Updates and Errata

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The pages listed below contain revisions that have been made to this course book since it was last printed. The rest of this file provides the corrected, print-ready pages, along with the reverse of each page. To update your book, print the pages on both sides of your paper by following the directions provided on the next page. Then simply filter the pages into your course book.

Revised Pages	Date Revised	Description of Revision
Chapter 1		
Pages 1-7 & 1-8	November 2003	Revised chart (should read 64.696 instead of 65.696) on 1-8
Pages 1-9 & 1-10	November 2003	Revised paragraph under head "Specific Heat" should read one lb rather than gallon on 1-10
Chapter 2		
Pages 2-7 & 2-8	November 2003	Revised information icon in margin on 2-8
Chapter 6		
Pages 6-15 & 6-16	November 2003	Revised chart on 6-16
Chapter 7		
Title page & 7-2	November 2003	Revised second paragraph. Added a sentence at the end of the paragraph on 7-2
Pages 7-5 & 7-6	November 2003	Revised "flaring" and "swaging" definitions in the margin on 7-5
Chapter 8		
Pages 8-39 & 8-40	November 2003	Added information icon to the "Safeties" section on 8-40
Chapter 9		
Pages 9-7 & 9-8	November 2003	Revised illustration (should read "spray" instead "stray" on 9-7
Chapter 10		
Pages 10-11 & 10-12	November 2003	Rotated image and added a note icon for the top image on 10-12
Chapter 11		
Pages 11-19 & 11-20	November 2003	Revised illustration on 11-19
Pages 11-21	November 2003	Added caution icon to the margin
page 11-22	November 2003	Fixed second paragraph to "nonconductive," rather than "conductive" carpet files.

Revised Pages	Date Revised	Description of Revision
Chapter 12		
Pages 12-23 & 12-24	November 2003	Under the Probable Cause section it Should read “Frozen compressor due to locked or damaged motor.” And recommended action should read “ repair or replace”
Pages 12-27 & 12-28	November 2003	Revised heading in chart to “Recommended Action” on both pages
Back Matter		
Discussion Question Answers	November 2003	Revised chapter 7 question number 3 answer; chapter 11 question 1 answer
Exercises Answers	November 2003	Revised exercise 4-2 and 9-1 answers

- **Latent heat of condensation** is the amount of heat that must be removed from a substance in order to change a vapor back into a liquid.

- **Latent heat of vaporization** is the amount of heat that must be added to a liquid at its boiling point to change it into a vapor.

Discuss

Explain the different types of latent heat.

The relationship between sensible (can be sensed with a thermometer) heat and latent (cannot be sensed with a thermometer) heat in regard to heat and temperature can be seen in **Figure 1-4**, which tracks temperature and Btu changes of one gallon of water. Start at point A, where the water is at 0°F. The movement from Point A to Point B indicates a rise in temperature to 32°F, which adds 16 Btu because it takes .5 Btu of heat to raise 1 lb. of ice 1 degree Fahrenheit. The movement from Point A to Point B demonstrates sensible heat. Moving between Points B and C, the water stays at 32°F, but it has picked up 144 Btu. The water is now in liquid form (an example of latent heat). Moving from Point C to Point D adds 180 Btu of sensible heat, and the water has remained in liquid form. At Point D the water is at 212°F. Moving from Point D to Point E, the water is vaporized, and 970 Btu are added. During this process, the water stays at 212°F, but it has changed state from a liquid to a vapor. Any additional heat at Point E and above will be sensible heat, and the vapor will be considered superheated. (Superheat is discussed in more detail below.)

Overhead 1-1

Use OH 1-1 to show the relationship between sensible heat and latent heat.

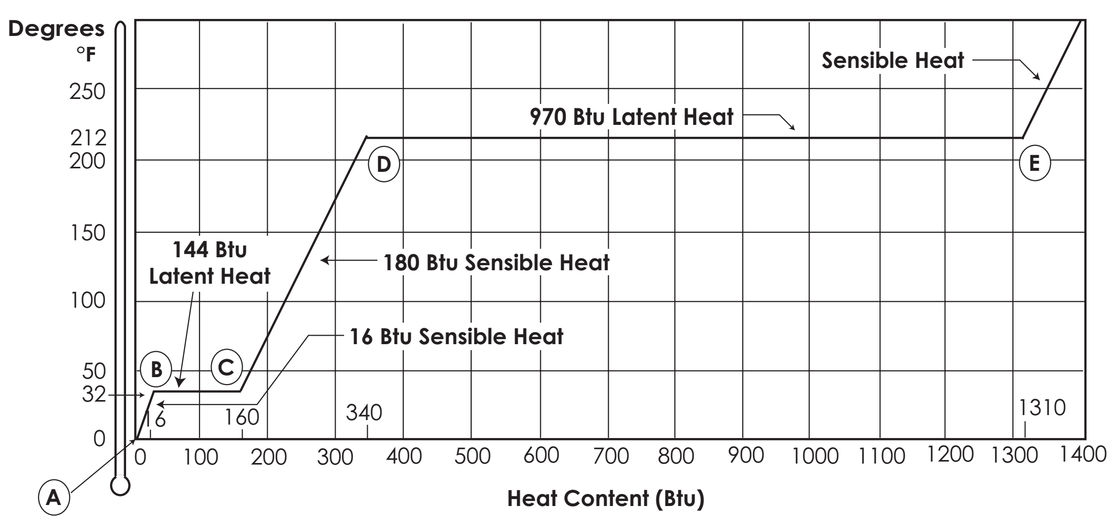


Figure 1-4 Btu Graph for One Pound of Water

In addition to understanding the terms sensible heat and latent heat, we will need to define saturation, superheat, and subcooling as they relate to refrigeration.

Discuss

Explain how saturation temperature changes as pressure changes.

Define superheat and explain its importance.

Saturation Temperature

Saturation temperature, or the boiling point, is the temperature at which a substance corresponds to a pressure. For example, water boils at 212°F at a pressure of 14.7 psia. **Figure 1-5** illustrates the boiling temperature of water for certain pressures. If we change the pressure, we then change the saturation temperature. In refrigeration, the same rule applies. In a typical evaporator using R-22 refrigerant for comfort cooling, we would look for a temperature of 40°F. The pressure that corresponds to this temperature at saturation is 68.5 pounds per square inch gauge (psig). Gauge pressure (psig) is the pressure that is read from the equipment in most mechanical rooms. Most gauges include the 14.7 pounds of regular atmospheric pressure at their starting point, so zero gauge pressure is really 14.7 psig. The building engineer refers to a temperature-pressure chart (see **Figure 1-6**) that lists the temperatures and pressures at saturation for various refrigerants.

Boiling Temp. (°F)	PSIA	Inches Hg. Absolute	Standard Atmosphere Gauge Pressure
298	64.696	134.00	50 psig
227	19.696	40.00	5 psig
212	14.696	29.92	0 psig
192	9.747	19.85	10.07 In. Hg. Vac.
161	4.856	9.89	20.03 In. Hg. Vac.
50	0.178	0.362	29.56 In. Hg. Vac.
40	0.122	0.248	29.67 In. Hg. Vac.

Courtesy of Carrier Corporation

Figure 1-5 The Boiling Temperature of Water

Key Concept

Superheat

Superheat is the temperature (additional sensible heat) above a substance's saturation temperature. Superheat also raises the temperature above a substance's corresponding pressure temperature. For example, if R-22's pressure is at 68.5 psig, its saturation temperature will be 40°F. If more sensible heat is added to the refrigerant to raise the temperature to 45°F, its pressure stays at 68.5 psig. The refrigerant would have 5 degrees Fahrenheit of superheat. In a superheated state, the refrigerant will be 100 percent vapor (no liquid refrigerant present). Superheat is important to the refrigeration system because the compressor is designed to pump only vapor, and a superheat reading at the compressor inlet ensures that only vapor will enter the compressor. A liquid cannot be compressed.

Vacuum-Inches of Mercury—*Italic* Figures

SPORLAN TEMPERATURE-PRESSURE CHART

Pressure-Pounds Per Square Inch Gage **Bold** Figures

TEMPERATURE °F	REFRIGERANT (SPORLAN CODE) R-22(V)	R-410A(Z)	R-407C(N)	R-12(F)	R-134a(J)	TEMPERATURE °F	REFRIGERANT (SPORLAN CODE) R-22(V)	R-410A(Z)	R-407C(N)	R-12(F)	R-134a(J)	TEMPERATURE °F	REFRIGERANT (SPORLAN CODE) R-22(V)	R-410A(Z)	R-407C(N)	R-12(F)	R-134a(J)
-60	*11.9*	*0.9*	*16.0*	*19.0*	*21.6*	12	34.8	65.4	29.0	15.9	13.2	42	71.5	123.6	64.6	38.9	37.0
-55	*9.2*	1.8	*13.7*	*17.3*	*20.2*	13	35.8	67.0	29.9	16.5	13.8	43	73.0	125.9	66.1	39.8	38.0
-50	*6.1*	4.3	*11.1*	*15.4*	*18.6*	14	36.8	68.6	30.9	17.1	14.4	44	74.5	128.3	67.6	40.8	39.0
-45	*2.7*	7.0	*8.1*	*13.3*	*16.7*	15	37.8	70.2	31.8	17.7	15.1	45	76.1	130.7	69.1	41.7	40.0
-40	0.6	10.1	*4.8*	*11.0*	*14.7*	16	38.8	71.9	32.8	18.4	15.7	46	77.6	133.2	70.6	42.7	41.1
-35	2.6	13.5	*1.1*	*8.4*	*12.3*	17	39.9	73.5	33.8	19.0	16.4	47	79.2	135.6	72.2	43.7	42.2
-30	4.9	17.2	1.5	*5.5*	*9.7*	18	40.9	75.2	34.8	19.7	17.1	48	80.8	138.2	73.8	44.7	43.2
-25	7.5	21.4	3.7	*2.3*	*6.8*	19	42.0	77.0	35.9	20.4	17.7	49	82.4	140.7	75.4	45.7	44.3
-20	10.2	25.9	6.2	0.6	*3.6*	20	43.1	78.7	36.9	21.1	18.4	50	84.1	143.3	77.1	46.7	45.4
-18	11.4	27.8	7.2	1.3	*2.2*	21	44.2	80.5	38.0	21.8	19.2	55	92.6	156.6	106.0	52.1	51.2
-16	12.6	29.7	8.4	2.1	*0.7*	22	45.3	82.3	39.1	22.5	19.9	60	101.6	170.7	116.2	57.8	57.4
-14	13.9	31.8	9.5	2.8	0.4	23	46.5	84.1	40.2	23.2	20.6	65	111.3	185.7	127.0	63.8	64.0
-12	15.2	33.9	10.7	3.7	1.2	24	47.6	85.9	41.3	23.9	21.4	70	121.5	201.5	138.5	70.2	71.1
-10	16.5	36.1	11.9	4.5	2.0	25	48.8	87.8	42.4	24.6	22.1	75	132.2	218.2	150.6	77.0	78.6
-8	17.9	38.4	13.2	5.4	2.8	26	50.0	89.7	43.6	25.4	22.9	80	143.7	235.9	163.5	84.2	86.7
-6	19.4	40.7	14.6	6.3	3.7	27	51.2	91.6	44.7	26.1	23.7	85	155.7	254.6	177.0	91.7	95.2
-4	20.9	43.1	15.9	7.2	4.6	28	52.4	93.5	45.9	26.9	24.5	90	168.4	274.3	191.3	99.7	104.3
-2	22.4	45.6	17.4	8.2	5.5	29	53.7	95.5	47.1	27.7	25.3	95	181.9	295.0	206.4	108.2	113.9
0	24.0	48.2	18.9	9.2	6.5	30	54.9	97.5	48.4	28.5	26.1	100	196.0	316.9	222.3	117.0	124.1
1	24.8	49.5	19.6	9.7	7.0	31	56.2	99.5	49.6	29.3	26.9	105	210.8	339.9	239.0	126.4	134.9
2	25.7	50.9	20.4	10.2	7.5	32	57.5	101.6	50.9	30.1	27.8	110	226.4	364.1	256.5	136.2	146.3
3	26.5	52.2	21.2	10.7	8.0	33	58.8	103.6	52.1	30.9	28.6	115	242.8	389.6	274.9	146.5	158.4
4	27.4	53.6	22.0	11.3	8.6	34	60.2	105.7	53.4	31.8	29.5	120	260.0	416.4	294.2	157.3	171.1
5	28.3	55.0	22.8	11.8	9.1	35	61.5	107.9	54.8	32.6	30.4	125	278.1	444.5	314.5	168.6	184.5
6	29.1	56.4	23.7	12.4	9.7	36	62.9	110.0	56.1	33.5	31.3	130	297.0	474.0	335.7	180.5	198.7
7	30.0	57.9	24.5	12.9	10.2	37	64.3	112.2	57.5	34.3	32.2	135	316.7	505.0	357.8	192.9	213.5
8	31.0	59.3	25.4	13.5	10.8	38	65.7	114.4	58.9	35.2	33.1	140	337.4	537.6	380.9	205.9	229.2
9	31.9	60.8	26.2	14.1	11.4	39	67.1	116.7	60.3	36.1	34.1	145	359.1	571.7	405.1	219.5	245.6
10	32.8	62.3	27.1	14.7	12.0	40	68.6	118.9	61.7	37.0	35.0	150	381.7	607.6	430.3	233.7	262.8
11	33.8	63.9	28.0	15.3	12.6	41	70.0	121.2	63.1	37.9	36.0	155	405.4	645.2	456.6	248.6	281.0

To determine ***subcooling*** for refrigerant R-407C use BUBBLE POINT values (Temperatures above 50°F — Gray Background); to determine ***superheat*** R-407C, use DEW POINT values (Temperatures 50°F and below).

Courtesy of Sporlan Valve Company

Figure 1-6 Temperature-Pressure Chart

Key Concept

Discuss

Explain why subcooling is important to a refrigeration system.

Define specific heat.

Subcooling

Subcooling is the temperature (removal of additional sensible heat) below a substance's condensing temperature. It is the cooling of liquid refrigerant below its condensing temperature. It is the opposite of superheat in that in a subcooled state, the refrigerant will be 100 percent liquid (no refrigerant vapor present). Using the R-22 example, which has a saturation temperature of 40°F at 68.5 psig, if the temperature is lowered to 35°F at 68.5 psig, the subcooling reading is 5 degrees Fahrenheit. This is crucial in any refrigeration system because metering devices require a 100 percent liquid refrigerant in order to operate at full efficiency. Otherwise, gas bubbles will form at the metering device inlet, causing inefficient performance.

Discuss

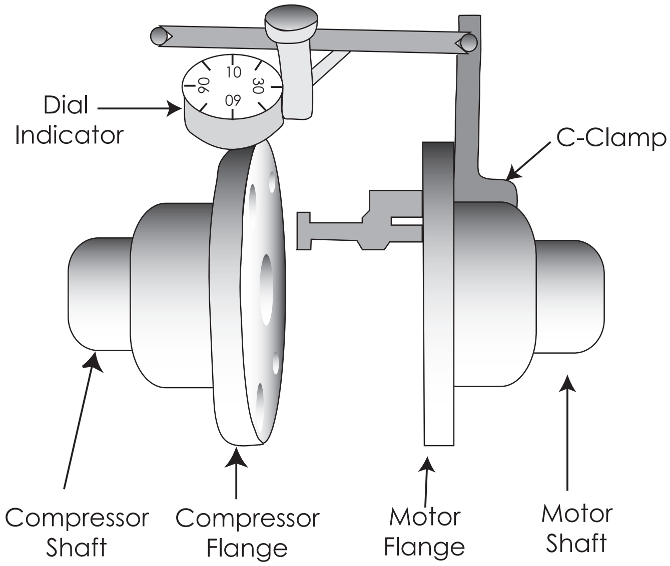
Define specific heat.

Specific Heat

Specific heat is the amount of heat necessary to raise the temperature of 1 lb. of any substance 1 degree Fahrenheit. Earlier we stated that it takes 1 Btu to raise the temperature of 1 lb. of water this 1 degree. This means that the specific heat value for water is one. Different substances have different specific heat values (see **Figure 1-7**). Therefore, when choosing components for a system, the design engineer will look at how fast or how slow the materials are able to transfer heat.

Material	Specific Heat	Material	Specific Heat
Air	0.17	Ice at 32°F	0.487
Alcohol	0.58	Limestone	0.217
Aluminum	0.21	Machine Oil	0.40
Brass	0.09	Marble	0.21
Brick	0.22	Mercury	0.03
Cast Iron	0.119	Nickel	0.11
Charcoal	0.20	Parrafin Wax	0.69
Cement	0.370	Salt	0.21
Concrete	0.156	Sand	0.195
Copper	0.095	Silver	0.056
Ethylene Glycol	0.60	Solder	0.04
Gasoline	0.50	Steel	0.11
Glass	0.199	Turpentine	0.42
Gold	0.031	Water	1.0
Granite	0.195	Wood (Oak)	0.57
Helium	1.250	Wood (Pine)	0.67
Hydrogen	3.420	Zinc	0.095

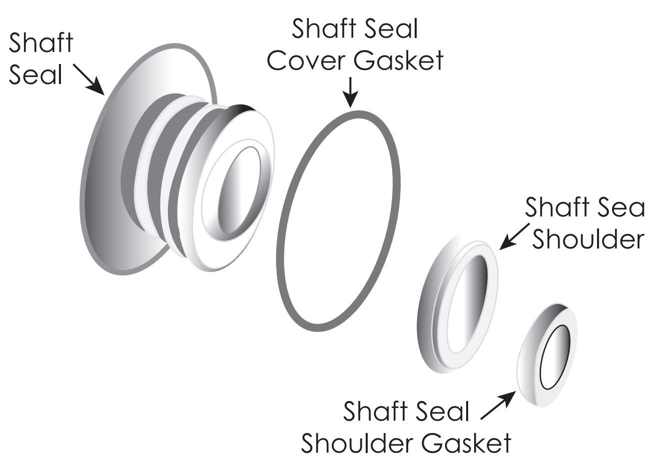
Figure 1-7 Specific Heats of Solids and Liquids



Courtesy of Carrier Corporation

Figure 2-6 Dial Indicator

An open compressor requires a shaft seal. Because the shaft protrudes from the compressor, the shaft seal serves two purposes: it keeps the refrigerant and oil in the system (where they belong), and it prevents air and moisture from entering the system. **Figure 2-7** shows the parts of a shaft seal. A few common types of shaft seals are a stationary bellows, a packing gland, and a diaphragm. The oil inside the compressor lubricates the seal to prevent it from hardening and cracking, which would allow refrigerant to leak out or, in the case of systems running below atmospheric pressure, air and moisture to be drawn in.



Courtesy of Carrier Corporation

Figure 2-7 Parts of a Shaft Seal

The possibility that the shaft seal could leak is the main disadvantage of using an open compressor. Because the cost of refrigerants is increasing, this can become very costly for your organization. Open compressors do have some great advantages, though. Since the motor and drives are external, the pumping capacity of the compressor can be changed simply by changing the rpm of the motor or changing the size of the drive. This gives the operator and design engineer more flexibility in choosing a compressor because a larger motor can be put in. Another advantage is that because the motor is external, if it fails, only it needs to be repaired or replaced. The entire compressor need not be discarded. (Motor failure will be covered in more detail in Chapter 10, "Operating and Safety Controls and Electrical Components.")

Information

When you change a motor, the amperage could change. Check fuses and the motor starter to ensure your safety. Refer to the motor nameplate for electrical specifications.

45 Minutes

Types of Compressors

The different designs that fall under the open, hermetic, and semi-hermetic compressors are:

- reciprocating
- scroll
- screw
- rotary
- centrifugal

Key Concept

Discuss

Explain how a reciprocating compressor works, including the crankshaft, connecting rods, pistons, and valves and valve plates.

Overhead 2-1

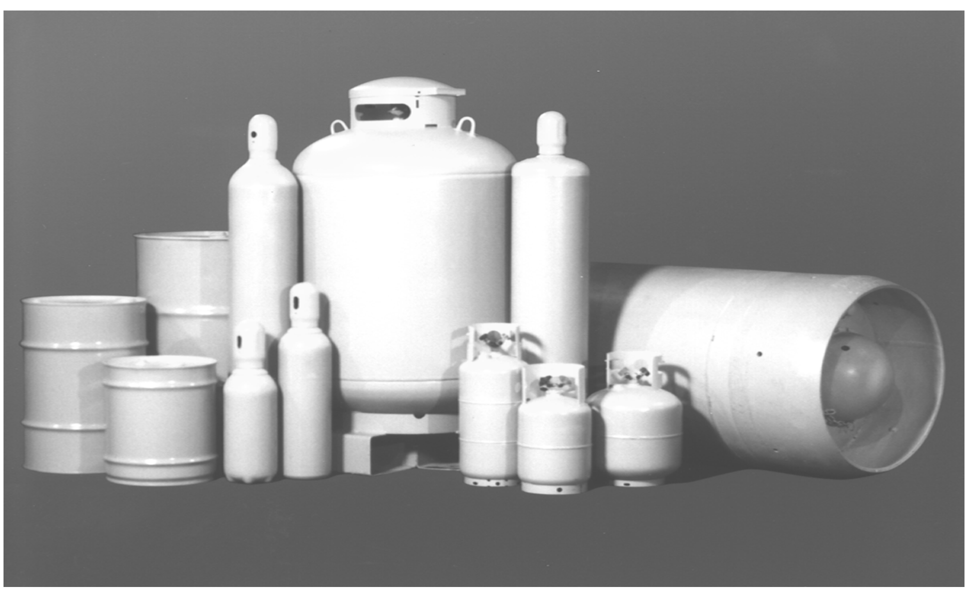
Use Figure 2-8 to explain the basic operation of a reciprocating compressor.

Reciprocating Compressor

The reciprocating compressor (see **Figure 2-8**) is similar to the internal combustion engine and, consequently, is known as the industry workhorse. It is a positive displacement pump; that is, the pump increases the pressure of the refrigerant gas by lowering the volume of the compression chamber. The compressor uses a back-and-forth motion with the use of various machine-precision components. Some of the key components of a reciprocating compressor are the crankshaft, connecting rods, pistons, valves, and valve plate.

Courtesy of Robinar

Figure 6-5 Recovery Machine



Courtesy of National Refrigerants, Inc.

Figure 6-6 Department of Transportation Approval Tanks

Required Levels of Evacuation for Air Conditioning, Refrigeration, and Recovery/Recycling Equipment (Except for small appliances, MVAC's, and MVAC-like equipment) Inches of Hg Vacuum		
Type of Air Conditioning or Refrigeration Equipment	**Using Recovery or Recycling Equipment Manufactured before November 15, 1993**	**Using Recovery or Recycling Equipment Manufactured on or after November 15, 1993**
HCFC-22 equipment, or isolated component of such equipment, normally containing less than 200 pounds of refrigerant.	0	0
HCFC-22 equipment, or isolated component of such equipment, normally containing 200 pounds or more of refrigerant.	4	10
Other high-pressure equipment, or isolated component of such equipment, normally containing less than 200 pounds of refrigerant.	4	10
Other high-pressure equipment, or isolated component of such equipment, normally containing 200 pounds or more of refrigerant.	4	15
Very high-pressure equipment.	0	0
Low-pressure equipment.	25	29

Note: MVAC = Motor Vehicle Air Conditioning

Courtesy of U.S. EPA

Figure 6-7 Refrigerant and Oil Management

Reclaiming involves the refrigerant being sent back to a reprocessing facility to be cleaned under the ARI 700 Standard, which certifies that the refrigerant is of the same quality as new refrigerant. This is typically done off site at a processing facility and laboratory suitable for testing and certification. Typically, used refrigerant can be taken back to a local air conditioning supplier, who will then send it to a processing facility.

Each level (recover, recycle, reclaim) provides a better quality than the preceding level, but is also more expensive and time consuming.

Chapter 7

Various Refrigeration Systems

Learning Objectives

1. Describe the six different types of refrigeration systems, and list their advantages/disadvantages in different applications.
2. Explain the principle of operation of heat pumps.
3. Identify the different types of heat pumps.

10 Minutes

Introduction

Among the many different types of refrigeration systems found in modern office buildings are:

- split system
- packaged rooftop unit
- packaged indoor unit
- through the wall unit
- heat pump
- computer room unit

The first item to consider when choosing a system is the amount and type of cooling (comfort cooling, industrial process cooling, freezers) needed for the application. The budget allocated for the installation and ongoing maintenance also plays a major role in system selection. The type of energy available (oil, gas, or electric) and the geographical area will likewise influence system requirements and available services.

Each air conditioning unit has different physical, economic, and design requirements. Consider the following questions when deciding which refrigeration system to purchase and install. In some cases, a mechanical engineer or a manufacturer's representative will need to be consulted.

- Will the building structure support the unit's weight?
- Where is the electrical service located? What voltages are available? Is there sufficient capacity?
- How will the piping be run to each component?
- What type of condenser (air or water) will be used, and how will the heat be rejected from the space?
- Are noise and vibration a factor?
- What are the air quality and humidification/dehumidification requirements?

sories will be found, such as filter driers, strainers, sight glasses, and receivers. Because the condensing unit is in a remote location, it requires less space and the interior noise levels are reduced. Attention must be paid to airflow when installing an air-cooled condensing unit. If there is a lack of airflow around the condenser, or if hot air is recirculated, the system may shut down because of high head pressure.

Tubing

Since the indoor section and the condensing unit are separate, they are connected by the recirculating tubing (copper is the preferred choice) through which the refrigerant moves. In packaged systems, all of the connecting tubing is installed at the factory to guarantee that the correct diameter is designed and installed. Tubing for a split system is installed in the field, which can lead to problems. For example, the diameter of the tubing chosen may be too small or too big, or the system may not be thoroughly evacuated, leaving moisture and debris. (This will be discussed in more detail in Chapter 11, "Leak Testing, Evacuation, and Charging.")

Discuss

Explain the risks of installing tubing in the field and why air conditioning and refrigeration tubing should be used.

It is important to use air conditioning and refrigeration (ACR) tubing, not standard plumbing pipes. ACR tubing is measured by the outside diameter (OD) and charged with nitrogen to keep the moisture out and the tubing dry prior to installation. Plumbing pipe is typically measured by the inside diameter (ID). Copper tubing may be either soft or hard. Soft copper tubing is typically bent at turns, uses fewer fittings, and comes in 25 and 50 feet rolls. Hard copper tubing is installed using fittings to make bends and join the sections, and usually comes in 10 or 20 feet lengths. With hard tubing, there are more chances for leaks and the greater possibility of dirt and contamination during installation.

Figure 7-2 compares the difference between plumbing and ACR copper tubing. The ACR tubing should not be undersized because it could cause excessive pressure drops. If the tubing is too large, oil will not be allowed to return to the compressor properly as the flow rate will be too slow. In some cases, oil traps will need to be installed to ensure proper oil return. The suction tubing between the evaporator and the compressor should be insulated to prevent condensation and to increase the superheat of returning vapor.

Information

When installing ACR tubing, always refer to the manufacturer's specifications to ensure you have selected the correct size.

There are several ways to connect tubing — **brazing**, **flaring**, or **swaging** the tubing together. The line set (the suction and liquid line connecting the system components) may be charged with refrigerant or nitrogen and, in some cases, it has "quick-connect" fittings to make the installation easier.

Brazing. Similar to soldering, only with a hotter flow temperature of the solder. Usually above 1,200°F.

Flaring. Placing a flare nut over a tube and clamping it to another fitting. The pipe is flared with a flaring tool.

Swaging. Connecting two pieces of tubing of the same diameter by expanding one tube over the other and soldering it. Swaging requires a special swaging tool.

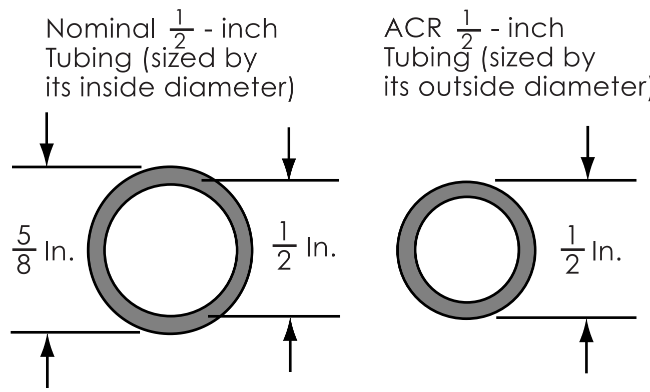


Figure 7-2 Plumbing vs. ACR Copper Tubing

15 Minutes

Packaged Rooftop Unit

Key Concept

Discuss

Explain a packaged rooftop unit. Define commissioning. Compare multi-zone and variable air volume (VAV) units.

As the name implies, the packaged rooftop unit typically is found on the roof of a low-rise building usually up to three or four stories tall. There are a few exceptions where the rooftop unit will be installed on a high-rise building. All the components — compressor, evaporator, condenser, metering device, and auxiliary equipment — are in one package, and connected to an energy source and ductwork within the building. **Figures 7-3** and **7-4** illustrate the vertical and horizontal discharge ducting features of two styles of rooftop unit. The two are mainly the same except for how the supply air and return air ducts are attached to the rooftops. In Figure 7-3 the ductwork is mounted underneath the unit in a vertical arrangement; the ductwork comes in from the side in a horizontal arrangement in Figure 7-4. There are three types of rooftop units as classified by the heating and cooling applications: cooling only, heating only, or both heating and cooling. The most common is both heating and cooling.

Multi-zone. Different areas can be separately controlled.

Commissioning. Initial start-up and verification of proper operation of the original design specification.

Other means of classifying rooftop unit designs are the **multi-zone** unit and the variable air volume (VAV) type. The multi-zone unit allows a large area of various heating and cooling requirements (loads) to be cooled or heated simultaneously. This system is available only in larger tonnages. Controls for this size system are more elaborate and require more expertise in installation and **commissioning**. Although the equipment and installation costs are greater, energy savings during operation typically offset these costs.

- Lithium bromide solution flows from the solution pump through two transfer devices. In the absorber transfer device (item A1), the solution draws noncondensables from the absorber by siphon effect and is then discharged into the secondary heat exchanger (item B). In the heat exchanger, noncondensables separate from the solution and pass into the condenser.

- The noncondensables are drawn from the condenser by the condenser transfer device (item A2) and are **entrained** in solution. The mixture enters the purge separation pot (item C) where the noncondensables collect in a storage chamber (item D) and solution flows back to the heat exchanger and absorber.

Entrained. To be trapped or become an integral part of.

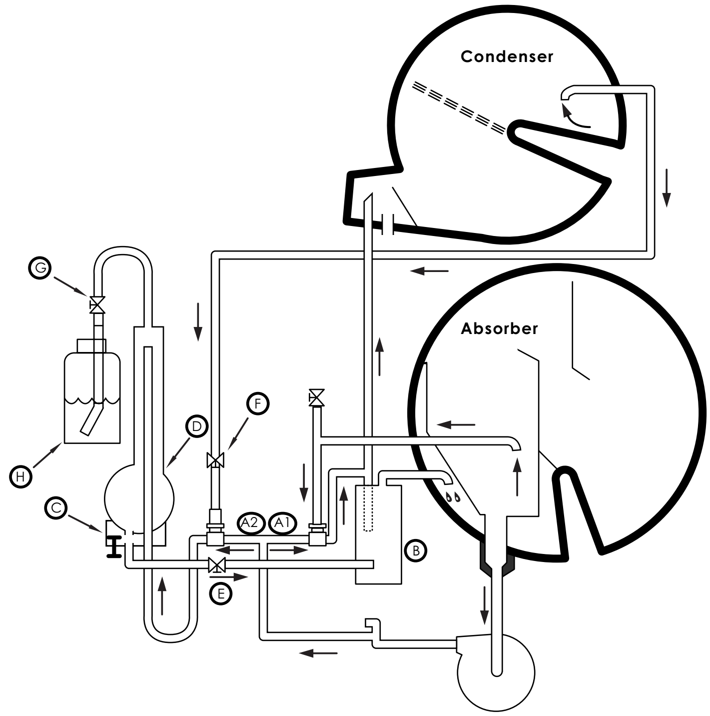
- As the storage chamber fills with noncondensables, the solution level is depressed to a predetermined level near the bottom of the storage chamber. At this point, an indicator light on the machine control panel signals the need to exhaust the purge.

- Exhausting these noncondensables is begun by closing both the solution return valve (item E) and the purge valve (item F). Solution is forced into the chamber by the pump, and the noncondensables are compressed to above atmospheric pressure. The exhaust valve (item G) is opened to bleed the noncondensables into the exhaust bottle (item H) and then reclosed. To return the purge to automatic operation, valve E is reopened to allow solution flow to the absorber, and the valve is reopened to resume noncondensable purging.

This type of purge operation is automatic, motorless, and continuous. It is not intended to remove large quantities of noncondensables and cannot be used to evacuate the machine after servicing.

Overhead 8-4

Use Figure 8-26 to illustrate the sequence of a non-mechanical purge unit.



Courtesy of Carrier Corporation

Figure 8-26 Non-Mechanical, or Motorless, Purge Unit

Safeties

Some safeties found on compression chillers, such as flow switches and low pressure control, are also found on absorption chillers. The different safeties for absorption chillers include

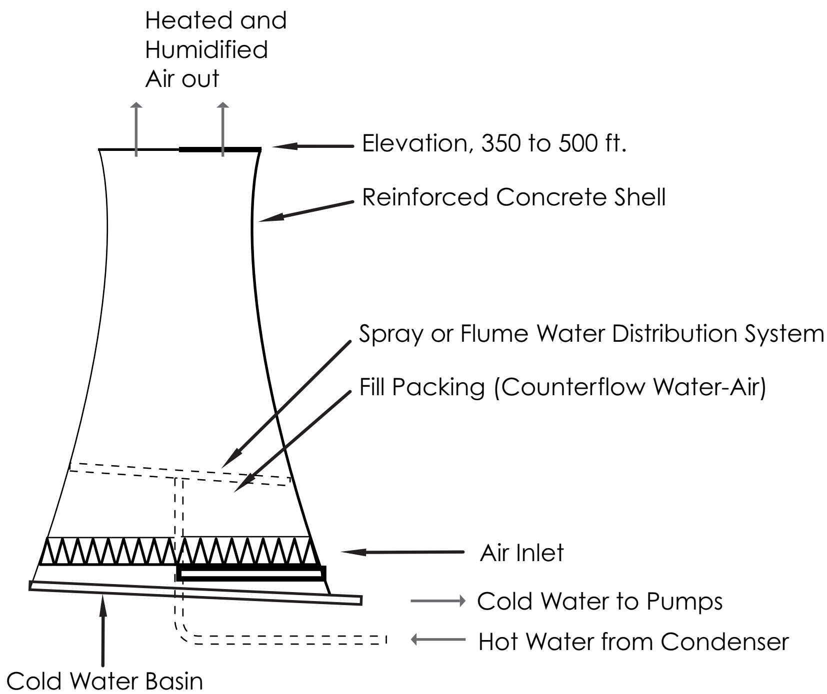
Information

At no time should an operator bypass or tamper with the safety.

- a sensor that monitors solution temperature at the absorber outlet to detect and prevent the conditions that promote crystallization
- a sensor to detect high pressure and high temperature in the generator

Refer to each manufacturer's literature for exact safety-setting parameters.

Figure 9-4 illustrates yet another type of natural draft tower. Called a hyperbolic tower, it is customarily used in large facilities, such as power plants. Many plants of this design rely on rivers or lakes as their water source. Water returning enters the top of the tower and is forced out through spray nozzles. The water strikes interior fill material and breaks up into tiny droplets (this improves the efficiency of water evaporation). The natural flow of air through the fill and across the water surface increases the evaporation rate prior to the water falling into the basin (sump) of the tower. The water is then drawn through an inlet screen (to remove any debris in the tower), out the tower outlet, and typically to a pump to be recirculated.



Courtesy of National Environmental Balancing Bureau

Figure 9-4 Hyperbolic Tower

Mechanical Draft Towers

Key Concept

Mechanical draft in cooling towers is either forced or induced by a fan. In a forced-fan draft tower, the air is forced over the water; in the induced-fan draft tower, air is drawn through the water. The direction of the airflow in relation to the water flow will indicate the design of water and airflow within the tower. **Figure 9-5a** shows a forced-draft counterflow tower in which air is forced across the water in opposite directions (counterflow). Compare this to **Figure 9-5b**, which is an induced-draft crossflow tower in which the air is drawn through the water. You will notice that in the counterflow

Discuss

Explain the difference between forced-fan and induced-fan mechanical draft towers.

design, the air and water flow in opposite directions. Usually, the counterflow design takes up less space, but is taller than the crossflow. With the crossflow tower design, the water flow is vertical while the airflow is horizontal. **Figure 9-6a** illustrates a counterflow design; the air enters at the bottom and moves in an opposite direction to the water. In **Figure 9-6b**, the crossflow design shows the air flowing horizontally across the vertically flowing water.

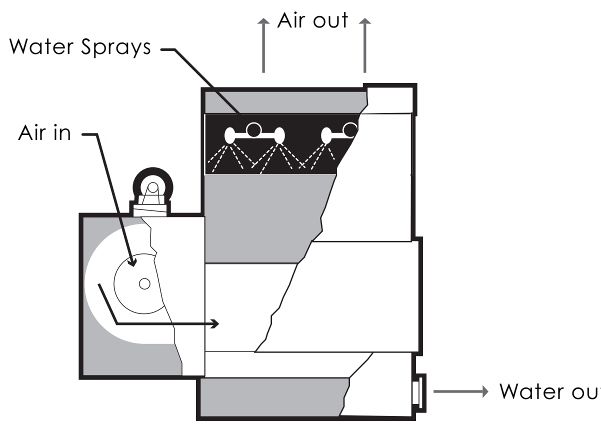


Figure 9-5a Forced-Draft Counterflow Tower

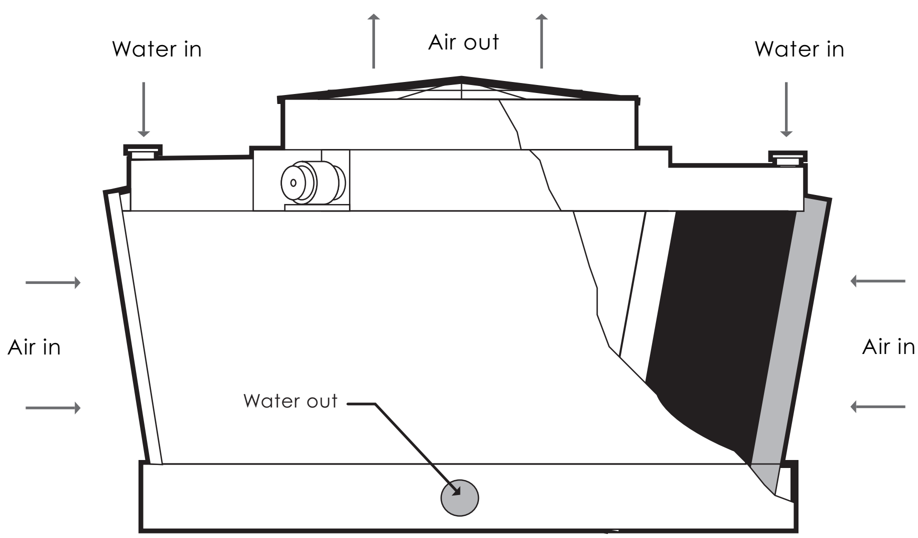


Figure 9-5b Induced-Draft Crossflow Tower

Control Adjustments

Key Concept

Since different applications require a variety of controls, there must be a way to adjust the controls to compensate for the varying conditions. These adjustments may be field adjustable or fixed at the factory. Each control device has two calibration adjustments: range of the control and differential setting.

Discuss

Define range of the control and differential setting.

Range of the Control

Range is defined as the difference between the minimum and the maximum operating points within which the control will function accurately. A control may have a maximum cut out of 300 psig and a minimum cut out of 100 psig. The range, therefore, is 200 psig. Controls should never be set outside of their range because they will be inaccurate at such settings, and frequently, they will not operate.

Overhead 10-1

Use OH 10-1 to define differential setting.

Differential Setting

Differential is defined as the difference between the cut-in (enable) and the cut-out (disable) points of the control. For example, if the cut out point of the control is 300 psig and the load is cycled back on at 200 psig, the differential would be 100 psig. When setting the differential, be careful not to make the differential too narrow because the system could short cycle, leading to safety shutdown.

Relay, Contactor, and Starter

On the following two pages, **Figures 10-8a** (a relay), **10-8b** (a contactor), and **10-8c** (a starter) illustrate three devices typically used to start and stop motors in such refrigeration system equipment as compressors, evaporators, and condenser fans. When energized, these devices deliver electric power directly to those components. In most cases, the control signal from the thermostat will pass through many safeties before it gets to the relay, contactor, or starter.

The contacts on a relay, contactor, or starter are generally labeled normally open (N.O.) or normally closed (N.C.). Depending on the signal sent to them from the control device, these contacts will either open or close when energized and do the opposite when de-energized. Looking at these devices on a schematic, the contact position listed on them (N.O. or N.C.) shows when the coil of that device is in the de-energized mode.

Relays are usually used in smaller amperage systems, such as a 1/4 horsepower evaporator motor. The contactor performs the same function as the relay, but it is normally used in larger applications. Neither the relay nor the contactor contains overloads (but they can be bought and installed on some contactors). Motor starter devices are typically used on large equipment using high amperage motors. The overloads on a starter are used to shut down the equipment in the case of an unusually high amperage draw, such as when the motor bearings are seized or a phase is lost on a three phase system.

Note

Relay shows that contacts between numbers 1 and 3 and 4 and 6 are normally open. Contacts between numbers 1 and 2 and 4 and 5 are normally closed. The other two terminals connect to the relay coil.

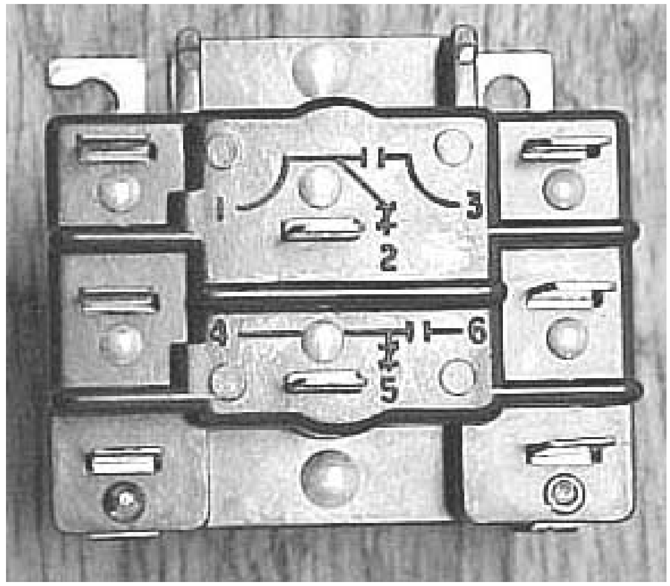


Photo by Robert Burgess

Figure 10-8a Relay

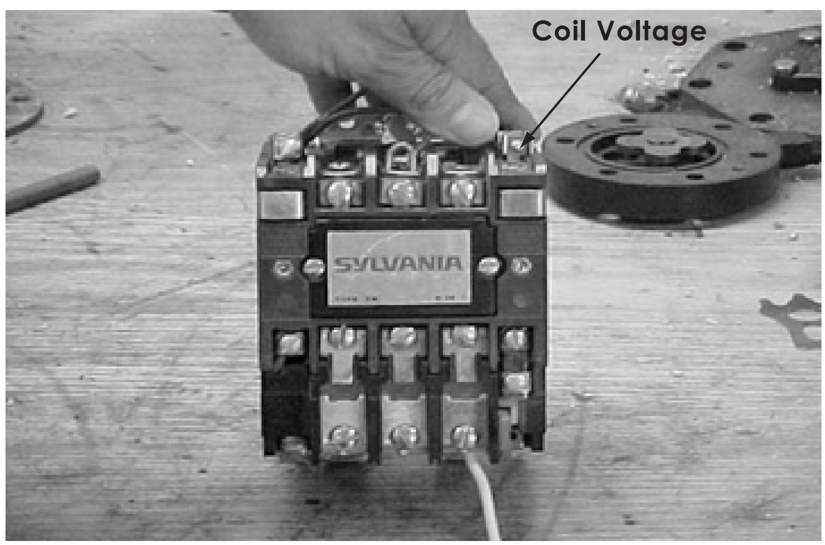
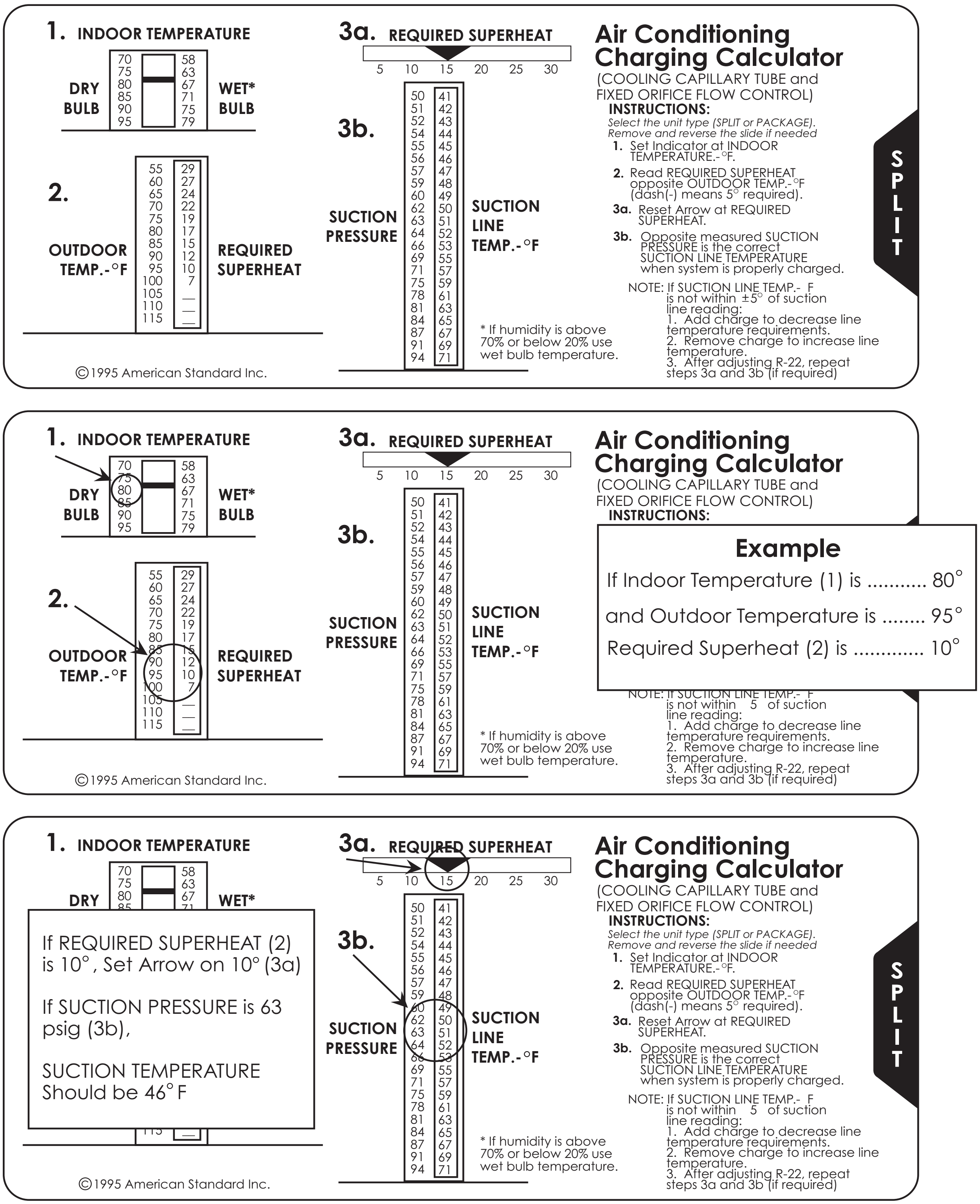


Photo by Robert Burgess

Figure 10-8b Contactor

Example Slide Rule Calculation - R-22



Courtesy of The Trane Company

Figure 11-12c AC Charging Calculator

This method of charging is effective *only* when the indoor conditions are within 2°F of desired indoor comfort conditions and the suction line pressure and temperature are stabilized.

Caution: USE LIQUID LINE HEAD PRESSURE METHOD IF INDOOR CONDITIONS ARE ABOVE NORMAL TEMPERATURE AND HUMIDITY.

1. Read and record outdoor ambient air dry bulb (D.B.) temperature entering condensing unit.
2. Read and record suction line pressure and temperature at the service valve or service port at compressor.
3. Enter proper table below as *determined by the model number* at the intersection of suction pressure and outdoor ambient temperature.
   Suction line temperature should coincide with the table reading.
4. If suction line temperature is not the same, adjust refrigerant charge.
   Adding R-22 will raise suction pressure and lower suction line temperature.
   Removing R-22 will lower suction pressure and raise suction line temperature.
   Caution – If adding R-22 raises both suction pressure and temperature, the unit is overcharged.
5. Fifteen to thirty minutes after adjusting the charge. Steps 1 through 3 are to be repeated after suction line temperature and pressure have stabilized.
6. Should the intersection of the suction pressure and outdoor ambient temperature fall in the open areas of the tables, the following are likely causes:

Left of Numbers	**Right of Numbers**
A. Low indoor airflow	A. Gross overcharge
B. Restricted refrigerant line	B. Defective compressor
C. Low charge	C. Indoor conditions above desired comfort

Model Series (-) (-)ACC-, (-)ACW-
Standard Efficiency

Outdoor Ambient °F	Suction Pressure at Compressor – PSIG																
	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84
	Suction Line Temperature at Compressor – °F																
Above 100								43	44	45	46	48	49	50	52	53	
100							43	44	46	47	48	50	51	52	54	55	
95						45	47	48	50	51	52	54	55	56	57	58	
90						50	52	53	55	56	57	59	60	61	63		
85					53	54	56	57	59	60	61	63	64				
80				56	58	59	61	62	64	65	66	68					
75			59	60	62	63	65	66	68	69	70						
70		61	63	64	66	67	69	70	72	73							

Model Series (-)AFC-, (-)AFW-
High Efficiency

Outdoor Ambient °F	Suction Pressure at Compressor – PSIG																
	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84
	Suction Line Temperature at Compressor – °F																
Above 100							42	43	44	45	46	48	49	50	52	53	
100						45	47	48	50	51	52	54	55	56	58	59	
95						50	52	53	55	56	57	59	60	61	63		
90					55	57	58	60	61	62	64	65	66				
85				58	60	61	63	64	66	67	68	70					
80				63	65	66	67	68	70	71	72						
75		66	68	69	71	72	74	75									
70		71	73	74	76												

Model Series (-) AGD-, (-)AHD-
Super High Efficiency

Outdoor Ambient °F	Suction Pressure at Compressor – PSIG																
	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84
	Suction Line Temperature at Compressor – °F																
Above 100							42	43	44	45	46	48	49	50	52	53	54
100						43	45	46	48	49	50	52	53	54	56	58	
95						50	52	53	55	56	57	59	60	61	63	64	
90					56	57	59	60	62	63	64	66	67	68			
85					63	64	66	67	69	70	72	74					
80				68	70	71	73	74	76	77	78						
75			70	72	74	75	77	79									
70		72	74	76	77	78											

Courtesy of Rheem

Figure 11-12d Superheat Method — Capillary Tube System

Chiller Leak Testing, Evacuation, and Charging

10 Minutes

In regard to leak testing, evacuation, and charging chillers, a few differences need to be pointed out. To properly leak test a low-pressure chiller, which operates in a vacuum, a method is needed to increase this pressure. With the machine turned off and with at least a partial system charge, two common methods are used to increase pressure (never raise the low side pressure above 10 psig as the rupture disc is set for 15 psig). One method is to run warm water through the cooler in order to increase the low side pressure. A process to regulate the temperature is necessary because the system can heat up rapidly, increasing system pressure which could result in a ruptured disc blowing or a relief valve popping. Another method to increase system pressure is to use an external heat blanket on the cooler. Some manufacturers will also have options that can be added to the equipment that will increase system pressure. If there is no refrigerant in the chiller, nitrogen and a tracer gas can be added to the system to increase pressure. Never put in refrigerant in the liquid state, only as a gas for the tracer. If liquid refrigerant is put in below a manufacturer's safe pressure level, the liquid refrigerant could flash at low temperatures, leading to frozen tubes. When evacuating a chiller, a large vacuum pump is needed in order to accelerate the evacuation process. In some cases, more than one vacuum is used to ensure a deep vacuum and to save time.

Key Concept

Discuss

Explain the two common methods to increase pressure in a low-pressure chiller prior to leak testing. Describe what can be done if there is no refrigerant in the low-pressure chiller.

Caution

Only *experienced technicians* should perform this type of repair.

Appendix A

Trouble Analysis

Problem	Symptom	Probable Cause	Recommended Action
Compressor fails to start.	Electric circuit test shows no voltage on line side of motor starter.	Power failure.	Check for blown fuse or broken lead.
		Disconnect switch is open.	Determine why switch was opened. If everything is satisfactory, close switch.
	Electric circuit test shows voltage on line side but not on motor side of fuse.	Fuse blown.	Replace fuse. Check load motor.
	Electric circuit tester glows but not at full brilliance.	Low voltage.	Check with voltmeter.
	Full voltage at motor terminals but motor will not run.	Burned out motor.	Repair or replace.
	Inoperative motor starter or broken contact.	Burned out holding coil.	Repair or replace.
	Compressor will not operate.	Frozen compressor due to locked or damaged motor.	Repair or replace.
	Compressor can be restarted by resetting oil failure protection switch. Compressor runs for a short time and again stops.	Oil failure protection control switch has cut out.	Check oil level and oil.
	Starter will not pull in.	Overload contacts are open.	Determine cause of failure. Reset overload contacts.
		Open control circuit.	Locate open control to determine cause.
Compressor short cycles.	Normal operation except too frequent stopping and starting.	Intermittent contact in electrical control circuit.	Repair or replace faulty control.
	Normal operation except too frequent stopping and starting on low pressure control switch.	Low pressure control differential set too close.	Reset differential in accordance with job conditions.
		Lack of refrigerant.	Repair refrigerant leak and recharge.
	Suction pressure too low, frosting at filter drier.	Restricted liquid line filter drier.	Replace core.
	Compressor will not load or unload. Cuts out on low pressure switch.	Inoperative compressor.	Repair or replace faulty control.

Problem	Symptom	Probable Cause	Recommended Action
Compressor loses oil.	Oil level too low.	Insufficient oil charge.	Add oil.
	Oil level gradually drops.	Improper pipe size or design.	Resize lines, provide oil traps.
	Oil around compressor base and low crank-case oil level.	Liquid flood back. Excessively cold suction.	Readjust superheat setting, check remote bulb contact with suction line.
		Crankcase fittings leak oil.	Repair oil leak and add proper compressor oil.
Compressor runs continuously.	High temperature in conditioned area.	Excessive load.	Check for excessive or ventilation load. Check for inadequate insulation of space.
	Low temperature in conditioned area.	Thermostat controlling at too low a temperature.	Reset or repair thermostat.
	Bubbles in sight glass.	Lack of refrigerant.	Repair leak and charge.
	Compressor noisy or operating at abnormally low discharge pressure or abnormally high suction pressure.	Leaky valves in compressor.	Overhaul compressor.
	Compressor fully or partially unloaded, but will not stop.	Solenoid stop valve leaking.	Repair valve.
Compressor is noisy.	Compressor cuts out on oil failure protection control.	Lack of oil.	Add oil.
	Compressor knocks.	Internal parts of compressor broken.	Overhaul compressor.
	Abnormally cold suction line.	Liquid flood back.	Check and adjust superheat. Check for loose remote bulb on suction line.
		Expansion valve stuck in open position.	Repair or replace expansion valve.
	Compressor jumps base.	Compressor loose on base.	Tighten compressor hold down bolts.
System short of capacity.	Expansion valve hisses.	Flash gas in liquid line.	Add refrigerant.
	Temperature change in refrigerant line through filter drier or solenoid stop valve.	Clogged filter drier or solenoid stop valve.	Replace filter drier core, clean valve.

Appendix B

Absorption Machine Troubleshooting Guide

Problem/Symptom	Probable Cause	Recommended Action
Machine will not start or shuts down (panel run lights out, pumps off).	No power to control panel.	Check for building power failure. Check main circuit breaker.
	Control panel fuse blown.	Examine circuits for ground or short. Replace fuse.
	Control panel disconnect switch open.	Rotate disconnect switch arm counterclockwise to close.
	Control panel switches not set correctly.	Depress and release reset switch. Place both pump switches on. Capacity Control and Cycle Guard switches at Auto and Stop/Start switch at start.
	Chilled water or condensing water pump overloads or flow switches open.	Check chilled water and condensing water pumps, starters and valves.
	Solution pump overloads open.	Push overload reset button. Measure pump discharge pressure to check for solution crystallization.
	Refrigerant pump overloads open.	Push overload reset button.
	Low refrigerant temperature cut out.	Depress and release reset switch after refrigerant has warmed at least 3 degrees. Measure refrigerant temperature. Recalibrate or replace switch if temperature is above setpoint. Check capacity control setting and operation if temperature is below switch setting.
	Low refrigerant level (some models).	Depress and release reset switch. Measure refrigerant pump discharge pressure. If below atmospheric pressure, the absorber valve is malfunctioning and must be corrected. If above atmospheric pressure, check the low switch.

Problem/Symptom	Probable Cause	Recommended Action
Leaving chilled water temperature too high.	Control point adjuster (electronic) or controller (pneumatic) set too high.	Reset control in control panel.
	Excessive cooling load (machine at capacity).	Check for cause of excessive load.
	Excessive chilled water flow (above design).	Check pressure drop per selection data and reset flow.
	Low condensing water flow (below design).	Check pressure drop per selection data and reset flow.
	High supply condensing water temperature (above design).	Check cooling tower operation and temperature controls.
	Low steam pressure or hot water temperature (below design).	Raise to design per selection data.
	Inadequate steam condensate drainage (condensate backs up into tube bundle).	Check operation of steam traps, strainers, valves and condensate receivers.
	Fouled tubes (poor heat transfer).	Clean tubes. Determine if water treatment is necessary.
	Machine needs octyl alcohol.	Check solution sample and add octyl alcohol, if necessary.
	Noncondensables in machine.	Check absorber loss.
	Capacity control malfunction.	Check calibration and operation of capacity controls.
	Solution crystallization (solution flow blockage).	Check refrigerant charge and thermoswitch calibration.
	Absorber valve (some models) or low-level extender valve (some models) malfunction.	Check operation of valve and low-level control.
Leaving chilled water temperature too low (machine running, chilled water temperature below design).	Control point adjuster (electronic) or controller (pneumatic) set too low.	Reset control in control panel.
	Capacity control malfunction.	Check calibration and operation of capacity control.

Discussion Question Answers

Chapter 1

1. Refrigeration is the process of removing heat from a place where it is objectionable and transferring it to a place where it is not objectionable; air conditioning is the process that maintains comfort conditions in a defined area.
2. Sensible heat is the measure of the internal heat of a substance; when it changes, the temperature changes, but not the state (solid, liquid, or gas).
3. Superheat is the additional sensible heat (measured as temperature) above a substance's saturation temperature; the refrigerant is vapor when superheat is present; it is important because the compressor is designed to pump only vapor, and a superheat reading at the compressor inlet ensures that only vapor (no liquid) will enter the compressor.
4. Subcooling is the removed sensible heat (measured as temperature) below a substance's condensing temperature; the refrigerant is liquid when subcooling is occurring; subcooling is important because the metering devices require a 100 percent liquid refrigerant in order to operate at full efficiency.
5. Pressure is the force per unit area; it is expressed in pounds per square inch; as pressure changes, so does the boiling point, or saturation temperature.

Chapter 2

1. A reciprocating compressor uses a piston to reduce refrigerant volume within a cylinder; a hermetic compressor has the motor and compressor sealed in the same housing and is not field serviceable; a semi-hermetic compressor has the motor and compressor in the same housing, which is bolted together instead of sealed, making it field serviceable.
2. An open compressor is one that uses an external source, such as an electric motor, steam engine, or automobile engine, to drive it; the open compressor shaft extends outside the body housing of the compressor; advantages include ease of changing pumping capacity by changing rpm of the motor or the size of the drive, and ease of changing the motor should it fail.
3. A scroll compressor is a high-precision machine that uses two scrolls — a stationary one and an orbiting one that interact to compress and move gas. The two main types are non-compliant scrolls, which do not touch each other, and compliant, where the scrolls do touch lightly.
4. A screw compressor is a positive displacement pump that uses a pair of helical rotors, male and female, with the male rotor being the one typically connected to the motor shaft; the female rotor rides in bearings and is driven by the male rotor, not the motor.
5. There are two types of rotary compressors — rotary vane and stationary vane; both are positive displacement pumps and are typically found in smaller tonnage. In the rotary vane, the rotor is centered on the shaft, but the shaft is positioned off center and has two or more spring-loaded vanes that move with the rotor; the stationary vane does not have rotating vanes — it has a stationary spring-loaded valve located inside the compression chamber, with a centered shaft but an attached rotor off center.

Chapter 3

1. A metering device controls the flow of liquid refrigerant from the condenser to the evaporator.
2. A thermostatic expansion valve controls the rate of flow of the liquid refrigerant compared to the rate of evaporation in the evaporator; it works off of three pressures — bulb, evaporator, and superheat spring.
3. Measure evaporator pressure and convert the pressure reading to temperature; record the temperature reading at the sensing bulb location; subtract the sensing bulb temperature from the converted temperature reading.
4. A capillary tube is a fixed-orifice device that controls the rate at which the refrigerant is fed to the evaporator; it features an inexpensive, simplistic design that has no moving parts and is slow to respond to changes in evaporator

loads; such a tube must be properly sized relative to its length and inside diameter.

5. Use a low-side float valve on flooded systems and in systems with multiple evaporators; its purpose is to maintain a constant level of liquid refrigerant in a flooded evaporator.

Chapter 4

1. An evaporator is a device that absorbs the heat surrounding it to cause the liquid refrigerant inside it to boil until the refrigerant leaves as a superheated (saturated) gas.
2. A flooded evaporator is always filled with liquid refrigerant and may be fitted with a device to prevent liquid from going back to the compressor; it contains tubes and sometimes is called a cooler.
3. The condenser rejects the heat absorbed from the evaporator and the heat of compression from the compressor to a secondary medium, such as air or water or both.
4. A condenser de-superheats the refrigerant initially; in the middle section of the condenser, it rejects the most heat, changing the refrigerant from a vapor back to a liquid; in the last section, the refrigerant temperature is lowered below the condensing temperature (subcooling).
5. Head pressure can be controlled through fan cycling — cycling the fan on and off, or varying the speeds; condenser flooding — flooding the condenser coil with liquid refrigerant and slowing down the rate of vapor condensation in order to increase head pressure; and damper control — a head pressure control that uses inlet or outlet dampers to stop airflow from moving across the condenser.

Chapter 5

1. An accessory is any device that is added to a refrigeration system for the convenience of the operator and/or to improve the effectiveness and performance of that system; that is, extras not required for basic operation of the system.
2. The muffler removes or dampens the hot gas pulsations set up by a reciprocating compressor; usually located on either the suction side or the discharge side of the compressor.
3. A suction accumulator prevents liquid refrigerant from entering the suction side of the compressor; it should be installed as close as possible to the compressor on the suction side.
4. A fusible plug is a threaded connection filled with a metal alloy designed to melt at a specific temperature; when that temperature is reached, the fusible plug will melt and all the refrigerant within the system will escape; it is typically used on small systems.
5. Filter driers are located on the liquid and/or the suction line; driers are used to remove moisture, acid, and/or dirt and debris from the system.

Chapter 6

1. A refrigerant is a fluid that absorbs heat by evaporating at a low temperature and pressure, and gives up heat by condensing at a high temperature and pressure.
2. Pressure of the system, density of the refrigerant (molecular weight), and size of the opening all affect the leakage rate of a refrigerant.
3. Some of the older refrigerants are pure chemical compounds; others, called azeotropics and zeotropics, are blends of multiple components in different volumes; azeotropics behave as a single component while in a liquid and/or vapor state.
4. Recovery refers to the removal of all the refrigerant from a system and storage of it in an external container; recycle is filtering the removed refrigerant and reusing it; reclaiming involves the refrigerant being sent back to a reprocessing facility to be cleaned under the ARI 700 Standard.
5. Oil is classified as animal, vegetable, mineral, or synthetic; only mineral and synthetic are suitable for modern refrigeration systems.

Chapter 7

1. The indoor section of a split system typically consists of the evaporator, fan(s), metering device, and a connection for the suction and liquid lines; if the indoor section is used for an air conditioning application, a connection with ductwork is needed for supply and return air.
2. Customarily, a packaged rooftop unit is installed on the roof of a low-rise building (up to three or four stories tall); in a few exceptions, they are found on high-rise buildings; all the components are in one package and connected to an energy source and ductwork within the

building; these units are classified as cooling only, heating only, or both heating and cooling (the most common).

3. The packaged indoor unit is located indoors and usually has a water-cooled condenser; advantages include less ductwork and corresponding use of space, higher efficiency of water-cooled condensers (as compared to air-cooled condensers), and water-side economizer; disadvantages include higher noise level and loss of valuable space.
4. A heat pump is a system that is able to change the direction of the refrigerant flow and in so doing cools the designated building space during the summer and heats it during the winter; it can be a split system, a rooftop unit, an indoor packaged unit, or a through the wall unit.
5. The defrost cycle is required to prevent coil freeze up due to the temperature and moisture in the air generated during the heating mode; the outdoor coil is the evaporator during the heating mode, and operates at temperatures around and below freezing (so moisture in the outside air starts to freeze on the coil).

Chapter 8

1. To avoid losing all cooling capability if the compressor breaks down and to control the load and wear on the compressors (most compressor wear occurs at start up and from cycling on and off), this type of chiller uses multiple compressors.
2. Inlet guide vanes are used to control capacity and to direct the flow of the refrigerant into the impeller of a centrifugal compressor.
3. A purge system removes noncondensables (air), a vapor that will not change into a liquid at the temperature and pressure created within the system; a low-pressure chiller runs in a vacuum and any leak would allow air into the chiller instead of refrigerant leaking out.
4. Flow switches, refrigerant low temperature cut out, high temperature bearing cut out, high temperature motor winding cut out, low chilled water temperature cut out, rupture disc, and lock out timer are all safeties attached to chillers.
5. Crystallization occurs when the temperature of the solution has been reduced in relationship to the amount of salt dissolved in the solution; the temperature of the solution determines how much lithium bromide can be held in the solution; by lowering the temperature, some salt will precipitate out of the solution.

Chapter 9

1. A cooling tower is a device that uses the evaporation of water to reject both the sensible and the latent heat absorbed in a refrigeration system; the water from the condenser that is to be cooled is distributed in the tower through spray nozzles, splash bars, or fill, exposing a great deal of the water to air, thereby increasing the evaporation rate and the evaporative cooling effect.
2. Approach is the difference between the temperature of the water leaving the tower and the entering air wet-bulb temperature; it is a function of tower capability.
3. The two types of natural draft towers are induction, or counterflow, and crossflow; an induction, or counterflow, tower induces large quantities of air into the tower by injecting the water through spray nozzles at one end of the tower, with the water falling down (vertically) and the air moving up (vertically) against the water; with a crossflow tower, the air moves horizontally across as the water falls down vertically.
4. Fill material should ensure that the water flows down slowly and breaks up into tiny droplets or flows as thin film, increasing efficiency by promoting more evaporation.
5. When water droplets (not vapor) leave the tower with the discharge air, this condition is known as drift.

Chapter 10

1. Operating controls maintain the desired cooling load; safety controls are designed to monitor the system and respond to extreme variations; both are meant to help maintain and protect the system.
2. The low-pressure safety cut out stops the refrigeration equipment if suction pressure falls below a predetermined minimum operating pressure; factors that can contribute to low suction pressure are low charge, dirty filter and/or dirty coil, inoperative or malfunctioning evaporator fan, or low load on the system.
3. The high-pressure safety cut out stops the refrigeration equipment (usually the compressor) before excessive pressure occurs; typical causes are a dirty condenser coil or

inoperative or malfunctioning condenser fan; if water-cooled, it could be lack of water, too high a water temperature, or lack of heat transfer due to scale on the tubes.

4. Range is the difference between the minimum and the maximum operating points within which a control will function accurately; differential setting is the difference between the cut in (enable) and the cut out (disable) points of the control.
5. A capacitor is a device used to temporarily store electric energy in a circuit by establishing an electrostatic field between two conducting media; the two common types are the run capacitor and the start capacitor.
6. To keep a system from operating even if a safety device automatically resets itself, add an impedance relay to the system.

Chapter 11

1. Leaks can be detected using soap bubbles, an electronic leak detector, a halide leak detector, an ultrasonic leak detector, and an ultraviolet leak detector.
2. Air drafts should be kept to a minimum; the leak detector tip should be moved slowly; check low-lying areas around the equipment because the refrigerant is heavier than air and will settle in low areas.
3. After ignition, the flame from acetylene or propane gas heats a copper disc; attached to this bottle of gas is a hose that is used as a sniffer to check for leaks; air is drawn through the hose and into the burner of the detector; when a leak is detected, the flame will change to a greenish color.
4. An ultrasonic leak detector locates ultrasonic sounds that are emitted when a gas leaks from a system; these ultrasonic sounds can be hard to hear because of surrounding noise or a small leak; wearing a headset can overcome this problem; it can detect sounds from other equipment; an ultraviolet leak detector uses a fluorescent additive that is circulated throughout the refrigeration system; an ultraviolet light is used to check for leaks; a fluorescent glow is emitted around the leak.
5. The steps in testing for a leak are: add an inert gas as a tracer for the leak detector; charge the system with approximately 10 percent of the system designed refrigerant; charge the remainder of the system with the inert nitrogen gas.
6. The system should be in a vacuum; open up both the low and high side ports on the gauge manifold and bleed out any air in the hoses so that it does not enter the system; enter the required amount of total refrigerant charge needed into the charging scale controls and push the start button; close the high side handle on the manifold and finish charging through the low side; start the compressor.

Chapter 12

1. High suction pressure can be caused by high heat load, overcharge (too much refrigerant), inefficient compressor (leaking or open valves), thermostatic expansion valve bulb loose and uninsulated, and/or condenser air or water restricted or too warm; low suction pressure can be caused by loss of refrigerant (leak in the system), lack of airflow, low load conditions (economizer carrying most of the load), and/or refrigerant restriction.
2. High head pressure can be caused by overcharge, water-cooled condenser with high water temperature and lack of water flow, air-cooled condenser fan(s) not running or at the wrong speed, noncondensables, and/or restriction; low head pressure can be caused by inefficient compressor valves or internal relief valve failure, low on charge, low water temperature (water-cooled) or ambient air temperature (air-cooled), and/or low load conditions.
3. High superheat can result from low charge, metering device malfunctioning, restriction, moisture, and/or high load; low to no superheat can result from refrigerant overcharge, thermostatic expansion valve overfeeding (caused by an improperly attached sensing valve), low load conditions, oversized metering device, and/or lack of airflow.
4. High subcooling is due to overcharge, condensing water too cold, ambient condenser air too cold, oversized condenser, and/or inefficient compressor; low to no subcooling is due to low charge, thermostatic expansion valve overfeeding, and/or high load.
5. High amperage draw can be caused by noncondensables in the system, loose wire connections, and overheating; an inefficient compressor draws lower amperage.

Exercise Answers

Exercise 1-1

Fill in the blanks in the diagram.
Answers: (heart of system) compressor, (smaller box below heart) metering device, (larger box below heart) liquid receiver, (under high-pressure side, top to bottom) hot gas at high pressure, condenser, liquid at high pressure (under low-pressure side, top to bottom) vapor at low pressure, evaporator, cold liquid at low pressure

Exercise 2-1

Match the type of compressor with its description.
Answers: 1-B, 2-E, 3-A, 4-C, 5-D

Match the type of compressor with its characteristic.
Answers: 1-C, 2-E, 3-B, 4-D, 5-A
Answers: (1) scroll and screw; (2) centrifugal

Exercise 3-1

Superheat calculation
Answer: 50°F - 45°F = 5°F superheat

Match the type of metering device with its characteristic.
Answers: 1-D, 2-C, 3-A, 4-E, 5-B

Match the type of metering device with its characteristic.
Answers: 1-A, 2-D, 3-E, 4-B, 5-C

Exercise 4-1

True/False
Answers: (1) True, (2) False, (3) False, (4) True, (5) True, (6) False, (7) True

Fill in the blanks.
Answers: (1) full, (2) quantity, temperature, (3) work

Exercise 4-2

True/False
Answers: (1) False, (2) True, (3) True, (4) False, (5) False, (6) False, (7) False

Fill in the blanks.
Answers: (1) warm air, (2) counterflow, (3) water

Exercise 5-1

Match the refrigeration accessory with its purpose.
Answers: 1-G, 2-D, 3-J, 4-B, 5-I, 6-H, 7-A, 8-F, 9-E, 10-C

Exercise 6-1

True/False
Answers: (1) True, (2) False, (3) False, (4) True, (5) False, (6) False, (7) True, (8) True

Fill in the blanks.
Answers: (1) mineral, synthetic, (2) viscosity, (3) pour point; cooling, heating, (4) flash point; fire point

Exercise 7-1

Fill in the blanks.
Answers: (1) condensing; refrigerant tubing, (2) indoor, (3) small; large, (4) controls, (5) together; air, (6) indoor, (7) outside; air

Exercise 7-2

Answers: (1) direction, (2) condenser; evaporator, (3) defrost cycle, (4) time; temperature, (5) discharge; suction

Exercise 8-1

True/False
Answers: (1) True, (2) False, (3) False, (4) False, (5) True, (6) False, (7) True, (8) True, (9) False, (10) True, (11) True, (12) False, (13) False, (14) True, (15) True

Exercise 9-1

Match the cooling tower with its basic operation or description.
Answers: 1-C, 2-E, 3-A, 4-D, 5-F, 6-B

Answers: (1) fans, convective currents, natural wind currents, induction from the sprays, (2) through the distribution pan and spray nozzles, and spread over fill material, (3) evaporation, leaks from piping, and drift, (4) removing sediment, minerals, and dissolved solids from a cooling tower by draining water with a high amount of dissolved solids and replacing it with water that has a relatively low amount of dissolved solids

Exercise 10-1

Fill in the blanks.
Answers: (1) temperature; electrical contacts
(2) sub-base
(3) air pressure
(4) safety; operation
Answers: (5) low charge, dirty filter or coil, evaporator fan not functioning properly, low load on the system, (6) dirty condenser coil, condenser fan not functioning properly, lack of water, water temperature too high, scale on tubes restricting heat transfer, (7) net oil pressure, the difference between the oil pump discharge and suction pressure, (8) the minimum and the maximum operating points within which the control will function accurately, (9) the cut-in (enable) and the cut-out (disable) points of the control

Exercise 10-2

Match the electrical component with its basic function or description.
Answer: 1-B, 2-D, 3-E, 4-A, 5-C

Exercise 11-1

Match the leak detection equipment with its characteristic.
Answers: 1-D, 2-A, 3-E, 4-C, 5-B

Exercise 11-2

True/False
Answers: (1) False, (2) False, (3) True, (4) True, (5) False, (6) True, (7) False

Exercise 12-1

Match the problem with the likely outcome(s).
Answers: (1) A D H, (2) B C D E, (3) F, (4) C E F, (5) B D G, (6) D E, (7) A E F, (8) C F G, (9) A G H, (10) B G, (11) A C, (12) C H

Exercise 12-2

Fill in the blanks.
Answers: (1) amperage draw, (2) compression; compressor, (3) evaporator, (4) low oil pressure, (5) metering devices; filter driers, (6) filter; evaporator coil