Fundamentals of Refrigeration

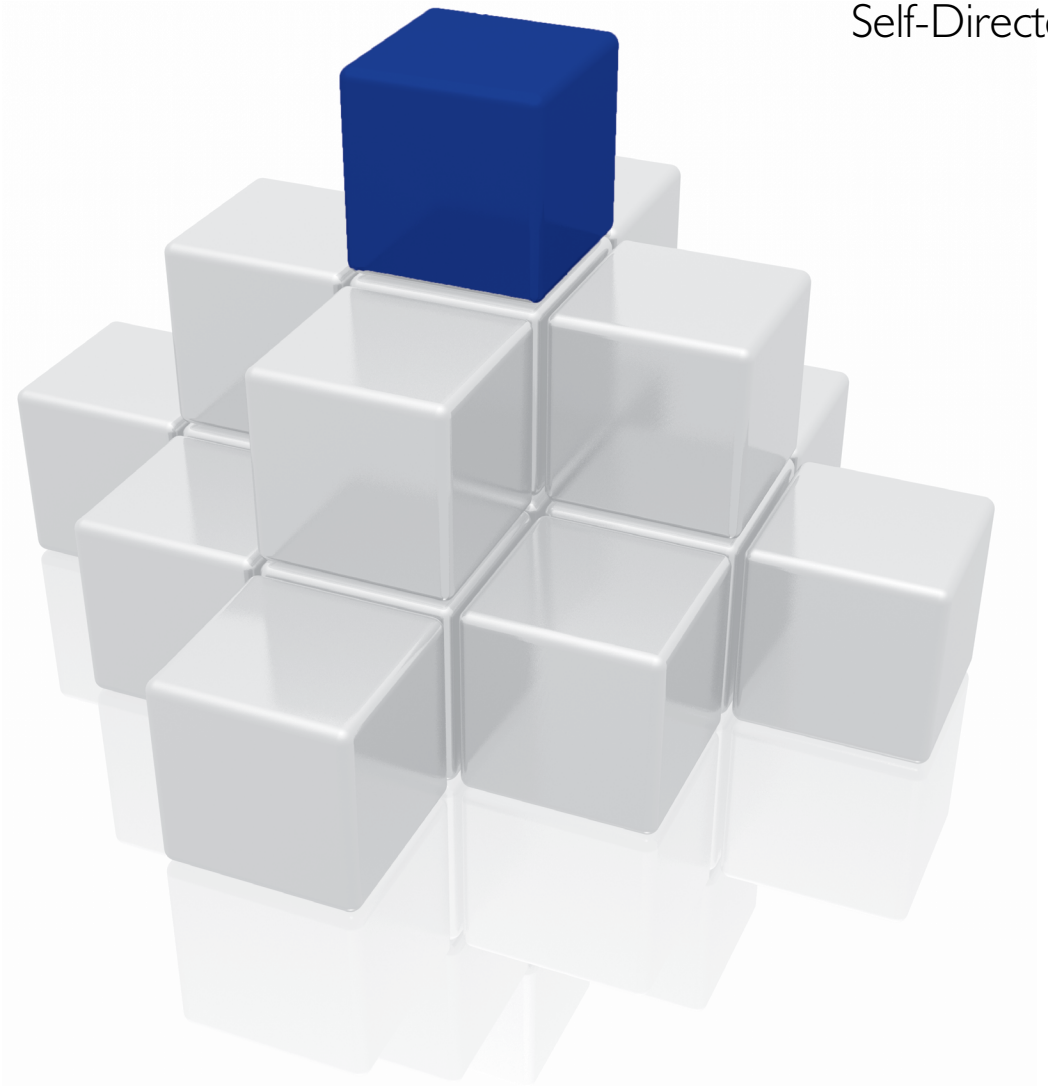
Second Edition

Donald L. Fenton

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Fundamentals of Refrigeration

Second Edition

Donald L. Fenton

A Course Book for Self-Directed or Group Learning

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Donald L. Fenton was born in Doylestown, PA, and raised in the Trenton, NJ, area. He attended Kansas State University (KSU), and during his undergraduate summers he worked as an engineer trainee at the Naval Air Propulsion Test Center near Trenton. In 1969, he obtained a bachelor's degree in Mechanical Engineering from KSU and went on to receive master and doctorate degrees in Mechanical Engineering from the University of Illinois at Urbana-Champaign in 1971 and 1974, respectively.

Upon completing his graduate studies, Don worked at the Fine Particles Section of the IIT Research Institute in Chicago, where he conducted contract research in the areas of air-quality assessment and air-pollution control. In 1977, he relocated to New Mexico State University in Las Cruces, where he taught classes and researched solar energy and combustion systems for nine years. In 1986, he moved to KSU, where he currently teaches a variety of undergraduate and graduate courses, including Thermal Systems Design, in the thermal science area. He also conducts research, some ASHRAE sponsored, relating to the energy field. Don is the department head of the Mechanical and Nuclear Engineering Department at KSU. He is a registered professional engineer and has consulted on many industrial projects.

Don resides in Manhattan, KS, with his wife, Mary. Their three sons, Adam, James, and Michael have completed college and are developing their own careers. A great joy for Mary and Don is to visit their grandchildren, Charlie, Lydia, Audrey, and George in Newnan, GA.

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Preface

Refrigeration has been in existence for over 150 years, and over the years many books have been written explaining its theory and application. Despite this, a modern introduction to refrigeration was not published until 1999, when ASHRAE recognized this need and commissioned Donald L. Fenton to author the first edition of *Fundamentals of Refrigeration*. This text is a revised edition of the 1999 text with the notable addition of a final chapter presenting example applications of refrigeration.

This second edition continues as an introduction to the field of refrigeration. The three major areas of refrigeration are covered: comfort cooling or air conditioning, commercial refrigeration, and industrial refrigeration. The text is divided into chapters that are sequenced in a logical progression from the first principles that underpin refrigeration theory, through thermodynamic cycles and practical details, and finally to four prevalent applications— compressor racks in supermarkets, refrigeration warehouses, meat processing, and a pharmaceutical application. Exercises are available at the end of each chapter for students and readers to assess their understanding of the material and to apply their knowledge to new situations. Current ASHRAE Handbook volumes are used as references throughout, as these are readily available and contain the latest results of ASHRAE and other research.

The intended audience for this book is anyone seeking an introduction to refrigeration based on thermodynamic principles. The text contains the thermodynamic property data and other information necessary to understand the material and to complete the exercises. Two quite different kinds of users are targeted in this book. One is the recent mechanical engineering school graduate who didn't study refrigeration while in college. The other is the veteran technician who has worked in the refrigeration field for a number of years. Both of these, and anyone who falls between, will benefit from this book. The presentations in the text use familiar lines of reasoning and appropriate explanations suitable for all students and readers seeking an introduction to refrigeration. Consequently, this text strives to be both effective and useful as an introduction to refrigeration.

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Acknowledgments

Refrigeration is a major component of ASHRAE's collective research effort and knowledge base. Certainly, the *ASHRAE Handbook—Refrigeration*, published by ASHRAE every four years, maintains the best up-to-date information on refrigeration systems and their application. Acknowledgement is due to ASHRAE for maintaining these activities for the past 50 years. Much of the technical data used in this book was drawn from these Handbooks.

Additionally, ASHRAE is acknowledged for providing support of the author in developing the text, example illustrations, and homework exercises.

Several leaders in the refrigeration field have made suggestions that improved the text, corrected errors, and changed several exercises to make them more effective. These people include: George Briley, Ronald Cole, Brian Friecke, Daniel Kramer, Douglas Rindl, Donald Siller, and Ronald Vallort. Additionally, Justin Smith, while a senior mechanical engineering student at Kansas State University and using a draft copy of the text while studying refrigeration in a special topics course, corrected numerous errors. Special acknowledgment is made to Professor Will Stoecker for first introducing me to the industrial refrigeration field and mentoring me often on the topic.

Very special acknowledgement is reserved for my wife, Mary, who proofread the entire text and corrected many grammatical and context errors. Also, sincere thanks to my three sons, Adam, James, and Michael, for allowing me to develop this work when it meant time not spent with them.

Donald L. Fenton
Manhattan, KS

April 15, 2010

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Fundamentals of Refrigeration

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Fundamentals of Refrigeration

Study Objectives

Chapter 1 introduces the concept of refrigeration and explains how several different refrigeration systems operate. The classification of refrigeration systems and sample applications of refrigeration are discussed. After studying Chapter 1, you should be able to

- ❑ define refrigeration;
- ❑ name and briefly describe at least two methods of refrigeration;
- ❑ name and describe the four basic components of a vapor-compression refrigeration system;
- ❑ describe the purpose of a heat-pump system; and
- ❑ identify three applications of refrigeration.

Instructions

Read the material in Chapter 1. At the end of the chapter, complete the skill development exercises without referring to the text. Review those sections of the chapter as needed to complete the exercises.

Introduction

Refrigeration is the action of removing heat from an enclosed space or material for the purpose of lowering its temperature (it is important to note that cold is not added to the material). Consequently, a refrigeration system must provide a means by which heat can moved away. Refrigeration systems do this by providing a cold surface near the material to be cooled. This surface, colder than the material, causes heat to transfer from that material through the cold surface. Because heat only flows from a warmer body to a colder body, the temperature of the cold surface must be less than that of the refrigerated material.

Figure 1-1 shows a diagram of a generic refrigeration system represented by the rectangle in the center. A refrigeration system is the collection of equipment that generates cold and hot surfaces to perform refrigeration. Observe that the temperature of the cold surface is less than the temperature of the

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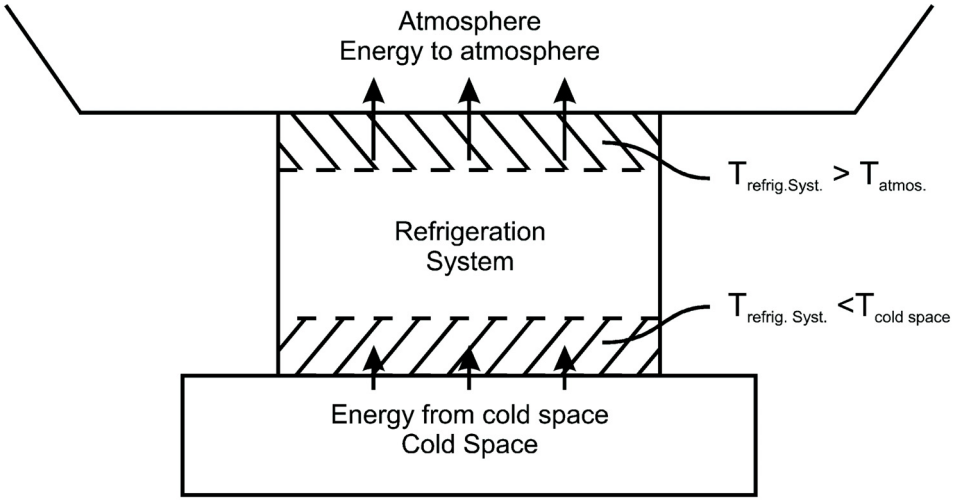


Figure 1-1 Generic refrigeration system.

refrigerated space or material. Once heat or thermal energy passes through the cold surface, the objective of the refrigeration system is to transport the energy to another location—a hot surface whose temperature is higher than the surrounding outside environment. Figure 1-1 shows the movement of heat from the refrigerated material through the refrigeration system and out to the surrounding atmosphere.

Again, observe that because heat only flows from a warm body to a cold body, the hot surface temperature must be greater than that of the surroundings. In summary, a refrigeration system removes heat from one body and transfers it to another body.

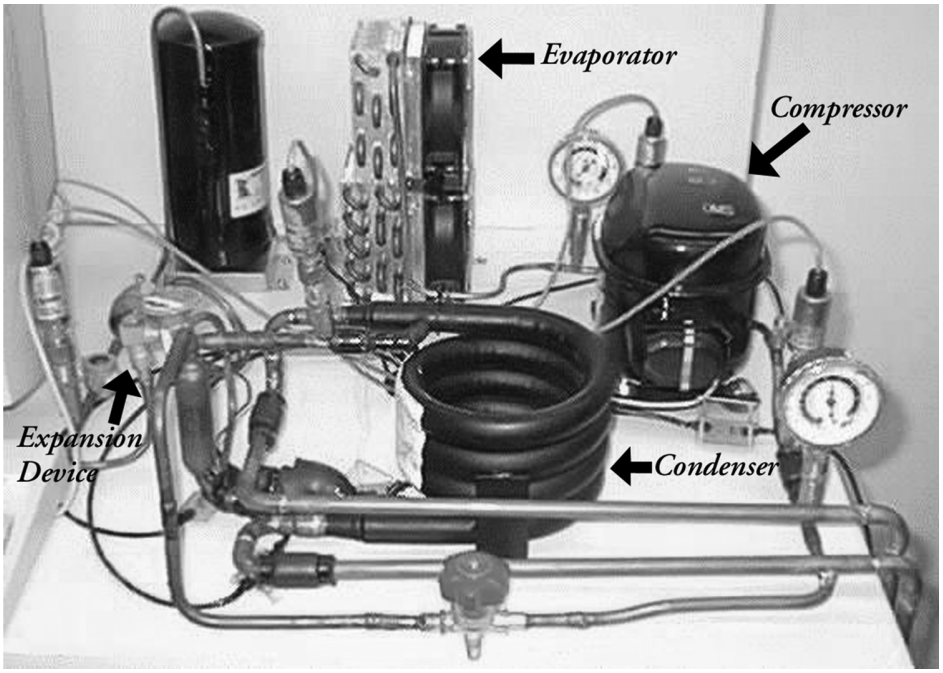
Types of Refrigeration Systems

Several types of refrigeration systems are available, and each accomplishes the same task of removing heat from a space or material. The material may be a gas, liquid, or solid. For example, the refrigeration system in a domestic refrigerator cools the inside air to a temperature less than the surroundings, thus maintaining an appropriate temperature for the storage of food. The means by which the cold surface is generated in the refrigerated space distinguishes one refrigeration system from another.

Vapor-Compression System

The vapor-compression system is the most common refrigeration system currently in use. A vapor-compression system passes a fluid called a *refrigerant* through four components in sequence: evaporator, compressor, condenser, and

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Figure 1-2 A small vapor-compression system showing the components comprising the cycle.

expansion device. Figure 1-2 displays a typical small vapor-compression system. Since the fluid circulates through the system and returns to its original position, the system is also referred to as a *cycle*. The evaporator is the component where the actual cooling occurs. A mixture of liquid and vapor refrigerant at low pressure and low temperature enters the evaporator. The temperature of the refrigerant mixture in the evaporator is somewhat less than the temperature of the refrigerated space or material. Therefore, the evaporator absorbs heat from the space or material, causing the liquid refrigerant to boil or vaporize. The heat transported from the refrigerated space or material causes the space to maintain the needed temperature. The low-pressure, low-temperature refrigerant vapor leaves the evaporator and enters the compressor; upon exiting the compressor, the pressure and temperature are increased to that within the condenser. The condenser transfers heat from the high-pressure, high-temperature refrigerant vapor to the surroundings, causing condensation of the vapor into a liquid. The liquid refrigerant flows to the expansion device, which decreases the pressure and causes the formation of a low-temperature mixture of vapor and liquid that enters the evaporator.

In the vapor-compression system, the refrigerant circulates in sequence among the four components, which constitutes the vapor-compression cycle. An important feature of the cycle is the conversion of the refrigerant from liquid to vapor and back again as it moves through the system. In this way, the

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refrigerant is not consumed during operation of the system. All components of the system operate continuously, because the refrigerant is flowing steadily through the system.

Air-Cycle System

The air-cycle system is different from the vapor-compression system in that the refrigerant (air) does not undergo the conversion from vapor to liquid and back again. In the air-cycle system, air from the refrigerated space enters a compressor, which increases the air's pressure and temperature. The air then passes through a heat exchanger, which results in the high pressure air being cooled to a temperature near the outside ambient temperature. Next, the air moves through an expansion device that reduces the air pressure to that of the refrigerated space. The temperature of the air is also reduced by the expansion device to a value somewhat less than that of the refrigerated space. Finally, the chilled air is re-introduced to the refrigerated space, where it mixes with and lowers the temperature of the somewhat warmer air. Air continues to be drawn from the refrigerated space, passing through the refrigeration cycle, until the desired space temperature is achieved.

A variation of the air-cycle system is used in commercial aircraft to provide cabin air conditioning. The compressed air is supplied by bleeding a small airstream from the compressor of the gas turbine engine providing propulsion. Cooling the high-pressure airstream is accomplished using a heat exchanger (coil) over which passes high-altitude ambient air. When the cooled high-pressure air is expanded to cabin pressure, the temperature decreases to somewhat below the cabin air temperature. The mixing of the expanded cool air with the cabin air cools the air in the cabin. To keep the cabin pressure from increasing, an equal amount of warm air is allowed to flow out as the chilled air is introduced. What differentiates the air-cycle system in aircraft cabin cooling is that the air does not complete a cycle, but rather begins as air entering the engine's compressor and ends by leaking from the aircraft cabin. This type of cycle is usually referred to as an *open cycle* because the same air does not continue to circulate through the cycle.

Absorption System

An absorption system method of refrigeration is similar to a vapor-compression system in several respects. Figure 1-3 shows a simplified schematic diagram of an absorption refrigeration system. First, a refrigerant fluid sequentially moves through the components of the system. Second, the refrigerant moves through a condenser, expansion device, and evaporator in a manner similar to that of the vapor-compression cycle. The difference lies in how the low-pressure, low-temperature refrigerant vapor is changed to a high-pressure, high-temperature vapor. In the absorption cycle, the vapor leaving the evaporator is absorbed by a liquid solution in a vessel called an absorber. Heat

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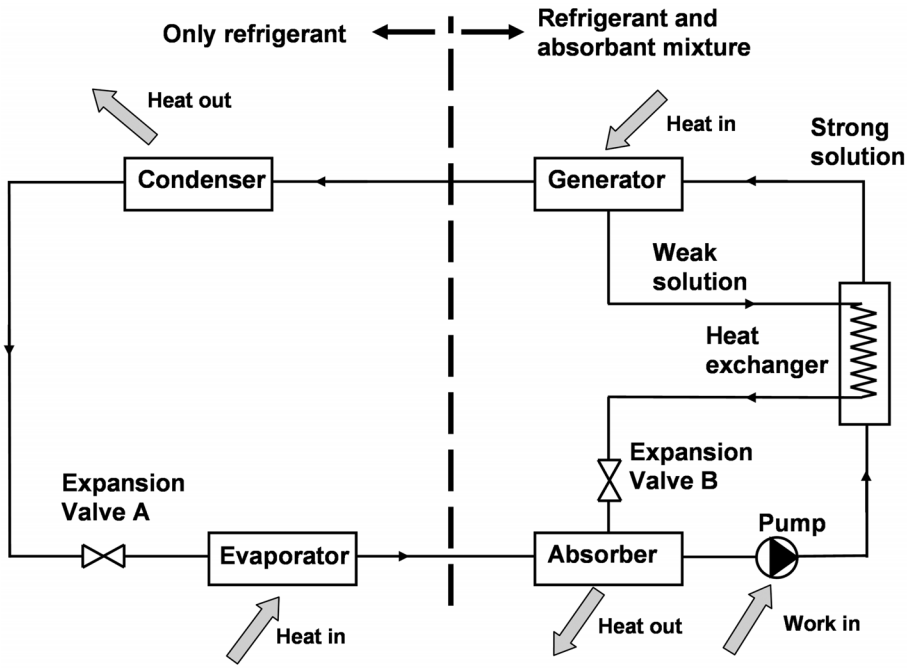
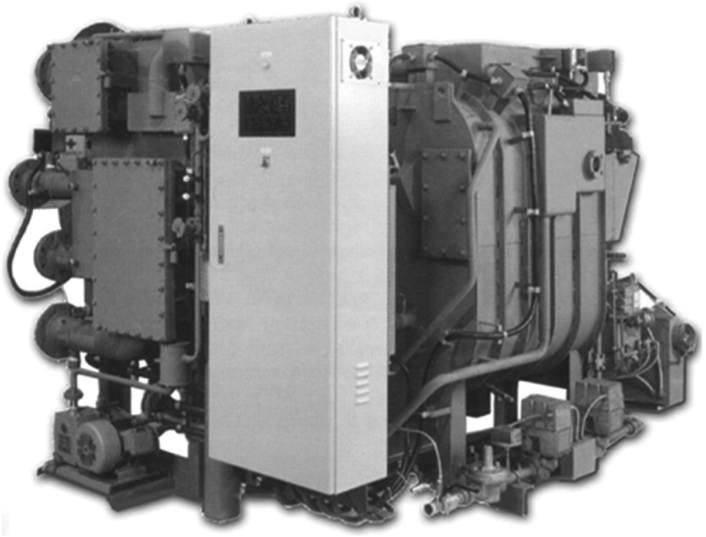


Figure 1-3 Simplified schematic diagram of an absorption refrigeration system.

must be removed from the absorber to maintain the affinity that the vapor has for the solution. A pump increases the pressure of the liquid solution to the level of the condensing pressure; the liquid solution then enters another vessel called a generator. Heat is added to the generator, driving the refrigerant vapor out of the solution. At this point, the refrigerant enters the condenser, where the energy absorbed by the refrigerant is transferred to the atmosphere. The refrigerant then passes through an expansion device, which lowers its temperature and pressure. Finally, the low-temperature, low-pressure refrigerant enters the evaporator, completing the cycle. A significant quantity of heat at a moderate temperature is needed to operate the absorption system, and a relatively small input of electrical power is necessary to operate the pump. Thus, for example, when waste heat is available from a steam boiler, an absorption system may be employed to provide low-cost refrigeration. Figure 1-4 shows an absorption system used to provide chilled water for air conditioning a commercial building.

Water and ammonia are commonly paired in absorption refrigeration systems, with ammonia serving as the refrigerant. Because ammonia is the refrigerant, temperatures below the freezing point of water are possible. The success of the ammonia-water pair is due to ammonia's large affinity for water. Another common fluid pair is water and lithium bromide. In this pair, water is the refrigerant, and the lowest achievable temperature is limited by its freezing temperature of 32°F. Absorption systems for air conditioning generally use the

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Figure 1-4 An absorption refrigeration system used to supply chilled water for a commercial building.

water-lithium-bromide pair, because sufficiently low temperatures are produced.

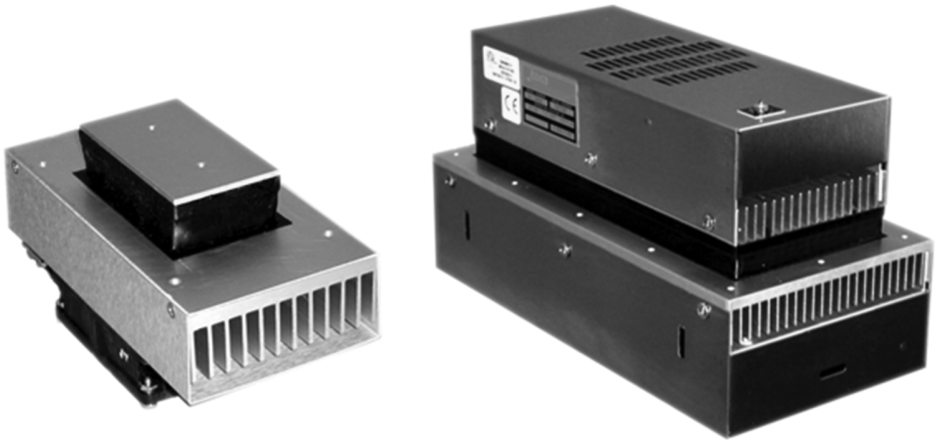
Thermoelectric System

In the 1960s, semiconductor materials were developed that allowed for commercial production of thermoelectric systems for refrigeration. These systems depend on the Peltier effect, first observed by Jean Peltier in 1834, which states that when an electric current passes through junctions of two dissimilar metals, one junction is cooled and the other is heated. Consequently, a cold surface is generated, whereupon heat may be absorbed. The hot surface receives the heat or thermal energy from the cold junction for transfer into the environment. Many junctions placed in series and attached to a plate forming a cold side and another plate for the hot side provide one approach to constructing a practical system. Figure 1-5 shows a thermoelectric cooler in two configurations: with a flat cold plate and using an air fan.

Evaporative Cooler

In climates where the air contains little moisture (such as the desert Southwest of the United States), the evaporative cooler is commonly used to cool residential and commercial buildings. The evaporative cooler typically consists of

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(a) **(b)**

Figure 1-5 Thermoelectric coolers in two configurations: (a) with a flat cold plate and (b) using an air fan.

pads over which water is dripped. This promotes contact between the water and a warm dry airstream entering the evaporative cooler by means of a fan. The air is cooled by the evaporation of water. Reductions in air temperature may exceed 20°F, depending on how dry the outside air is. For evaporative cooling to be successful, the building must allow some conditioned air to exit, thereby allowing the cooled air to enter.

Major Processes of Vapor-Compression Refrigeration

The processes necessary for several different types of refrigeration were described briefly in the previous section, "Types of Refrigeration Systems." We now direct our attention to the widely used vapor-compression refrigeration system, which is the focus of this course. Figure 1-6 shows the vapor-compression cycle and the relationship between the four components: evaporator, compressor, condenser, and expansion device. In this system, an expansion device is selected to carry out the refrigerant's sudden decrease in pressure. Each of the components is connected at its inlet and outlet by a pipe transporting the refrigerant to the other components. As shown in Figure 1-6, the refrigerant in the evaporator absorbs heat from the cold space, while the condenser rejects heat to the surroundings.

The expansion valve and compressor divide the system into a low-pressure side and a high-pressure side. The evaporator is on the low-pressure side and the

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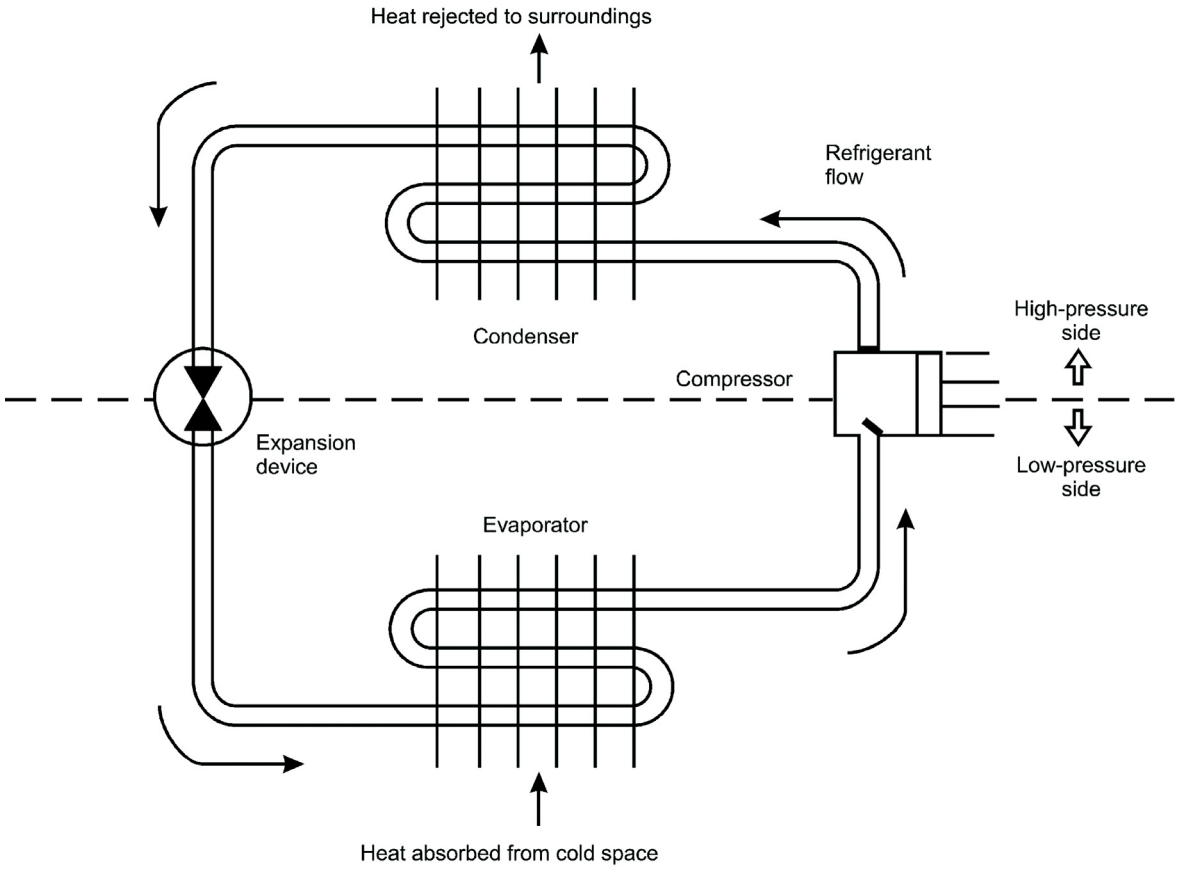


Figure 1-6 Vapor-compression system.

condenser is on the high-pressure side. In Figure 1-6, the compressor is shown with a reciprocating piston and two valves, one for the suction line from the evaporator and one for the discharge line to the condenser. While Figure 1-6 does not accurately show the geometry of the valves in the compressor, note that when the piston moves away from the compressor's top (or head), the suction valve is pulled open by the low pressure in the cylinder, and the discharge valve is forced closed by the high-pressure refrigerant in the discharge line. When the piston moves toward the compressor's head, the suction valve is closed by the higher pressure inside the cylinder, and the discharge valve opens when the pressure in the cylinder exceeds the pressure in the discharge line. In this way, the compressor takes in low-pressure refrigerant vapor and discharges high-pressure vapor to the condenser. To perform its function, the compressor requires power, which ultimately goes into the refrigerant and is revealed by an increase in pressure and temperature.

The refrigerant vapor leaving the compressor is at a temperature exceeding that of the surroundings, thus allowing heat transfer from the refrigerant to the surroundings. The vapor entering the condenser loses heat to the surroundings and begins converting to a liquid (i.e., condenses). It is this condensation

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process that rejects most of the heat. The temperature in the condenser, under ideal conditions, is constant, depending on the pressure of the refrigerant. The heat transfer rate in the condenser regulates the condensing temperature.

In Figure 1-6, vertical lines are shown on the condenser and evaporator to represent fins (thin metal plates) augmenting the heat transfer rate. This is one particular design for these components and the term *coil* is normally applied to this configuration. Individual fans may force air through the coils, thereby further increasing the heat transfer rate.

The expansion device has two functions in the ideal vapor-compression cycle shown in Figure 1-6. First, it reduces the pressure of the liquid refrigerant by passing it through a restriction, thereby forming a mixture of liquid and vapor at a low temperature for the evaporator. Second, the expansion valve regulates the flow of refrigerant to the evaporator. In the cycle shown in Figure 1-6, just enough refrigerant is given to the evaporator so that all the liquid evaporates upon leaving. Inside the evaporator, the conversion of liquid to vapor occurs at constant temperature and pressure for the ideal cycle. The vaporization or boiling of the refrigerant inside the evaporator is the process responsible for the absorption of heat from the cold space. The necessary low temperature is produced by the low pressure of the refrigerant maintained by the compressor.

Later in this course, this ideal vapor-compression cycle is addressed further. Greater detail is provided as to why the system operates as it does, and demonstrations are given for how to make calculations concerning the heat transfer rates and other performance characteristics. Variations on this basic cycle are also presented, including multistage systems for when the needed pressure increase is too large for a single compressor. Deviations of actual cycles from the ideal cycle are also discussed.

Heat-Pump Cycle

A refrigeration cycle and a heat-pump cycle differ only in purpose. A refrigeration cycle is applied to remove heat from a body. In contrast, a heat-pump cycle is applied to add heat to a hot body. Heat-pump cycles are used to heat the interior of a building above the outdoor temperature or to provide a supply of heat to an industrial process operating at an elevated temperature.

In a vapor-compression system, the same equipment is used to construct both refrigeration and heat-pump cycles: compressor, condenser, expansion device, and evaporator. In a vapor-compression heat pump, the working fluid or refrigerant passes through the components in the above order, but the condenser is placed near the need for heat. For example, in an air-source heat-pump cycle applied to heat a residential building, where both the condenser and evaporator exchange heat with air, the condenser is located inside and the evaporator outside. With the use of a reversing valve, the flow direction of the refrigerant may be reversed and the unit converted to a refrigeration cycle. Figure 1-7 shows a schematic diagram of the refrigeration and heat-pump cycles in conjunction with a reversing valve. The reversing of the refrigerant

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flow direction causes the condenser and evaporator to swap positions. Note that the figure, while showing how the refrigerant flow direction is reversed, does not show the use of two separate expansion devices. Two expansion devices (one used for refrigeration and one used for the heat pump) are needed to properly control the refrigerant flow rate for each cycle. Generally, check valves are used to prevent backflow of the refrigerant in actual reversing cycles.

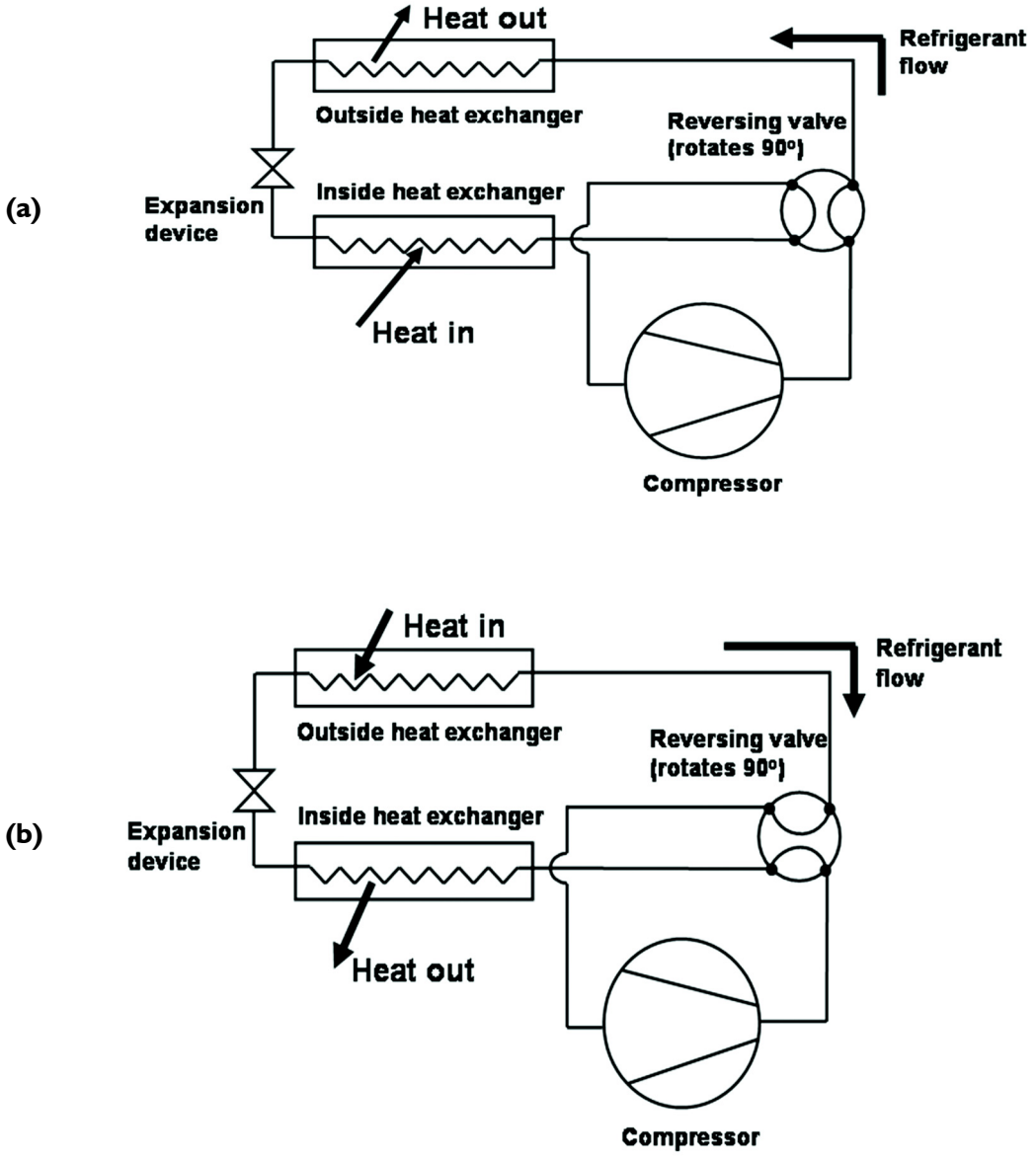


Figure 1-7 Schematic diagrams of (a) a vapor-compression refrigeration system using a reversing valve and (b) a vapor-compression heat-pump cycle with the refrigerant flow reversed.

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The Field of Refrigeration

The field of refrigeration can be loosely divided into three categories: domestic, commercial, and industrial refrigeration. Typical cooling capacities for these categories are as follows:

- Domestic—less than 70,000 Btu/h
- Commercial—more than 70,000 Btu/h
- Industrial—small to very large

The refrigeration and air-conditioning fields are intertwined, but each has its own separate considerations as well. Domestic or residential refrigeration systems include the household refrigerator, food freezer, and the central air-conditioning system. Commercial refrigeration includes larger refrigeration systems than domestic refrigeration requires. Examples of commercial units include supermarket cold-food display cases as well as restaurant walk-in coolers and freezers. Industrial refrigeration is characterized by the application of refrigeration systems to achieve specific goals, such as the cooling and freezing of foods or the removal of heat from material streams in chemical, petroleum, and petrochemical plants. Within the field of air conditioning, refrigeration finds its greatest application in the cooling of air for human comfort. In terms of measures such as units manufactured, total sales volume, and employment level, comfort air conditioning overshadows both commercial and industrial refrigeration.

However, human-comfort air conditioning involves considerations beyond only the cooling of air. The term *air conditioning*, when applied to human comfort, refers to those processes of air treatment that control temperature, humidity, cleanliness, and ventilation to meet the comfort requirements of the occupants in the space. So, air conditioning involves air-heating processes, air-quality control, appropriate regulation of air velocity, and thermal radiation in addition to the refrigeration or cooling processes. Generally, cooling for human comfort requires that refrigeration equipment operate over a relatively narrow range of temperatures, approximately 35°F to 55°F. As this temperature range is small and the market for refrigeration equipment is large, suppliers have standardized their offerings and packaged them for large-volume production, thereby achieving lower unit costs.

In contrast to the air-conditioning field, industrial refrigeration involves custom-designed systems, because the equipment operating temperatures vary significantly for each system. The temperature range of concern for the industrial-refrigeration designer extends to approximately –100°F. Temperatures from below –100°F to near absolute zero (–459.67°F) are covered in the field of cryogenics. These fields are bordered by flexible boundaries, which, from time to time, refrigeration engineers and technicians successfully cross to participate in design and development.

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Refrigeration systems may also be categorized by the type of application in which they are used. The categories that follow are not absolute. Rather, they serve to organize the field of refrigeration in several different ways so as to provide a better understanding. The lines between categories are not absolute, and systems and their applications occasionally cross from one category to another.

Residential Air Conditioning

Residential air conditioning includes the room air conditioner and unitary or central system where the condenser and compressor are located outdoors and the evaporator coil is placed in the air-supply duct near the air-handling unit. Another system type called a heat pump uses the same basic four components (see the previous "Vapor-Compression System" section) and provides both summer cooling and winter heating.

Vehicle Air Conditioning

The most common air-conditioned vehicle is the private automobile, but tractors, buses, trucks, trains, aircraft, and ships are air conditioned as well. This application is characterized by the refrigerated space receiving a large quantity of solar radiation. Also, public transportation vehicles present the added challenge of quickly cooling a large number of people occupying a relatively small space.

Medium- and Large-Sized-Building Air Conditioning

Commercial buildings may require cooling even during cold outside conditions, depending on the heat loads generated internally by people, lights, and office equipment. The responsibility of the refrigeration system is to provide needed cooling so that the people inside the building can function comfortably and effectively. The refrigeration system may consist of a central water-chilling plant as part of a mechanical room. The air-conditioned spaces may be served by one or more air-supply and return-duct systems linked to the central chiller. Another approach is to pipe the chilled water to heat exchanger coils within the air-conditioned spaces where a fan forces the conditioned air through the coil. Single-story building applications sometimes employ rooftop units that supply conditioned air directly to the occupied space.

Transport Refrigeration

Perishable products transported by trucks, rail cars, and cargo containers use vapor-compression refrigeration systems to maintain the required temperature, preventing loss. These transport refrigeration units are similar to those used in

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other commercial applications where the compressor is powered by an electric motor or internal combustion engine (gasoline or diesel) that allows for mobile operation. Air returning from circulating over the products is cooled by the refrigeration system and blown again across the product to maintain the desired interior temperature.

Residential Refrigeration

Vapor-compression is the most-used refrigeration system for domestic full-sized refrigerators and freezers. The refrigerator's function is to generate one or more low temperature spaces suitable for the storage of food. Typically, 32°F to 39°F is suitable for fresh food storage. Freezer sections of combination refrigerators-freezers and individual freezers must maintain approximately 0°F storage temperature. However, smaller units, which may be portable, may use ammonia-water absorption or thermoelectric refrigeration for application in hotel rooms, recreational vehicles, and portable coolers, as their operating noise is considerably less.

Refrigerated Vending Machines

Refrigerated vending machines use vapor-compression refrigeration systems to maintain bottle and can beverages as well as other perishable food products such as ice cream at appropriate temperatures.

Industrial Air Conditioning

This course defines the broad area of industrial air conditioning to include adjusting hostile environments for worker comfort and generating conditioned air appropriate for manufacturing processes. The list of activities involving refrigeration under this category is huge, represented by the following:

- **Spot Cooling.** Cooled air for worker relief in a hot environment where it is impractical to cool the entire plant (such as an ore smelting plant).
- **Environmental Laboratories.** Conditions ranging from the simulation of hot desert climates to those of severe winters (such as chambers for automobile tests concerned with hot and cold engine starts).
- **Printing.** Humidity regulation needed for proper handling of the paper and drying of ink.
- **Textiles.** Regulation of humidity so that static electricity is reduced and fibers have suitable strength and flexibility to travel at high speed through the machines without failure.

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- **Precision Parts and Cleanrooms.** Maintaining the required temperature and humidity to control dimensional variation for metal parts, prevent rust, and reduce dust particles with filtration.
- **Photographic Products.** Proper temperature and humidity to reduce deterioration of photographic raw materials and precisely controlled temperatures for film coating processes.
- **Mine Air Conditioning.** Air cooling and ventilation for worker safety and comfort mandated by the mine's high humidity and high temperature and the need for adequate oxygen.

Industrial Refrigeration

Industrial Refrigeration is another broad area for the application of refrigeration. A large category within industrial refrigeration is the processing and storage of food, while the pharmaceutical and chemical industries also use specialized refrigeration systems. A partial list of applications is provided in the following subsections.

Unfrozen- and Frozen-Food Storage

The time period during which most foods can be safely stored is significantly increased as temperature is reduced. Foods stored at temperatures slightly above their freezing temperature include beef, chicken, fish, eggs, bananas, oranges, apples, tomatoes, lettuce, cabbage, potatoes, onions, and many others. Foods stored at temperatures below freezing include ice cream, fish, poultry products, beef, pork, concentrated fruit juice, prepared foods, and candy.

Process Freezing

Process freezing is the rapid freezing of some foods to minimize growth of ice crystals and extend safe storage time. Common methods of food process freezing include air-blast freezing, where a low-temperature airstream flows past the product; immersion freezing by a low-temperature brine; and contact freezing, where the product (such as ice cream cartons) is placed between cold plates.

Food Processing

Refrigeration may be required in food processing where the food's chemical nature is altered. Example processes that require refrigeration include the curing of milk curds for cheese production; beer fermentation, where the removal of heat is necessary to complete the process; wine storage after fermentation at below room temperature for a period of six months to two years; and fruit juice concentrate production, where refrigeration is used to condense water vapor

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removed from fruit juice. The freeze-drying process also uses refrigeration to condense water removed from food products.

Chemical and Process Industries

Numerous processes that require special refrigeration systems include the separation of gases, the condensation of gases, solidification by freezing one chemical in a mixture, storage of a liquid at a low temperature avoiding high pressure, and the removal of heat from a chemical reaction.

Additional Applications

Additional applications include drinking fountains, dehumidifiers, ice makers, ice-skating rinks, manufacturing plants, environmental test chambers and wind tunnels, construction (freezing soil for excavation and concrete cooling during hardening), and water desalination.

Next Step

The information in Chapter 2 provides a review of thermodynamics, which is important for understanding the processes that comprise the vapor-compression refrigeration system.

Summary

Chapter 1 introduced the refrigeration system as the means by which heat is removed from a material or space and transported elsewhere. Refrigerationsystem types, including vapor-compression, air cycle, absorption, and thermoelectric systems, were discussed, and their essential features were provided. Evaporative cooling was also presented, in which an airstream is cooled by the evaporation of water. The field of refrigeration was categorized by capacity, refrigerating temperature, and application. The boundaries of the categories overlap but, nevertheless, provide structure to the field of refrigeration. You should now be able to

- ❑ define what is meant by the term *refrigeration*;
- ❑ describe the refrigeration systems;
- ❑ discuss the similarities and differences between air conditioning and industrial refrigeration;
- ❑ describe the basic operation of three refrigeration system types;
- ❑ identify and describe the four major components in a vapor-compression refrigeration system;
- ❑ Describe the purpose of a heat-pump system and how it is different from a refrigeration system; and
- ❑ list five major applications of refrigeration and give an example of each.

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Skill Development Exercises for Chapter 1

Complete these questions by writing your answers on the worksheets at the back of this book.

1-1 After arriving home from a long day at work, you open your refrigerator door and remove a bottle containing a cold beverage. What refrigeration-cycle processes occurred to produce your cold drink?

1-2 Describe in your own words the meaning of the word *refrigeration*.

1-3 For the vapor-compression refrigeration system, name the four major components and their functions.

1-4 Describe in your own words the purpose of the heat pump-system.

1-5 Explain the similarities and differences between the fields of air conditioning, commercial refrigeration, and industrial refrigeration.

1-6 Name and describe three applications of refrigeration systems in both the air-conditioning and industrial-refrigeration fields.