Absorption Chillers

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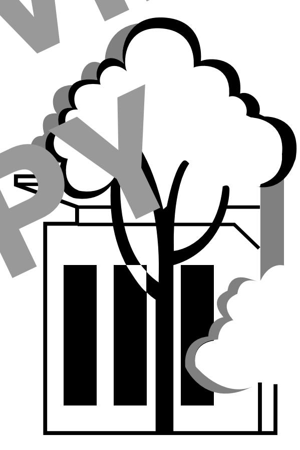
ABSORPTION CHILLERS

Lesson One

Principles of Absorption Chiller Systems



TPC Training Systems

44001

Lesson

1 Principles of Absorption Chiller Systems

TOPICS

Basics of Mechanical Refrigeration Systems
Basics of Absorption Refrigeration Systems
History of Absorption Systems
Absorption Terminology
Simple Single-Effect Absorption Cooling Cycle
Common Absorption Fluid Pairs

OBJECTIVES

After studying this Lesson, you should be able to…

- Explain the differences between a mechanical refrigeration system and an absorption system.
- Describe the basic components in a simple absorption system and their functions in the refrigeration cycle.
- Distinguish between the characteristics of a weak solution and a strong solution and explain the function of each in the absorption cycle.
- Define the terminology associated with absorption systems.
- Describe the steps in a simple single-effect absorption cooling cycle.

KEY TECHNICAL TERMS

Desorption 1.09, 1.27 the process in which heat is added to a weak solution to drive refrigerant vapor from the solution, thus concentrating the solution and permitting refrigerant vapor to transfer to the condenser

Sorbent 1.09, 1.35 fluid that absorbs or desorbs; the portion of the absorption system solution that helps transport the refrigerant through the absorption cycle

Weak solution 1.13, 1.37 a mixture of refrigerant and sorbent in which the sorbent has taken on its limit of refrigerant vapor; a solution with a relatively low percentage of sorbent and a relatively high percentage of refrigerant

Strong solution 1.14, 1.36 the solution remaining after a weak solution has given up most of its refrigerant vapor; a solution with a relatively high percentage of sorbent and a relatively low percentage of refrigerant

Surfactant 1.32 an additive material that reduces the surface tension of a solution, thus enhancing the rate of absorption

This Unit will discuss absorption refrigeration as used in commercial refrigeration and in air-conditioning chillers. Early absorption chillers were used in the late 1800s and were quite popular in residential refrigerators in much of the first half of the 1900s. Even Albert Einstein obtained a patent for an absorption system to cool an ice box. Absorption chillers again became popular in the 1980s. Today absorption chillers are available in a range of sizes from 30 to 2600 tons.

In this Lesson, you will read about the differences between mechanical refrigeration systems and absorption systems. This Lesson describes the basic absorption cycle and the steps and components required to make it work. It also defines the terminology related to absorption systems, which should help you understand not only the basics in this Lesson but also the more advanced systems in later Lessons.

Basics of Mechanical Refrigeration Systems

1.01 Absorption refrigeration may be a new concept for those who are familiar with mechanical refrigeration. Perhaps the best way to understand absorption refrigeration is to compare it to mechanical refrigeration. The paragraphs that follow provide a brief review of a simple mechanical refrigeration system. The next section describes a simple absorption refrigeration system. As you read descriptions of the two kinds of systems, the differences will become clear to you.

1.02 The simple mechanical refrigeration system has only four main components, as follows:

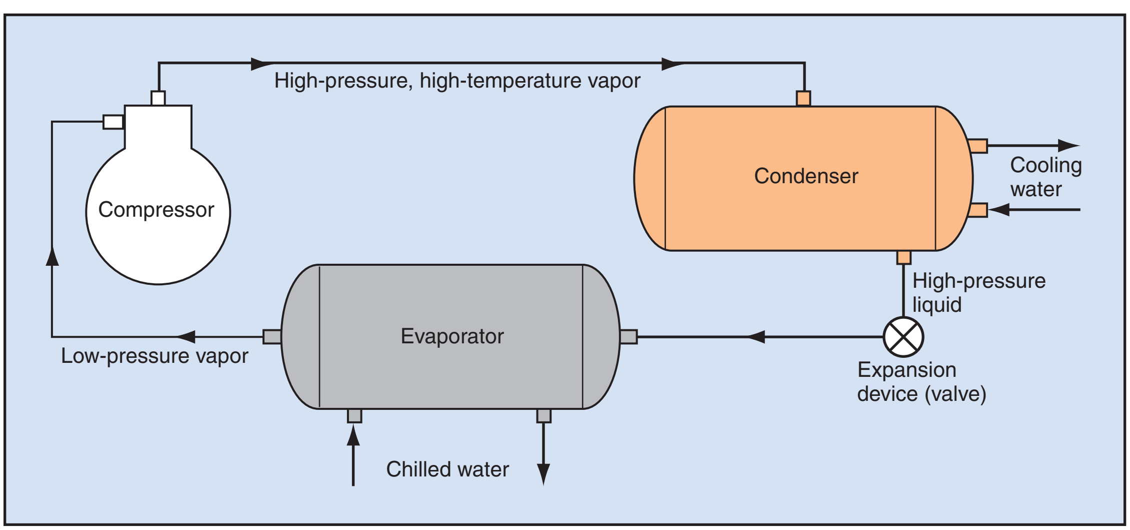
- compressor
- condenser
- expansion device
- evaporator.

These components are shown in Fig. 1-1.

1.03 In this mechanical refrigeration system, the refrigerant enters the compressor as a low-pressure vapor from the evaporator. In the compressor, the pressure and temperature of the refrigerant are increased because of the compression energy put into the refrigerant vapor. This energy is sufficient to raise the refrigerant to a pressure at which the refrigerant vapor can be condensed into a high-pressure liquid.

1.04 The high-pressure liquid refrigerant flows through the expansion device, which provides a throttle to lower the pressure of the refrigerant liquid

Fig. 1-1. Simple mechanical refrigeration system



as it enters the evaporator. (For this reason, the expansion device is sometimes referred to as a *throttle valve*.) As the liquid refrigerant passes through the expansion device, some of the liquid flashes to a vapor and cools the remainder of the liquid to the evaporator temperature.

1.05 In the evaporator, the liquid refrigerant boils because of the heat input received from the desired cooling of a product load. When the liquid refrigerant is boiled to a low-pressure vapor, it is drawn into the compressor to begin the process over again.

1.06 All mechanical refrigeration systems are based on the sequence of events just described. This is true when they are extremely small, as in home refrigerators or window air conditioners. This is also true if they are extremely large industrial systems or air-conditioning chillers of 3000 hp or more.

1.07 The mechanical part of the system compresses the refrigerant from a low pressure to a high pressure by means of a compressor. The compressor might be a positive-displacement machine—for example, a reciprocating piston compressor, a scroll compressor, or a helical screw compressor. All of these compress the vapor by physically reducing the volume of the trapped refrigerant.

1.08 The compressor might, instead, be a dynamic centrifugal machine, which compresses the refrigerant by whirling it at extremely high speeds within the rotor. The vapor is then collected and the speed reduced, which converts the energy from the whirling into an increase in refrigerant pressure.

Basics of Absorption Refrigeration Systems

1.09 A simple absorption system differs from the mechanical system just described. A main difference is that the absorption system has no compressor. The compressor is replaced by a heat source called a *generator*. Another main difference is that the refrigerant is carried by an absorbent material (*sorbent*) that can readily mix with the refrigerant to form a binary (two-material) solution. This binary solution can release the refrigerant (*desorb*) when heated.

1.10 Figure 1-2 shows a very basic absorption system. The main components are as follows:

- generator
- condenser
- expansion valve

Fig. 1-2. Basic absorption system

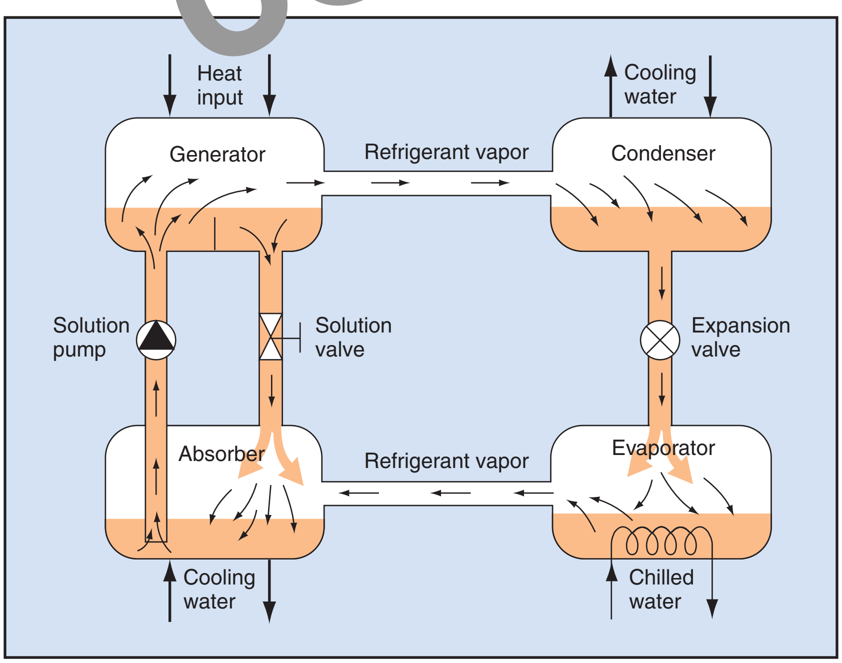
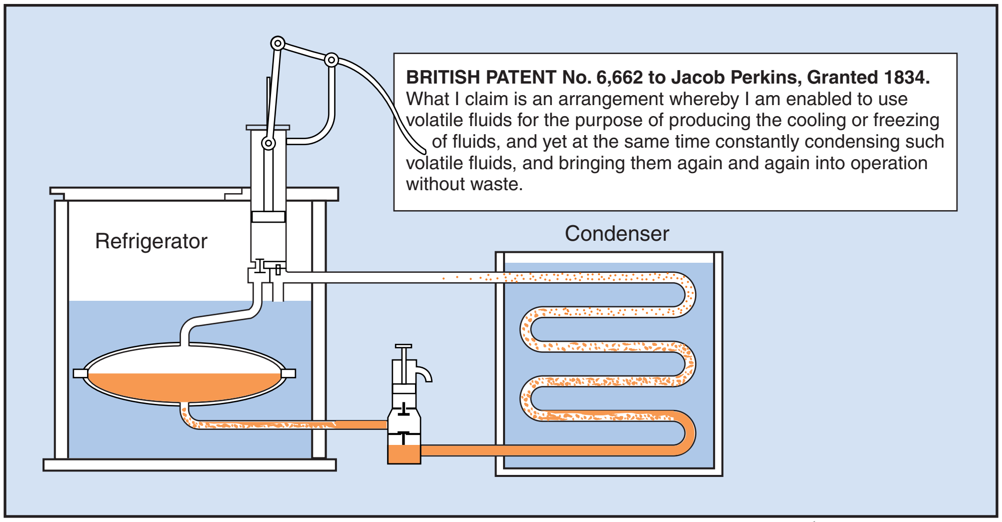


Fig. 1-3. Early patent for refrigeration machine



- evaporator
- absorber
- solution pump
- solution valve.

1.11 In the generator, energy is added to the binary fluid to drive the refrigerant from the solution. The refrigerant vapor pressure is increased during this operation, and the vapor is transferred to the condenser. In the condenser, cooling water removes the heat energy, and the refrigerant condenses to a high-pressure liquid.

1.12 The liquid is then passed through an expansion device where the pressure is lowered to the evaporator pressure level. In the evaporator, the refrigerant boils to a vapor, and the vapor is then drawn into the absorber. In the absorber, the refrigerant vapor readily dissolves into the absorbent fluid. Absorption technicians say that the absorbent has an affinity for the refrigerant vapor.

1.13 When the absorbent fluid has taken on its limit of refrigerant vapor, the mixture is called a *weak solution* because it is greatly diluted. This weak solution is pumped to the generator, where heat is applied to drive the refrigerant vapor off to the evaporator.

1.14 When the weak solution loses the refrigerant vapor, it becomes a *strong solution* because it is highly concentrated with little refrigerant left. The strong solution returns to the absorber, ready to pick up more refrigerant vapor from the evaporator.

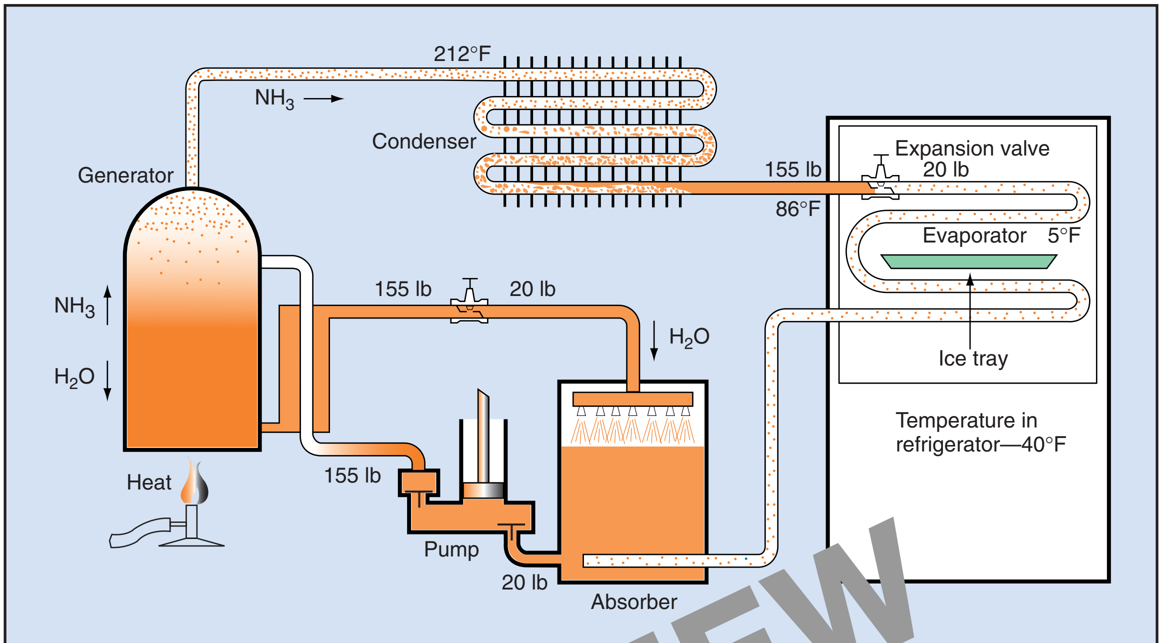
1.15 The refrigerant moves around the entire circuit of this absorption system. The sorbent, however, is confined to a smaller circuit between the absorber and the generator and back again. The refrigeration portion of the system—the action from the condenser through the expansion device and the evaporator—is the same in both mechanical and absorption units.

History of Absorption Systems

1.16 Both absorption and mechanical refrigeration reach back to the ancient civilizations when the evaporation of water into air was used both to cool water and to make ice. In the 1700s, Dr. William Cullen produced cold water by using a suction pump to pull a partial vacuum on ether. The lower pressure reduced the saturation temperature of the ether. Cullen can be considered the originator of all refrigeration, both mechanical and absorption. Figure 1-3 shows an 1834 British patent for an ether refrigeration machine designed by an American, Jacob Perkins.

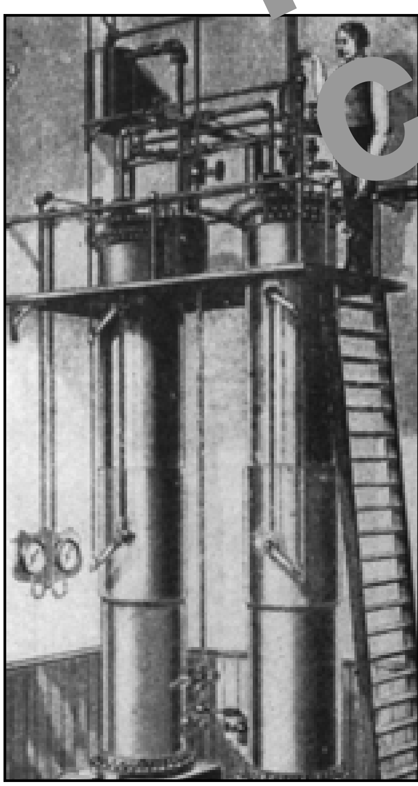
1.17 In 1859 Ferdinand Carré designed and patented the first successful commercial ammonia/water absorption system, shown in Fig. 1-4 on the following page. The machine was produced in several European countries and in the United States.

Fig. 1-4. Carré's ammonia/water absorption system



The design was improved over the years—for example, Fig. 1-5 shows an 1890s four-ton ammonia/water absorption machine—and was a long-time commercial success in the United States. The development of commercial mechanical ammonia refrigeration continued until about 1915. At that time, absorption units were nearly forgotten as electric motor-driven enclosed ammonia compressors gained commercial attention.

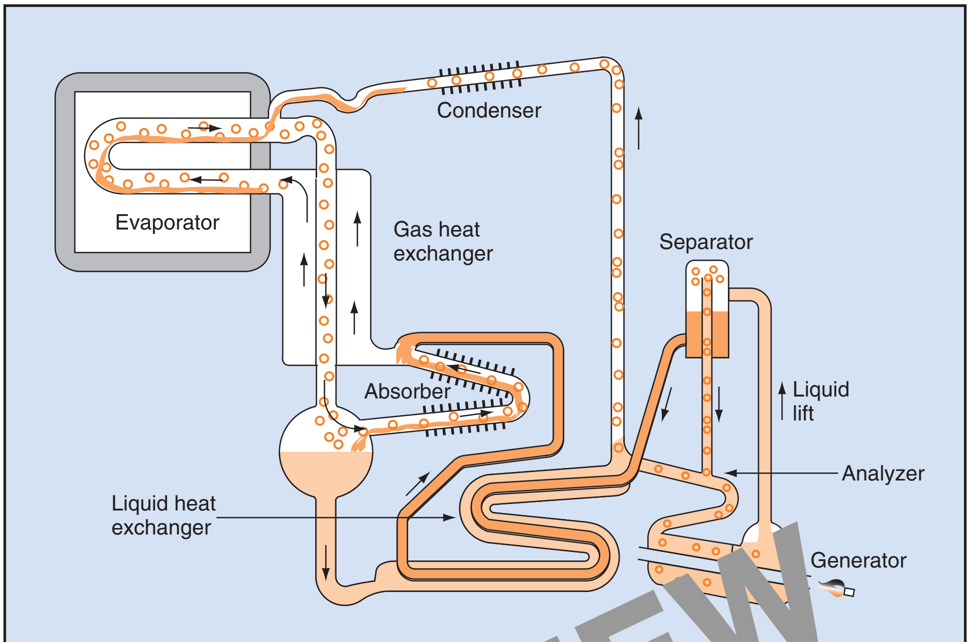
Fig. 1-5. Early four-ton ammonia/water absorption machine



1.18 Small absorption units, typically for residential refrigerators, became popular in the 1920s through the 1940s. In the 1930s, absorption refrigerators were produced by Electrolux in Sweden and Servel in the United States. The early units were designed to use ammonia as the refrigerant and water as the sorbent. Figure 1-6 shows a typical arrangement. Other designs included methyl chloride as the refrigerant and ethylene as the sorbent. During this time, Dr. R. S. Taylor of Servel produced a list of 66 fluids suitable as refrigerant/sorbent solutions.

1.19 In the 1940s, Servel began using a water/lithium bromide solution in their absorption systems. The first commercial large-scale air-conditioning absorption units were also designed around this time. Carrier had chillers ranging from 115 to 200 tons capacity. (One ton equals 12,000 Btu/hr capacity.) In the 1950s and 1960s, large absorption chillers constituted about 25% of the large-tonnage air-conditioning market. In 1969, for example, about 1000 absorption chillers

Fig. 1-6. Typical home refrigerator absorption system



were sold in the United States. The size of the units available increased to 350 tons.

1.20 In 1973, the oil embargo and energy crisis created the perception of a natural gas shortage. This caused the price of natural gas to increase. Because most of the absorption units were fired by natural gas, the market for absorption units declined rapidly. In the 1980s, however, the cost of electricity began to increase. In addition, the popularity of nuclear power began to decrease and no new fossil-fueled power plants were being built. This situation reduced the relative cost of natural gas, and the market for absorption chillers was reestablished.

1.21 Currently, absorption chillers have a reasonable share of the large-tonnage air-conditioning market. The range of sizes has been extended and now reaches from 30 to 2600 tons.

The Programmed Exercises on the next page will tell you how well you understand the material you have just read. Before starting the exercises, remove the Reveal Key from the back of the book. Read the instructions printed on the Reveal Key. Follow these instructions as you work through the Programmed Exercises.

1-1. The expansion device is sometimes called a(n) ________.	1-1. THROTTLE VALVE Ref: 1.04
1-2. Liquid refrigerant boils in the ________.	1-2. EVAPORATOR Ref: 1.05, 1.12
1-3. The binary solution in an absorption system consists of a(n) _______ and a(n) ________.	1-3. REFRIGERANT; SORBENT Ref: 1.09
1-4. Heat in the absorption system generator releases ________ from the binary solution.	1-4. REFRIGERANT Ref: 1.11
1-5. The maximum refrigerant vapor from the evaporator is dissolved in the sorbent in the ________.	1-5. ABSORBER Ref: 1.12, 1.13
1-6. Early absorption units used ________ as the refrigerant and ________ as the sorbent.	1-6. AMMONIA; WATER Ref: 1.18
1-7. The popularity of absorption units increases as the cost of natural gas ________.	1-7. DECREASES Ref: 1.20
1-8. Current absorption units are available in sizes from ________ to ________ tons.	1-8. 30; 2600 Ref: 1.21

Absorption Terminology

1.22 In the Lessons to follow, there are a number of terms specific to absorption refrigeration that you must understand in order to follow the absorption cycle. These terms are presented here and can be used as a reference throughout the remainder of the Unit. Other important familiar terms are also reviewed here.

1.23 **Absorption.** Absorption is the process whereby refrigerant vapor is absorbed into a concentrated (strong) solution. During the absorption process, the heat of condensation and the heat of dilution of the vapor are released into the solution. The fluid must be cooled to allow additional refrigerant to be absorbed into the solution at the low-pressure evaporator condition.

1.24 **Coefficient of performance (COP).** For a chiller, the COP is the ratio of the cooling capacity to the required heat input energy. For a heat pump, it is the ratio of the heat energy output capacity to the required heat energy input. The COP is used as a tool in comparing the efficiencies of equipment from various manufacturers.

1.25 **Condensation.** Condensation refers to the change of state of the refrigerant vapor when it cools from a superheated vapor to the saturation temperature and when it becomes a liquid as the result of latent heat removal.

- A *change of state* refers to a process in which a substance changes from a vapor to a liquid or from a liquid to a vapor.
- A *superheated* vapor has a temperature that is above the saturation temperature of that vapor at a given pressure.
- *Latent heat* is the heat added or removed at constant temperature during a change of state.
- The *saturation temperature* is the temperature at which the vapor condenses to a liquid at a given pressure with the removal of latent heat. It is also the temperature at which the liquid boils to a vapor with the addition of latent heat.

1.26 **Crystallization.** Crystallization is the freezing or conversion of the solution into a solid or slushy mass when the percentage of sorbent at a given temperature is excessive. Water/lithium bromide solutions are subject to this problem. Ammonia/water solutions do not crystallize at normal operating conditions.

1.27 **Desorption.** Desorption is the process in which heat is added to a dilute (weak) solution to drive refrigerant vapor from the solution. This concentrates the solution and permits the released refrigerant vapor to transfer to the condenser.

1.28 **Effect vs. stage.** The terms *single-stage* and *single-effect* are used interchangeably to describe the type of absorption system. Similarly, the terms *multiple-effect* and *multistage* are used interchangeably, as are the terms *two-stage* and *double-effect* or *dual-effect.*

1.29 **Evaporation.** Evaporation is the boiling or vaporization of the liquid refrigerant at a low pressure. The vaporization results from the heat supplied from the product or cooling effect required.

1.30 **Heat pump.** In reference to absorption systems, a heat pump is equipment that uses heat from a high-temperature source to raise the quantity and temperature of heat. This kind of equipment is referred to as a *type 1* heat pump. (Note that this heat pump is different from the system, also called a heat pump, that is used to provide heat in the winter and air conditioning in the summer.)

1.31 **Heat transformer.** A heat transformer is an absorption system that raises the temperature of energy from available sources at reduced quantities using the latent heat and chemical mixing heat of the fluid solutions. This kind of equipment is referred to as a *type 2* heat pump.

1.32 **Performance additive.** This term refers to the addition of very small quantities of chemical surfactants to lithium bromide solutions. The *surfactant* reduces the surface tension of the solution and enhances the rate of absorption of water vapor into the solution. In other words, the performance additive makes it easier for the water vapor and lithium bromide to combine in the absorber.

1.33 **Refrigerant.** A refrigerant is a volatile substance that readily changes state from a liquid to a vapor and back again. Refrigerant performs the following functions within the absorption system:

- It leaves the solution at the generator and travels as a vapor to the condenser where it is liquefied.

- It performs the refrigeration process in the evaporator by boiling at a low pressure to provide cooling.

- After leaving the evaporator as a low-pressure vapor, it is reabsorbed into the solution at the absorber.

1.34 **Solution.** A solution is a liquid with at least two components, one soluble in the other. This combination is called the *working fluid* or the *fluid pair* in an absorption system. The two commonly used fluid pairs are water/lithium bromide and ammonia/water.

1.35 **Sorbent.** The sorbent is the portion of the solution that helps transport the refrigerant through the absorption cycle. It readily absorbs the refrigerant from the evaporator and also releases the refrigerant as a vapor in the generator. Note that the sorbent remains in the absorber/generator portion of the cycle and does not contribute to the refrigeration effect.

1.36 **Strong (concentrated) solution.** A strong solution is a solution with a relatively high percentage of the sorbent and a relatively low percentage of the refrigerant.

1.37 **Weak (dilute) solution.** A weak solution is a solution with a relatively low percentage of sorbent and a relatively high percentage of refrigerant.

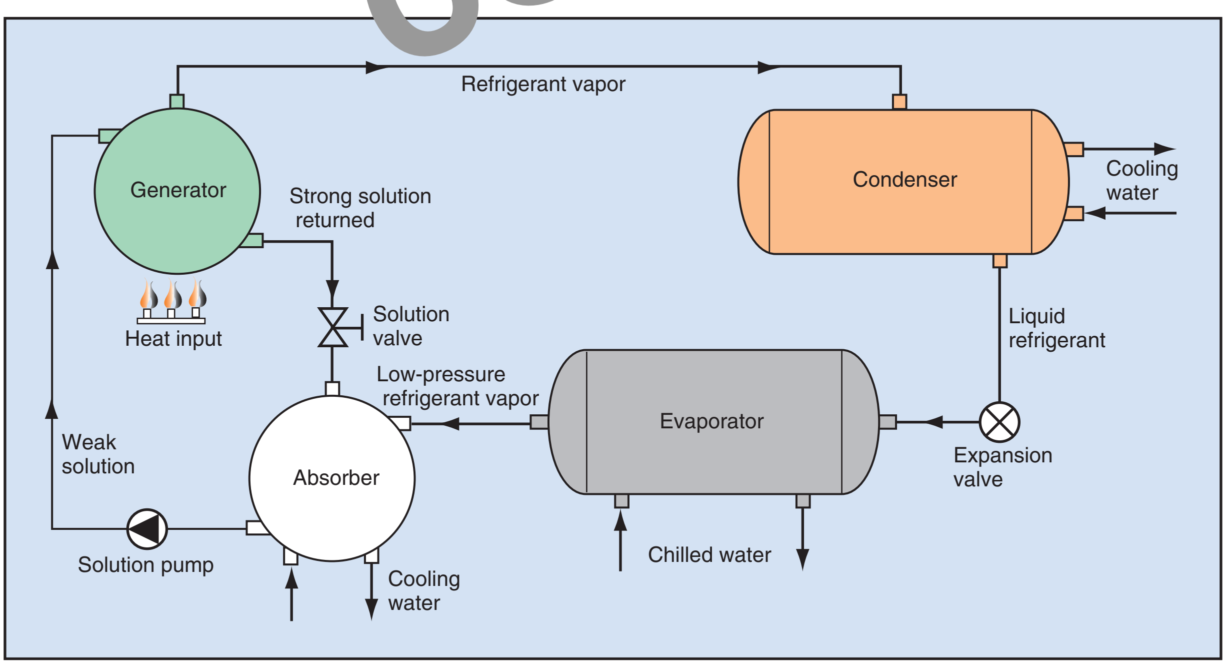
Simple Single-Effect Absorption Cooling Cycle

1.38 A simple single-effect absorption cooling system provides a good place to begin the study of absorption systems. Refer to Fig. 1-7 as you read the description of what each part of the system does. Although this description could start anywhere in the cycle, it will begin in the generator and work its way through each of the components.

1.39 In the *generator* the weak solution is received from the absorber. The weak solution contains a high percentage of refrigerant and a low percentage of sorbent. Heat is added within the generator to raise the pressure of the refrigerant and to drive the refrigerant vapor from the solution. The heat may come from steam, hot water, or a direct-fired natural gas flame. The solution, after giving up the refrigerant, returns to the absorber.

1.40 The *condenser* receives the high-pressure refrigerant vapor from the generator and removes heat

Fig. 1-7. Basic single-effect absorption cooling cycle



from the vapor to condense the refrigerant to a high-pressure liquid. The heat removal is typically provided by cooling water supplied from a cooling tower.

1.41 Between the condenser and the evaporator, the liquid refrigerant flows through an *expansion device* (*throttle valve*). The purpose of the expansion device is to meter the flow of refrigerant and to provide for the pressure difference that is maintained between the condenser and the lower-pressure evaporator. In passing through the expansion device, some of the liquid refrigerant flashes to a vapor. This refrigerant cools the remaining liquid to the evaporator temperature as it enters the evaporator.

1.42 Within the *evaporator*, the cooled liquid refrigerant is sprayed over the coils, which contain the fluid that is being cooled. In an air-conditioning system, this fluid is typically water. The heat that is removed from the fluid as it is cooled transfers to the refrigerant and causes the low-pressure refrigerant to boil to a vapor. The heat required during this process provides the refrigeration effect that cools the fluid.

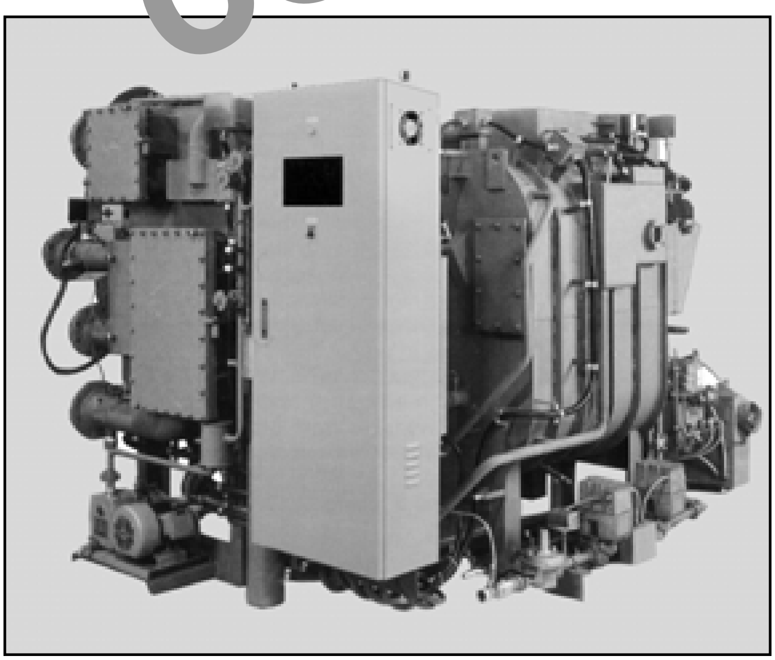
1.43 The vapor from the evaporator is drawn into the *absorber*. The process of the refrigerant being absorbed into the solution creates a low pressure that continuously draws vapor from the evaporator and maintains the evaporator pressure. Therefore, it also controls the temperature within the evaporator.

1.44 The absorption of the refrigerant into the solution tends to generate heat as a result of the absorption process. This heat needs to be removed so that the rate of absorption remains constant. The cooling is provided by a circuit of the condenser cooling water that is directed through the absorber.

1.45 When the solution has taken on sufficient refrigerant, it is pumped through the *solution pump*, which is usually a hermetic centrifugal model. This pump raises the pressure of the weak solution to the pressure level of the generator. The pump must have a large enough capacity to handle the quantity of solution required by the evaporator capacity.

1.46 Once the weak solution has reached the generator, the system cycles the refrigerant continuously. The weak solution gives up the refrigerant and becomes a strong solution because it has a high percentage of sorbent. This strong solution is directed back through a *solution valve* to the absorber. The solution valve throttles the solution to maintain the pressure difference between the absorber and the higher-pressure generator.

Fig. 1-8. Direct-fired, double-effect water/lithium bromide absorption chiller



1.47 All absorption cycles follow the basic concepts shown in this single-effect system. Practical systems have additional components to improve the control and efficiency of the cycles. Some systems include dual-effect and triple-effect components that remove more refrigerant from the solution and increase thermal efficiency. For example, Fig. 1-8 on the previous page shows a modern direct-fired, double-effect water/lithium bromide absorption chiller. These systems are discussed in later Lessons.

Common Absorption Fluid Pairs

1.48 As mentioned previously, the two common fluid pairs are water/lithium bromide and ammonia/water. In the water/lithium bromide system, water is the refrigerant and lithium bromide is the sorbent. In the ammonia/water system, ammonia is the refrigerant and water is the sorbent.

1.49 You may be familiar with ammonia as a refrigerant, but few people consider water as a refrigerant. The pressures on these systems are very different.

- With ammonia as the refrigerant, the condensing pressure with cooling water at 85°F is about 200 psig and the evaporating pressure for chilling water is about 50 psig.
- With water as the refrigerant, the condensing pressure with cooling water at 85°F is less than 1 psia and the evaporating pressure for chilling water is about 0.1 psia.

Because both the condenser and the evaporator operate within a high vacuum, so does the entire water/lithium bromide system.

1-9. In the absorption process, refrigerant is absorbed into a ________ solution.	1-9. STRONG Ref: 1.23
1-10. The coefficient of performance (COP) is used to compare the ________ of equipment from various manufacturers.	1-10. EFFICIENCY Ref: 1.24
1-11. As superheated refrigerant vapor cools to the saturation temperature, it ________.	1-11. CONDENSES Ref: 1.25
1-12. Refrigerant vapor is driven from the absorption solution during the process of ________.	1-12. DESORPTION Ref: 1.27
1-13. An absorption system heat transformer is also known as a type 2 ________.	1-13. HEAT PUMP Ref: 1.31
1-14. A strong solution has a relatively ________ percentage of sorbent and a relatively ________ percentage of refrigerant.	1-14. HIGH; LOW Ref: 1.36
1-15. Common absorption system generator heat sources are ________, ________, and ________.	1-15. STEAM; HOT WATER; NATURAL GAS Ref: 1.39
1-16. Unlike an ammonia/water absorption system, a water/lithium bromide system operates within a high ________.	1-16. VACUUM Ref: 1.49

Answer the following questions by marking an "X" in the box next to the best answer.

1-1. Which of the following mechanical refrigeration components is unnecessary in absorption systems?

☐ a. Compressor
☐ b. Condenser
☐ c. Evaporator
☐ d. Expansion device

1-2. An absorption system generator heats the binary solution to

☐ a. cause some refrigerant liquid to flash to vapor
☐ b. drive refrigerant from the solution
☐ c. drive sorbent from the solution
☐ d. increase the sorbent's affinity for the refrigerant

1-3. In an absorption system, a highly concentrated ________ solution enters the ________.

☐ a. strong; absorber
☐ b. strong; generator
☐ c. weak; absorber
☐ d. weak; generator

1-4. Although the refrigerant cycles through the entire absorption system, the sorbent cycles only between the

☐ a. absorber and evaporator
☐ b. absorber and generator
☐ c. condenser and evaporator
☐ d. condenser and generator

1-5. At the low-pressure evaporator condition, the solution can absorb additional refrigerant if it is

☐ a. compressed
☐ b. cooled
☐ c. desorbed
☐ d. heated

1-6. Conversion of the absorbent solution to a solid or slushy mass is called

☐ a. condensation
☐ b. crystallization
☐ c. desorption
☐ d. evaporation

1-7. Which of the following acts as a performance additive?

☐ a. Heat transformer
☐ b. Sorbent
☐ c. Surfactant
☐ d. Working fluid

1-8. In an absorption system, refrigerant

☐ a. cycles only between the condenser and evaporator
☐ b. is dissolved in a sorbent throughout the cycle
☐ c. is most diluted on leaving the generator
☐ d. provides cooling in the evaporator

1-9. When leaving the generator, refrigerant vapor travels to the ________ and the solution travels to the ________.

☐ a. absorber; condenser
☐ b. condenser; absorber
☐ c. evaporator; solution pump
☐ d. expansion valve; condenser

1-10. Which of the following substances is commonly used as either a sorbent or a refrigerant?

☐ a. Ammonia
☐ b. Lithium bromide
☐ c. Methyl chloride
☐ d. Water

SUMMARY

A simple mechanical refrigeration system has four main components—compressor, condenser, expansion device, and evaporator. A simple absorption system has seven main components—condenser, expansion device, evaporator, generator, absorber, solution pump, and solution valve—but no compressor. A simple mechanical system uses a refrigerant that circulates throughout the entire system. An absorption system uses a fluid pair consisting of a refrigerant and a sorbent. The refrigerant moves around the entire circuit, but the sorbent cycles only between the absorber and the generator.

Successful commercial ammonia/water absorption systems date from 1859. Small absorption units were once popular in home refrigerators. Large units were later used for commercial air conditioning, as they are today. Current absorption chillers are available in sizes from 30 to 2600 tons.

The following are representative of the many absorption terms defined in this Lesson. A *strong solution* has a relatively high percentage of sorbent and a relatively low percentage of refrigerant. A *weak solution*, on the other hand, has a relatively low percentage of sorbent and a relatively high percentage of refrigerant. *Desorption* is the process in which heat is added to a weak solution to drive refrigerant vapor from the solution. The terms *stage* and *effect* are used interchangeably. A *surfactant* is a performance additive that reduces surface tension, thus improving absorption.

In a simple single-effect absorption cooling cycle, the generator receives the weak solution from the absorber and adds heat to drive the refrigerant out of the solution. The solution (now a strong solution) returns to the absorber while the high-pressure refrigerant passes to the condenser where heat is removed. Some of the refrigerant liquid flashes to a vapor as it passes through the expansion device, cooling the remaining liquid as it enters the evaporator. In the evaporator, the liquid refrigerant removes heat from fluid in the coils and boils to a vapor. The vapor is drawn through a solution valve and into the absorber, where refrigerant is absorbed into the solution (now a weak solution) and then pumped to the generator by the solution pump.

The two common fluid pairs are water/lithium bromide and ammonia/water. In both cases, the first term is the refrigerant and the second term is the sorbent. The water/lithium bromide system operates within a high vacuum.

Answers to Self-Check Quiz

1-1. a. Compressor. Ref: 1.09

1-2. b. Drive refrigerant from the solution. Ref: 1.11

1-3. a. Strong; absorber. Ref: 1.14

1-4. b. Absorber and generator. Ref: 1.15

1-5. b. Cooled. Ref. 1.23

1-6. b. Crystallization. Ref: 1.26

1-7. c. Surfactant. Ref: 1.32

1-8. d. Provides cooling in the evaporator. Ref: 1.33, 1.42

1-9. b. Condenser; absorber. Ref: 1.39, 1.40

1-10. d. Water. Ref: 1.48

Contributions from the following source are appreciated:

Figure 1-8. McQuay Air Conditioning