Absorption refrigeration units produce chilled water for air-conditioning systems in buildings and for process cooling requirements in industrial applications. This study unit presents several topics related to absorption refrigeration, which uses lithium bromide as the absorbent. Due, in part, to fuel availability and cycle simplicity, absorption refrigeration units are frequently used in place of the more conventional vapor compression refrigeration units.

Your study of absorption refrigeration begins with an introduction to the basic principles of lithium bromide absorption refrigeration systems. You’ll then be presented with information on the function of each component within the system, typical component arrangements, and capacity control options. The final topic you’ll study is the recommended operation and maintenance of a lithium bromide absorption unit.

**When you complete this study unit, you’ll be able to**

- Convert pressure into several different pressure units
- Describe the basic building air-conditioning cycle
- Determine the cost in dollars per hour per ton for various energy sources
- Explain the chemical characteristics of lithium bromide solutions
- List the name and function of each component within the absorption system
- Explain the basic thermal cycle associated with each absorption system component
- Describe how an absorption unit’s capacity is controlled
- List and describe weekly, monthly, and seasonal maintenance requirements
- Explain the care and handling requirements for lithium bromide solutions
Remember to regularly check "My Courses" on your student homepage. Your instructor may post additional resources that you can access to enhance your learning experience.
Absorption refrigeration units produce chilled water for air-conditioning systems in buildings and for process cooling in industrial applications, such as mainframe computers and certain types of machinery. The absorption cycle is one of the oldest known refrigeration systems and one of the simplest operating cycles in use today. Absorption refrigeration units are frequently used instead of the more conventional vapor compression refrigeration units due, in part, to fuel availability and cycle simplicity. Vapor compression cycles include a compressor. There’s no compressor in an absorption system, and there are few moving parts within the whole unit. In absorption units, the compressor is replaced by a small liquid pump and the addition of heat by steam or natural gas. Eliminating the compressor results in minimal electrical power usage by absorption equipment. The actual cooling of chilled water within the absorption unit is accomplished by evaporating a liquid—just as the human body is cooled by the evaporation of perspiration.

There are considerable differences between compression and absorption refrigeration equipment. The two types of refrigeration units contain different components and operate under different operating principles. However, both types of refrigeration units are used to produce chilled water for industrial and air-conditioning applications. This study unit describes component arrangements and their operation.
within the absorption cycle. In addition, the study unit discusses capacity control of absorption cycle units as well as operation and maintenance guidelines.

**Pressure and Temperature Relationships**

The temperature at which water boils, or changes into steam, depends on pressure. When subjected to standard atmospheric pressure, water boils at 212° Fahrenheit (F). Standard atmospheric pressure, which is the pressure at sea level, is equal to 14.696 pounds per square inch (psi). In industrial work, however, the rounded value of 14.7 psi is generally used. As air pressure increases, the water’s boiling point also increases. Likewise, as air pressure decreases, the water’s boiling point decreases. These examples imply a direct relationship between air pressure and the boiling point of water, since a change in one results in a similar change in the other.

When referring to pressure, you must specify *gauge pressure* or *absolute pressure*. If standard atmospheric pressure (14.7 psi) is chosen as the reference, pressures are called gauge pressures. *Positive* gauge pressures are those that have values above atmospheric pressure. A *vacuum*, or a *negative* gauge pressure, is any pressure that has a value below atmospheric pressure. If zero absolute pressure is chosen as the reference, the pressures are called *absolute* pressures. The *barometer* is a common device for measuring the absolute pressure of the atmosphere.

The relationship between gauge, atmospheric, and absolute pressures is shown in the following equation.

*Equation 1*

\[ p_{\text{abs}} = p_{\text{gauge}} + p_{\text{atm}} \]

In this equation,

- \( p_{\text{abs}} \) = absolute pressure
- \( p_{\text{gauge}} \) = gauge pressure
- \( p_{\text{atm}} \) = local atmospheric pressure
Gauge pressure should be expressed as *pounds per square inch (psi)*, and absolute pressure should be expressed as pounds per square inch absolute (psia). Often, gauge pressure will be expressed in units of psig. Because general industrial practice is usually concerned with gauge pressure, a given pressure value is assumed to be gauge pressure unless absolute pressure is specified.

One example is a boiler that's rated for 30 psi, which means that it has an operating pressure of 30 pounds per square inch gauge, or 30 psi above atmospheric pressure. Another example is a pump that's discharging at 60 psi, which means 60 psi above atmospheric pressure.

Another way to express pressure is in *inches of mercury (in. Hg)*, where “in.” is the abbreviation for inches and “Hg” is the chemical symbol for mercury. A barometer, for example, measures pressure in inches of mercury (in. Hg). Gauge pressures are indicated as inches of mercury, and absolute pressures are indicated as *inches of mercury absolute*, or *in. Hg abs*. The standard atmospheric pressure of 14.7 psi is equal to 29.92 in. Hg. Accordingly, 1 in. Hg represents a pressure of 0.491 psi, and 1 psi is equivalent to 2.036 in. Hg.

A pressure equivalent chart is shown in Figure 1. The lowest line on the chart represents the absolute zero pressure of 0.0 psia and 0.0 in. Hg abs. Standard atmospheric pressure can be expressed as 0.0 psi, 14.7 psia, 29.92 in. Hg abs, or 0.0 in. Hg.

![Pressure Equivalent Chart](image-url)
**Example:** A gauge on a pressure vessel reads 30 psi. Calculate the equivalent pressures in the units of psia, inches of mercury (in. Hg), and inches of mercury absolute (in. Hg abs).

**Solution:** First, convert the 30 psi reading to absolute pressure by using Equation 1.

\[
p_{\text{abs}} = p_{\text{gauge}} + p_{\text{atm}}
\]

\[
p_{\text{abs}} = 30 \text{ psi} + 14.7 \text{ psia}
\]

\[
p_{\text{abs}} = 44.7 \text{ psia}
\]

**Answer:** The value 30 psi is equal to 44.7 psia.

Next, convert 30 psi to inches of mercury. To do this, look at Figure 1. In the figure, you can see that 40 psi is equal to 81.44 in. Hg. Set up a simple ratio as shown below to calculate \(X\), which is the equivalent pressure in inches of mercury.

\[
\frac{81.44 \text{ in. Hg}}{40 \text{ psi}} = \frac{X \text{ in. Hg}}{30 \text{ psi}}
\]

To solve this ratio, cross-multiply as shown here.

\[
81.44 \text{ in. Hg} \times 30 \text{ psi} = X \text{ in. Hg} \times 40 \text{ psi}
\]

\[
2443.2 = X \text{ in. Hg} \times 40 \text{ psi}
\]

Then, divide both sides of the equation by 40 psi as shown.

\[
\frac{2443.2}{40} = \frac{X \text{ in. Hg} \times 40 \text{ psi}}{40 \text{ psi}}
\]

\[
61.08 = X \text{ in. Hg}
\]

**Answer:** The value of 30 psi in inches of mercury (when rounded) is 61.1 in. Hg.

Finally, convert 30 psi to inches of mercury absolute. To do this, first convert it to psia by adding 14.7. You get a result of 44.7 psia. Then, look at Figure 1. In the figure, you can see that 54.7 psia is equal to 111.37 in. Hg abs. Set up a simple ratio to calculate \(Y\), which is the equivalent pressure in inches of mercury absolute.
To solve this ratio, cross-multiply as shown here.

\[
\frac{111.37 \text{ in. Hg abs}}{54.7 \text{ psia}} = \frac{\text{Y \ in. Hg abs}}{44.7 \text{ psia}}
\]

Then, divide both sides of the equation by 54.7 psia.

\[
\frac{4978.239}{54.7 \text{ psia}} = \frac{\text{Y \ in. Hg abs} \times 54.7 \text{ psia}}{54.7 \text{ psia}}
\]

\[91.009 = \text{Y \ in. Hg abs}\]

**Answer:** The value of 30 psi in inches of mercury absolute (when rounded) is 91.0 in. Hg abs.

To obtain a partial vacuum, air must be removed from a sealed vessel. A pressure indicated as vacuum denotes a pressure that’s less than atmospheric pressure. As air is removed from a sealed vessel, the amount of pressure exerted by the air within the vessel is decreased. For a partial vacuum to exist within a vessel, the pressure outside the vessel must be greater than the pressure inside the vessel. As soon as the seal of the vessel is removed or broken, air will enter the vessel and reduce the vacuum.

An absolute vacuum corresponds to a pressure of 0.00 psia and has never been reached. Therefore, in industrial applications, the pressures commonly designated as vacuum are, strictly speaking, partial vacuums. A partial vacuum of 0.5 in. Hg abs indicates a pressure that’s 0.5 in. Hg greater than absolute zero. This pressure level could also be stated in in. Hg vacuum. Since atmospheric pressure is 29.92 in. Hg abs, a partial vacuum of 0.5 in. Hg abs pressure corresponds to a pressure of 29.92 – 0.5 = 29.42 in. Hg vacuum. The following example illustrates this point.

**Example:** A partial vacuum of 0.3 inches of mercury absolute (in. Hg abs) exists within a sealed vessel. Calculate the various representations of this pressure.
Solution: The partial vacuum of 0.3 in. Hg abs indicates a pressure that’s 0.3 in. Hg greater than absolute zero. It can also be stated as a vacuum by finding the difference between the pressure level and atmospheric pressure. According to Figure 1, standard atmospheric pressure is equal to 29.92 in. Hg abs. So, you can subtract as follows:

\[
29.92 - 0.3 = 29.62 \text{ in. Hg vacuum}
\]

To obtain the equivalent pressure in pounds per square inch absolute, convert in. Hg abs to psia using the method discussed in Example 1. Look at Figure 1 again. In the figure, you can see that 111.37 in. Hg abs is equal to 54.7 psia. Set up a simple ratio as shown below to calculate \(Z\), which is the equivalent value of 0.3 inches of mercury absolute in psia.

\[
\frac{111.37 \text{ in. Hg abs}}{54.7 \text{ psia}} = \frac{0.3 \text{ in. Hg abs}}{Z \text{ psia}}
\]

To solve this ratio, cross-multiply as shown.

\[
111.37 \text{ in. Hg abs} \times Z \text{ psia} = 54.7 \text{ psia} \times 0.3 \text{ in. Hg abs}
\]

\[
111.37 \text{ in. Hg abs} \times Z \text{ psia} = 16.41
\]

Then, divide both sides of the equation by 111.37 in. Hg abs.

\[
\frac{111.37 \text{ in. Hg abs} \times Z \text{ psia}}{111.37 \text{ in. Hg abs}} = \frac{16.41}{111.37 \text{ in. Hg abs}}
\]

\[
Z \text{ psia} = 0.1473
\]

Answer: The value 0.3 inches of mercury absolute is equal to 0.1473 psia.

To obtain the equivalent pressure in pounds per square inch, first change inches of mercury absolute to psia, and then subtract 14.7 psia.

\[
0.1473 \text{ psia} - 14.7 \text{ psia} = -14.55 \text{ psi}
\]

Answer: The value 0.1473 psia is equal to -14.55 psi. This can also be expressed as 14.55 psi vacuum.
As previously stated, the boiling temperature of water varies directly with pressure. As a partial vacuum is created in a closed system containing water, the pressure of the air surrounding the water is lowered, and the temperature at which the water will boil or evaporate is also lowered. If the pressure of the air surrounding the water can be lowered below atmospheric pressure, the water will evaporate or boil at a temperature lower than 212° F. At 1.0 in. Hg abs, water boils at a temperature of 79° F. At 0.18 in. Hg abs, water boils at 32° F.

Absorption Cycle Units in Air-Conditioning Applications

The term absorption cooling is used for any process which obtains its cooling effect when a vapor is absorbed by a liquid solution. In an absorption unit, the vapor is a refrigerant and the liquid solution that absorbs the refrigerant is known as the absorbent. In absorption refrigeration units, the two most common refrigerant-absorbent pairs are water-lithium bromide (LiBr) and ammonia-water. In the former, the refrigerant is low-pressure water vapor; in the latter, it’s ammonia. Absorption cooling is used in ammonia absorption units for commercial refrigeration and in lithium bromide systems for commercial air conditioning.

This study unit is primarily concerned with the lithium bromide absorption systems that are used in air-conditioning installations. The advantage of these systems is their simple operation; thus, they’re used in a variety of applications. The absorption unit that uses a water-lithium bromide mixture has two shortcomings. First, the evaporator temperature can’t fall significantly below 40° F because the water could freeze. Second, the generator must be operated at sufficiently high temperatures to prevent the crystallization of the lithium bromide salts. Later in this study unit, the generator will be discussed in more detail.

For air-conditioning applications, the refrigeration equipment generally produces chilled water that’s circulated to air-handling units to furnish cool air to spaces within a building. A schematic diagram of this type of air-conditioning system
is shown in Figure 2. The heating medium, or energy source, enters the absorption refrigeration unit. The heating medium supplied to the absorption refrigeration unit can be either steam, hot water, or a direct flame. Steam is usually supplied at pressures between 2 and 15 psi. If hot water is used as the heating medium, it’s usually furnished at temperatures between 225° F and 270° F. Some manufacturers supply units that can use hot water at entering temperatures of up to 400° F.

The top water loop in Figure 2 represents cooling water from a cooling tower, which is circulated through the absorption refrigeration unit using the condenser-water pump. Due to requirements within the absorption cycle, the condensing water must be provided to the unit at a temperature below 90° F. For some installations, a source of natural water that comes from a lake or river, for example, is available to provide a constant supply of water within this temperature range. Although the condenser-water pump is still necessary in these installations, the cooling tower can be eliminated. The condenser-water pump would then take its suction from the natural source of water, pump the condenser water through the absorption refrigeration unit, and then discharge the water into the natural source.
The water to be cooled by the absorption unit is shown in the lower loop. This water, known as chilled water, travels through the absorption refrigeration unit to release its heat before passing through the cooling coil. In the cooling coil, the chilled water removes heat from the air passing over the coil before returning to the absorption refrigeration unit to start the cooling process again. The chilled water is circulated through the chilled water loop by a chilled-water pump.

In the air-handling unit, a fan is used to blow air over the cooling coil, where the temperature of the air is lowered. The cool air is then circulated to various parts of the building by means of ductwork and an air-distribution system. The absorption refrigeration unit is generally designed to furnish chilled water at a temperature between 42° F and 48° F, depending on building requirements. The refrigeration unit is usually selected to produce a temperature drop of between 4° F and 10° F to the water as it passes through the absorption unit.

**Limitations and Commercial Availability**

Throughout this study unit and in absorption machine specifications, you’ll frequently encounter terms such as hermetically sealed, Btu, single-effect, double-effect, and tons of refrigeration. The term hermetically sealed will often appear in the description of refrigeration equipment. A piece of equipment, such as a pump, that’s hermetically sealed is housed in an airtight casing and isn’t influenced by conditions outside the unit. A photograph of a hermetically sealed pump located on a commercially available absorption unit is shown in Figure 3.

The British thermal unit (Btu) is the standard unit for measuring thermal energy. One Btu is the amount of heat required to raise the temperature of one pound of water 1° F.

The terms single-effect and double-effect refer to the number of generators in a particular system. The difference between single-effect and double-effect, as well as the characteristics of generators, will be discussed later in this study unit. For now, we’ll assume that the systems we evaluate are single-effect units.
Refrigeration equipment is generally rated in tons of refrigeration. A *ton of refrigeration* is defined as the amount of cooling required to convert one ton, or 2,000 pounds (lbs), of water at 32° F into ice at 32° F in a 24-hour (hr) period. The latent heat of ice is 144 Btu per pound. The term *latent heat* means that 144 Btu must be removed from a pound of water at 32° F to convert it to ice at 32° F. To freeze 2,000 pounds of water at 32° F into ice at 32° F, the following amount of heat must be removed:

\[
2,000 \text{ lbs} \times 144 \text{ Btu per lb} = 288,000 \text{ Btu per ton of water per 24 hrs}
\]

This amount of cooling, 288,000 Btu per ton per 24 hours, constitutes a standard ton of refrigeration. The standard commercial ton is often defined on an hourly basis. This is equivalent to the absorption of 288,000 Btu/24 hours, or 12,000 Btu per hr, which corresponds to a ton of refrigeration. The unit of Btu per hour or Btu/hr is usually abbreviated as Btuh.

**Example:** How many tons of refrigeration are required for a cooling load of 90,000 Btuh?

**Solution:** Divide as shown.

\[
\frac{90,000 \text{ Btuh}}{12,000 \text{ Btuh}} = 7.5 \text{ tons}
\]

**Answer:** A cooling load of 90,000 Btuh would require 7.5 tons of refrigeration.
Lithium bromide absorption refrigeration equipment is commercially available in units from 50 to 1660 tons of refrigeration nominal capacity. *Nominal capacity* is the output of a given unit under a specified set of conditions. The actual capacity of any given piece of equipment will vary with factors such as inlet condensing-water temperature, temperature of the chilled water leaving the unit, and the temperature of the heating medium as it enters the unit. For instance, a 90 ton nominal capacity unit will be rated somewhere between 50 and 105 tons actual capacity, depending upon design conditions. Refrigerating units are also capable of operating at reduced load. With proper controls, they can operate continuously at a capacity as low as 10% of their rating.

Absorption units can be used in almost any air-conditioning or industrial application where a sufficient heating medium is available. Heating mediums for commercially available units include hot water, high-temperature hot water, steam, and direct flame from natural gas. Depending on the manufacturer, some lithium bromide chillers can use steam at practically any pressure, including low-pressure steam produced by a heating boiler or exhaust steam. Ideal steam operating pressure for single-effect machines is typically between 9 and 12 psig. If steam at a higher pressure is available, its pressure must be reduced by means of a pressure-reducing station.

In addition to heating medium guidelines, care must also be taken in the actual placement of the absorption unit. This is necessary due to freezing concerns of the water contained within the unit. Water is very important in this type of system because it’s used as the refrigerant and it’s also circulated throughout the chiller. This means that the equipment must be placed in a location where the ambient temperature won’t fall below approximately 45° F. A minimum chilled-water temperature of 40° F can be obtained from the unit. Since water is the refrigerant, the evaporator temperature must always be above 32° F to prevent freezing.
Both vapor compression and absorption refrigeration equipment produce chilled water for industrial and air-conditioning needs. However, the two types of refrigeration equipment differ in several ways. A centrifugal refrigeration unit, or centrifugal chiller, is a very common type of vapor compression cycle equipment. Centrifugal chillers are available in the same general size range as lithium bromide absorption refrigeration equipment. Generally, an absorption refrigeration unit weighs more and occupies more floor space than a centrifugal-compression refrigeration unit of a comparable capacity. The added weight and the greater size of the absorption unit is due to the large amount of heat-transfer surface required for operation. This topic will be addressed later in the study unit.

Unlike the centrifugal chiller, which contains a compressor, the absorption machine contains only a few rotating parts, including circulating pumps. Absorption equipment, therefore, is practically vibration-free and requires no special foundations; thus, installation is easier. The floor space required to house an absorption unit, however, is generally much greater than that required for a centrifugal unit of equivalent size. In addition, an exhaust stack is usually required. Both of these items (increased floor area and stack requirement) increase the difficulty and cost associated with absorption-unit installation.

In comparison to the centrifugal unit, some advantages of the absorption unit include lack of dependence on oil, ease of electrical installation, and simplicity of the refrigerant. Unlike centrifugal units, which rely heavily on oil, any oil present in an absorption unit is generally used by an auxiliary device. In addition, the absorption unit is much easier than the vapor compression unit to install electrically. The sole electric power requirement is used to drive the pumps. The pumps are comparatively small; for example, the 1,000-ton absorption unit needs only a total electric motor capacity of about 20 horsepower (hp).
The refrigerant used in the absorption system is water as opposed to the chemical refrigerants used in vapor compression cycles, such as HCFC-22, CFC-11, and HFC-134. Many of the refrigerants used by vapor compression cycle chillers cause depletion of the earth’s ozone layer if released into the atmosphere. Service technicians must be properly trained and licensed to work on these systems. In addition, some vapor compression cycle refrigerants, when released, pose serious health risks to people in the vicinity of the unit.

Although absorption units include fewer moving parts, require less electricity, and use a less troublesome refrigerant, the mechanical installation is more expensive for the absorption unit as compared to the centrifugal unit. The absorption unit requires more condenser water than is required by the centrifugal unit. This is due to the fact that the condenser water-cooling circuit in an absorption system must be designed to remove more than twice as much heat as in the centrifugal type of system. The extra amount of heat that must be removed is due to the heating medium used in the absorption system. A chemical reaction takes place in the absorber, producing heat when LiBr absorbs water vapor. In addition to the heat derived from the cooling load, the heat of vaporization from the steam must also be removed.

This additional heat requires a more expensive cooling tower, or other larger source of condenser water, as well as a larger-capacity piping circuit and increased pumping capacity to handle the greater condenser-water flow to the absorption unit. The absorption system requires about double the heat rejection of a centrifugal system or a cooling tower that’s about one-third larger. This means that a larger-capacity cooling tower is required and larger pipe sizes will be necessary to carry the greater flow of water. If condenser water is obtained from a natural source, then a cooling tower isn’t needed; however, provisions must still be made for the increased water flow that’s required.
Economic Considerations

The practicability of installing an absorption refrigeration unit, rather than a vapor compression refrigeration unit, may depend on both cost and fuel availability. The cost to obtain and use steam, hot water, or natural gas for the absorption machine should be compared to the cost of obtaining and using the necessary electric power for the vapor compression machine. In many geographic areas, commercial buildings operate heating equipment during the heating seasons to maintain comfortable space temperatures. Many times, this heating equipment isn't operated during the cooling season when outdoor temperatures are above approximately 70°F. In these cases, the feasibility of operating the heating equipment during the cooling season should be carefully evaluated before refrigeration equipment selection.

In some buildings, steam is available for heating during the winter season and throughout the year for various processes. An example would be a hospital where steam would be used for heating during the winter months and for sterilization during the entire year. In many commercial buildings with kitchen facilities, steam is frequently used throughout the year for food preparation. The economics of using this steam as a source of heat in an absorption chiller during the air-conditioning season should be considered.

Frequently, the steam capacity available for heating the building during the winter heating season can be utilized to economically cool the building during warmer seasons. Using heating equipment throughout the year generally means more efficient use of the equipment. Many industrial applications have quantities of low-pressure process steam that are normally wasted, and this steam can be used to provide energy for an absorption unit without any increase in cost.

The economics of selecting an absorption unit in place of a centrifugal unit will depend upon the cost of obtaining the necessary energy. Several examples are included below to demonstrate the process of estimating fuel cost. Since steam is the most popular heating medium for absorption units, the following cost examples will be based on the use of steam. The steam required by most lithium bromide units is approximately 18.5 pounds per hour per ton (lb/hr/ton) of
refrigeration produced. The cost of installing and maintaining this boiler capacity must be considered in any economic analysis. Let’s walk through the steps required for a good economic analysis.

**Example:** The boilers in a building are oil-fired. They require approximately 18.5 pounds of steam per hour per ton of refrigeration produced. They use fuel that costs 0.70 dollars per gallon that’s rated at 140,000 Btu per gallon. Assume that the overall boiler efficiency is 85%. The heat required to evaporate water at 12 psi is equal to about 950 Btu per pound. What will be the operating cost associated with oil usage for these boilers?

**Solution:** The operating cost associated with oil usage can be calculated using Equation 2.

**Equation 2**

\[
\text{Cost of oil} = \frac{(S_r)(h_{fg})(F_c)}{(Q)(E)}
\]

In this equation,

- \(S_r\) = steam required, in pounds per hour per ton
- \(h_{fg}\) = heat required to evaporate water, in Btu per pound
- \(F_c\) = cost of fuel, in dollars per gallon or in dollars per decitherm
- \(Q\) = heat value of the fuel, in Btu per gallon or in Btu per decitherm
- \(E\) = efficiency, in percent

Set up the equation, and substitute the known values for the boilers in the example. The value of \(S_r\) is 18.5 pounds per hour per ton; the value of \(h_{fg}\) is 950 Btu per pound; the value of \(F_c\) is 0.70 dollars per gallon; the value of \(Q\) is 140,000 Btu per gallon; and the value of \(E\) is 85%, or 0.85.

\[
\text{Cost of oil} = \frac{18.5 \text{ lb per hr per ton} \times 950 \text{ Btu per lb} \times 0.70 \text{ dollars per gal}}{140,000 \text{ Btu per gal} \times 0.85}
\]

\[
\text{Cost of oil} = \frac{12302.5}{119000}
\]

\[
\text{Cost of oil} = 0.10338, \text{ or } 0.103 \text{ dollars per ton (rounded)}
\]
Answer: The cost of oil is 0.103 dollars per hour per ton.

Example: Now, let’s consider the boilers from the previous example again. The electrical requirements of the single-effect absorption unit are approximately 20 kilowatts (kW) for a 1,000-ton unit, or approximately 0.02 kW per ton. Assume that electricity costs 0.10 dollars per kilowatt-hour (kWh). What is the operating cost associated with electricity usage for these boilers?

Solution: The operating cost associated with electricity usage can be calculated using Equation 3.

Equation 3

\[ \text{Cost of electricity} = (K) (E_c) \]

In this equation,

\( K \) = electrical requirements, in kilowatts per ton
\( E_c \) = cost of electricity, in dollars per kilowatt-hour

Substitute the known values for the example into Equation 3.

\[ \text{Cost of electricity} = 0.02 \text{ kW per ton} \times 0.10 \text{ dollars per kWh} \]
\[ \text{Cost of electricity} = 0.0020 \text{ dollars per hour per ton} \]

Answer: The cost of electricity is 0.0020 dollars per hour per ton.

Example: Calculate the total operating cost for these boilers.

Solution: The total operating cost equals the cost of oil plus the cost of electricity.

\[ \text{Total operating cost} = 0.103 + 0.0020 \]
\[ \text{Total operating cost} = 0.105 \text{ dollars per hr per ton} \]

Example: Now, instead of oil, assume that the boilers from the previous examples use natural gas that costs 0.045 dollars per decitherm (note that there are 10,000 Btu per decitherm). The overall boiler efficiency remains the same at 85%. Electrical requirements and cost are unchanged. The heat required to evaporate water at 12 psi is equal to about 950 Btu per lb. The operating cost associated with natural gas usage can be calculated using Equation 2.
The cost of natural gas is 0.093 dollars per hour per ton.

**Example:** Calculate the total operating cost for these boilers.

**Solution:** The total operating cost equals the cost of natural gas plus the cost of electricity. (The cost of electricity is the same as for the oil-fueled system as previously calculated.)

\[
\text{Total operating cost} = \text{cost of gas} + \text{cost of electricity}
\]

\[
\text{Total operating cost} = 0.093 + 0.0020
\]

\[
\text{Total operating cost} = 0.095 \text{ dollars per hr per ton}
\]

In these examples, it’s assumed that this amount of steam (20 pounds per hour per ton) is generated solely for the refrigeration equipment. If the steam, or a portion of it, could also be used for another operation, such as process steam, and still be used for the refrigeration equipment, then a portion of this cost could be charged to the process and the cost of operating the air-conditioning equipment would be lowered.

**Example:** Centrifugal-compression refrigeration units require an input of 0.6 to 1.0 kW per ton of refrigeration output. Assuming that the centrifugal unit requires 1.0 kW per ton and that electricity costs 0.10 dollars per kWh, the operating cost can be calculated as follows:

\[
1.0 \text{ kW per ton} \times 0.10 \text{ dollars per kWh} = 0.10 \text{ dollars per hour per ton}
\]

For this example, the cost of operating a centrifugal refrigeration unit ($0.10/hr/ton) is slightly different than the costs associated with operating a steam absorption unit operating on oil ($0.12/hr/ton) or natural gas ($0.095/hr/ton).
However, the operating costs depend heavily on the prices of electricity, oil, and natural gas, which vary depending upon geographic location. An example of the economic justification of absorption refrigeration equipment was the U.S. Navy’s selection of lithium bromide units for atomic submarines. The atomic reactor furnishes a constant supply of hot water. Using an absorption machine eliminated the need to generate or store electricity or fuel to drive a prime mover for a mechanical-compression system. An absorption refrigeration unit was the logical selection.

Now, take a few moments to review what you’ve learned by completing Self-Check 1.
Self-Check 1

At the end of each section of Lithium Bromide Absorption Systems, you'll be asked to pause and check your understanding of what you've just read by completing a “Self-Check” exercise. Answering these questions will help you review what you've studied so far. Please complete Self-Check 1 now.

1. A gauge on a pressure vessel reads 80 psi. Calculate the equivalent pressures in the following units:
   a. psia
   b. in. Hg
   c. in. Hg abs

Indicate whether each of the following statements is True or False.

_____ 2. If the pressure of air surrounding a body of water is raised above atmospheric pressure, the water will boil at a temperature above 212°F.

_____ 3. Due to the possibility of freezing the water, the evaporator temperature within an absorption cycle can’t fall significantly below 40°F.

_____ 4. Within an absorption cycle, the generator's temperature must be sufficiently low to avoid crystallization of the lithium bromide salts.

_____ 5. The absorption refrigeration unit is generally designed to furnish chilled water at a temperature of between 32°F and 38°F.

_____ 6. How many tons of refrigeration are required for a cooling load of 120,000 Btuh?

Check your answers with those on page 89.
BASIC PRINCIPLES OF LITHIUM BROMIDE ABSORPTION SYSTEMS

Theory of System Operation

Both the absorption and vapor compression refrigeration cycles evaporate and condense a liquid refrigerant. The condensing process in both refrigeration cycles occurs at a higher pressure level, while the evaporation process occurs at a lower pressure. However, the two refrigeration cycles differ in the method used to achieve this pressure difference. The absorption cycle uses the ability to maintain different lithium bromide concentrations and, thus, different vapor pressures to produce the required pressure differential. The vapor compression cycle uses a compressor to control the pressure within the system. The absorption cycle uses chemical processes, whereas the vapor compression cycle uses mechanical processes to maintain the pressure differential within the system. Both cycles require energy for operation, that is, heat in the absorption cycle and mechanical energy in the compression cycle.

Single-Effect Absorption Units

A comparison of a vapor compression refrigeration cycle and a single-effect absorption refrigeration cycle is shown in Figure 4. Both types of machines cool chilled water by vaporizing a refrigerant at a low pressure in the evaporator. Also, both types of machines condense vapor at a higher pressure and temperature in the condenser so that it may be reused in the cycle. In the vapor compression system, the vapor formed in the evaporator is drawn to the lower-pressure area created by the suction action of the compressor’s piston or impeller. In the absorption machine, the vapor is also drawn to a lower-pressure area through a pressure-reducing valve. In this lower-pressure area, the vapor is absorbed by the concentrated (strong) LiBr solution. The low-pressure area in the absorption machine is maintained by controlling the concentration of the absorbent solution in the absorber.
In the vapor compression cycle, the compressor moves the refrigerant vapor from the low-pressure side of the system (which includes the evaporator) to the high-pressure side of the system (which includes the condenser). The refrigerant is then condensed through the condenser and expanded on the way to the evaporator where it’s fully vaporized.

Figure 5 illustrates the basic schematic of a single-effect steam absorption chiller, and Figure 6 shows a commercially available single-effect steam absorption chiller. In an absorption system, like the vapor compression cycle, the vapor is condensed in the condenser and the liquid refrigerant
FIGURE 5—Schematic of a Typical Single-Effect Steam Absorption Chiller (Courtesy of York International Corp.)
expands on the way to the evaporator where it’s partially vaporized. Refrigerant is vaporized in the evaporator by the removal of heat from the chilled-water loop. When the refrigerant or water evaporates, it removes heat from its surroundings, and thus provides the chilled water. A partial vacuum is created in the evaporator to lower the temperature of this evaporation process. Remember, there’s a direct relationship between boiling temperature and pressure.

In the absorption cycle, evaporation of some water and chilling of the remaining water occurs in the evaporator. The water that evaporates is absorbed by a LiBr salt solution in the absorber. The dilute LiBr salt solution is then pumped to the generator by a solution pump. Within the generator, which is on the high-pressure side of the system, heat is applied to the dilute LiBr salt solution. This causes the solution to boil and give up refrigerant vapor at the higher pressure, thereby concentrating the LiBr salt solution. The water vapor driven off is then cooled and condensed in the

**FIGURE 6—A Commercially Available Single-Effect Steam Absorption Chiller** (Courtesy of York International Corp.)
condenser by means of the cooling water. The condensed liquid refrigerant flows back to the evaporator, where the evaporation process starts again.

Both the vapor compression and absorption cycles perform the same basic function. They both use low-pressure refrigerant in the evaporator to remove heat from the chilled water loop and then transfer it as a high-pressure refrigerant vapor to the condenser, where the heat is removed from the cycle. The main difference between the cycles is in their respective methods of transferring the refrigerant from the evaporator to the condenser.

**Double-Effect Absorption Units**

The term *double-effect* refers to a cycle which includes a second generator, shown schematically in Figure 7 and photographically in Figure 8. Both figures depict a commercially available direct-fired, double-effect unit. Sometimes, the term double-effect is replaced by the word *two-stage*, depending on the chiller manufacturer. All major components in a double-effect machine are similar to those within the single-effect chiller, except for an additional generator (labeled as the first- and second-stage generators in Figure 7), pumps, and heat exchangers. The systems also operate similarly and will be discussed in greater detail later in this study unit. Due to the increased temperature provided by the second generator, the double-effect absorption unit provides about 50% to 80% more cooling capacity than a single-effect unit.

**Chemical Characteristics of Lithium Bromide Solutions**

You know that a salt shaker can clog up on a humid day because salt takes moisture from the air. Under these circumstances, salt can be thought of as an absorber. The chemical name for table salt is sodium chloride. Absorption refrigeration units require absorbers for their operation. A salt known as lithium bromide, identified chemically as LiBr, is the absorber in this equipment. Vapor compression cycles use a pure substance as the refrigerant, such as HCFC-22. However, the absorption cycle uses a mixture of an absorbent (LiBr) and a refrigerant (water) as its working fluid.
FIGURE 7—Schematic of a Direct-Fired Double-Effect Absorption Refrigeration Unit

FIGURE 8—A Direct-Fired Double-Effect Absorption Refrigeration Unit (Courtesy of York International Corp.)
Figure 9 shows an equilibrium diagram for water solutions containing lithium bromide. The left vertical axis corresponds to the vapor pressure of pure water. The right vertical axis indicates the boiling or evaporating temperature of pure water in degrees Fahrenheit corresponding to the pressure values on the left axis in inches Hg abs. For example, at 0.3 in. Hg abs vapor pressure, pure water will evaporate at 45° F.

The horizontal scale at the bottom of Figure 9 represents the concentration of lithium bromide by weight. A 60% solution, for example, is 60% lithium bromide and 40% water by weight. The diagonal lines running from the upper-left corner downward towards the right represent the temperature of the lithium bromide-water solution. From Figure 9, you can see that a solution of approximately 54% LiBr concentration at 100° F has a vapor pressure of approximately 0.4 in. Hg abs. This vapor pressure will allow water to evaporate at 53° F. The slanted vertical lines left of the curve labeled “crystallization line” in Figure 9 indicate the specific gravity of the solution. Specific gravity increases as the percentage of lithium bromide in the solution increases. Throughout this text, the term solution will be used when referring to the lithium bromide-water solution.

The lithium bromide solution has the same characteristics as a water solution of sugar. More sugar can be dissolved if the water is warm than if the water is cool. As the solution cools, sugar will settle out of the solution or precipitate and form crystals. The same result will be caused by adding an excessive amount of sugar to the water. The crystallization line for lithium bromide is indicated in Figure 9. This line indicates the conditions at which the solution begins to crystallize or change from a liquid to a solid. The absorption unit should operate under conditions indicated to the left of and above the crystallization line to retain the solution in a fully liquid state.
Crystallization will begin if the condition of the solution passes below or to the right of the crystallization line. Crossing the crystallization line doesn’t necessarily result in complete unit solidification or freeze-up. Even if complete solidification should occur, it wouldn’t generally harm the machine. As lithium bromide solidifies, it contracts rather than expands. Because the pumps won’t pump solids, crystallization will cause an interruption in the unit operation.

In a lithium bromide absorption refrigeration unit, the lithium bromide is the absorbent and water is the refrigerant. For example, in an absorption unit, the solution might have 60% concentration of LiBr with a solution temperature of about 105°F. At this condition, as shown in Figure 9, the solution has a vapor pressure of about 0.27 in. Hg abs and a corresponding boiling temperature of about 43°F. It’s important to understand that air has been removed from the absorption cycle, and that it’s the vapor pressure of the solution that determines the temperature at which the refrigerant water will vaporize. In operation, the refrigerant water absorbs heat from the chilled-water loop in the evaporator, and a portion of the refrigerant changes from a liquid to a vapor through boiling. At a solution temperature of 105°F, water refrigerant within the solution vaporizes at a temperature of 45°F due to a decrease in pressure to 0.27 in. Hg abs.
Let’s return to the salt shaker that clogs up in the summer. If the salt is heated, some of the water vapor will be driven off. In other words, a warm salt-water solution doesn’t retain as much vapor as a cool solution. This principle is used in the lithium bromide units. In the generator, the solution is heated to drive off the water vapor. When the solution is cooled, it’s capable of absorbing more water vapor as shown in Figure 9.

Now, let’s revisit the example involving a solution of 60% LiBr with a 105° F solution temperature and a pressure of 0.27 in. Hg abs. Holding the pressure of 0.27 in. Hg abs constant while heating the solution to a temperature of 120° F requires moving in a straight line to the right on Figure 9 until a temperature of 120° F is reached. At this point, the concentration will increase to 64%. This brief example demonstrates how a LiBr solution that previously was 40% water by weight now contains only 36% water by weight. The other 4% water was evaporated from the solution by adding heat, making the solution more concentrated.

**Comparison with the Ammonia-Water System**

An ammonia absorption system operates at a pressure that’s slightly above atmospheric. Water is the absorbent and ammonia is the refrigerant in the ammonia system. The principles of ammonia refrigeration are the same as those for the lithium bromide system. Heat drives ammonia vapor from the ammonia-water solution; the vapor is condensed and then evaporated to produce the chilling effect. The vapor is then absorbed by the water and pumped back to the generator, where heat is again applied. The process is then repeated.
A typical ammonia absorption system is shown in Figure 10. The heating medium enters the generator (1) and drives ammonia gas from the solution. This gas passes to the condenser (2), where it's condensed by means of cooling water for removing heat. Since its temperature is above the temperature corresponding to the pressure in the evaporator, the liquid ammonia flows to the cooler (3) or space to be cooled. The ammonia evaporates, thereby producing the chilling effect. The ammonia gas is then drawn into the absorber (4), where it's absorbed by the water. A pump (5) pumps this ammonia-water solution to the heat exchanger (6) and then to the generator, where it's acted upon by the heating medium and starts another cycle.

The water is the refrigerant in the lithium bromide system instead of the absorbent as it is in the ammonia system. It's necessary to operate the lithium bromide system at a much lower pressure to obtain evaporation of the water within the desired temperature ranges. In the ammonia system, the vessels operate slightly above atmospheric pressure. If any leakage should occur, it would be leakage of the water and ammonia solution out of the unit to the surrounding atmosphere. This presents a problem because ammonia is a toxic gas. In the lithium bromide system, the vessels operate under a vacuum. Any leakage that occurs will be leakage of outside air into the vessels; and any solution that might happen to escape from the vessel would be safe and nontoxic.
Absorption System Components

This section describes the basic components contained within an absorption machine. Recall that the absorption cycle uses water as the refrigerant and lithium bromide as the absorbent. Complete schematics depicting single-effect and double-effect absorption units are shown in Figures 5, 7, and 11. Refer to these schematics frequently as you proceed through the following sections.

Circulating Pumps

The cycles shown in Figures 5 and 7 illustrate absorption chillers manufactured by the same company. Each chiller includes two circulating pumps—a refrigerant or evaporator pump and a solution or concentrator pump. Other chiller manufacturers include these two pumps plus a third pump, called an *absorber pump*, as shown in Figure 11. Figure 11 includes a schematic of a single-effect steam or hot water absorption refrigeration unit.

When comparing the two single-effect chillers that are shown in Figures 5 and 11, another striking difference exists in the basic arrangements. Figure 5 depicts a chiller with a two-shell arrangement where one vessel includes the condenser/generator pair and the other vessel includes the evaporator/absorber pair. Figure 11 shows another manufacturer’s chiller with only one vessel that includes the condenser, concentrator, evaporator, and absorber.

Most manufacturers use hermetically sealed, electric-motor-driven centrifugal pumps for absorption system applications. In hermetic pumps, the pump and motor housings are all in one casing, the pump packing is eliminated, and some of the refrigerant being circulated by the pump passes through the housing and cools the motor. The schematic in Figure 11 shows a unit equipped with three pumps, but it actually has only a single, hermetic motor assembly with three pump impellers on a common shaft.
A solution or concentrator pump is shown in Figure 12. A dilute solution of water-LiBr collects at the bottom of the absorber vessel. The solution pump moves this dilute solution through a heat exchanger for preheating before sending it to the generator.
Generator

The generator is often referred to as the concentrator and is shown in Figure 13. It’s in the concentrator that the heating medium—generally direct flame, steam, or hot water—circulates and provides the energy necessary for the operation of the system. The heating medium causes evaporation or boiling off of the water that the lithium bromide solution picked up in the absorber. As the water vapor is driven off and cooled by the condenser, the remaining solution becomes more concentrated; it’s from this concentrating action that the vessel derives its name. The concentrator pump forces the dilute lithium bromide solution from the absorber into the concentrator. As the solution in the concentrator loses water vapor and becomes more concentrated, it flows back to the absorber by gravity or pump action, depending on the chiller manufacturer.
**Condenser**

The *condenser* receives water vapor from the concentrator. By the passage of cool water through the condenser tubes, the water vapor is cooled and condensed as shown in Figure 14. The condenser consists of a coil in which the condenser water is circulated and a sump into which the water vapor condenses. The water vapor, which condenses in the condenser, flows by gravity to the evaporator, where it's ready to be evaporated and start its cycle through the unit.

![FIGURE 14—Condenser](Courtesy of York International Corp.)

**Evaporator**

The *evaporator* is the component responsible for chilling water (Figure 15). The liquid refrigerant is admitted through a pressure-reducing device. So that it will vaporize at a sufficiently low temperature, the temperature at which vaporization occurs is lowered as pressure is reduced. To change a substance into a vapor, heat is necessary; and this heat is taken from the chilled water that's circulated through the evaporator.

By absorbing a certain amount of heat equal to the latent heat of vaporization, the refrigerant liquid changes into a vapor. Since the chilled water provides this heat to the refrigerant, the temperature of the chilled water is reduced. The water vapor from the evaporator is drawn into the absorber, while the chilled water goes through the air-conditioning system as shown in Figure 2.
The evaporator consists of a steel shell, which contains a coil for chilled water circulation, as well as a sump, evaporator or refrigerant pump, and a discharge spray header. The evaporator pump takes its suction from the evaporator sump, which contains the refrigerant water received from the condenser, and discharges it through the spray header system. The spray system delivers the water in the form of a spray mist. As the water is broken up into a mist, the amount of exposed water surface is increased and evaporation can take place in the evaporator over a large quantity of tube bundles. The spray system increases the rate of evaporation of the water and reduces the size of the equipment.

Absorber

The absorber is the component to which the vapor goes after the evaporator. The concentrated solution from the generator is sprayed over the absorber tube bundles. This strong solution creates the extreme vacuum that exists in the evaporator by pulling the refrigerant vapor into the solution. This absorption of the refrigerant vapor generates heat that’s removed by the cooling water as shown in Figure 16.
In most absorption chiller designs, the absorber and the evaporator are located within the same shell. The absorber consists of a steel shell which houses a sump, absorber or solution pump, cooling water coil, and a discharge spray header. The sump contains the lithium bromide solution. The lithium bromide solution from the sump is circulated by the absorber pump and sprayed into the absorber. The purpose of the spray system in the absorber is the same as that of the spray system in the evaporator; that is, more surface area of the lithium bromide solution will be available to absorb water vapor from the evaporator.

Heat Exchanger

In most systems, a shell-and-tube type heat exchanger is located between the absorber and the concentrator as shown in Figure 12. The weak lithium bromide solution going from the absorber to the concentrator is at a lower temperature than the concentrator. Heat will be added to the weak solution within the concentrator to drive off water vapor and concentrate the solution. The temperature of the weak solution leaving the absorber must be raised for the concentration process to take place.
**Purge System**

Since the absorption refrigeration equipment operates in a partial vacuum of approximately 0.30 in. Hg abs, any leakage that might occur will be air leaking into the unit. Any air leaking into the system must be eliminated because it will cause a loss of vacuum. A loss of vacuum means a loss of refrigerating effect, and provisions must be made to prevent it. The partial vacuum must be regained quickly if a leak should develop, and this is the reason for the inclusion of a purge system.

Air and other noncondensable gases leaking into the unit become suspended in the solution. Water vapor carrying noncondensable gases passes into a purge chamber. It’s necessary to remove these noncondensable gases from the purge chamber and discharge them from the system.

At least three types of purge systems are used commercially. One makes use of a vacuum pump, either a single-stage reciprocating or a vane-type vacuum pump, which is connected to the purge chamber through an oil trap. This type of system is manually started and shut off. To prevent the possibility of oil and oil vapors being sucked back into the machine and contaminating the solution, an oil trap is used. There’s also the problem of water vapor contaminating the oil in the vacuum pump. The vacuum-pump oil requires frequent changing.

The second purge system is an automatic system employing a purge chamber that has a lower pressure than the absorber. Any noncondensable gases are drawn into the purge chamber, where they’re evacuated by means of a vacuum pump. This pump is operated by a timer to empty the purge chamber.

The third system is also an automatic system and operates while the absorption unit is running. Advantages of this system are that it requires no electric power and is completely self-contained. This hermetic unit functions in a manner similar to the vacuum pump described previously. It draws noncondensable gases from the absorber into the purge chamber and automatically discharges them into the atmosphere. The apparent advantages of this type of purge system
are its simplicity and freedom from maintenance, combined with the fact that it eliminates the necessity for manual operation. However, the operator has no method of determining the amount of purging that’s done.

Air in an absorption unit is a common cause of crystallization. It aids the solidifying of the absorbent solutions and interferes with the refrigeration cycle. Air leakage into the unit also increases the steam consumption. The oxygen in the air reacts with the solutions to attack and deteriorate the inside metal surfaces of the machine. Based on these results of air within the absorption cycle, purge systems are critical to the unit’s life and operation.

Now, take a few moments to review what you’ve learned by completing *Self-Check 2*. 
Self-Check 2

1. Which of the following actions occur within the absorption unit’s evaporator?
   a. Cooling of chilled water
   b. Evaporation of refrigerant into vapor
   c. Collection of refrigerant liquid in a sump
   d. All of the above

2. Which of the following actions occurs within the absorption unit’s absorber?
   a. Cooling of chilled water
   b. Absorption of water vapor by concentrated solution
   c. Evaporation of refrigerant into vapor
   d. All of the above

Indicate whether each of the following statements is True or False.

_____ 3. Heat is added to the absorption cycle in the condenser.

_____ 4. Some commercially available absorption chillers include only one shell which includes the condenser, generator, evaporator, and absorber.

_____ 5. The basic physical difference between single-effect and double-effect absorption machines lies in the addition of an extra generator.

_____ 6. If complete solidification of the LiBr solution should occur, it would destroy the absorption machine.

Check your answers with those on page 90.
COMPONENTS

Component Thermal Cycles

Many commercial absorption refrigeration units are arranged with the condenser and concentrator in one shell and the evaporator and absorber in the second shell. Other commercial absorption refrigeration units group all components into a one-shell design. Regardless of the physical configuration of the absorption refrigeration unit, the absorption cycle consists of several thermal cycles. For you to become familiar with the operation of the complete unit, an analysis of each cycle is examined separately in the following sections. The first several sections include the analysis of each component within a single-effect absorption unit. Next, you’ll examine how a double-effect machine differs from a single-effect machine.

Evaporator-Absorber Operation

An evaporator-absorber pair that are connected by a vapor passageway are shown in Figure 17. Both the evaporator and the absorber operate under a partial vacuum of about 0.3 in. Hg abs. At this pressure, the refrigerant in the evaporator will vaporize at a lowered boiling point of approximately 45° F. The refrigerant in the evaporator boils due to the heat it extracts from the building’s chilled water. The chilled water enters the evaporator at approximately 54° F and exits at approximately 46° F. Generally, the building’s chilled water will be cooled 4° to 12° in the heat transfer process occurring in the evaporator. The amount of temperature drop, or the temperature differential, depends upon the selection of the unit.

To improve the vaporization process within the evaporator, a spray system is added. The spray system includes an evaporator pump and a discharge header. The pump takes its suction from the evaporator sump and discharges the water through the spray header shown in Figure 17. The spray system breaks up the particles of water and distributes a mist over the entire chilled-water tube surface to improve vaporization.
Since lithium bromide has a strong affinity for water, the refrigerant vapor created in the evaporator through the vaporization process will freely migrate to the absorber. In the absorber, the vapor is absorbed by the lithium bromide. The rate of absorption of LiBr is dependent on the surface area between the water vapor and the LiBr. An absorbent pump and a discharge spray system are added to the absorber to increase the surface area and aid in the absorption of the water vapor.

When lithium bromide solution absorbs water vapor, heat is generated. This heat, consisting of the heat of condensation of the absorbed water vapor plus a reaction heat between the lithium bromide and the water, creates the need for a cooling coil. Reducing the temperature of the solution also increases the capacity of the solution to absorb water vapor. The
temperature of the solution within the absorber must then be lowered to the proper level for the absorption process to be continuous.

To remove heat from the absorber, a cooling coil is added through which condenser water passes. At a temperature lower than the lithium bromide solution, the condenser water can remove heat from the lithium bromide solution. Condenser-water entering the absorber will be 80° F to 90° F. The temperature rise through the absorber is approximately 10° F.

In most commercial designs, the evaporator and absorber are located within a common vessel similar to the one shown in Figure 18. The system functions exactly as the system previously described and illustrated schematically in Figure 17. As mentioned, absorber and evaporator pumps are used for circulation in the respective spray systems. The building’s chilled water being cooled circulates through the heat-transfer coil in the evaporator. The condenser water passes through a heat-transfer coil in the absorber. The refrigerant water vapor is then free to pass from the evaporator to the absorber, as shown by the arrows.
Concentrator or Generator Operation

Lithium bromide solution in the absorber is continually being weakened or diluted by the water vapor that it’s absorbing from the evaporator. As the absorber’s solution becomes more dilute, it has less ability to absorb refrigerant vapors. To overcome this effect, a concentrator or generator is added to the system, as shown in Figure 19. The concentrator pump takes the dilute lithium bromide solution from the absorber and pumps it into the concentrator. The concentrator maintains a pressure of approximately 2.0 in. Hg abs.

In the concentrator, the dilute solution comes in contact with a hot medium. Depending on absorption chiller type, this hot medium may be either steam, hot water, or direct flame. In the concentrator sump shown in Figure 19, the heating coil contains either steam or hot water. If the heating medium is

---

**FIGURE 19—Basic Absorber-Concentrator Cycle**
steam, the pressure is typically between 2 and 15 psi. If the heating medium is hot water, its temperature is between 225° F and 270° F.

In the concentrator, the heating medium heats the solution and vaporizes the refrigerant. During this vaporization process, the refrigerant is separated from the LiBr solution, and the resulting LiBr solution become stronger or more concentrated. The strong lithium bromide solution flows by gravity back to the absorber.

**Heat Exchanger Operation**

You’ve just read how the overall absorption cycle requires heat to be removed from the absorber and heat to be added to the concentrator. However, Figure 19 shows hot, concentrated LiBr solution being added directly to the absorber, and cool, weak LiBr solution being added directly to the concentrator. Ideally, the hot LiBr solution would be precooled prior to entering the absorber, and the cool LiBr solution would be preheated prior to entering the concentrator. A simple solution is to add a solution heat exchanger in the lines between the absorber and concentrator, as shown in Figure 20.

The heat exchanger is a shell-and-tube type with warm concentrated solution from the concentrator in its shell and cool dilute solution from the absorber in its tubes. Heat transfer occurs between the two solutions. The warm concentrated solution from the concentrator has its temperature lowered and will be more effective as an absorbent when it arrives in the absorber. The cool dilute solution from the absorber takes heat from the concentrated solution and has its temperature raised and will require less heat to cause vaporization when it reaches the concentrator. Since heat recovery is obtained without measurably increasing the required input to the system, the heat exchanger is an economy measure.
Concentrator-Condenser Operation

Recall that water vapor in the concentrator is driven off the LiBr solution by the heating medium. This vapor must be condensed to a liquid before it can be reused in the evaporator. As shown in Figure 21, a condenser and condenser water coil are added to the overall absorption cycle to accomplish this condensation. Since the pressures within the condenser and concentrator are approximately equal, these two components are enclosed in the same physical shell, as shown in Figure 22. The condenser is at a much lower temperature than the concentrator. Due to this temperature difference, vapor migrates to the condenser from the concentrator.
The coil within the condenser contains circulated condenser water. Since it has just been heated by the heating medium circulated through the concentrator, the water vapor entering the condenser is at a relatively high temperature. As the warm water vapor comes in contact with the relatively cool condenser-water coil, the water vapor condenses and forms water, which collects in the condenser. The water vapor, arriving in the condenser, will be at a temperature of about 210° F to 220° F. The condenser water will enter the condenser coil at approximately 90° F to 100° F and leave the condenser coil at a temperature approximately 10° F higher. A typical absorption refrigeration unit will require from 3.0 to 3.6 gpm of a condenser water per ton of refrigeration.
In most commercial designs, the concentrator and the condenser are located within a common vessel, similar to that shown in Figure 22. The system functions exactly as the system described above and illustrated schematically in Figure 21. The water vapor is drawn to the condenser from the concentrator due to a temperature difference, as previously mentioned, and takes the path shown by the arrows in Figure 22. The water vapor in the condenser strikes the relatively cool coil through which the condenser water is being circulated. Contact with the cooling coil condenses the vapor into refrigerant water, which returns to the evaporator.

**Condenser-Evaporator**

A schematic arrangement of the condenser and evaporator is shown in Figure 23. The water vapor driven off in the concentrator enters the condenser and condenses upon contact with a cooling coil. Through a throttling pipe or pressure reducing valve, the condensed water flows back to the evaporator, where it’s again circulated by the evaporator pump through the evaporator spray system. As discussed before, the liquid refrigerant in the evaporator, which consists of pure water, is vaporized due to its contact with the building chilled-water coil and then starts another cycle through the entire system.
**Single-Effect Complete Cycle**

The complete absorption refrigeration system of a single-effect system is shown in Figure 24. Water vapor leaves the evaporator and enters the absorber, where it’s absorbed by the lithium bromide solution in the absorber sump. The absorber pump takes its suction from the sump and distributes the lithium bromide solution through the spray system. The concentrator pump also takes its suction from the absorber sump and discharges the diluted lithium bromide in the concentrator or generator. Before the diluted solution reaches the concentrator, it passes through a heat exchanger, where it’s preheated.

The heating medium in the concentrator drives the water vapor from the solution and concentrates the solution. The strong solution leaves the concentrator, and on its way to the absorber, the strong solution flows through the heat
exchanger, where it gives up some heat to the weak solution flowing to the concentrator. The water vapor that’s driven off in the concentrator flows to the condenser, where the water vapor is condensed and then returned to the evaporator through a pressure-reducing valve. The condenser water first enters the absorber, where it removes heat of absorption; the condenser water then flows to the condenser, where it cools the water vapor.

Following the condenser, the liquid refrigerant returns to the evaporator and falls into the evaporator sump. The evaporator pump takes its suction from this sump and discharges the water through a spray system onto the chilled-water coil. The water that’s sprayed in the evaporator vaporizes on the cooling coil and extracts heat from the chilled-water loop.

FIGURE 24—Single-Effect Absorption Refrigeration Diagram
The three pumps shown in Figure 24—the absorber pump, concentrator pump, and evaporator pump—are generally integral parts of the unit. The absorber pump and the concentrator pump are sometimes driven by a single motor, while a single motor drives all three pumps in some units. Along with the other components, the heat exchanger is also an integral part.

**Double-Effect Complete Cycle**

The term *double-effect* is sometimes replaced by *two-stage*, depending on chiller manufacturer. All major components and their respective operations in a double-effect machine are similar to the components within the single-effect chiller except for an additional generator, pumps, and heat exchangers. As a result of the increased temperature provided by the second generator, the double-effect absorption unit provides about 50% to 80% more cooling capacity.

The complete absorption refrigeration system of a commercially available double-effect, steam-fired chiller is shown in Figure 25. Water vapor leaves the evaporator and enters the absorber, where it’s absorbed by the lithium bromide solution in the absorber sump due to its high affinity for water vapor. The absorber pump takes its suction from the sump and distributes the lithium bromide solution through the spray system. The concentrator pump also takes its suction from the absorber sump and discharges the diluted lithium bromide in the low-temperature concentrator or generator. Before the diluted solution reaches the concentrator, it passes through a low-temperature heat exchanger where it’s preheated.

In the low-temperature concentrator, the heating medium used to boil the solution is vapor from the high-temperature generator. During this process, the high-temperature vapor condenses and is sent to the condenser. The intermediate concentrated solution leaves the low-temperature generator and flows to either the high-temperature generator pump or the absorber pump as shown in Figure 25.
Before entering the high-temperature concentrator, the intermediate concentrated solution is preheated by the high-temperature heat exchanger. In the high-temperature generator, the heating medium (steam, hot water, or direct flame) drives the water vapor from the intermediate solution and concentrates the solution. The strong solution leaves the concentrator. On its way to the absorber, the strong solution flows through both heat exchangers, where it gives up some heat to the weaker solution flowing to each concentrator. The water vapor that's driven off in the high-temperature concentrator flows to the low-temperature concentrator before entering the condenser. In the condenser, the pure water vapor is condensed and returned to the evaporator through a pressure-reducing valve. The condenser water first enters the absorber where it removes heat of absorption; the condenser water then flows to the condenser where it cools the water vapor.
Following the condenser, the liquid refrigerant returns to the evaporator and falls into the evaporator sump. The evaporator pump takes its suction from this sump and discharges the water through a spray system onto the chilled-water coil. The water that’s sprayed in the evaporator vaporizes on the cooling coil and extracts heat from the chilled-water loop. The four pumps shown in Figure 25—the absorber pump, low-temperature and high-temperature generator pumps, and evaporator pump—as well as the two heat exchangers, are generally integral parts of the unit. Each pump includes an integral motor.

**Flow Rate Calculations**

During the analysis of an absorption chiller, three flow rates must be considered for condenser water, heating medium, and chilled water. To determine the amount of condenser water in gallons per minute required by the absorption unit, the number of tons of refrigeration produced by the unit must be multiplied by the unit’s required condenser water per ton of refrigeration as shown in the following example. The temperature of the condenser water leaving the absorption unit will be approximately 20 degrees higher than the temperature of the condenser water entering the absorption unit.

**Example:** A refrigeration unit requires 4 gallons per minute of condenser water per ton of refrigeration. What condenser-water flow is required for a 500-ton refrigeration unit?

**Solution:** Multiply as shown.

\[
4 \text{ gpm per ton} \times 500 \text{ tons} = 2,000 \text{ gpm}
\]

Next, the amount of heating medium used in the concentrator must be considered. If steam is used as the source of heat, approximately 19 to 20 pounds per hour is required per ton of refrigeration. If hot water is the heating medium, approximately 0.4 to 1.0 gallons per minute will be required per ton of refrigeration. The exact required flow of hot water will depend upon the temperatures of the hot water entering and leaving the concentrator.
The chilled-water flow rate through the evaporator will depend on the capacity of the unit and the chilled-water temperatures involved. The chilled water entering the unit will be at a temperature of about 54° F, while the leaving chilled-water temperature will be about 46° F.

Equation 5 shows the relationship between the capacity of the unit, the chilled-water flow through the unit, and the chilled-water temperature differential.

*Equation 5*

\[ T_d = \frac{Btuh}{(500 \times \text{gpm})} \]

In this equation,

- \( T_d \) = temperature drop of the chilled water through the evaporator
- \( Btuh \) = nominal cooling capacity of the unit in Btu per hour
- \( \text{gpm} \) = chilled water flow through the evaporator

Remembering that a ton of refrigeration is equal to 12,000 Btu per hr, Equation 5 can be rewritten as Equation 6.

*Equation 6*

\[ T_d = \frac{12,000 \times \text{Tons}}{(500 \times \text{gpm})} \]

In this equation,

- \( \text{Tons} \) = nominal cooling capacity of the unit in tons of refrigeration

By rearranging Equation 6, a direct expression to solve for gallons per minute can be found as shown in Equation 7.

*Equation 7*

\[ \text{gpm} = \frac{24 \times \text{Tons}}{T_d} \]

**Example:** In a 1,000-ton absorption refrigeration unit, water enters at 54° F and leaves at 46° F. To produce this temperature drop, how much water is necessary?

**Solution:** Substitute the known values into Equation 7, and solve as shown here.
Answer: Thus, a 1,000-ton unit is capable of chilling 3,000 gpm of water from a temperature of 54° F to a temperature of 46° F.

**Commercial Availability**

Several variations in the physical arrangement of the absorption system components are available. As previously discussed, the evaporator and the absorber are arranged within a common shell in some absorption machines, and the concentrator and the condenser are arranged within a single shell as shown in Figure 6. In other units, all four components are arranged within a single shell as shown in Figure 11. Three-shell units have also been furnished for special applications. In each of these arrangements, the refrigeration cycle functions in the same manner as discussed in preceding sections. The advantages and disadvantages of each arrangement are discussed in the following sections.

**Shell Arrangements**

Most manufacturers produce their units in the two-shell arrangement. A typical two-shell arrangement, as shown in Figure 26, contains all of the components included in Figure 24. In Figure 26, the evaporator and the absorber are contained within a single shell, and the concentrator and condenser are contained within another single shell. The concentrator-condenser assembly is physically located above the evaporator-absorber assembly. The same three pumps are required for this arrangement. Mounting one shell above the other provides gravity return of the concentrated lithium bromide solution from the concentrator through the heat exchanger to the absorber.
A single-shell arrangement is shown schematically in Figure 27. Here, all the major components are arranged within a single shell and the heat exchanger is located outside the shell. Operation of the system housed within a single shell is the same as the operation of a two-shell unit.

A special arrangement of the major components is shown in Figure 28. In this case, the absorber and the evaporator are combined in the lower shell while the generator and condenser are housed in separate shells connected by a vapor duct. This arrangement can be used where there are space limitations.
Commercially Available Absorption Refrigeration Chillers

An example of a single-effect absorption unit from the Trane Company is shown in Figure 29. Units of this type are available in 23 different sizes, ranging from 101 to 1660 tons. A Trane Company unit rated at 750 tons nominal capacity is approximately 24 ft 5 in. long, 7 ft 2 in. wide, and 10 ft 0 in. high and has an operating weight of over 65,000 lb. The various components of the Trane Company unit are shown in Figures 30 to 33. Operation of Trane units is similar to the basic performance cycle discussed earlier.

FIGURE 29—Single-Shell Absorption Unit (The Trane Company)
Figure 30 shows the evaporator cycle, during which the evaporator pump takes its suction from the evaporator sump or the refrigerant pan and discharges the water through the spray heads. This spray system distributes the refrigerant water evenly over the evaporator tube bundle. In this manner, the external surfaces of the evaporator tubes are wetted uniformly and not submerged.

Water that returns from the system to be chilled is passed through the evaporator tubes. The water inside the tubes is at a higher temperature than the water being sprayed over the tube bundle, and the water in the tubes gives up its heat to the water being sprayed over the tubes. Thus, the water in the tubes is cooled and leaves the evaporator to return to the system.

As shown in the absorber section illustrated in Figure 31, the vapor produced in the evaporator passes through eliminators prior to entering the absorber. The eliminators are baffles separating entrained refrigerant droplets from the vapor, allowing only the vapor to proceed to the absorber while any droplets fall back into the refrigerant pan. The lower pressure in the absorber, necessary for the water vapor to flow from the evaporator to the absorber, is controlled by maintaining the temperature and concentration of the absorbent solution in the absorber.
The water vapor from the evaporator is absorbed by the lithium bromide solution being sprayed from the absorber spray system over the absorber tube bundle. The water refrigerant is mixed with and becomes part of the absorption solution, thereby diluting it as the solution passes down into the absorber sump. Cool condenser water passes through the absorber tube bundle and removes the heat of condensation and absorption.

The absorber sump has two openings. One connects to the absorber pump, drawing a portion of the dilute solution from the absorber sump and mixing it with more concentrated solution. This intermediate concentrated solution is then circulated by the absorber pump to the spray header. In this intermediate concentrated form, the solution is now able to absorb more refrigerant vapor.

The concentrator section is shown in Figure 32. The concentrator pump circulates the dilute solution through the heat exchanger and then into the concentrator. The dilute solution flows into the concentrator, containing a submerged tube bundle through which low-pressure steam or hot water flows and boils the water out of the diluted solution. The lithium bromide solution, now concentrated, flows from the concentrator sump back to the absorber through the heat exchanger to repeat the process of picking up more water vapor.
The heat exchanger shown in Figure 32 is of the shell-and-tube type. The concentrated solution flowing from the concentrator circulates through the shell; the cooler dilute solution, passing from the absorber to the concentrator, flows through the tubes. This heat-exchanger design causes heat to be transferred between the two solutions. The heat exchanger preheats the dilute solution before it enters the concentrator while cooling the concentrated solution which is returning to the absorber.

The condenser section is shown in Figure 33. The vaporized water, separated from the solution in the concentrator, passes to the condenser due to a slightly lower pressure in the condenser. On its way to the condenser, the refrigerant vapor passes through the condenser eliminators or baffles that collect any entrained concentrated-solution droplets.
Lithium Bromide Absorption Systems

and prevent their carryover into the condenser. Any collected droplets drain down the eliminators and into the concentrator.

Once through the eliminators, the water vapor contacts the cooler external surface of the condenser tube bundle and condenses. The condenser water flowing through the condenser tube bundle, after passing through the absorber tube bundle, is sufficiently cooled to maintain the condensing process and to create the lower pressure needed in the condenser to draw refrigerant vapor from the concentrator.

Carrier Corporation, York Corporation, and Dunham Bush are large manufacturers of two-shell absorption chillers. A typical York unit is shown in Figure 34. A York unit rated at 704 tons nominal capacity is approximately 22 ft 3 in. long, 6 ft 6 in. wide, and 11 ft 7 in. high and has an operating weight of approximately 48,000 lb. The cycle diagram for a typical York unit was shown in Figure 5, and the diagram for the units manufactured by Carrier Corporation would be similar. This diagram is also very similar to the unit shown in Figure 26. The condenser-water bypass, capacity control valve, automatic motor less hermetic purge, and the hermetic pumps will be discussed later in this study unit.

![Figure 34—York Single-Effect Absorption Unit](Courtesy of York International Corp.)
Solution Pumps

Solution pumps are either hermetically sealed or open with mechanical seals. A hermetically sealed pump is shown in Figure 35. The assembled unit is shown in Figure 35A, and a section through the pump is shown in Figure 35B. The pump and motor components are all assembled within a common housing. The lithium bromide circulates through this housing and cools and lubricates the bearings and motor. This lithium bromide keeps motors operating at their most efficient temperature. Since the refrigerant water being circulated is allowed to flow throughout the pump and motor housing, there’s no need for a shaft seal. This eliminates the possibility of air leakage through the shaft seal. Maintenance of the shaft seals is also eliminated.

FIGURE 35—Hermetically Sealed Pumps (A) Assembled Unit; (B) Sectional View (Reproduced by permission of Carrier Corporation)
An assembly where the absorber-solution pump and the concentrator-solution pump are mounted on a single shaft and driven by a single motor is shown in Figure 36. This unit is the hermetic type and is constructed in the same manner as the pump shown in Figure 35. A similar type of pump and motor assembly, except that the unit is the open type, is shown in Figure 37.
Each pump discussed so far is equipped with shaft seals. A section through a typical pump with mechanical seals is shown in Figure 38. In this illustration, the pump discharge contains a tapping from which water is obtained for the water seal. Remember that the pressure of the pump discharge is still considerably below atmospheric pressure. If leakage occurs, it will be air leaking along the shaft, through the shaft seals, and into the system. To prevent this, a well-maintained, quality shaft seal is necessary.

**Purge System**

The *purge system* used on the Trane Company units is shown in Figure 39. This system is operated manually and is used only when the operator feels purging is necessary. In this system, a motor-driven vacuum pump is used to remove the air and other noncondensables from the system to maintain the required vacuum within the unit. This purge system is shown schematically in Figure 40.
The purge chamber (in Figure 40) is located in a position to continuously collect the noncondensables from the absorption unit. The vacuum pump takes its suction from the purge chamber and discharges to the atmosphere. A manual shut-off valve, a solenoid valve, and an oil trap are located in the vacuum pump suction line. The manual shutoff valve is provided to shut down the system manually when it's necessary to perform any maintenance on the unit. The solenoid valve is connected to the vacuum pump circuit and opens when the pump is operating. It closes when the pump stops, thereby preventing any air from flowing back into the unit.
The pressure in the purge chamber is maintained slightly below the pressure in the absorber. In that way, non-condensable gases and water vapor are drawn into the purge chamber. The water vapor is condensed by a cooling unit, which has cooling water running through the coils. A lithium bromide absorbent solution is led into the purge chamber to absorb the condensed water and return it to the absorber. By means of the vacuum pump, the non-condensable gases flow to the atmosphere.

The Carrier Air Conditioning Company makes use of the hermetic purge system shown in Figure 41. This purge system is automatic and requires no electric power. It provides a continuous purging action. Contamination of the absorption cycle with oil is nearly impossible. The controls for this purge system are located internally and not exposed to air. This configuration practically eliminates the need to replace parts because of wear or corrosion.

Like Trane’s purge system, York Corporation uses an automatic, continuous purge system operated by a motor-driven vacuum pump for purging purposes. A water-cooled purge chamber is used to store any noncondensable gases. Gases are removed from the chamber during periodic maintenance, using the electric motor-driven vacuum pump.

**FIGURE 41—Hermetic Purge System** (Reproduced by permission of Carrier Corporation)
Decrystallization

Crystallization is the result of too much water being removed from the lithium bromide solution or a drop in temperature of a warm, concentrated solution. The possible causes associated with crystallization include air in the machine, low-temperature condenser water, or electric power failure. When one of these things happens, the LiBr solution can become so concentrated that crystals begin to form. The crystals plug piping and render the equipment inoperable.

Most major absorption chiller manufacturers include a device that detects the start of crystallization. Trane Company’s device, shown in Figure 42, consists of two elements. First, a sensing device (in this case a float chamber) is installed in the concentrated solution line between the concentrator and the heat exchanger. The second component consists of a two-position valve. If crystallization begins to develop, resistance to flow increases in the heat exchanger and a subsequent rise in fluid would occur in the concentrated solution line leading to the heat exchanger. The sensing device will detect this level increase, and the two-way valve will be opened to allow the dilution of the concentrated solution.

A diagram of the automatic decrystallization system used by Trane Company is shown in Figure 43. Crystallization will first occur in the heat exchanger. Formation of crystals in the shell of the heat exchanger blocks the normal return of the
solution from the concentrator to the absorber. Since the refrigeration cycle has been interrupted, this blockage will cause the machine to shut down.

Once the external malfunction has been corrected, the machine can be re-energized. The solution pumps will go back into operation and flow will occur through the bypass tube, which carries hot solution from the overloaded concentrator and returns it to the absorber, where it’s picked up by the concentrator pump and pumped through the tubes of the heat exchanger. The hot solution will warm the mixture of crystals and liquid in the shell of the heat exchanger, thereby dissolving the crystals. The machine will then be able to return to normal operation.

Other manufacturers’ units are arranged so that in the event of emergency shutdown or power interruption, the weak solution from the absorber will drain down and occupy the external or high-temperature areas of the machine that normally contain strong or intermediate-strength solution. As the machine cools, the internal pressures equalize and a considerable amount of the refrigerant in the evaporator flows into the generator. This dilutes the solution and tends to prevent any crystallization as the machine cools to room temperature. This arrangement tends to prevent crystallization or, if crystallization does occur, helps to make start-up as quick as possible.
Capacity Control

The output capacity of some of the earlier absorption units produced was controlled by throttling the condenser water. This was a simple arrangement, but it created problems. As the quantity of condenser water was reduced, the condenser-water temperature increased and the temperature of the water leaving the condenser also was higher. A general temperature increase occurred throughout the unit and the absorption process was decreased, thereby decreasing the refrigerating effect of the machine. Over time it was found that the higher temperature of the condenser water created scaling problems, and operating expenses were increased by the cost of water treatment to combat scaling. This type of system isn’t often used in the field today.

Throttling of the Heating Medium

An electronically actuated control valve on most modern absorption chillers can modulate capacity from 10% to 100% of design by adjusting the flow of the heating medium to the unit. Modulating the heat input to the concentrator controls the degree of concentration occurring in the concentrator and, therefore, the solution concentration in the absorber. The less concentrated the solution in the absorber, the less affinity exists for water vapor that will result in an increase in pressure and temperature within the absorber-evaporator. The higher evaporator temperature results in a reduced temperature differential between the evaporator and the chilled water. The final result will be a decrease in capacity.

A schematic diagram of this type of control is shown in Figure 44. In this system, an aquastat is located in the chilled-water line leaving the evaporator. An aquastat is similar to a thermostat, except that it’s used to measure water temperature. It contains electrical contacts that make or break at preselected temperatures. The aquastat is set to maintain a predetermined water temperature. The refrigerating capacity of the unit is varied by controlling the automatic valve in the line where the heating medium enters the concentrator. This valve is controlled directly by the aquastat in the chilled-water outlet line. On partial load, the aquastat will
cause the automatic valve to be partially closed, thereby restricting the amount of heating medium flow to the concentrator. This, in turn, restricts the refrigerating capacity of the overall refrigeration unit. When full capacity is required, the aquastat will cause the automatic valve to go to the full-open position, and the full-rated capacity of the unit will then be available.

Variation of Solution Concentration

Another way to vary and control the refrigerating effect produced by the unit is to vary the concentration of the solution. A schematic diagram of this type of control is shown in Figure 45. The control employs a three-way valve that's mounted in the weak-solution line to the concentrator on the outlet side of the heat exchanger. The valve is arranged so that the flow of weak solution to the concentrator is reduced.
when full capacity isn’t required. The valve then bypasses the weak solution to the strong-solution line from the concentrator to the absorber. The result is a short-circuiting effect.

As the capacity of the refrigeration unit is further reduced, a greater portion of this solution will be short-circuited back to the absorber. As shown in Figure 45, this three-way automatic valve is controlled by an aquastat located in the chilled-water line leaving the evaporator. The aquastat is set to maintain a fixed discharge-water temperature. By adjusting the three-way automatic valve, the aquastat maintains a fixed discharge-water temperature.

![FIGURE 45—Throttling by Varying the Solution Concentration](image)

Now, take a few moments to review what you’ve learned by completing *Self-Check 3*. 
Self-Check 3

1. The primary function of an absorption unit’s evaporator is to
   a. reject heat to the condenser water.
   b. remove heat from the building’s chilled-water loop.
   c. add heat to the dilute LiBr solution to concentrate the solution.
   d. add heat to the building’s chilled-water loop.

2. Why does water vapor migrate from the evaporator to the absorber?
   a. The liquid spray within the absorber entraps the water vapor.
   b. A large pressure difference exists between the evaporator and absorber.
   c. The lithium bromide solution in the absorber has a strong affinity for water.
   d. The temperature is much lower in the absorber.

3. A heat exchanger typically exists between these two components within an absorption machine.
   a. Evaporator and absorber
   b. Absorber and generator
   c. Generator and condenser
   d. Evaporator and generator

Indicate whether each of the following statements is True or False.

_____ 4. Within the absorption refrigeration unit, the generator and concentrator describe the same component.

_____ 5. All commercial absorption refrigeration units are arranged with the condenser and concentrator in one shell and the evaporator and absorber in the second shell.

_____ 6. The evaporator/absorber pair operates at a lower pressure than the condenser/concentrator pair.

Check your answers with those on page 90.
OPERATION AND MAINTENANCE

General routine maintenance and troubleshooting for a typical absorption unit are discussed in the following sections. Because of the variations associated with chiller types and chiller manufacturers, it’s always best to closely review chiller operation and maintenance (O & M) manuals in detail prior to servicing a new unit.

The actual selection of a lithium bromide absorption refrigeration machine will generally be made with the assistance of a manufacturer’s representative. Since most manufacturers provide what they refer to as “start-up supervision” for each new machine, this text will only briefly discuss the start-up procedure for a new machine.

A new absorption unit must be installed in accordance with the manufacturer’s recommendations. Generally, the manufacturer of the unit will provide installation personnel with sufficient drawings and diagrams to completely install and connect the equipment. The manufacturer of the unit should also supervise the pre-startup checks, the charging of the system, and the startup and adjustments of the equipment. Most manufacturers provide a checklist to be used during installation.

Once a new absorption machine is installed and put into operation, it must receive certain routine maintenance and service like all large refrigeration systems. However, the absorption system components have been designed to provide maximum operational reliability with a minimum of maintenance attention. These units typically are turned on and off automatically by the building’s energy management system or via a simple time lock. In addition, the unit must be checked occasionally for proper purging of noncondensables.

Water Treatment Study

The service life of the components that carry water will depend upon the chemical composition of the water being circulated. The building’s chilled-water loop is a closed circuit and isn’t as prone to fouling as the condenser-water circuit.
If the condenser water is obtained from a cooling tower, makeup water must be continuously added at the tower and the water system must be treated to compensate for this addition of raw water. If the condenser water is obtained from a lake or a river, the condition of the entering water can be very critical since all of the cooling water is raw water.

It’s generally recommended that the services of a qualified water-treatment company be engaged to make tests of the refrigerant water that’s to be used in the system. They should test for the water pH value, copper level, solution concentration, and undecomposed inhibitors. The pH value of the water must be determined to be certain the water will be compatible with the materials used in the construction of the absorption unit. The water hardness should be determined to indicate the amount of scaling that can be expected in the unit.

If either the pH value or the water hardness doesn’t fall within the acceptable limits established by the manufacturer of the unit, water treatment will be required. The amount and type of water treatment required will be determined by advice from the equipment manufacturer, the water-treatment company representative, and the overall system design.

**Care and Handling of Lithium Bromide**

Eventually it will become necessary to handle the lithium bromide solution, either in adding solution to the system or in removing the solution for repair of the equipment. Certain precautions should be exercised in handling the solution. Lithium bromide is nontoxic, nonflammable, and nonexplosive, and can be handled easily in open containers. The solution is chemically stable and, even after years of use in the absorption machine, generally doesn’t undergo any noticeable change in its chemical properties.

Lithium bromide solution is corrosive when exposed to air. If any solution is spilled, it should be wiped up and the surface should be rinsed with fresh water as soon as possible. To prevent corrosion, metal containers used for handling the lithium bromide should be rinsed with fresh water after. In addition, lithium bromide solution may be irritating to the
skin and should be washed off with soap and water. If it gets into the eyes, wash with fresh water and consult a physician immediately.

**Operating Procedures**

It should be noted that each manufacturer provides instructions for starting and stopping the machine, and those instructions should be carefully followed. However, the following procedures are typical and can be used as a guide. If the machine has been shut down for a few days, the following start-up procedure is used:

1. Open the main heating-medium supply valve.
2. Push the START button on the push-button station.
3. Turn the system switch to the ON position.

If the machine is to be shut down for a few days, the following shutdown procedure is used:

1. Turn the system switch to the OFF position.
2. When the unit completes the dilution or pump-down cycle and stops, push the STOP button on the push-button station.
3. Close the main heating-medium supply valve.

When the unit is to be started at the beginning of the cooling season, a complete check of the equipment should be made before any valves or switches are touched. Since the unit was shut down for a period of time, it’s possible that leaks have gone unnoticed or that the equipment is out of adjustment. For this reason, the liquid level in all the equipment should be checked and all automatic valves should be checked for operation. Thermostats and aquastats should also be checked for calibration. Before attempting to start the system at the beginning of the cooling season, perform the following system checks and maintenance procedures:

1. Perform the monthly and seasonal maintenance procedures as discussed later.
2. Vent and fill the cooling-water circuit and cooling-tower sump.
3. Check refrigerant level in the evaporator sump.
4. Make certain that the automatic temperature-control system is energized and that sufficient air pressure is available for the pneumatically operated components, if applicable.

5. Place all chilled-water and cooling-water valves in the operating position.

6. Perform start-up procedures 1, 2, and 3 as listed under “Operating Procedures.”

7. With the system in operation, turn the purge unit switch ON and then open the manual shutoff valve in the purge line. Allow the purge unit to function for a minimum of 6 to 8 hours.

8. The unit is now ready to be returned to service; open the heating-medium supply valve.

9. Push the START button on the push-button station.

When the unit is to be shut down at the end of the cooling season, perform the following operations:

1. Turn the system switch to the OFF position.

2. After the unit has completed the pump-down cycle and has stopped, push the STOP button on the push-button station.

3. Close the main heating-medium supply valve.

4. Vent and drain the cooling-water circuit.

5. Service all auxiliary pumps, cooling tower, etc., in accordance with the instructions provided by the system manufacturer.

6. Only drain the chilled-water circuit if repair is required.

7. Disconnect the automatic temperature-control system and service it in accordance with the instructions provided by the manufacturer.

8. Open all fused disconnect switches.

9. Since the solution of lithium bromide dissolved in water will remain within the unit until the next cooling season, it will be necessary to provide a heated enclosure for the absorption chiller to prevent the refrigerant water within the chiller from freezing.
Periodic Maintenance

Absorption refrigeration equipment is very simple in its operation and doesn’t require detailed routine maintenance. However, the auxiliary equipment required for each installation will vary and may require more routine maintenance than the absorption unit.

To maintain absorption refrigeration capacity, it’s most important to check the vacuum within the equipment and to purge noncondensable gases from the unit once a week. It’s necessary that the system be in operation when it’s purged. Referring to Figure 40, with the refrigeration system in operation, start the purge vacuum pump and then open the manual shutoff valve in the purged line. Normally, one to two hours of purging weekly will free the unit of any accumulation of noncondensable gas. After the equipment has been purged, close the manual shutoff valve in the purged line and then stop the pump.

During the first several weeks of system operation, clean the pump motor-cooling circuit magnetic strainers weekly. Thereafter, clean the strainers on a monthly schedule. A weekly operational check should be made to determine the degree of system tightness. On a charged system, excessive air leakage into the system can be determined by unit performance and by observing the amount of air the purge pump discharges into a container of water. A discharge rate in excess of one bubble per minute (after getting rid of residual gases) is excessive and indicates a leak which must be located and corrected. Accordingly, the first step is to check the purge system for leaks. To do this, follow the manufacturer’s instructions.

If the leak isn’t in the purge system, it must be in the refrigeration system and must be located and corrected. The amount of leakage can be determined as follows:

1. Operate the purge pump until the bubble rate indicates the purge piping has been evacuated. Then open the purge valve.

2. Operate the purge pump to rid the system of residual gases prior to checking the rate of leakage with the solution pump in operation or the system in operation.
3. To check the rate of leakage, operate the purge pump and observe the bubble rate. A rate in excess of one bubble per minute after getting rid of residual gases is considered excessive and requires leak detection and elimination.

All of the strainers and traps in the steam and water lines should be removed and cleaned monthly. In addition, the hermetic motor-cooling circuits should be checked. Close the shutoff valves, thereby isolating the hermetic pump motor-cooling circuits from the rest of the system. Remove and clean the cooling-circuit magnetic-strainer elements.

Use new gaskets when reassembling the strainers. Before reopening the shutoff valves, purge the air from the motor-cooling circuit by connecting a line from an external water source to the access valve and opening the access valve. When water appears, close both access valves and reopen the shutoff valves, thereby returning the motor-cooling circuit to normal operation.

The purge equipment should be given a close inspection once per month. The drive belts should be cleaned with solvent. The pulley alignment and V belt tension should be checked. The belt should depress approximately $\frac{1}{2}$ to $\frac{3}{4}$ in. under light hand pressure applied midway between the pulleys. If the tension isn’t correct, the equipment should be adjusted to obtain the right tension.

The condition and level of the oil in the sump of the purge-system vacuum pump should also be checked monthly. A record should be kept of the amount of oil that’s added. An excessive addition of oil would indicate a leak in the oil system or an oil separator which isn’t functioning properly. The oil should also be checked for contamination. The bigger factor would be the presence of moisture. Frequently, the oil is the type that discolors if excessive moisture is present. The method of testing for the presence of moisture should be obtained from the supplier of the lubricating oil.

At times, air-conditioning equipment and absorption refrigeration equipment aren’t operated year-round. When this is the case, the equipment is checked and put into operation at the start of the cooling season and is then left in operation until the end of the cooling period. For this reason, a major check
of the equipment is necessary prior to seasonal startup, and
more elaborate maintenance should be performed during the
season when the equipment isn’t operating.

The monthly recommended operations discussed above
should be performed. The oil in the purge system vacuum
pump should be changed. The purge pump motor should
be lubricated. All automatically operated valves should be
serviced. The operation of each of the system controls should
be observed, settings should be checked, and the required
adjustments made.

To maintain system efficiency, a quantity of octyl alcohol
should be added to the lithium bromide solution. The alcohol
acts as a wetting agent and aids in the absorption of water
vapor by the lithium bromide. The amount of alcohol to be
added and the correct procedure for adding it will be found
in the manufacturer’s instructions.

**Tube and Vessel Maintenance**

There are reliable commercial organizations in some cities
that offer a specialized service for cleaning and examining
the water sides of pressure vessels. They’ll usually determine,
through analysis, the type of dirt or scale to be removed so
that the proper cleaning solution can be used for the specific
job. Using ultrasound testing equipment, specialty contrac-
tors can also examine the thickness of the vessel walls to
ensure proper strength. Due to the corrosive action of LiBr,
the chiller’s vessels can unknowingly corrode away with
improper vessel care. Chiller operators have been known to
lean up against an older unit, only to find that they’ve caved
in a portion of the vessel.

The inside surface of a vessel on a new absorption unit will
include a thin layer of rust. This rust film is a loose oxide
scale and doesn’t provide good protection against further
corrosion. Corrosion will be continuous, and water acts as a
conductive agent which aids in corrosion. In addition, LiBr
solution is also highly corrosive. Loose rust in an absorption
unit at high enough levels can cause premature bearing and
spray header failures.
However, the most serious concerns associated with corrosion are the loss of metal and the formation of sludge in the solution. Any large amount of corrosion in the system results in sediment that’s circulated in the solution as well as sediment that settles out in various parts, such as the heat exchanger. Sediment plugs the spray nozzles. Eventual removal of the sediment is necessary and is best done under the supervision of a manufacturer’s representative.

To control the progression of corrosion and the flow of loose rust particles, a nonporous film must be developed over the internal rust layer within the vessel. An inhibitor is an oxidizing agent that aids in the formation of this film to slow the corrosion process. Inhibitors also help in restoring ruptures within the protective film. Several types of inhibitors exist; two common inhibitors include lithium nitrate and lithium chromate.

The necessity for tube cleaning will be indicated by symptoms such as a drop in capacity. The frequency with which tubes need to be cleaned varies with the local water characteristics, atmospheric contamination, operating conditions, and so forth; however, it’s a good practice to check the conditions of the tubes prior to the beginning of each cooling season. Tube fouling is commonly due to the following types of deposits:

1. Dirt, rust, or sludge carried from some other part of the system into the tubes usually doesn’t build up to coat the entire tube surface, but it does lie in the bottom of the tubes. This accumulation will eventually restrict water flow through the tubes, reducing the heat-transfer surface of the tubes. This type of tube fouling is easily seen and can be removed by brushing.

2. Scale is a layer of mineral material that precipitates out of the water and forms a hard coating on the inside surfaces of the tubes. This coating is often invisible, but it always reduces the transfer of heat.

Although other types of scale do form depending upon local water conditions, the most common types of scale found within the tubes are calcium carbonate, calcium sulfate, and silica. Since scale is usually invisible when the tubes are wet, it’s best to blow the water out of the tubes and then allow the tubes to dry before checking for scale. After the tubes have
dried, calcium scale will usually appear as a white coating inside the tube; silica scale may not show up at all. Any scale can usually be flaked off the inside of the tube with a small knife.

The only positive method of identifying the type of scale is chemical analysis, although an analysis of the water used in the system will indicate the type of scale which can be expected to form. Scale is best removed by chemical means, which will be discussed later in this study unit.

It’s difficult to determine whether a drop in system capacity is due to fouled tubes alone or to a combination of troubles. An operating data sheet will serve as a guide to establish standard temperature differences across the various components. When the system is new and the tubes are clean, obtain the following data:

1. Evaporator tubes—record the temperature difference between chilled water leaving the evaporator and the refrigerant within the evaporator.
2. Condenser tubes—record the temperature difference between the cooling water leaving the condenser and the refrigerant leaving the condenser.

If the system capacity eventually decreases and displays the following symptoms, dirty tubes are most likely the cause of the problem.

1. If the temperature differences between the chilled water leaving the evaporator and the refrigerant within the evaporator becomes steadily greater, reduced heat transfer is indicated and the evaporator tubes should be cleaned.
2. If the temperature difference between the cooling water leaving the condenser and the refrigerant leaving the condenser becomes steadily greater, scaled or dirty condenser tubes are indicated.

Although many commercial agents are available for removing a specific scale, commercial hydrochloric (muriatic) acid has proved to be a good cleaning agent for most scales. However, it’s best to follow manufacturer’s instructions for the recommended cleaning agent for the tube material. If it becomes necessary to clean the condenser tubes, it’s a good practice
to clean the absorber tubes at the same time. If the chilled-water system is kept clean during installation and is filled with clean water, it shouldn’t be necessary to clean the evaporator tubes often. If the water is very hard, however, water treatment may be necessary.

**Brush Cleaning of Tubes**

If tube fouling consists of dirt and sludge, the collection can usually be removed by brushing. Drain the water side of the vessel to be cleaned (cooling water or chilled water), remove the water heads, and thoroughly clean each tube with a soft-bristle bronze brush. *Do not use a steel-bristle brush*; it may damage the tubes. Improved results can be obtained by admitting water into the tube during the cleaning process. Many manufacturers specialize in equipment that makes tube cleaning a relatively easy task.

**Chemical Cleaning of Tubes**

If tubes are fouled with a hard-scale deposit, they should be chemically cleaned. It’s important that the tubes be cleaned by brushing before they’re chemically cleaned. If the relatively loose foreign material is removed before chemical cleaning, the solution will have less material to dissolve and flush from the tubes. Consequently, a more satisfactory cleaning job will be accomplished in less time. The equipment and connections required for chemical cleaning of the condenser cooling-water circuit are shown in Figure 46. A similar arrangement is necessary for the evaporator circuit.

During the chemical cleaning process, recirculate the chemical solution through the tubes for four to six hours. If the scale is calcium carbonate, the chemical solution will continue to foam as long as scale is being dissolved. If the scale is calcium sulfate, little or no foaming will take place during the chemical-cleaning process. After the recirculation period, the tubes should be rechecked for scale to determine whether chemical cleaning should be repeated.
As the scale is dissolved during the cleaning process, the chemical solution becomes weaker because part of the scale combines chemically with the acid. This makes it difficult to check the actual strength of the solution after cleaning has started. Since it may become necessary to check if the chemical solution is strong enough to dissolve scale, any known calcium carbonate (baking or washing soda or limestone) may be used as an indicator.

The check consists of simply dipping the known calcium carbonate into a small container of the recirculated solution. If active foaming takes place, it’s assumed that the chemical is still strong enough to continue cleaning. If there’s little or no foaming, the solution is no longer effective and a new charge of solution should be used. By setting aside a small container of fresh chemical solution, a comparison of fresh and recirculated solutions can be made.

After the cleaning operation has been completed, drain the chemical solution. It’s now necessary to remove all chemical to prevent rusting. Fill the cleaned vessel with fresh water and drain it. Then fill the tubes and water heads with a 0.05% by weight solution of sodium hydroxide. This solution will neutralize any chemical remaining in the system, and it should be left in the system for one hour before it’s drained. Again fill the circuit with fresh water, and drain. Continue flushing until only clear water is discharged from the drain.
Routine Checking and Testing

When the refrigeration equipment is originally selected, it's sized to handle the maximum cooling load that might be encountered. During most hours of operation, the equipment will be operating at a capacity that's different from this rated condition. It should be kept in mind that only under full-load operating conditions will the readings of the various thermometers and pressure gauges indicate whether the system is functioning properly.

When the unit is in good operating order, it will always provide a given flow of chilled water at a given discharge-water temperature. The unit will automatically control the amount of heating medium that it requires for the cooling load. For this reason, one of the few factors that won't vary with the load on the unit will be the discharge-water temperature. If a unit is selected to provide 46° F chilled water, the equipment should be capable of consistent self-adjustment so that the discharge chilled-water temperature is always 46° F.

During normal chiller operation, the entering steam pressure or entering heating-water temperature shouldn't vary from the design value. Controls should be installed to ensure that the condenser-water temperature will remain within a certain range. The factors that will vary with the capacity of the unit will be the temperature of the chilled water returning from the building, the temperature of the condenser water leaving the unit, and the flow of either steam, hot water, or natural gas to the unit (depending on unit type).

When the load on the equipment decreases from rated capacity, the load reduction will have an effect on the readings of the various thermometers. For example, a unit rated at 1,000 tons nominal capacity circulates 3,000 gpm of chilled water. At design conditions, the chilled water leaves the refrigerating equipment at 46° F and returns to the equipment at 54° F. This unit will require 4,000 gpm of condenser water at a temperature of 85° F. The condenser water leaving the unit has a temperature of 105° F under design conditions. The unit will be furnished with 20,000 lb per hr of steam supplied at 12 psi.
Now assume that the equipment is operating on a milder day and the total cooling load is exactly one-half of the design load of 1,000 tons. The chilled-water circulating pump will still continue to circulate 3,000 gpm of chilled water. The supply chilled-water temperature will still be 46°F. Due to a 50% reduced load, however, the return chilled water will be 4°F hotter than the supply rather than 8°F under design conditions. This chilled water then returns to the absorption chiller at 50°F rather than at the design temperature of 54°F.

The absorption chiller is now circulating the full flow of 3,000 gpm, but it’s only required to chill this quantity of water through a 4 degree temperature drop from 50°F to 46°F, rather than the design conditions of 54°F to 46°F. The automatic controls of the chiller will then sense that chilling capacity must be reduced. This will result in a reduction of the amount of heating medium that must be provided to the unit. Since the heating medium is steam in this example, the reduction will be in the pounds per hour of steam consumed. If the heating medium were hot water, the result would be an increased temperature of the heating water as it left the system. If, for example, original design conditions at rated load allowed for a heating-water temperature drop of 30°F through the unit, at half capacity, the heating-water temperature drop would be only 15°F through the unit. Because reduced heating is being done in the concentrator, a decreased amount of cooling will be required by the condenser.

Generally, the unit will be operating at some point between 10% and 100% of the rated capacity. There’s generally no way to find the percent of capacity required by the building and then to relate this load to the output of the absorption chiller. A general check of the equipment would consist of reading the chilled-water temperatures across the chiller and a comparison of those temperatures with the chilled-water temperature across the air-conditioning unit equipment. An additional part of the check is the rate of flow produced by the chilled-water circulating pump. These factors would then give an indication of the load on the chiller which could be related to entering heating-medium conditions and the performance tested. From this information, operating efficiency could be calculated.
## Troubleshooting Guide

The following guide, adapted from one prepared by the Carrier Corporation for troubleshooting lithium bromide systems, is presented to give some indication of the problems that may occur and their possible causes.

<table>
<thead>
<tr>
<th>PROBLEM</th>
<th>POSSIBLE CAUSE</th>
</tr>
</thead>
</table>
| Crystallization at start-up      | Condenser water too cold  
Air in apparatus  
Improper purging                             |
| Crystallization during operation | Condenser water too cold  
Steam pressure or hot-water temperature above design point  
Vapor condensate temperature too low  
Equipment requires the addition of octyl alcohol  
Improper purging  
Air leakage |
| Low refrigeration capacity       | Air in machine  
Condenser tubes dirty  
Improper purging  
Equipment requires the addition of octyl alcohol  
Improper setting of capacity-control valves  
Insufficient condenser-water flow or too high a condenser-water entering temperature  
Solution temperature leaving the generator too low  
Overflow tube cold |
| Machine shuts down on safety control | Motor overloads  
Hermetic pump thermo-overload tripped  
Shutdown on low-temperature cutout |
| Crystallization during shutdown  | Dilution less than seven minutes  
No load during the dilution cycle  
Condenser water pump off during dilution cycle  
Improper closing of capacity control valve  
Machine shutdown with air in it |
| Suspect air leakage              | Leakage into vacuum side of machine |
| Loss of vacuum at shutdown       | Leakage into vacuum side of machine  
Valve in purge system leaks |
| Failure to keep machine purged   | Leakage at a rate greater than the capacity of the purge system  
Purge system not operating properly |
Most of these faults can be corrected by the maintenance personnel. Remember, however, that the refrigeration equipment is operating under a very high partial vacuum. It’s not easy to open the machine, perform maintenance, reassemble the machine, and return it to service. When the equipment must be opened for maintenance, the work should be done under the supervision of an experienced person such as the manufacturer’s representative.

Now, take a few moments to review what you’ve learned by completing Self-Check 4.
Self-Check 4

1. It’s generally recommended that the services of a qualified water-treatment company be engaged to make tests of the refrigerant water that’s to be used in the system. They should test for
   a. the water pH value.
   b. copper level.
   c. solution concentration.
   d. All of the above

2. The pH value of the water should be determined
   a. to be certain the water will be compatible with the materials used in the construction of the absorption unit.
   b. to indicate the amount of scaling that can be expected in the unit.
   c. Both a and b
   d. Neither a nor b

Indicate whether each of the following statements is True or False.

_____ 3. Inhibitors aid in the development of a film on the interior of a vessel to reduce corrosion and loose rust particles from entering the system.

_____ 4. Corrosion occurs continuously within the absorber’s vessels.

_____ 5. If the condenser water is obtained from a lake or a river, no water treatment is required.

_____ 6. The building’s chilled-water loop is a closed circuit and isn’t as prone to fouling as the condenser-water circuit.

Check your answers with those on page 90.
**Self-Check 1**

1. a. \( p_{\text{abs}} = 80 \text{ psi} + 14.7 \text{ psia} = 94.7 \text{ psia} \)

   b. Set up a ratio and solve for \( X \).

   \[
   \frac{81.44 \text{ in. Hg}}{40 \text{ psi}} = \frac{X \text{ in. Hg}}{80 \text{ psi}}
   \]

   \( 81.44 \text{ in. Hg} \times 80 \text{ psi} = X \text{ in. Hg} \times 40 \text{ psi} \)

   \( 6515.2 = X \text{ in. Hg} \times 40 \text{ psi} \)

   \[
   \frac{6515.2}{40} = \frac{X \text{ in. Hg} \times 40 \text{ psi}}{40 \text{ psi}}
   \]

   \( 162.88 = X \text{ in. Hg} \)

   c. Set up a ratio and solve for \( Y \).

   \[
   \frac{111.37 \text{ in. Hg abs}}{54.7 \text{ psia}} = \frac{Y \text{ in. Hg abs}}{94.7 \text{ psia}}
   \]

   \( 111.37 \text{ in. Hg abs} \times 94.7 \text{ psia} = Y \text{ in. Hg abs} \times 54.7 \text{ psia} \)

   \( 10546.739 = Y \text{ in. Hg abs} \times 54.7 \text{ psia} \)

   \[
   \frac{10546.739}{54.7 \text{ psia}} = \frac{Y \text{ in. Hg abs} \times 54.7 \text{ psia}}{54.7 \text{ psia}}
   \]

   \( 192.811 = Y \text{ in. Hg abs} \)

2. True

3. True

4. False

5. False

6. \[
\frac{120,000 \text{ Btuh}}{12,000 \text{ Btuh}} = 10 \text{ tons}
\]
Self-Check 2
1. d
2. b
3. False
4. True
5. True
6. False

Self-Check 3
1. b
2. c
3. b
4. True
5. False
6. True

Self-Check 4
1. d
2. c
3. True
4. True
5. False
6. True
Lithium Bromide Absorption Systems

EXAMINATION NUMBER

01401200

Whichever method you use in submitting your exam answers to the school, you must use the number above.

For the quickest test results, go to http://www.takeexamsonline.com

When you feel confident that you have mastered the material in this study unit, go to http://www.takeexamsonline.com and submit your answers online. If you don’t have access to the Internet, you can phone in or mail in your exam. Submit your answers for this examination as soon as you complete it. Do not wait until another examination is ready.

Questions 1–20: Select the one best answer to each question.

1. Some commercial absorption refrigeration units are arranged so that the
   A. evaporator and absorber are in one shell.
   B. evaporator and condenser are in one shell.
   C. absorber and concentrator are in one shell.
   D. absorber and condenser are in one shell.

2. Crystallization in a lithium bromide system can be caused by
   A. a rise in temperature of a warm concentrated solution.
   B. a power failure to the system.
   C. too little water being removed from the system.
   D. a rise in temperature and too little water being removed.

3. The evaporator temperature in a lithium bromide absorption system should not fall significantly below
   A. 22° F.
   B. 12° F.
   C. 40° F.
   D. 32° F.
4. A lithium bromide solution has a temperature of 170° F and a concentration of 61 percent. Using this information and Figure 9 in your study unit, the saturation temperature is
   A. 64° F.       C. 92° F.
   B. 84° F.       D. 102° F.

5. A 700 ton refrigeration unit requires 3 gallons per minute (gpm) of condenser water per ton of refrigeration. What condenser water flow is required?
   A. 210 gpm
   B. 233 gpm
   C. 2100 gpm
   D. 2330 gpm

6. Which of the following statements about an absorption system is correct?
   A. An absorption system has no compressor.
   B. An absorption system has many moving parts.
   C. An absorption system has no pumps.
   D. An absorption system is difficult to install.

7. The generator in a lithium bromide absorption system is sometimes referred to as the
   A. absorber.
   B. concentrator.
   C. condenser.
   D. evaporator.

8. A pressure gauge reads 57 pounds per square inch (psi). The equivalent pressure in inches of mercury absolute (in. Hg abs) is
   A. 29.93 in. Hg abs.
   B. 71.74 in. Hg abs.
   C. 145.98 in. Hg abs.
   D. 158.72 in. Hg abs.

9. Which of the following statements about lithium bromide is correct?
   A. Lithium bromide is highly explosive.
   B. Lithium bromide is highly flammable.
   C. Lithium bromide is noncorrosive.
   D. Lithium bromide is nontoxic.

10. How many tons of refrigeration are required to cool a load of 60,000 British thermal units (Btu) per hour?
    A. 0.2
    B. 5
    C. 30
    D. 416
11. Which of the following is the correct description of what happens to the vapor in a lithium bromide absorption system?
   A. The vapor is removed from the low-pressure side and discharged into the high-pressure side by a compressor.
   B. The vapor is first absorbed and then condensed before a solution pump moves it to the high-pressure side of the system.
   C. The vapor is first absorbed and then condensed before a solution pump moves it to the low-pressure side of the system.
   D. The vapor is removed from the high-pressure side and discharged into a low-pressure side by a compressor.

12. Crystallization in a lithium bromide absorption system will first occur in the
   A. concentrator.
   B. absorber.
   C. evaporator.
   D. heat exchanger.

13. In a lithium bromide system,
   A. water is the absorbent.
   B. water is the refrigerant.
   C. lithium bromide is the refrigerant.
   D. octyl alcohol is the absorbent.

14. Which of the following pressures is not equal to standard atmospheric pressure?
   A. 0 psig
   B. 14.7 psia
   C. 29.92 in. Hg abs
   D. 5 in. Hg

15. Oil costs $1.24 per gallon and is rated at 130,000 Btu per gallon. The boiler efficiency is assumed to be 75 percent. The steam required is 20 pounds per hour per ton of refrigeration produced, and the heat required to evaporate water is 950 Btu per pound. Assume the electrical requirements to be 0.03 kW per ton and the cost to be $0.06 per kWh. What is the operating cost in dollars per ton per hour due to electricity usage?
   A. $0.0018
   B. $0.1812
   C. $0.2434
   D. $0.4216

16. Using the information provided in Question 15, calculate the operating cost in dollars per ton per hour due to oil usage.
   A. $0.0018
   B. $0.18
   C. $0.24
   D. $0.42

17. Large amounts of loose rust in an absorption unit can cause
   A. an explosion.
   B. increased fuel usage.
   C. a protective coating.
   D. premature bearing and spray header failure.
18. In comparison to a 500 ton centrifugal chiller, a 500 ton absorption chiller requires
   A. minimal installation costs.
   B. a larger cooling tower.
   C. a special foundation.
   D. large quantities of oil.

19. Rust attached to the interior surface of an absorption chiller’s vessel is
   A. normal.
   B. abnormal.
   C. protective.
   D. conductive.

20. Capacity control of an absorption unit
   A. increases with higher evaporator temperatures.
   B. increases as more solution is short-circuited back to the absorber.
   C. is controlled by a valve where the heating medium leaves the concentrator.
   D. is achieved by controlling the flow rate of the heating medium.