore, a change in evaporator temperature is reflected by changes in the suction pressure.

For example, when using the refrigerant R-717, if the boiling temperature of the refrigerant in the evaporator is –18°C, then the evaporator pressure will be about 309 kPag. If the temperature increases to –16°C, then the evaporator pressure will be about 328 kPag. A pressure-actuated control, connected to the suction line, can start and stop the compressor. It is possible to maintain the evaporator temperature within close limits over varying load conditions using this system. This arrangement is shown in Figure 4.

Figure 4 – Suction-Pressure Controlled Compressor



In this case, the pressure-actuated control used is a switch. A bellows or diaphragm that senses the suction pressure of the compressor actuates the switch. The control is similar to a thermostat, except it operates in the reverse manner. This control opens the compressor power switch when the suction pressure drops to the cut-off setting, and closes the switch when the pressure rises to a preset differential.

In some instances, a suction pressure-actuated control cannot be utilized:

a) If an automatic expansion valve is used as a metering device. Automatic expansion valves maintain a constant evaporator pressure. In this situation, the compressor would not cycle off.

b) With a capillary tube or orifice-type metering device, since these do not prevent liquid refrigerant flow from the high to the low sides of the system when the compressor shuts down. The pressures on both sides would equalize soon after the compressor stops. The rising evaporator pressure would then restart the compressor almost immediately. The frequent starts and stops would cause premature compressor failure, and excessive power consumption.

Humidity-Actuated Control (Humidistat)

In some air conditioning systems, refrigeration is used to lower the humidity of the air by condensing the moisture on the cold surfaces of the evaporator or dehumidifier. A humidistat can be used both for humidity measurement and to start and stop refrigerant flow to an evaporator. A liquid solenoid valve, coupled with a metering device, is used in conjunction with the humidistat.

Objective 2

List the safety shutdown devices specific to centrifugal compressor water chillers.

Safety shutdown devices protect equipment from damage, either due to mechanical failure or human error. In the world today, there is a greater awareness of ODP (ozone depleting potential) and GHG (greenhouse gases); it is necessary to prevent leakage and accidental discharge of refrigerant, so that it remains contained within the system.

If a component in a refrigeration system fails, it may cause a system breach and a **catastrophic leak**. Therefore, it is important to protect pressure-retaining components – including the compressor itself – from failure.

Centrifugal Chiller Safety Controls

Centrifugal chillers are equipped with several safety devices that protect the system against abnormal conditions during startup and operation. Modern **chiller** systems have sophisticated controls and HMIs, to monitor safety controls and conditions prior to startup and during operation. The HMI can also be connected to a central computerized control system that operates the building HVAC system.

Low Chilled Water Temperature Cut-Off Switch

This safety device consists of a thermostat that senses the temperature of the chilled water leaving the chiller. If the water temperature is too low, the water may freeze in the evaporator. Since water expands when it freezes, this will damage the evaporator tubing and tube sheet.

If the temperature drops approximately 2.5 to 3°C below the set point of the control thermostat, it will shut down the compressor. When the water temperature rises approximately 5 to 6°C, the thermostat will allow the compressor to restart.

Chilled Water Flow Switch

This switch, installed in the chilled water outlet line, protects the chiller from freezing due to lack of water flow. It opens the compressor motor circuit when water flow drops below the safe minimum flow. It also prevents the compressor from starting if flow has not been established.

Inlet Vane Closed Switch

The inlet vane closed switch is a proximity switch. It is closed when the chiller capacity control vanes are in the closed position. This is a necessary precondition for centrifugal compressor startup. With closed vanes, the compressor can be started under a no-load condition. If the vanes are open and the compressor is off, it cannot start.

Low Oil Pressure Cut-Off

This safety shutdown device will prevent the compressor from operating when lube oil pressure is below a safe minimum value. This prevents compressor damage or destruction, and the possibility of a catastrophic refrigerant leak that may result. The low oil pressure cut-off normally requires a manual reset. This alerts the operator that a low oil pressure condition occurred, and may require more careful monitoring of the compressor oil pressure to determine the cause.

Condenser High Pressure Cut-Off

This high limit switch will shut down the compressor when the condenser pressure reaches an excessively high value. This switch requires a manual reset before the compressor can restart. Inadequate condenser cooling water or airflow, or condenser fouling, is generally the cause of a high condenser pressure trip.

Refrigerant Low Temperature Cut-Off

This safety switch is a low limit thermostat. It senses the temperature of the refrigerant in the chiller. If the temperature drops low enough for water to freeze, the switch opens and shuts down the compressor.

Motor Demand Limiter

Most centrifugal chillers have a motor **demand limiter**, which limits the maximum current flow to the compressor drive motor. This control overrides the water temperature sensor if the motor load reaches the maximum amperage setting.

A common and useful purpose of this control is that it limits the current flow when the machine first starts. Usually, the chilled water temperature is considerably higher than set point at the time of startup; however, the actual system load may be lower. If there is no restriction placed on the current flow, the motor will draw maximum current until the temperature of the water comes down to the chilled water set point. This results in a very high and very costly electrical demand. Also, the water could reach its set point temperature very quickly under a low load start. If the compressor does not automatically unload fast enough, the unit could trip on low chilled water temperature.

The motor demand limiter can be adjusted to 40%, for example, and left there until the chilled water has been brought down to the required temperature. Increasing the demand limiter in gradual steps through 60%, 80% and 100% helps reduce the maximum electrical demand and the possibility of motor damage due to high current flow.

The motor demand limiter sets the permissible opening of the compressor inlet vanes. The power consumed by the compressor motor is proportional to the mass of refrigerant moved per unit time. The inlet vanes restrict the flow of refrigerant, and thus the current draw of the compressor drive motor.

Instead of demand limiters, some chillers use soft loading strategies on startup. These have the same effect on reducing electrical demand and preventing low temperature trips on startup. Soft loading is a PLC control strategy that brings the chilled water loop temperature from its start value to its set point in a controlled manner. Soft loading prevents the chiller from going to full capacity during the **pull down** period.

Chillers that use variable speed drives can limit demand by varying compressor speed.

Compressor Vibration Shutdown

There is often a vibration switch on each motor and compressor bearing. If the vibration on any bearing reaches a certain set point, an alarm sounds to warn the operator of a vibration problem. The compressor will stop if the vibration on that bearing increases further (to the shutdown set point).

Suction Scrubber High Level Shutdown

On chillers equipped with a suction scrubber, if the liquid level rises to a certain point, an alarm will sound to alert the operator of a high level in the scrubber. If the level continues to rise, a float switch will shut down the compressor to keep liquid from getting into the compressor.

High Bearing Temperature Shutdown

Each compressor and motor bearing is equipped with a temperature probe. If the temperature rises to a certain point (determined by the bearing manufacturer), a high bearing temperature alarm activates. This allows the operator to either take action to reduce the bearing temperature, or to prepare a standby chiller for service. If the temperature continues to rise, the compressor will shut down.

Motor Winding Temperature Cut-Off

Motor windings can fail if they get too hot. This may occur if the compressor and motor are overloaded. To protect the motor, chillers have overcurrent protection and locked rotor protection. In either case, if high motor current persists during the start or run period, the power to the compressor drive motor is shuts off.

Restart Inhibit

Restart inhibit keeps compressors from short-cycling, or restarting in a short period of time. Motors sustain high currents when starting, which can damage motor windings. The restart inhibit feature allows the motor to cool off for 10 or more minutes before it can be restarted.

Motor Overload Protection

Motor overloading leads to overheating and eventual failure. One type of overload used with centrifugal chillers employs a current transformer with a resistor in the motor circuit. An increase in current flow causes a greater voltage drop across the resistor in the electrical circuit. An electronic circuit amplifies this change in voltage, to operate relays that control the compressor inlet vanes.

If vane control fails to prevent overload, the relay operates a solenoid valve to force a pneumatic or hydraulic drive motor to close the vanes. This is achieved by applying oil or air pressure to one side of the piston and bleeding the other side.

Objective 3

Describe typical refrigeration system safety shutdown devices.

Limiting and Safety Controls

Refrigeration systems must be equipped with safety devices. These devices provide protection from damage that might occur due to equipment malfunction or operator error.

High-Pressure Cut-Off

During operation, the condenser pressure may become excessively high. This may be due to:

c) Insufficient cooling of the high-pressure vapour in the condenser

d) Lack of cooling airflow

e) Atmospheric conditions
- Extremely warm temperatures
- High humidity
- Lack of wind

f) Fouling of the condenser heat transfer surfaces

g) **Non-condensable gases** accumulated in the system

Refrigerant gas condenses under the normal temperature and pressure conditions found in the condenser. Under these same temperatures and pressures, other gases (such as air or products of lube oil decomposition) cannot condense. These gases accumulate at the top of condensers and liquid receivers. In the condenser, non-condensable gases occupy space, impede heat transfer, and raise condenser pressure.

Refrigeration system piping and components are designed according to various ASME codes, to specific high and low side design pressures. To prevent the pressure from exceeding the design pressure, **Clause 7.2** of the **CSA B52 Mechanical Refrigeration Code** states that, with few exceptions:

> *"Pressure-limiting devices shall be provided on all systems operating above atmospheric pressure."*

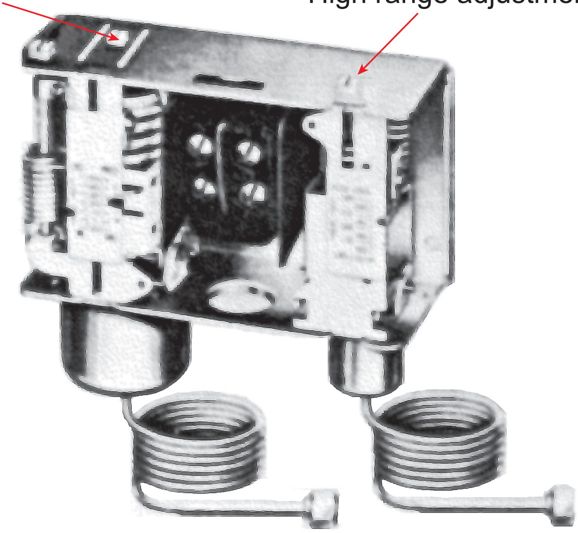
It also states:

> *"On systems equipped with a pressure-relief device, the setting of this device shall not be more than 90% of the system high-side design pressure… the pressure-limiting device shall stop the action of the pressure-imposing element."*

CSA B52 also requires this device to be connected between the compressor and the first stop valve in the discharge line. The sensing line must not have an intervening valve, because closing that line would render the pressure-limiting device inoperative.

This pressure-limiting device is much like the high-pressure cut-off of a boiler. It has a set point and a non-adjustable differential. The high-pressure cut-off has a manual reset button, so operator intervention is necessary. The operator must determine the cause of the high pressure and rectify the condition before restarting the compressor. Often, the high-pressure cut-off is in the same housing with the suction pressure control, if one is present to control the compressor motor. Figure 5 illustrates one combination type.

Figure 5 – Combined Low-Pressure Control and High-Pressure Safety Cut-Off



Low-Pressure Cut-Off

This pressure operated safety switch protects the system against abnormally low suction pressure and temperature. The following situations would cause these conditions to occur:

a) If the pressure actuated operating control fails to stop the compressor at its cut-off pressure (a low suction pressure).

b) In a system with a temperature actuated motor control, if the evaporator ices up excessively and stops proper heat transfer. In this situation, the refrigerated space or medium would rise to above its temperature set point. However, the thermostat would run the compressor continuously.

A low-pressure cut-off control operates on the same principle as the high-pressure safety cut off control. It may also have a manual reset lever. The low-pressure and high-pressure cut-offs are often in the same housing. This combination control has a manual reset, and it alerts the operator if the compressor shuts down before temperature conditions are satisfied.

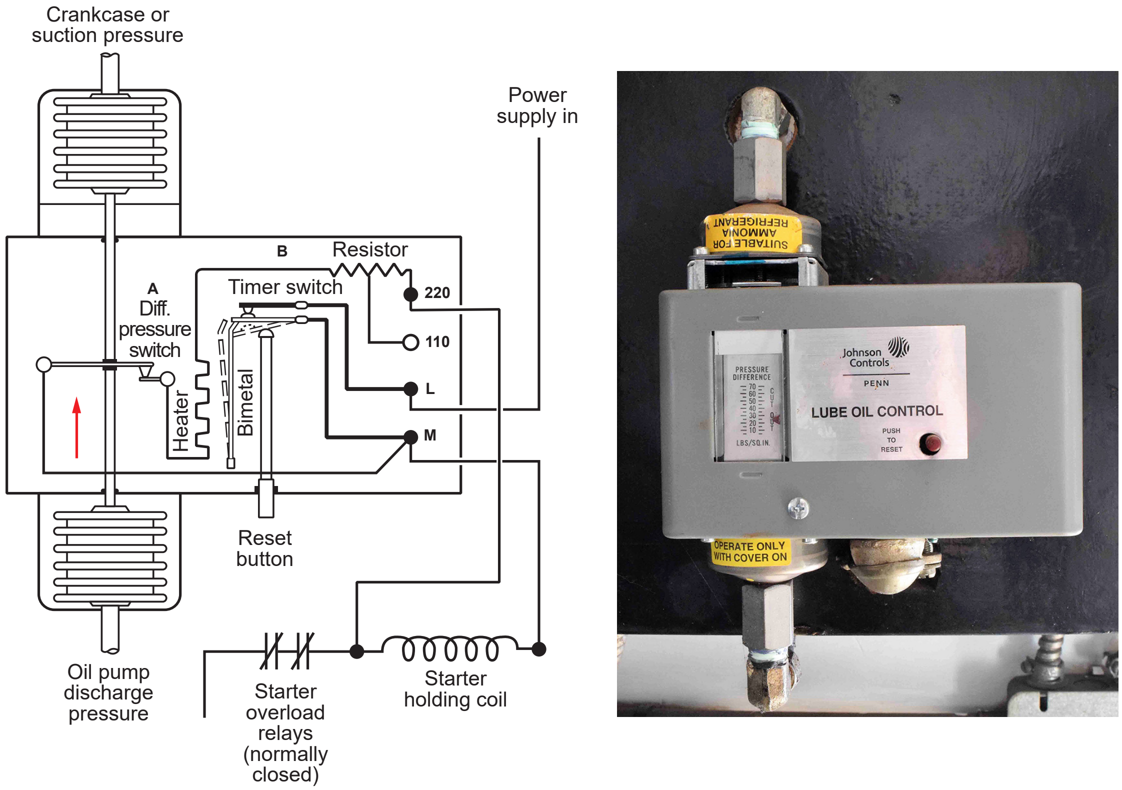
Low Limit Thermostat

The low limit thermostat is useful for systems where equipment damage can occur if the temperature drops to below the minimum setting of the operating thermostat. It is important to ensure that chilled water never freezes, since this can cause extensive damage to the evaporator. To prevent freezing, the sensing element of a low limit thermostat goes into the water, at the coldest point of the chiller. The thermostat is set to open the control circuit of the compressor at a temperature several degrees above the freezing point.

Low Oil Pressure Cut-Off Switch

If a forced lubrication system fails, it could cause extensive damage to a refrigeration compressor. Therefore, the compressor must have an oil pressure failure switch. This switch will shut down the compressor when the oil pressure drops below the safe minimum limit for longer than a predetermined period. Figure 6 shows an example of this device.

Figure 6 – Low Oil Pressure Cut-Off Switch



Refrigeration compressor crankcases and oil sumps are both under low-side pressure. The compressor bearings operate within the surrounding low-side pressure environment.

Low side pressure varies during normal compressor operations. For example, many compressors **pump down** the low side before they cycle off. This reduces the low side pressure to just above atmospheric, which is well below normal.

During the pump down cycle, the oil pump supply pressure falls considerably. When the temperature of the refrigerated space increases, a liquid line solenoid valve opens to admit refrigerant to the evaporator. The evaporator pressure rises, and the compressor starts.

There are wide variations that occur in the low side (and crankcase) pressure. Therefore, sensing only the oil pump discharge pressure is an unreliable indicator of whether the bearings are receiving adequate lube oil. In fact, a normal single-point oil pressure-sensing switch would cause frequent nuisance shutdowns, compressor bearing failure, or both. In this case, it is important to measure the difference between the oil pump supply pressure and the crankcase pressure. This is the useful or "net" lube oil pressure.

For example, consider a compressor with an oil supply pressure of 620 kPa and a crankcase pressure of 480 kPa. In this case, the useful (net) oil pressure is 620 – 480 = 140 kPa. This net pressure must be maintained to prevent compressor bearing damage.

Refer to Figure 6. The low oil pressure cut-off control is a differential pressure switch with two opposed bellows. One bellows senses oil pump discharge pressure. The other bellows senses crankcase pressure. The variations, in the relative positions of the bellows, operate a differential pressure switch (A). This switch controls a small heater located near a bimetal strip. The bimetal bends when it is hot, and allows a timer switch (B) to open. The timer switch is wired into the compressor motor run circuitry. Two things happen when the switch opens:

1. The compressor stops.
2. The current through the heater stops.

After the bimetal cools, it cannot automatically restore the timer switch. The operator must depress the reset button. This button moves the timer switch contacts together, and allows the bimetal to bend under the timer switch, holding the contacts closed.

When the compressor first starts, the net oil pressure is zero. During startup, the oil pump continues to develop oil pressure. The cut-off switch timer allows the compressor enough time (usually from 30 to 120 seconds) to start and establish the correct oil pressure differential. If this pressure differential does not establish within the required amount of time, the compressor motor shuts off. After the proper oil pressure differential increases to the required set point pressure, the differential pressure switch opens and de-energize the heater circuit before the bimetal strip opens the timer switch contacts. The compressor then continues to operate normally.

During normal operation, if the differential oil pressure is greater than the suction pressure by the required amount, the timer heater circuit stays open, and the heater stays cool. This keeps the timer switch closed, and the compressor continues to run. If the differential oil pressure drops too low, the bellows arrangement closes the differential pressure switch and energizes the heater circuit. After about 30 to 120 seconds, the bimetal becomes hot enough to bend and it opens the compressor motor circuit. This may occur if the sump oil level is too low, if the oil is foaming, or if the oil pump is not working properly.

Before manually resetting the switch, the heater and the bimetal strip must cool off. Once the bimetal strip is cool, pressing the reset button causes the compressor to start. Therefore, before resetting the cut-off, the operator should investigate the cause of the low oil pressure condition and correct the problem.

Flow Switch

Flow switches are operated by the force exerted on a flexible vane immersed in a flowing fluid. These switches are used in chilled water lines, cooling water lines, and air ducts.

Flow switches are often used as safety lockout switches, if the fluid flow becomes insufficient or ceases. For example, in a chilled water system, the compressor must not run if a chilled water pump fails. Otherwise, the compressor may not be able to unload fast enough, and evaporator freeze-up may occur.

Flow switches can also be used to close flow indicator circuits.

High Oil Temperature Cut-Off

If the oil temperature is too high, it cannot adequately lubricate the bearings. High oil temperature could indicate fouling or failure of the lube oil cooler, or failure of the cooling medium. If the oil temperature rises to above 80°C, the compressor shuts down immediately. This often requires a manual reset.

The high oil temperature cut-off sensing element may have a bimetallic strip or a thermistor. A thermistor changes electrical resistance quickly, in response to temperature changes. Thermistor-type cut-offs respond faster than bimetal strips, so they are used when reaction speed is more critical.

High Motor Temperature Cut-Off

If the drive motor windings get too hot, the high motor temperature cut-off stops the compressor. Hot windings lead to premature winding insulation failure. This may be due to any one of the following:

- High machinery room ambient temperature
- Overloading
- Damaged motor fan
- Excessive dirt buildup on the motor
- Blocked cooling passages

Bimetal or thermistor temperature sensing elements may be used.

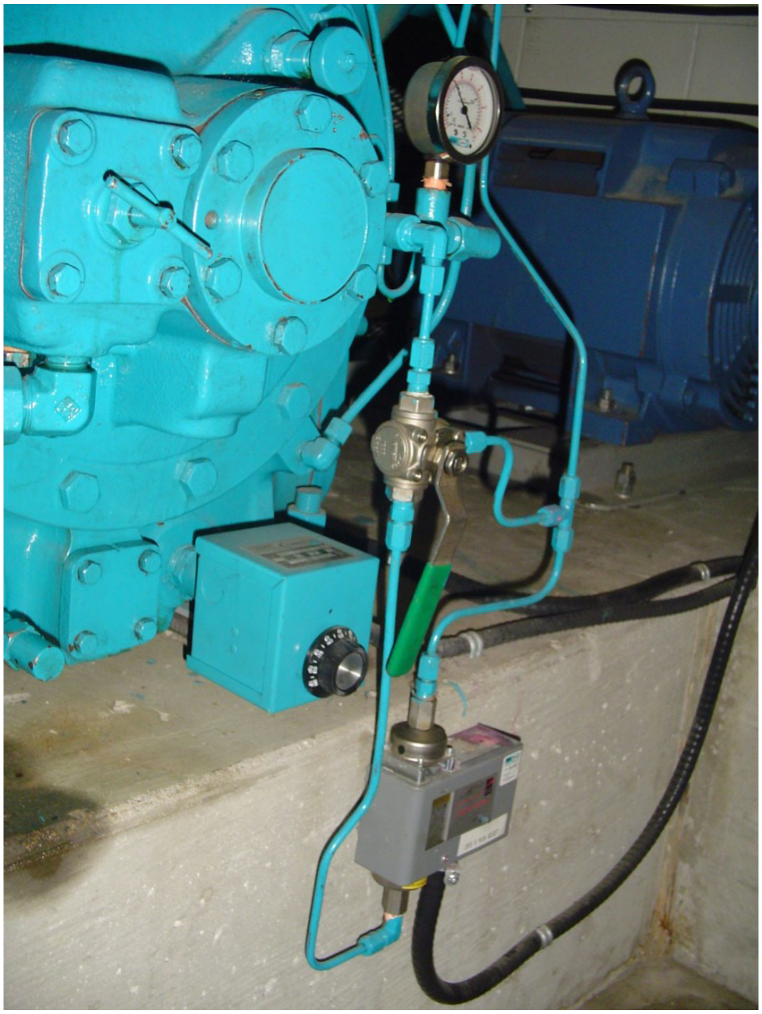
Low Oil Temperature Start Inhibit and Cut-Off Switch

When compressor lube oil is cool, it dissolves more refrigerant than when it is hot. Dissolved refrigerant dilutes the lube oil, which causes excessive bearing wear. As well, when the compressor starts, refrigerant in the oil vaporizes, and forms bubbles. When the lube oil pump draws bubbles, it may lose its prime and starve the bearings of oil.

When the lube oil temperature is below 60°C, a lube oil heater starts to raise the oil temperature. Below 35°C, the inhibit switch keeps the compressor from starting.

Figure 7 shows a crankcase heater, installed near the base of a reciprocating compressor. The heater has a temperature set point adjustment dial. A low oil pressure cut-off can also be seen.

Figure 7 – Crankcase Oil Heater



Objective 4

Describe the construction and operation of refrigerant metering devices.

Refrigeration Metering Devices

The refrigerating capacity of a system depends, in part, on the mass of refrigerant circulated per unit time. Consider two identical refrigeration systems. They have the same high and low side pressures; the same size and make of compressor; the same evaporator and condenser; and use the same refrigerant. With all things equal, the system kW rating (or tonnes) depends on how much refrigerant circulated through the system over a period of time. The circulation rate depends on two things:

1. The mass of refrigerant the compressor circulates.
2. The rate at which refrigerant enters the evaporator.

Refrigeration system pressures and temperatures must remain constant while the system is in operation. For this to occur, the amount of refrigerant fed to the evaporator must always equal the amount of refrigerant circulated by the compressor.

At low load, less refrigerant circulates. As cooling load increases, refrigerant flow must increase in proportion. The flow of refrigerant through the compressor is controlled with various compressor capacity control methods, including on-off cycling and unloading. A metering device regulates the flow of refrigerant through the evaporator.

Without an automatic metering device, the evaporator may receive either an insufficient or excessive amount of refrigerant. In the first case, the evaporator pressure and temperature drops. But, because too little refrigerant is fed, the evaporator runs too dry. The vapour becomes excessively superheated, and the evaporator tonnage drops too low to adequately cool the refrigerated space. As well, excessively superheated low-pressure vapour may inadequately cool the compressor.

If too much refrigerant enters the evaporator, the cooling load will not be able to vaporize all the refrigerant. The remaining liquid will enter the compressor suction line and destroy the compressor.

In some older refrigerating systems, the flow of liquid refrigerant to the evaporator is manually controlled. In modern systems, the metering devices operate automatically; however, some very large systems require qualified operators in attendance at all times.

There are six basic types of metering devices. These are:

1. Hand-operated expansion valve
2. Automatic (constant pressure) **expansion valve** (AEV)
3. Thermostatic expansion valve (TEV)
4. Low-pressure float valve
5. High-pressure float valve
6. Capillary tube

Hand-Operated (Manual) Expansion Valve

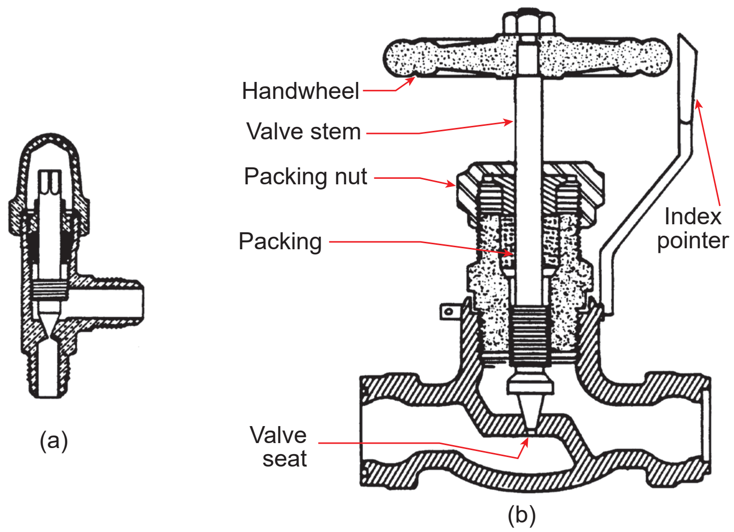
Figure 8(a) is a **manual expansion valve** used in small capacity refrigerating systems. Depending on the refrigerant, it may be made of brass or stainless steel. It is connected to the piping system by flared compression fittings, threading, or welding.

In order to withstand the severe requirements of throttling service, this type of valve is equipped with a valve stem, with a tapered end, and a matching tapered valve seat. The spindle has a fine thread which makes precise adjustment possible. To adjust the valve, remove the cap, and turn the spindle with a wrench or key.

Figure 8(b) is another type of hand operated expansion valve which is suitable for larger flows. It has an index pointer for greater precision in adjustment.

These manual expansion valves are seldom used in modern refrigeration systems. However, they are occasionally used in bypass lines around automatic control valves, or for defrosting systems.

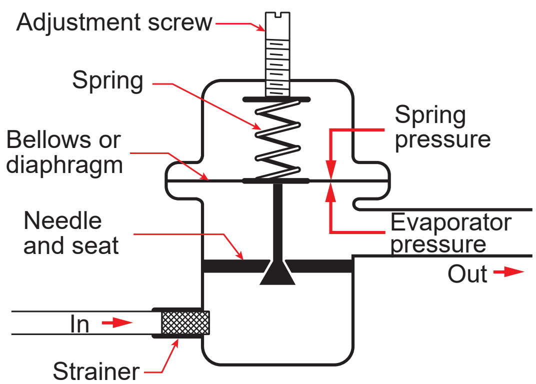
Figure 8 – Manual Expansion Valves



Automatic Expansion (Constant Pressure) Valve

The **automatic expansion valve (AEV)** is actually a pressure-regulating valve. This valve maintains constant pressure in the evaporator whenever the compressor is running, regardless of load. This valve also automatically shuts off the liquid flow, when the compressor stops. A sketch of an automatic expansion valve is shown in Figure 9.

Figure 9 – Schematic Diagram of Automatic Expansion Valve



The valve stem is attached to a bellows or diaphragm in the upper part of the valve housing. A spring exerts a downward force on the diaphragm, which opens the valve. The evaporator pressure, acting upward against the diaphragm, counteracts this force, and closes the valve. The spring tension is adjusted so that, during operation, the two forces balance each other. This ensures that the valve is sufficiently open to allow enough liquid to flow into the evaporator, to maintain the desired pressure and, therefore, the desired temperature.

A thermostat stops the compressor when the temperature of the refrigerated space or medium drops below set point. The expansion valve stays open and allows liquid to enter the evaporator. This liquid continues to vaporize, which causes the evaporator pressure to increase. The increased evaporator pressure acts on the underside of the valve diaphragm, overcomes the downward force of the spring, and closes the valve. This stops the flow of liquid refrigerant into the evaporator.

The thermostat restarts the compressor when the temperature of the refrigerated space or medium rises above set point. This causes the evaporator pressure to drop to where the pressure on the diaphragm becomes less than the downward spring force. The valve then opens to allow liquid refrigerant to enter the evaporator.

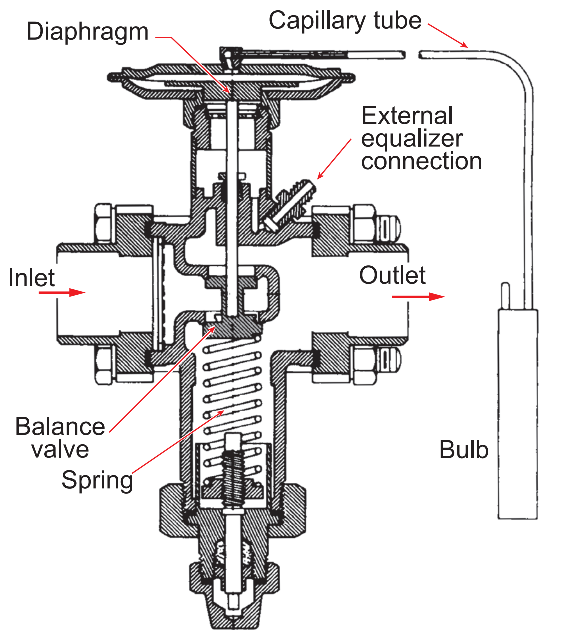
AEVs are used on small refrigerating units, such as refrigerators and freezers. These machines have relatively steady loads and small compressors that can start easily under load. Due to their inherent disadvantages, AEVs are not used in larger multi-evaporator systems, or systems with highly variable cooling loads.

Consider a system with a single compressor and two evaporators, each fed with an AEV. A thermostat, located in the refrigerated space, controls the compressor. The cooling load calls for the compressor to operate continually. This lowers the pressure in the coils, and causes both AEVs to stay open. If the load in the refrigerated space is uneven, one evaporator may have sufficient load to vaporize all the refrigerant fed to it. The other may not have enough load, and could admit liquid refrigerant into the compressor suction line, which will damage the compressor. The thermostatic expansion valve was designed to overcome this problem.

Thermostatic Expansion Valve

The **thermostatic expansion valve (TEV)** is the most widely used metering device. It is similar in construction to the automatic expansion valve, but features a thermal power element which consists of a bellows or a diaphragm chamber connected to a temperature-sensing bulb by means of a small internal diameter tube (capillary tube). The bulb is often charged with the same refrigerant used in the system. The refrigerant in the thermal bulb is in liquid form, and the rest of the element is filled with refrigerant vapour. Figure 10 shows a cross-sectional view of a diaphragm type TEV, and a TEV installed on an R-410A chiller.

Figure 10 – Thermostatic Expansion Valve

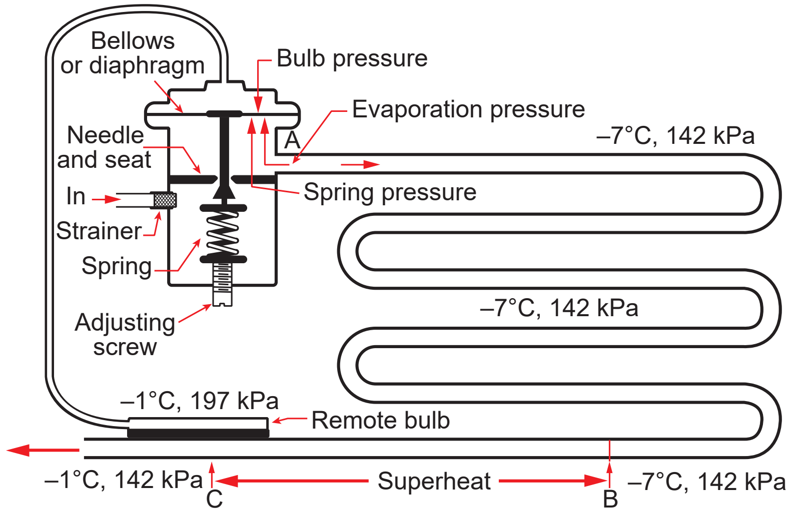


A simplified diagram of a TEV installed on the inlet of an evaporator is shown in Figure 11. The thermal bulb is strapped to the piping at the evaporator outlet. The bulb is sensitive to refrigerant temperature changes at the evaporator outlet. A change in outlet temperature changes the pressure of the refrigerant in the thermal power element.

The TEV adjusts the amount of liquid admitted to the evaporator so that, under all load conditions, nearly the entire evaporator surface is used to transfer heat to the evaporating liquid refrigerant. It also ensures that no liquid leaves the evaporator with the vapour.

To verify there is no liquid in the vapour leaving the evaporator, the vapour must be superheated. Typical TEVs maintain a constant superheat of around 6°C above the evaporator saturation temperature. See Figure 11. At point B, all liquid has evaporated, but the vapour temperature is still at the saturation temperature that corresponds to the evaporator pressure. Between B and C, however, the heat absorbed by the vapour causes its temperature to rise above the saturation temperature, and it becomes superheated.

Figure 11 – Schematic Diagram of Thermostatic Expansion Valve



The bulb has a fixed internal volume. As the bulb temperature increases, the pressure inside the bulb also increases. This internal pressure exceeds the evaporator saturation pressure.

Three forces control the operation of the expansion valve:

1. The force exerted by the thermal element, which opens the valve.
2. The forces exerted by the evaporator pressure, which closes the valve.
3. The force exerted by the spring, which also closes the valve.

Consider an increase in cooling load. A load increase requires additional refrigerant circulation. If insufficient liquid refrigerant enters the evaporator, the refrigerant receives more superheat than normal. This raises its temperature above saturation temperature, and above the normal superheat set point. The pressure in the thermal element rises and increases the force on the diaphragm. This opens the valve and allows more liquid refrigerant to enter the evaporator.

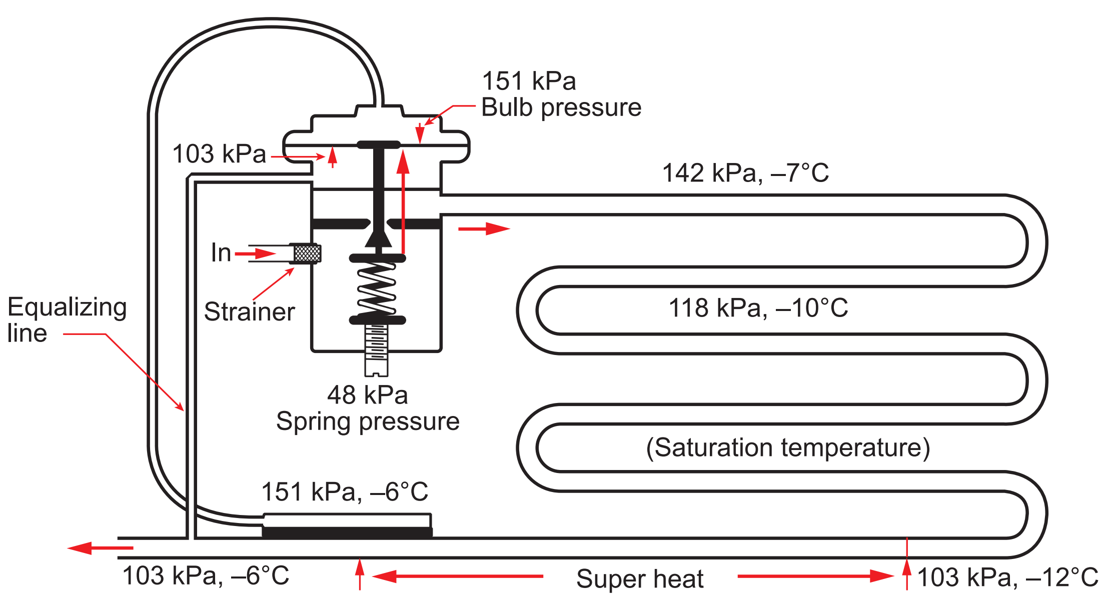
Now, consider a decrease in cooling load. This requires less refrigerant circulation. If too much liquid enters the evaporator, it reduces or eliminates the superheat, and the pressure drops in the thermal element. This pressure drop reduces the force on the diaphragm. The valve partially closes and reduces the flow of liquid refrigerant.

The TEV shown in Figure 11 works quite well provided the pressure drop across the evaporator is small. However, in many coil type evaporators, pressure drop can be quite large. This causes a reduction in temperature and pressure near the evaporator outlet. The reduction in temperature then causes a pressure reduction in the thermal element, which reduces the size of valve opening.

For the valve to open wide enough to supply the proper amount of liquid refrigerant to match the cooling load, the refrigerant superheat must increase further. This means that more of the heat transfer surface area will provide superheat, instead of evaporating liquid refrigerant. The net result will be reduced evaporator capacity.

To compensate for a large drop in evaporator pressure, a thermal expansion valve may have an equalizing line, to connect the underside of the diaphragm with the outlet of the evaporator instead of the inlet. This creates a reduction in the upward force exerted by evaporator pressure, to compensate for the downward force of the thermal element. The valve can now admit enough liquid to maintain 5°C to 6°C of superheat at the outlet and provide maximum evaporator capacity. Figure 12 shows a diagram of an evaporator that has a thermal expansion valve with an equalizing line.

Figure 12 – Thermostatic Expansion Valve with Equalizing Line



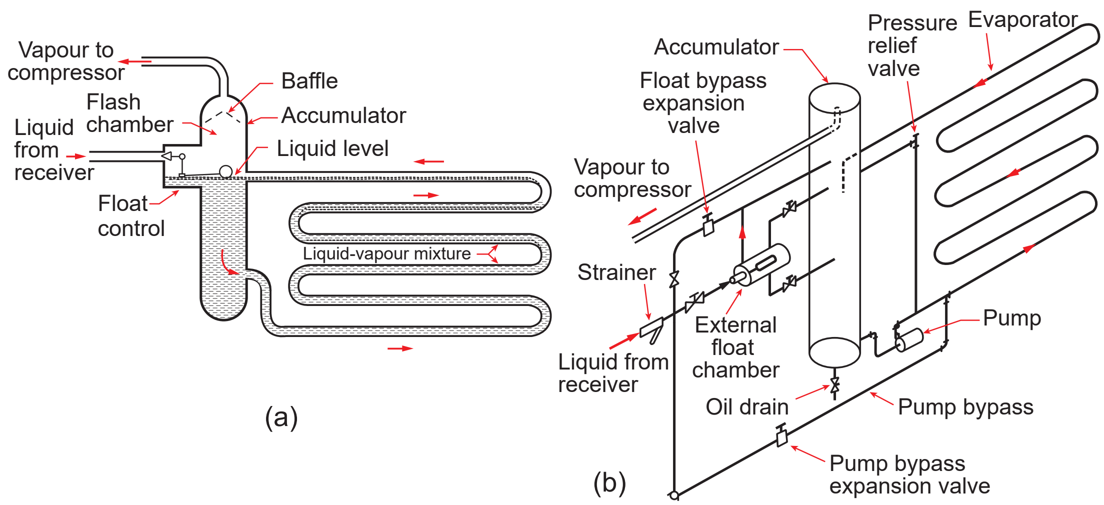
Low-Pressure Float Valve

In a flooded evaporator, the **low-pressure float valve** maintains a constant level of liquid refrigerant. Its name derives from the fact that the float is installed in the low side of the system.

The float responds to the level of the liquid in the evaporator, and controls a valve that opens or closes to maintain the desired level, regardless of cooling load. The float may be installed directly in the evaporator or in the accumulator (Figure 13(a)). It may also be installed in an external float chamber, attached to the **low-pressure receiver** (accumulator) of a liquid overfeed system (Figure 13(b)). External float valves are common on large water chillers, or on pasteurization coolers, where rapid response to changes in product flow is necessary to ensure all product is properly chilled.

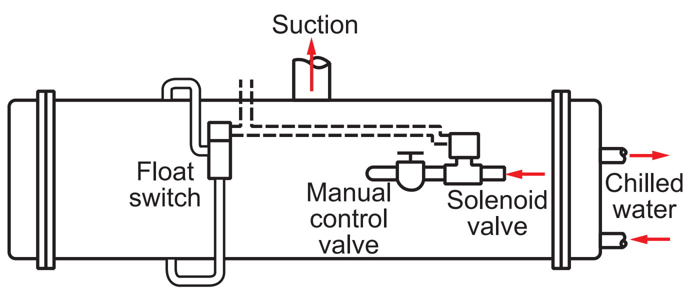
On large capacity systems, a bypass line (Figure 13(b)) with a hand-operated expansion valve, is usually installed around the external float chamber. This provides cooling if the float valve fails. Isolation valves on the liquid and vapour connections to the low-pressure receiver allow the float chamber to be isolated for repairs, without having to evacuate the refrigerant from the evaporator. In liquid overfeed systems, a liquid refrigerant pump provides forced circulation of refrigerant through the evaporator. If the pump fails, cooling can be maintained with a manual expansion valve that bypasses the pump.

Figure 13 – Flooded Coil-Type Evaporator with Low-Pressure Float Valve



Another method to control refrigerant level in large flooded evaporators uses a low-pressure float switch in combination with a solenoid valve. The float switch is mounted in a float housing, which is connected to the evaporator. The switch controls the operation of a solenoid valve in the liquid refrigerant line between the receiver and evaporator. This system is shown in Figure 14.

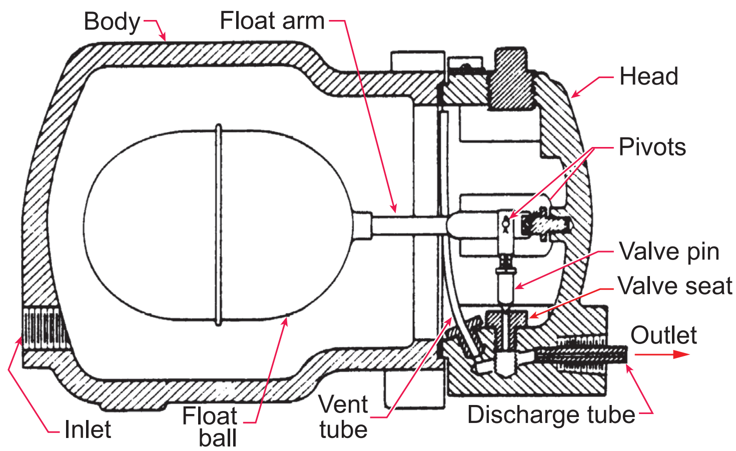
Figure 14 – Water Chiller with Electric Level Control



High-Pressure Float Valve

Like the low-pressure float valve, the **high-pressure float valve** is also a control valve operated by a liquid level. However, the high-pressure float is located on the high side of the system, and operated by the liquid refrigerant level on that side. Figure 15 shows a cross-sectional view of this valve.

Figure 15 – High-Pressure Float Valve

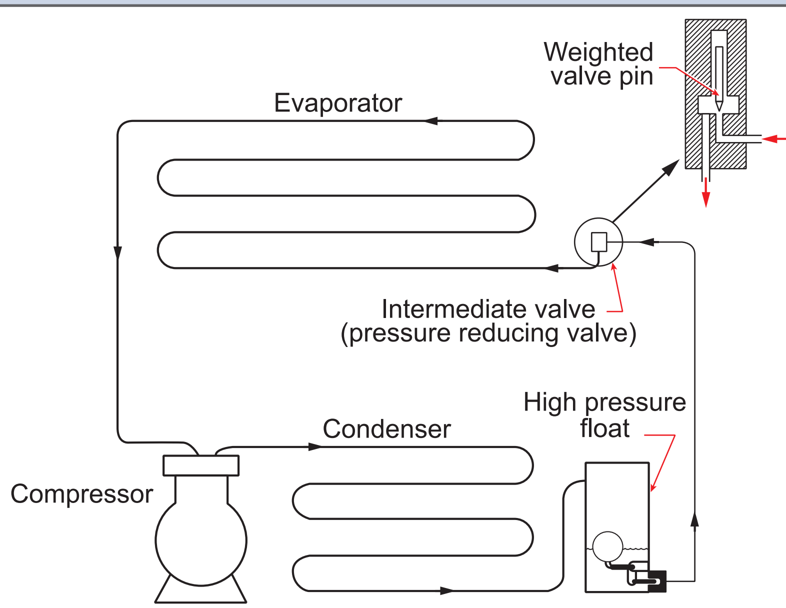


The float maintains a constant level in the float chamber. If the evaporation rate increases, the compressor pumps more vapour to the condenser. This causes more liquid refrigerant to flow into the float chamber. The level in the chamber then rises, and the float valve opens to allow more liquid to flow to the evaporator.

Since the liquid refrigerant flows directly from the condenser into the valve housing, there is no provision in the system to store the refrigerant, other than in the evaporator. For this reason, the amount of refrigerant charge in a system with a high-pressure float valve is critical. Too much refrigerant in the evaporator may cause liquid to carry over with the vapour to the compressor. Insufficient liquid will starve the evaporator and reduce system capacity.

Figure 16 is an installation of a high-pressure float valve. An intermediate pressure-reducing valve is usually placed before the evaporator, immediately after the float valve, to reduce frosting of the line.

Figure 16 – High-Pressure Float Valve Installation

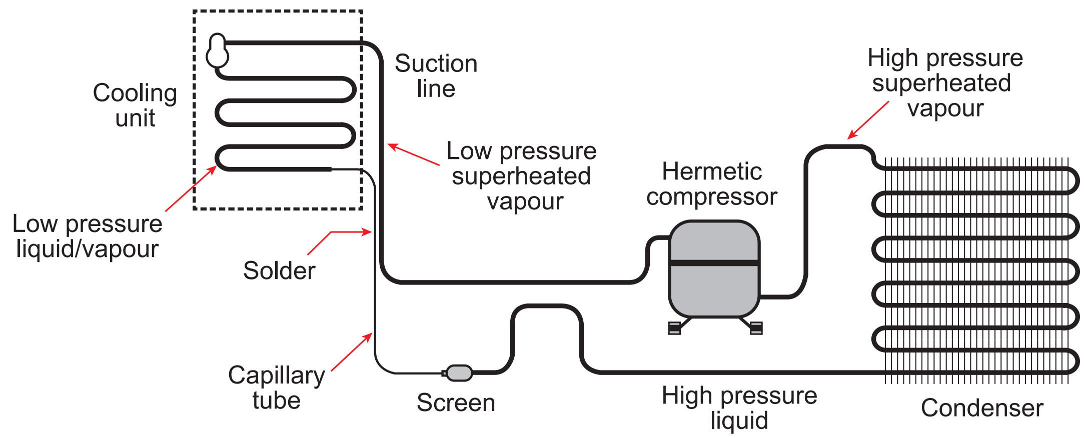


Capillary Tube

The capillary tube is the simplest of all metering devices. It consists of a fixed length of tubing with a very small inside diameter. Because of the high resistance resulting from its length and small bore, it creates a considerable pressure drop along its length. Therefore, it restricts the flow of liquid from the condenser to the evaporator, and maintains the pressure difference between the high side and the low side. Because the bore of the tube is so small, capillary tubes are limited in application to small refrigeration units.

Figure 17 shows the installation of a capillary tube in a low capacity system.

Figure 17 – Refrigeration System with Capillary Tube



(Courtesy of Borg-Warner)

In Figure 17, the solder connection permits heat exchange between the cool vapour leaving the evaporator, and the warm refrigerant liquid entering the evaporator. This improves system efficiency by using cool low side refrigerant vapour to subcool the liquid refrigerant. When subcooled, the refrigerant produces less flash gas in the evaporator. This increases the net refrigerating effect of the system.

The capillary tube has a small capacity, and it is not very sensitive to load changes. Therefore, it is used only on small refrigerating equipment with fairly constant loads, such as domestic refrigerators, freezers, and air conditioners.

Objective 5

Describe the different methods used to control evaporator capacity.

Refrigeration systems are designed to meet maximum cooling loads. Most of the time, the cooling load is not at the maximum. For this reason, refrigeration systems must be able to modulate their cooling capacity to meet lower cooling loads effectively and efficiently. Otherwise, the refrigeration system must be cycled on and off, which is inefficient, costly, and hard on the machinery. On-off control is only a reasonable capacity control solution for small household or commercial appliances.

To have efficient control over the capacity of a refrigeration system that operates continuously, there must be control over the evaporator capacity (evaporator tonnage). When the evaporator capacity changes, it affects the amount of vapour produced. Therefore, the evaporator and compressor capacities require simultaneous control.

Evaporator Capacity Control

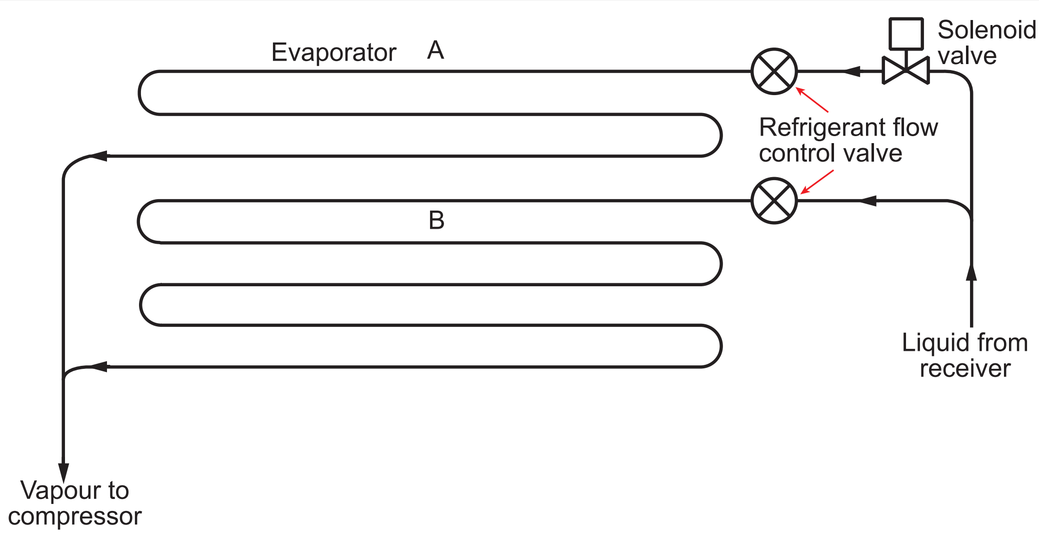
Evaporator capacity can be controlled by using sectional evaporators or evaporator dampers.

Sectional Evaporators

A sectional evaporator is divided into two or more sections (Figure 18), each with a refrigerant flow control valve. Sections of the evaporator can be shut off as the cooling load decreases.

The evaporator in Figure 18 has two sections, A and B. When the load decreases, a solenoid valve, installed in the liquid refrigerant line, closes to make section A inoperative. The area of each section is proportional to the reduction in cooling load.

Figure 18 – Two-Section Evaporator



Evaporator Dampers

An evaporator may be equipped with a face damper, to vary the quantity of air passing over the evaporator coils (Figure 19). These face dampers are controlled by a positioner that opens and closes according to a control signal. The positioner is designed so it will only close completely for maintenance, or in the event of a fire alarm shutdown.

One problem with using only face dampers is that the airflow varies with cooling load. In HVAC applications, when the dampers close, the reduction in airflow reduces the ventilation air to unacceptable levels.

Figure 19 – Face Damper Control

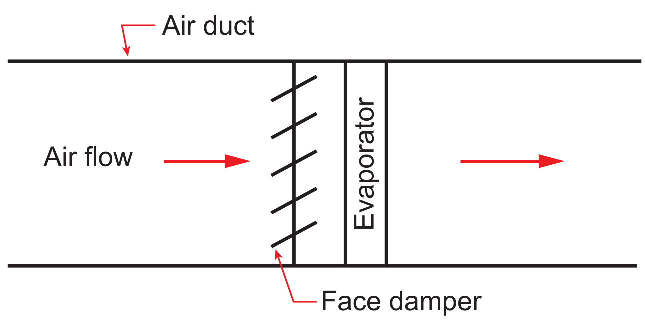
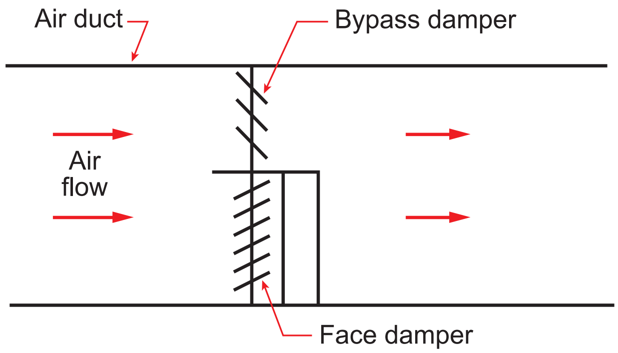


Figure 20 shows another type with both face and bypass dampers. The dampers are connected to the same damper drive, so that the bypass damper opens as the face damper closes. Varying the amount of air that passes through the evaporator coils controls the cooling capacity. Regardless of the damper position, the quantity of air that passes through the duct remains constant.

Figure 20 – Face and Bypass Damper Capacity Control



Multispeed blowers and dampers are often used in combination. This provides a better balance between the amount of air supplied by the fan, and the amount required for cooling.

Objective 6

Describe the different methods used to control the capacity of refrigeration compressors.

Compressor Capacity Control

Constant speed electric motors usually drive refrigeration compressors. The capacity of the compressor is designed for maximum calculated cooling load, and it often exceeds the actual load. Therefore, it is necessary to regulate compressor capacity.

There are various methods used to control compressor capacity:

a) Intermittent operation:
   - Two-position start-stop control

b) Continuous operation with reduced output:
   - Cylinder unloading
   - Cylinder bypass
   - Hot gas bypass
   - Compressor speed control
   - Suction throttling
   - Variable inlet guide vanes
   - Variable position slide valves

Intermittent Operation

The compressor stops when the desired low temperature of the substance to be cooled is reached. It starts up again when the temperature rises to a certain level. This method is only used on small systems, with fairly constant loads. When the compressor starts, it consumes a lot of power. If used on large compressors, the demand charges for the repetitive starting would be too costly.

Continuous Operation with Reduced Output

There are many ways to control compressor capacity by reducing output during continuous operation. Reciprocating, centrifugal and screw compressors have different methods of control.

Reciprocating Compressor Capacity Control

In larger systems, especially when operated on light loads, frequent starts and stops would put undesirable stresses on the motor and switchgear, cause power fluctuations, and create a very high and costly electrical demand. Therefore, in these systems, the compressor operates continuously, but at reduced capacity.

The following reduce the capacity of reciprocating compressors:

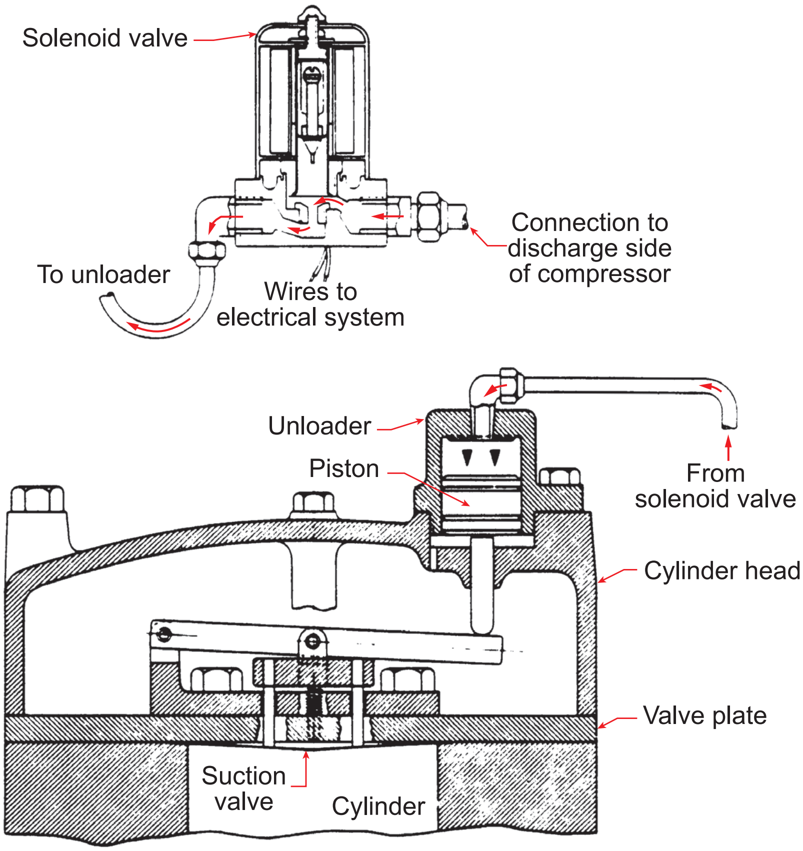
- Cylinder unloading
- Cylinder bypass
- Hot gas bypass
- Variable speed drive

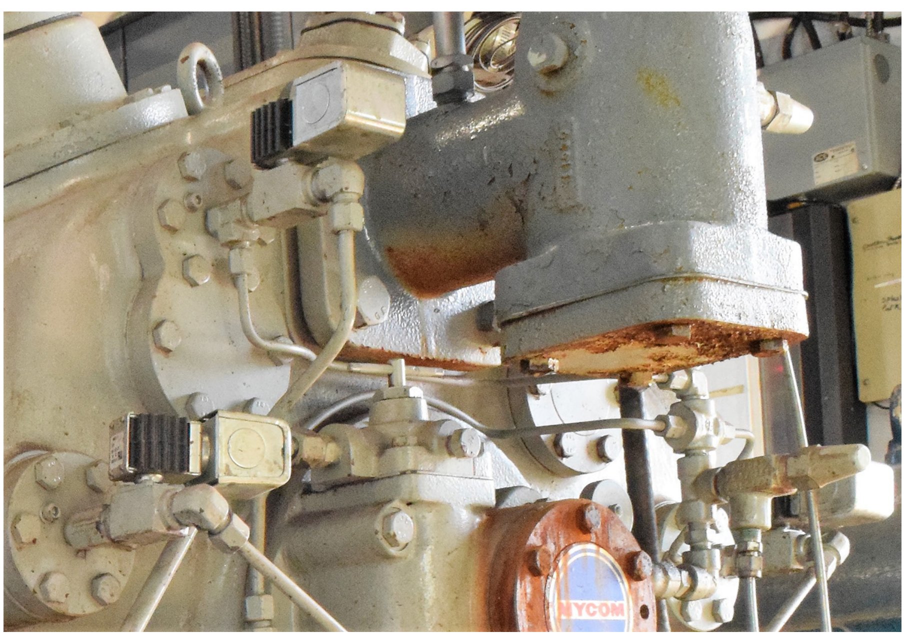
Cylinder Unloading

Cylinder unloading is a method used to reduce capacity. It deactivates one or more cylinders in sequence, as the cooling load dictates.

Cylinder unloaders keep the intake valves of one or more cylinders in the open position. This prevents compression of the vapour drawn in during the suction stroke. Figure 21 shows a cylinder unloader and the controlling solenoid valve.

Figure 21 – Cylinder Unloader and Solenoid Valve





As the compressor suction pressure falls to a preset value, a pressure switch, sensing low pressure on the suction side, energizes a solenoid valve. The valve opens and admits refrigerant, at condenser pressure, to the **unloader** piston. This pressure moves the unloader piston downward to depress the suction valves, and holds them in the open position.

When this occurs, refrigerant vapour is drawn into the cylinder during the suction stroke. The vapour discharges back to the suction line during compression. When the suction pressure rises to a certain value, the pressure switch de-energizes the solenoid valve. This causes the unloader piston to return to its normal position, and allows the suction valves to operate once again.

A similar unloader is required on an intermittently driven (on-off) compressor, so the compressor can start in an unloaded condition until it reaches operating speed. This condition reduces the starting current of the electric motor. Capacity control of multi-cylinder continuously operating compressors may be accomplished by unloading one or more cylinders. The cylinders load and unload in sequence, in response to changes in load.

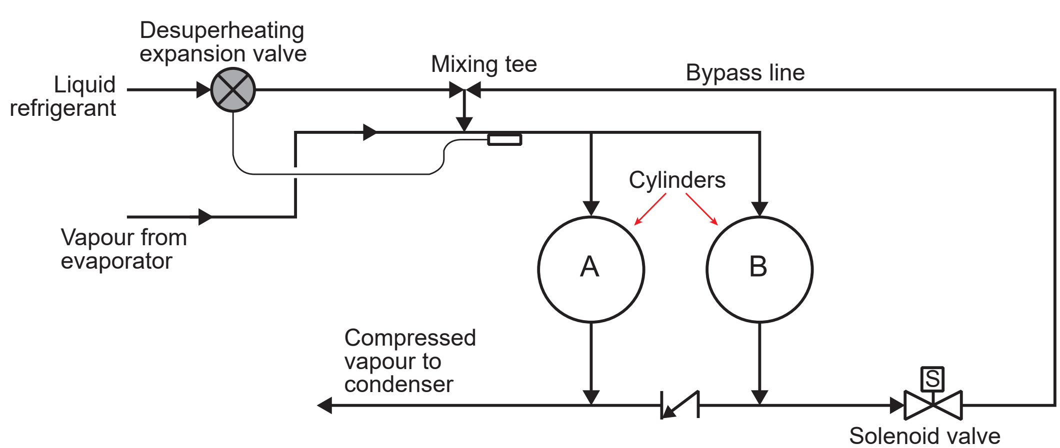
Cylinder Bypass

Another method of controlling the capacity of reciprocating compressors is to bypass the discharge from one or more cylinders back to the suction side of the compressor. This is the **cylinder bypass** method. Figure 22 shows a two-cylinder compressor that can bypass one cylinder.

When the suction pressure at the compressor drops to a preset value, a pressure switch energizes a normally closed solenoid valve. This permits refrigerant to discharge from cylinder "B" and flow back into the compressor suction line. The discharge from cylinder "A" is allowed to pass to the condenser. A check valve in the line that connects the two cylinder discharge lines prevents the cylinder "A" discharge from bypassing to the suction. In this situation, the compressor capacity is reduced to 50%.

When the suction pressure increases to the preset cut-off pressure, the pressure switch de-energizes the solenoid. The bypass line closes, and the compressor returns to full capacity operation.

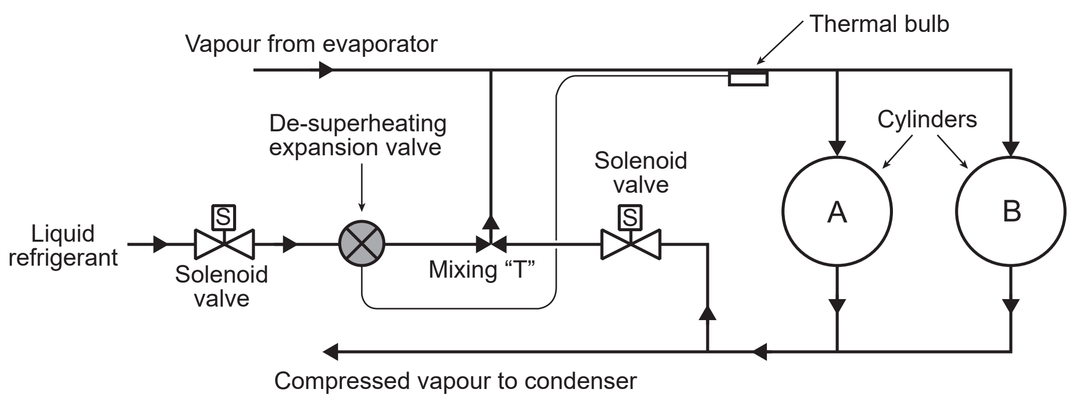
Figure 22 – Cylinder Bypass



Hot Gas Bypass

Figure 23 shows a simple **hot gas bypass** capacity control. When a reduction of compressor capacity is required, a normally closed solenoid valve, located in the bypass line, is energized by the pressure or temperature at the compressor inlet. When energized, some hot high-pressure gas is allowed to go directly into the suction line.

Figure 23 – Hot Gas Bypass



This type of capacity control has several disadvantages. Because compression occurs normally, there is little or no reduction in power consumption when the bypass line is open. As well, the compressor can overheat.

The simple hot gas bypass is used only on small compressors. It is often used in conjunction with other types of capacity control when it is necessary to provide capacity control down to 0% loading or to unload a compressor before starting. It is also used with some centrifugal compressors.

Centrifugal Compressor Capacity Control

The following reduce the capacity of centrifugal compressors:

- Speed control
- Suction throttling
- Variable inlet guide vanes

Speed Control

Centrifugal compressor capacity varies according to its rotational speed. There are several ways of controlling this speed. Large compressors may be driven with steam turbines. In this case, a temperature-sensing device, located in the chilled water outlet, controls the speed of the compressor by regulating the steam flow to the turbine. If the compressor is driven by an electric motor, a variable frequency drive can be employed to vary the speed. Finally, hydraulic couplings, installed between a constant-speed driver and the compressor, can also vary compressor speed.

Suction Throttling

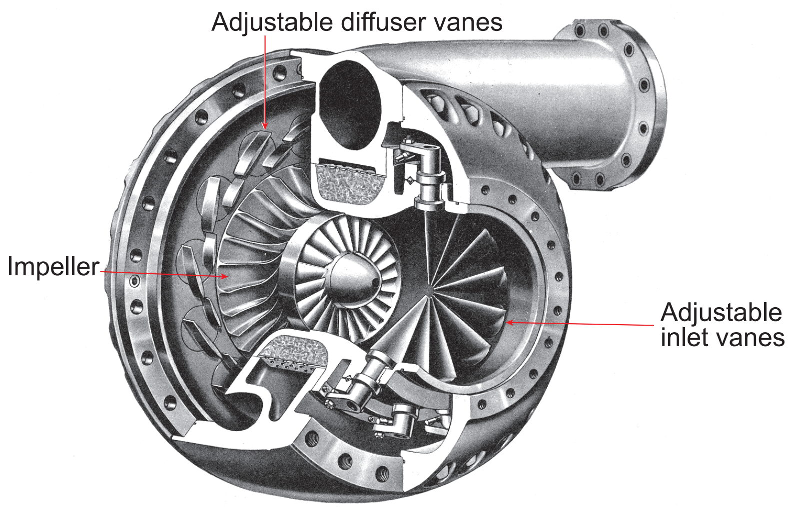
To achieve suction throttling, a butterfly damper installed at the inlet to a centrifugal compressor. The damper can be easily adapted to automatic control with the use of a piston type positioner. However, its application is not economical because the input power to the compressor does not decrease by the same amount as the capacity. Variable inlet guide vanes have replaced suction throttling.

Variable Inlet Guide Vanes

Centrifugal compressors commonly use variable inlet guide vanes for capacity control (see Figure 24). The vanes are linked so that they operate together. A rack and gear arrangement, attached to a piston, operates the vanes. An increase in air or oil pressure moves the piston and rack against the force of a spring. This opens the inlet vanes. When the air or oil pressure to the piston decreases, the spring returns the vanes to the closed position. A vane position indicator shows the position of the blades. A vane switch acts as a safety device to prevent the compressor from starting, unless the vanes are closed (fully unloaded).

The inlet guide vanes can occupy an infinite number of positions. Therefore, inlet vane control can finely adjust centrifugal compressor capacity. As well, inlet vane dampers control compressor capacity very efficiently, compared to suction throttling. As the vanes move towards the closed position to reduce compressor capacity, they swirl the refrigerant vapour in the same direction that the compressor impeller turns. This results in a reduction in the compressor power consumption. So, as compressor capacity is reduced, compressor power consumption is also reduced.

Figure 24 – Centrifugal Compressor with Diffuser Vanes



(Courtesy of Worthington Corporation)

The photos in Figure 25 show centrifugal compressor inlet vanes, removed from a centrifugal chiller undergoing maintenance. On the left, the inlet vanes are in the fully unloaded position. On the right, the inlet valves are in the fully loaded position.

Figure 25 – Centrifugal Compressor Inlet Vanes

Screw Compressor Capacity Control

The following reduce the capacity of screw compressors:

- Variable position slide valve
- Variable speed drive

Variable Position Slide Valve

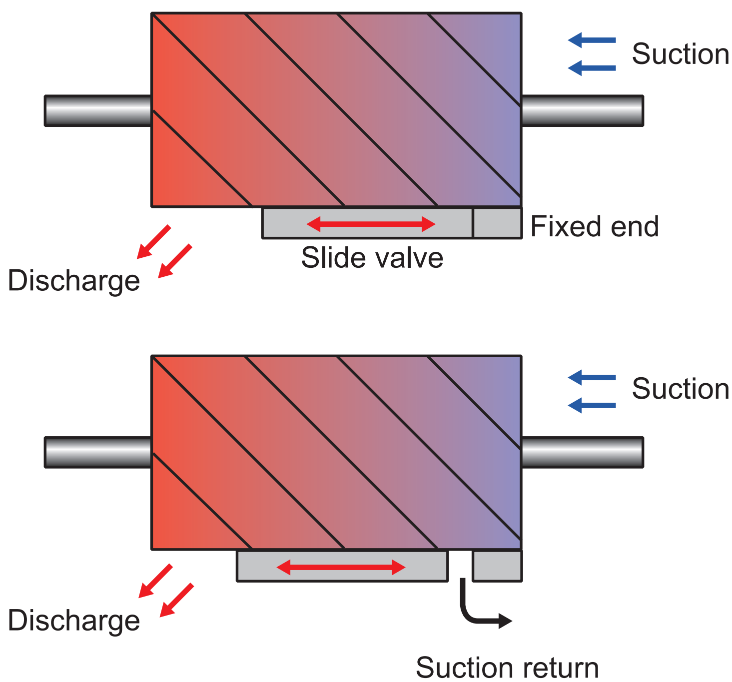
Constant speed screw compressors often use variable position slide valves to adjust their capacity. Slide valves also permit either unloaded or low-load compressor starts. Screw compressors with variable position slide valves are far more economical than compressors with start-stop capacity control.

A slide valve is a variable opening in the screw compressor housing. The slide valve may be positioned in steps, depending on the required cooling capacity. These steps provide 50, 75, and 100 percent capacity. Solenoid valves operate in sequence, applying hydraulic pressure (lube oil) to a piston that moves the slide valve into the correct position. Some compressors have infinitely variable, stepless capacity control, ranging from 10 to 100 percent capacity.

A slide valve position indicator mounted on the compressor shows the operator how much load is on the compressor. Slide valve position switches can also be used to indicate the compressor capacity on a central computerized control display.

Figure 26 shows how the slide valve works. In the top diagram, the compressor is fully loaded. The slide valve is against the fixed end. Refrigerant is drawn in on the right-hand side of the screw, and compressed over its entire length. In the bottom diagram, the compressor is partially unloaded. Compression begins at the leading edge of the slide valve. In a low load position, compression begins at a point further into the compressor housing. Therefore, only a portion of the screw is involved in gas compression. The part of the suction gas that is not compressed is diverted back to the suction inlet of the compressor.

Figure 26 – Screw Compressor Capacity Control Using Slide Valve



Variable Speed Drive

Variable speed drives, including variable frequency drives (VFDs), have been successfully used for capacity control in screw-type air compressors. These drives are being increasingly applied to refrigeration screw compressors. Screw compressors are categorized as positive displacement machines. Therefore, their capacity (kg/h) changes with rotational speed.

In the case of an HVAC chiller, a temperature controller monitors the chilled water supply temperature. On startup, when the load is low but the chilled water temperature is high, built-in control algorithms prevent the VFD from operating the compressor at full capacity. This keeps the chilled water temperature from overshooting the temperature set point. As well, this limits the start-up current.

During regular operation, the temperature control algorithm adjusts the capacity of the compressor via a control output signal to the VFD. If the chilled water supply temperature is too low, the compressor speed decreases. If the temperature is too high, the compressor speed increases.

Chapter Summary

This chapter discussed controls used to help refrigeration plants operate safely and efficiently, under varying conditions. Though designed to operate at particular high side and low side temperatures, load changes and atmospheric conditions influence system operation.

Refrigeration systems need capacity controls to automate the response to load changes. These controls include:

- HMIs
- Metering devices
- Evaporator capacity controls
- Compressor capacity controls

These devices automatically adjust the refrigeration plant operation, so that the cooling load matches the plant cooling capacity at all times. The control system manages complex system interactions in real time. This means that manual intervention is not continually required while the equipment is in operation.

Occasionally, operating conditions deviate from design parameters. These deviations may cause product spoilage or system damage, which is costly, and may even be dangerous. Therefore, refrigeration plants are equipped with safety limits that prevent damage due to excessively high system pressures or excessively low temperatures. These safety switches include:

- Low water temperature cut-offs
- Discharge pressure cut-offs
- Low oil pressure cut-offs
- Flow switches
- And others

Operators must be aware of the function of all operating and safety limit controls in the plant. When a control fails, or operates outside of normal parameters, the operator must be able to control elements of the system manually. With this knowledge, operators can respond effectively when adverse conditions arise in their plants.

Chapter 4

Refrigeration System Operation and Maintenance

Learning Outcome

When you complete this chapter you should be able to:

Describe the operating principles and maintenance of refrigeration systems.

Learning Objectives

Here is what you should be able to do when you complete each objective:

1. Discuss refrigeration auxiliaries.
2. Describe refrigeration system leak test procedures.
3. Describe how a refrigeration system is dried and charged prior to startup.
4. List the steps for adding oil to an in-service refrigeration compressor.
5. Describe the startup and shutdown procedure for a compression refrigeration system.
6. Describe operational log sheets and preventative maintenance procedures for refrigeration systems.
7. Describe how a refrigeration system is purged of non-condensable gases.
8. Discuss refrigeration condenser operation and maintenance requirements.
9. Explain typical problems and resolutions related to refrigeration systems.

Chapter Introduction

It is important for Power Engineers to know the layout and types of equipment that are unique to the refrigeration systems they operate. They must learn and commit to memory the location of valves, separators, economizers, and oil pots, as well as other systems components. It is important to properly understand the function of these components in order to start, stop, operate, and maintain the equipment in a safe and economical manner.

Power Engineers need to know the various codes and standards that apply to power engineering, and must keep themselves current with any updates or changes. Codes such as **CSA B52** and **ASME B31.5** apply directly to the installation, repair, and operation of refrigeration systems. **IIAR** standards are particularly helpful with regard to ammonia system installation, repair, commissioning, operation, and maintenance.

These are as important to the refrigeration plant operator as the **ASME BPVC** is to the steam plant operator. These codes and standards should be part of the refrigeration plant engineer's professional library.

This chapter contains generic operation, maintenance, and troubleshooting guidelines. These are NOT universal practices. The data provided by the equipment manufacturer is the best source for system specific information. Manufacturer and supplier websites are the most valuable sources of information on how to operate, maintain, and troubleshoot specific refrigeration equipment. Always follow site-specific procedures.

Objective 1

Discuss refrigeration auxiliaries.

Pressure Gauges

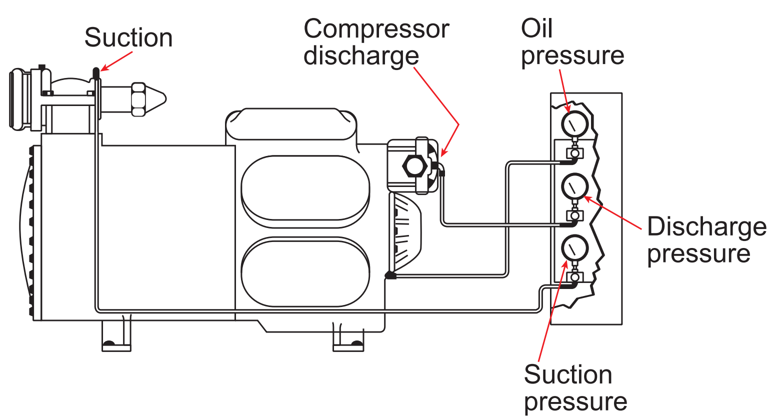
Pressure gauges indicate the conditions inside a refrigeration system. They display the pressures for the evaporator and condenser. Plus, under normal conditions, they indicate the corresponding saturation temperatures.

The **CSA B52 Mechanical Refrigeration Code** does not require permanently installed pressure gauges on any refrigeration system. However, in ammonia refrigeration systems (and larger HFC and HCFC systems), permanent gauges are normally installed. One gauge connects to the high-pressure side of the system. Another gauge connects to the low-pressure side. These gauges are usually connected to the compressor discharge and suction, and are mounted on or near the compressor. They should be equipped with pulsation dampeners, to prevent the pointers from flickering due to pressure pulsations. These pulsations lead to premature wear of the gauge internal mechanisms.

Pressure gauges are rarely installed on low capacity commercial refrigeration systems. However, these systems usually have provision for attaching gauges. Double-seated compressor service valves have back seats and flared ends, to permit the installation of service gauge sets. When these connections are not available, a permanent connection may be added to permit service gauge installation. These connections consist of a saddle, a piercing valve, and a service gauge connector. The saddle can be bolted or brazed onto the refrigerant pipe. After securing the valve in place, the piercing valve is turned inward, so it can pierce the refrigerant tube. Then, the gauge set can be attached, and the valve opened to measure the refrigerant pressure.

Figure 1 displays a typical gauge connection. There are three gauges mounted on a separate gauge board. They indicate the compressor suction, compressor discharge, and oil pump discharge pressure. This type of connection reduces the effects of compressor vibration.

Figure 1 – Gauge Connections



The oil pressure gauge is connected to the oil pump discharge. Oil pressure differential is the useful oil pressure. To find the differential, subtract the compressor suction pressure from the oil pressure on the gauge.

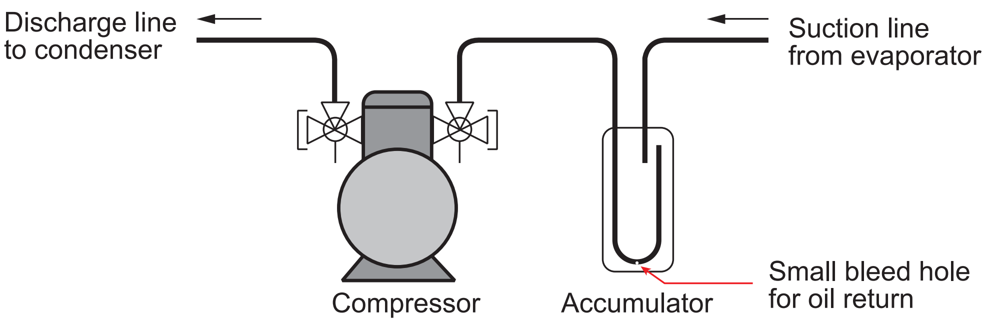
Accumulator/Surge Tank/Surge Drum

On some refrigeration systems, the metering or control action is too slow to keep pace with load changes. Also, capillary tubes cannot shut off the refrigerant flow when evaporator load is light or when the compressor cycles off. In both cases, liquid may occasionally enter the suction line and damage the compressor.

An accumulator is a simple liquid trap located in the compressor suction line. It collects and holds the liquid so that it does not enter the compressor. Heat is absorbed through the accumulator wall. This heat vaporizes the trapped liquid, and returns it to the compressor suction. Accumulators must have no insulation; otherwise, liquid refrigerant could accumulate, and it would eventually become entrained in the compressor suction.

Figure 2 shows an example of an accumulator.

Figure 2 – Accumulator Installation

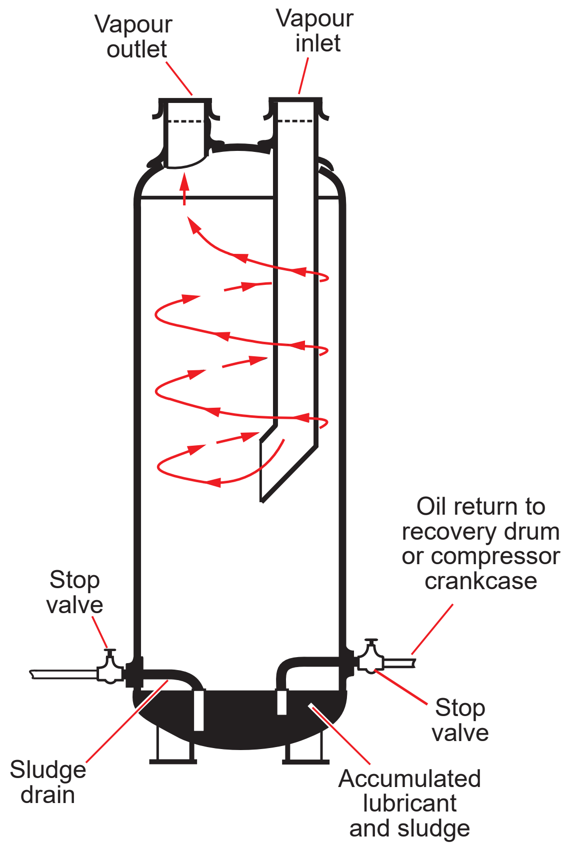


Oil Separator

During operation, a certain amount of oil leaves the compressor along with the high-pressure vapour. It is therefore necessary to separate the oil from the vapour and return it to the compressor crankcase. This maintains the oil level in the crankcase, and reduces the need for oil addition.

If not separated from the vapour, oil will enter the condenser. The oil will coat the heat transfer surfaces, and impede heat transfer. This will result in high compressor discharge pressure, and increased power consumption. Installing an oil separator in the discharge line, between the compressor and the condenser will help to avoid this issue. One design of oil separator is shown in Figure 3.

Figure 3 – "Sterne" Oil Separator

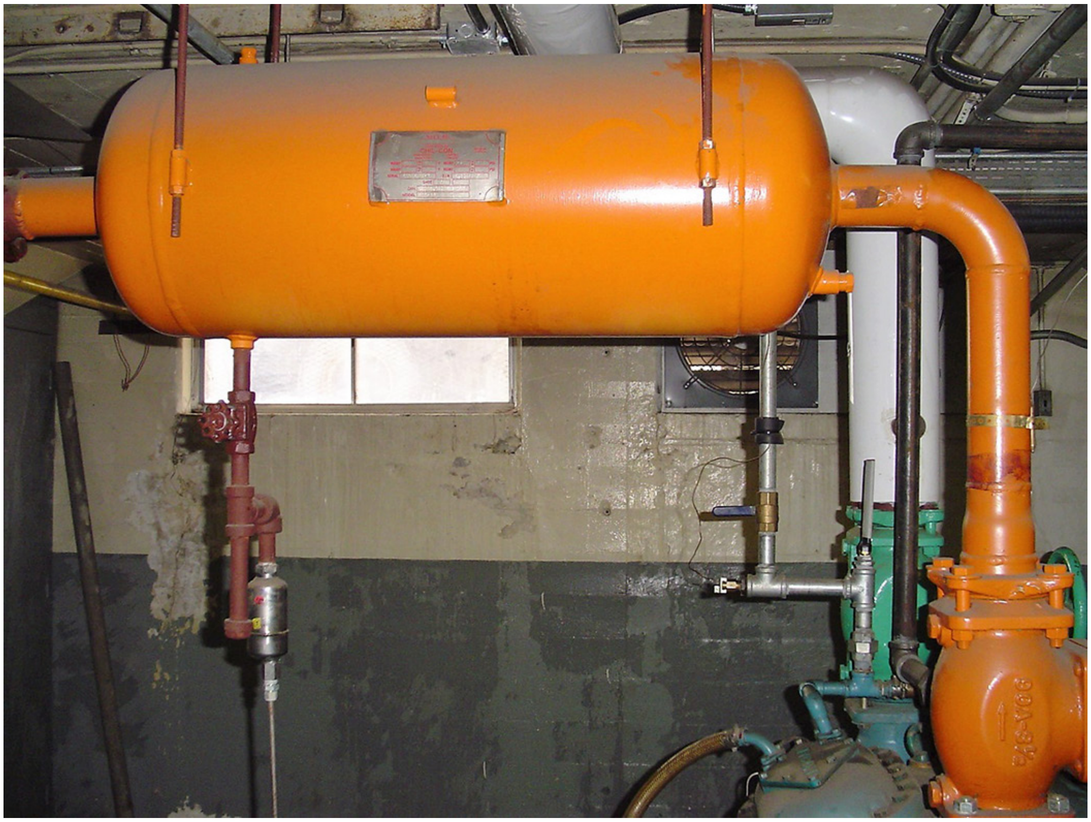


On entering the separator casing, the refrigerant vapour takes an abrupt change in flow direction. This throws the entrained oil droplets out of the vapour stream. The droplets collect at the bottom of the separator, and they are returned to the compressor crankcase.

The sludge drain blows off sludge or scale that collects in the bottom of the vessel. At regular intervals, the oil drain valve should be cracked open to allow the oil in the separator to return to the crankcase. A sight glass allows the operator to determine the oil level in the accumulator.

Figure 4 shows an oil separator used in an ammonia refrigeration system. The hot vapour discharged from the compressor enters the separator at the right-hand side of the vessel. The accumulated oil returns to the compressor through the piping arrangement on the bottom left-hand side of the vessel. The return piping arrangement has an isolation valve, a dirt leg, and a filter. The filter catches impurities to prevent them from entering the compressor sump.

Figure 4 – Oil Separator in Ammonia Refrigeration System

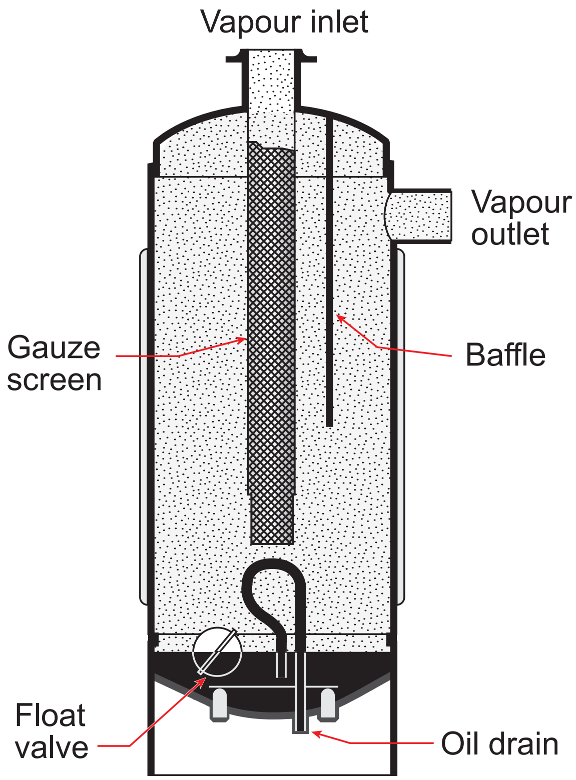


Refrigerating systems using oil-miscible refrigerants, such as HFCs and HCFCs, also use oil-separating devices in the compressor discharge line. One type is shown in Figure 5. It is only possible to extract oil from these refrigerants while they are in the vapour state.

Installing an automatic float trap may reduce the need for an operator to drain the oil manually. When sufficient oil collects, the float opens the drain valve. This allows the oil to return to the compressor crankcase.

To prevent HFCs and HCFCs from condensing and draining to the crankcase with the oil, it is necessary to keep the trap hotter than the condensing temperature. This is done by placing the separator close to the compressor, and protecting it from cold air drafts.

Figure 5 – Oil Trap for HFC and HCFC Systems



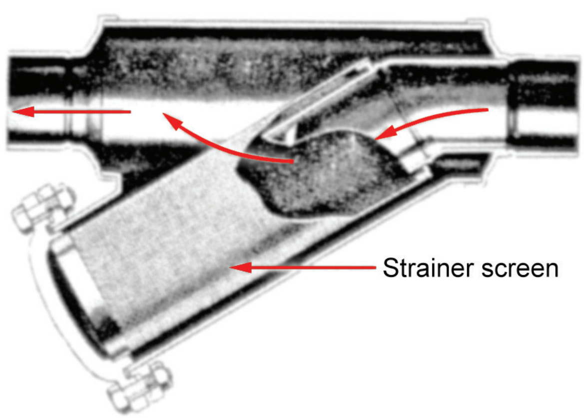
Suction Strainer

The refrigerant vapour may carry particles of foreign matter, such as line scale or corrosion, into the compressor. This can prevent the compressor valves from seating properly, or it can cause damage to compressor parts. Installing strainers in the compressor suction lines will keep these particles from entering compressors.

Figure 6 is a cross-sectional view of a typical strainer. It has a fine mesh screen basket, placed in a strainer housing. It can be removed for cleaning without disconnecting any piping.

Many smaller compressors, especially those of the hermetic type, are equipped with built-in suction strainers.

Figure 6 – Suction Strainer



Filter-Drier

The main function of a filter-drier is to remove moisture from liquid refrigerant. If not removed, moisture in a refrigeration system will cause the following problems:

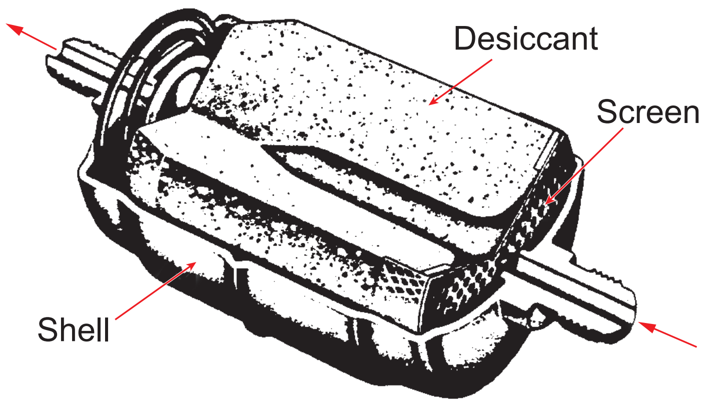
a) Ice buildup in the metering device, which disrupts its operation

b) Acid formation, which results in:
   - Corrosion
   - Sludge formation in the compressor crankcase
   - Deterioration of motor insulation in hermetic and semi-hermetic compressors.

Filter-driers also remove particulate and scale from the liquid refrigerant before it flows to the metering device. This protects the metering device from plugging.

Figure 7 is a cross-sectional view of a filter-drier used in a small refrigerating system. It has a sealed shell that contains a drying agent (a desiccant), which removes moisture either by adsorption (silica gel or activated alumina) or by chemical reaction (calcium sulfate). The filter-drier is installed in the liquid refrigerant line, ahead of the expansion valve. It is important to replace this filter-drier when the desiccant reaches its moisture holding capacity. In larger systems, the driers open up so the desiccant (supplied as a cartridge) can be replaced.

Figure 7 – Refrigerant Drier



Sight Glass and Moisture Indicators

It is common practice to install a sight glass in the liquid refrigerant line of a commercial refrigerating system to observe the liquid flow. The sight glass is a small housing equipped with one or two lenses.

When there is insufficient refrigerant in the system, the pressure drop through the liquid line to the metering device increases. This causes vapour to develop in the liquid line. This vapour shows up in the form of bubbles, as it passes through the sight glass. Vapour bubbles also show up if the flow in the liquid line is restricted, and cause a pressure drop. This makes part of the liquid flash into vapour prematurely.

Special chemicals that change colour in the presence of moisture can detect if there is any moisture in liquid refrigerants. The moisture indicator is usually combined with the sight glass. The indicator is simply a chemical dot, placed under the sight glass lens, so it is exposed to the liquid. The dot changes colour when moisture is present. The sight glass dot in Figure 8 changes from green to yellow when moisture is present. This indicates that the filter-drier needs replacement.

Figure 8 – Sight Glass with Moisture Indicator

The purpose for which it is used will determine the location of the sight glass. If used to indicate whether the system is fully charged, the sight glass should be at the receiver or liquid receiver outlet. When used to indicate if the refrigerant contains any flash vapour, the glass goes before the expansion valve. If the glass has a moisture indicator, and the liquid line from the receiver has a drier, the glass will be between the drier and the expansion valve, to allow the operator to see if the drier is plugging, or if desiccant expiration has occurred.

Economizers

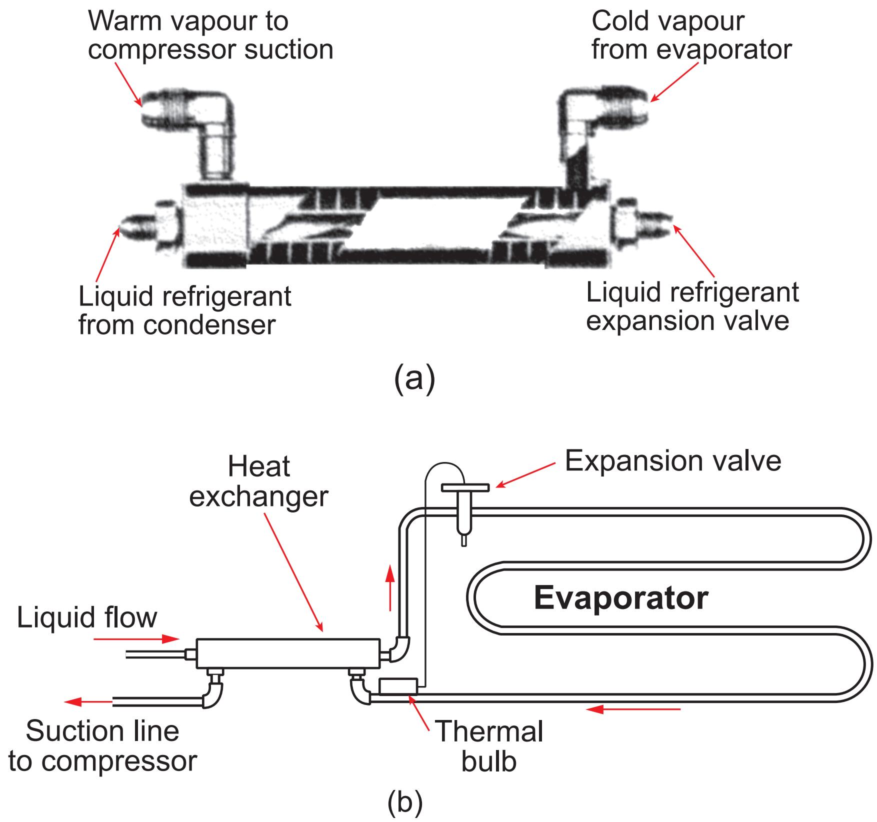
An economizer is a heat exchanger. It transfers heat, from the relatively warm liquid that flows to the evaporator, to the vapour drawn from the evaporator.

There are three reasons to use economizers:

1. They reduce the temperature of the liquid refrigerant. This generates less flash gas in the evaporator. This increases the evaporator capacity (net refrigerating effect).
2. They prevent the liquid from flashing. The liquid can flash due to the pressure drop that occurs as the refrigerant flows through the liquid line.
3. They increase the temperature of the vapour that passes though the economizer. The flow of liquid into the evaporator is automatically controlled to match the load. However, some liquid may carry over from the evaporator into the suction line when rapid load fluctuations occur. If any liquid passes through the evaporator, the economizer will evaporate it before it reaches the compressor suction. In this way, the economizer can help prevent liquid slugging of the compressor.

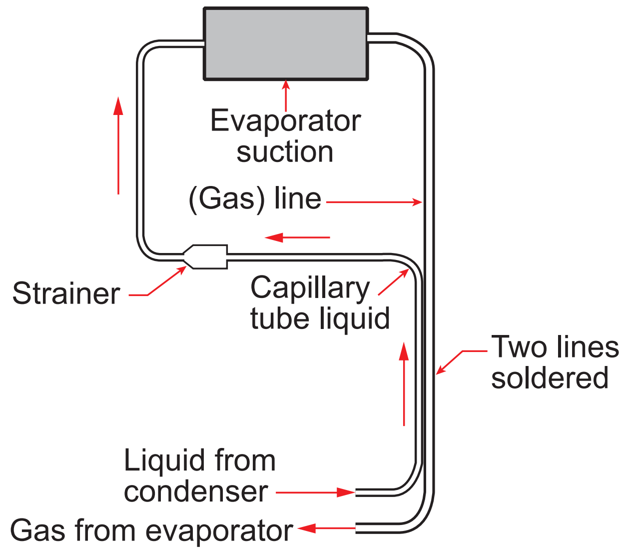
Figure 9(a) shows a refrigerant heat exchanger used in small and medium capacity refrigeration systems. Figure 9(b) shows the location of the heat exchanger.

Figure 9 – Economizer



To eliminate the use of a separate heat exchanger in low capacity systems equipped with a capillary tube for liquid refrigerant control, it is common practice to solder the capillary tube to the suction line so heat transfer can take place. This is shown in Figure 10.

Figure 10 – Soldered Liquid and Suction Lines



Distributor

Sometimes, a large direct-expansion type evaporator will have more than one refrigerant circuit. If so, the entering liquid refrigerant must be evenly distributed to each circuit. This will ensure cooling occurs equally at all points in the evaporator coils. A distributor, placed in the liquid line directly downstream from the expansion valve, feeds the refrigerant to each coil equally.

Figure 11 is a cutaway view of a pressure drop type distributor. Figure 12 shows both horizontal and vertical views of a manifold type distributor connected to an evaporator.

Figure 11 – Liquid Refrigerant Distributor

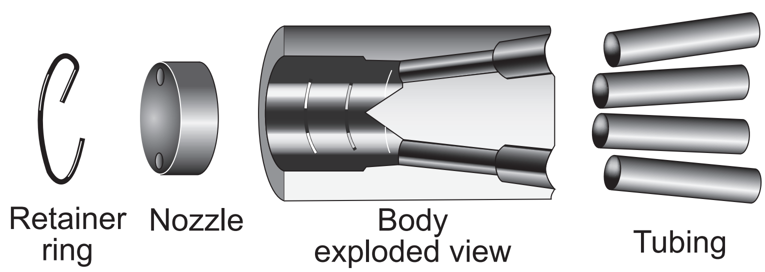
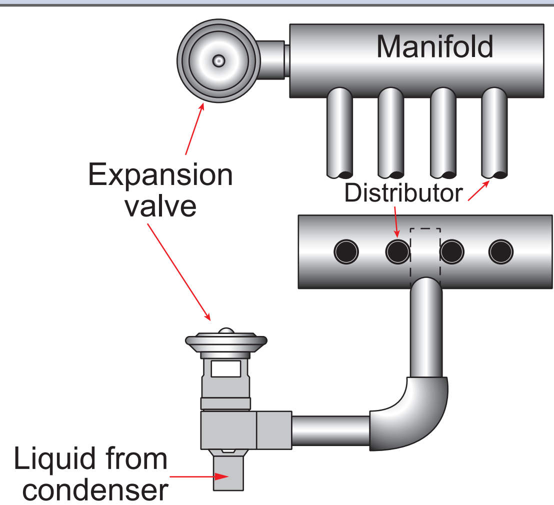


Figure 12 – Distributing Manifold



Vibration Absorber

Compressor, forced convection evaporators, condensers, and other refrigeration system components can create vibration and noise. These will transmit through the rigidly connected piping. Sometimes, the noise amplifies to objectionable levels. Using vibration absorbers to connect piping to the main components of the refrigeration system will prevent this transmission.

Figure 13 shows a typical vibration absorber. Figure 14 indicates where they are commonly installed. For maximum effect, the absorbers should be located as close to the compressor as possible.

Figure 13 – Vibration Absorbers

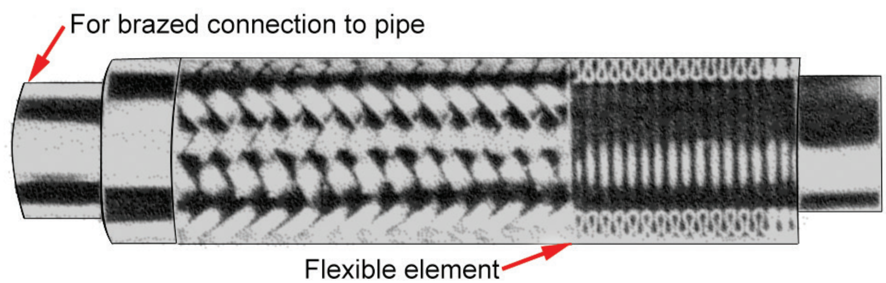
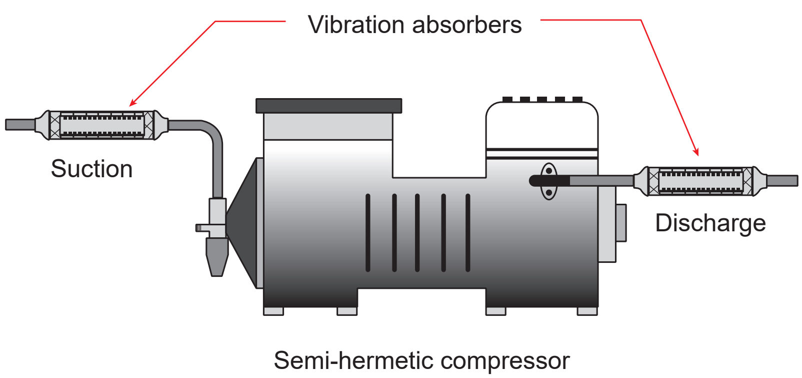


Figure 14 – Vibration Absorber Location



Refrigerant Piping and Tubing

In general, the type of piping and tubing used in a refrigeration system depends on the application they are for, the sizes required, and the refrigerant used. The **CSA Standard B52: Mechanical Refrigeration Code** requires that piping, tubing, valves, fittings, and related parts should conform to the minimum requirements set forth in the **ASME Code B31.5: Refrigeration Piping and Heat Transfer Components**.

Ammonia piping, covered under the **International Institute of Ammonia Refrigeration (IIAR)** standard, **IIAR 2 Standard for Safe Design of Closed-Circuit Ammonia Refrigeration Systems**, has several specific requirements.

At times, these codes and standards disagree with each other. In order to maintain the highest safety design standards, best practice dictates that the most restrictive code should be referenced. From a jurisdictional standpoint, however, Canadian code always takes precedence, unless legislation stipulates otherwise.

Materials

Piping must consist of the proper material for the application. **ASME B31.5** lists a variety of ferrous and non-ferrous materials for use as refrigeration system piping. Materials used for piping must be compatible with the refrigerant. As well, these materials must be suitable for low temperature service. Any materials that can become brittle at low temperature cannot be used.

Ammonia Service

Piping or tubing for ammonia service must be steel, and listed as permissible in **ASME B31.5**. The **CSA B52**, the **ASME B31.5**, and the **IIAR Standards**, all prohibit the use of copper and copper alloy pipes and tubes.

Steel pipe should be Type S (seamless) or Type E (electric resistance welded). The **ASME B31.5** code prohibits Type F (furnace butt-weld) pipe in ammonia service, except for water-based secondary coolants (brine).

Galvanized pipe should not be used. **IIAR 2** stipulates that zinc should not be used to contain, nor should it contact, ammonia.

Piping sizes DN 150 (NPS 6) and smaller must be at least Schedule 40; except for pipe smaller than DN 50 (NPS 2), which must be at least Schedule 80. If the pipe is to be joined with threaded connections, Schedule 80 must be used as a minimum, regardless of the pipe diameter.

The **ASME B31.5** code prohibits malleable iron and cast iron fittings in ammonia service. **IIAR Standard 2** states that only Class 3000 or stronger fittings shall be used when attachments are made by socket welding or threading.

Tubing, if used, can be carbon steel or stainless steel. **IIAR Standard 2** limits the use of tubing to compressors, compressor packages, and packaged systems.

HFC and HCFC Service

All HFC and HCFC refrigerants may use either copper or steel piping. Steel should be used for all larger diameter piping, due to its higher strength.

CSA B52 permits only Type K or L, hard-drawn copper tubing, when the installed piping is subject to mechanical injury. Soft annealed copper tubing can also be used; however, it must not exceed 35 mm OD (1-3/8 inch).

ASME B31.5 permits gray iron, malleable iron, and ductile iron fittings in HFC and HCFC refrigeration systems; however, they are limited to service above –20°C. Ductile iron fittings cannot be used above 6895 kPa.

Piping Connections

In general, the least number of fittings should be used. This reduces piping system pressure drop and the possibility of leaks.

ASME B31.5 permits the following ways of connecting refrigeration system piping:

- Threaded connections
- Flanged connections
- Flared connections
- Compression fittings
- Welded connections
- Brazed connections
- Soldered connections
- Flareless connections

Threaded joints should be made with tapered pipe threads. When tightening a threaded connection, the joint must never be loosened for the purpose of alignment. Threaded joints should not be used for pipe sizes over DN 100 (NPS 4). Threaded fittings can be seal welded after installation. Threaded copper and brass fittings can be used, but not in ammonia service. After making up the threaded joint, all exposed threads must be coated with grease, or another suitable coating, to protect the exposed threads from corrosion.

Welding is the most commonly used method to join steel piping. Welded joints provide leak-free connections. Fittings can be socket welded or butt-welded. Threaded fittings can be seal-welded, as long as the joint is assembled without any type of thread sealant, lubricant, or dope. Only certified and qualified pressure welders must perform welding.

The class of flange selected for flanged connections must be suitable for the design pressure. Connections must be made up carefully, to ensure that gasket loading is equal. Gaskets must be compatible with the refrigerant chemistry and system pressure.

Though **ASME** permits soldering, **CSA B52** prohibits all soldered joints in copper piping and tubing. Brazing metals are stronger and better suited for higher temperature operation. Lengths of tube are swaged at one end and then brazed together. Copper tubing is often silver brazed.

Flare fittings and compression fittings are commonly used for pressure sensing lines, oil return lines, and other applications where small diameter tubing is sufficient, and occasional disassembly is required. Fittings and tubing may be steel or copper.

Ammonia Service

Per **ASME B31.5**, threaded joints shall not be used for piping larger than DN 50 (2 in). Unions must be forged steel, without a brass seat. Flanges, when used, must be the raised face type. Gasket material must be compatible with ammonia, and suitable for the pressure application. Joint compound must not contain copper or copper-alloys.

Other Piping System Considerations (Non-Code)

Piping should be kept clean to minimize corrosion. Bare piping need to be repainted on a regular basis to help prevent corrosion. Insulation should be repaired or replaced as necessary.

Horizontal lines should slope downward in the direction of refrigerant flow. The minimum recommended slope should be 4.2 mm per metre.

As good practice, flared compression fittings may be used to join soft temper copper tubing up to 19 mm outside diameter (OD). Above this size, and for hard temper copper tubing, joints should be made with silver brazed fittings. Thin-wall steel tubing may be joined by using either flared or compression fittings.

Stop Valves

Manual stop valves are used in refrigeration systems to isolate parts of the system, or transfer refrigerant from one part of the system to another. This is so that maintenance and repair work can be performed without releasing refrigerant to the environment. **CSA B52 Code** states:

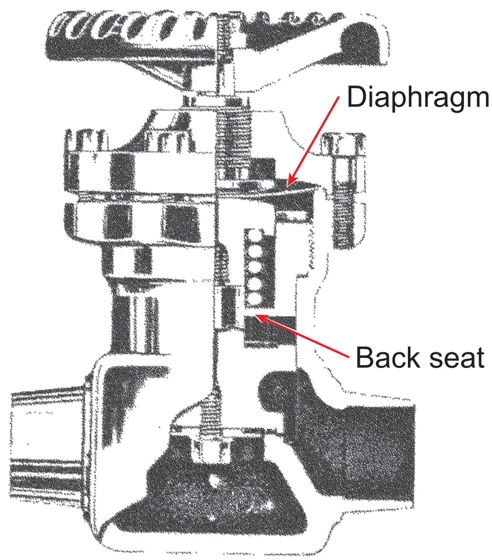
> *Systems containing more than 50 kg of refrigerant shall have stop valves installed at the following locations:*
>
> - *on each suction inlet of each compressor, compressor unit, liquid refrigerant pump, or condensing unit;*
> - *on each discharge outlet of each compressor, compressor unit, liquid refrigerant pump, or condensing unit;*
> - *on each inlet of each liquid receiver, except for self-contained systems or when the receiver is an integral part of the condenser or condensing unit;*
> - *on each outlet of each liquid receiver; and*
> - *on each inlet and outlet of condensers when more than one condenser is used in parallel in the system.*

These valves are special for refrigeration service. They are designed to prevent the escape of refrigerant to the atmosphere, yet remain easy to operate.

The valve shown in Figure 15 has a diaphragm and a back seat, which both prevent refrigerant from escaping along the valve stem. The diaphragm prevents escape to atmosphere. When the valve is fully open, the back seat prevents escape into the space between the upper seat and the diaphragm.

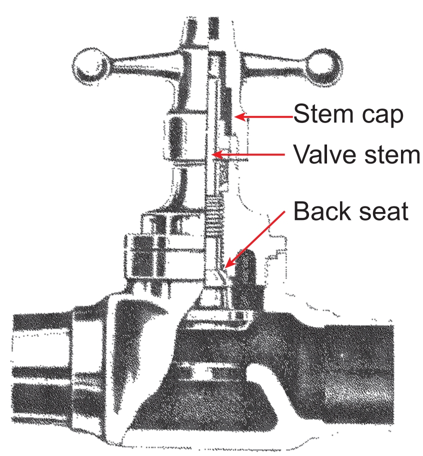
Valves with packed stems (Figure 16) are constructed with a back seat. When fully open, the back seat is closed, which prevents refrigerant leakage. Some valves also have a scraper, to prevent dirt and ice from damaging the packing gland.

Figure 15 – Diaphragm Type Refrigeration Valve



As an added precaution against leakage along the valve stem, many packed valves have a valve cap that covers and seals the valve stem. The cap must be removed to operate the valve. The valve shown in Figure 16 has a combination valve cap and valve stem wrench. To operate the valve, remove the stem cap and turn it upside down. The square recess at the top of the stem cap fits on the square end of the valve stem. The stem cap acts as a handle to open and shut the valve. After the valve is operating, turn the stem cap over and put it back in place to prevent refrigerant leakage.

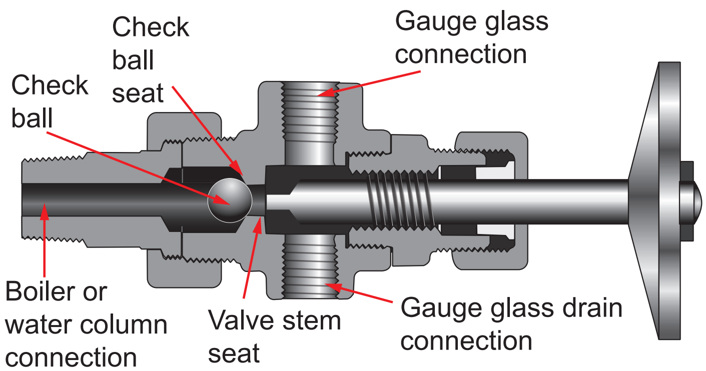
Figure 16 – Refrigeration Valve with Stem Packing



Receiver Gauge Glass

Larger liquid receivers should be fitted with gauge glasses so the liquid level is easily visible. The **CSA B52 Code** states that liquid level gauge glasses must have shut-off valves that close automatically to prevent loss of refrigerant, in case the glass breaks. This type of valve is shown in Figure 17.

Figure 17 – Safety-Type Gauge Glass Fitting

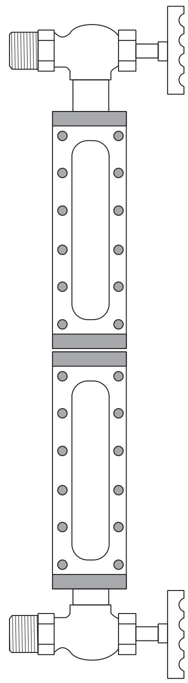


The gauge glass valves work the same way as those used for steam boilers. They are installed on both the vapour space and the liquid space connections. If the glass breaks, the pressure of the refrigerant forces the steel ball to press tightly against the ball seat, which prevents the loss of refrigerant. After the glass is replaced, the balls are unseated with the unseating spindle. This allows the liquid to flow back into the gauge glass. The unseating spindles are back seated when they are fully open, to prevent leakage along the spindle and packing during normal operation.

CSA B52 also requires gauge glasses to be adequately protected against damage. This will reduce the likelihood of having to deal with a broken gauge glass.

Because most refrigerants are clear in colour, reflex glass (Figure 18) is used to indicate level. Reflex glass uses prismatic action to indicate the presence of clear liquids as black. This makes it easy to see the level.

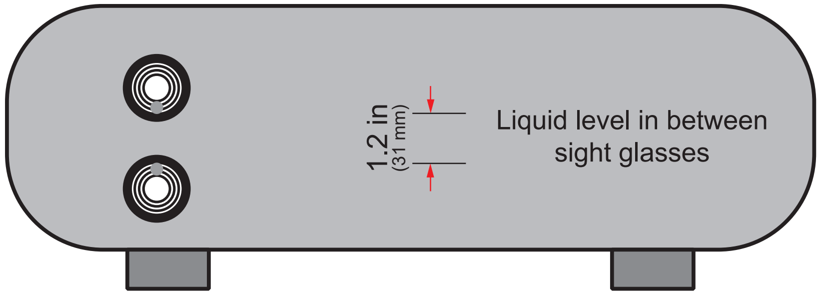
Figure 18 – Reflex Glass Level Indicator



Another common method of indicating liquid level is to use multiple "bull's eye" sight glasses (Figure 19). The glass is either a reflex design or uses small brightly coloured flotation balls to indicate the refrigerant level.

In some cases, there are two glasses placed vertically. The upper glass has a ball at the bottom. The lower glass has a ball at the top. The level is between the two glasses.

Figure 19 – Bull's Eye Sight Glasses



Receiver level indicators

Purge/Charging Valve

The purge valve and charging valve are usually either packed or diaphragm type angle valves. The purge valve will vent non-condensable gases from the system. The charging valve will charge the system with refrigerant. The open ends of these valves are usually capped, to prevent escape of refrigerant from the system when the valves are not in use.

Pressure-Relief Devices

Regardless of its size, a refrigeration system is a closed pressure system. The possibility always exists that the pressure in the system, or its components, may build up excessively for any of these reasons:

- Extreme temperature conditions
- Malfunctioning controls
- Inadvertently closed stop valves

Pressure buildup, above the design pressure, could result in rupture of some part of the system.

General Provisions

To prevent over-pressurization, **Part 7.3** of the **CSA B52 Mechanical Refrigeration Code** requires every system to have one or more pressure-relief devices to protect it. In particular, it is critical to protect the parts listed below from over-pressurization:

- Parts that contain liquid refrigerant
- Parts that are larger than 152 mm (6 in) internal diameter
- Parts that can be isolated with the use of valves

These pressure-relief devices must be connected as directly as possible to the parts of the system they are to protect.

All pressure-relief devices in refrigeration service must discharge to the outside of the building, if the system contains any of the following:

- A Group A3 or B3 refrigerant
- More than 3 kg (6.6 lb) of a Group A2, B1, or B2 refrigerant (such as ammonia)
- More than 50 kg (110 lb) of a Group A1 refrigerant (such as R-134a)

No stop valves are permitted between a relief device and the part of a system it protects.

Two of the most common pressure-relief devices used in refrigeration systems are the fusible plug and the spring-loaded relief valve.

Fusible Plugs

Fusible plugs are commonly used in smaller systems. They are only used to protect smaller volume components (containing less than 0.085 m^3 of refrigerant).

The fusible plug contains an alloy that melts at a specified temperature, to relieve pressure. When the plug melts, the entire refrigerant charge escapes. A new plug and a new refrigerant charge are required before the system can go back into operation.

Fusible plugs must be marked with the melting temperature in degrees Celsius. The plugs may be located above or below the liquid refrigerant level, except on the low side.

Primarily, these plugs protect against explosions, in case of fire. They are not reliable or accurate overpressure relief devices. Consider a low temperature fusible plug that melts at 74°C. The minimum high side design temperature for R-134a using an air-cooled condenser is 1282 kPag. At 74°C, when the fusible plug releases, the pressure in the receiver will be around 2350 kPa, which is nearly double the minimum high side design pressure. This is well within the factor of safety for the vessel; however, due to the significant over-pressurization that may occur, the vessel would no longer be safe for continued service.

Fusible plugs are non-reclosing pressure-relief devices. When activated, they release large quantities of refrigerant, until the system is empty; or until the component they serve is isolated. This has significant environmental and economic impact. Therefore, reclosing pressure-relief devices (such as spring-loaded safety valves) are preferred.

Safety Valves

Safety valves are devices that allow liquids or gases (vapours) to escape a pressure system or piece of equipment when the pressure or temperature exceeds pre-set limits. These valves act as a "fail-safe" and help to prevent overpressure situations and protect downstream or upstream equipment. In refrigeration systems they can be found on vessels and compressors.

Vessels

Refrigeration safety valves are different from those used in steam or hot water service. They do not have manual try levers or exposed springs. This is because refrigerant must be contained within the system, and manual tests are never conducted. In lieu of manual tests, **CSA B52 Part 8.4** states that pressure-relief valves must be replaced or recertified at no longer than five-year intervals.

If any of the following applies to a pressure vessel, **CSA B52** requires it to be protected by a pressure-relief device:

a) It contains liquid refrigerant

b) It has an internal gross volume exceeding 0.085 m^3

c) It can be isolated using valves

The device must have enough capacity to prevent the pressure in the vessel from rising more than 10% above the setting of the pressure-relief device. This requirement negates the use of fusible plugs as the sole method of over-pressure protection for larger volume vessels.

Vessels with an internal volume of 0.28 m^3 (10 ft^3) or greater require two full-capacity safety valves piped in parallel. These valves must be installed with a three-way valve. The three-way valve places only one of the two valves in service at a time. This allows the removal and replacement of the safety valves at regular service intervals.

Figure 20 shows a dual safety valve piping arrangement that meets this requirement. The valves shown are mounted on the oil separator of a packaged screw compressor. The three way valve has a removable cap located over the valve stem, to prevent leakage. The valve stem must be operated fully in either direction, so that only one valve is in service at a time. The valve stem must not be kept in the intermediate position. Otherwise, both valves are exposed to service conditions, which means that both valves would simultaneously require replacement or recertification. Note that each valve has a service tag that indicates its date of installation or last recertification date.

Figure 20 – Dual Safety Valve Installation

In a refrigeration system, high side safety valves often discharge into the low side. This relieves excessive pressure from the high side. It also recirculates the refrigerant so that it is not lost to atmosphere. However, **CSA B52 Part 7.3** states this arrangement is only permissible provided that:

a) The high side pressure-relief devices are not affected by backpressure.
b) The low side of the system is equipped with pressure-relief devices.
c) The relief devices on the low side of the system have sufficient capacity to protect the pressure vessels that are relieved into the low side, and to protect all pressure vessels on the low side.
d) The low side pressure-relief devices are vented to the outside of the building.

Compressors

Positive displacement compressors can develop enough pressure to damage piping, vessels, pipe fittings, and their own casings. To prevent this from occurring, every positive-displacement compressor with a discharge stop valve must be equipped with a pressure-relief valve.

The **CSA B52 Code Part 7.2** requires every positive-displacement compressor to have pressure-relief devices. These devices must be mounted between the compressor and the compressor discharge stop valve. It must have adequate capacity to prevent rupture of the compressor. It must also be able to prevent the pressure from increasing to more than 10% above the maximum allowable working pressure of any component located in the discharge line between the compressor and the discharge stop valve. The compressor manufacturer will specify the pressure-relief valve capacity.

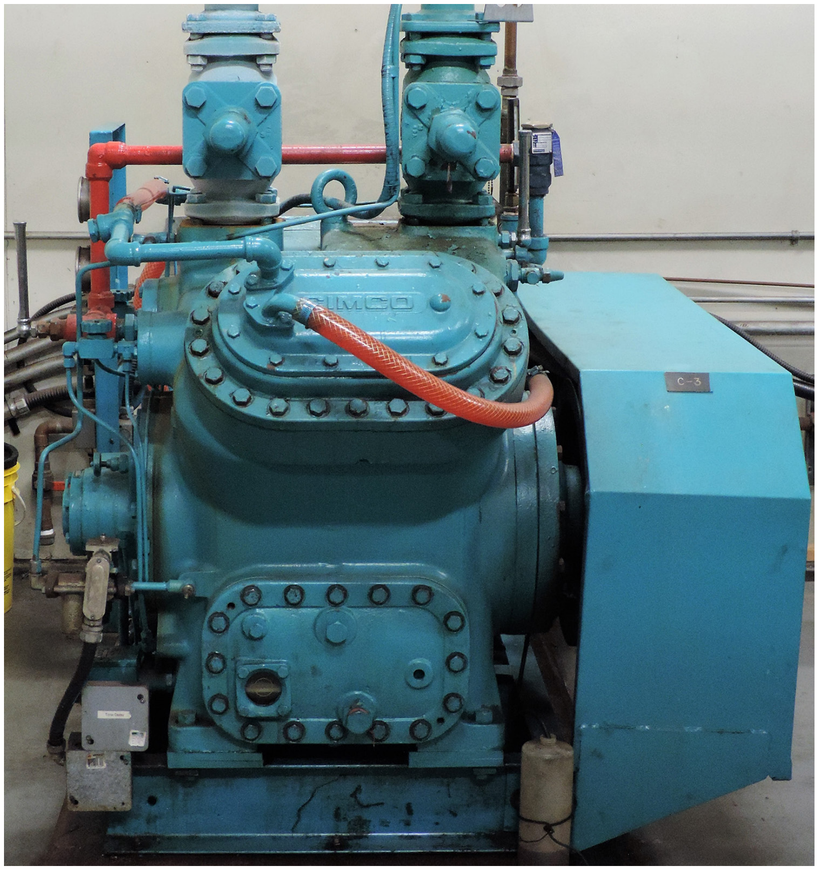
The pressure-relief device discharges into the low-pressure side of the system or to the outside atmosphere.

Figure 21 shows a safety valve set up to protect a positive-displacement compressor.

Figure 21 – Safety Valve for Positive-Displacement Compressor Protection

Figure 22 shows a refrigeration compressor safety valve, with its discharge line piped to the suction side of the compressor. The safety valve is at the upper right side of the picture. The safety valve discharge pipe is painted orange, and terminates on the left side.

Figure 22 – Compressor Safety Valve Piped to Suction



Emergency Discharge

The **CSA B52 Code Annex B** has guidelines to rapidly discharge refrigerants into the atmosphere during a fire or other emergency. This is optional; however, many jurisdictions enforce it.

Annex B states:

> *Systems designed for operation over 103 kPa (15 psig) and containing 182 kg (400 lb) or more of Group A1 or 91 kg (200 lb) or more of all other refrigerants shall be constructed so that, in an emergency, the refrigerant can be safely and rapidly discharged into the atmosphere.*

The emergency discharge system consists of:

a) Piping connected to the top of a liquid receiver or any other vessel where liquid refrigerant is stored.

b) An emergency discharge valve, located outside of the building.

c) A diffuser, located at a high elevation, to spread the refrigerant vapour over a large area.

The emergency discharge line is connected directly to the top of the receiver or other vessel (the vapour space), as shown in Figure 23. There must be no other valve between the emergency valve and the vessel. An emergency switch that stops the refrigeration equipment must be installed beside the emergency valve. The switch is beside the valve in Figure 24.

The emergency valve shall be installed:

a) On a horizontal pipe.
b) In a glass fronted box painted bright red.
c) Outside of the building.
d) So that no one can operate it except the plant operator, a firefighter, or an authorized person who needs to open the valve in an emergency. To prevent tampering, the valve must be at least 2.3 m (7 ft) above grade.

CSA B52 Part 7.3 contains the discharge requirements for the emergency discharge systems. They are the same as for pressure-relief devices. The point of discharge must not be less than:

- 4.6 m (15 ft) above the adjoining ground level, or an accessible roof level
- 7.6 m (25 ft) from any window, ventilation opening, or exit

Figure 23 – Emergency Discharge Line

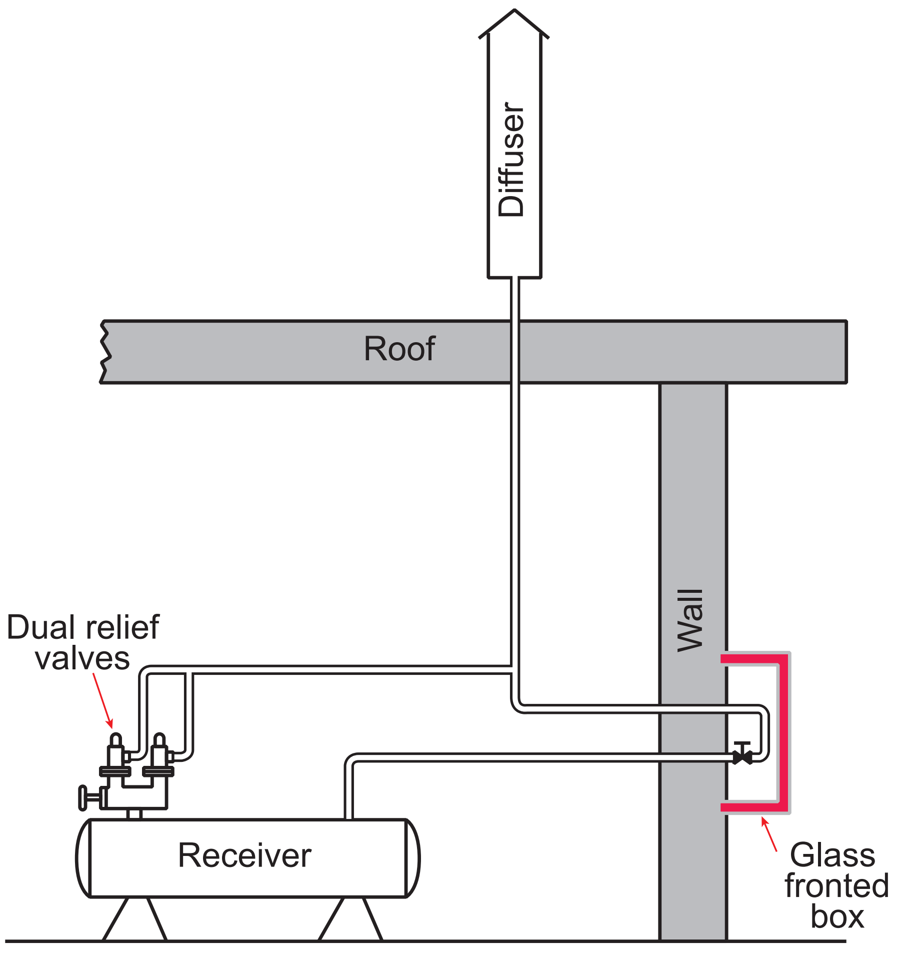
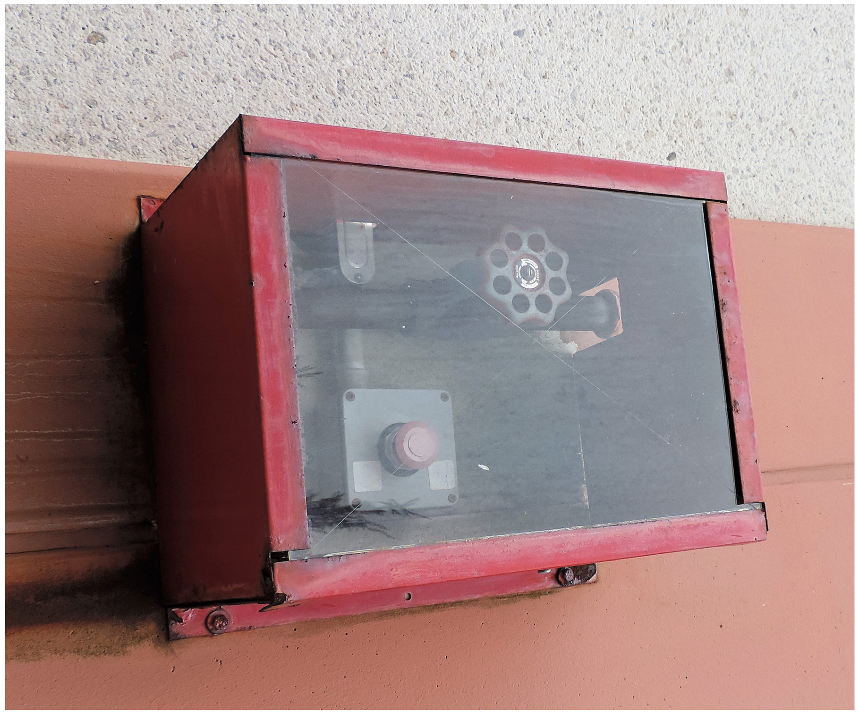


Figure 24 – Emergency Discharge Valve and Equipment Shutdown Switch



Objective 2

Describe refrigeration system leak test procedures.

System Leak Testing

After a refrigeration system is installed, repaired, or modified, the entire system must be thoroughly inspected for leaks. Every refrigerant-containing part of a system that is erected on the premises, except factory-tested components, must be tested and proved tight after installation and before operation.

Positive Pressure Pneumatic Testing

Inert gases, such as dry nitrogen or carbon dioxide, are used as the testing medium. High-pressure cylinders supply the gas. The cylinders connect through a pressure-reducing valve to either the high- or low-pressure side of the system.

CAUTION

Never use oxygen and flammable gases to test the system pressure. An explosion could result. Nitrogen gas is commonly used to test for leaks in refrigeration systems. Nitrogen is an asphyxiant. A large leak of nitrogen test gas can also be hazardous. Ensure the surroundings are well ventilated when leak testing a system. Always wear personal gas monitors.

The field pressure test procedure that follows is based on the requirements of:

- **IIAR Standard 5: Start-up and Commissioning of Closed Circuit Ammonia Refrigeration Systems**
- **ASME B31.5**
- **CSA B52 Mechanical Refrigeration Code**

CAUTION

Unlike hydrostatic testing, pneumatic testing can result in a devastating explosion. Take measures to protect personnel from the potential of piping component rupture during pneumatic tests.

Preparation for Pressure Testing

All piping joints must remain uninsulated. Welded joints should remain unpainted and free of rust, dirt, oil, and other foreign materials, until after field leak testing is complete. The jurisdictional inspector should witness the field test.

Before the test, the following preparations must be made:

1. Before applying pressure, examine all the piping, to ensure that it is tightly connected.
2. Valve off and isolate any refrigeration component that has been factory tested, to which the test pressure may cause harm. This includes pressure switches and pressure transducers.
3. Remove all safety pressure-relief devices that may be subject to the test pressure. Cap or plug the openings.
4. Using their manual lifting stems, manually open all solenoid, pressure regulating, check, or other control devices.
5. Cap, plug, or lock shut all valves and devices that lead to the atmosphere.
6. Open all other valves.

Essentially, the valve lineup must permit the high and low-pressure sides of the system to initially be tested together, at the same pressure.

Pressurization Procedure

The test gas must be introduced into the system gradually, either through the charging valve, or another suitable injection point installed with a stop valve. The test pressure must be verified using a calibrated pressure gauge located on the part of the system being tested. No leak repairs are to be made while that part of the system is under pressure.

Always use a suitable dry gas, such as nitrogen or air, for field leak testing. Do not use the following fluids to leak test an ammonia refrigeration system:

- Oxygen or any combustible gas or combustible mixture of gases
- Carbon dioxide
- Halocarbon refrigerants
- Water or water solutions.

The high side and low side of the system must be leak tested at the greater of the design pressure shown in **CSA B52 Table 4**, or the system design pressure. This takes into account that systems may be designed for higher pressure than the minimum stipulated in Table 4. The system must be held under pressure until proven tight with no more than a 1% loss in pressure, after accounting for temperature changes.

Dry nitrogen gas is supplied in large, pressurized cylinders. For safety, and to prevent over-pressurization of the system, the cylinder used for pressure testing must have the following:

- A shut-off valve.
- A bleed valve.
- A pressure regulator, to control the supply pressure. It should be located between the nitrogen cylinder and the refrigeration system.
- An adjustable pressure-relief valve. It should be located on the refrigeration system side of the regulator. The valve must be rated for the full discharge capacity of the nitrogen regulator, and set to the relevant test pressure.
- Calibrated cylinder and line pressure gauges.

A pressure test is performed as follows:

1. Connect the nitrogen cylinder to the valve that charges the system.
2. Set the pressure regulator to the required low side minimum design pressure, according to **CSA-B52 Code, Table 4**. For example, R-717 has a low side minimum design pressure of 951 kPa. R-134a has a low side minimum design pressure of 593 kPa. If the design pressure is higher than that specified in Table 4, set the regulator to the design pressure.
3. Gradually raise the pressure in the system. To find major leaks, apply a preliminary test at up to 170 kPa. For large systems, gradually increase the pressure to one-half of the test pressure. Then, increase the pressure in steps, approximately one-tenth of the test pressure, until the required test pressure is reached. Shut off the cylinder when the line pressure gauge reads the required low side pressure.
4. Isolate the high and low sides from each other. This allows the high side to be tested at high side pressure without damaging the low side components. To do this, close the hand expansion valve or solenoid valve at the evaporator inlet. Then, close the compressor discharge valve.
5. Set the pressure regulator for the minimum high side design pressure, according to **CSA B52 Table 4**. The minimum design pressure varies whether the condenser is air cooled, or water-cooled. For example, R-717 has a minimum high side design pressure of 2016 if air cooled, and a minimum design pressure of 1473 kPa if cooled with water or with an evaporative condenser. If the design pressure is higher than that specified in **Table 4**, set the regulator to the design pressure.
6. Open the nitrogen cylinder shut-off valve, and increase the high side pressure.
7. Close the cylinder shut-off valve, and disconnect the nitrogen cylinder.

CAUTION

A pneumatic pressure applied to a refrigeration piping system under test shall not exceed 130% of the design pressure of any system component.

Leak Testing

The system can now be leak tested at low side pressure. Because the test gas (nitrogen) is inert, it is hard to detect by any method other than a soap bubble test. Examine all joints, regardless of connection method. Some leaks may be difficult to find using a bubble test. As an additional requirement, **CSA B52** states that the system must sustain the test pressure for a minimum of 2 hours.

If leaks are found, they must be repaired. Weld joints must have the defective weldment removed, and the joint must be re-welded. Brazed joints can be cleaned, re-fluxed, and re-brazed.

CAUTION

Depressurize piping systems and components before attempting to make repairs. Never perform repairs while a piping system is still pressurized.

After completing the repairs, leak test the system again until it proves to be leak free. With HFC and HCFC refrigerants, a small amount of “tracer” gas may be added to the system to assist with leak detection. The tracer gas is the same refrigerant normally charged in the system. With the added tracer gas, sensitive electronic refrigerant leak detectors can be used. Do not use tracer gas with ammonia systems.

If no further leaks are discovered during the pressure test, leave the system pressurized for about 24 hours. If the system will be left unattended, disconnect the nitrogen or carbon dioxide cylinder. Disconnection will prevent accidental over-pressurizing of the system if any of the valves between the cylinder and the system should leak. If the pressure in the system has not changed after this period (allowing for pressure changes due to changes in ambient temperature), bleed the gas off from the high and low sides of the system. Re-install any controls or relief devices previously removed for the pressure test. The system is now ready for drying and charging.

Sub-Atmospheric Pressure Testing

Detecting leaks in a system that operates below atmospheric pressure is more difficult. Leakage of air into the system will cause the purge unit to cycle more often than usual. This will result in a loss of refrigerant because it is impossible to totally separate air from the refrigerant during purging.

To test a sub-atmospheric pressure refrigeration system for leaks, it is necessary to shut down the compressor, and to pressurize the system with dry nitrogen to break the vacuum. Follow the steps below to complete this task:

1. Shut down the compressor and place the purge switch on manual.
2. Connect a nitrogen cylinder to the charging valve.
3. Open the charging valve fully.
4. Set the pressure-reducing valve on the test unit to the pressure recommended by the manufacturer. Then, slowly open the shut-off valve on the cylinder.
5. Observe the pressures on the evaporator and condenser gauges. Close the nitrogen cylinder shut-off valve when both gauges read an adequate positive pressure. Be cautious not to over pressurize the system; otherwise, this can damage the rupture disc in the chiller.
6. Test all the joints using an electronic refrigerant leak detector or a soap and water solution.
7. Make repairs to any leaks found. Start the purge system. Allow the necessary time for the non-condensable gases to release.

Leak Detectors

Leak detectors will find leaks during construction of new plants. They also find leaks during ongoing checks, while systems are in operation. These detectors include:

- Electronic leak detectors
- Litmus paper
- Phenolphthalein paper
- Sulfur candles
- Soap and water

The two most common leak detection methods are the soap and water test, and the electronic leak detector.

Electronic Leak Detector

The electronic leak detector (Figure 25) draws vapour through a tube fitted with a sniffer at the end. The operator moves the sniffer over the area where there might be a leak. The detector measures the electrical resistance of the vapour sample. As long as air is drawn into the detector, the resistance does not change. As soon as the sample contains refrigerant, the change in resistance causes the detector to react. Accompanied by a light and a buzzer sound, the meter displays the presence of refrigerant. Sniffers are available to detect ammonia, HFCs, and HCFCs.

Figure 25 – Electronic Leak Detector

Litmus Paper Detector

Wetted strips of litmus paper can help detect leaks in ammonia systems. These specially formulated papers change colour in the presence of an acid or a basic condition. Blue litmus paper turns red when exposed to acidic conditions. Red litmus paper turns blue when exposed to basic conditions. Since ammonia dissolves in water to produce a basic ammonium hydroxide solution, red litmus paper turns blue in the presence of ammonia. When moved about a joint or valve spindle, a change in the paper colour to blue indicates an ammonia leak.

Phenolphthalein Paper

Often confused with litmus paper, phenolphthalein paper is for when a more sensitive ammonia test is required. These papers are white and change to red when exposed to a solution with a pH greater than 8.3, which includes solutions of ammonium hydroxide.

Sulfur Candle Test

The use of a sulfur candle can also detect ammonia leaks. A thick white smoke emerges when the candle flame comes in contact with leaking ammonia.

CAUTION

The sulfur dioxide formed when a sulfur candle burns is an irritating and toxic gas. Use this method only in locations that are well ventilated.

Soap and Water

Leaks in any pressurized system can be found by using a solution of soap and water. Simply brush the solution on the area where the leak is suspected. If a leak is present, bubbles will appear. If this method is used, wash off the solution after the test; otherwise, it will dry and the soap will collect dirt on the outside of the system.

Objective 3

Describe how a refrigeration system is dried and charged prior to startup.

System Drying and Evacuating

Any moisture or water vapour that is present in a refrigerating system causes serious operating problems. When exposed to low temperatures produced by the system, moisture entrained in the refrigerant causes icing or "freeze-up" at the expansion valve. In systems using HFCs and HCFCs as the refrigerant, acid forms and reacts with oil to produce a sludge which corrodes metal parts.

The acids also remove copper from heat exchanger surfaces. The copper redeposits at points of high temperature, such as bearings and compressor exhaust valves. This is a process called "copper plating."

Quite often during operation, large, specially designed, temporary driers are installed in the system. As the liquid refrigerant passes through the drying agent, any existing moisture is absorbed.

Before charging an empty refrigerating system, the entire system is put under a very high vacuum (5000 microns or 0.67 kPa absolute pressure) with a special vacuum pump. Do not use the system compressor, because it is not designed for this purpose and could be seriously damaged. Do not attempt to evacuate the system unless the temperature of the surrounding air is 20°C or higher. As the air is removed from inside the system, the reduction in pressure will cause the moisture to evaporate and be removed with the air.

Some switches and controls may not have vacuum protection. Before evacuating the system, valve off or disconnect these switches.

After sufficient vacuum has been obtained, admit the dry nitrogen gas to break the vacuum. The vacuum pump evacuates the gas from the system, to once again produce a high vacuum. This second vacuum will remove the last traces of moisture from the system. Allow the system to remain under vacuum as recommended by the refrigeration system manufacturer. If the system pressure does not increase, the system is free of leaks and moisture. The system is now ready to be charged with refrigerant.

It is critical to ensure that all the air evacuates from the system. If not adequately evacuated, air will remain inside a system. Air is a non-condensable gas that accumulates in the condenser during operation. It will cause high compressor discharge pressures and temperatures.

System Charging

Before proceeding with the actual charging process, check the entire system to ensure all the components are ready for operation. Open valves where necessary, adjust controls to the required setting, and test the sequence of controls and interlocks.

CAUTION

Only those who are technically qualified, trained, and certified to handle refrigerant and to operate refrigeration systems, should attempt to charge refrigeration systems. The information in this objective is general in nature, and designed to help Power Engineers understand the refrigeration system charging process.

The initial refrigerant charge is added to the high-pressure side of the system. The refrigerant drum is connected to the liquid charging valve located in the liquid line, between the liquid shut-off valve on the receiver or liquid receiver and the expansion valve. A dehydrator should be installed in the line between the refrigerant drum and the liquid charging valve. Sometimes a pressure gauge is also connected in the charging line; however, this is not always necessary since the pressures in the system can also be observed on the compressor panel gauges (see Figure 26).

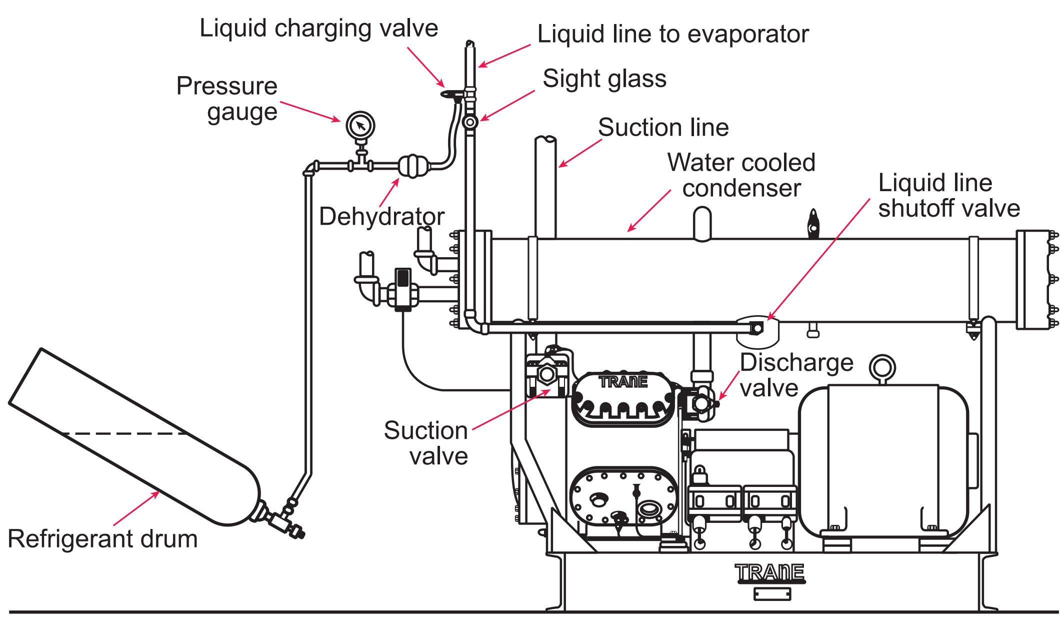
CAUTION

When handling refrigerants, always use goggles for eye protection. Even safe refrigerants can cause serious injury by freezing the moisture in the eyes. Wear neoprene gloves and protective clothing to prevent freeze burns. Wear, or keep close at hand, protective breathing equipment.

Charging ammonia refrigeration systems must involve several people. One person should be an observer with the appropriate PPE, and the means to summon help. All unnecessary personnel should be clear of the area when ammonia systems are charged.

Purge the air in the charging line by leaving the connection at the charging valve slightly loose and cracking open the drum valve. After the air has been forced out of the charging line, close the drum valve, and tighten the connection to the charging valve. Invert the drum so only liquid will pass through the charging line.

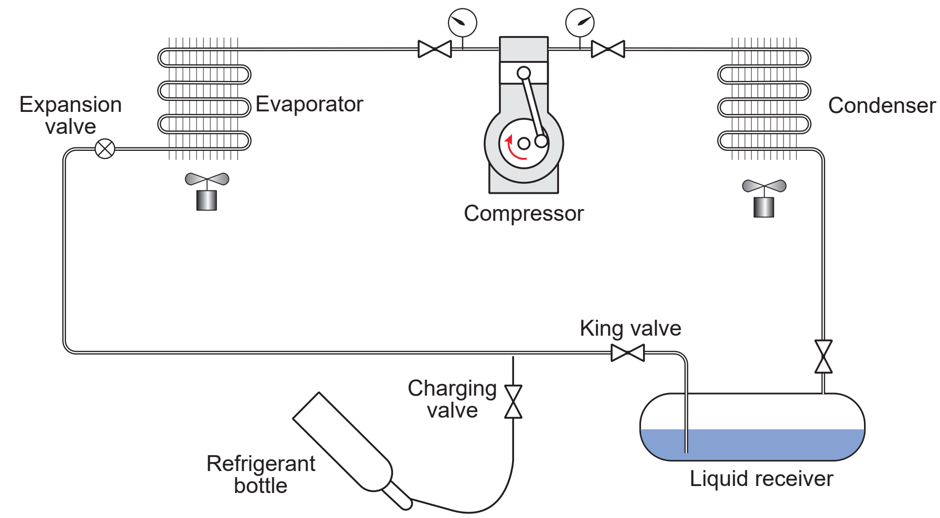
Figure 26 – Refrigeration System Charging Arrangement



(Courtesy of Trane)

Figure 27 shows a simple overview of the refrigeration system valves. The "King" valve is also called the liquid line shut-off valve. The charging cylinder and charging arrangement are simplified to illustrate the charging procedure.

Figure 27 – Charging Liquid to a Refrigeration System



In preparation for charging the system in Figure 27:

1. Make sure the liquid line shut-off valve (King valve) is closed at the receiver outlet.
2. Open the compressor suction and discharge valves.
3. Either turn on the cooling water supply for the condenser; or, if an air-cooled or evaporative condenser is used, start the condenser fan.
4. Move the thermostat to its lowest setting, if a thermostat controlled solenoid stop valve is used in the liquid line, or manually open the valve.

Open the liquid charging valve. Then, crack open the drum valve to admit liquid refrigerant slowly into the system. If the refrigeration system uses ammonia, the vacuum is broken with gas, not liquid. The cylinder must be upright to charge it with gas. Feed the ammonia gas until the pressure in the system reaches about 690 kPag.

It will take a considerable amount of refrigerant to break the existing high vacuum in the system, and raise the system pressure to atmospheric pressure. The compressor will start once the pressure begins to rise above atmospheric pressure and above the setting of the low-pressure cut-off switch. The system now operates normally, except that the refrigerant drum is now supplying the liquid that flows into the evaporator.

To evaporate the refrigerant, the evaporator must have a source of heat energy during the charging operation (just as in normal operation). Increase the system load as much as possible, by opening doors and operating evaporator coil fans.

While the system is charging, the refrigerant passes through the system, condenses, and accumulates in liquid form in the condenser or liquid receiver. During the charging procedure, the liquid line shut-off valve remains closed.

Charging continues until the system contains the amount of refrigerant required by the manufacturer. This can be determined by placing the refrigerant drum on a weigh scale. This can also be verified if the receiver is equipped with a sight glass.

When the proper amount of refrigerant is in the system, close both the drum valve and the charging valve. Now, open the liquid shut-off valve (King valve). Monitor the flow of refrigerant through the sight glass. If bubbles appear in the flow after the system has settled down to normal, it may be necessary to add more refrigerant.

In small refrigeration systems, frost formation on the compressor suction line indicates overcharging. This causes high suction and discharge pressures, and high compressor power consumption. A secondary concern is that liquid refrigerant could be forced into the compressor, especially in capillary tube systems.

Monitor the operation of the entire system, to ensure it is functioning as required. If everything appears normal, disconnect the charging line. Be careful while disconnecting, as the line contains some refrigerant that is under pressure.

After the system has been in operation for some time, it may be necessary to periodically add a small amount of refrigerant. The refrigerant is often added in its vapour state by connecting the drum, in an upright position, to the suction line of the compressor. Take care so that no liquid refrigerant carries over from the drum into the compressor.

Objective 4

List the steps for adding oil to an in-service refrigeration compressor.

Refrigeration compressors are internally lubricated. Because of this, compressors pass oil through the discharge piping along with refrigerant vapour. A consequence of this is that the compressor sumps will gradually run out of lube oil. Therefore, the oil must return to the crankcase from the system, or fresh oil must be added.

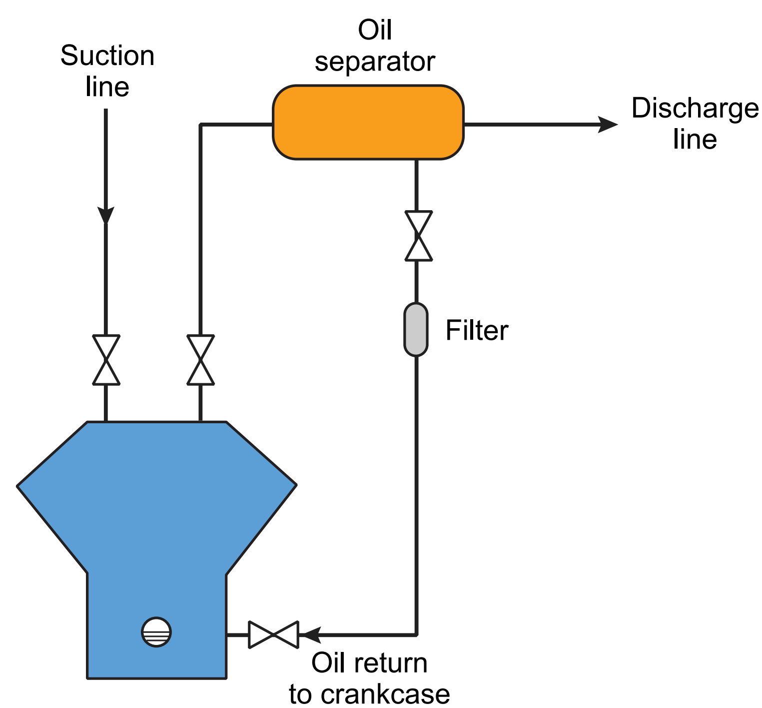
Refrigeration compressors are sealed units, to prevent the escape of refrigerant. One cannot merely pull out a dipstick, remove a cap, and add oil with a funnel. Hand pumps and pressure rated hoses with quick-connectors are commonly used.

Adding oil can be a dangerous proposition, especially when the refrigerant in the system is pressurized, toxic, and flammable (such as with an ammonia system). To add oil, it is necessary to access the compressor crankcase, which contains refrigerant vapour at low side pressure. Refrigerant leaks and oil sprays may occur during this procedure. Ensure the ventilation system is running at full capacity while adding oil. Personal protective equipment, specific site procedures, and training are essential before attempting to add oil to a refrigeration compressor.

Adding Oil to a Compressor

Refrigeration compressors have bull's eye gauge glasses to show the crankcase oil level. Normal oil level is about ½ the glass. If the oil level is low, first try to return lube oil from the oil separators back to the crankcase. If the oil separators are equipped with float-operated drain valves, this happens automatically. Otherwise, it is necessary to return the oil manually. Figure 28 shows an arrangement for returning oil to the crankcase from a separator.

Figure 28 – Oil Return System



If the oil level is still low after the oil returns to the crankcase, oil must be added. To add oil, charge it into the crankcase with a hand pump. This may be done with the compressor in operation, only if the following two conditions are met:

a) The compressor manufacturer permits it.

b) The crankcase pressure is not excessive (690 kPa maximum is generally specified by pump manufacturers).

Take precautions to ensure air and moisture do not enter the system while adding oil. To add oil:

1. Obtain a container of the correct oil.
2. Place the suction of the oil pump into the oil container.
3. Before attaching the hose to the oil-charging valve on the compressor, prime the oil pump discharge line. Bleed off any air through the oil pump, oil line, and the quick connector.
4. Open the charging valve. Operate the hand pump until the oil level is half-way up in the gauge sight glass.

Figure 29 shows a hand pump used for charging oil into a compressor.

Figure 29 – Oil Charging Arrangement

When oil charging is complete:

1. Close the fill valve.
2. Disconnect the hose from the fill valve.
3. Return the oil and pump to their storage area.
4. Clean up oil spills.

Use of a hand pump is the easiest way to add oil. However, if a hand pump is unavailable, the compressor suction can be used to draw oil into the crankcase. This method must be acceptable to the compressor manufacturer, and must be an approved plant procedure.

Refer to Figure 30:

1. Throttle the suction valve while the compressor is in operation. Allow the compressor to continue operating in order to create a slight vacuum in the crankcase.
2. Connect one end of the hose to the oil fill valve on the compressor. Raise the other end of the hose so that it fills with oil, in order to remove all the air. Then, submerge the free end into a container with fresh lube oil.

On Track

Make sure to add the correct oil type to the system. Proper selection of the oil depends on the type and operating temperature of the refrigerant.

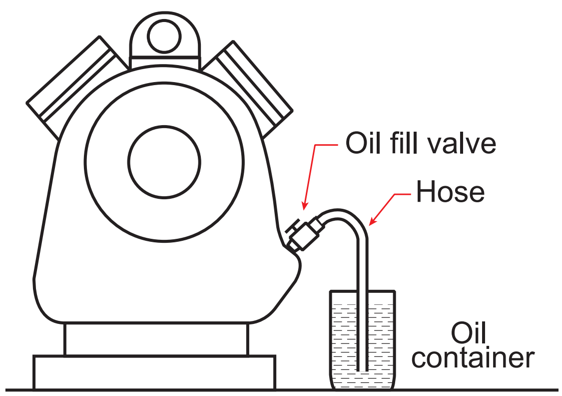
3. Now crack open the oil fill valve. Slowly allow the oil to be drawn into the crankcase until the crankcase oil level indicator reaches the proper level. Then, close the oil fill valve.
4. Fully open the compressor suction valve, and return the system to normal operation.

On Track

Never allow the end of the hose to come above the surface of the oil. This will draw air into the system.

5. Remove the hose and cap the oil fill valve fitting.

Figure 30 – Adding Oil to a Refrigerating Compressor Crankcase



Each compressor manufacturer supplies detailed instructions on the correct procedures for adding oil. Regardless of the method used, take extreme care not to introduce contaminants (such as air, water, or dirt) into the machine. Also, ensure the oil compatibility, quantity, and viscosity are correct.

Draining Oil from Compressor and System

CAUTION

Do not drain oil from systems that are not isolated from system pressure!

Compressor Oil

Use the following steps to remove excess oil from the compressor crankcase, or to change the oil:

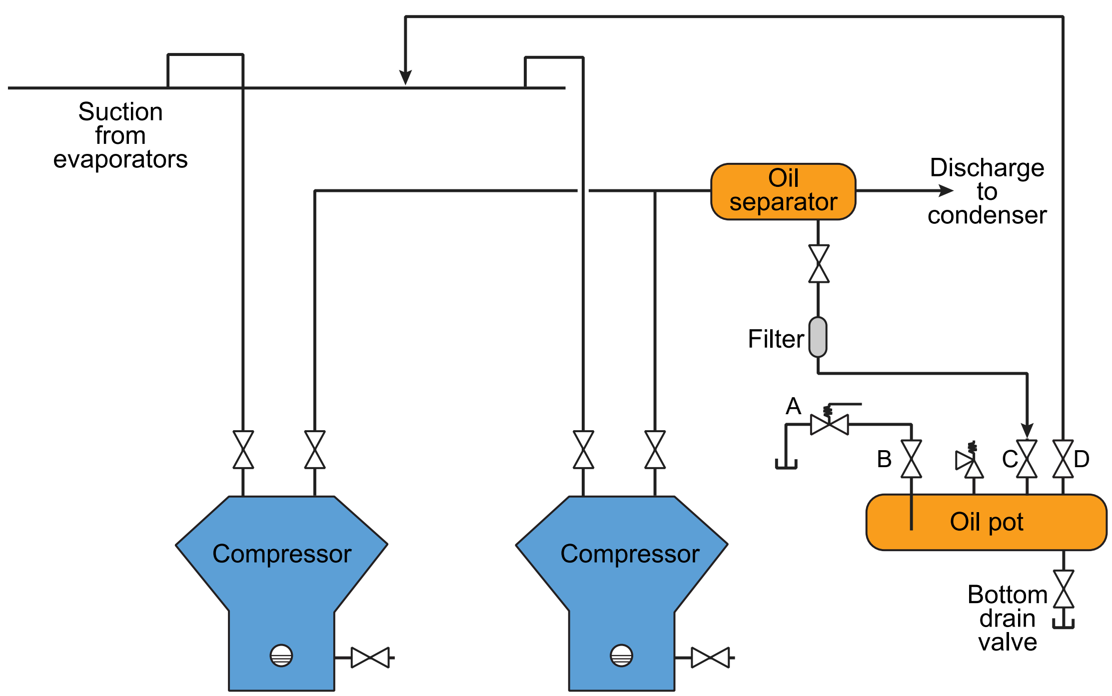
1. Pump down the compressor until the pressure in the crankcase approximately equals atmospheric pressure. To do this, slowly close the compressor suction valve, and monitor the compressor suction (or crankcase) pressure gauge.
2. Shut off the compressor.
3. Isolate the compressor suction and discharge valves.
4. Lock out the compressor so it cannot start until the job is finished. Follow site-specific lockout procedures.
5. Drain the oil either by opening the drain valve, or removing the drain plug. Exercise caution when removing drain plugs as crankcase pressure will blow out oil and refrigerant vapour.

Oil Pots

Oil separators that do not automatically drain to the crankcase should be manually drained at regular intervals. In many plants, oil separators (and other system components) do not return oil directly to the compressor. Rather, they may drain to oil pots. These pots are small pressure vessels that remain open to the system to gather oil. They are equipped with valves so that they can be isolated from the system and safely emptied of oil. Some pots have pipes that return oil to the compressor.

An oil pot installation is shown in Figure 31. Valve A is a quarter-turn, spring-loaded "dead man" valve, which closes automatically. Valve B is a guard valve used to isolate the oil return line. Valve C lets oil flow from the separator into the oil pot. Other valves (not shown) allow oil to flow into the pot from other system low points. Valve D permits any liquid refrigerant that accumulates in the oil pot to evaporate and re-enter the suction line. The oil pot must have a safety valve, in case all the other valves are closed. Otherwise, the oil pot could over-pressurize.

Figure 31 – Oil Pot Installation



In normal operation, valves C and D are open. When the separator is full of oil and ammonia, a float-operated trap (not shown) dumps the oil and ammonia into the oil pot. Thus, the pot is maintained at low side pressure. Any refrigerant liquid that enters the pot evaporates and is entrained with the compressor suction flow. Valves A and B are normally closed, and the end of the drain pipe is capped.

Liquid ammonia is less dense than lube oil. The boiling ammonia in the oil pot creates a frost line at the interface between the liquid ammonia and the oil. As the oil pot fills, the frost line moves higher up the side of the oil pot. When the oil pot is full, it needs to be drained. The following is a typical procedure for draining the oil pot. Refer to Figure 31.

1. Close the liquid supply valve (C) and wait. Allow sufficient time for the ambient heat to fully evaporate any residual liquid ammonia from the oil pot. This is indicated when all the frost is melted from the exterior of the oil pot. Depending on the location and service of the oil pot, this could take up to a full day.
2. Gather PPE, an oil receptacle, and a work permit. Arrange an operator to be present as a dedicated backup. The backup (buddy) must have full PPE and a method to summon help. PPE may include chemical resistant gloves, aprons, safety glasses with face shield, and full-face respirator. Before the oil pot is drained, some plants may require that the eyewashes and safety showers be tested.
3. Close the vent line valve (D). This fully isolates the oil pot from the system.
4. Place the drain receptacle to collect the oil, and carefully remove the plug or cap from the oil drain line. The purpose of the plug is to prevent seepage of oil while the pot is in service. There is often residual oil from the previous drain. Proceed with caution when removing the plug.
5. Open the “dead man” valve (A). Oil should not flow. Never prop open the dead man valve.
6. While holding the dead man valve open, slowly open the oil drain shut-off valve (B) to start the flow of oil from the pot. Use the oil drain valve to throttle the oil flow from the pot to the receptacle. If there is an unexpected increase in oil flow, release the dead man valve. This quickly stops the oil flow. During the drain process, the flowing oil often appears frothy and brown in colour. The process is complete when the oil flow begins to be intermittent with vapour from the pot.
7. Securely close the oil drain valve (B) while holding the dead man valve (A) in the open position. This enables oil or vapour contained in the line between valve A and B to flow out. Then, allow the dead man valve to close.
8. Open vent valve (D) and supply valve (C).
9. Crack open the dead man valve (A) to ensure that isolation valve (B) is holding tight. If not, tighten valve B. Then, crack the dead man valve again to ensure valve B is holding.
10. If the isolation valve (B) is holding, reinstall the pipe plug or cap at the outlet of valve A.
11. Carefully place the oil receptacle in a well-ventilated area to let any ammonia vapour absorbed in the oil to off-gas.
12. After the oil has settled, record the amount of oil drained. This will provide information on compressor oil consumption.
13. Ensure that the oil is collected and disposed of according to jurisdictional and environmental regulations.

Objective 5

Describe the startup and shutdown procedure for a compression refrigeration system.

Equipment manufacturers supply the startup and shutdown procedures for their own refrigeration systems. The procedures listed in this objective are generic. Before starting or stopping a system, operators must review and follow the manufacturer recommendations and the standard operating procedures for the plant.

Reciprocating or Rotary Compressor System Startup

The following general guidelines apply to systems equipped with reciprocating and rotary compressors. These guidelines apply to new systems and systems which have been out of operation for a prolonged period of time for maintenance or seasonal shutdowns.

Before Starting the Compressor:

1. The operator needs to be familiar with the entire refrigeration system and all its accessories before operating the equipment.
2. Check that power is available to circuit breakers, compressors, water pumps, and cooling tower.
3. Ensure that a qualified operator or instrumentation technician has properly set up the high- and low-pressure shutdown switches.
4. Ensure that all other instrumentation work on the refrigeration system was completed.
5. Ensure that all mechanical work on the compressor and the rest of the system was completed.
6. If the compressor is equipped with an oil sump heater, make sure the heater is energized. Ensure that the oil temperature is high enough to drive off any refrigerant, prior to startup.
7. Check the operation of system interlocks. For example, the compressor should not be able to start if the fans in an air conditioning system are not operating, or if the evaporative condenser is not running properly.
8. Open block valves in the cooling water supply and return lines of water-cooled condensers. If not tied in with the compressor starting system, start fan motors of air-cooled or evaporative condensers. Open the water supply valve to the evaporative condenser sump and check the water level.
9. Check the oil level in the compressor. It should be at or above the centre of the sight glass.
10. Ensure the lubricators (if equipped) are full of oil.
11. All block valves in the system should be open, except bypass valves used for other purposes.
12. Solenoid valves in the various liquid lines should be closed and on automatic control.
13. Ensure that suction, discharge, and oil pressure gauges are connected. Any valves in the connecting lines should be open.
14. Make sure all work permits have been completed, signed off, and returned to the maintenance coordinator or the control room.

Starting the Compressor

Before starting the compressor, all of the above conditions must be satisfied.

1. On smaller capacity compressors, open the suction and discharge valves.
2. On larger compressors, open the suction and discharge valves, as well as the bypass valve between the suction and discharge. It is necessary to open the bypass valve so that the compressor can start in an unloaded state. This will avoid an excessive starting torque, which has a high power draw. Once the compressor is up to speed, slowly close the bypass valve. If there is no bypass valve, before starting, close the suction valve and open the discharge valve. When the compressor is up to speed, slowly open the suction valve.
3. Check the whole system. Observe the temperature and pressure gauges. Correct any operating difficulties immediately, before proceeding.
4. Check controls for proper operation and reset if necessary.
5. Check superheat setting of thermostatic expansion valves and adjust if required.
6. Check the operation of the water-regulating valve in the water supply line to the condenser. If the compressor discharge head pressure is too high, adjust for increased condenser water flow.
7. Check the liquid refrigerant sight glass for bubbles. If any appear, refrigerant may need to be added. However, complete the rest of the checks before adding more refrigerant.
8. Check the oil level in the crankcase after the compressor has operated for about 15 to 20 minutes. If the compressor is pressure lubricated, check the oil pressure.
9. Check the entire system with a leak detector.

Reciprocating or Rotary Compressor Refrigeration System Shutdown

When a system has to be shut down for a prolonged period, it needs to be pumped down. All of the refrigerant should be stored in the liquid receiver. This practice will prevent unnecessary strain on the low-pressure side of the equipment, and loss of refrigerant while the system is in shutdown.

It is essential to pump down a direct expansion evaporator any time the compressor is in shutdown. It is necessary to remove all of the refrigerant from the evaporator. This prevents liquid slugging and compressor damage on startup.

The following procedure is for a system that has a direct expansion evaporator.

1. Close the liquid line shut-off or "king" valve on the receiver outlet. This stops the flow of refrigerant to the evaporator.
2. If the liquid line has a solenoid valve, hold it open so that all the liquid can be withdrawn from the line.
3. With the entire system in operation, lower the pressure on the low side until the compressor suction gauge indicates 14 kPa. It may be necessary to manually hold the low-pressure cut-off in the closed position.
4. As soon as the pressure reaches about 14 kPa (2 psi), stop the compressor. Close the compressor suction and discharge service valves. Never pump down below 7 kPa to 14 kPa (1 to 2 psi); a slight positive pressure will prevent air from being drawn in through minor leaks or the compressor shaft seal. Close all other valves in the system. Check the part of the system that contains the refrigerant charge for any leaks.

5. Close the cooling water supply to the compressor and water-cooled condenser, if so equipped. For equipment that is subject to freezing temperatures, drain all of the water.
6. If the system has an evaporative condenser, close the make-up water supply, drain the water, and flush the condenser.
7. Open the master power switch for the system, and lock it in the open position. Ensure that proper tags indicate the lockout and the reason for the shutdown.

Centrifugal Compressor Chiller System Startup

In older systems, most of the auxiliary equipment (such as the chilled water-circulating pump, condenser cooling water pump, and cooling tower fan) had to be started individually. In modern systems, all equipment is electrically interlocked. Simply pressing the start button on the control panel activates the equipment, in the proper sequence. Larger complex chiller systems may still need to have some auxiliary equipment started manually.

Prior to starting up the centrifugal compressor of a chilled water system after a prolonged shutdown, complete the procedure below.

1. Check oil levels in the compressor, pumps, motors, and gearboxes. An abnormally high oil level in the compressor oil sump indicates refrigerant absorption by the oil. To drive the refrigerant out of the oil, either energize the oil sump heater (installed for this purpose), or raise the thermostat setting if the heater is already in operation. Ensure that the heater is working.
2. Check the refrigerant level.
3. Open the stop valves in the chilled water system. Check the chilled water expansion tank for proper level.
4. Check the water level in the cooling tower. Open the make-up water valve and all the valves in the cooling water system.
5. Close the main circuit breakers.
6. Energize the power to the electrical control system. If the system is equipped with pneumatic controls, make sure the required air supply pressure is available.
7. Start the purge unit to remove any air that may have entered the system. Allow the unit to operate for at least 10 minutes before starting the compressor (the time will depend upon the size of the system).
8. If the compressor is equipped with a separate oil pump, turn the pump on. Operate it for 10 minutes before starting the compressor. The oil temperature should then be up to the required minimum.

Once all of the pre-startup procedures above are properly completed, the system is ready for the startup process.

1. Set the chiller demand limiter to its lowest setting.
2. Start the compressor by initiating the start sequence through either the building management control system (facility control system), or a local panel. This starts the chilled water-circulating pump. This will also prove the chilled water flow, and will enable the return water temperature control.
3. If the return chilled water temperature is at or above the cut-in setpoint, the control relay will start the condenser cooling water pump.
4. The cooling tower fan may operate, depending on whether the condensing water temperature at the time is above or below control point temperature.
5. At this point, if all protective controls are energized and satisfied, the compressor motor will start.

During the starting sequence, the inlet damper or vanes automatically hold in the closed position. This allows the compressor to start in an unloaded state, and reduces starting torque and starting current draw. After the compressor has reached normal speed, the thermostat takes over control of the damper or vane operator when it senses the temperature of the water leaving the chiller.

After the compressor comes up to normal speed and takes on load, check oil and refrigerant levels continually for the next 30 minutes. Turn on the water supply to the oil cooler and adjust the supply to maintain bearing temperatures within the recommended range. Be alert for any unusual sounds. Check the operation of auxiliary equipment. Check operating temperatures and pressures.

Operate the system at reduced capacity for several hours to bring the chilled water loop temperature down gradually. This will prevent the compressor motor from cutting out on overload, or from tripping off the chiller due to low chilled water or low refrigerant temperature.

Shutting Down a Centrifugal Compressor Water Chiller

All that is required to stop an automatically controlled refrigerating system is to press the stop button on the control panel. However, if the auxiliary equipment is not electrically interlocked, each item must be stopped separately after the compressor has been shut down.

If the system is to be shut down for an extended period of time, follow these steps:

1. Close all valves.
2. Open the main circuit breakers.
3. If exposed to freezing temperatures, drain the water from the cooling tower and lines.

Observe any other precautions recommended in the manufacturer operating and maintenance manual.

Objective 6

Describe operational log sheets and preventative maintenance procedures for refrigeration systems.

Routine Operation and Log Sheets

To properly care for refrigerating equipment, follow the manufacturer instructions closely. Always keep in mind that reliable operation of this equipment depends upon the care and attention it receives.

The **CSA B52 Mechanical Refrigeration Code** contains the following statement regarding the posting of instructions:

> *It shall be the duty of the owner of a refrigeration system or systems with a prime mover or movers having a capacity exceeding 125 kW (175 hp) to place in a conspicuous location and as near as practicable to the refrigerant compressor(s) a card giving directions for operating the system, including precautions to be observed in case of breakdown or leakage, as follows:*
>
> *a) the telephone number of the appropriate first-response organization for an emergency situation;*
>
> *b) instructions for shutting down the system in case of emergency;*
>
> *c) the name, address, and day and night telephone numbers for obtaining service; and*
>
> *d) the name, address, and telephone number of the nearest regulatory authority, and instructions to notify the authority immediately in case of emergency.*

Since most refrigeration systems are fully automatic and require only intermittent attention, they are often checked haphazardly. This allows adverse conditions to develop unnoticed, and in time, this neglect leads to breakdowns and costly repairs.

It is strongly recommended that a regular operational routine be set up for each system. All observations and readings should be recorded at regular intervals during each day of operation. Experience shows that these records are necessary to indicate and inform the operators of changes in system operation. Daily logs should be followed up by monthly preventive maintenance.

Log sheets may be obtained from inspection and insurance companies, or refrigeration system manufacturers. The building operators can also develop them for a particular facility.

Code Requirements

National and local codes and regulations govern the installation and operation of refrigeration systems when their size exceeds certain limits. These codes ensure safe installation and uniform performance. They:

a) Permit only qualified personnel to install commercial equipment.

b) Require the proper authorities to inspect each installation.

c) Require specific safety devices be installed in the system.

d) Require the system to have a proper design, and use the proper materials.

e) Require all of the electrical and piping work to conform to code requirements.

The **CSA B52 Mechanical Refrigeration Code, ASME B31.5 Refrigeration Piping and Heat Transfer Components Code**, and various **IIAR standards** contain clauses that deal with:

- Instructions
- Signage
- Permissible materials
- Charging and discharging of refrigerants
- Owner's responsibilities

It is important for Power Engineers that deal with refrigeration systems to continually upgrade their knowledge. This ensures that they remain code-compliant throughout their careers.

Preventive Maintenance

Preventive maintenance (PM) is a system of regularly scheduled inspections and lubrications. Depending on the equipment, a PM may include adjustments, minor part replacements, and minor repairs. PMs are necessary to keep the refrigerating plant and equipment in good operating condition.

There are many benefits to having a good PM program in place. These include:

a) More dependable service from the equipment
b) Increased operating efficiency and a reduction in energy consumption
c) Elimination or reduction of major breakdown repairs
d) Reduction of overall maintenance costs
e) Efficient scheduling of maintenance operations
f) Reduced spare parts inventory requirements
g) Control of labour and material cost
h) Better means of identifying causes of breakdowns
i) Extended life expectancy of plant and equipment
j) Accumulation of historical records for each piece of equipment

The refrigerating system must have a preventive maintenance program in place to ensure reliable system operation. The manufacturer operating instructions are the most important source of information for setting up the program. PM checks take place weekly, monthly, semi-annually, and annually.

Weekly Maintenance

1. Check operation of the compressor lubrication as per the manufacturer instructions. This includes the pump, cooling coil, and heater. Observe the oil reservoir level at the sight glass. Marking the level on the sight glass is beneficial. Keep a record of the date and amount of oil added.
2. Observe the lubricating oil pressure. Note any variation from the previous week. The oil discharge pressure should be 140 to 245 kPa above the suction pressure, depending on the type of lubrication system and the manufacturer recommendations.
3. Check the vane seal oiler on the centrifugal compressors. If there is a noticeable drop in oil level, replace the leaking seal.
4. If the system has a positive displacement compressor, stop the compressor and check the shaft seals for excessive oil leakage. Check the seal with a refrigerant leak detector if an open compressor is used.
5. Check the frequency of purge pump operation on units with centrifugal compressors. If a leak develops, the purge pump will operate more frequently. The chiller control panel indicates the run times for the purge unit.
6. Check the condition of the air filters. Clean or replace filters as necessary.
7. Clean the screen at the pump inlet and the spray nozzles on units with evaporative condensers.
8. Clean all screens and remove pipe blockages in the cooling tower.

Monthly Maintenance

1. Check the operation and condition of the cooling tower or evaporative condenser float valve.
2. Lubricate all fan and motor bearings monthly or as directed by the manufacturer. Use recommended lubricants. Do not over grease bearings.
3. Check the pump packing glands for proper adjustment.
4. Check the V-belt tension and alignment.
5. Inspect the condition of condensing equipment. Clean if necessary. Check the cooling tower water. Treat water if algae or scaling is evident.
6. Clean the tower sump strainer screen.

Semi-Annual Maintenance

1. Check the operation of pumps and the condition of the couplings.
2. Check the condition of stands, supports, and vibration isolators on cooling towers.
3. Check the operation of safety controls, such as the low oil-pressure cut-out and condenser high-pressure cut-out.

Annual Maintenance

1. Service the motors on the compressor and pump.
2. Check the condition of stands, supports, guards, insulation, and vibration absorbers on the compressor and pump.
3. Check the condition of the unit exterior. Remove rust and repaint, as necessary.
4. Drain the condensing system, clean scale or sludge formation, and check piping.
5. Flush the pumps and sump tank on the cooling tower or the evaporative condenser, if used. Remove corrosion from metal and repaint.
6. Replace worn fan belts.
7. Check the condition of the electrical starters and contactors.
8. Check the condition of the controls and recalibrate, if necessary.
9. Check and clean the condenser heat transfer surfaces, if fouled.

Objective 7

Describe how a refrigeration system is purged of non-condensable gases.

System Purging

Effect of Non-Condensable Gases

Non-condensable gases in a refrigerating system cause the high side pressure to rise above the pressure that corresponds to the saturation temperature of the refrigerant. For instance, when the saturation temperature of R-717 is 30°C, the corresponding head pressure should be 1167 kPa (1066 kPag). If the pressure gauge indicates 1350 kPa, and the condenser cooling is normal, the excess pressure is being caused by non-condensable gases in the system. This means that the condenser pressure is considerably higher than the saturation pressure that corresponds to the temperature of the refrigerant in the condenser.

Higher than normal head pressure is undesirable. It increases power consumption, reduces compressor capacity, and overstresses the compressor parts. High temperatures that accompany higher pressures are detrimental to compressor valves and lubrication.

Non-condensable gases consist mainly of air that may have leaked into the system by improper operating or maintenance procedures, such as insufficient evacuation prior to charging, or failure to bleed air from oil charging lines. Air infiltration can also occur when part of the system operates below atmospheric pressure. Non-condensable gases can also be the product of oil impurities or lube oil deterioration.

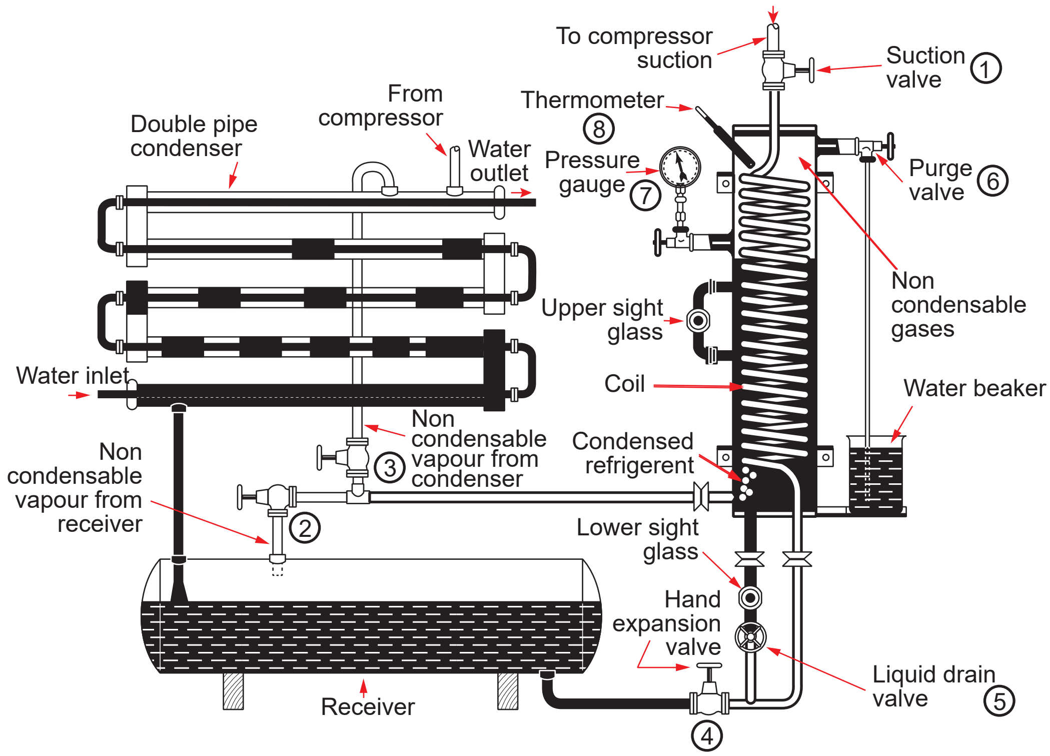
Remove non-condensable gases from the system either by manual or automatic purging. The purge connections are made at the highest point of the condenser and receiver, since this is where these gases tend to collect.

Numerous varieties of purging devices are available. Purgers refrigerate the mixture of refrigerant and non-condensable gases. The resulting liquid refrigerant returns to the receiver. The non-condensable gases are vented to atmosphere. Some purgers also eliminate water.

Manual Purging System

The purger shown in Figure 32 is a manual device, and must be operated on a regular schedule. Other purgers are designed to operate continuously and automatically. They require only occasional attention by the operator.

Figure 32 – Manual Purger



Purge the condenser and receiver separately. To operate the purger, open the suction and vapour inlet valves 1 and 2. Refrigerant vapour that contains the non-condensable elements will enter the purger housing. Partially opening expansion valve 3 will admit liquid refrigerant into the coil. Since the coil is open to the compressor suction, the liquid will evaporate and cool the surrounding gases to a temperature that corresponds to the compressor suction pressure, which causes the refrigerant vapour that is present in the purger to condense.

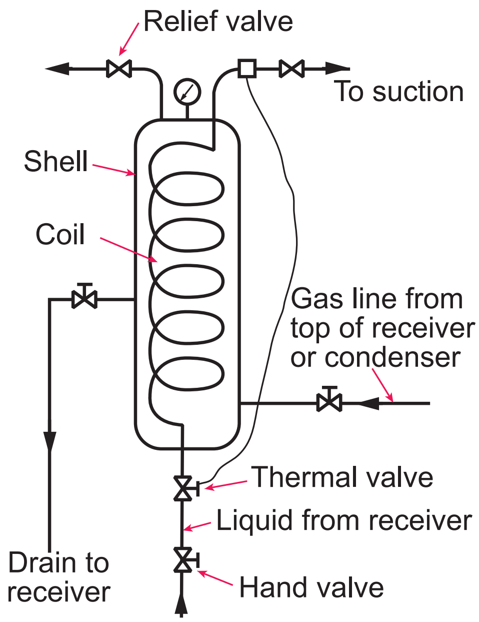
When a liquid level appears in the upper sight glass, close manual expansion valve 3, and open liquid drain valve 4. This allows the condensed refrigerant to pass through the coil to the compressor suction. When the liquid level drops to the lower sight glass, close liquid drain 4 and purger vapour inlet valve 2. Open purge valve 5 to vent the gases to the atmosphere via the water beaker. Venting enables the escaping gas to be seen. Venting also acts to seal atmospheric air from leaking into the system.

After the gases have left the purger, open vapour inlet valve 2 on the receiver or condenser. Repeat the process until all non-condensable gases have been removed. This condition is indicated by the temperature as shown on the purge vessel pressure gauge 6 (saturation temperature) falling to that indicated on the thermometer 7.

Automatic Purgers

Most large refrigeration systems are equipped with an automatic purger. Although there are various designs, most purgers – whether automatic or manual – operate on the principle shown in Figure 33.

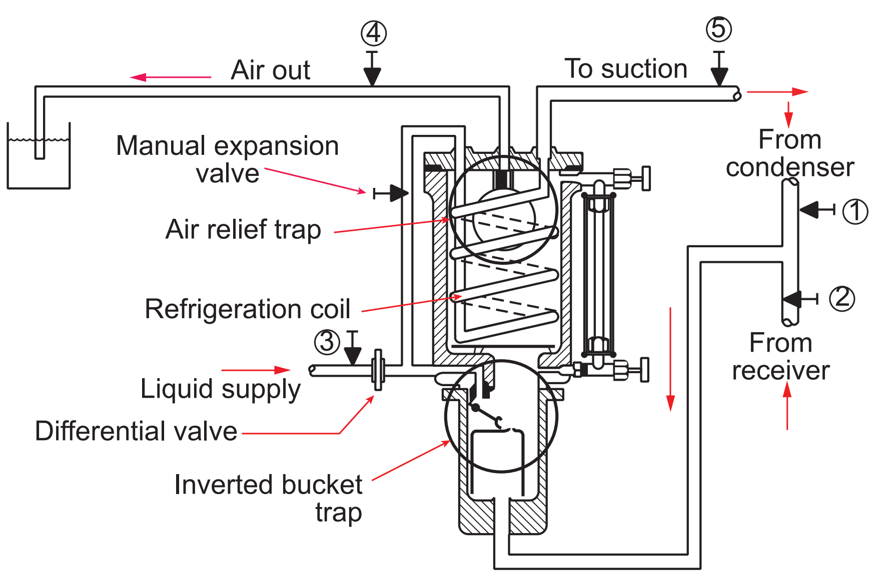
Figure 33 – Basic Purger Design



The non-condensable gases that enter the purger may carry with them a considerable amount of refrigerant vapour. To prevent this vapour from escaping to the atmosphere with the gases, the purger is equipped with a chilling coil, which causes the vapour to condense and separate from the gas mixture. The liquid refrigerant settles to the lower part of the purger where it drains back to the receiver, usually by means of an automatic float trap. The non-condensable gases rise to the upper part of the purger where they release to the atmosphere through an air relief valve.

Figure 34 shows another automatic purging system.

Figure 34 – Automatic Purger



(Courtesy of Armstrong International Inc.)

To prime the purger with refrigerant, crack open valve 4, and open valve 3. After the rising liquid level has closed the air relief trap, valve 4 will be open fully. Open either valve 1 to purge the condenser, or valve 2 to purge the receiver; both valves must not be open at the same time. The differential valve is a spring-loaded check valve used to reduce the pressure at the purger liquid outlet. This enables gas to enter and liquid to discharge.

Entering gas is trapped in the inverted bucket. This floats the bucket and closes the liquid discharge valve. If there is only refrigerant vapour in the purge gas, it bubbles through the bucket vent and condenses due to the cooling effect of the coil. No gas reaches the top of the purger to actuate the vent mechanism. When the inverted bucket drops, it releases liquid refrigerant to the refrigeration coil through the manual expansion valve. From there, it finds its way into the compressor suction.

When non-condensable gases reach the purger, the refrigerant gas condenses and the non condensable gases rise to the top of the purger. The non-condensable gases displace the liquid at the top of the purger and the liquid level drops. This causes the float to drop, which opens the air relief trap valve. The air and non-condensable gases then pass out from the purger. Any refrigerant vapour is condensed by the cooling action of refrigerant passing through the refrigerant coil.

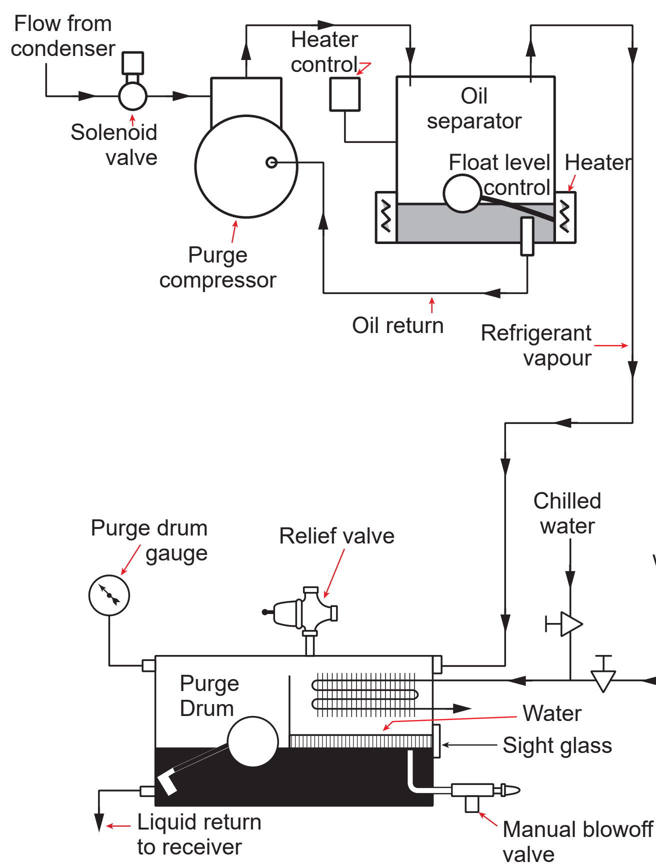
As more non-condensable and refrigerant gases enter the purger, they lift the inverted bucket, which closes the liquid valve. The process then repeats.

The actual piping and valve arrangement will vary depending on system type, pressure, and compressor controls.

Purging of Centrifugal Chillers

Figure 35 is a schematic of a purge system suitable for refrigerants, such as R-123, that operate at below atmospheric pressure. The purging cycle can operate either manually or automatically.

Figure 35 – Automatic Purger for Low-Pressure HVAC Chiller



(Courtesy of Trane)

When the purge unit starts, the solenoid valve opens. This allows a mixture of refrigerant vapour and non-condensable gases to flow from the condenser to a purge compressor. The compressed gas flows into the oil separator, where it is heated. This prevents the refrigerant from condensing and mixing with the entrained oil from the purge compressor.

Oil collects at the bottom of the oil separator. It returns to the crankcase of the purge compressor through a float valve and oil return line.

The vapour then leaves the separator, and condenses in the purge drum. This causes the non-condensable gases to rise to the top of the drum. When the pressure in the purge drum exceeds the relief valve setting, the non-condensable gases discharge to atmosphere. The condensed refrigerant passes through the float valve, and returns to the receiver.

Any accumulated water on the surface of the liquid refrigerant in the purge drum is indicated in the sight glass. Open the manual blowoff valve to remove the water.

Whenever non-condensable gases are released through the relief valve, a small amount of refrigerant always discharges with the gases. These refrigerant losses increase with the size of the installation. If the losses become excessive, check the system for leaks at the earliest possible time.

Each manufacturer uses different purging systems. Operators should be familiar with the operation and maintenance requirements of the purge system in their building.

Objective 8

Discuss refrigeration condenser operation and maintenance requirements.

Operation and Maintenance of Condensers

Defective condenser operation may result from dirty cooling water on the waterside surface of the coils, or from a coating of oil on the refrigerant side. The use of proper compressor lubricating oil will help considerably in keeping the refrigerant side clean.

Trouble also results from the presence of non-condensable gases in the condenser, which needs to be purged periodically. The presence of these gases reduces the capacity of the condenser. This causes high compressor discharge pressures and temperatures.

If the cooling water contains scale-forming dissolved solids, they may deposit on the waterside surfaces of the condenser in shell-and-tube, double tube, and evaporative condensers. The scale accumulation decreases the rate of heat transfer through the tube or coil walls. It will seriously reduce the efficiency of the condenser, not to mention the whole refrigeration system. Likewise, a similar effect will occur if lubricating oil deposits are permitted to accumulate on the refrigerant side surfaces of the tubes or coils. Inspect the internal and external surfaces of condenser tubes or coils at frequent intervals, and clean them whenever deposits become discernible. Installation of a water softening system may prove to be economical, especially in locations where water is exceptionally hard.

Regarding cooling towers, monitor water conditions for airborne contaminants, solids buildup, and bacterial growth. A condition known as legionnaire's disease, a pneumonia-like reaction to the Legionella Pneumophila bacteria; the bacteria is often found in contaminated water. The bacteria can be spread through the air with contaminated water droplets. Biocide must be added to the cooling water to prevent bacterial growth. Always wear personal protective equipment, such as a respirator and gloves, when working in the direct vicinity of a cooling tower.

To clean the waterside surfaces of shell-and-coil and double-tube condensers, take the unit out of service, and circulate an acid or other chemical solution through it. Such an operation will require advice from a qualified water treatment specialist, or the manufacturer of the unit. Straight tube shell-and-tube condensers are commonly cleaned mechanically, by passing mechanical cleaners through the tubes. This is usually performed annually.

Water-cooled condensers are prone to galvanic corrosion. To inhibit this corrosion, sacrificial anodes are installed in the condenser water boxes. Inspect the anodes on an annual basis, and renew them if necessary.

Air-cooled condensers have closely spaced fins that clog with dirt. Clean the fins regularly with a cleaning solution and a stream of water. Do not use a pressure washer. The high-pressure water will bend the cooling fins and restrict airflow. Bent cooling fins can be straightened with a special comb.

Condenser fan blades may become weak at their attachment points. When this occurs, fan blades can fly off and sever the condenser coil tubing. Inspect fan blades and fan bearings for integrity. Replace fans and bearings if necessary. Drive belts also require inspection and replacement. Always replace belts in matched sets.

Objective 9

Explain typical problems and resolutions related to refrigeration systems.

Troubleshooting Refrigeration Systems

When trouble develops in a refrigerating system, the cause is not always easy to pinpoint since the system contains many components and controls. To help the operator analyze the trouble, most manufacturers provide troubleshooting guides for their equipment.

The best way to troubleshoot is by using a series of steps that begin with the simplest of conditions, such as no power. Then, probable causes are eliminated in a logical manner. The history of the unit can often be used to focus in on issues, but it can also create preconceived ideas as to causes and effects. Experience can often lead operators to immediately suspect a system component, because it may have been a problem source in the past. It is critical to rule out the basic issues before starting to dismantle, replace, or repair equipment.

The following guide may be used when manufacturer instructions are not available. Though this general guide applies to systems with reciprocating compressors, many of the items also apply to systems with centrifugal compressors.

Table 1 – Troubleshooting Guide

POSSIBLE CAUSE	SYMPTOMS	CORRECTIVE ACTION
Trouble: Compressor Fails to Start		
No power	Fuses or circuit breaker is open.	Check circuit for shorts or grounds. Replace fuses or close circuit breaker after fault is corrected.
Thermal overloads of motor	No power on motor terminals.	Check motor circuit and motor for grounds. Correct fault. Find reason for overloads tripping. Reset overloads.
Low voltage	Circuit tester glows but at reduced brilliance.	Check with voltmeter. Call power company.
Defective starter	Test for burned-out coil or damaged contacts.	Repair or replace.
Burned out motor	Full voltage at motor terminals but motor does not run.	Repair or replace.
Open control circuit	No power on terminals of starter holding coil.	Locate open operating or safety control and determine cause. Correct and reset control.
Broken or sheared coupling	Motor runs, compressor does not.	Repair or replace. Check alignment.
Seized compressor	Motor hums but does not start. Starter trips on overload.	Repair compressor.

POSSIBLE CAUSE	SYMPTOMS	CORRECTIVE ACTION
Trouble: Compressor Short-Cycles		
1. Intermittent contact in electrical circuit	Compressor operates normally but starts and stops frequently.	Repair or replace faulty control.
2. Low pressure controller differential set too close	Compressor operates normally but starts and stops frequently.	Reset the differential.
3. Leaky liquid line solenoid valve	Valve may hiss when closed. Temperature change in refrigerant line through closed valve.	Repair or replace the valve.
4. Dirty or iced evaporator	Reduced air flow due to: a) dirty air filters b) broken fan belt c) improperly adjusted fan belt	Clean or defrost evaporator. Check filters and fan drive.
5. Insufficient condensing	Excessively high discharge pressure. Compressor cuts off on high-pressure cut-out.	Check operation of condenser fan, water supply.
6. Over charge of refrigerant	High discharge pressure.	Recover excess refrigerant.
7. Non-condensable gases	High discharge pressure.	Purge system.
8. Lack of refrigerant	Normal operation but frequent starting and stopping on low pressure cut-out.	Check for leaks, repair, and recharge.
9. Water regulating valve inoperative or restricted	High discharge pressure.	Clean or repair water valve.
10. Restricted liquid line strainer or solenoid stop valve	Suction pressure too low, frosting at strainer.	Clean strainer or valve.
11. Faulty motor	Motor starts and stops rapidly.	Repair or replace motor.
Trouble: Compressor Runs Continuously		
1. Excessive load	High temperature of substance to be cooled.	Check for excessive warm air infiltration, or for inadequate insulation of space to be cooled.
2. Thermostat set too low or defective	Low temperature of substance to be cooled.	Reset or repair thermostat.
3. Welded contacts or stuck electrical control in motor starting circuit	Low temperature of substance to be cooled.	Repair or replace faulty control.
4. Lack of refrigerant	Bubbles in sight glass.	Repair leak and charge system.
5. Overcharge of refrigerant	High discharge pressure.	Recover excess refrigerant.
6. Leaky valves in compressor	Compressor noisy or is operating at abnormally low discharge pressure or abnormally high suction pressure.	Overhaul compressor.
7. Solenoid valve stuck open	Low temperature of substance to be cooled.	Repair valve.

POSSIBLE CAUSE	SYMPTOMS	CORRECTIVE ACTION
Trouble: Compressor or System Noisy		
1. Coupling loose or misaligned	Coupling bolts loose, vibration.	Tighten coupling, check alignment.
2. Lack of oil	Compressor cuts out on oil failure control.	Add oil.
3. Dry or scored seal	Squeaky seal during operation.	Check oil level; replace seal.
4. Internal parts loose or broken	Compressor knocks.	Overhaul the compressor.
5. Liquid floods back to compressor	Compressor knocks; abnormal cold suction line.	Check rating and adjustment of expansion valve. Replace valve if defective.
6. Compressor or motor loose on base	Compressor or motor jumps on base.	Tighten hold-down bolts.
7. Improper piping support	Piping vibrates.	Relocate, add, or readjust hangers and supports.
8. Water regulating valve is dirty, water pressure too high	Water valve chatters or hammers.	Clean valve; reduce supply pressure.
Trouble: System Short of Capacity		
1. Flash gas in liquid line	Expansion valve hisses.	Determine cause of flashing. If it is due to high temperature and loss of sub cooling, correct it. If it is due to refrigerant shortage, locate and repair leak, and recharge as required.
2. Clogged strainer or stop valve	Temperature difference in liquid line before and after strainer or valve.	Clean the strainer or replace the valve.
3. Ice or dirt on evaporator	Reduced airflow.	Defrost coil or clean the evaporator.
4. Expansion valve stuck or obstructed	Short-cycling or continuous operation.	Repair or replace the valve.
5. Excess pressure drop in evaporator	Superheat is too high.	Reset thermostatic expansion valve.
6. Improper superheat adjustment	Short-cycling or continuous operation.	Adjust thermostatic expansion valve.
7. Expansion valve improperly sized	Short-cycling or continuous operation.	Replace with correct valve.

POSSIBLE CAUSE	SYMPTOMS	CORRECTIVE ACTION
Trouble: Discharge Pressure Too High		
1. Insufficient supply to condenser or water too warm	Water temperature at outlet too high.	Increase water supply, adjust water regulating valve.
2. Fouled tubes in shell-and-tube condenser	Water temperature at outlet too low.	Clean tubes.
3. Air passages through air-cooled condenser dirty	Temperature difference between air in and out too large, low air volume.	Clean condenser.
4. Improper operation of evaporative condenser	Low air or spray water volume. Scaled coil surface.	Correct air or water flow. Clean coil surface.
5. Non-condensable gases in system	Very hot condenser.	Operate purge system, if applicable, otherwise, remove refrigerant charge and replace with new refrigerant.
6. Overcharge of refrigerant	Very hot condenser.	Recover excess refrigerant.
Trouble: Discharge Pressure Too Low		
1. Too much condenser water	Water temperature at outlet is too low.	Adjust the water-regulating valve.
2. Lack of refrigerant	Bubbles in sight glass.	Check for leaks, locate, and repair, Add refrigerant.
3. Broken or leaky compressor discharge valves	Suction pressure rises faster than 35 kPa per minute after compressor shuts down.	Repair or replace valves.
4. Leaky relief bypass valve	Low discharge pressure and high suction pressure.	Inspect valve, replace if necessary.
Trouble: Suction Pressure Too High		
1. Excessive evaporator load	Compressor runs continuously.	Reduce load. Check for excessive fresh air or infiltration, poor insulation.
2. Expansion valve overfeeding	Suction line abnormally cold. Liquid is flooding to compressor.	Regulate superheat. Check remote bulb attachment to suction line.
3. Expansion valve stuck open	Suction line abnormally cold. Liquid is flooding to compressor.	Repair or replace valve.
4. Expansion valve too large	Abnormally cold suction line. Liquid is flooding to compressor.	Check valve rating, replace if necessary.
5. Broken suction valves in compressor	Noisy compressor, reduced capacity.	Repair or replace valves.

POSSIBLE CAUSE	SYMPTOMS	CORRECTIVE ACTION
Trouble: Suction Pressure Too Low		
1. Lack of refrigerant	Bubbles in sight glass.	Check for leaks, locate and repair, then charge system as required.
2. Evaporator dirty or iced up	Compressor short-cycles.	Clean or defrost.
3. Clogged liquid line filter-drier	Temperature change in liquid line before and after filter-drier.	Replace cartridge or entire unit.
4. Expansion valve sensing element has lost charge	No flow of refrigerant through valve.	Replace sensing element/power head if possible, if not replace valve.
5. Obstructed expansion valve	Loss of capacity.	Clean valve.
6. Contacts on controller stuck in closed position	Conditioned space is too cold.	Repair or replace control. Adjust control range to the correct value.
7. Compressor capacity control range set too low	Compressor short cycles	Reset control range.
Trouble: Oil Pressure Too Low		
1. Insufficient oil charge	Oil level is too low.	Add oil.
2. Excessive liquid refrigerant in crankcase	High oil level, oil is foaming.	Energize crankcase heater. Adjust expansion valve for higher superheat.
3. Worn or defective oil pump	Normal oil level, low pressure.	Repair or replace pump.
4. Poor suction due to leak in suction line or plugged strainer	Normal oil level, low pressure.	Repair leak, clean strainer.
5. Oil pressure-relief valve not closing properly	Normal oil level, low pressure.	Repair or replace the valve.
Trouble: Compressor Loses Oil		
1. Oil does not return from oil separator	Oil level drops steadily.	Check operation of the return valve in the separator.
2. Oil trapped in evaporator or lines	Oil level drops steadily.	Check pitch of lines and refrigerant velocities.
3. Clogged return oil strainer or valves	Oil level drops steadily.	Clean, repair, or replace strainer and valves.
4. Liquid flooding back to compressor	Excessive cold suction, noisy compressor operation.	Re-adjust superheat setting, check remote bulb contact.
5. Leaking joints or fittings on crankcase	Oil around compressor.	Repair leaks.

Many compressor motors run on high voltage (4160 volts and over). Small systems use motors with start capacitors. These electrical hazards must be managed to ensure worker safety. If it necessary to open equipment or electrical boxes to do the troubleshooting, a lock out procedure must be in place before anyone begins to work on the unit.

Much of the troubleshooting will require electricians and refrigeration mechanics who have experience with the high voltages, refrigerant hazards, and controls used in refrigeration systems. These tradespeople should be contacted only after the operator has exhausted all basic and probable causes of failure.

Often, troubleshooting requires electrical diagrams that show all switches, disconnects, and controls. These are often found mounted on the electrical cabinet closure or unit. The internet has also become an extremely useful source for information, wiring diagrams, service manuals and troubleshooting guides from the manufacturers and suppliers websites.

Chapter Summary

This chapter introduced a number of specific auxiliaries used in refrigeration systems, including accumulators, oil separators, filter-driers, sight glasses, moisture indicators, economizers, distributers, oil pots, and purgers. Each one serves an important purpose in a refrigeration system.

Oil separators prevent oil from entering condensers, which would impede heat transfer. Along with oil pots, separators can return oil to the compressor crankcase, or simply to remove oil from the system. Filter-driers and moisture indicators work together to keep the refrigerant moisture free. They will also prevent internal system freeze-up, acid, and sludge formation. Sight glasses help to determine if a system has adequate charge, or to observe the level in liquid receivers and chillers. Purgers remove non-condensable gases from the system, which reduces compressor power consumption, and improves heat transfer in the condenser.

Understanding of the function of these auxiliaries helps operators perform normal duties safely and effectively. Some tasks are performed intermittently, such as recovering and draining oil, adding oil to compressors, leak testing, and purging non-condensable gases. Others are scheduled on a regular weekly or monthly basis. As well, operators must be able to safely start, stop, and pump down refrigeration systems. Again, the interaction of the various components must be well understood in order to perform these tasks.

Power Engineers are involved with systems that require repair, or are undergoing modifications. This involves the design, installation, and commissioning of refrigeration systems and their components. It is important for operators to understand the selection of materials and the assembly methods of refrigeration system piping components. The refrigeration plant operators frequently have a hand in system commissioning. This includes pressure testing, leak testing, drying, evacuating, and charging the systems.

Inevitably, even the smoothest operating systems will break down. Equipment manufacturers provide troubleshooting guides to help operators and technicians repair problems as they arise.

Chapter 5

Absorption Refrigeration Systems

Learning Outcome

When you complete this chapter you should be able to:

Describe the operating principle, maintenance, and operation of absorption refrigeration systems.

Learning Objectives

Here is what you should be able to do when you complete each objective:

1. Describe the basic absorption system, comparing the differences to the compression system.
2. Describe the theory and operation of an ammonia absorption refrigeration system.
3. Describe the theory and operation of a lithium bromide absorption refrigeration system.
4. Explain the operation of absorption refrigeration systems with respect to crystallization and dilution.
5. Describe the major parts and systems of an absorption system including the heat exchanger bypass system; pump motor lubrication and cooling system; and purging system.
6. Describe the startup and shutdown procedures for an absorption refrigeration system.
7. Describe the preventive maintenance to perform on an absorption refrigeration system.
8. Explain typical problems and resolutions related to an absorption refrigeration system.

Chapter Introduction

Mechanical energy, supplied by an electric motor or steam turbine, drives the refrigeration compressor. In an absorption refrigeration system, heat energy drives the system instead of mechanical energy.

Both systems use low cost energy sources (such as waste heat) to provide cooling. Other sources of heat can also be used, including steam, hot water, and fuel firing. Because they use heat energy instead of mechanical energy, absorption systems do not require compressors. This reduces the electrical energy consumption.

This chapter describes the operation and maintenance of two types of absorption systems:

1. Ammonia
2. Lithium bromide

Large-scale ammonia absorption plants are used in industrial settings. Lithium bromide systems are used for large HVAC chillers.

Objective 1

Describe the basic absorption system, comparing the differences to the compression system.

Basic Absorption Refrigeration Systems

In the compression refrigeration system, the compressor does several jobs:

1. It maintains a low evaporator pressure by withdrawing refrigerant vapour as it is produced.
2. It raises the vapour pressure (and corresponding saturation temperature) of the refrigerant to the point where it can be condensed at ambient temperature in a condenser.
3. It causes refrigerant to flow from the low side to high side.

Like the compression refrigeration system, absorption systems require a condenser, a liquid receiver, an expansion valve, and an evaporator. However, a compressor is not required. These other methods perform its functions:

a) A low-pressure **absorber** that contains a liquid (the absorbent) withdraws the refrigerant vapour from the evaporator.
b) A high-pressure **generator** that contains and heats up a concentrated absorbent/refrigerant solution. This drives the refrigerant vapour out of solution, and raises its vapour pressure.
c) A heat source adds energy to the system.
d) A pump moves the concentrated solution from the low-pressure absorber to the high pressure generator.

Comparison of Absorption and Compression Systems

Economy of Operation

The availability of waste heat when cooling is required is often the basis for the decision to use an absorption system in industrial or air conditioning applications. Many absorption systems use waste heat from boiler flue gas or gas turbine exhaust. To supplement their operation when waste heat is unavailable, the same units may use direct firing, steam, or hot water. The ability to use a variety of energy sources makes it flexible to choose what the most economical source is at certain times.

Sometimes it is necessary to keep a steam or hot water boiler in operation for other purposes. It may be highly economical to use steam heat, hot water, or flue gas waste heat for an absorption system generator, rather than to use electrical power for a compression refrigeration system. A critical factor is the simultaneous availability of waste heat and the requirement for cooling. Conventional mechanical refrigeration systems can be used when these alternative heat sources are unavailable.

The pumps in an absorption system require less power than a refrigeration compressor; therefore, an absorption system uses less electrical energy than a compression refrigeration system of similar capacity. Starting an absorption chiller does not create a huge electrical demand, so demand charges are low. Because an absorption system uses less electricity, the emergency generator can be smaller.

Environmental Impact

Absorption refrigeration systems use only natural refrigerants: R-717 (ammonia) and R-718 (water). This reduces the contribution to global warming should a refrigerant leak occur. Absorption systems also minimize global warming potential (GWP) by greatly reducing electricity consumption and production of greenhouse gases. Finally, unlike CFCs and HCFCs, R-717 and R-718 are not ozone-depleting substances (ODS), and are not being phased-out.

Safety in Operation

In a compression refrigeration system, if slugs from the liquid refrigerant carry over, they may cause damage to the compressor.

In an absorption system, carryover from the evaporator will not cause damage. This allows the continuous operation of the system, without having to change set points or continuously monitor the load. In this system, slugging and evaporator freezing are not a problem.

Size

Packaged absorption systems for HVAC service do not require much more space than compression systems, despite the additional number of vessels required. The footprint of a packaged absorption system is not much more than that of a packaged HVAC chiller of the same capacity.

Capacity

Absorption chillers for HVAC service are available in capacities up to around 6000 kW (1545 TR). Centrifugal chillers are available in up to double that capacity.

Cooling Water Requirements

Absorption systems need more cooling water than compression systems. This is because the absorption system condenser needs to reject more heat. The condenser rejects the heat added in the generator, plus the heat absorbed in the evaporator. This is significantly more heat than the compressor adds from compression.

Maintenance

An absorption system needs more equipment and piping. It takes about the same amount of labour hours to maintain the pumps as it takes to service a refrigeration compressor.

Sound

Absorption systems are very quiet in operation. They are well suited for concert halls, theatres, and other areas where the noise of a compression system would affect human comfort.

Objective 2

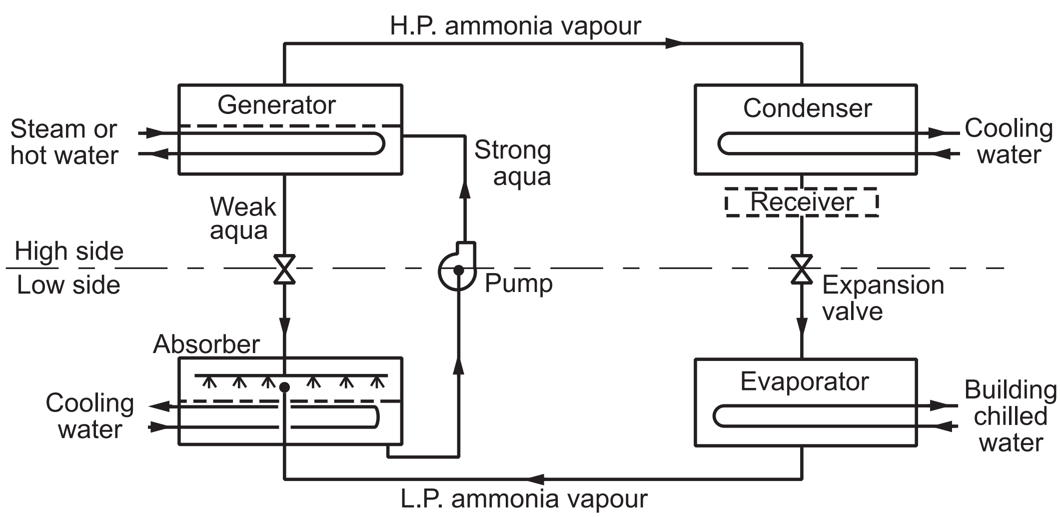
Describe the theory and operation of an ammonia absorption refrigeration system.

Ammonia Absorption System

During the early development of absorption refrigeration, ammonia was the most commonly used refrigerant. In an ammonia absorption system, the liquid absorbent used is water. It can absorb ammonia vapours in large quantities, at the same rate that the evaporator produces the vapour. Figure 1 displays a basic ammonia absorption system.

A controlled amount of high-pressure liquid ammonia passes through the expansion valve, and goes into the low-pressure evaporator. The refrigerant absorbs heat from the chilled water, and lowers the chilled water temperature. The heat absorbed by the refrigerant causes it to evaporate into low pressure, low-temperature ammonia vapour.

Figure 1 – Basic Ammonia Absorption System



The low-temperature, low-pressure vapour is then drawn into the absorber, where it dissolves into a spray of water. The rapid absorption of ammonia by the absorber maintains the low pressure in the evaporator. This solution of refrigerant vapour and water forms a concentrated aqueous solution, called **strong aqua**.

A pump transfers the strong aqua from the low-pressure absorber to the high-pressure generator. In the generator, a heat source (steam, hot water, direct-fired burner, or waste heat) raises the temperature of the strong aqua. This boils off the ammonia absorbed by the water in the absorber, and produces high-pressure, high-temperature ammonia vapour. The water left in the generator is called **weak aqua**, which flows back to the absorber. The generator must produce a pressure and temperature high enough to raise the ammonia temperature above that of the cooling medium used in the condenser.

The high-pressure, high-temperature ammonia vapour leaves the generator and enters the condenser. The cooling coils in the condenser convert it back to liquid. The rejected heat transfers to a cooling tower. The liquid ammonia drains from the condenser to the receiver, where it is stored until re-introduced to the evaporator.

Ammonia absorption systems are used for cold storage, food processing, or other applications where extremely low temperature cooling is required. Ammonia absorption systems can cool well into the –30°C range, which cannot be done with lithium bromide systems. However, ammonia absorption is rarely used for air conditioning purposes because of the toxic properties of ammonia. The lithium bromide absorption system is more suitable for HVAC use.

Objective 3

Describe the theory and operation of a lithium bromide absorption refrigeration system.

Lithium Bromide Absorption (Water Vapour) System

Lithium bromide (LiBr) absorption systems are large-capacity packaged water chillers, used in HVAC service. They use R-718 (water) as a refrigerant, and a lithium bromide solution as the absorbent.

On Track

When this objective refers to water acting as a refrigerant, it will be called either by its ASHRAE designation (R-718) or it will be called "the refrigerant."

This will reduce confusion when referencing chilled water, cooling water, and refrigerant water.

The boiling point of R-718 is reduced by lowering the pressure in the evaporator below atmospheric. To lower the saturation temperature of R-718 to a temperature useful for cooling, the system must operate under an extremely high vacuum.

For example, when the pressure is 1.7 kPa absolute (0.247 psia), R-718 boils at around 15°C (59°F). If the pressure is reduced to 0.87 kPa absolute (0.127 psia), the boiling point drops to 5°C (41°F). These numbers can be confirmed with steam tables.

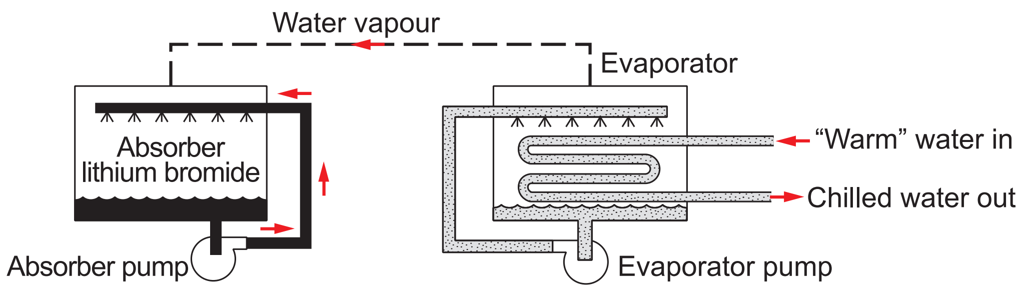
Since very low temperatures are not required for air conditioning purposes, lithium bromide absorption systems maintain an evaporator temperature of 4°C to 7°C (40°F to 45°F). This requires an absolute evaporator pressure of 0.84 to 1.01 kPa (0.12 to 0.15 psi). These pressure conditions create a sufficient temperature differential between the chilled water and the refrigerant so that rapid heat transfer can take place.

The basic operating cycle of a lithium bromide absorption unit is based on two factors:

1. The lithium bromide solution has the ability to readily absorb water vapour.
2. R-718 boils at low temperatures when under a high vacuum. R-718 enters the evaporator, and removes about 2490 kJ/kg from the chilled water loop as it evaporates.

Since R-718 vaporizes easily and quickly when it is in a finely divided state, the evaporator is equipped with a pump that forces the refrigerant through a spray header. The evaporator is fitted with a coil through which chilled water circulates. The chilled water is cooled by evaporation of the refrigerant sprayed on the outside of the tubes. See Figure 2.

Figure 2 – Low Side Components of an LiBr Absorption System

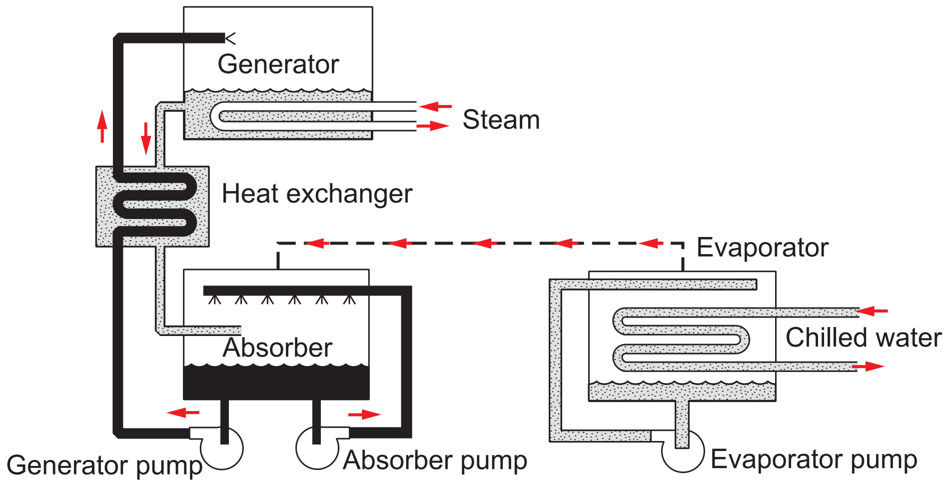


Similarly, to speed up the absorption of refrigerant vapour by the lithium bromide, the absorber is equipped with a pump, which circulates the aqueous lithium bromide solution through a spray header. The spray provides much greater contact with the refrigerant vapour, increasing the absorption rate.

When the lithium bromide solution absorbs R-718, it becomes dilute (weak), and its ability to absorb more refrigerant vapour decreases. The weak solution is pumped to a generator (also called a **concentrator**) where heat is applied by a steam or hot water coil, or by a burner. R 718 boils off and the concentrated solution returns to the absorber where it absorbs more refrigerant vapour. This principle is shown in Figure 3.

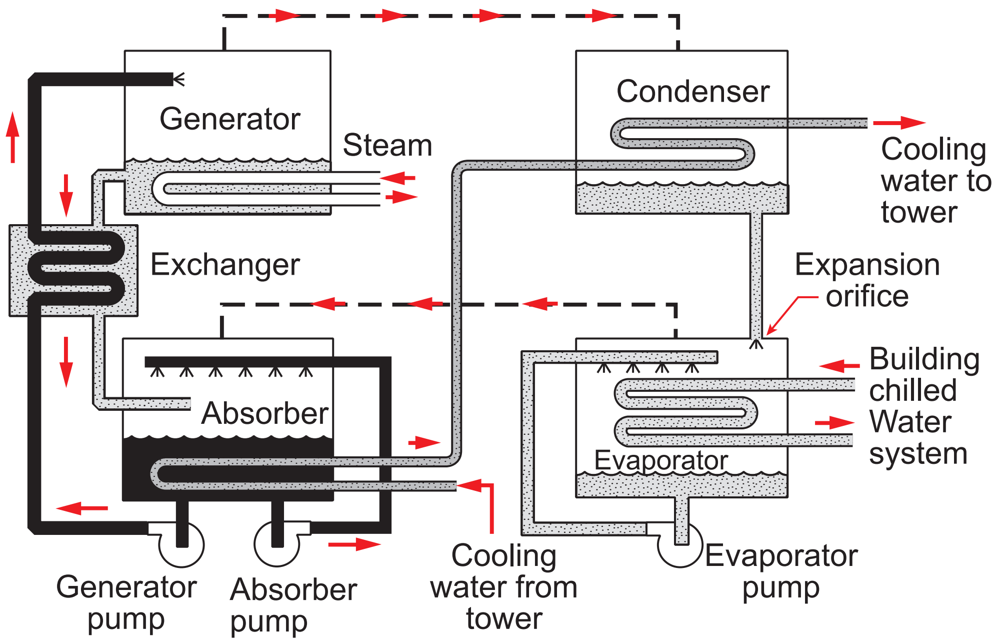
The weak solution going to the generator must be heated. The strong solution coming from the concentrator must be cooled. Therefore, a heat exchanger is necessary in the solution circuit to conserve energy. The exchanger transfers heat from the concentrated solution to the weak solution.

Figure 3 – LiBr System, with Generator



The refrigerant boiled from the weak solution raises the pressure in the generator to about 10 kPa (1.45 psia) absolute. At this pressure, R-718 is at around 46°C (114°F). In the condenser, the cooling water coils condense this refrigerant vapour back to liquid. It then flows from the condenser through an expansion orifice (i.e. a restriction) into the evaporator, repeating the cycle. See Figure 4.

Figure 4 – Complete LiBr Absorption Refrigeration System



The absorption reaction liberates heat. This heat must be removed to enable the absorption process to continue. The cooling water first passes through a tube bundle located in the absorber. Here, the cooling water picks up the heat generated during the absorption process. The water then passes through the condenser, and picks up additional heat as it condenses the refrigerant.

In review, the high-pressure, high-temperature refrigerant enters the low-pressure, low temperature evaporator after it passes through the expansion orifice. As the refrigerant enters the evaporator, it vaporizes at low temperature and cools the chilled water. An evaporator pump then sprays the refrigerant over the chilled water coils to speed up the heat transfer process.

The low-pressure, low-temperature refrigerant vapour is absorbed in the absorber section by the lithium bromide solution flowing from the generator through a heat exchanger. The absorber pump continually withdraws some of this solution from the bottom of the absorber section and recirculates it back to the absorber through spray nozzles. This increases the absorption of the refrigerant vapour, which increases the temperature of the lithium bromide solution. This produces and maintains the low pressure in the evaporator and the absorber. A cooling water coil cools to cool the absorber chamber. The spray eventually absorbs enough refrigerant to become a weak lithium bromide solution.

The low-temperature, low-pressure water vapour is drawn into the absorber. A spray of strong lithium bromide solution then mixes with the vapour. The water vapour gives up its latent heat and changes back to a liquid. The lithium bromide uses this heat as sensible heat, which increases the solution temperature. Cooling water removes the sensible heat from the solution so that the absorption process can continue.

As the water vapour condenses into the lithium bromide solution, this produces and maintains the low pressure in the evaporator and the absorber. A pump sprays the solution over the vapour, to make the absorption process quicker. The spray eventually absorbs enough water to become a weak lithium bromide solution.

A generator pump moves the weak solution from the low-pressure absorber through the heat exchanger, and into the high-pressure generator.

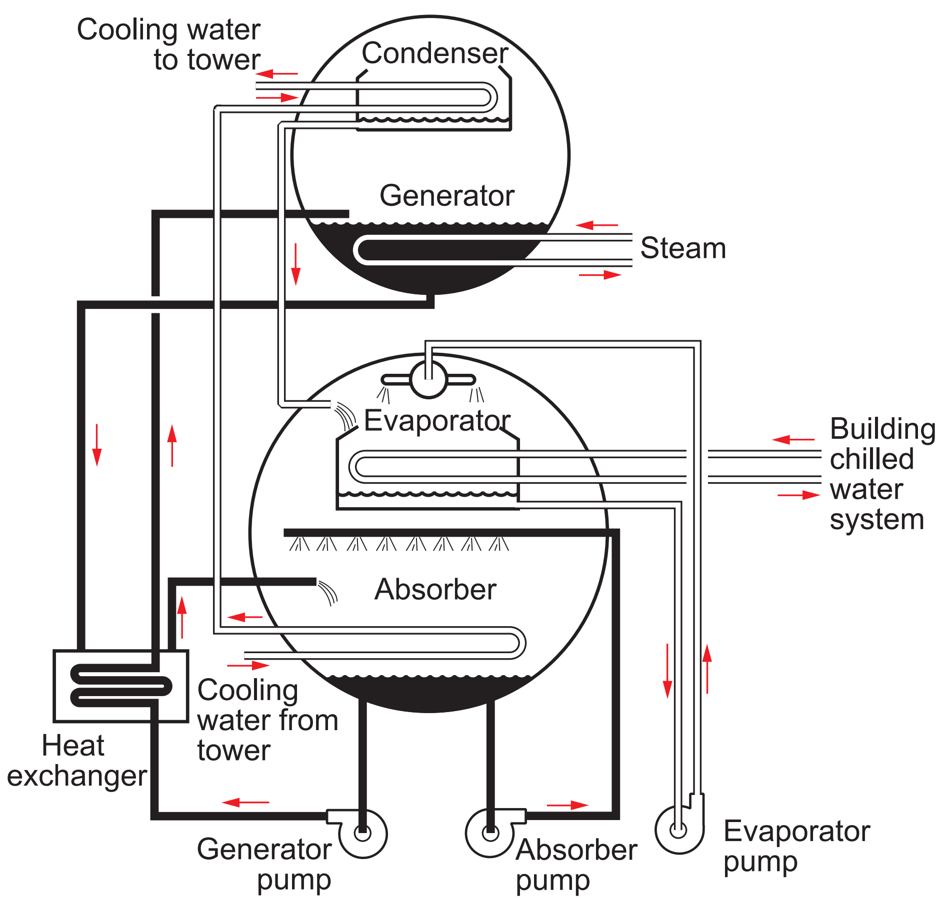
The weak lithium bromide solution heats up in the heat exchanger, so less heat needs to be added in the generator. At the same time, the exchanger cools the concentrated solution going to the absorber, so less cooling water is required in the absorber.

In the generator, heat is added to boil the weak solution, which drives off the absorbed refrigerant. This results in a high-pressure, high-temperature refrigerant vapour that is hot enough to be condensed in the condenser. The pressure created in the generator must be high enough so that the condensing temperature of the refrigerant vapour is above the temperature of the cooling water. The concentrated lithium bromide then returns to the absorber through the heat exchanger.

The refrigerant vapour leaves the generator and enters the condenser, where it condenses back into liquid. The liquid then returns to the evaporator.

The absorption cycle described above is divided into a high-pressure side of 10 kPa (1.45 psia) and a low-pressure side of 0.84 kPa (0.12 psia). The high side consists of the generator and condenser. The low side consists of the evaporator and absorber.

Figure 5 – Lithium Bromide Absorption System



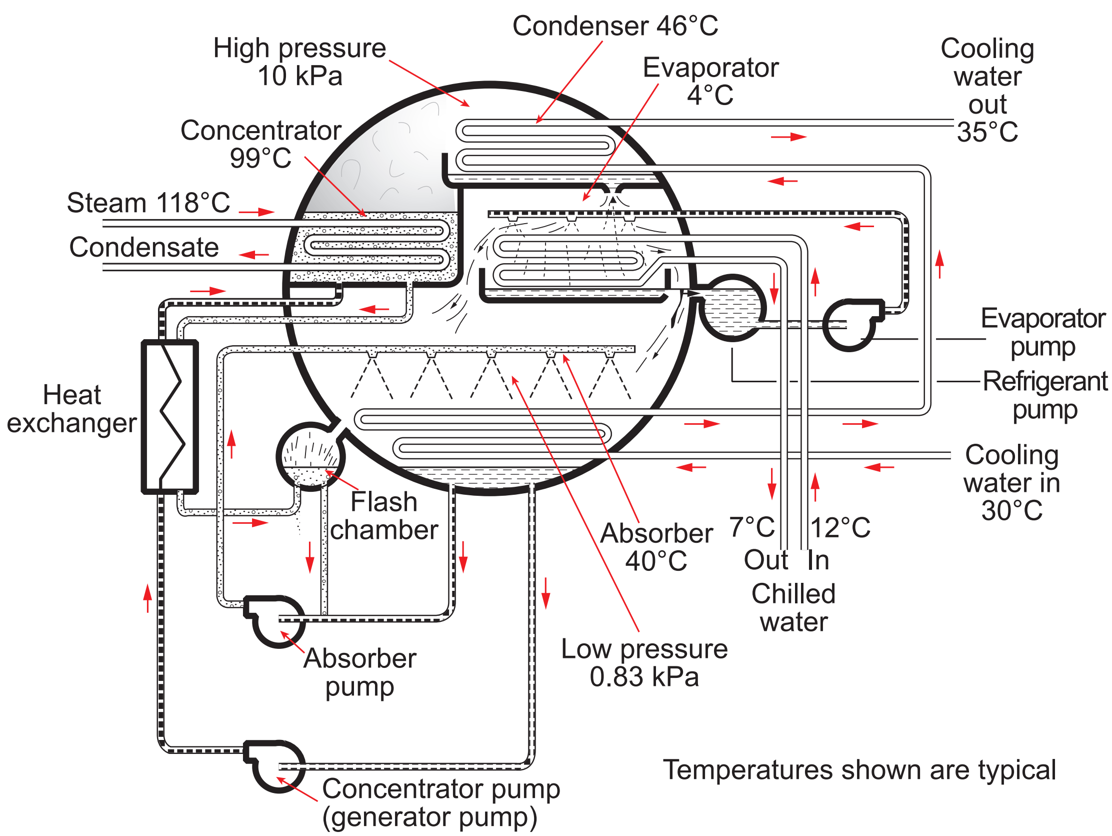
(Courtesy of Carrier Corporation)

In actual absorption machines, the high side units are often combined in one vessel, and the low side units in another vessel. This is shown in Figure 5.

In another absorption system design, the four main components (evaporator; absorber; generator or concentrator; and condenser) are enclosed in a single shell. Figure 6 shows this arrangement.

Lithium bromide absorption systems must operate under an extremely high vacuum. Maintenance of this vacuum is vital for proper operation. Air infiltration must be prevented. For this reason, these absorption units are all built on the "hermetic" principle. This means that the parts of the units, which are under vacuum, are completely seal welded. The pumps are also of hermetic design, so no external seals are used. All lithium bromide absorption units are equipped with purge systems, to remove non-condensable gases that may infiltrate the system, despite the hermetic construction.

Figure 6 – Hermetic Absorption Chiller



Objective 4

Explain the operation of absorption refrigeration systems with respect to crystallization and dilution.

Concentration and Crystallization of a Solution

When a salt is dissolved in water, the two substances form a solution. At a given temperature, only a specific amount of salt can dissolve in water. When the solution contains as much salt as it possibly can, it is said to be saturated. The solution has then reached its maximum salt concentration. Adding more salt will not increase the concentration. The additional salt will not dissolve; rather, it will remain as crystals.

On Track

The solubility of a solid in a liquid, and the maximum concentration of a solution, depends on its temperature. This is a key concept for understanding crystallization in a lithium bromide chiller.

Most salt solutions, including that of lithium bromide, follow the rule that the higher the solution temperature, the more salt can be dissolved. From this principle it follows that when a saturated solution is heated, it becomes "unsaturated," because it will be able to contain a higher salt concentration at the higher temperature. Conversely, when a saturated solution cools, it is not be able to hold all the salt in solution. Some salt will precipitate out of solution. This process is called crystallization.

Crystallization occurs when the temperature of a solution is lowered so far that its salt concentration exceeds the maximum concentration the solution can possibly hold at the lower temperature. Crystallization of a solution is a problem in lithium bromide systems. When it occurs, the precipitated salt can restrict or even block circulation.

Temperature, Pressure, and Concentration Changes during Lithium Bromide Absorption Cycle

With basic knowledge of the behaviour of a salt solution, it becomes much easier to understand the operating principle of a lithium bromide absorption refrigeration unit. Refer to Figure 6.

The unit is divided into two pressure sections:

1. The low-pressure section has an evaporator and an absorber.
2. The high-pressure section has a concentrator (generator) and a condenser.

Since there is no air in the unit, the pressures in the high and low-pressure sections are the same as the vapour pressure in their respective sections. The vapour pressure, in turn, depends on the temperature and concentration of the solution in each section.

As described previously, the low temperature and high concentration of the lithium bromide solution in the absorber reduces the vapour pressure in the low-pressure section to about 0.83 kPa absolute. The solution temperature in the concentrator is approximately 99°C (210°F). Here, the lithium bromide solution is diluted with refrigerant. Therefore, the vapour pressure in the high-pressure section is around 10 kPa absolute.

Observe how the concentration of the solution changes in the unit. Start at the point in the cycle where the low temperature dilute solution is drawn from the absorber by the concentrator pump. This solution is pumped through the heat exchanger to the concentrator. In the heat exchanger, the dilute solution picks up heat from the strong solution leaving the concentrator. This raises the temperature of the dilute solution, which increases the vapour pressure. The concentration, however, remains constant.

In the concentrator, additional heat is supplied and the temperature of the solution increases to its boiling point. The vapour pressure rises to about 10 kPa. The vapour condenses on the surfaces of the cooling coils in the condenser, and causes vapour to flow from the concentrator to the condenser. This disrupts the equilibrium of the solution in the concentrator. As more heat is added to this solution, more water evaporates, and the solution becomes more concentrated. If the amount of heat added is controlled, it follows that the final concentration of the solution leaving the concentrator can be controlled.

The concentrated solution leaving the concentrator flows back through the heat exchanger to the absorber, and transfers heat to the dilute solution entering the concentrator. At the same time, the vapour pressure of the concentrated solution drops considerably. The low temperature concentrated solution flows to the flash chamber connected to the absorber. Here the pressure of the solution is equalized with that in the absorber. Any excess sensible heat is removed by evaporation (flashing) of some of the water in the solution.

The concentrated solution mixes with some of the dilute solution drawn from the absorber by the absorber pump. This mixed or intermediate solution is sprayed over the absorber tube bundle, where it cools and absorbs refrigerant vapour drawn from the evaporator.

More molecules of water vapour are absorbed than leave the solution. This means that the solution in the absorber is not in equilibrium. As a result, the solution becomes increasingly dilute.

Concentration and Dilution

It may seem strange that the solution, after having been concentrated, should again mix with dilute solution, since the concentrated solution is better able to absorb water vapour than the intermediate solution. There are two reasons for mixing dilute and concentrated solutions together to form an intermediate solution.

First, the concentrated solution, after having been cooled in the heat exchanger, will be very close to its saturation point. If sprayed directly on the absorber cooling coils, its temperature would drop below that required to keep the salt in solution, and salt crystals would precipitate. Dilution keeps this from occurring.

Secondly, a higher solution flow rate is required in the absorber than in the concentrator. Some recirculation of the dilute solution is required to obtain this higher rate.

Action of the Refrigerant

The refrigerant collected in the lower part of the condenser is at a pressure of 10 kPa. Its corresponding condensing temperature is 46°C (115°F). The refrigerant passes through several small openings as it enters the evaporator section. Since the pressure in this section is only 0.83 kPa corresponding to a boiling point of 4°C (39°F), the enthalpy of the refrigerant entering the evaporator is considerably higher than that of saturated liquid at low pressure in the evaporator. This causes part of the refrigerant to flash.

The remaining refrigerant, cooled to about 4°C, together with the liquid refrigerant recirculated by the evaporator pump, is distributed over the chilled water-cooling coil in the evaporator. It picks up sensible heat from the chilled water, which lowers its temperature. From the perspective of the refrigerant, this sensible heat is latent heat, and it causes the refrigerant to continually evaporate. The refrigerant vapour formed in the evaporator is drawn into the absorber section where it is absorbed by the lithium bromide solution.

Crystallization in an Absorption Unit

After giving up part of its heat in the heat exchanger, the concentrated lithium bromide solution approaches its saturation point. Crystallization could occur if the temperature of the solution continues to drop before it mixes with the dilute solution.

For this reason, before shutting down a lithium bromide absorption system, it has to go through a dilution cycle. During this cycle, the dilute and concentrated solutions are mixed. This prevents crystallization when the temperature drops during the shutdown period.

Crystallization is of particular concern when a power failure occurs and the unit cannot operate through its normal dilution cycle. If the unscheduled shutdown were to last for any length of time, the temperature of the concentrated solution could drop so much that crystallization would occur. This would block passages, especially in the heat exchanger.

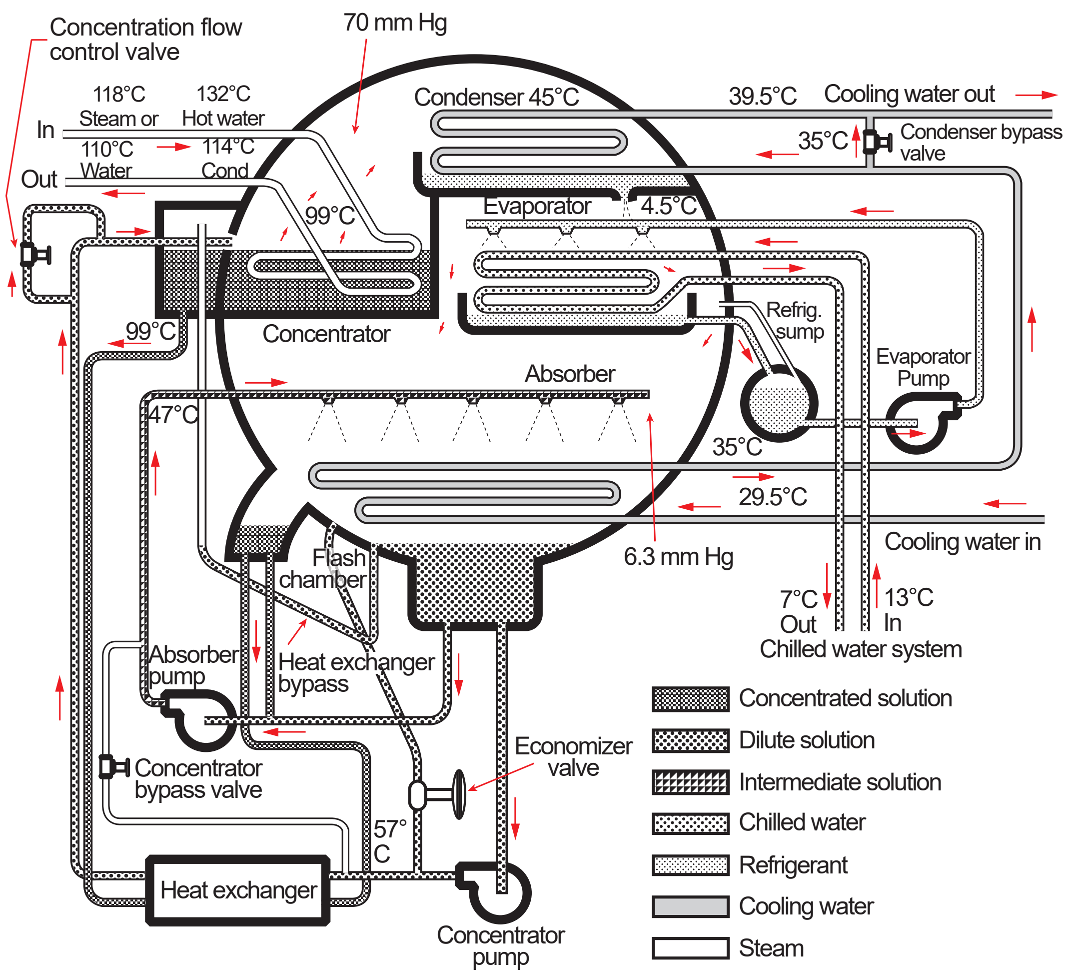
Objective 5

Describe the major parts and systems of an absorption system including the heat exchanger bypass system; pump motor lubrication and cooling system; and purging system.

Heat Exchanger Bypass

Figure 7 shows a pipe that leads directly from the concentrator to the absorber, called the heat exchanger bypass.

Figure 7 – Lithium Bromide Absorption Unit



(Courtesy of Trane, a Division of American Standard)

The purpose of this bypass is twofold:

1. It limits the level of the solution in the concentrator by bypassing excess solution directly back to the absorber. During startup, the level in the concentrator has a tendency to rise since the proper pressure difference between concentrator and absorber is not yet established. The bypass holds the solution at the design level.
2. The bypass conducts the full flow of hot concentrated solution directly back to the absorber, in case the regular return through the heat exchanger is blocked by crystallization. This direct return increases the temperature of the diluted solution pumped through the heat exchanger to the concentrator. The extra heat may dissolve the crystals blocking the return passages. This also guarantees a supply of fluid for the concentrator and absorber pumps so that circulation can be maintained if the return line is restricted.

The lower loop of the bypass tube is filled with solution at all times. This forms a loop seal between the high and low-pressure sides of the system.

Pump Motor Lubrication and Cooling

To prevent the infiltration of air into this high vacuum unit, the concentrator, absorber, and evaporator circulating pumps used on an absorption unit are of the hermetic type. The specially constructed motors have passages for liquid cooling. These motors are also equipped with plastic or carbon bearings; the liquid circulated by the pump usually lubricates the bearings.

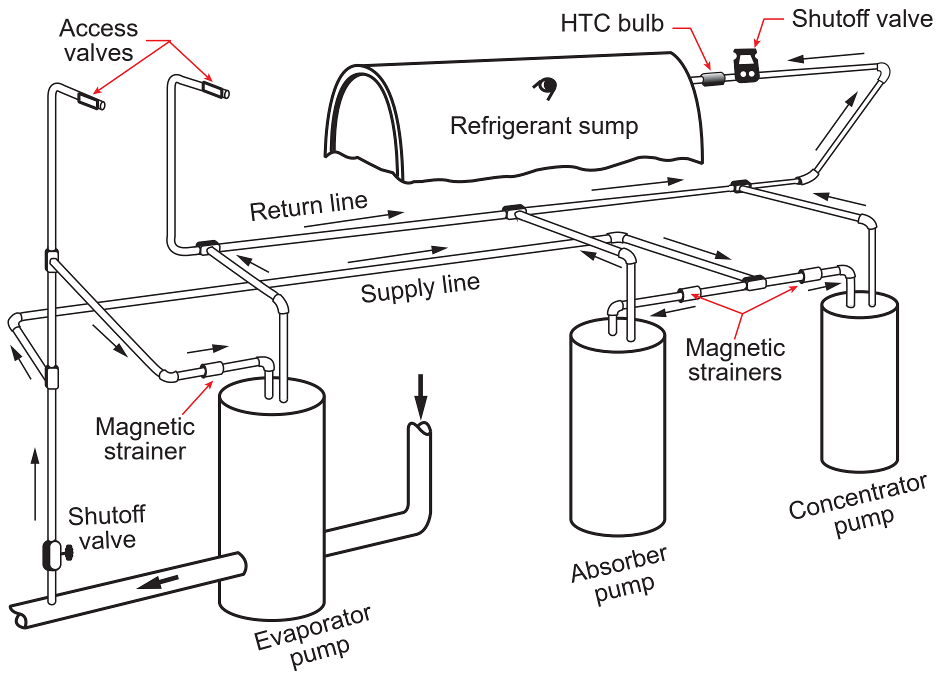
Since the seal material is impervious to moisture, the hermetically sealed motors protect the stator windings from direct contact with the fluid. Some motors may have a very thin stainless steel liner between the rotor compartment and the stator laminations and windings. The fluid that cools the motor also lubricates the motor bearings. It is very important that no solid particles, such as scale or metallic slag, be allowed to enter the motor assembly. To protect the motor from the possibility of bearing scoring or cutting of the liner by stray particles, a strainer with a screen and a magnetic core is installed on the coolant inlet of each fluid cooled motor. These strainers must be cleaned whenever the system is opened for maintenance.

On older absorption systems, the evaporator, absorber, and concentrator pumps were usually installed as separate units. On some newer models, the concentrator and absorber pumps are often combined in one housing, and are driven by a single motor.

Some manufacturers combine all three pumps into a tandem housing, driven by one motor. Cooling and lubrication of the motor follow the same principles, regardless of the layout.

Figure 8 shows a three-motor cooling and lubrication arrangement. Note that the coolant supply originates at the discharge of the evaporator pump. It then distributes to the three motors through a common supply line. The return from each motor leads to a common return line, which discharges the warm coolant into the refrigerant sump. Also, note the HTC bulb. This high temperature cut-off device trips the motor circuit if the coolant return from any one of the motors has a high temperature.

Figure 8 – Pump Lubrication and Cooling Circuits



(Courtesy of Trane)

System Purging

There are always some non-condensable gases in an absorption unit. The most common cause is an air leak somewhere in the unit. Accumulation of these gases has detrimental effects on the operation of the unit:

Reduced capacity and higher chilled water outlet temperature: The non-condensable gases increase the vapour pressure in the absorber. This raises the evaporation temperature of the refrigerant in the evaporator. The result is a higher than normal temperature of the chilled water leaving the evaporator coils, and a decrease in system cooling capacity.

Crystallization: Normally, a reduction in load results in a decreased evaporator and absorber temperature. The heat supply to the concentrator then cuts back. The unit continues operation, but with a more dilute solution. If the reduction in capacity is the result of non-condensable gases, the heat supply to the concentrator does not cut back, since the chilled water outlet temperature is higher than normal. The concentration of the solution leaving the concentrator may become high enough for crystallization to occur in the heat exchanger when the solution is cooled by the dilute solution coming from the absorber, which is at a lower than normal temperature due to the reduced load.

Corrosion: Oxygen in the non-condensable gases combines with the lithium bromide solution to produce a corrosive solution. This mixture then attacks the metal components of the system.

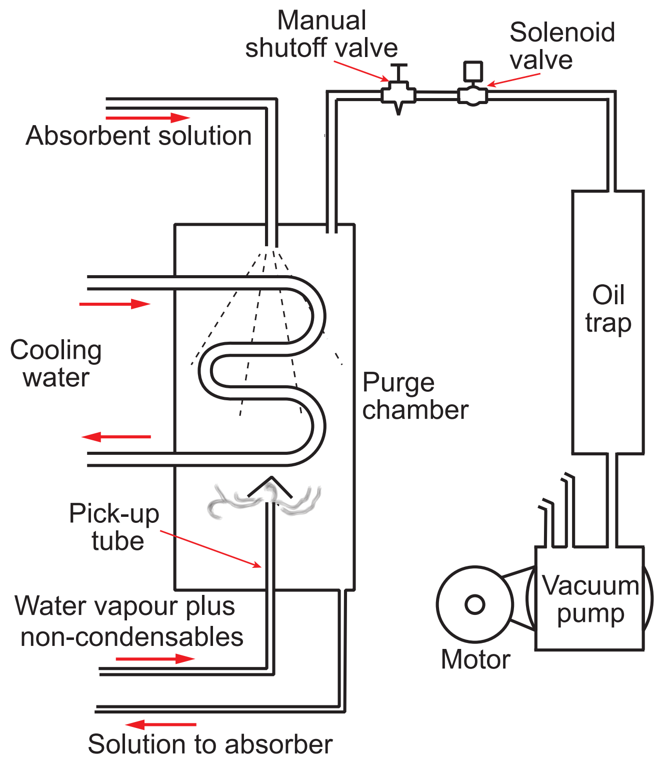
It is vital to purge non-condensable gases from the absorption unit. There are two types of purge systems:

1. Systems with a mechanical vacuum purge pump
2. Automatic continuous purge systems that are non-mechanical.

Mechanical Purge System

Figure 9 illustrates the basic principle of a mechanical purge system. It consists of a purge pickup tube, purge chamber, manual shutoff valve, safety solenoid valve, oil trap, and vacuum pump.

Figure 9 – Basic Mechanical Purge System



(Courtesy of Trane)

The purge chamber is basically a small absorber. It is mounted externally on smaller units, and internally on larger ones. It is fitted with a cooling coil that maintains the temperature (and therefore the pressure) at a lower level than that in the absorber. A small amount of lithium bromide solution, taken off the line leading to the absorber spray headers, is sprayed over the cooling coil.

The non-condensable gases, and some refrigerant vapour, collect in the absorber, since it has the lowest pressure in the entire unit. A pickup tube draws these gases from the absorber into the purge chamber, where they make contact with the lithium bromide solution. The solution on the surface of the coil absorbs the refrigerant vapour. The dilute solution falls to the bottom of the purge chamber and drains back to the absorber. The non-condensable gases collect near the top of the purge chamber, and the vacuum pump draws them off. This compresses the gases to a pressure high enough to discharge to the atmosphere.

The vacuum pump is a two-stage oil sealed rotary vane pump. It is a low volume pump, able to operate with very low suction pressure. The pump suction line contains an oil trap and a solenoid valve. The oil trap stops the oil from being drawn into the absorption unit. The solenoid valve is a fail-safe device. If the power fails or the vacuum pump drive belt breaks, the valve automatically closes to prevent air from leaking back into the system.

Automatic Purge System

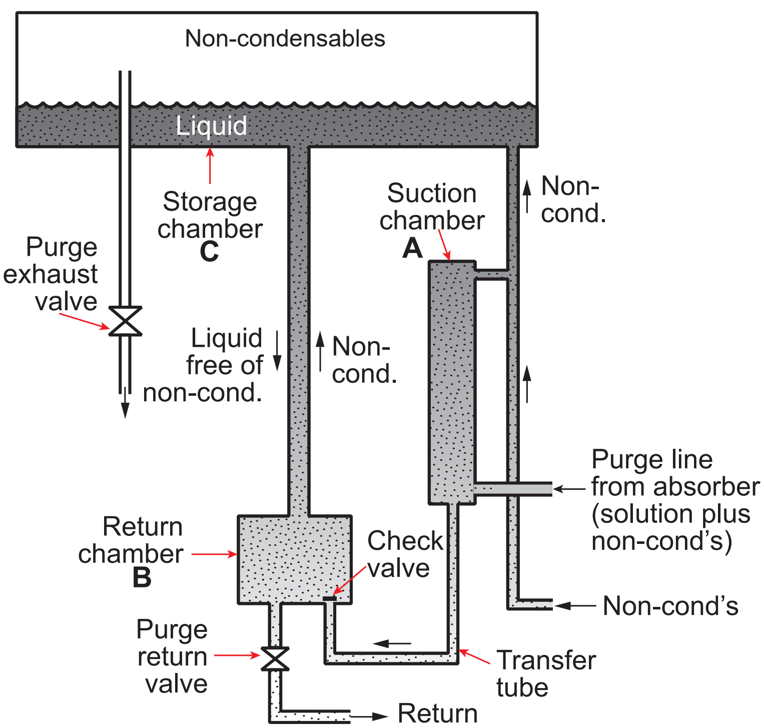
Figure 10 shows a purge unit that automatically keeps the absorption unit free of non-condensable gases, without using a vacuum pump. It consists of a hermetically sealed welded assembly of three cylindrical vessels.

The suction chamber (A) functions as a low-pressure vessel, and draws non-condensable gases from the absorber. In the return chamber (B), the non-condensable gases separate from the lithium bromide solution. The storage chamber (C) collects the non-condensable gases before they discharge to atmosphere.

The operation of the unit is as follows.

1. A measured amount of weak lithium bromide solution enters the suction chamber (A). Since the chamber is under low pressure, it draws in non-condensable gases. Some of the bromide solution also flows into the storage chamber (C).
2. The solution and non-condensable gases flow from the suction chamber (A) to the return chamber (B) via a check valve. The non-condensable gases then separate out of the lithium bromide solution and bubble up into the storage chamber (C). The solution returns to the absorber through the purge return valve.
3. The non-condensable gases trapped in the storage chamber (C) cannot return to the system. As the storage chamber fills with non-condensable gases, it displaces the solution into the return chamber, and then to the absorber. When the solution in storage chamber (C) is at a predetermined low level, it triggers a switch that turns on an indicator light on the control panel. This signals the need to exhaust the purge unit.

Figure 10 – Automatic Purge Unit



(Courtesy of Carrier Corporation)

To start the purge, the purge return valve is closed. The solution supply now compresses the non-condensable gases above atmospheric pressure and refills part of the storage chamber. The purge exhaust valve now cracks open. The non-condensable gases trapped in the upper part of the storage chamber bleed to atmosphere, usually via a hose with the end submerged in a water-filled bottle. This helps the operator to observe the escaping gases. After purging all the gases, the purge exhaust valve closes, and the purge return valve opens to start a new cycle.

Objective 6

Describe the startup and shutdown procedures for an absorption refrigeration system.

Startup Sequence for an Absorption Chiller

This is a typical startup sequence for an absorption unit. Automated controls ensure that each step in the sequence is complete before the next step is begins.

1. The operator manually initiates the sequence by pressing a push button, or it can initiate automatically from a control point on an HMI.
2. The chilled water pump motor starts.
3. A flow switch detects the chilled water flow.
4. The chilled water temperature rises to the point where cooling is required, as detected by a temperature switch.
5. The condenser cooling water pump motor starts.
6. The cooling water temperature controller starts and assumes control of the cooling tower fan motor.
7. An automatic start switch places the absorption unit into operation.
8. After a pre-set time delay, the absorber, and generator pump motors will start.
9. The chilled water temperature controller assumes control of the steam or hot water flow to the generator.
10. If the chilled water temperature drops below its control range, a dilution cycle and system shutdown is initiated.

Operation

Depending on the make and model, the startup and shutdown procedures for various absorption units will differ. It is not possible to discuss each procedure separately; therefore, this text only provides general guidelines. Since many of these units operate on a seasonal basis, the following guidelines are for seasonal startup and shutdown.

Seasonal Pre-Start Service

1. Lock out all sources of energy.
2. Clean all cooling and chilled water strainers, and the cooling tower sump.
3. Check the lubricant in the circulating pumps and cooling tower fans. Also, check to ensure they rotate freely.
4. Open the necessary valves in the cooling and chilled water systems. If the systems were drained during shutdown, fill them with clean water. Vent all the air from the systems. It may take one or two days of circulation to remove all the air.
5. Add the required water treatment chemicals.

6. Check and clean the magnetic strainers in the absorption unit pump motor cooling circuit.
7. If the absorption unit is equipped with a mechanical purge system, check the purge pump. Follow the manufacturer's recommended procedure.
8. If the refrigerant sump is empty, connect a temporary clean water supply for pump motor lubrication and cooling.
9. Start all pumps briefly (for a few seconds) to ensure they will start.
10. Ensure that there is a sufficient charge of lithium bromide in the system.

Seasonal Startup

1. Open the air supply valve to the pneumatic control system. Check the air supply pressure. It should not exceed 140 kPa (20 psig).
2. Make sure starting switches are in the OFF position. Then close the main breakers.
3. Place the condenser water pump and cooling tower fan switches in the AUTOMATIC position.
4. Open the manual shut-off valve in the steam or hot water supply line to the unit. If using a temporary water supply for the unit pump motor circuit, open the supply valve. Limit water pressure to 35 kPa (5 psig).
5. Start the auxiliaries and the absorption unit. Follow the manufacturer recommended procedures.
6. When the refrigerant sump is full, stop the unit. Disconnect the temporary water supply to the pump lubrication and cooling circuit. Open the valves in the regular supply circuit and restart the unit.
7. After the absorption unit has been operating for approximately 30 minutes, start the purge unit. Check all temperatures, pressures, and flows. Enter the required data on the log sheet.
8. Add **octyl alcohol** to the unit as recommended.

Seasonal Shutdown

1. Turn the unit switch on the control panel to OFF. Allow the machine to complete the dilution cycle.
2. Stop the chilled water pump. This stops the cooling water pump and cooling tower fan.
3. Close the manual steam or hot water supply valve.
4. Open all breakers.
5. Turn off the air supply to the pneumatic control system.
6. Drain the cooling water circuit.
7. Service all the auxiliary pumps, the cooling tower and the fan, etc. Follow the manufacturer's instructions.
8. Service the purge pump (if so equipped).

Startup after Short Shutdown (Weekend or Less)

1. Open the manual shut-off valve in the steam or hot water supply line.
2. Start up the unit according to the manufacturer's recommended procedures.
3. Start the purge unit after operating for 30 minutes.

Shutdown for Short Period (Weekend or Less)

1. Turn the unit switch on the control panel to OFF. Allow the machine to complete the dilution cycle.
2. Stop the chilled water pump. This stops the cooling water pump and cooling tower fan.
3. Close the manual steam or hot water supply valve.

Objective 7

Describe the preventive maintenance to perform on an absorption refrigeration system.

Maintenance

Performing preventative maintenance, often referred to as a "P.M", on refrigeration equipment and its auxiliaries is an important part of refrigeration system upkeep. Scheduled maintenance work will increase the lifespan and efficiency of the equipment and system. In absorption refrigeration systems preventative maintenance tasks include:

- Purge systems
- Clear strainers
- Reclaim solution
- Check circulation equipment
- Water treatment
- Add octyl alcohol
- Set control systems
- Complete log sheets

Mechanical Purge System

Perform the following checks on a monthly basis:

1. Check pulley alignment and V-belt tension. The belt should move inward midway between the pulleys about 15 mm (5/8 inch) under light thumb pressure.
2. Clean the belts of dust, dirt, and lint.
3. Change the oil in the vacuum pump. Run the pump until the oil is hot, after which the oil will drain freely. Follow the manufacturer instructions closely to avoid damaging a shaft seal.

Lubricate the pump motor on a yearly basis. Use the manufacturer instructions.

Strainers

Clean all strainers and traps in the steam or hot water supply, condensate return, and cooling water circuits two weeks after seasonal startup, again at midseason, and at seasonal shutdown.

Clean the magnetic strainer in the cooling and lubrication line to the absorption unit pump motors monthly.

Reclaiming the Solution

During normal operation, some lithium bromide solution may carry over into the refrigerant. Take a refrigerant sample weekly. Measure its relative density. If contamination exists, reclaim the solution by draining part of the refrigerant into the solution circuit through either an automatically or manually operated valve. This refrigerant evaporates out of the solution again in the concentrator. It returns to the evaporator via the condenser. The result is that the refrigerant in the evaporator is free of lithium bromide.

Circulating Pumps, Cooling Tower Fan

Once a week, check for:

a) Proper oil level in oil-lubricated bearings
b) Leakage from stuffing boxes and seals
c) Bearing temperatures
d) Unusual sounds
e) Vibration

Grease the bearings as recommended by the manufacturer.

Water Treatment

For the cooling water:

a) Perform daily checks of the pH and TDS (total dissolved solids) of the water.
b) Add chemicals and adjust the bleed off, as required.
c) Check for algae growth in the cooling tower.
d) Add biocide to control bacterial growth.

For the chilled water, check the strength of the anti-corrosion agent monthly.

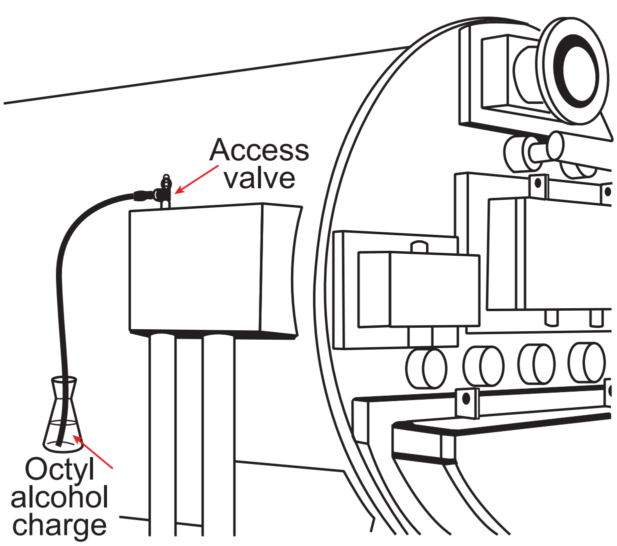
Octyl Alcohol Charge

Octyl alcohol is a wetting agent that helps the lithium bromide solution absorb water vapour, which increases the efficiency of the system. Add it to the system at intervals as recommended by the manufacturer.

To add octyl alcohol to a system:

1. Connect a charging tube to the access valve located on top of the concentrator sump, as shown in Figure 11.
2. Raise the open end of the tube and fill it with distilled water. This removes all the air.
3. Place the open end of the tube in a flask that contains the recommended amount of alcohol. Do not spill the alcohol on clothing as it has a long lasting smell.
4. With the unit in operation, slowly open the access valve, and allow the system to draw in the alcohol. Quickly close the valve the instant that the last of the alcohol leaves the flask.

Figure 11 – Charging Alcohol into the System



Control System

When the manufacturer places the unit into service, the control system of the absorption refrigeration unit is set and adjusted by the service representative. This is one of the benefits of purchasing a packaged unit.

If a malfunction occurs, unless the operator is fully familiar with the controls and how to service them, the recommendation is to call a service company. Tinkering with controls often aggravates the problem.

Log Sheets

Recording periodic readings of pressure and temperature conditions is the best way to spot gradual changes in the performance of the absorption unit. These readings may be on log sheets or computer printouts. This helps the operator to:

a) Recognize operating conditions and their trends

b) Diagnose unit troubles

c) Plan maintenance requirements

If ever presented in a court of law, these log entries hold legal status.

Objective 8

Explain typical problems and resolutions related to an absorption refrigeration system.

Troubleshooting Absorption Refrigeration Systems

The following guide may help determine the cause of several common problems encountered when operating an absorption refrigeration system.

ABSORPTION REFRIGERATION SYSTEM TROUBLESHOOTING GUIDE

TROUBLE	POSSIBLE CAUSE	CORRECTIVE ACTION
Decreased Capacity	Non-condensable gases in machine	Search for and stop leaks. Purge.
	Purging ineffective	Check purge equipment and valves.
	Lithium bromide requires octyl alcohol	Add octyl alcohol charge.
	Fouled condenser	Clean condenser tubes. Check water treatment.
	Cooling water too warm	Check cooling tower, pumps, strainers, and valves.
	Faulty capacity control setting	Check for loose connections; re-adjust setting.
	Low solution temperature in generator	Check control valves, strainers, steam traps, steam pressure, or hot water temperature.
Crystallization Following Startup	Non-condensable gases in machine	Purge the machine.
	Faulty purging	Check the purge system.
	Condenser cooling water too cold	Adjust cooling tower control.
Crystallization During Normal Operation	Non-condensable gases in machine	Purge the machine.
	Faulty purging	Check the purge system.
	Condenser cooling water too cold	Adjust cooling tower control.
	Lithium bromide solution requires octyl alcohol	Add octyl alcohol charge.
	Steam temperature too high	Reduce steam pressure.
	Low refrigerant temperature	Reduce flow rate of condensing water.
Crystallization at Shutdown	Chilled water pump inoperative during dilution cycle	Check pump operation.
	Dilution cycle is too short	Adjust control to recommended setting.
	Improper operation of capacity control	Check chilled water thermostat and steam or hot water control valve. Check low limit control.
Safety or Interlock Shutdown	Motor temperature control trips out	Reset. Determine reason for trip.
	Chilled water flow switch opens	Reset. Determine reason for opening.
	Low temperature control switch opens	Reset. Determine reason for opening.
	Chilled water pump trips out	Reset. Determine reason for trip.

Chapter Summary

This chapter introduced absorption refrigeration systems. It discussed reasons for choosing this type of system over a compression system. This included several economic and environmental advantages of the absorption system.

Absorption systems do not require compressors. Instead, they have absorbers, pumps, heat sources, and concentrators that perform the functions of the compressor. Like compression refrigeration systems, absorption systems require condensers, evaporators, and metering devices. Ammonia systems also have liquid receivers.

Ammonia absorption is used in large industrial facilities, such as cold storage and packing houses. Lithium bromide systems are only used in HVAC service, because they cannot achieve low temperatures. Both use natural refrigerants, with zero ODS and GWP.

In a lithium bromide system, water (R-718) is the refrigerant. To boil water at low temperature, these systems must operate under a deep vacuum. Therefore, the associated pumps and vessels must be hermetically sealed units, and purgers are necessary to keep air out of the system.

Because lithium bromide systems use a hygroscopic salt solution to absorb the refrigerant vapour, solubility issues may arise. These include the precipitation of lithium bromide salt crystals that interfere with chiller operation. Special shutdown procedures must be used to prevent crystallization. System temperatures must be carefully controlled, and non-condensable gases continually purged, to prevent crystal formation.

As with all refrigeration equipment, it is important to follow manufacturer operating and maintenance procedures. The best source of operating and troubleshooting information comes directly from the manufacturer. Although, troubleshooting guides from other sources may be helpful as well.

Chapter 6

Refrigeration Plant Safety

Learning Outcome

When you complete this chapter you should be able to:

Outline the potential hazards inherent to refrigeration plants, the CSA requirements intended to mitigate hazards, and typical responses taken in the case of a significant leak.

Learning Objectives

Here is what you should be able to do when you complete each objective:

1. *Identify and provide a basic explanation of the CSA B52 Code requirements for refrigeration plant machinery rooms.*
2. *Identify safe practices for refrigeration plant operation and maintenance.*
3. *Describe the appropriate emergency response to a significant refrigerant leak.*
4. *Describe the Canadian Environmental Emergency Regulations and how they relate to refrigeration plants.*

Chapter Introduction

Jurisdictions enact legislation and develop regulations for the care and operation of large refrigeration plants, and place them under the authority of Power Engineers. This is because refrigeration plants pose various hazards to both workers and the public. These hazards include:

- Pressure vessel or pressure piping explosion
- Combustion explosion
- Asphyxiation
- Cardiac arrest
- Chemical burns
- Freeze burns (frostbite)
- Chemical reactions

This chapter covers the safety features found in refrigeration plants, as well as safe operation and maintenance practices. When refrigerant leaks occur, plant operators must be prepared to carry out a safe, effective, and environmentally responsible emergency response plan. For this reason, this chapter also addresses appropriate emergency response.

Objective 1

Identify and provide a basic explanation of the CSA B52 Code requirements for refrigeration plant machinery rooms.

Refrigeration Plant Safety Code Requirements

All refrigeration systems are hazardous, but to varying degrees. The degree of hazard will depend upon:

1. The toxicity or flammability of the refrigerant fluid
2. The amount of refrigerant in the system
3. The building occupancy class
4. The leakage probability of the system
5. The internal pressure of the refrigeration system

As plant operators or managers, it is important for Power Engineers to know how to handle any emergencies that arise. Especially hazards related to a particular plant, its safety systems, and the function of the various safety systems that mitigate hazards.

1. Toxicity or Flammability of the Refrigerant Fluid

Some refrigerants are toxic, to various degrees. These include R-717 (ammonia) and R-123.

R-717 is used in industrial refrigeration systems and in ice arenas. It is toxic in concentrations over 0.03% by volume in air.

R-123 is used in large HVAC chillers. It is toxic in concentrations over 0.1% by volume in air.

Some refrigerants are flammable and explosive. These include R-290 (propane) and R-717. **CSA B52** considers R-290 to be more flammable and explosive than R-717.

R-290 has an explosive range between 2.1% and 9.5% in air.

R-717 has an explosive range between 15% and 28% in air. R-717 leaks can be detected at extremely small concentrations in air, and are therefore likely to be stopped before concentrations reach the explosive range in air.

Refrigerants that are neither toxic nor flammable are also dangerous. Many refrigerants are heavier than air. If a major leak occurs, dense refrigerant gas accumulates in low spots, and displaces air. In high enough concentrations, the refrigerant can asphyxiate individuals entering the low-lying space.

Ammonia is lighter than air. It is therefore best to measure ammonia concentrations at various elevations should a leak occur.

Often, refrigerants are changed to meet environmental regulations. This may result in a change in machinery room requirements. For example, R-123 chillers are often installed to replace R-11 chillers. R-11 is a Group A1 refrigerant that is no longer produced in North America. It has low toxicity, but is an ozone depleting substance. R-123 is safer for the environment, but is a toxic Group B1 refrigerant. R-11 chillers had no specific machinery room requirements; however, R-123 chillers do, depending on the occupancy. Many buildings therefore must be retrofit with machinery rooms when replacement refrigerants are specified.

2. Amount of Refrigerant in the System

A refrigerant is only harmful at certain concentrations in air. For example, an ammonia concentration of 2 to 5 parts per million in air by volume creates a pungent odour. However, at this concentration, the atmosphere will not be explosive or toxic.

R-134a, in a concentration of less than 5% in air, will not cause cardiac arrest.

R-290, in a concentration of less than 0.53% in air, is not explosive.

Therefore, refrigeration system designers consider the amount of refrigerant in the system and the volume of the enclosure that the refrigerant could leak into. Every effort is made to design systems so that, if all the refrigerant leaks because of a catastrophic failure, the resulting concentrations will not be hazardous to those exposed.

3. Building Occupancy Class

Buildings that house refrigeration systems serve a variety of purposes. These buildings are categorized according to their use:

- Residential
- Institutional
- Public Assembly
- Commercial
- Industrial

Residential buildings have ordinary living spaces. Refrigerants leaks could have devastating effects in these buildings, especially if they occur at night when occupants are asleep.

Institutional buildings present similar risks. In hospitals and penal institutions, hundreds of occupants may be housed or confined (i.e. not able to leave freely). Their ability to escape in the case of an emergency may be restricted due to medical reasons or incarceration.

Public Assembly buildings, such as theaters, schools, and ice rinks, concentrate large numbers of people together. This increases their exposure risk and reduces their ability to escape.

Commercial buildings include stores, malls, office buildings, and restaurants. Many people gather in these locations; therefore, they have greater exposure risk if a catastrophic refrigerant leak should occur. Again, this is because of the reduced ability to leave quickly.

Industrial facilities include ice-making facilities, meat packing plants, cold storage facilities, and other processing facilities that use refrigeration systems. Only authorized personnel can access these plants. Because of this restricted access, the hazard to the public is lower in these facilities.

4. Leakage Probability of the System

CSA B52 classifies refrigeration systems as having either a low or a high leak probability. These are defined as follows.

High-Probability System

A high-probability system is one where components that contain refrigerant are located in such a manner that the refrigerant could leak into the occupied space. The leak may be due to a failed connection, seal, or pressurized component. An example of a high leak probability system is the commonly used direct expansion system. It uses cooling coils directly fed with refrigerant. If a component should fail, refrigerant could enter the occupied space through HVAC ducting or other means.

Low-Probability System

Low-probability systems include indirect closed and double indirect systems. The most common examples are chilled water systems used in residential, commercial, public assembly, and institutional buildings. Chilled brine systems used in public assembly buildings are also indirect.

In an indirect system, all joints, connections, and components that contain refrigerant are effectively isolated from the classified area. For example, consider a commercial building cooled with chilled water. The refrigerant used to chill the water may be R-123, which is toxic. The components in this system that contain R-123 must be confined to an isolated location. This will prevent refrigerant from leaking into parts of the building used for commercial purposes.

5. Internal Pressure of the Refrigeration System

Refrigeration systems can be classified as low pressure or high pressure. The same pressure limitations apply to refrigeration plants. High-pressure plants operate with a high side pressure greater than 100 kPa. Low-pressure plants have high side pressures below 100 kPa.

Many jurisdictions do not have mandatory operator requirements for low-pressure refrigeration plants. These plants are less likely to develop devastating leaks or sustain catastrophic pressure component failure.

Refrigeration System Design Rules

Refrigeration system designs have varying degrees of safety, based on the factors above. The rules of design are in the **CSA B52 Code**. Designers must consider:

a) How much of the refrigerant will potentially leak.

b) How toxic or flammable the refrigerant is.

c) How probable it is for refrigerant to leak into the classified space.

d) The type of occupancy the system will service.

e) Which features to add in order to eliminate or mitigate the risks.

Ammonia refrigeration systems may be direct or indirect. Many Power Engineers work with these systems. Similar rules may apply to systems that contain other refrigerants, depending on the combinations of the safety factors already discussed.

Direct Systems

Direct systems that use ammonia are only permitted for industrial occupancies. Safety considerations include the following:

a) The refrigeration machinery (e.g. pumps and compressors) must be in a contained area, separate from the rest of the building, with tight construction and tight-fitting doors.

b) Access to this area must be restricted to authorized personnel.

c) Areas where refrigerant vapour can leak and concentrate must have ammonia detectors installed. These detectors must provide a warning at a concentration of 300 ppm or less.

d) No flame-producing device or hot surface above 425°C can be located in the vicinity where a leak could occur.

e) All parts that contain refrigerant, except piping, low side components, condensers, and parts outside the building, must be installed in a special machinery room. Systems over 75 kW (19 TR) must be installed in Class T machinery rooms, which have more stringent requirements.

Indirect Systems

Curling rinks and hockey arenas commonly use indirect brine systems, cooled with ammonia refrigerant. Unlike the direct system, there is no lessening of the system requirements for plants under 75 kW (19 TR) capacity. For indirect ammonia systems in public assembly, all parts that contain refrigerant, except piping, low side components, condensers, and parts outside the building, must be installed in a Class T machinery room.

Class T Machinery Rooms

Practically every ammonia refrigeration plant operated by Power Engineers must be located in a Class T machinery room. Below are some of the requirements for this room.

Access Restriction

Access to the machinery room shall be restricted to authorized personnel. Figure 1 shows a typical sign, placed on a machinery room door, used to restrict access.

Figure 1 – Door Sign on Class T Machinery Room

Doors

Each machinery room must have a door or doors that open outward and are self-closing (and tight fitting if they open into the building). The doors must not open to a public corridor or any room used for assembly. The room must have at least one door that exits directly to the outside. Other exits that communicate with the building are permitted, but must go through a vestibule equipped with self-closing, tight-fitting fire doors.

Figure 2 shows an exit door in a machinery room. Notice the "panic" bar on the door, operating certificates, and readily accessible fire extinguisher. These items meet the requirements of **CSA B-52**, jurisdictional licensing requirements, and building codes.

Side Track

Refrigeration plants, whether standalone or part of a larger facility, are subject to the requirements of codes such as the **CSA B-52**. However, they must also meet jurisdictional and local regulations which may control the building's configuration and safety features.

Figure 2 – Inside Door of Class T Machinery Room

Openings and Penetrations

There must be no openings that permit escaping refrigerant to pass into other parts of the building. All pipes that pierce the interior walls, ceiling, or floor of a Class T machinery room must be tightly sealed where they pass through, and must not open into the machinery room.

Open Flames and Hot Surfaces

There must be no flame-producing device or hot surface over 427°C permanently installed in the room.

Ventilation

Machinery rooms must be ventilated to the outdoors. Most systems require mechanical ventilation, using one or more power-driven fans. Readily accessible fan switches must be installed inside and outside the machinery room. The fan switches outside the machinery room must be capable of starting the ventilation system, but not stopping it.

Figure 3 shows views of opposite ends of a Class T machinery room. One end has a ventilation fan (left) and the other an exhaust damper (right).

Figure 3 – Ventilation Fan and Exhaust Damper

All locations must be equipped with vapour detectors that automatically start the ventilation system and activate an alarm based on elevated ambient ammonia levels. The alarm's upper set point should be lower than a concentration of 300 ppm. The detectors must be located where a refrigerant leak has a maximum concentration. In the case of ammonia, multiple detectors may be required at different locations and elevations.

Figure 4 shows an ammonia leak detector panel with a digital readout, alarm horn, and simple controls. Sensors in multiple locations feed signals to this control panel. It has contact closure outputs for local or remote alarms, alarm horns, alarm beacons, and the ventilation system.

Figure 4 – Control Panel for Ammonia Leak Detection System

Machinery Shutdown Switch

There must be a switch provided directly outside the machinery room, for the sole purpose of shutting down the equipment in an emergency. Figure 5 shows the machinery shutdown switch (red plate), to the left of the ventilation system start switch, and below the alarm beacon.

Figure 5 – Machinery Shutdown Switch, Ventilation Start Switch, and Alarm Beacon

Power Engineers must know how to inspect, maintain, and repair the elements of Class T machinery rooms to ensure their own safety as well as that of the public. Most of these systems are easy to inspect and repair without specialized training. However, some systems may require the attention of licensed tradespersons, including electricians, refrigeration mechanics, or instrumentation technicians. Table 1 has guidelines for routine inspections of Class T machinery rooms.

Table 1 – Routine Class T Machinery Room Checks

Item	Check	Repair
Doors	• Door closer operates correctly • Door weather-stripping is in good condition • Door panic hardware works	• Replace defective door closer • Replace damaged weather-stripping • Repair or replace panic hardware
Ventilation system	• Test manual switch inside machinery room • Test switch outside machinery room • Test fan startup using leak detection system • Check operation of air dampers • Check ventilation fan drive belts	• Troubleshoot ventilation fan circuit • Check for defective fan motor • Check for defective damper drive motor • Replace broken or frayed drive belts
Refrigeration leak detector	• Test according to manufacturer instructions • Check that alarm beacons flash • Check that alarm horns activate • Check that the ventilation system starts or accelerates to high speed, according to the design • Check other ventilation system components for correct operation	• Calibrate refrigerant leak detector • Replace refrigerant leak detector head as required • Troubleshoot defective beacon or horn • Troubleshoot ventilation system
Wall penetrations	• Check that all pipes or ducts that pass through walls are properly sealed	• Seal wall penetrations with suitable material
Ducts	• Check that duct joints are well sealed	• Seal or re-seal the duct joints with proper duct sealant
Signage	• Check that restricted access signage is in place and suitably located	• Install or replace signs

Other Refrigeration Plant Safety Systems

The **CSA B52 Code** requires numerous other pieces of equipment for the safe operation of a refrigeration plant. These include safety limit controls, safety valves, stop valves, emergency discharge systems, piping systems, and operator instructions.

Safety Limit Controls

Like boilers, refrigeration systems have pressure vessels, pressure piping, and fittings with maximum allowable working pressures. For this reason, all ammonia compression refrigeration systems must have pressure-limiting devices (see Figure 6). These devices operate in a similar manner to the high-pressure cut-offs of boilers. They are piped to sense the high side pressure. When tripped, they shut off the compressors, and require a manual reset.

The **CSA B52** code requires these controls to be set to not more than 90% of the system high side design pressure. In most plants, this is also 90% of the high side safety valve setting.

As with boilers, the pressure-limiting devices must be connected to the piping without any intervening stop valves that could render the device inoperative. This means that the high-pressure limit control must be connected to the compressor discharge pipe, before the compressor discharge isolation valve.

Figure 6 – Pressure Limiting Devices

Safety Valves

Safety valves are installed to protect the pressure vessels, pressure piping, and pressure-imposing elements (compressors).

Compressor Protection

Positive-displacement compressors are capable of developing enough pressure to damage connected piping, vessels, and pipe fittings. These compressors can also develop enough pressure to rupture their own casings. To prevent this from occurring, every positive-displacement compressor with a discharge stop valve must be equipped with a pressure-relief valve.

From an environmental and safety standpoint, refrigerant should only be discharged to the atmosphere as a last resort. Therefore, the safety valves installed on compressors usually discharge to the low side of the system. In this case, pressure is relieved, and refrigerant is contained within the system. Figure 7 shows a safety valve installed on an ammonia compressor.

Figure 7 – Compressor Safety Valve

Vessel and Piping Protection

Refrigeration system piping and vessels are designed to ASME codes. **ASME BPVC VIII Division 1** requires pressure relief protection for pressure vessels. These vessels may include liquid receivers, chillers, condensers, and evaporators.

Commonly, high side safety valves of ammonia refrigeration systems discharge into the low side, to reduce the likelihood of ammonia discharge to the atmosphere. For this to be acceptable, the low side must have enough installed relief capacity for the entire refrigeration system. In this common situation, the high side safety valves will have reduced discharge capacity because of the backpressure exerted by the low side. Therefore, specially rated high side safety valves that are not affected by backpressure must be used. Figure 8 shows safety valves installed on a low side ammonia chiller.

Figure 8 – Dual Safety Valves on a Chiller

Note that two valves are mounted on a single fitting. The fitting is a three-way valve that places only one safety valve in service at a time. This allows one valve to be isolated so that it can be tested, recertified, serviced, or replaced. To use this type of fitting, each safety valve must meet the total relief capacity requirement. When removing a safety valve from a dual valve setup, never plug the vacant opening. Always have a spare safety valve on hand to install in the space created. The spare valve must be recently certified or in new condition, and of proper capacity and set point.

The **CSA B52** code also requires overpressure protection for lengths of piping that contain liquid refrigerant, and that can be isolated. If a section of pipe is isolated and the temperature increases, hydrostatic liquid expansion may over pressurize the pipe and fittings, and cause them to rupture.

Stop Valves

Refrigeration equipment requires regular servicing and occasional repairs. This may involve removing or opening up system components. Best practice dictates that refrigerant should not be released to the atmosphere. Therefore, refrigeration systems must be designed so that individual components or piping can be isolated for servicing. In order to isolate system components, stop valves must be provided in the following locations:

a) On each suction inlet of each compressor, liquid refrigerant pump, or condensing unit.
b) On each discharge outlet of each compressor, liquid refrigerant pump, or condensing unit.
c) On each inlet of each liquid receiver.
d) On each outlet of each liquid receiver.
e) On each inlet and outlet of condensers, when more than one condenser is used in parallel.

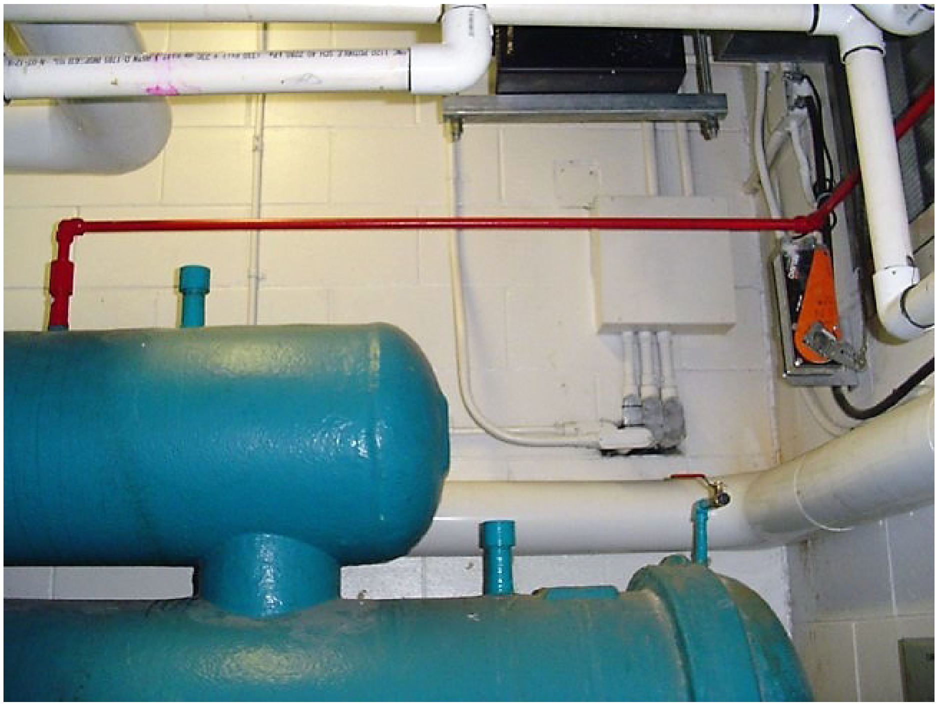
Emergency Discharge Systems

The **CSA B52** has guidelines to rapidly discharge refrigerants into the atmosphere during a fire or other emergency. It is an optional part of the code; however, many Canadian jurisdictions enforce it.

The emergency discharge system consists of a:

a) A piping connection to the top of a liquid receiver or other vessel where liquid refrigerant is stored (see Figure 9).
b) An emergency discharge valve, located outside of the building (see Figure 10).
c) A diffuser, located at a high elevation, to spread the ammonia vapour over a large area (see Figure 11).

Figure 9 – Emergency Discharge Line Connection on a Chiller



The emergency discharge valve must be in a bright red box with a glass front, located at least 2.3 m above the adjacent ground. This is so the valve cannot be operated by anyone other than the plant operator, a firefighter, or some other emergency personnel. The emergency discharge piping system can have no other valve installed in it. Beside the valve, there must be a power switch to shut down the refrigeration plant in the case of an emergency. This is shown in Figure 10.

Figure 10 – Emergency Discharge Valve and Equipment Shutdown Switch

Though not a code requirement, in ammonia systems, it is common practice to paint the emergency discharge and safety valve piping in a bright red. The colour makes it easy to identify this piping when construction or renovations are taking place in the plant. It also makes it easier to identify the pressurized ammonia lines so that no one accidentally cuts into them, or strikes them with mobile equipment. The diffuser pipe shown in Figure 11 is easy to identify by its red colour.

Figure 11 – Diffuser for Safety Relief and Emergency Discharge

Safety Valve Discharge Piping

From the safety valves, ammonia can be discharged to the atmosphere through a diffuser (see Figure 11), or into a special water-filled tank. Water has a great affinity for ammonia. At 25°C, 100 grams of water can dissolve around 30 grams of ammonia. Therefore, it is possible for a large storage tank of water to absorb an entire ammonia refrigerant charge. **CSA B52** code has instructions for determining the size of water tank needed to absorb the ammonia charge. One requirements is that the tank must be large enough to contain the water and ammonia without overflowing. Another stipulation is that the tank must be kept warm enough so that the water does not freeze.

To discharge refrigerant via a diffuser, its terminus must be a safe distance from doorways, operable windows, or mechanical air intakes. The **CSA B52** code specifies the minimum distances from these openings.

Operator Instructions

For refrigeration systems larger than 125 kW (32 TR), the owner of the system must provide directions on how to operate it, including precautions to be observed in case of breakdown or leakage. The instructions must be in a conspicuous location, and as near as practicable to the compressor or compressors.

As a minimum, the instructions must include:

a) The telephone number of the first-response organization, in case there is an emergency.
b) Instructions for shutting down the system, in case there is an emergency.
c) The name, address, and telephone numbers (day and evening) of the company used to service the unit.
d) The name, address, and telephone number of the closest regulatory authority.
e) Instructions for notifying the authority, in case there is an emergency.

It is also advisable to have an emergency evacuation plan prepared and readily available.

Maintenance Requirements

The **CSA B52 Code** spells out some special maintenance that must be performed at regularly scheduled times.

Safety Valves, Pressure Limiting Devices, and Other Controls

Safety valves in refrigeration service do not have try levers; therefore, these valves must be replaced every five years. Alternatively, they can be removed and recertified. Simple try lever tests cannot (nor should they) be performed.

Pressure limiting devices must be tested at least once every 12 months for set point accuracy and for their ability to properly stop the compressor.

Other safety devices, such as low oil pressure cut-offs and high discharge temperature cut-offs, must be tested at least once every 12 months for set point accuracy and for their ability to properly stop the equipment.

Leak Detectors

Leak detectors must function at the specified refrigerant concentration. They must be tested at least annually, to verify that they are in accordance with the manufacturer instructions. Detectors that fail the test must be immediately calibrated, repaired, or replaced.

Equipment Specific Maintenance

All safety related maintenance recommendations made by the equipment manufacturer must be followed. This includes adjustments, repairs, calibration, and component replacement at the intervals specified by the manufacturer.

Visual Inspection of the Plant

CSA B52 requires visual inspection of refrigeration plant equipment. This includes quarterly inspection of all refrigeration lines, vent lines, outlets, and system components. Check for:

- Vibration
- Corrosion
- Physical damage
- Blockage
- Insulation damage, including both piping and vessel insulation

Leak Testing

Testing for refrigerant leaks must be carried out periodically. The normal places where leaks occur are at:

- Valves
- Valve Stem Packing
- Threaded Connections
- Flanged Connections
- Flared Joints

The location of a leak may be determined with:

- Moist red litmus paper
- Moist filter paper impregnated with phenolphthalein
- Sulfur candles
- Electronic refrigerant "sniffers"

Chemical test papers change colour in ammonia vapour. Sulfur candles form a white fog when in contact with ammonia.

Condensers should be checked at all connections, and throughout the coil. Air-cooled condensers can sustain damage from weakened fan blades or damaged fan bearings. Water-cooled condensers should be checked for leaks by isolating the coolant, carefully cracking open a vent, and testing the atmosphere at the connection for escaped refrigerant.

A similar process can be followed for an evaporator. Fan-coil evaporators and blast freezers can sustain damage from weakened fan blades or damaged fan bearings. Chillers should also be tested periodically, especially if the fluid is brine, which may be a factor in accelerated corrosion. Follow the manufacturer recommendations for testing. If no specific instruction is available, follow the water-cooled condenser procedure.

CAUTION

NEVER take apart or crack open any piping connection on a refrigeration system, even if the connection is part of a chilled brine or water loop, without first testing for refrigerant at a vent. Treat all refrigerants with caution. **DO NOT** rely on the sense of smell. Many refrigerants are odourless and toxic, and many will displace atmospheric oxygen.

Many refrigerants are heavier than air and will accumulate in low areas. Avoid low areas if there is a possibility of a leak. If the equipment is near floor level, test first before commencing work. Keep a refrigerant tester on at all times, and carry a calibrated personal oxygen monitor near your head. Ammonia is lighter than air, so keeping low is better for ammonia. Ammonia stinks, and is only slightly dangerous at first breath or taste. This is the warning to get out, get help, and get the proper PPE.

Housekeeping

Housekeeping is very important. It allows safe and quick egress from a machinery room. Tripping over pails or mops while trying to get out of a dangerous situation makes matters worse.

Objective 2

Identify safe practices for refrigeration plant operation and maintenance.

Hazards of Ammonia

Anhydrous ammonia is very corrosive. Ammonia is hygroscopic and highly soluble in water. Exposure to it may result in chemical burns to skin, eyes, and lungs. Human tissues, such as mucous membranes in the nasal passageways and in the lungs, are inherently moist. Humans also excrete perspiration, saliva, and tears. Anything moist attracts and dissolves ammonia. This forms highly corrosive ammonium hydroxide. Exposure to ammonia will damage eye tissue, mucous membranes, and skin. If inhaled, it damages the lungs, too.

When released to the atmosphere, ammonia dissolves readily in atmospheric moisture. This forms a dense caustic white cloud. **NEVER** enter a visible cloud of ammonia. It will cause serious lung damage!

At atmospheric pressure, ammonia boils at about −33°C. It also has a very high latent heat of evaporation. Therefore, even a small amount sprayed on the skin or eyes can cause frostbite as well as chemical burns.

Table 2 outlines the potential effects of exposure to a wide range of ammonia vapour concentrations.

Table 2 – Potential Effects of Ammonia Exposure

Concentration (ppm)	Effects
2	• Normal odour threshold
5 to 50	• Headaches • Loss of the sense of smell • Nausea • Vomiting
70	• Tingling or burning in eyes, nose, or throat • Watering of the eyes • Sneezing • Coughing
70 to 300	• Irritation to the nose, mouth, and throat that becomes intolerable after a few minutes • Coughing and wheezing • Shortness of breath
300 to 500	• Immediately dangerous to life and health • Lung irritation/possible burning in lungs • Coughing • Fluid in the lungs (pulmonary edema) • Severe shortness of breath • Death
Over 2000	• Fatal after a few breaths

Anyone repeatedly exposed to ammonia may have a significantly reduced ability to detect ammonia by smell. Do not rely on smell to assess ammonia concentrations. Always use personal protective equipment when there is a possibility of exposure above 50 ppm.

Work Practices

There are a few common **work practices** that Operators will carry out for refrigeration plant operation and maintenance. Most of the time, Operators will be required to safe out the equipment, while trained Maintenance personnel completes the job scope. It is important to follow procedures and be aware of all the potential hazards these operations can potentially have, regardless if it is you or someone else doing the actual work.

Disassembly

Refrigeration systems require occasional repair and regular maintenance. This may involve disassembling part of the unit. Before disassembly of any part of a refrigeration system, ensure that all refrigerant, including vapour, is removed, and that the internal pressure is 0 kPa.

Hot Work and Leak Checks

To perform hot work on refrigerant lines, they must first be purged using inert gas to reduce combustion and toxicity hazards. When maintenance, system modifications, or leak repairs are complete, the system must be pressure tested to determine system integrity, according to **CSA B52** code. If the system leaks, shut down the unit until it can be properly repaired.

Refrigerant Storage

Some facilities store refrigerant on site in compressed gas cylinders. Refrigerant cylinders must be stored a safe distance from an open flame or hot surfaces. They should be handled with care, because of the potential for frostbite due to escaping liquid refrigerant.

Routine Maintenance

Always perform any maintenance activity that may create a discharge of refrigerant (such as adding compressor oil, draining oil pots, or manual purger operation), with the aid of a "buddy." The buddy should have a water source readily available, and a means for signaling for emergency assistance.

If a serious ammonia leak occurs, spraying a water mist through the vapour can effectively reduce the concentration of ammonia in air. However, do NOT apply water directly to liquid ammonia. It can produce a violent vapour.

Oil Removal

Many accidents occur while removing oil from oil pots. Ammonia compressors pump oil with the ammonia gas. Because oil and ammonia are non-miscible, the oil drops out in various parts of the piping system. Ammonia is less dense than lube oil. The ammonia floats above the oil. Oil that accumulates in the bottom of evaporators and other low points in the system must be removed. Attach a flexible hose to a drain valve, place the end of the hose in a bucket of water, and open the valve slightly until there is no oil left in the oil pot.

If an oil drain is left open, it will cause a deadly release of refrigerant. Many jurisdictions require the installation of self-closing emergency stop valves (also called "dead man valves") at all oil drain points in the system.

This valve is manually opened against the force of a spring. When the handle is released, the valve springs shut. Figure 12 shows a dead man valve on an oil recovery pot at the base of a chiller. Note the guard valve situated closest to the pot. It is good practice to cap off the oil drain downstream of the dead man valve when oil is not being drained from the system.

Figure 12 – Dead Man Valve for Draining Oil from a Refrigeration System

Oil pots should be located where they are readily accessible. This not only helps operators drain oil, but it allows them to leave the area quickly if necessary. Operators should not be required to climb over pipes or equipment to access oil drain points.

Some refrigerants cause refrigeration compressor oil to become acidic in the presence of moisture. Use PPE when handling used oil.

Ammonia Pipe Labelling

It is very important to know which pipes in the plant contain refrigerant. Often, these pipes run adjacent to pipes that contain other elements, such as compressed air and potable water.

As a plant grows in capacity or there is equipment to reconfigure, piping system modifications need to take place, which is quite common. Cutting into the wrong pipe during repairs or renovations can be hazardous or even catastrophic. Colour coding the pipes helps to ensure the piping and instrumentation diagrams are up-to-date; it reduces the chances of operator error; and it significantly lowers the chances of accidentally damaging the refrigeration piping.

It has been common practice to paint emergency discharge and safety valve discharge piping bright red. However, in many plants, ammonia circulates through the entire facility in liquid or vapour form. The **International Institute of Ammonia Refrigeration (IIAR)** has developed a method for identifying plant ammonia piping (shown in Figure 13).

Side Track

Pipe colour identification should be consistent throughout the plant. Several pipe identification standards exist. And, sometimes they are contradictory. It is important to know the pipe identification scheme used in the plant, and to apply it consistently.

According to the **IIAR**, ammonia pipe labels must have the word **AMMONIA** in black letters on an orange background. An arrow indicates the direction of refrigerant flow. The label also has several colour bands.

One band shows the refrigerant state:

- Yellow indicates liquid.
- Blue indicates vapour.
- If the label has both colour bands, then liquid and vapour are both in the same pipe.

Another colour band indicates whether the piping is high side or low side:

- Red indicates high pressure.
- Green indicates low pressure.

Figure 13 – Ammonia Piping Label

Valves should have a permanent tag that will not fade or easily fall off. The tag should indicate the valve number in the system, the fluid, and its state.

Objective 3

Describe the appropriate emergency response to a significant refrigerant leak.

Every plant layout is unique. Some plants have components that contain refrigerant confined to machinery rooms, accessible only to Power Engineers and service technicians. Cold storage and other industrial refrigeration facilities may have these components located throughout the building, where a system leak can affect all warehouse staff. Some plants are in remote locations. Others are located in residential neighbourhoods. For these and other reasons, it is important to develop and follow site-specific procedures for emergency response. This objective describes a generalized response to significant refrigerant leaks.

Personal Protective Equipment

Employers must provide, and ensure that workers use, appropriate protective equipment to prevent repeated or prolonged skin contact with liquid refrigerants. They must also ensure that workers use them. Typical PPE includes:

- Impervious clothing
- Gloves
- Splash-proof safety goggles
- Face shields

As well, employers must provide, and ensure that workers wear, appropriate respiratory protection. Where atmospheric conditions are immediately dangerous to life or health, such as during a leak, employers must provide workers with supplied-air respirators or escape-only respirators. DO NOT use air-purifying respirators in an IDLH atmosphere.

Emergency Response Plan

CSA B52 Code requires owners to provide employees with a written emergency response plan. This may be in addition to an Environmental Emergency (E2) response plan. The plan must include an explanation of:

- Worker roles
- Lines of authority
- Necessary training
- Communication protocols
- PPE requirements

Action in the Event of a Significant Leak

It is imperative to follow the plant emergency response plan in the event of a significant refrigerant leak. The following information is general, and encompasses the types of action to take.

Sometimes, when a refrigerant leak occurs, there is no way to immediately identify the potential exposure to a respiratory hazard for the workers or facility occupants. Always consider these leaks as IDLH, and take the appropriate emergency response.

Properly functioning and calibrated refrigerant leak detectors should activate alarms and beacons to alert plant operators and facility occupants. As well, mechanical exhaust ventilation should start automatically and operate at maximum capacity.

As an additional precaution, prior to entering the machinery room, manually activate the mechanical exhaust ventilation system. Stop the refrigeration machinery. Shut down the HVAC fans and machinery without entering the machinery room, by using the switches outside the room. Allow the mechanical exhaust ventilation to bring refrigerant concentrations to within the Permissible Exposure Limit (PEL) for the specific refrigerant. According to OSHA, the PEL for ammonia is a time-weighted average of 50 ppm.

If concentrations remain above an acceptable level, proper respiratory protection and other PPE must be worn before entering the machinery room.

Human safety is the first consideration when a leak occurs. It is better to permit a leak to continue than to endanger the lives of occupants. Individuals that are not required to address the emergency must evacuate the premises, and muster to a safe location. Call emergency services. Cordon off the area surrounding the leak. Do not allow anyone to enter the area until the emergency is over and airborne refrigerant concentrations are safe.

Any decision to vent refrigerant through an emergency discharge system should be made by trained emergency services personnel. Such a decision could impact the air quality over a large geographic area. This may involve the evacuation of nearby neighbourhoods. In this case, more emergency responders will likely be required.

Persons trapped in an ammonia leak should breathe as little as possible and open their eyes only when necessary. Some protection is possible by holding a wet cloth over the nose and mouth. A trapped person should remain close to the floor, since ammonia vapour rises. Then, proceed to the source of ventilation air by travelling against the airflow.

First Aid

First aid certification courses are general in nature; they do not cover the specific treatment of refrigerant exposure. Below are some guidelines for administering first aid to those exposed to ammonia liquid or vapour. Keep in mind that the following measures are not comprehensive, and are not a substitute for expert medical attention. Always secure emergency medical treatment for individuals burned or overcome by ammonia prior to administering first aid.

CAUTION

Only trained and certified individuals should administer First Aid. Prior to administering first aid, ensure the victim is in a safe location, and secure the assistance of emergency medical services.

Move persons exposed to ammonia to a warm and fume-free location. Place them in a reclining position with head and shoulders elevated. Keep the victim warm with blankets.

Skin Contact

If liquid ammonia contacts a person's skin, immediately bring the victim to a safety shower. Flood the affected area with water for at least 15 minutes. If no safety shower is available, immerse the affected body parts in relatively warm water.

The victim's clothing may be frozen to the skin. Once the clothing thaws, remove it so that water can irrigate the skin directly. Continue flooding the skin for an additional 15 minutes.

Do not apply ointments or cover burns with dressing. Instead, cover the affected area with a clean cloth, to provide protection until medical care arrives. If ammonia entered the nose or throat but the victim can still swallow, have them drink large quantities of water. Never give anything by mouth to an unconscious person.

Eye Contact

Speed is essential to prevent blindness. Immediately take the victim to the nearest eyewash station. If an eyewash station is not nearby, use any clean water source. Irrigate the eyes with generous amounts of clean water for at least 30 minutes. During this time, make sure to hold the eyelids open. The victim must receive prompt medical attention from a physician.

Those working with or near ammonia refrigeration systems can be accidentally exposed to ammonia. For this reason, workers in refrigeration plants should not wear contact lenses.

Inhalation

A conscious person who has inhaled ammonia should be taken to an uncontaminated area that has copious amounts of fresh air. If overcome by ammonia, the victim should be immediately carried to a safe, location and given artificial respiration, if necessary. If the victim is breathing, oxygen may be administered.

Site-Specific Training

To be effective emergency responders, Power Engineers that work with refrigerants and refrigeration plants must be well trained in site-specific procedures. This training is in addition to the training already received as part of the Power Engineer training. Site-specific training usually includes:

a) Properties of the refrigerant in use
b) Toxicity and flammability
c) Safe handling procedures
d) Emergency procedures, addressing fires, spills, accidental releases, and evacuation
e) Written safe work procedures
f) Use of PPE, including respiratory protection
g) Working alone (even entering a machinery room may be considered working alone)
h) Testing and verifying leak detection equipment
i) First aid
j) Maintenance procedures, such as:
   - Draining oil
   - Adding oil to the compressors
   - Manually purging non-condensable gases
   - Isolating areas or parts of the system
   - Pumping down parts of the system
   - Switching equipment

Objective 4

Describe the Canadian Environmental Emergency Regulations and how they relate to refrigeration plants.

Canadian Environmental Protection Act (CEPA)

The **Canadian Environmental Protection Act (CEPA)** is "an act respecting pollution prevention and the protection of the environment and human health in order to contribute to sustainable development."

According to **Section 193** of **CEPA 1999**, an environmental emergency is:

a) an uncontrolled, unplanned or accidental release, or release in contravention of regulations, of a substance into the environment; or
b) the reasonable likelihood of such a release into the environment.

Environmental Emergency (E2) Regulations

The Environmental Emergency (E2) Regulations came into force under the authority of the **CEPA** in 2003. The intention of the regulations is to protect the environment and human life, by preventing, preparing for, responding to, and recovering from environmental emergencies.

Under **E2 Regulations**, any person who owns or has the charge, management, or control of a listed substance on a fixed facility may be required to:

a) Identify the listed substance and where it is located
b) Prepare an environmental emergency plan
c) Implement, update, and test the plan annually
d) Provide notice of closure or decommissioning
e) Report environmental emergencies involving regulated substances

Note that in regulated refrigeration plants, Power Engineers are the ones who have charge of, manage, or control these hazardous substances.

Environmental Safety of Refrigerants

There are currently 215 substances listed under the **E2 Regulations**, including anhydrous ammonia. Ammonia refrigeration plants require an **E2** plan if the total amount of refrigerant on site equals 4.5 tonnes or more.

Environmental emergency plans must:

a) Identify any environmental emergency that may occur at the facility in question and the harm or danger it may cause.

b) Describe the measures for preventing, preparing for, responding to, and recovering from any environmental emergency.

c) List the individuals who carry out the plan when an environmental emergency happens. Also, describe their roles and responsibilities.

d) Identify the training required for each of those individuals.

e) List the emergency response equipment that is part of the **E2** plan, and the location of the equipment.

f) List how affected members of the public will be notified of the emergency and how they will be kept informed of the emergency measures being taken.

Every environmental emergency plan must:

- Be site-specific
- Address the full range of hazards present on the site
- Include site plots and safety data sheets (SDS) for each regulated substance
- Maintain records of annual testing
- Be updated annually
- Be verified annually with a test
- Include site-specific training

Employers should develop scenarios for accidental release based on a possible environmental emergency that may occur. This should focus primarily on a worst-case scenario that would involve the largest possible substance release. Alternative scenarios that would release lesser amounts of substance should also be developed.

The ultimate responsibility for **E2** compliance falls on the owner of the plant. It is their responsibility to develop and seek approval of the **E2** plan. Shift employees are responsible for carrying out the plan. This includes:

a) Developing the scenarios

b) Validating the plan

c) Emergency responses to be taken

d) Documentation of tests and events

e) Communications mandated by the regulations

Chapter Summary

Jurisdictions legislate the care and operation of large refrigeration plants, and place them under the authority of properly trained, certified, and qualified Power Engineers. This is because refrigeration plants pose many hazards to both workers and the public.

This chapter covered the safety features found in refrigeration plants, as well as safe operation and maintenance practices. Plant operators must be prepared to carry out safe, effective, and environmentally responsible emergency response plans.

Site-specific training enables Power Engineers to respond more effectively to an emergency in their plant. Some of the critical elements are:

- Equipment operation
- Equipment isolation
- Equipment shutdown
- Emergency plans
- First aid training

CHAPTER 7

Ammonia Refrigeration Safety

Learning Outcome

When you complete this chapter you should be able to:

Apply safety procedures to ammonia refrigeration systems.

Learning Objectives

Here is what you should be able to do when you complete each objective:

1. *Discuss the basic guidelines for oil removal from piping or vessels on ammonia refrigeration systems.*
2. *Discuss the properties and testing of secondary refrigeration systems.*
3. *Describe the steps and precautions to take when pumping down a compression refrigeration system.*
4. *Explain the specific points to isolate and lock out for various maintenance on specific refrigeration plant equipment.*

Chapter Introduction

Safety is the prime concern of the ammonia refrigeration system operator. This chapter emphasizes testing of secondary refrigeration systems, safe operation of ammonia refrigeration systems, and maintenance of refrigeration equipment. This content was developed in response to recommendations made by Technical Safety British Columbia (TSBC) in its investigation reports of the October 2017 ammonia leak at the Fernie Memorial Arena in Fernie, BC, which resulted in the deaths of three people, and the October 2018 ammonia leak at a pet food manufacturing plant in Langley, BC, which prompted an extensive evacuation of the area.

Note that this content appears in PanGlobal's ***Textbook Addendum: Ammonia Refrigeration Safety*** and will appear in ***Refrigeration Plant Operator,*** **Edition 3** and ***Power Engineering Fifth Class,*** **Edition 4**.

Objective 1

Discuss the basic guidelines for oil removal from piping or vessels on ammonia refrigeration systems.

Purpose of Oil Removal

A buildup of oil or oil products on the refrigeration side of the coils in a condenser prevents efficient heat transfer and reduces the efficiency of the condenser, and therefore the efficiency of the refrigeration system as a whole. Oil buildup will result in high compressor discharge pressure and increased power consumption by the compressor motor.

Guidelines for Oil Removal Procedures

A sample procedure, including sketches, for draining oil from a refrigeration system is found below. The following guidelines from TSBC are for removing oil from the piping and vessels of an ammonia refrigeration system.

> *The following are basic guidelines around the removal of oil from piping or vessels on an ammonia refrigeration system using an oil pot and is not a procedure:*
>
> - *It is imperative that there be a site-specific procedure that is based on the manufacturer's recommendations and is readily available. The procedure should clearly define the steps required using photos and valve labelling. The procedure should consider lock-out/tag-out of the valves as needed.*
> - *The frequency of [oil] removal should be established to prevent further carry-over into other parts of the system.*
> - *A site hazard review should be completed that focuses on potential sources of ammonia release and the means to prevent releases.*
> - *A site-specific Job Hazard Analysis [JHA] should be completed prior to starting the draining of oil from the system.*
> - *The oil drain procedure should be part of an overall oil management program that tracks the use of oil and outlines the requirement to investigate unusual oil use or losses.*
> - *If an oil pot is not available, then it is important that live pressure not be directly used to remove the oil to atmosphere. A dedicated pressure vessel with [ASME-approved] hard pipe, pressure gauges, relief [valves], and isolation valves should be used to remove the oil.*
> - *Oil draining is a long, slow process. Enough time should be scheduled to complete the task.*
> - *A second person should be available to provide assistance.*
> - *Oil draining should not be left unattended.*

These guidelines have also been recommended by TSBC as considerations when developing standard operating procedures (SOPs).

1) *Ensure all operators have been trained on the procedure prior to implementation.*
2) *Ensure all operators have been trained on the PPE [personal protective equipment] requirements for the job, including, but not limited to, the use of full-face masks and SCBA [self-contained breathing apparatus] as needed.*
3) *Ensure the operators have and use portable ammonia detectors during the oil drain.*
4) *If an oil pot is used to collect the oil and it has a vent back to the system, then use the outside frost as an indication as to whether the liquid ammonia has fully evaporated back into the system. Do not use hot water to boil off the ammonia if there are components on the pot that can be damaged by temperature shock, such as sight glasses. Hot water can also result in damage due to over-pressurization and subsequent loss of containment.*
5) *Do not drain oil until all liquid ammonia is confirmed to have been vented off.*
6) *The oil receptacle should be designed to prevent release of ammonia into the immediate work area.*
7) *If pressure is required to remove the oil from a separator pot, then close the drain valve and open the vent valve to the pressure side to pressurize the pot. The vent valve can now be closed and the drain valve reopened.* ***Never use live pressure from the system to directly push oil out from an oil pot****.*
8) *All oil drains should come with a self-closing or emergency stop valve upstream of the oil drain valve.*
9) *The oil drain valve should come with a plug that is removed before draining and reinstalled after draining.*
10) *The oil receptacle should be moved to a safe location and allowed to off-gas in a controlled fashion or disposed of off-site.*

TECHNICAL SAFETY BC

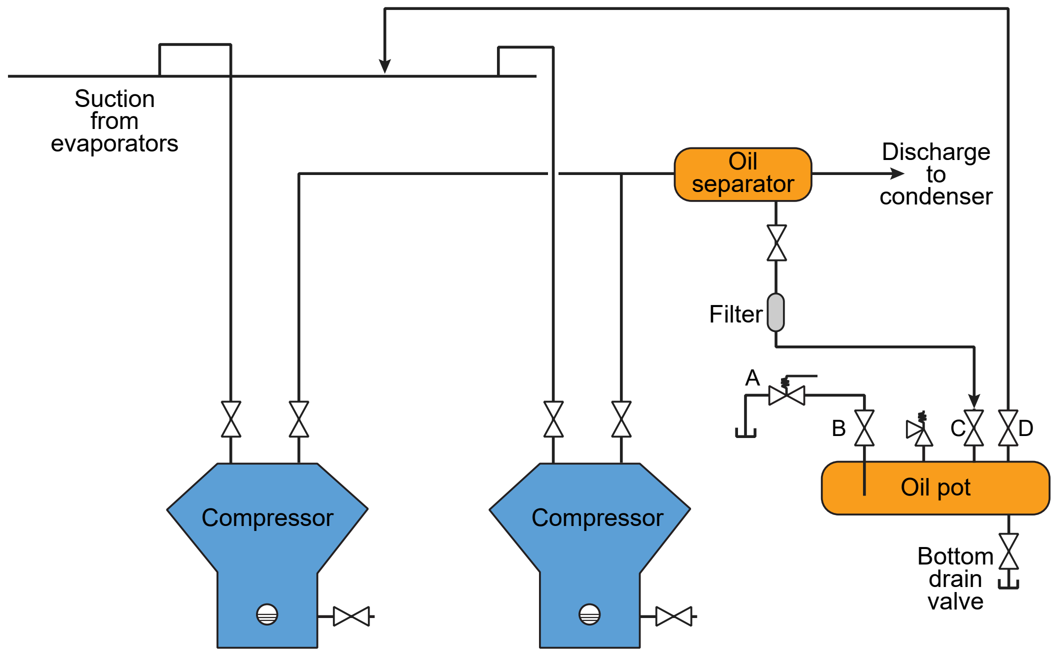
CAUTION

Never use system pressure to directly push oil out from an oil pot. Do not drain oil from systems that are not isolated from system pressure!

Example Procedure

The following procedure for draining compressor oil and oil pots is provided here as an example of the safety considerations identified above.

Figure 1 – Oil Pot Installation



Compressor Oil Removal

When excess oil is removed from the compressor crankcase or the oil has to be changed, use the following procedure:

1. Pump down the compressor until the pressure in the crankcase approximately equals atmospheric pressure. This is done by slowly closing the compressor suction valve and monitoring the compressor suction (or crankcase) pressure gauge.
2. Shut off the compressor.
3. Isolate the compressor suction and discharge valves.
4. De-energize and lock the compressor so it cannot be started until the job is finished. Follow site-specific lockout procedures.
5. Drain the oil by either opening the drain valve or removing the drain plug. Exercise caution when removing the drain plug because crankcase pressure will blow out oil and refrigerant vapour.

Oil Pot

Oil separators that do not automatically drain to the crankcase should be manually drained at regular intervals. In many plants, oil separators (and other system components) do not return oil directly to the compressor, but drain to oil pots, instead. These pots are small pressure vessels that are left open to the system to gather oil. The pots are equipped with valves so that they can be isolated from the system and safely emptied of oil. Some pots are piped to return oil to the compressor. An oil pot installation is shown in Figure 1.

Valve A is a deadman valve. It has a quarter-turn spring-loaded handle that closes automatically when released.

Valve B (oil drain shut-off valve) is used to isolate the oil return line.

Valve C (liquid supply valve) lets oil flow from the separator into the oil pot. Other valves (not shown) allow oil to flow into the pot from other system low points.

Valve D (vent line valve) permits any liquid refrigerant that accumulates in the oil pot to evaporate and re-enter the suction line.

A safety valve must be installed on the oil pot in case all the valves are closed. Such a situation could over-pressurize the oil pot.

In normal operation, valve C is open. When the separator is full of oil and ammonia, a float-operated trap (not shown) dumps oil and ammonia into the oil pot. Valve D is also normally open. The pot is thus maintained at low-side pressure. Any refrigerant liquid that enters the pot evaporates and is entrained with the compressor suction flow. Valves A and B are normally closed, and the end of the drain pipe is capped.

Liquid ammonia is less dense than lube oil. Boiling ammonia in the oil pot creates a frost line at the interface between the liquid ammonia and the oil. As the oil pot fills, the frost line moves higher up the side of the oil pot. When the oil pot is full, it needs to be drained. The following is a typical procedure. Refer to Figure 1.

1. Remove the oil pot from service by closing the liquid supply valve (C). Ammonia will continue to evaporate from the pot. Allow adequate time—up to 24 hours—for the separation of ammonia from the oil prior to draining. When all the ammonia has evaporated, there will be no frost on the outside of the pot.

Note: Ammonia boils at –33°C when at atmospheric pressure.

2. Perform a JHA. Identify all apparent hazards and develop a plan to mitigate the risks associated with each. Carefully review the safety data sheets for both ammonia and oil. Operators should familiarize themselves with the escape route and location of the emergency shower and/or eyewash station. Wear the appropriate PPE, which may include chemical resistant gloves, safety glasses, face shield, full-face respirator, and a chemical apron. A second operator should be present, equipped with proper PPE and a method for summoning help if needed.
3. Complete the oil pot isolation by closing the vent valve (D).

CAUTION

Never drain the oil pot under system pressure. A proper isolation will minimize the release of ammonia into the working area.

4. While holding the deadman valve (A) open, slowly open the oil drain shut-off valve (B) to begin draining the oil pot into a containment system. Once the oil flow becomes intermittent with some vapours, the oil drain process is complete.

CAUTION

Never prop open the spring-loaded handle of the deadman valve. This handle is a safety device, and propping it open renders it ineffective.

5. Close the oil drain valve (B) while holding the deadman valve (A) in the open position. Then, close the deadman valve (A).
6. If additional oil needs to be drained, follow the developed procedure for the use of the bottom drain valve on the oil pot.

7. Place the oil pot back in service by opening the vent valve (D) and the liquid supply valve (C). Ensure that the oil drain shut-off valve (B) is tightly closed by cracking open the deadman valve (A).

CAUTION

The drained oil may still contain some ammonia. Place the container holding the drained oil in a well-ventilated area to allow the remaining ammonia to evaporate.

8. Record the volume of oil that was collected and then dispose of the oil according to jurisdictional and environmental regulations.

Objective 2

Discuss the properties and testing of secondary refrigeration systems.

Properties of Secondary Refrigerants

Secondary, or indirect, refrigeration systems use a heat exchanger to transfer heat from the location being cooled to the primary refrigerant. The ideal secondary refrigerant will have the following qualities:

- Chemical stability
- Low viscosity
- Good heat transfer
- High specific heat
- Noncorrosive
- Inexpensive

The secondary refrigerant is often called the *brine system*. Although the word *brine* is defined as a saltwater solution, refrigeration systems use the word brine to describe the secondary refrigerant, which includes salts and glycols. The brine is reduced to a desired temperature in the evaporator or chiller. A brine pump, generally a centrifugal pump, transports the brine to the areas being cooled. The brine system is equipped with an expansion tank to allow the brine to expand without significantly increasing the pressure of the system. Figure 2 shows a small glycol expansion tank.

The brine system is generally a low-pressure system that is open to atmosphere, and the vessels, piping, and fittings are designed for low pressure. The use of a brine system prevents the main refrigerant, which may be a hazardous material such as ammonia, from circulating in public areas. The use of secondary refrigerants also allows the refrigeration system to use multiple evaporators providing brine at different temperatures.

Figure 2 – Glycol Expansion Tank

Air-conditioning systems may use water as the secondary refrigerant if the temperature requirements are not below 0°C. Lower temperatures may be achieved by adding a salt or glycol to the water to form a brine. The most common types of brine are calcium chloride ($CaCl_2$), sodium chloride (NaCl), ethylene glycol ($C_2H_6O_2$), and propylene glycol ($C_3H_8O_2$). Sodium chloride and propylene glycol are commonly used in the food industry.

The brine used in the secondary refrigerant loop will have a specific concentration for the temperature required. For example, a solution of 22% by weight of calcium chloride will have a relative density of 1.21 and a freezing temperature of –23°C (–9.4°F).

Refrigeration System Testing

The operator of a refrigeration facility should perform regular testing on the secondary refrigeration system. A salinity test is a common brine system test. The salinity of, or concentration of salt in, the secondary refrigerant is proportional to the freezing temperature of the brine. The brine should therefore be maintained at the proper concentration. Figure 3 shows a **hydrometer** testing apparatus that is commonly used for testing a sodium chloride brine system. The scale provides a reading of percent sodium chloride saturation. Using correlation tables, the freezing temperature can be obtained. For example, a reading of 71 means 71% of a saturated brine solution. This would give a freezing temperature of about –15°C (5°F). Each hydrometer is calibrated to a specific temperature. Any deviation of the sample temperature from the calibration temperature of the hydrometer must be accounted for.

Figure 3 – Hydrometer Measuring NaCl Solution

Ammonia refrigeration systems require regular testing of the brine for any levels of ammonia. This test can be performed by the operator on a regular basis. There are a variety of test strips available to test for the presence of ammonia. A pH test can also be used to indicate the presence of ammonia in the brine system. **The presence of ammonia in the brine indicates a leak in the primary refrigerant piping and must be dealt with immediately**. If an ammonia leak is suspected, the system must be shut down and the leak repaired by qualified maintenance personnel.

CAUTION

There are several types of test strips available. Each of these test strips will respond to aqueous ammonia only; dry, gaseous ammonia will not be detected. If the strips are used to detect leaks around flanges and valves, the test strip must be wetted first. Standard litmus paper will change from red to blue, indicating the presence of OH^- ions, which is a positive test for ammonia. Phenolphthalein test strips will turn from blue to red in the presence of ammonia. Specialized ammonia test strips will show a different colour for different low concentrations. The refrigeration operator should be aware of which tests strips they are using.

On Track

The condenser cooling water should also be checked for ammonia. The presence of ammonia in this cooling water is an indication of a leak in the condenser. The system should be shut down and properly isolated for repairs by qualified maintenance personnel.

Brine Tests

A sample of the secondary refrigerant should be drawn and sent to a qualified lab facility for a complete analysis at least once a year. The method of drawing a brine sample and the types of tests performed by the operator should be a part of the facility's SOPs.

The lab will test for several different constituents, compare the results to a recommended control range, and recommend actions to be taken. Some examples of tests for calcium chloride, as well as recommended actions for out-of-range results, are discussed below. The numbers used in the following descriptions are specific to the example shown in Figure 4. The recommended ranges for your plant may be slightly different.

Specific Gravity

Testing the specific gravity and freezing point of brine indicates the strength, or concentration, of the brine. The concentration and freezing point of brine are inversely proportional. A calcium chloride brine should have a specific gravity of at least 1.21, which corresponds to a freezing temperature of –23°C (–9.4°F). The brine must be adequately concentrated to avoid freezing during operation. The brine concentration can be increased by adding calcium chloride.

On Track

Brine pumps are generally selected based on a standard calcium chloride specific gravity of 1.21, giving a freezing temperature of –23°C (–9.4°F).

Ammonia (NH_3)

The recommended value for ammonia is 0 ppm. Trace amounts of ammonia may result in a recommendation of a second lab test to see if the ammonia level is increasing, indicating a small leak. A higher ppm of ammonia is an indication of a serious problem, and the system should be immediately shut down and properly isolated for repairs.

CAUTION

Increasing or high concentrations of ammonia are an indication of a dangerous situation and must be dealt with immediately. The system should be immediately taken out of service and properly isolated. The ventilation fans should be operated and the area should be monitored for any leakage to the environment. See your SOPs for the proper procedures for your facility.

pH

This test is an indication of the acidity or alkalinity of the brine and an indication of existing or potential corrosion problems. A pH outside the recommended range of 8.5 to 9.5 may require the addition of chemicals to the system to raise or lower the pH. If the pH is significantly out of the recommended range, the addition of caustic soda will increase the pH, and the addition of a mild acid will lower the pH.

A high pH can also suggest the presence of ammonia in the system.

Iron

High levels of iron in the brine are an indication that piping is being corroded. An iron reading above the recommended maximum of 10 ppm may have a suggested action of filtering the brine or changing the filter cartridge in systems with filtration.

Solids

High levels of suspended solids (from chemicals falling out of solution or contaminants) may build up in pipe bends in the areas being cooled. If testing reveals an unacceptably high concentration of solids, the lab will recommend filtration.

Inhibitor

An inhibitor may be added to the brine to prevent corrosion and scale buildup. The inhibitor in the analysis shown below should be kept in the range of 20 to 30 ppm to prevent scale on the inside of the piping.

Zinc Chromate

Zinc chromate has been determined to be a carcinogen and is no longer used as a corrosion inhibitor. Some older refrigeration plants may still have zinc chromate that requires testing.

Sample Lab Analysis

Figure 4 is a sample lab analysis report for an ice arena with an ammonia refrigeration system and $CaCl_2$ as the secondary refrigerant. –

Figure 4 – Secondary Refrigerant Chemical Analysis

Sample Brine Analysis Report			
Date:		Facility:	
Secondary refrigerant Type:		Calcium chloride	
Parameter	**Actual**	**Control range**	**Action**
Ammonia	0 ppm	0 ppm	None
Appearance	Clear	Clear	None
pH	7.5	8.5-9.5	Add 2.0L of NaOH
Specific gravity	1.18	≥ 1.2	Add 7 bags of $CaCl_2$
Freezing point (°C)	−19°C	≥−20.5°C	
% Calcium chloride	19.4%	≥ 21.5%	
Suspended solids	<30 ppm	<30 ppm	None
Suspended iron	<30 ppm	<30 ppm	None
Dissolved iron	<10 ppm	<10 ppm	None
Phosphate inhibitor (cPO_4)	0 ppm	10-30 ppm	Add 3 units of cPO_4

Objective 3

Describe the steps and precautions to take when pumping down a compression refrigeration system.

Pumping Down a Compression Refrigeration System

A refrigeration system pump down is performed to move as much of the refrigerant as possible from the low-pressure side and store it in the liquid (high-pressure) receiver. There are several reasons to store the refrigerant in the high-pressure receiver:

- Automatic pump-down systems may be used on some systems to reduce the amount of refrigerant migrating to the compressor oil sump, and also to reduce the possibility of liquid slugs entering the compressor on startup.
- Manual pump down of a refrigeration system is usually done to perform maintenance on the low-pressure side of the system. Care must be taken to ensure that the pressure on the low side does not go below atmospheric pressure. (Note: In rare situations, pressure below atmospheric pressure is required.) Too low of a pressure may result in air being drawn into the system and may damage some components.

The SOPs for your plant should be followed when pumping down the low-pressure side. The general steps for pumping down a refrigeration system include the following:

1. If the low-pressure side will be reduced to below atmospheric pressure, ensure that the low-side pressure gauge is a compound gauge, indicating pressure and vacuum, and any devices that may be damaged are isolated. Start the refrigeration system and operate it normally.
2. Ensure that the pressure gauges on the low- and high-pressure sides are functioning properly. See Figure 8.
3. Leave the cooling water on to the condenser.
4. For an indirect refrigeration system, leave the brine pump running.
5. Have a small load on the system to provide heat to the evaporator.
6. Ensure that any bypass lines around the expansion valve are isolated.
7. Close the expansion valve, isolating the refrigerant flow to the evaporator.
8. Observe the low-pressure gauge and watch for changes.
9. Allow the pressure to drop until the low-pressure switch (LPS) shuts off the compressor.
10. If a pressure lower than the low cut-off pressure is required, bypass the switch and restart the compressor.

CAUTION

There must be specific SOPs for running the compressor below the cut-off pressure.

CAUTION

If the pressure is being reduced below atmospheric pressure, extra care must be taken to ensure that no air is drawn into the refrigeration system so that components of the system will not be damaged.

11. Once the desired low-side pressure is achieved, shut down and isolate the compressor.
12. Open, lock, and tag the breaker for the compressor motor. Do Not Operate.
13. Remove the load to the evaporator and shut down the brine pump.
14. Shut down the cooling water to the condenser.
15. Follow proper tag and lockout procedures for the maintenance being performed.

Objective 4

Explain the specific points to isolate and lock out for various maintenance on specific refrigeration plant equipment.

Equipment Isolation

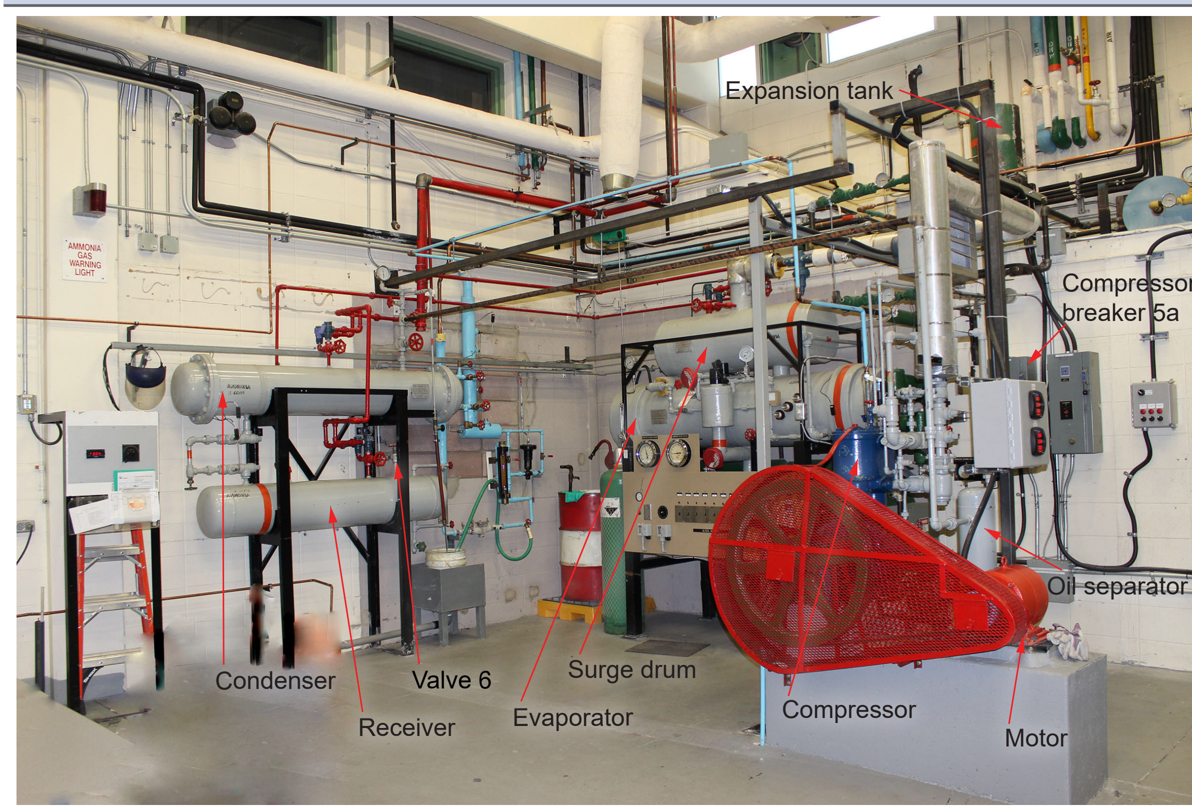
Please review **Unit A-4, Chapter 2** for more information on equipment isolation. All lock keys and an isolation list should be locked in a safety lock box that allows a contractor to install their own lock.

Please adhere to your plant guidelines concerning required PPE. This may include special gloves, eye protection, face shields, respirators, or SCBAs. When working with ammonia, a water hose and wet rags should be readily available.

The intent of this objective is to provide learners with the general concept of refrigeration equipment isolation. Do not memorize these isolation procedures, but look at why there is a specific step at a specific location. Each facility will have site-specific SOPs that should be followed.

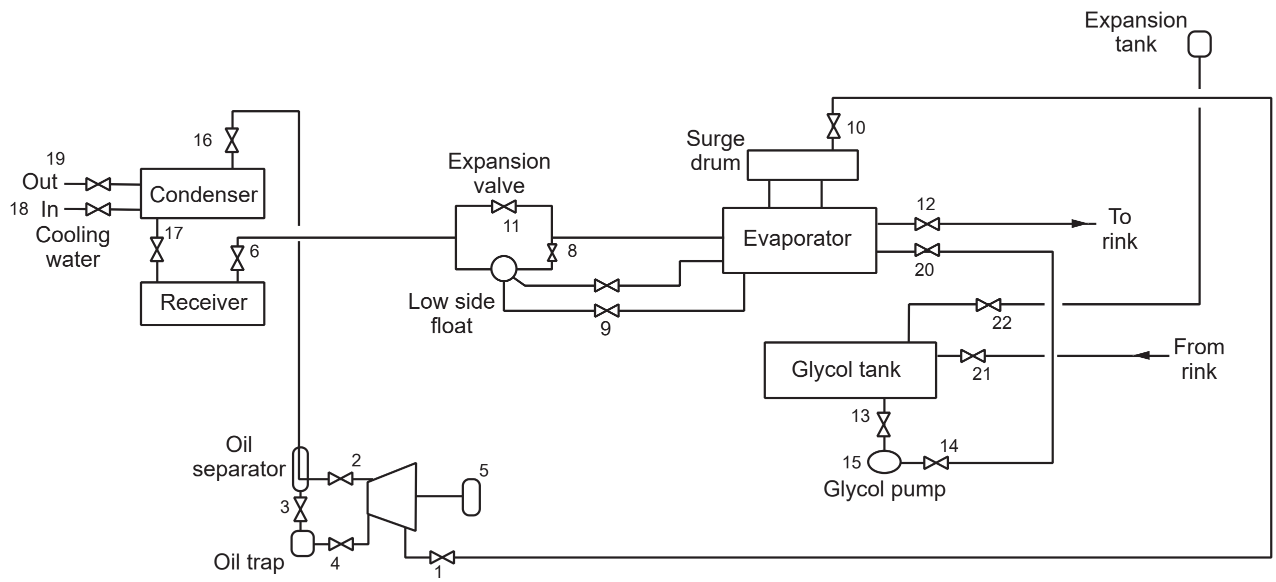
Figure 5 shows an overall view of an ammonia refrigeration system that has been taken out of service because it no longer meets code requirements. Key components for the following procedures are labelled to give an orientation to the equipment.

Figure 5 – Ammonia Refrigeration System



The same system is shown as a line drawing in Figure 6. The numbers shown on the figures will be used in the specific equipment isolation descriptions.

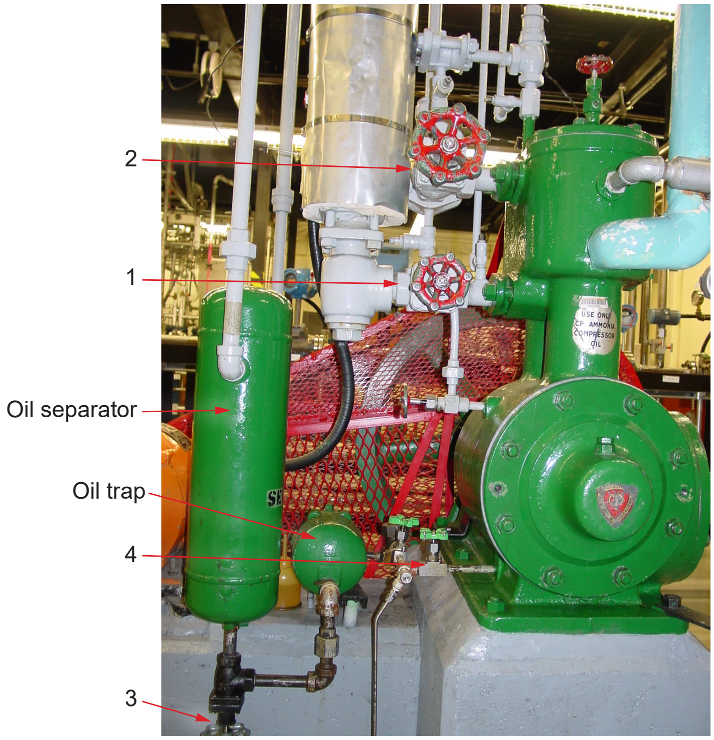
Figure 6 – Ammonia Refrigeration System Line Drawing



Compressor Isolation

The compressor may need to be isolated to change the oil in the compressor or to do major repairs to the compressor. Figure 7 shows a close-up of the compressor, piping, and valves. Table 1 lists all the points to be locked out or opened and tagged when isolating the compressor.

Figure 7 – Compressor Isolation Points



On Track

Ensure that the crankcase heaters are on, if equipped. This will allow a large percentage of the ammonia to boil off from the oil. After a period of time (see SOPs for details), turn off the crankcase heaters, open the breaker, and tag it Do Not Operate. Opening the breaker will protect workers from thermal burns and possible shock.

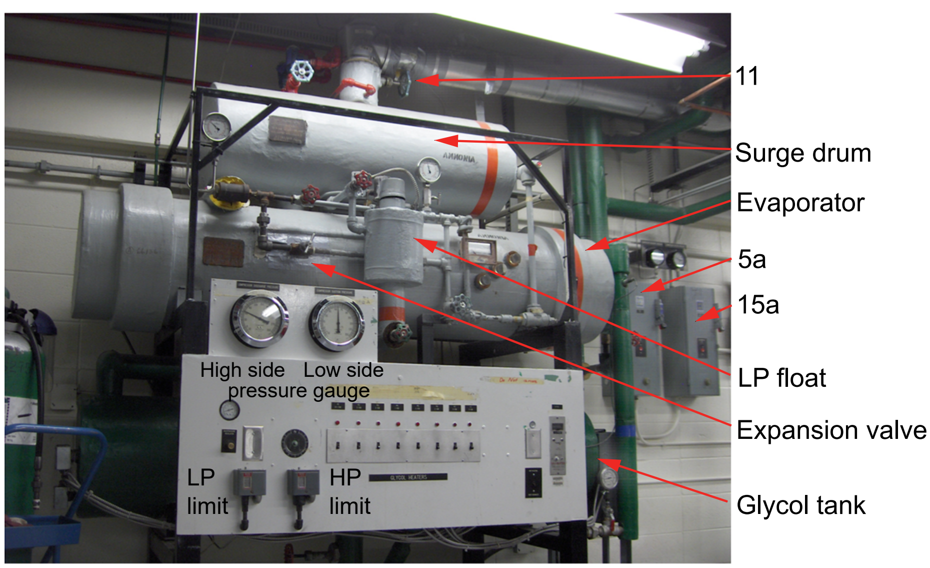
Table 1 – Compressor Isolation – Lockout and Tag

Component	Figure	Actions	Reason
Drain valve from the oil separator	#3, Figures 6 and 7	Close, lock, and tag DO NOT OPERATE	Prevent oil from draining back into the compressor Prevent air from entering the ammonia discharge piping
Valve from the oil trap	#4, Figures 6 and 7	Close, lock, and tag DO NOT OPERATE	Prevent oil from draining back into the compressor Prevent air from entering the ammonia discharge piping
Compressor discharge valve	#2, Figures 6 and 7	Close, lock, and tag DO NOT OPERATE	Prevent ammonia vapour from entering the compressor
Suction valve	#1, Figures 6 and 7	Lock and tag DO NOT OPERATE	Prevent ammonia vapour from entering the compressor
Compressor breaker	#5a, Figures 5 and 8	Open, lock, and tag DO NOT OPERATE	Prevent accidental startup of ammonia compressor

Evaporator (Chiller) Isolation

If there is a suspected leak in the evaporator, it must be isolated for maintenance and further investigation. Figure 8 shows the main components that need operator attention when isolating the evaporator. Table 2 lists the points to be locked out or opened and tagged during this procedure.

Figure 8 – Evaporator and Surge Drum



CAUTION

Do not isolate the glycol while the evaporator is still under pressure. The evaporator is a registered pressure vessel and was built to ASME Section 1 specifications. The glycol vessel and piping are open to atmosphere through the expansion tank and do not have to meet ASME Section 1 specifications, nor do the vessel or piping require a pressure relief device. A leak in the exchanger between the refrigerant and glycol may cause the glycol line and vessel to over-pressurize above their safe operating design.

CAUTION

Although the low-pressure side may be close to atmospheric pressure, there is still a significant amount of refrigerant vapour in the evaporator. The remaining refrigerant vapour may have to be removed by a third-party contracting company prior to opening the evaporator to atmosphere.

Table 2 – Chiller Isolation – Lockout and Tag

Component	Figure	Actions	Reason
Discharge valve from the liquid receiver	#6, Figures 5, 6, 10	Close, lock, and tag DO NOT OPERATE	Stop the flow of ammonia to the evaporator
Compressor breaker	#5a, Figures 5, 8	Open, lock, and tag DO NOT OPERATE	Prevent accidental rotation of the motor and compressor
Glycol pump breaker	#15a, Figure 8	Open, lock, and tag DO NOT OPERATE Caution: the glycol may have absorbed a considerable amount of ammonia.	Prevent circulation of glycol through the evaporator
Valve leaving the surge drum	#10, Figure 6	Close, lock, and tag DO NOT OPERATE Note: the compressor suction gauge is no longer measuring evaporator pressure when this valve is closed.	Isolate the evaporator from the compressor to prevent a backflow of ammonia into the surge drum and evaporator
Expansion valve	#11, Figures 6, 8	Close, lock, and tag DO NOT OPERATE	Isolate the refrigerant line from the receiver to prevent refrigerant flow
Low-side float valve discharge	#8, Figure 6	Close, lock, and tag DO NOT OPERATE	Isolate the refrigerant line from the receiver to prevent refrigerant flow
Low-side float valves from the evaporator	#9, Figure 6	Close, lock, and tag DO NOT OPERATE	Isolate the low-side float valve from the evaporator
Breaker for the low-side float		Open and tag	Prevent the low-side float from attempting to open the refrigerant valve
Glycol supply valve to the evaporator	#20, Figures 6, 9	Close, lock, and tag DO NOT OPERATE	
Glycol outlet valve leaving the evaporator	#12, Figures 6. 9	Close, lock, and tag DO NOT OPERATE	

Secondary Refrigerant Isolation, Including Brine Pump

The secondary refrigeration side of the system is the pump and piping that will move the brine to the area being cooled. This may be a curling or hockey ice rink or some other location that requires cooling. The secondary refrigeration system is isolated before maintenance on the pump or piping is performed.

Figure 9 – Glycol Storage Tank and Piping

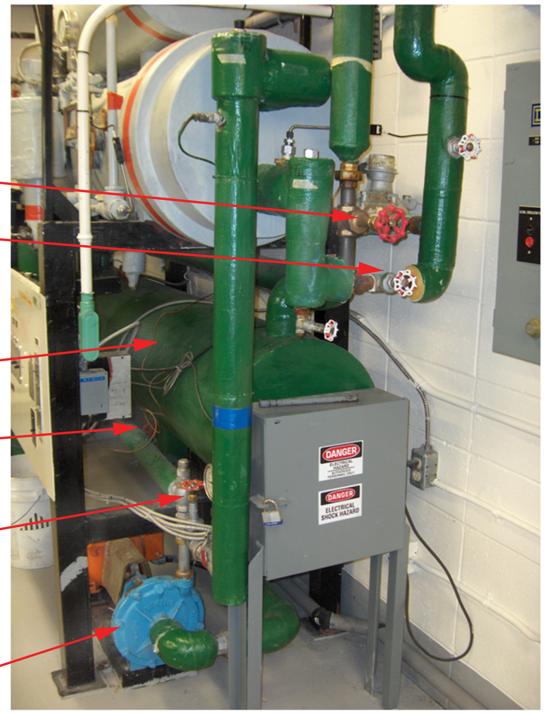


Table 3 – Secondary Refrigerant Isolation (Including Brine Pump) – Lockout and Tag

Component	Figure	Actions	Reason
Outlet valve from the liquid receiver	#6, Figures 5, 6, 10	Close, lock, and tag DO NOT OPERATE	Prevent ammonia from entering the evaporator
Glycol pump breaker	#15a, Figure 8	Open, lock, and tag DO NOT OPERATE	Prevent circulation of glycol through the system
Glycol pump suction valve	#13, Figures 6, 9	Close, lock, and tag DO NOT OPERATE	
Glycol pump discharge valve	#14, Figures 6, 9	Close, lock, and tag DO NOT OPERATE	
Glycol outlet valve from the evaporator	#12, Figures 6, 9	Close, lock, and tag DO NOT OPERATE	

Condenser Isolation

The condenser and receiver are isolated when maintenance is performed. An example of such maintenance is tube repair on the condenser.

Figure 10 – Condenser Receiver

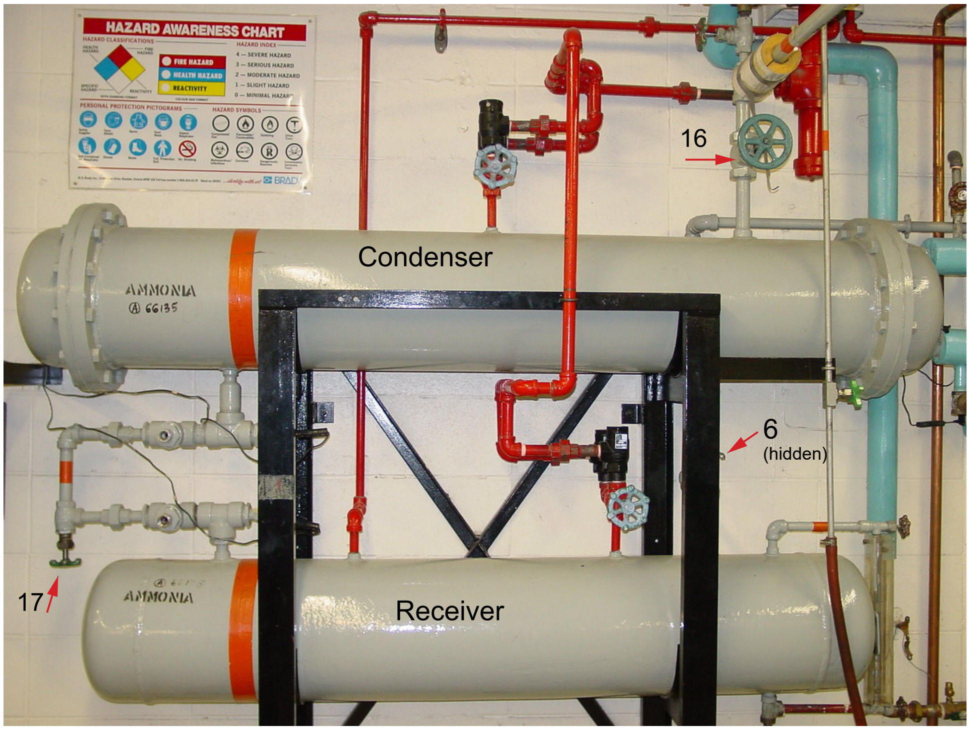


Figure 11 – Cooling Water

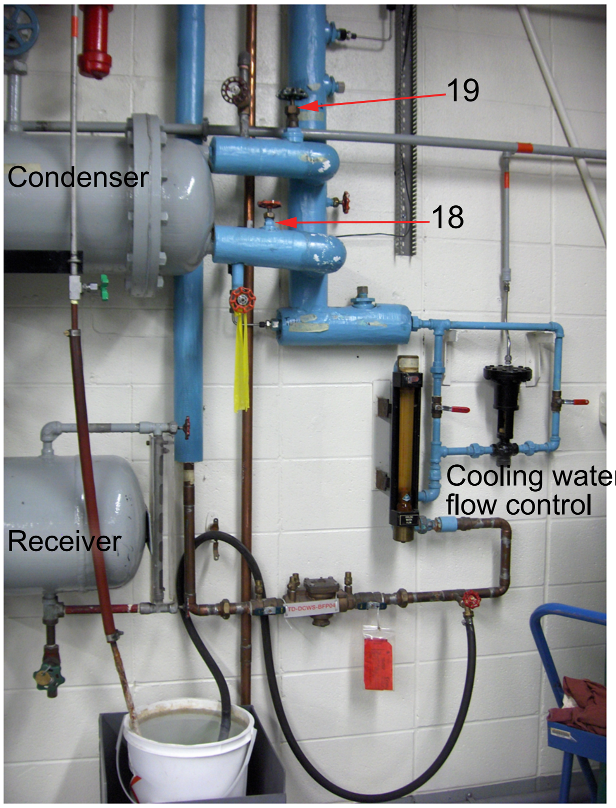


Table 4 – Condenser Isolation – Lockout and Tag

Component	Figure	Actions	Reason
Compressor	Figure 5	Shut down, isolate, and tag (see Compressor Isolation)	Stop the flow of ammonia to the condenser
Condenser inlet valve	#16, Figures 6, 10	Close, lock, and tag DO NOT OPERATE	
Condenser outlet valve to the receiver	#17, Figures 6, 10	Close, lock, and tag DO NOT OPERATE	Stop the flow of ammonia to the condenser
Receiver outlet valve	#6, Figures 5, 6, 10	Close, lock, and tag DO NOT OPERATE	Prevent the flow of ammonia back into the condenser
Cooling water inlet	#18, Figures 6, 11	Close, lock, and tag DO NOT OPERATE	Stop the flow of cooling water to the condenser
Cooling water outlet	#19, Figures 6, 11	Close, lock, and tag DO NOT OPERATE	Isolate the cooling water to the condenser

Chapter Summary

Safety in ammonia refrigeration systems is the result of thorough maintenance, regular testing, and correct operation. Without these processes in place, ammonia refrigeration systems have the potential to cause great damage. This chapter covered oil removal, a necessary step to keep refrigeration systems running efficiently. It described brine testing, which can warn operators of scale buildup, corrosion, or leaks in the system. It laid out the steps for pumping down compression refrigeration systems without damaging components of the system. Finally, it described in detail how to correctly isolate equipment.

For all of the procedures described above, it is essential to follow site-specific SOPs.

Unit Summary

This concludes the unit on refrigeration systems. This unit covered:

- Refrigeration thermodynamics
- Refrigeration safety
- Compression refrigeration systems and components
- Absorption refrigeration systems and components
- Refrigeration system controls

Power Engineers are responsible for the safe and efficient operation of all thermal systems in a plant, including those devoted to cooling processes. This unit provided a basic understanding of refrigeration theory, compression and absorption systems, and the safety factors that need to be considered under different control strategies.

The refrigeration industry is relatively safe. Most of the hazards are common to many work situations, rather than specific to refrigeration. The effects of refrigerant toxicity are highly mitigated when appropriate operator training is completed.

A self-assessment tool is available on MyPower LMS. Login using the unique user ID and password found on the inside front cover of Unit 1.

Notes

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UNIT B-9

Knowledge Exercises and Unit Glossary

Knowledge Exercises – Chapter 1

Name: ______________________________ Date: ________________________________

Instructor: ___________________________ Course: ______________________________

Objective 1

1. *Change of state* is also called _________________ _________________.

2. List the ASHRAE designations for the following refrigerants:
   a) Ammonia _____________
   b) Freon 22 _____________
   c) Propane _____________

3. Compare the boiling point of ammonia and R-134a at atmospheric pressure.

Objective 2

4. What are the standard operating conditions used for comparison of refrigeration systems?

5. The part of a refrigerating system most similar to a boiler feedwater valve is the _____________________ _________________.

Chapter 1 (Cont.)

6. Make a simple sketch of a vapour compression refrigeration system. Include all major system components.

7. Name the two most important heat exchangers in a refrigeration system.

Objective 3

8. Sketch an indirect refrigeration system used for cooling air.

Chapter 1 (Cont.)

9. Explain why the refrigerant temperature in a chilled water cooler must not go below 0°C.

10. An evaporator is designed for a temperature difference of 15°F between the evaporator and the air being cooled. What is this temperature drop in Celsius?

Objective 4

11. What causes flash gas in the evaporator?

12. An ice rink is flooded with 40 125 L of water at 0°C. The refrigeration plant can turn all this water into ice at 0°C in a period of 11 hours.

    a) How many kilojoules of heat must be removed from the water to turn it into ice?

    b) How many kilojoules of heat per hour must be removed from the water?

    c) How many tonnes of refrigeration are required?

    d) How many USCS tons of refrigeration are required?

13. An ammonia refrigeration plant operates with a 35°C condenser temperature, and a −10°C evaporator temperature. Determine the following, using the ammonia refrigeration tables. Assume no superheat and no subcooling.

    a) The specific enthalpy of the refrigerant entering the evaporator

    b) The specific enthalpy of the refrigerant leaving the evaporator

    c) The NRE

Chapter 1 (Cont.)

14. An R-134a plant has a high side pressure of 920 kPag, and a low side pressure of 440 kPag. If the atmospheric pressure is 101.3 kPa, calculate the pressure ratio of the compressor.

Objective 5

15. Give the common name, the ASHRAE designation, and the chemical formula for a refrigerant that is toxic, somewhat flammable, and in common use.

16. A B2 refrigerant is more ________________ than an A2 refrigerant.

17. The element found in refrigerants that contributes to ozone depletion is ________________________.

18. Name a low-pressure refrigerant, suitable for use in large chilled water plants.

19. Identify the properties of an ideal refrigerant.

Objective 6

20. Why is it ideal for evaporators to operate above atmospheric pressure?

Chapter 1 (Cont.)

21. Is it better for a refrigerant to have a high or a low specific volume in its vapour state? Explain why.

22. What is the NRE of R-717, at standard conditions?

Objective 7

23. Explain how non-toxic and non-flammable refrigerants can still be dangerous.

24. Explain three reasons why refrigerants must be kept dry.

25. What affects the rate of refrigerant leakage from a refrigeration system?

Chapter 1 (Cont.)

26. What is the explosive range for ammonia in air?

Knowledge Exercises – Chapter 2

Name: ______________________________ Date: ________________________________

Instructor: ___________________________ Course: ______________________________

Objective 1

1. Identify the components found on the high pressure and low pressure sides of a compression refrigeration system.

2. Sketch a simple refrigeration system and label all the parts. Identify the components as high side or low side. Indicate the state of the refrigerant (vapour, liquid, or both) in each part of the refrigerant circuit.

Chapter 2 (Cont.)

3. Explain why large refrigeration systems use multiple compressors.

4. Name six devices used to protect refrigeration compressors.

5. What is the purpose of a refrigeration compressor crankcase heater?

Objective 2

6. What is the difference between direct and indirect refrigeration?

7. The most common brine used in ice arenas is a solution of ________________________ ________________________. Depending on the concentration, this brine can be cooled as low as _________ degrees Celsius without freezing.

Chapter 2 (Cont.)

8. In a direct expansion system, what could happen if an evaporator developed a leak?

Objective 3

9. Describe the advantages of purchasing a packaged refrigeration unit over installing individual components.

10. Name three reasons why economizers are installed on packaged water chillers.

11. How do economizers reduce centrifugal compressor power requirements?

Chapter 2 (Cont.)

Objective 4

12. Describe the three main functions of refrigeration compressors.

13. List four types of rotary compressors used in refrigeration service.

14. What bearing materials should not be used in ammonia refrigeration compressors? Why?

15. What is the function of a booster compressor?

Objective 5

16. Name the three basic types of evaporators.

Chapter 2 (Cont.)

17. The ___________ evaporator has no recirculation of liquid or gas, and contains only a small amount of liquid refrigerant at any time.

18. Regarding evaporators, what is meant by the term "flooded"?

19. Why do liquid overfeed systems require low-pressure receivers?

20. Why are some chillers equipped with surge drums?

21. Describe the advantages and disadvantages of air-cooled condensers.

Chapter 2 (Cont.)

22. Draw a simple diagram of a double-tube condenser. Label the direction of refrigerant and cooling water flow.

Knowledge Exercises – Chapter 3

Name: ______________________________ Date: ________________________________

Instructor: ___________________________ Course: ______________________________

Objective 1

1. What happens if the refrigeration plant capacity does not match the cooling load?

2. What are the units used to rate refrigeration plant capacity?

3. Explain how thermostats may control refrigeration system compressor operation.

4. When equipped with temperature-actuated controls, a refrigeration compressor may short-cycle. How is this prevented?

5. A temperature limit control cuts-in at –5°C, and cuts-out at –8°C. What is the differential setting? What is the range?

Chapter 3 (Cont.)

6. Draw a simple diagram of a refrigeration compressor controlled by a cooling thermostat.

7. Explain the operation of a compressor controlled by suction pressure.

Objective 2

8. What is the purpose of the low chilled water temperature cut-off switch?

9. What feature prevents centrifugal compressors from starting at full load?

Chapter 3 (Cont.)

10. What are the conditions that may cause an HVAC chiller to trip on low chilled water temperature when first started? What can on operator do to prevent such a trip?

Objective 3

11. Which conditions can lead to excessively high condenser pressure?

12. What are non-condensable gases? How are they a problem in a refrigeration system?

13. An ammonia system has a high side design pressure of 1500 kPa. It is equipped with a high side safety valve set to 1500 kPa. What is the maximum setting for the pressure-limiting device required under CSA B52 code?

Chapter 3 (Cont.)

14. The oil supplied by an ammonia compressor lube oil pump is at 430 kPa. The compressor crankcase pressure is 250 kPa. What is the net lube oil pressure?

15. Explain why refrigeration compressor low oil pressure cut-off switches sense differential pressure.

16. How does a low oil pressure cut-off switch protect a refrigeration compressor if the oil pump fails when the compressor is running?

Objective 4

17. When comparing identical refrigeration systems, what determines refrigerating system capacity?

18. What happens when a hand-operated expansion valve flows more refrigerant than the evaporator needs to meet the cooling load?

Chapter 3 (Cont.)

19. What happens when a hand-operated expansion valve flows less refrigerant than the evaporator needs to meet the cooling load?

20. Draw a simple diagram that shows how automatic expansion valves work.

21. Why are thermostatic expansion valves called "constant superheat" valves?

Chapter 3 (Cont.)

22. Why do some TEVs use external equalizer piping connections?

23. What type of evaporator would use a low-pressure float valve?

Objective 5

24. Why is it important to control the capacity of an evaporator?

25. Why are face dampers not used to control evaporator capacity in HVAC applications?

Chapter 3 (Cont.)

26. Why are face and bypass dampers better for evaporator capacity control than face dampers?

Objective 6

27. List the common methods of controlling the capacity of refrigeration compressors that are in continuous operation.

28. How does cylinder unloading reduce the capacity of a refrigeration compressor?

Chapter 3 (Cont.)

29. With the aid of a sketch, describe the operation of a cylinder bypass system for refrigeration compressor capacity control.

30. What are the disadvantages of a hot gas bypass capacity control?

Chapter 3 (Cont.)

31. With the aid of a simple sketch, explain the operation of a screw compressor slide valve.

Knowledge Exercises – Chapter 4

Name: ______________________________ Date: ______________________________

Instructor: ___________________________ Course: ____________________________

Objective 1

1. Why are the refrigeration system accumulators always uninsulated?

2. Why do refrigeration compressors require oil separators?

3. What problems does moisture in a refrigeration system create?

4. What is the minimum schedule permitted for threaded DN 25 pipe, when in ammonia service?

Chapter 4 (Cont.)

5. A refrigeration system contains 60 kg of refrigerant. What are the CSA B52 code requirements for stop valves?

6. How often must refrigeration system safety valves be replaced or recertified? Why does CSA B52 require this?

7. Under what conditions is it permissible for high side safety valves to discharge into the low side of a refrigeration system?

Chapter 4 (Cont.)

8. Sketch an emergency discharge line arrangement. Label all parts.

Objective 2

9. What fittings must be used on a nitrogen cylinder for safety, and to prevent system over-pressurization, when pressure testing a new refrigeration piping system?

10. What media must never be used to pressure test an ammonia piping system?

Chapter 4 (Cont.)

11. List three methods of detecting leaks in ammonia systems that are not used for detecting leaks in systems charged with HFCs or HCFCs.

Objective 3

12. Sketch an arrangement for charging a mechanical refrigeration system. Label the system parts.

13. Before charging an empty refrigerating system, why is it necessary to put the system under a very high vacuum?

Objective 4

14. Is it feasible to use a dipstick to check the refrigeration compressor oil level?

15. What is the normal reciprocating compressor oil level?

Chapter 4 (Cont.)

16. Sketch an arrangement for returning lube oil from an oil separator to the compressor crankcase.

Objective 5

17. When pumping down the low side, why is it necessary to keep the evaporator pressure above atmospheric?

18. To pump down an evaporator, the _______ or _______________________ valve must be closed.

Objective 6

19. State the names of three organizations that develop codes and standards related to the installation and operation of ammonia refrigeration systems.

20. How much greater should the compressor lube oil pump discharge pressure be over the crankcase pressure?

Chapter 4 (Cont.)

21. A centrifugal chiller purge unit shows steadily increasing run-times over several weeks. What may be the problem?

Objective 7

22. How do non-condensable gases form in refrigeration systems?

23. Non-condensable gases are purged from the ________ of the ________________ and the __________________.

24. Sketch a simple purger, and explain its basic operating principles.

Chapter 4 (Cont.)

Objective 8

25. Name two substances that commonly foul heat transfer surfaces of water-cooled condensers.

26. Biocide is added to cooling tower and evaporative condenser water to control the bacteria that causes _______________ disease.

27. What kinds of water-cooled condensers must be chemically cleaned?

Objective 9

28. Name two electrical hazards associated with troubleshooting of refrigeration compressors.

29. What is the best source for up-to-date equipment troubleshooting information?

30. Name two trades that are well suited to troubleshoot refrigeration system problems.

Knowledge Exercises – Chapter 5

Name: ______________________________ Date: ________________________________

Instructor: ___________________________ Course: ______________________________

Objective 1

1. List the common heat sources for absorption refrigeration systems.

2. Describe the environmental impact of absorption refrigeration systems.

3. Describe the machinery in an absorption refrigeration system used to perform the functions of a compressor.

Objective 2

4. When would an ammonia absorption refrigeration system be preferred to a lithium bromide system?

Chapter 5 (Cont.)

5. Draw a schematic of an ammonia absorption refrigeration system. Label all components. Show the direction of flows. Identify the high side from the low side.

6. Describe the purpose of the absorber in an ammonia absorption refrigeration system.

7. Describe the purpose of the generator in an ammonia absorption refrigeration system.

Chapter 5 (Cont.)

Objective 3

8. What is the refrigerant used in a lithium bromide absorption refrigeration system? Give its common name and its ASHRAE designation.

9. List the low side components of a lithium bromide absorption refrigeration system.

10. List the high side components of a lithium bromide absorption refrigeration system.

11. Why is lithium bromide used as the absorbent in a lithium bromide absorption refrigeration system?

Objective 4

12. Explain the relationship of temperature and the solubility of lithium bromide in water.

13. What is the purpose of the dilution cycle that occurs before a lithium bromide absorption system shuts down.

Chapter 5 (Cont.)

14. Why is concentrated solution from the concentrator mixed with dilute solution to form an intermediate strength solution?

Objective 5

15. State two purposes of the heat exchanger bypass line.

16. What are the four main effects of non-condensable gases in a lithium bromide absorption system?

Chapter 5 (Cont.)

17. Sketch a simple mechanical purge system used in a lithium bromide absorption system, and explain its operation.

Chapter 5 (Cont.)

Objective 6

18. For a lithium bromide absorption system, what items should be on a seasonal pre-start service checklist?

19. List the items to complete on a seasonal shut down for a lithium bromide absorption system.

Objective 7

20. What chemical is usually added to lithium bromide absorption systems to help the salt solution absorb water?

Chapter 5 (Cont.)

21. Describe the steps to add octyl alcohol to a lithium bromide absorption system.

Objective 8

22. What may be the cause of crystallization on lithium bromide absorption system shutdown?

23. A lithium bromide absorption system contains insufficient octyl alcohol. What problems may arise?

24. What condition decreases capacity, causes crystallization after startup, and crystallization during normal operation of a lithium bromide absorption system?

Knowledge Exercises – Chapter 6

Name: ______________________ Date: ______________________

Instructor: ______________________ Course: ______________________

Objective 1

1. What determines the degree of hazard of a refrigeration system?

2. Compare the toxicity of R-123 and R-717.

3. Compare the risk faced by occupants of public assembly buildings to the occupants of industrial buildings, if an ammonia leak should occur.

4. What are high leak probability and low leak probability refrigeration systems?

5. What is the maximum alarm set point for an ammonia vapour detector?

Chapter 6 (Cont.)

6. Identify 7 potential hazards in refrigeration plants.

7. If an ammonia leak detector identifies that the ammonia concentration in a certain area is 3 PPM, will the alarm go off? Why?

8. Why is it necessary to take extra precautions when assessing the refrigeration safety needs of occupants in institutional buildings?

Objective 2

9. What is a "dead man valve"? Where are they found? What purpose do they serve?

10. Why should a maintenance "buddy" have ready access to water?

Chapter 6 (Cont.)

11. An ammonia pipeline contains high-pressure liquid. What are the labelling requirements according to IIAR?

Objective 3

12. What are the typical PPE provisions in a refrigeration plant?

13. What should a person do if trapped by an ammonia leak?

14. What first aid should be given to a person who gets ammonia sprayed on their skin or clothing?

15. List five maintenance procedures for which a refrigeration plant engineer would require site-specific training.

Chapter 6 (Cont.)

Objective 4

16. What is the Canadian Environmental Protection Act?

17. According to CEPA, what is an environmental emergency?

18. What is the purpose of the Environmental Emergency (E2) Regulations under the CEPA?

Knowledge Exercises – Chapter 7

Name: ______________________________ Date: ________________________________

Instructor: ___________________________ Course: ______________________________

Objective 1

1. Oil buildup in a refrigeration system:
   a) Enhances heat transfer
   b) Prevents heat transfer
   c) Reduces compressor power consumption
   d) Reduces compressor discharge pressure

2. While draining the oil pot:
   a) Use system pressure to expedite the process.
   b) Use hot water to boil off the residual ammonia.
   c) Do not drain the oil until all liquid ammonia has evaporated.
   d) Do not isolate the oil pot from the system.

3. The frost line on an oil pot:
   a) Rises as oil accumulates in the system
   b) Drops as oil accumulates in the system
   c) Remains unchanged
   d) Indicates the refrigerant vapour level only

Objective 2

4. Phenolphthalein test strips:
   a) Turn blue in the presence of $CaCl_2$
   b) Turn blue in the presence of ammonia
   c) Turn red in the presence of ammonia
   d) Turn red in the presence of $CaCl_2$

5. If a lab analysis report shows high levels of ammonia, the recommended action is to:
   a) Start the ventilation fans
   b) Add $CaCl_2$ to the brine
   c) Shut down the system and isolate for maintenance
   d) Isolate the expansion tank to prevent offensive odours

Chapter 7 (Cont.)

6. The freezing temperature of the secondary refrigerant:
   a) Is linearly proportional to its concentration
   b) Is inversely proportional to its concentration
   c) Is linearly proportional to its percentage of saturation
   d) Is linearly proportional to its specific gravity

7. With respect to the secondary refrigerant, the pH test is an indication of:
   a) Brine concentration
   b) High levels of iron
   c) Susceptibility of the system to corrosion
   d) Brine freezing temperature

Objective 3

8. List the steps to pump down the low-pressure side of a compression refrigeration system.

9. Why must care be taken to ensure that pressure does not go below atmospheric when pumping down the low side?
   a) Because it will contaminate the ammonia
   b) Because it may result in air being drawn into the system, which could damage some of the components
   c) Because it is not rated for low pressure
   d) Because it will cause the refrigerant to backflow

10. When is a compression refrigeration system pump down required?
   a) To move the refrigerant to the low-pressure side of the system
   b) To drain the system
   c) To perform maintenance on the low-pressure side of the system
   d) To perform maintenance on the condenser or receiver

Objective 4

11. What step must be taken in the event of a suspected evaporator leak?
   a) Use a test strip to determine the presence of ammonia.
   b) Isolate the glycol system immediately.
   c) Monitor minor leaks carefully during operation.
   d) Isolate the evaporator for maintenance.

Chapter 7 (Cont.)

12. A comprehensive lockout procedure includes:

    a) De-energizing electrical equipment by opening and tagging breakers

    b) Draining and flushing the system

    c) Isolating the system by closing, locking, and tagging valves

    d) All of the above

13. The secondary refrigerant:

    a) Is expanded in the evaporator

    b) Is circulated in the location that needs cooling

    c) Is typically ammonia

    d) Provides cooling to the primary refrigerant

UNIT B-9 GLOSSARY

Term	Definition
Absorber	A component of an absorption refrigeration system that contains fluid with a high affinity for the refrigerant in use. The fluid dissolves the refrigerant at the rate it is produced by the evaporator.
Accumulator	A low-pressure vessel, located between the evaporator and the compressor, used to prevent liquid refrigerant carryover to the compressor suction.
AEV	See *automatic expansion valve* (AEV).
American society of heating, refrigeration and air-conditioning engineers (ASHRAE)	A technical society specializing in the fields of heating, ventilation, air conditioning, and refrigeration. ASHRAE supports research and publishes standards for the HVAC industry.
Ammonia	A compound of nitrogen and hydrogen, commonly used as a refrigerant.
ASHRAE	See *American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE)*.
ASME B31.5	The ASME code that has rules for the construction of refrigeration piping and heat transfer components.
ASME BPVC VIII	The **ASME Boiler and Pressure Vessel Code** that has rules for the construction of pressure vessels.
Automatic expansion valve (AEV)	A pressure-actuated flow control device that regulates the supply of liquid refrigerant into an evaporator.
Backpressure regulator	An automatic valve or control device used to maintain a set pressure, and therefore a set temperature, in an evaporator.
Brine	In refrigeration, a liquid solution cooled by a refrigerant and used for heat transmission without changing its state. Also called a secondary coolant.
British thermal unit (btu, or BTU)	A unit of heat equal to about 1055 joules. It is the amount of energy needed to raise the temperature of one pound of water by one degree Fahrenheit.
BTU	See *British thermal unit* (Btu).
Catastrophic leak	A major uncontrolled release of refrigerant that presents serious danger to employees, building occupants, the public, or the environment.
Centrifugal chiller	A packaged refrigeration plant that uses a centrifugal compressor to lower the temperature of water.
Chilled water	Water which, when cooled, is used for the transmission of heat.
Chiller	An evaporator designed to cool water or brine.
Coefficient of performance (COP)	In refrigeration, the ratio of the heat absorbed by the evaporator (NRE) to the power consumed by the compressor.
Compressor	A mechanical device for increasing the pressure of a gas.
Concentrator	A component of an absorption refrigeration system that separates dissolved refrigerant from an absorbent solution, through the application of heat. Also called a Generator.
Condenser	A heat exchanger that causes a vapour to change to a liquid by removing latent heat.
Condenser capacity	The ability of a condenser to reject heat, in tonnes of refrigeration or kW.
Cooling medium	A substance to which a heat exchanger rejects heat.
COP	See *coefficient of performance* (COP).

Term	Definition
Crankcase	The part of a machine that encloses a crankshaft.
Cylinder bypass	A method of controlling reciprocating compressor capacity that uses a bypass piping arrangement to equalize the suction and discharge pressures of cylinders sequentially in response to the load requirements.
Cylinder unloading	A method of controlling reciprocating compressor capacity that effectively shuts off cylinders in sequence in response to the load requirements.
Demand limiter	A device or control strategy used to prevent excessive current draw during the initial startup of a piece of equipment.
Direct system	A refrigeration system with an evaporator arrangement, whereby liquid refrigerant is fed through a metering device and evaporates due to heat absorbed directly from the cooled medium.
Evaporator	The part of a refrigeration system in which liquid refrigerant changes state to produce a cooling effect
Evaporator capacity	The ability of an evaporator to absorb heat, in tonnes of refrigeration or kW.
Evaporator tonnage	See *evaporator capacity*.
Expansion valve	A device in a refrigeration system that regulates the flow of liquid refrigerant into the evaporator.
Generator (refrigeration)	A component of an absorption refrigeration system that separates dissolved refrigerant from an absorbent solution, through the application of heat. Also called a Concentrator.
Halocarbon	A chlorofluorocarbon or other compound in which the hydrogen of a hydrocarbon is replaced by halogens.
Halogen	A highly reactive nonmetallic element, occupying group VIIA (17) of the periodic table, including fluorine, chlorine, bromine, iodine, and astatine.
High side	Those parts of a compression refrigeration system subjected to condenser pressure.
High-pressure float valve	A flow control device that regulates the flow of liquid refrigerant into an evaporator by responding to the accumulations of liquid in the high-pressure side of the system.
Hot gas bypass	A piping system used to control compressor capacity, which directs the flow of hot, pressurized refrigerant gas back to the suction side of the compressor.
Hydrometer	A weighted and sealed hollow glass tube, with a scale that indicates specific gravity or relative density.
Indirect system	A refrigeration system whereby a secondary coolant or “brine” is circulated through the substance to be cooled.
Liquid receiver	A pressure vessel installed in the high side of a refrigerating system for storage of liquid refrigerant.
Lithium Bromide (LiBr)	A salt (LiBr) with a high affinity for water, used to develop low pressure in the evaporator of an absorption refrigeration system.
Low side	Those parts of a compression refrigeration system subjected to evaporator pressure.
Low-pressure float valve	A flow control device that regulates the flow of liquid refrigerant into a flooded evaporator, and is actuated by the level of refrigerant liquid in the evaporator.
Low-pressure receiver	A vessel installed in liquid overfeed refrigeration systems that provides a reservoir of low temperature liquid for circulation through the evaporators, and intercepts liquid returning from the evaporators to prevent slugging the compressor with liquid. Also called an accumulator.

Term	Definition
Manual expansion valve	An expansion valve operated by hand.
Mechanical refrigeration	A term describing a refrigeration system that uses mechanical means to transfer energy to and from a cooling medium.
Metering device	Any one of several devices used to control the flow of liquid refrigerant into an evaporator.
Miscibility	The property whereby substances can be mixed together or can dissolve into one another, in any proportion, without separating.
Natural refrigerant	A nonsynthetic refrigerant; a refrigerant found in nature.
Net refrigerating effect (NRE)	The heat absorbed by an evaporator during actual operating conditions.
Non-condensable gas	A gas that does not change state under the pressure and temperature conditions within a refrigeration or steam system.
NRE	See *net refrigerating effect* (NRE).
Octyl alcohol	An alcohol derived from octane. Octyl alcohol is used in lithium bromide absorption refrigeration to enhance the affinity of lithium bromide solution for water vapour, and to reduce the likelihood of crystallization.
ODP	See *ozone depleting potential* (ODP).
Ozone depleting potential (ODP)	The ability of a refrigerant or other substance to contribute to the depletion of the Earth's ozone layer.
p-h diagram	See *pressure-enthalpy diagram*.
Pressure-enthalpy (p-h) diagram	A chart that plots variations of pressure and enthalpy; used to illustrate properties of steam or refrigerants.
Pressure ratio	The absolute high-side pressure divided by the absolute low-side pressure.
Pull down	The act of reducing the temperature of a refrigerated medium, on initial cooling plant startup.
Pump down	A procedure for removing refrigerant liquid from a component of a refrigeration system, often for prolonged shutdown, maintenance, or repairs.
Refrigerated medium	The substance being cooled by a refrigerant.
Refrigerated space	The location being cooled by a refrigeration system.
Safe work practice	An industry term used to describe company written procedures for operating and maintaining equipment.
Saturation pressure	The pressure at which vapour and liquid can exist in equilibrium at a given temperature.
Saturation temperature	The temperature corresponding to a particular saturation pressure.
Short-cycling	The detrimental repetitive starting and stopping of equipment within a short time period.
Standard operating conditions	With regard to refrigeration, an evaporator temperature of –15°C and a condenser temperature of +30°C.
Strong aqua	In an ammonia absorption refrigeration system, a concentrated solution of water and ammonia produced in the absorber.
Subcooling	Cooling a liquid to below its saturation temperature.
Superheat	The process of heating a gas to above its saturation temperature.
TEV	See *thermostatic expansion valve* (TEV).

Term	Definition
Thermostatic expansion valve (TEV)	A metering device that regulates refrigerant flow into an evaporator, in response to changes in evaporator pressure and refrigerant gas superheat.
Ton	A US customary unit equal to 2000 lb.
Ton of refrigeration	A unit of heat transfer equal to 12 000 Btu/hr.
Tonne of refrigeration (TR)	A unit of heat transfer equal to 335 000 kJ/day.
Unloader	A mechanism for reducing the capacity of air and refrigeration compressors during operation or startup.
USCS units	United States Customary System units.
Weak aqua	In an ammonia absorption refrigeration system, a weak solution of water and ammonia produced in the generator.
Work practice	See *safe work practice*.

Additional Workspace

Additional Workspace

Additional Workspace

Additional Workspace