CENGAGE

FOURTH EDITION

COMMERCIAL REFRIGERATION

FOR AIR CONDITIONING TECHNICIANS

DICK WIRZ

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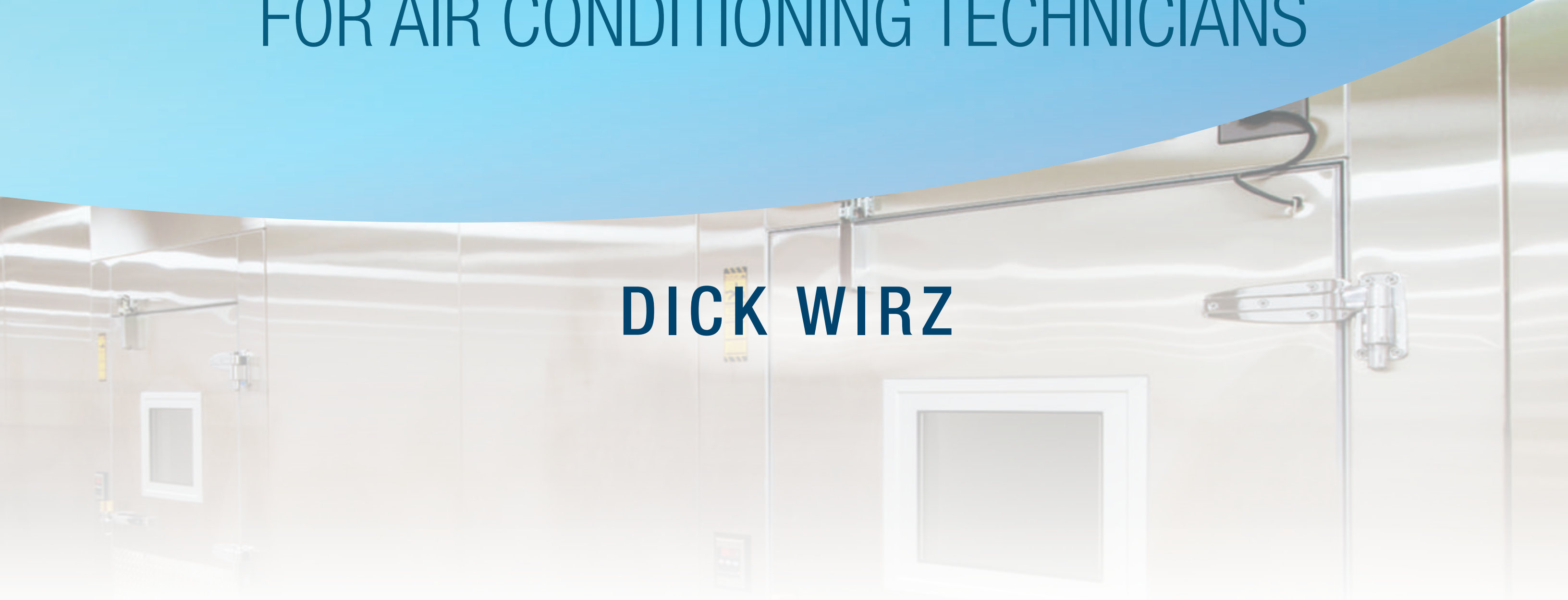

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CENGAGE

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***Commercial Refrigeration for Air Conditioning Technicians*, 4th Edition**

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CONTENTS

PREFACE

COMMERCIAL REFRIGERATION FOR AIR CONDITIONING TECHNICIANS

by Dick Wirz

This book is written for refrigeration technicians, air conditioning (A/C) technicians and advanced A/C students. Commercial refrigeration as a specific subject is taught in only about 10 percent of the schools that have HVACR programs. As a result, there are very few A/C students and technicians exposed to this related technology. The industry certainly needs technicians trained in A/C. However, if A/C technicians also understand commercial refrigeration, they will be more valuable to their companies and their customers.

ORGANIZATION

The first six of the fourteen chapters combine a review of refrigeration theory and an introduction to how those principles are specifically applied to commercial refrigeration equipment. Wherever possible, refrigeration concepts are compared with those of A/C. This makes it easier for HVACR students and technicians to relate what they already know about A/C to the field of commercial refrigeration.

Chapter 7 applies the information in the first six chapters to the troubleshooting of nine common refrigeration system problems. It also includes a diagnostic chart for the reader to use in class, as well as on the job. Chapters 4 and 8, on compressors and motor controls, also have their share of troubleshooting instructions. Chapter 9 covers retrofitting, recovery, evacuation, and charging in greater detail and with more practical applications than found in other HVACR textbooks.

Chapter 10 is an introduction to the fascinating world of supermarket refrigeration. It provides insights into the multicompressor rack systems, the various temperature applications, electronic controllers, and the supermarket equipment manufacturers' pursuit of providing optimum efficiency while addressing global environmental concerns.

Chapter 11 covers walk-ins and reach-ins, while Chapter 12 deals with the basics of ice machines. Chapter 13 is a short but important look at the role of the refrigeration technician in food preservation and health issues.

Chapter 14 looks at the business side of this industry. Many HVACR technicians eventually become part of management or even start their own companies. This chapter provides a glimpse of what their employers deal with on a daily basis. By gaining these insights, technicians can become a more supportive and vital part of their organizations.

FEATURES

Chapters 6 through 11 have Service Scenarios, which are real-life situations that exemplify concepts described in those chapters.

Throughout the book, there are tips called Technician's Rules of Thumb (TROT). These practical bits of information are a collection of practices that experienced technicians use to help them service equipment better and more quickly. There is a complete list of these rules of thumb included in the appendix. The appendix also contains pressure/temperature (P/T) charts for the refrigerants mentioned in the book as well as those currently used in most refrigeration applications.

SUPPLEMENTS

Most HVACR technicians are very visual learners. Therefore, both the print and digital versions of this text include many pictures and drawings to illustrate what has been written in the text. The supplements include PowerPoints for instructors to use in their classroom, MindTap to provide assessments of student learning and the answers to the Chapter Review Questions on the Instructor Companion Site.

We have made significant advancements in the digital offerings of this product. We continue to provide instructors with more online teaching opportunities through products such as MindTap, which integrate well in learning management systems.

WHAT IS NEW IN THE FOURTH EDITION

Of course, there were some corrections that needed to be made. It takes many skilled people to produce a technical book such as this, and extensive editing is done to prevent errors. Unfortunately, errors do occur. Thanks so much to all of you who took the time to email your comments and suggestions to me at teacherwirz@cox.net. Once notified, necessary updates can be made.

Key Terms have been added at the beginning of each chapter to provide students with a convenient list of terms introduced in that chapter. The Glossary provides definitions of the Key Terms. The review questions are a mix of multiple-choice and essay questions with rationales included.

MindTap includes electronic Flash Cards, Video links to service scenarios, and HVAC Simulations for the user.

Chapter 7, Refrigeration System Troubleshooting, has been completely revised and simplified. There is less emphasis on evaporator TD and condenser split in diagnosing and more on determining the proper evaporator and condensing temperatures. The examples utilize more current refrigerants. The diagnostic chart has combined similar problems in order to add three additional problem areas, yet still maintain a total of nine diagnoses.

Chapter 9, Retrofitting, Recovery, Evacuation, and Charging. The outdated sections about retrofitting R12 and R502 systems have been eliminated. Wherever possible throughout the book, discussion of R22 in commercial refrigeration examples has been replaced by R404A. High-glide refrigerants such as R448A are discussed at great length in Chapter 9. The reader will learn how to properly determine superheat, subcooling, and condensing and evaporator temperatures, and how to set operating controls on equipment with high-glide refrigerants. An overview of propane (R290) as a refrigerant is also included. Because of safety and liability concerns, the reader is directed to the equipment manufacturer for the specifics of proper handling of flammable refrigerants.

Chapter 11, Walk-in Refrigerators and Freezers. Two more insightful and interesting Service Scenarios have been added.

ABOUT THE AUTHOR

My career in HVACR started with a summer job in 1963. For the first eight years, I installed ductwork and serviced residential A/C and heating equipment. Over the next thirty years, I enjoyed the world of commercial refrigeration. I am a licensed Master HVACR Technician and Master Electrician in several states. I am certified by RSES (Refrigeration Service Engineers Society), North American Training Excellence (NATE), and ESCO (HVAC Excellence). For more than twenty-five years, I was president and co-owner of a successful commercial refrigeration company. After retiring in 2000, I enjoyed teaching HVACR and producing animated PowerPoints for HVACR instructors. In this way, I was able to repay some of the many benefits I have received from a very rewarding career in the HVACR industry.

I graduated from Virginia Tech with a degree in business management and a minor in mechanical engineering. Twenty years later, I returned to school to earn my master's in business administration in order to qualify as a community college professor upon retiring from my refrigeration company. To help me become a more effective instructor, I spent two years in a postgraduate program at George Mason University, where I earned a certificate in community college teaching. In 2014, I retired from full-time teaching after nearly fifteen years at Northern Virginia Community College, Woodbridge Campus. My wife and I continue to produce teaching aids under the corporate name of Refrigeration Training Services (www.hvacteaching.com) for HVACR programs in the form of animated PowerPoints.

ACKNOWLEDGMENTS

I would like to thank my wife, Irene, for her tremendous help in this project. She provided all the graphics used in the book and in the instructor PowerPoints. Without her editing, graphics, software expertise, and support, this book never would have become a reality.

I would also like to thank the many people who have contacted me since the first edition of the book was published. Your appreciation has enforced my belief that the tremendous amount of work that goes into this project has been beneficial to thousands of students, teachers, and technicians. Your comments helped shape the changes and updates in each edition.

A special thanks goes out to Holly Villarreal for her technical expertise and writing, and to Jess Lukin for so many service scenarios and pictures. Also to Gary Purdue, Bill McDonald, Manolo, and Mike Hynes for their service scenarios. Their real-life service situations have made the material in the book come alive and become more relevant. I hope some of you reading this will contribute for the next edition. Andre Patenaude of Emerson provided expert information and editing of the section about CO_2 in supermarket applications. I learned much from John Whithouse, Parker/Sporlan, who wrote an enlightening paper on high-glide refrigerants. Dave Demma, formerly with Sporlan and currently with United Refrigeration, Inc., provided me with on-the-job training with supermarket refrigeration many years ago. I have included his insights on properly checking for leaks on large supermarket systems. And finally Andy Shoen, formerly with Sporlan and currently with Sanhua, has been my go-to source for control valve questions for nearly twenty years. Networking with industry contacts such as these has helped make my writing relevant, accurate, and informative.

The information in this book has provided thousands of techs with a firm understanding of commercial refrigeration, which is so important to those who wish to progress and prosper in this industry. However, I will be 77 in 2021 when the fourth edition is published, and I am asking for the help of instructors and technicians who have used this book to provide me with comments as to what current information is needed.

This book is essential to providing a step-by-step learning experience upon which to build knowledge of commercial refrigeration. Cengage is doing all it can to make that learning accessible. In addition, I am especially impressed by those emerging in this digital age to make learning easy and fun. Bryan Orr of Kalos Services in Clermont, Florida, started HVAC School to provide free online training in HVACR "for techs by techs." Chris Stephans is a tech who has developed a vast collection of service scenarios under HVACR Videos on YouTube. Bryan and Chris are two fine examples of how additional training is readily available within our industry to supplement this book.

Teaching and training have been a rewarding, yet humbling, experience for me. Although I thought I knew HVACR well, I soon realized that there was much more I

needed to master in order to teach the subjects. Someone once told me, "You can never know everything about anything, but you have to keep trying." Now I realize how true those words are. I have become a lifelong student, and I encourage the same thirst for knowledge in those I teach. I believe you must agree because you have taken the time to pick up this book and read at least this much of it. Thank you.

FEEDBACK

Please use the email below to contact me. I enjoy hearing from techs all over the world who like this industry and have benefitted from what I have written. In addition, I appreciate the wealth of insightful comments made by instructors such as Jon Hamel of Truckee Meadows Community College and Joe Owens of Antelope Valley Community College.

Thank you for using this book. I am sure what you learn will be of great benefit to your success in this industry. I also hope this text will become an important part of your technical library. As you gain knowledge and experience, I encourage you to share it with others. If those you work with are doing a better job, it not only makes it easier for you but helps you progress higher in your organization. It is not a matter of *if* we will become teachers, but *when* we will become teachers.

Dick Wirz
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REFRIGERATION

1

CHAPTER OVERVIEW

This chapter begins by explaining what this book is about and for whom it is written. This is followed by a thorough review of the refrigeration cycle. Next, air conditioning is compared with commercial refrigeration; both their similarities and their differences are explained. The newer refrigerants used in commercial refrigeration are also covered. Finally, the four basic components of a refrigeration system are discussed.

OBJECTIVES

After completing this chapter, you should be able to

- Describe temperature ranges of refrigeration
- Describe the refrigeration cycle
- Relate refrigeration to air conditioning
- Describe the relationship between a refrigerant's pressure and temperature
- Describe the newer refrigerants used in commercial refrigeration systems
- Describe the relationship among the four basic components of a refrigeration system

KEY TERMS

Subcooling
Ambient
Superheat
Latent heat
Saturated
Sensible heat
Condenser split
De-superheat
Zeotropes
Glide
Dew point
Bubble point
TROT (Technician's Rules of Thumb)
Mirror image

INTRODUCTION

Most technicians tend to specialize in a single type of air conditioning (AC) application, such as residential, light commercial, or heavy commercial systems. However, very often, opportunities arise outside a technician's primary area of expertise, so it is smart to be knowledgeable in more than one specialty. For instance, a company that provides good service on a restaurant's AC may be asked to service its commercial refrigeration equipment. Likewise, a building engineer who competently handles the large chillers of a commercial building may have their responsibility expanded to include maintaining refrigeration and ice machines in the building's cafeteria.

The primary objective of this book is to help AC technicians understand commercial refrigeration. Someone once said, "Luck is preparation meeting opportunity." The more knowledge areas technicians master, the better they can take advantage of any opportunities that arise.

Therefore, *Commercial Refrigeration for Air Conditioning Technicians* is written for both experienced AC technicians and students who have a firm basis in AC theory. This first chapter is intended to be a review of basic refrigeration as well as an introduction to the similarities and differences between AC and commercial refrigeration.

Throughout this book, a key word or phrase used for the first time that may not be familiar to all readers will be in **blue** font type. A list of key words is on the first page of each chapter beside Chapter Overview and Objectives. These words and phrases will also be included in the glossary.

TEMPERATURE RANGES OF REFRIGERATION

The following is a list of the space temperatures of the more common ranges of refrigeration discussed in this book:

- 75°F, AC (comfort cooling)
- 55°F, high-temperature refrigeration
- 35°F, medium-temperature refrigeration
- –10°F, low-temperature refrigeration
- –25°F, extra-low-temperature refrigeration

Most of the examples in the next few chapters are concerned with medium- and low-temperature applications. Medium-temperature walk-in refrigerators (aka walk-in coolers) usually operate at a range of 35°F to 37°F, whereas reach-in refrigerators run at slightly higher temperatures, from 38°F to 40°F. Walk-in freezers normally run at –10°F, and reach-in freezers operate at about 0°F.

The difference between the temperatures in walk-ins and reach-ins is mainly due to how the box is used and how the equipment is designed. The lower temperatures of walk-ins allow them to keep large amounts of product fresh for relatively longer periods of time.

Reach-ins, on the other hand, are used more for convenience. Because they are smaller than walk-ins, reach-ins can be located closer to where they are needed. A reach-in is usually restocked from a walk-in at least once a day. Therefore, the slightly higher storage temperature of a reach-in is acceptable because the product is in the box for a relatively shorter period of time.

THE REFRIGERATION CYCLE

Figure 1-1 is an illustration of a very simple AC system showing a compressor and an expansion valve; cylindrical tanks represent the condenser and evaporator. The pressures and temperatures represent those of a standard-efficiency R22 AC system on a 95°F day.

NOTE: At one time, R22 was used in both AC and medium-temperature walk-ins. Therefore, it is used in this chapter to help the reader focus on temperature differences between AC and commercial refrigeration rather than the different refrigerant pressures currently used for the two types of equipment.

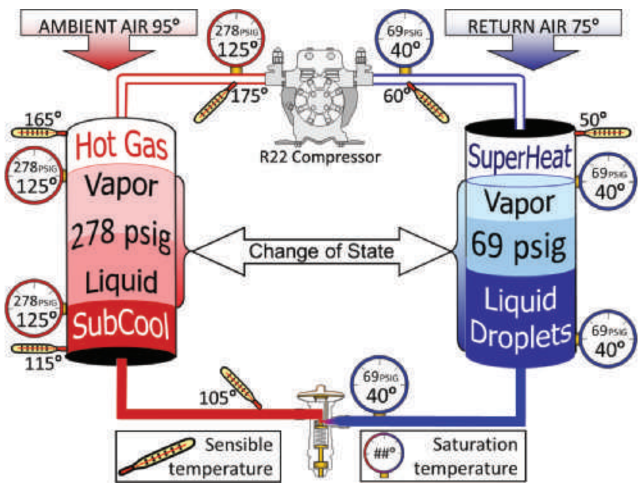
The compressor develops a pressure of 278 pounds per square inch gauge (psig) and discharges superheated vapor at 175°F. The vapor drops to 165°F when it enters the condenser and continues to be cooled by the air around the cylinder. When the vapor temperature falls to 125°F, the gases start to condense into droplets of liquid—the vapor has reached its condensing temperature, which is the saturation temperature of R22 refrigerant at a pressure of 278 psig (refer to the pressure/temperature [P/T] chart in the appendix). The condensing continues at 125°F until all the vapor turns to liquid at the bottom of the tank. Additional cooling, called **subcooling,** of that liquid by the 95°F **ambient** air reduces the temperature of the liquid to 115°F as it leaves the bottom of the condenser. By the time the liquid enters the expansion valve, it has been further subcooled to 105°F.

During this process, the pressure in the high side of the system, between the compressor outlet and the expansion valve inlet, remains constant at 278 psig. However, the refrigerant changes temperature when the hot discharge gas cools, then subcools, as it flows through the condenser. The significance of these different temperatures is important in understanding the refrigeration process.

Low-Pressure Side of the System

As the 278-psig liquid refrigerant goes through the thermostatic expansion valve (TEV), its pressure drops to 69 psig. The 209-psig decrease in pressure, from one side of the valve to the other, is accompanied by a decrease in temperature. The TEV acts like a garden-hose nozzle, changing the solid stream of liquid from the condenser to a spray mixture of vapor and liquid refrigerant droplets. Small droplets are more easily boiled off in the evaporator than a solid stream of liquid is. The R22 refrigerant boils, or evaporates, at 40°F when its pressure is reduced to 69 psig (refer to the P/T chart in the appendix).

FIGURE 1-1 **Simple R22 AC system.** *Courtesy of Refrigeration Training Services.*



The heat from the 75°F air blowing across the tank is absorbed into the refrigerant, causing the refrigerant droplets to boil. The refrigerant temperature remains at 40°F until all of it has vaporized. Only then will its temperature rise as it absorbs more heat from the surrounding air. By the time the suction vapor leaves the tank, the refrigerant temperature will be raised to 50°F. The temperature of the refrigerant above its 40°F boiling point (saturation temperature) is called **superheat.**

How Is Heat Absorbed into the Evaporator?

Starting at the TEV, a fog of liquid droplets is sprayed into the tank. The warm air blowing over the evaporator tank is cooled as its heat is absorbed into the boiling refrigerant. Much more heat is absorbed in the refrigerant as it boils off than is absorbed before or after it has boiled. Boiling, or the change of state from a liquid to a vapor, absorbs heat without a change in temperature. Strange as it may sound, this temperature change cannot be measured with a thermometer. Almost all the refrigerating effect achieved in the evaporator is accomplished as the refrigerant boils. The type of heat absorbed during the evaporation process is called **latent heat.** The ability to remove tremendous amounts of heat in a small area makes it possible for manufacturers to design refrigeration systems small enough to be used in both homes and businesses.

When the refrigerant is fully vaporized, it is totally **saturated** with all the latent heat it can absorb. The 40°F saturated vapor can raise its temperature only by absorbing **sensible heat.** This sensible heat can be measured with a thermometer, and any temperature rise above the refrigerant's saturation temperature is called superheat.

How Does the Condenser Get Rid of the Heat Absorbed by the Evaporator?

To reject the heat absorbed by the evaporator, as shown in Figure 1-1, the cool suction vapor must be raised to a temperature higher than the 95°F outside air. In Figure 1-1, the refrigerant temperature is increased to 125°F. The 30°F difference between the condensing temperature and the outdoor air is great enough to easily transfer heat from the hot condenser to the warm outdoor air.

NOTE: The greater the difference in temperature between two substances, the faster the transfer of heat from one to the other.

Compressing the 69-psig suction vapor to 278 psig increases its boiling point from 40°F to 125°F (see the P/T chart in the appendix). Raised to 125°F, the vapor from the evaporator releases latent heat to the cooler ambient air as the refrigerant condenses to a liquid.

NOTE: The difference between the condensing temperature of a refrigerant and the ambient temperature is called the **condenser split.**

EXAMPLE: 1

125°F condensing temperature – 95°F ambient = 30°F condenser split

In fact, the discharge vapor leaving the compressor is above 125°F. In addition to the evaporator's latent heat, the discharge vapor also contains the following sensible heat:

- Evaporator superheat
- Suction line superheat
- Compressor motor heat
- Heat of compression

In Figure 1-1, the 175°F hot gas leaving the compressor must **de-superheat,** or get rid of its superheat, before it can start condensing at its saturation temperature of 125°F. The condensing process continues at 125°F, rejecting latent heat into the ambient. Cooling the fully condensed liquid below its saturation temperature is called subcooling. To calculate subcooling, determine the condensing temperature from the head pressure and then subtract the temperature of the liquid line leaving the condenser.

EXAMPLE: 2

The head pressure is 278 psig, and the temperature of the liquid line at the condenser outlet is measured at 115°F. Therefore, 125°F condensing temperature – 115°F liquid line temperature = 10°F subcooling.

The liquid travels out of the condenser to the TEV, where the process starts again. This cycle removes heat from where it is not wanted (cooled space) and rejects it somewhere else (outdoors). This is the basic definition of the refrigeration process.

This section on the basic refrigeration cycle is nothing new for most readers. However, the review is still important to form a basis for much of what is discussed in the following chapters.

COMPARING COMMERCIAL REFRIGERATION WITH AC

What is the difference between the medium-temperature refrigeration system in Figure 1-2 and the AC system in Figure 1-1?

The pressures and temperatures on the condenser side are the same because they both use R22 refrigerant and reject evaporator heat into 95°F ambient air. However, the return air blowing over the evaporator in the medium-temperature system is only 35°F. Because the space temperature is lower, the evaporator temperature had to be lowered. In Figure 1-2, the evaporator was lowered to 25°F by reducing the pressure of the R22 refrigerant to 49 psig.

Therefore, a refrigeration system metering device drops the evaporator pressure and temperature to a level lower than that achieved by a metering device designed for an AC system. Similarly, a refrigeration compressor should be capable of increasing the lower evaporator pressure up to a level high enough to reject the heat into 95°F ambient air.

Figure 1-3 is a more elaborate diagram of an AC system, with labels to identify what is happening in the refrigerant circuit.

Figure 1-4 is similar to Figure 1-3, except that it shows the different temperatures and low side pressures of a typical walk-in cooler using R22.

Newer Refrigerants in Commercial Refrigeration

With the vast number of refrigerants available today, there are many different pressures relating to a single saturation temperature. Therefore, this book concentrates on using system temperatures so that the reader will better understand all refrigeration systems, no matter what refrigerant is used.

EXAMPLE: 3

The condensing and evaporator temperatures in Figure 1-4 will be the same regardless of the refrigerant the system uses: R22, R12, R502, R134a, or R404A.

Until about 2018, the following refrigerants were being used in new equipment:

- R404A—walk-in refrigerators and freezers
- R134a and R404A—reach-in refrigerators
- R404A—reach-in freezers

These refrigerants have a consistent temperature–pressure relationship. For each pressure (in psig) there is a specific saturation temperature, no matter whether the refrigerant was in a vapor state or a liquid state. An example of this is R410A, which is used in AC.

However, these refrigerants have been phased out and replaced by those having a high glide such as R448A. All 400 series refrigerants are **zeotropes** or blends of different refrigerants. Some have a low glide, some a high glide. **Glide** refers to the range of temperature between the refrigerant's vapor state and its liquid state. In a vapor state, the saturation temperature is the dew point. **Dew point** is used to calculate superheat. In a liquid state, the saturation temperature is the bubble point.

FIGURE 1-2 **Simple R22 refrigeration system.** *Courtesy of Refrigeration Training Services.*

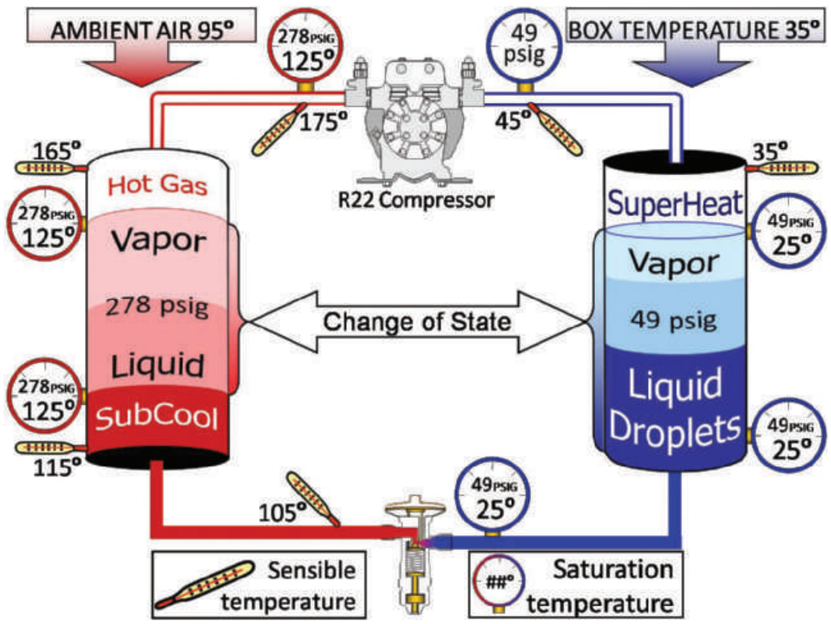


FIGURE 1-3 **Basic R22 AC system.** *Courtesy of Refrigeration Training Services.*

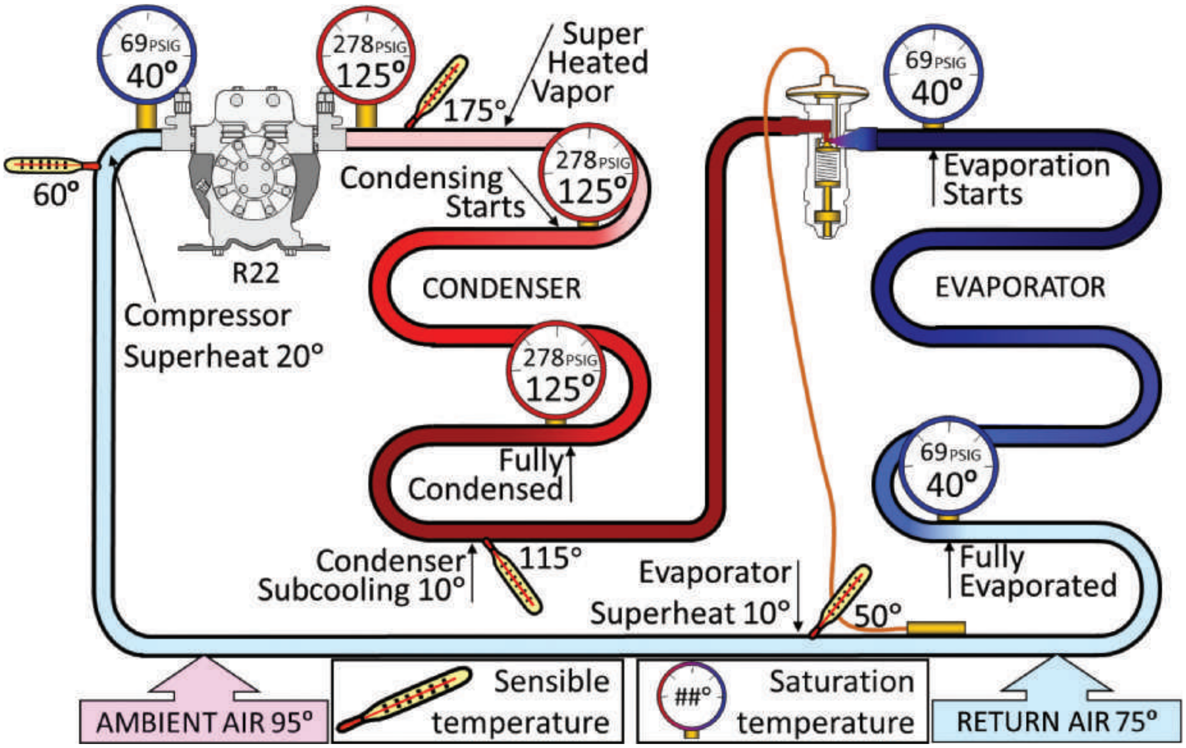
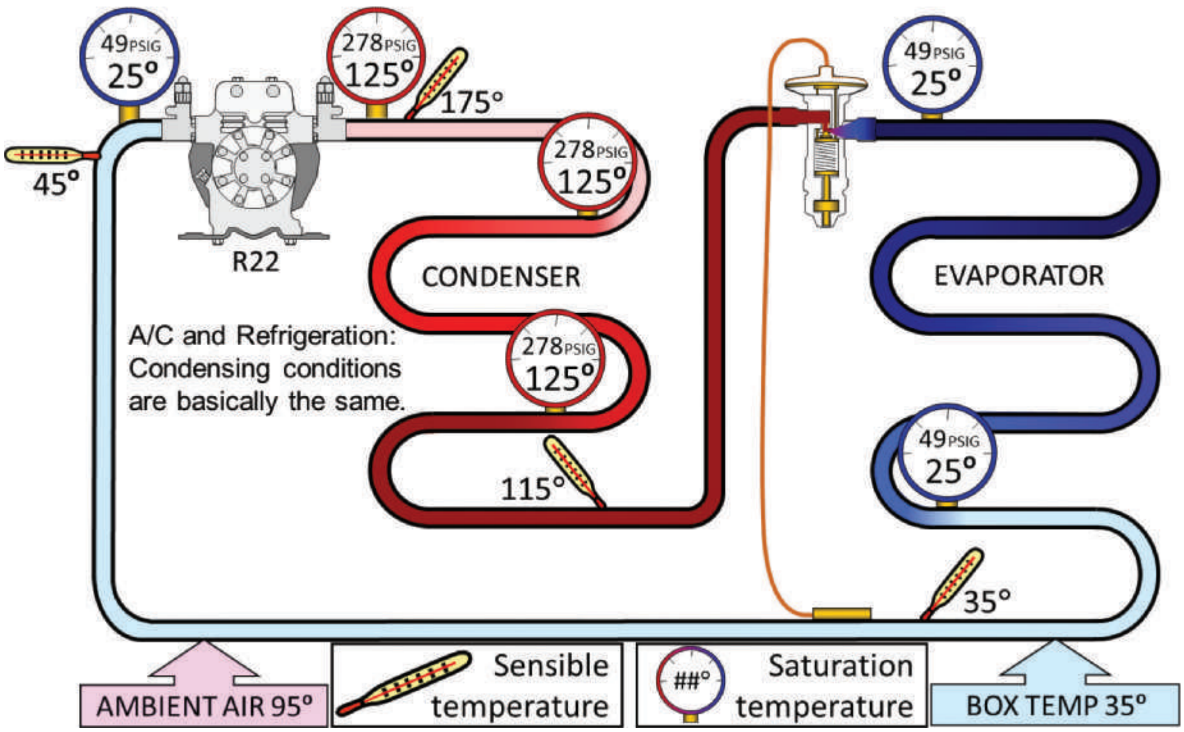


FIGURE 1-4 **Basic R22 walk-in cooler.** *Courtesy of Refrigeration Training Services.*



Bubble point is used to calculate subcooling. These terms will be more fully explained in later chapters. Although glide is a factor to contend with when diagnosing a system, technicians with a good understanding of how it applies will have nothing to fear. The intent of this book is to make sure of that.

THE FOUR BASIC COMPONENTS OF A REFRIGERATION SYSTEM

Chapters 2 through 5 cover in detail each of the four basic components of a refrigeration system. The following is a brief overview of the part each component plays in the refrigeration cycle (Figure 1-5).

Evaporator

Warm air from the space is blown over the evaporator. Heat from the air is absorbed into the refrigerant as it boils within the evaporator tubing. The heat remains in the refrigerant, which flows to another area and is ejected.

TROT

Sometimes when technicians are not able to obtain the exact information needed to solve a problem, they must rely on past experience with similar equipment under similar conditions. The technician has subconsciously determined approximate values for certain conditions. Although they may not be easy to put into words, every technician has developed certain rules of thumb that can be used to diagnose equipment problems.

The New Dictionary of Cultural Literacy defines the term *rules of thumb* as "a practical principle that comes from the wisdom of experience and is usually but not always valid."

Most experienced service and installation technicians use rules of thumb every day on the job. When used in this book, they will be referred to as **TROT (Technician's Rules of Thumb).** The acronym TROT is easy to remember if one thinks of a horse breaking into a trot when it wants to move faster. Likewise, a technician can both learn and work faster by using some rules of thumb. There will be a special notation in the text when TROT are relevant. In addition, the appendix has a complete list of all the TROT used in this book.

NOTE: Factory specifications and guidelines always take precedence over TROT. These rules of thumb should be used only when factory information is not available.

Condenser

The condenser is a **mirror image** of the evaporator. Instead of absorbing heat, it rejects heat. There is tremendous heat transfer as the refrigerant changes state. Latent heat is released as the vapor condenses into a liquid within the condenser.

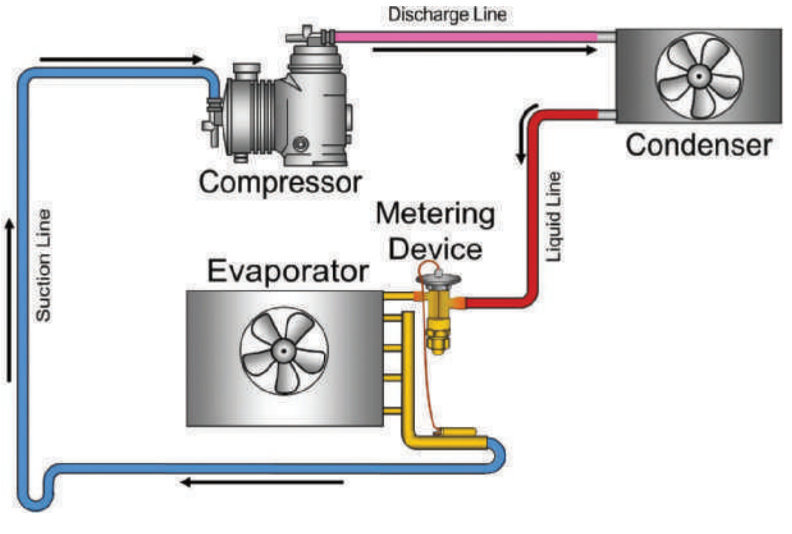
Compressor

The heat in the refrigerant can be removed only if it is exposed to relatively cooler ambient temperatures. Since the outside air can be 95°F or higher, the refrigerant temperature must be raised much higher. The compressor can raise the refrigerant temperature by raising its pressure. Therefore, the hotter it gets outside, the higher the compressor pressures become.

Metering Device

The metering device, either expansion valve or capillary tube, reduces the liquid pressure by forcing it through a nozzle or other small opening. Lowering the pressure of the refrigerant allows it to boil at a lower temperature. To make the refrigerant boil more easily, the metering device changes the stream of liquid into a dense fog of liquid droplets before it enters the evaporator.

FIGURE 1-5 **The four basic components of a refrigeration system.** *Courtesy of Refrigeration Training Services.*



SUMMARY

Most of the commercial refrigeration applications in this book operate at a range of 35°F to 40°F for medium-temperature units and 0°F to –10°F for low-temperature units. Whenever possible, explanations of how these systems operate will be in terms of evaporator and condensing temperatures, rather than suction and head pressures.

There are four basic components of the refrigeration system. The evaporator, condenser, compressor, and metering device are covered in greater detail in the next four chapters. A thorough understanding of these components is necessary before moving on to the many accessories, operating controls, and safety controls covered in later chapters.

Technicians should always follow factory specifications and recommendations. However, there are times when a Technician's Rules of Thumb (TROT) can help speed up the diagnostic process.

In commercial refrigeration, as in any service business, time is money. The quicker a technician can diagnose a problem, the more efficient they are. Better efficiency means more success for the technician and their company. Just as important to success is a technician's positive attitude as a result of working at something they enjoy. The goal of this book is to help the reader become a better technician, one who enjoys what they do and make a good living doing it.

There are some very talented female technicians in this trade, and many more are needed. In this book, gender neutral pronouns will be used to describe technicians. Not only is this fairer, but it is less cumbersome than to keep using *him/her*, *he/she*, and so on.

REVIEW QUESTIONS

1. What is considered the "normal" box temperature of a walk-in refrigerator?
   a. 35°F to 37°F
   b. 38°F to 40°F
   c. –10°F
   d. 0°F
2. What is considered the "normal" box temperature of a reach-in refrigerator?
   a. 35°F to 37°F
   b. 38°F to 40°F
   c. –10°F
   d. 0°F
3. What is considered the "normal" box temperature of a walk-in freezer?
   a. 35°F to 37°F
   b. 38°F to 40°F
   c. –10°F
   d. 0°F
4. What is considered the "normal" box temperature of a reach-in freezer?
   a. 35°F to 37°F
   b. 38°F to 40°F
   c. –10°F
   d. 0°F
5. Why is the temperature of walk-ins usually lower than the temperature of reach-ins?
   a. Walk-ins are designed for long-term storage and lower temperatures.
   b. Reach-ins are designed for long-term storage and lower temperatures.
   c. Reach-ins are small and cannot hold low temperatures.

Refer to figures 1-1, 1-2, 1-3, 1-4 to answer the question.

6. What is the pressure throughout the high side of the system?
   a. 229 psig
   b. 278 psig
   c. 49 psig
   d. 69 psig
7. Refer to figures 1-1, 1-2, 1-3, 1-4 to answer the question. At what temperature does the refrigerant condense?
   a. 125°F
   b. 115°F
   c. 100°F
   d. 95°F

8. Refer to figures 1-1, 1-2, 1-3, 1-4 to answer the question. What is the temperature of the subcooled liquid in the condenser?
   a. 125°F
   b. 115°F
   c. 95°F
   d. 10°F

Refer to Figure 1-4 for questions 9–11.

9. Refer to figure 1-4 to answer the question. What is the pressure drop across the TEV?
   a. 229 psig
   b. 278 psig
   c. 49 psig
   d. 69 psig
10. Refer to figure 1-4 to answer the question. R22 refrigerant at 49 psig boils at what temperature?
   a. 75°F
   b. 35°F
   c. 25°F
   d. 10°F
11. Refer to figure 1-4 to answer the question. What is the temperature of the superheated vapor at the outlet of the evaporator?
   a. 75°F
   b. 35°F
   c. 25°F
   d. 10°F
12. How can the latent heat in a cold suction line be transferred to higher outdoor air temperatures?
   a. Add heat to the suction vapor until it is higher than the ambient
   b. Compress the suction vapor until its condensing temperature is higher than the ambient
   c. Cool the discharge vapor until it condenses just above the ambient
13. What is the primary difference between the AC system in Figure 1-1 and the refrigeration system in Figure 1-2?
   a. The AC unit has to raise the head pressure higher.
   b. The refrigeration unit has to lower the evaporator temperature.
   c. The AC unit cannot use a TEV.

Questions 14–16 refer to refrigerants used up to 2018.

14. Which refrigerant is used most in recently installed walk-in refrigerators?
   a. R12
   b. R502
   c. R404A
   d. R134a
15. Which refrigerant is used in recently installed reach-in refrigerators?
   a. R12
   b. R502
   c. R123
   d. R134a
16. Which refrigerant is used most in recently installed walk-in freezers and reach-in freezers?
   a. R12
   b. R502
   c. R404A
   d. R134a
17. Why do zeotropic blends have temperature glide?
   a. The component refrigerants boil off at different rates.
   b. The refrigerants are so new they have not had time to stabilize.
   c. Glide makes the refrigerant blends more efficient.
18. Under what circumstances should a technician use TROT?
   a. When the technician is too rushed to look up the correct information
   b. When the factory information is not available
   c. When the technician has not had enough training
19. If the condensing temperature is 125ºF and the evaporator temperature is 25ºF, which refrigerants are being used?
   a. R22: 278 psig head, 49 psig suction
   b. R404A: 332 psig head, 63 psig suction
   c. R134a: 185 psig head, 22 psig suction
   d. all of these answer choices

2 EVAPORATORS

CHAPTER OVERVIEW

This chapter begins with an explanation of what an evaporator does and how it is designed to accomplish its functions. The concepts of evaporator temperature and temperature difference (TD) are introduced to help explain the function and performance of an evaporator.

The practice of superheat measurement is shown as the only reliable means of determining whether an evaporator has too much or too little refrigerant. Understanding these key concepts and conditions is essential to solving the complex system troubleshooting problems in later chapters.

Humidity is discussed as a function of TD, and moisture plays an important role in most commercial refrigeration applications. Because refrigeration evaporators operate below freezing point, the practice of defrosting both medium-temperature and low-temperature evaporators is covered in detail.

OBJECTIVES

After completing this chapter, you should be able to

- Describe evaporator defrost methodology
- Describe evaporator temperature
- Explain the significance of humidity in a walk-in
- Describe types of evaporators
- Calculate evaporator superheat and TD
- Describe hot pull-down
- Explain how airflow affects evaporator operation
- Describe types of evaporator problems
- Describe evaporator defrost methodology

KEY TERMS

Evaporator temperature
Temperature difference (TD)
Delta *T* (ΔT)
Hot pull-down
Design conditions
Dehumidifying
Benchmark
Low-velocity coils
DX (direct expansion) coil
Header
Saturated
Superheat
Flooding
Starving
Random defrost or off-cycle defrost
Differential
Cut-in
Cut-out
Planned air defrost
Pump-down solenoid
Hot gas defrost
Fail-safe
Defrost termination switch
Fan delay switch
DTFD

FUNCTIONS OF THE EVAPORATOR

The primary function of an evaporator is to absorb heat from the refrigerated space. The secondary function is to remove, or maintain, humidity in the space.

Evaporator Temperature

Evaporator temperature is the term used to describe the temperature of the refrigerant inside the evaporator tubing. It is not practical to drill a hole in the tubing to insert a thermometer. An easier and more accurate method is to take the suction pressure and compare it to a pressure/temperature (P/T) chart. For instance, if the suction pressure is 50 psig on an R22 walk-in cooler, according to the P/T chart, the temperature of the coil is about 26°F (see Figure 2-1).

Temperature Difference

The term **temperature difference,** or **TD,** is used in this book to stand for the difference between the evaporator temperature and the temperature of the refrigerated space. For instance, if the evaporator temperature of a walk-in refrigerator is 25°F and the box temperature is 35°F, then the TD will be 10°F (35°F − 25°F = 10°F). The reasons for using evaporator temperature, instead of the leaving air temperature of the evaporator, are ease and accuracy of measurement. With walk-ins and reach-ins, it is often difficult to measure discharge air accurately because of the turbulence of the air passing through the fan blades. However, the inlet air is always at the box temperature, and the evaporator temperature is easily determined from the suction pressure.

The air conditioning (AC) industry has always used **ΔT (delta *T*)** as the difference between supply and return air temperatures. For AC applications, it is easy to put temperature probes in the ductwork where the air is thoroughly mixed.

In the supermarket industry, there are a number of ways to measure temperatures to determine the appropriate TD or ΔT. For instance, one could use the temperature of the air discharged at the supply grille or "honeycomb," return air at the inlet grille, product or case temperature at the shelf area, and evaporator temperature from the suction pressure along with a P/T chart to determine the saturation temperature.

The important thing is for technicians to ensure they are using the same definition when discussing TD. In any discussion of temperature differences between two or more parties, they should clarify what they mean when using TD and ΔT.

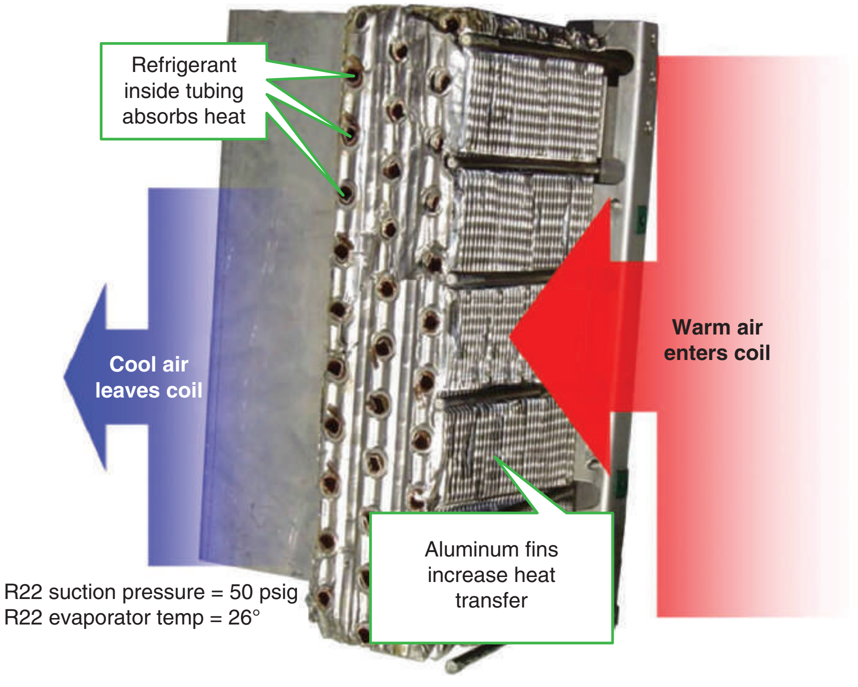
Refrigerant inside the Evaporator

Refrigerant boils inside the evaporator, absorbing latent heat. The temperature at which the refrigerant boils is referred to by several different terms:

- Evaporator temperature
- Suction temperature
- Saturation temperature
- Saturated suction temperature (SST)

Although these terms sound different, they all essentially mean the same thing.

FIGURE 2-1 **Cross-section of a Heatcraft evaporator.** *Photo by Dick Wirz.*



As the temperature of the air over the evaporator tubing increases, so does the temperature of the refrigerant inside the evaporator tubing. The rise in temperature causes the refrigerant to boil more rapidly. The more vigorous the boiling, the more the suction pressure rises. Therefore, if hot product is put into a reach-in, walk-in, or refrigerated case, the temperatures and pressures will rise accordingly. Conversely, as the temperature is lowered or the load falls due to blocked coils or fan problems, the pressures and temperatures will also fall.

This relationship of refrigerant temperature to box temperature is an important concept to understand to properly troubleshoot refrigeration systems.

What Happens on Start-up?

Hot pull-down refers to the start-up of a new system, a freezer after defrost, or when there is warm product in the box. This means there is a tremendous load on the system initially, and it will not have proper temperatures and pressures until it is near its intended **design conditions** or normal operating conditions. However, the abnormal system temperatures and pressures observed during a hot pull-down do give an indication of how excessive load affects a system. Consider what happens in the evaporator at the start-up of a warm walk-in refrigerator.

The expansion valve feeds refrigerant by fully opening 100 percent, but it is not enough to fill the evaporator. Therefore, the superheat (the difference between the evaporator temperature and the temperature of the refrigerant leaving the evaporator) is high. The suction pressure is also high because the warm air in the box boils off the refrigerant rapidly, raising both its pressure and its temperature.

As the box temperature falls, so do the pressures and the superheat. Finally, when the box is close to its design temperature, the suction pressure is equivalent to about 10°F below the box, and the superheat is also close to 10°F.

We have just seen what high load does to evaporator conditions. If a technician finds abnormally high pressures and superheat on a service call, they should first consider the load in the box before adjusting the thermal expansion valve (TEV), adding refrigerant, or condemning components. Technicians have been known to adjust an expansion valve open to lower superheat on initial start-up, only to have a flooded evaporator when the box temperature reaches design conditions.

Humidity and TD

Humidity is measured as a percentage of the moisture air can hold at a certain temperature. Strictly speaking, it should be called relative humidity (RH); however, in this book, we will simply use the term *humidity*. Raise the air temperature, and it can hold more moisture. Lower the air temperature enough, and the air will start to release its moisture when it reaches its dew point. When the temperature of outdoor air drops below its dew point, rain is likely. Or early on a summer's morning when the ground is colder than the dew point of the air above it, dew forms on the grass. Another example is when the steam from a hot shower condenses on the cooler surface of the bathroom mirror. In refrigeration, when air inside a refrigerated space drops below its dew point, it condenses on cool surfaces, namely the evaporator coil.

All refrigeration removes humidity from a space, some more than others. The process of pulling humidity out of a space is called **dehumidifying.** During refrigeration, an evaporator operates below the dew point temperature of the air passing over it. Therefore, the moisture in the air condenses on the cold tubing and evaporator fins, collects in the drain pan, and flows outside through the condensate drain line. The air leaving the evaporator now has less moisture, or lower humidity, than when it entered.

Air Conditioning TD and Humidity

The TD between the air entering the coil and the evaporator temperature has a lot to do with the amount of moisture condensed out of the air. For instance, on an AC coil, the TD is about 35°F (75°F return air temperature − 40°F evaporator temperature). From psychrometric charts, it can be determined that the air in the space will have a humidity of about 50 percent, which is desirable in a living space for comfort cooling. This low relative humidity allows moisture to evaporate from peoples' skin, making the room seem both cool and comfortable. If the evaporator had only a 25°F TD, the coil temperature would be 50°F instead of 40°F. The warmer evaporator would not remove as much water, which would result in higher space humidity. With 50 percent relative humidity as a **benchmark,** the higher the room humidity, the less comfortable the occupants will be.

NOTE: AC technicians are more familiar with the ΔT. This is the difference between the air handler's return air temperature and that of the supply air. The supply air is usually measured in the trunk line after it mixes well in the supply air plenum. In the previous example, a properly operating AC unit would have about a 20°F ΔT (75°F return air temperature – 55°F supply air temperature = 20°F ΔT). The evaporator temperature would be about 40°F.

Unfortunately for refrigeration technicians, the air discharged by the propeller fans of refrigeration evaporators has different temperatures at several places around the fan area. The difficulty of determining accurate leaving air temperatures has resulted in the use of coil temperature as a better method of measurement.

Walk-in TD and Humidity

In a walk-in cooler, such as in Figure 2-2(b), large coil surface and high air volume combine to produce a TD of only about 10°F (35°F box temperature − 25°F coil temperature). At a box temperature of 35°F with an evaporator TD of 10°F, the humidity in a walk-in refrigerator is about 85 percent. This high humidity is very good for foods such as meat and produce that need to be stored in a moist environment to prevent them from drying out. However, if the product in the walk-in is covered or contained, such as packaged meats or bottled beverages, then the equipment could be designed for a higher TD of 15°F to 20°F. Refer to Chapter 11, "Walk-in Refrigerators and Freezers," for how equipment matching affects TD.

Reach-in TD and Humidity

Reach-in refrigerators have a limited amount of interior space (see Figure 2-2(a)). Therefore, the evaporator must be as small as possible, yet capable of maintaining adequate temperatures for medium-temperature applications. The smaller evaporator still maintains about 38°F to 40°F, but at a higher TD of about 20°F. A TD this high results in a lower humidity of approximately 65 percent. Although unwrapped product dries out faster in a reach-in than in a walk-in, a reach-in is used primarily for short-term storage. Reach-ins are designed for convenience, where it is desirable to have refrigerated product easily accessible for customers or kitchen staff.

The amount of coil surface and the quantity of airflow can affect box humidity. For instance, high space humidity can be gained by using an evaporator with a large coil surface and greater British thermal units per hour (Btuh) capacity than its condensing unit. A lower fan speed can prevent damage to product that is sensitive to airflow. A combination of these two factors is used in **low-velocity coils.** These evaporators are often used in meat rooms, deli cases, and florist coolers (see Figure 2-3).

FIGURE 2-2 **A reach-in (a) and a walk-in (b).** *Courtesy of Master-Bilt Products.*

(a) (b)

TROT

EVAPORATOR TD AND HUMIDITY

AC = **35°F** TD at **50%** relative humidity (RH)

AC: **75°F** return temp minus **40°F** evaporator temp = **35°F** TD

Reach-ins = **20°F** TD at **65%** RH

Reach-in: **40°F** box temp minus **20°F** evaporator temp = **20°F** TD

Walk-ins = **10°F** TD at **85%** RH

Walk-in: **35°F** box temp minus **25°F** evaporator temp = **10°F** TD

High-humidity boxes = **8°F TD** at greater than **90%** RH (flower boxes, fresh meat, and deli cases)

NOTE: As a rule, the lower the evaporator TD, the higher the humidity.

These rules of thumb will be used for troubleshooting in a later section. However, to prevent misapplying these general statements, here are a few conditions and exceptions to keep in mind.

First, the AC ratings are in TD rather than ΔT. Also, AC is included in the list as a source of comparison with commercial refrigeration for those readers who are already familiar with ΔT and comfort cooling. The values given are based on "standard" units of 10 SEER (seasonal energy efficiency ratio) and below. The high-efficiency units have higher coil temperatures, which raises sensible cooling capacities to increase their ratings. However, this lowers the TD and raises indoor humidity, an issue that will not be covered in this text.

Although the TDs of reach-ins can vary between 15°F and 30°F, most of them operate in about a 20°F TD. Walk-ins range from 8°F to 20°F TD, and for most of the examples and troubleshooting in this book, 10°F TD will be used (see Figures 2-4 and 2-5).

These TD values can be used on both freezers and refrigerators. However, the humidity ratings are not applicable to freezers because the food is usually packaged.

Using TROT for TD and Troubleshooting

If a walk-in cooler is at 35°F box temperature, what should the evaporator temperature be? According to TROT, it should be 10°F lower than the box temperature, or 25°F (35°F box temperature minus 10°F TD = 25°F evaporator temperature). To verify the evaporator temperature, the technician should check the suction pressure as close as possible to the evaporator. If the system contains the refrigerant R22, the suction pressure will be about 49 psig. If it contains R404A, the pressure will be about 62 psig. If the suction pressure is taken at the compressor inlet, say 50 feet away, there may be a pressure reading about 2 pounds lower than at the evaporator. This pressure drop in the suction line is normal for a correctly installed remote system. A larger pressure drop would indicate a problem with pipe sizing or some restriction in the suction line.

FIGURE 2-3 **Low-velocity, high-humidity evaporator coil.** *Courtesy of Heatcraft Worldwide Refrigeration.*

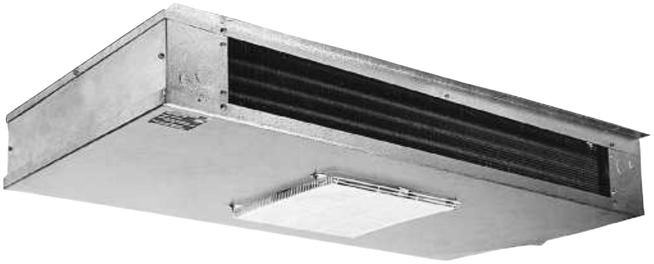
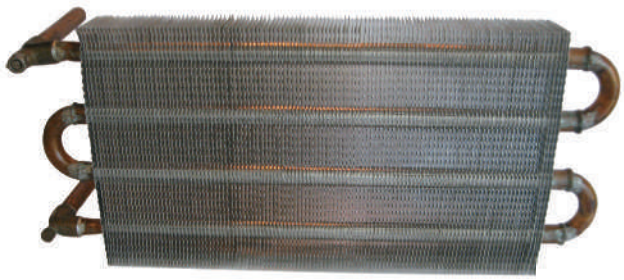


FIGURE 2-4 **Reach-in evaporator.** *Courtesy of Heatcraft Worldwide Refrigeration.*

FIGURE 2-5 **Walk-in evaporator.** *Courtesy of Heatcraft Worldwide Refrigeration.*

FIGURE 2-6 **The most common evaporator construction: copper tubing and aluminum fins.** *Photo by Sharon Rounds.*



Evaporator Materials

Manufacturers use different materials for their evaporators based on design conditions of heat transfer, cost, and corrosion resistance. Copper gives the best heat transfer but at a relatively high cost. Aluminum is the next best choice for heat transfer and is cheaper. To reach an effective balance of cost to heat transfer, most forced air evaporators are made of copper tubing with aluminum fins. The aluminum fins add surface area for optimum heat transfer (see Figure 2-6).

Manufacturers occasionally try to lower the cost of their equipment by replacing the copper tube evaporators with aluminum tubing. Eventually, the evaporators develop small leaks that are very difficult to repair. For this reason, aluminum evaporators are not popular with service technicians.

Reach-in sandwich and pizza preparation units, in which tomatoes and vinegar are often stored, can develop small pinhole leaks in the copper evaporator tubing from the corrosive effects of the acids in these foods. Therefore, manufacturers offer an optional epoxy coating on these coils to prevent the acids from attacking the copper.

Ice machine manufacturers are concerned about the minerals in water collecting on their evaporators. The greater the mineral buildup, the lower the heat transfer. Most ice machines, such as Manitowoc, use nickel-coated copper evaporators on which the ice is formed. Hoshizaki ice machines have had great success with stainless steel evaporators, even though stainless steel is not as efficient in its heat transfer and costs more than copper. Chapter 12, "Ice Machines," discusses ice machines more fully.

In water-cooled condensers, mineral buildup causes problems with heat transfer, water flow, and corrosion. Alloys of copper and nickel (cuprous nickel) have been very effective in reducing these problems. However, there is no evidence of their use in evaporators yet.

Heat Exchange Efficiency

Liquid is the most efficient heat exchange "medium." Because of its density, liquid provides better heat transfer than vapor does. For example, heat the end of a 7/8-inch piece of copper pipe until it is cherry red. What will cool it faster, blowing 70°F air over it or pouring 70°F water over it? The water, of course, will cool it much more quickly because the dense water absorbs heat more quickly than air does.

Liquid-to-liquid heat exchange is very efficient. One example is a chiller that has a float-type metering device that allows liquid to fill, or flood, the evaporator. The secondary refrigerant of water, glycol, or brine is circulated through the tubing covered by liquid refrigerant. The flooded evaporator is cooled as the surface of the liquid boils off and the vapor is pulled into the compressor.

In most of the evaporators covered in this book, the only liquid medium is inside the coil tubing. As air from the space passes over the evaporator coils, the liquid refrigerant boils off as it absorbs heat from the air. This boiling greatly increases heat transfer, as it causes the refrigerant to absorb latent heat.

To illustrate how heat transfer is increased by boiling, consider the concept of heating water taught in the first classes of basic refrigeration. It only takes 1 Btuh of heat to raise the temperature of 1 pound of water from 211°F to 212°F. However, it requires the addition of 970 Btuh to make 212°F water change state to a vapor at 212°F. The point is that the water must absorb nearly a thousand times more heat (latent heat) to boil than it does to simply change temperature (sensible heat). The heat contained in the air passing over evaporator tubing is efficiently absorbed into the refrigerant inside the tubing as the liquid refrigerant boils into a vapor.

If the liquid entering the evaporator is converted into small droplets, the boiling process is easier to accomplish. The metering device (TEV, capillary tube, or fixed nozzle) atomizes the incoming stream of liquid refrigerant into droplets. This is where the term **DX coil,** or **direct expansion coil,** comes from.

Flow Effect on Heat Exchange

The speed of air moving across an evaporator or the rate of liquid flow through tubing can change the rate of heat exchange. Readers familiar with AC are well aware of the effects air volume has on the system. In a standard AC system, the evaporator absorbs about 12,000 Btuh with approximately 400 cubic feet per minute (cfm) of airflow. If the air is too slow, or too fast, it will not cool and dehumidify properly.

In refrigeration, it is unusual to find ductwork or multispeed fans. The volume of airflow is designed into the fan–coil unit from the manufacturer. However, it is important to understand the effects on system pressures and temperatures if a fan motor has the wrong fan speed or burns out, if the fan blade turns in the wrong direction, or if the evaporator is dirty or iced up.

As airflow decreases, there is less heat for the refrigerant to absorb. With less heat, the refrigerant does not boil as much. Therefore, the suction pressure drops, as does the coil temperature. The lower evaporator temperature produces even more frost. Eventually, the entire evaporator will be covered with frost.

The frost acts as an insulator between the warm air in the box and the cold refrigerant in the evaporator. Therefore, because of the reduced heat transfer, the box temperature increases, and the thermostat (tstat) keeps the compressor running. Eventually, the frost will turn to ice, allowing the box temperature to rise high enough to cause food to spoil.

TYPES OF EVAPORATORS

Early in the evolution of refrigeration, the first evaporators were long sections of refrigeration pipe mounted near the ceiling of a refrigerated room. The warm room air rises to the ceiling; the cold pipes lower its temperature; and as the cold air falls, it cools the space. A natural and gentle circulation of air continues through the process of natural convection. This method of refrigeration produces a high-humidity environment perfectly suited to fresh meat and produce. The addition of aluminum fins on the copper pipe greatly increases the heat exchange and allows a smaller amount of tubing to accomplish the same refrigeration effect. These evaporators are known as finned tube convection coils, or gravity coils, and are still in use today, especially in full-service meat and deli cases in supermarkets. An interesting application is to preserve live crabs for the seafood industry. Crabs can survive outside water as long as they have a cool environment with very little air movement (see Figure 2-7).

More innovation came by adding a fan to force air across the coil surfaces. This further increased evaporator efficiency while greatly reducing the size of the evaporator. In fact, coils could be made small enough to fit inside a cabinet. Thus, the commercial reach-in refrigerator was born (see Figure 2-8).

FIGURE 2-7 **Gravity coil or convection coil.** *Photo by Dick Wirz.*

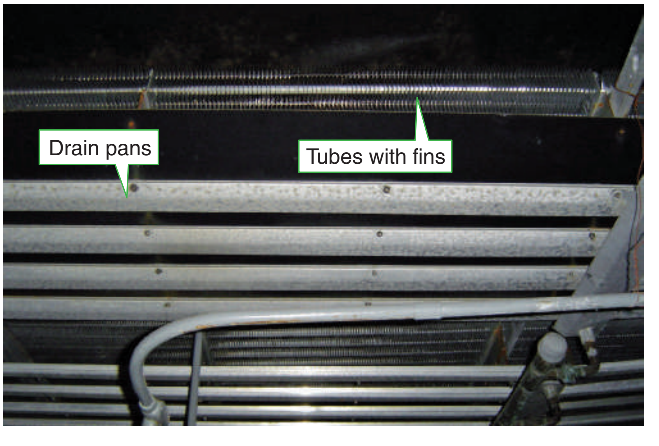
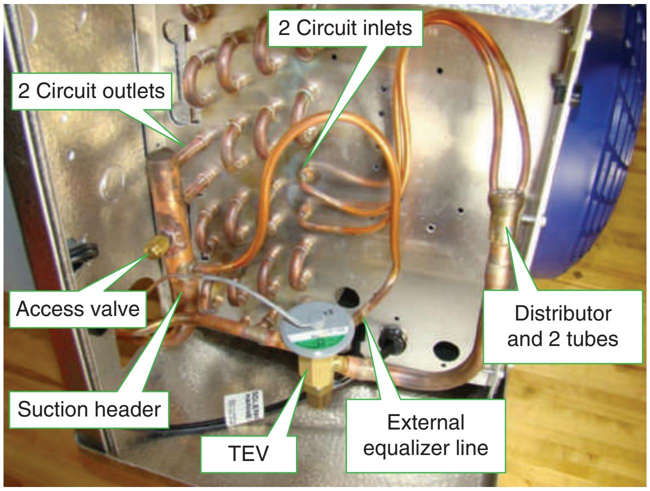


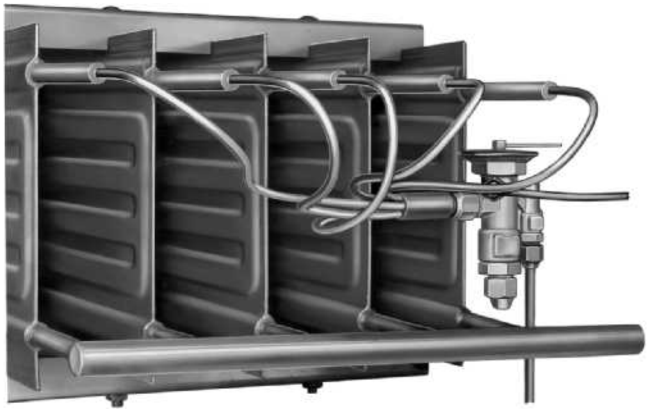
FIGURE 2-8 **Fan–coil unit.** *Courtesy of Heatcraft Worldwide Refrigeration.*

FIGURE 2-9 **A multicircuit evaporator coil.** *Photo by Dick Wirz.*



On the early large evaporators, the single-pipe design resulted in a significant pressure drop by the time the refrigerant left the coil. Because a drop in pressure causes a drop in the temperature of saturated refrigerant, the second half of the coil would be much colder than the first. This arrangement caused uneven coil temperatures and excessive coil frost. To solve this problem, the large evaporators were redesigned into smaller evaporator sections, or circuits. A multicircuit evaporator is like a group of single coils stacked on top of each other that are fed with one expansion valve. The outlet of each circuit is tapped into the side of a straight pipe, or **header.** This header becomes the suction line that returns the evaporator's superheated vapor to the compressor. Using multiple circuits is more efficient than a long single circuit and helps keep pressure drop and coil frosting to a minimum (see Figure 2-9).

FIGURE 2-10 **Stamped or "plate-type" evaporator.** *Compliments of Parker Hannifin–Sporlan Division.*



Stamped evaporators utilize two sheets of metal, with passages stamped into the metal where the refrigerant can flow. The extended surface of the plates provides good heat transfer between the refrigerant and other liquids. This method is used by some ice machine manufacturers and is one of the preferred methods of cooling the water in large commercial fish tanks (see Figure 2-10).

EVAPORATOR OPERATION

It is important that technicians understand what happens inside an evaporator and how different evaporators affect different conditions. Following is a sample of the evaporator type and proper operating conditions a technician could expect in a medium-temperature walk-in refrigerator.

A standard walk-in refrigerator designed for a 35°F box temperature would use a fan-coil unit designed for a 10°F TD. The evaporator temperature, or temperature of the refrigerant inside the evaporator, would be 10°F below the box temperature, or 25°F.

The most accurate measurement of evaporator temperature is obtained by using the suction pressure. In this application, an R22 system at 25°F suction would have a pressure of 49 psig, or 62 psig for R404A. To verify, refer to the P/T chart in the appendix.

The metering device changes the entering liquid to a dense fog of liquid droplets. During the same process, the high-pressure liquid is lowered to what is called the evaporator pressure, or suction pressure. This pressure relates to the evaporator temperature (use the P/T chart). During evaporation, the refrigerant remains the same temperature (its saturation temperature) throughout the coil until all droplets of liquid are vaporized or totally saturated with latent heat.

When the refrigerant nears the end of the evaporator, the fully **saturated** vapor can only absorb sensible heat. Although absorbing sensible heat does not contribute much to the overall refrigeration effect, being able to measure sensible heat with a thermometer is very important. Every 1°F the suction vapor is above its saturation temperature is 1°F of **superheat.**

MEASURING SUPERHEAT

Measuring the amount of superheat allows the technician to determine if all refrigerant has boiled off in the evaporator and to approximately measure the efficiency of coil operation. It can also be a measurement of the margin of safety against flooding the compressor with liquid refrigerant.

The four steps in calculating superheat are as follows:

1. Measure the suction pressure with gauges.
2. From the pressure, use a P/T chart to determine evaporator temperature.
3. Measure the temperature of the suction line at the outlet of the evaporator.
4. Subtract the evaporator temperature from the suction line temperature.

Because evaporator temperature is determined from suction pressure, accuracy depends on how physically close to the evaporator the pressure reading is taken. Many evaporators have an access valve at the evaporator outlet (see Figure 2-9). If not, the suction pressure taken at the condensing unit is usually adequate for determining the evaporator temperature.

Here is an example of a superheat calculation on a 35°F walk-in refrigerator (see Figure 2-11):

35°F (suction line) minus 25°F
(evaporator temperature) = 10°F superheat

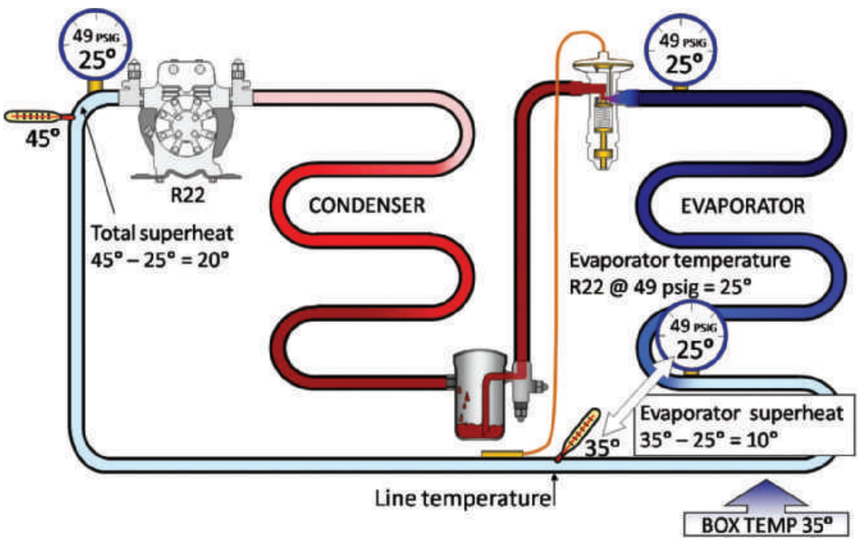
The amount of evaporator superheat designed into a system varies from as much as 15°F for some AC systems to as low as 3°F for most ice machines. As a rule of thumb, 10°F is usually adequate for commercial refrigeration systems. However, for optimum efficiency, the technician should check with the equipment manufacturer.

The technician should know which type of superheat measurement is recommended by the factory. An evaporator manufacturer might specify that most of its refrigeration evaporators are designed with a 10°F superheat and that this is calculated by using the suction line temperature at the evaporator outlet. However, a compressor manufacturer may recommend a 20°F compressor superheat. This is the total of the superheat in the evaporator plus the sensible heat picked up in the suction line. The compressor superheat, or total superheat, calculation is determined by taking the suction line temperature 6 inches from the compressor inlet, not at the outlet of the evaporator (see Figure 2-11). Compressor manufacturers want to make sure there is enough superheat at the compressor inlets to ensure that the compressors will not be damaged by liquid flooding from the evaporator.

Flooding and Starving Evaporators

A **flooding** evaporator is not boiling off enough of its refrigerant to prevent liquid from leaving the evaporator. Refrigerant that has not totally boiled off cannot pick up any sensible heat. A flooded system has no superheat. However, flooding is sometimes used to describe an evaporator that has a superheat much lower than normal.

FIGURE 2-11 **An example of pressures and temperatures on the low side of a refrigeration system.**
Courtesy of Refrigeration Training Services.



EXAMPLE: 1

A system with a normal superheat of 10°F is considered to be flooding if its superheat is below 5°F.

A **starving** evaporator is one in which the refrigerant is boiling off too soon. The refrigerant does not fill the evaporator sufficiently; therefore, it picks up more sensible heat than normal. A starving evaporator has high superheat.

EXAMPLE: 2

A system with a normal superheat of 10°F is considered to be starving if its superheat is above 20°F.

Hot Pull-down

If the box or space temperature is far above its normal or there is a heavy product load, the process of bringing down the temperature is called hot pull-down. During hot pull-down, none of the pressure–temperature relationships previously discussed seems to hold true. The metering device, whether it is capillary tube or TEV, feeds as much refrigerant as possible to the evaporator. However, the liquid refrigerant quickly boils off because of the high heat-load condition, resulting in a starving evaporator with high superheat.

Although in a hot pull-down the system is out of balance, it is advisable to wait until pressures and temperatures settle down and get closer to the system's usual, or design, conditions before determining things like TD and superheat.

According to TROT, superheat should be measured only when the system is within 5°F of design conditions. For instance, a walk-in box designed for 35°F operation will not be even close to its normal superheat until it has dropped to at least 40°F. Even then, it will probably be feeding more refrigerant than it does when it is nearer to 35°F, but at least it will be fairly close to the desired 10°F superheat.

Evaporator Problems

Evaporators have two main problems:

- Airflow problems: dirty or iced evaporator, fan motor, or blade problems
- Refrigerant problems: too much refrigerant or not enough, metering device problems, or distributor problems

Troubleshooting these problems is fully covered in later chapters. However, because both medium- and low-temperature refrigeration units develop frost, which can cause airflow problems, this is a good place to discuss how to get rid of frost.

Medium-temperature Evaporator Air Defrost

Medium-temperature commercial refrigeration usually operates at box temperatures between 34°F and 40°F, with evaporator temperatures at about 15°F to 25°F. Because the coil temperature is well below freezing, it is normal for frost to build up on the evaporator fins during the "on cycle" when the compressor is running.

When the tstat (thermostat) is satisfied, the compressor shuts off, and the evaporator fans continue to circulate air from the space through the coil fins. Because the space and product temperatures are above freezing, the evaporator warms up, and the frost melts. This process, called **random** (or **off-cycle**) **defrost,** occurs each time the tstat turns off the compressor.

To help ensure enough defrost time, commercial refrigeration tstats are designed with a relatively wide temperature **differential.** Differential refers to the difference between a control's **cut-in** and **cut-out.** The cut-in of a tstat is the setting at which the contacts close when there is a rise in box temperature. The cut-out is the setting at which the contacts open, stopping the refrigerating cycle. Tstats that sense box temperature usually have a differential of 4°F or 5°F, wide enough to air defrost the evaporator coil.

Planned Air Defrost

Sometimes the standard off cycle is not long enough to defrost the evaporator. This problem usually occurs when the box temperature is maintained between 34°F and 36°F. The evaporator can also develop too much frost when the box receives very heavy usage from warm product, due to bad door gaskets, or just because of excessive door openings.

Technicians have to plan when, and for how long, to shut off the compressor to clear frost from the coils. For this reason, it is called a **planned air defrost** and uses a time clock to shut off the compressor long enough to accomplish the necessary air defrosting.

Normally, defrosts are scheduled for times the box is not in use. For example, technicians usually set the clock to go into defrost at 2:00 in the morning for an hour or two. This gives the coil enough time to melt the frost accumulated during the day. The product temperature in the box may rise by a few degrees, but not enough to cause food spoilage. When the defrost period is complete, the compressor quickly restores the product to its original temperature.

Below 34°F box temperature, additional heat must be used to accomplish complete defrost. For example, meat cutters prefer meat at 28°F because at that temperature, it is firm and easier to cut. Therefore, a meat box will have a medium-temperature condensing unit, a medium-temperature expansion valve, and a freezer coil with electric heaters to accomplish defrosting.

FIGURE 2-12 Paragon 4000 series defrost clock for planned defrost. *Photo by Dick Wirz.*

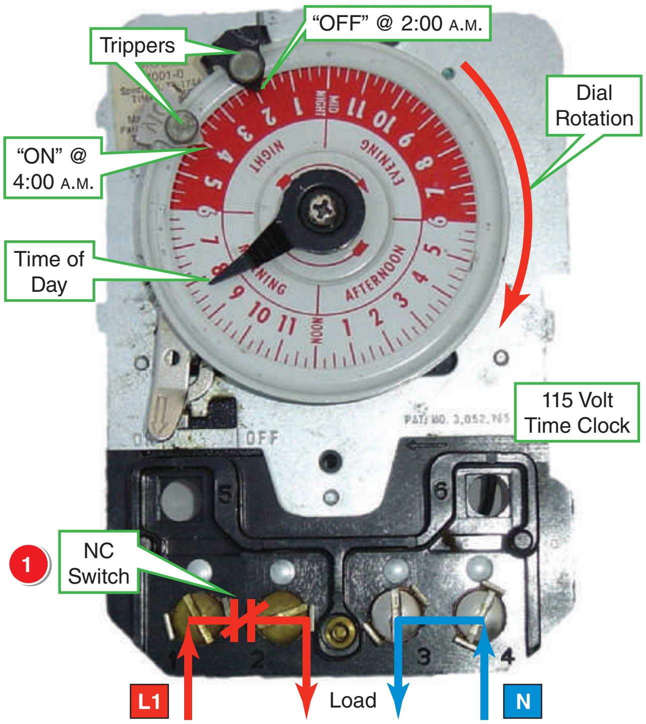
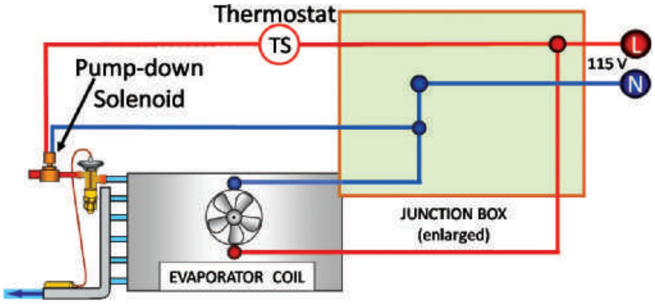


FIGURE 2-13 Basic wiring of 115-volt evaporator on a walk-in refrigerator. *Courtesy of Refrigeration Training Services.*



Usually, only one or two short defrosts are required every 24 hours.

The Paragon time clock in Figure 2-12 simply opens and closes a set of switches according to the setting of the "trippers." The clock opens a set of contacts and turns off the refrigeration when the black tripper reaches 2:00 A.M. The silver tripper closes the contacts and turns the refrigeration back on at 4:00 A.M.

Figure 2-13 shows the basic wiring of a walk-in refrigerator that uses a tstat and **pump-down solenoid.** When the tstat is satisfied, it breaks the circuit to the solenoid coil, allowing the solenoid plunger to drop, which stops the flow of liquid to the expansion valve. The compressor runs until the suction pressure drops or "pumps down" to the cut-out setting on the low-pressure control. The evaporator fans run continuously, circulating the air in the box.

When the temperature in the space rises, the tstat energizes the solenoid coil. The valve plunger lifts, allowing refrigerant to flow through the TEV into the evaporator and back to the compressor. When the suction pressure rises, the low-pressure control closes, and the compressor starts.

There are several reasons for using a pump-down solenoid with a remote condensing unit:

- When the solenoid closes, the compressor pulls refrigerant out of the low side of the system and stores it in the receiver before shutting down. This prevents refrigerant migration during the off cycle.
- By removing all refrigerant from the suction line, it eliminates the possibility of refrigerant vapor condensing to a liquid and slugging the compressor on start-up.
- Compressor starting is easier from an unloaded condition.
- Control wires are not needed between the tstat in the refrigerated space and the remote condensing unit.

When it is time for a planned defrost, contacts 2 and 3 open (see Figure 2-14). The magnetic coil on the solenoid valve is de-energized, stopping the flow of liquid refrigerant to the evaporator. The compressor pumps down and shuts off on low pressure. The fans run constantly, melting any frost as the evaporator temperature rises to the temperature of the refrigerator.

In Figure 2-15, the wiring is the same as in Figures 2-13 and 2-14, except for the addition of a two-pole switch to shut off the fan. Some customers want to shut off the fans while they are inside the cooler. In addition, the electrical inspector may require a switch to act as a disconnect for servicing the evaporator fan motor.

Whatever the reason, it is important to make sure the switch cuts power to the pump-down solenoid

FIGURE 2-14 Defrost clock used for planned defrost. *Courtesy of Refrigeration Training Services.*

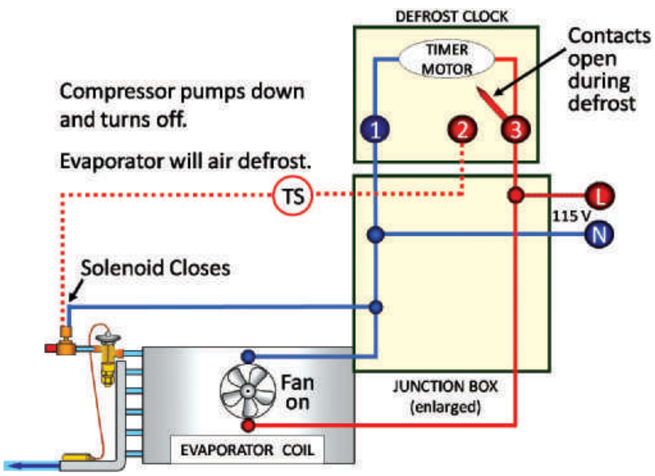


FIGURE 2-15 **Evaporator fan switch wiring.** *Courtesy of Refrigeration Training Services.*

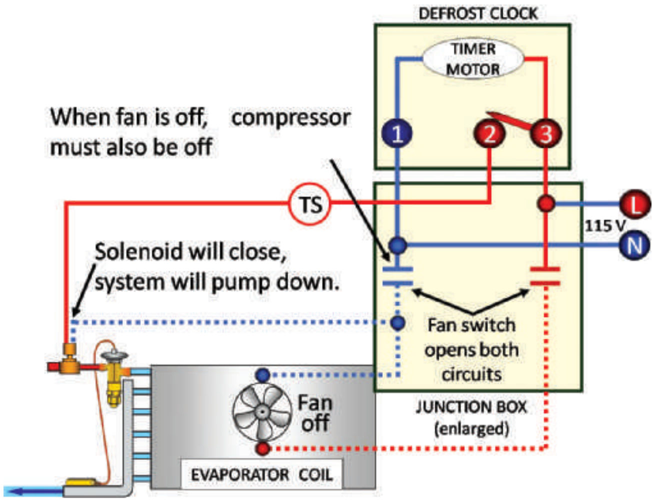
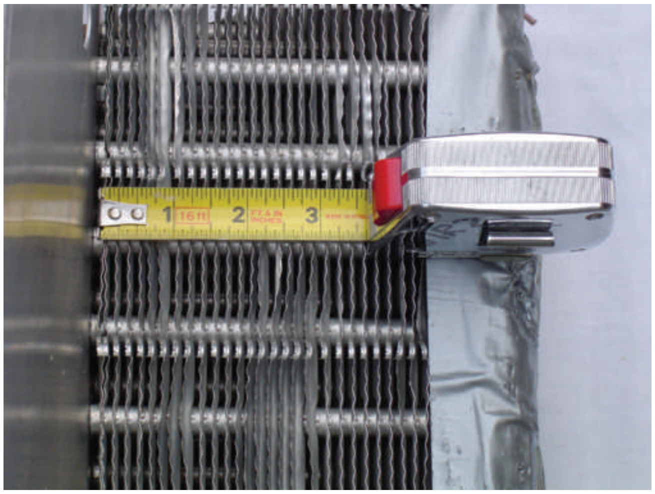


FIGURE 2-16 **Measuring evaporator fin spacing.** *Photo by Dick Wirz.*



so that the compressor is off whenever the fan is off. If not, the compressor will continue running, freezing the coil and causing refrigerant floodback.

When to Defrost

Following is a list of TROT for refrigerated space temperatures when the tstat should be able to perform random or off-cycle defrost, when a clock for planned defrost is needed, and when heat must be added to defrost the evaporator:

Box temperature 37°F (and above) = **off cycle** (no clock needed)
Box temperature 35°F = **planned** (clock only)
Box temperature 33°F (and below) = heat (and clock)

Most medium-temperature refrigeration systems automatically defrost during the off cycle as long as the box temperature is 37°F or higher and the product is the same temperature.

However, when the box temperature is lowered to 35°F, there is usually too much frost to melt during the off cycle. Therefore, a clock is installed to force the compressor to stay off long enough to defrost the coil.

If the box temperature is 33°F or below, there is no way the box is warm enough to air defrost. Therefore, supplemental electric strip heat or hot gas is needed for defrost.

Low-temperature Evaporator Defrost

Low-temperature evaporators require a time clock, controls, and a source of heat to melt their normal accumulation of frost. Also, because frost is produced easily when the coil temperature is below 0°F, the fin spacing must be wide enough to prevent frost bridging between fins for at least 4 to 6 hours of normal operation.

AC coils may have fin spacing of 15 fins per inch (fpi), whereas medium-temperature units operate at 10 fpi. However, freezer coil fin spacing should be no more than 7 fpi. The wider fin spacing slows the bridging of frost and eventual frost buildup (see Figure 2-16).

The most common defrost system for walk-in and reach-in freezer evaporators is electric resistance strip heaters. They are usually attached to coil fins at the air inlet side of the evaporator. The heaters and all the controls are preassembled at the factory, making it easier for the installers.

Hot gas defrost is primarily used in supermarket applications and ice machines because it is quick and efficient. During defrost, hot gas enters the evaporator downstream of the TEV. The hot refrigerant warms the tubing inside the evaporator, which is more effective than electric heaters that warm the fins outside the tubing. Installing a hot gas defrost system can be very labor intensive due to additional piping and valves. However, hot gas is more efficient because the compressor can generate the same amount of Btuh as electric heaters but with less electrical energy.

Defrost Operation of Freezers

The number of defrosts per day and the maximum length of defrost time depend on the conditions of operation and the location of the equipment.

EXAMPLE: 3

In the Washington, D.C., area, the high heat and humidity during the summer normally require four defrosts in a 24-hour period.

Under design conditions, an electric defrost will last for only about 15 to 20 minutes. However, occasional excessive frost will cause longer defrost times. If the defrost is too long, the clock has an adjustable

fail-safe setting that will automatically take the system out of defrost and put it back into refrigeration mode. The setting of the fail-safe varies depending on the climate where the system is located.

EXAMPLE: 4

Most technicians in the Washington, D.C., area set the fail-safe to 45 minutes.

Too many defrosts can be as bad as too few. Even in very humid climates, more than six defrosts a day may indicate a system problem that needs to be addressed. With too many defrosts, there is not enough time to properly freeze the product. Also, shorter defrosts may not fully defrost the evaporator. To verify complete defrosting, a technician should use a flashlight to check all sections of the evaporator. Remember, defrost heaters defrost frost, not ice. Once coil frost turns to ice, it has to be defrosted manually.

In hot, dry regions like Phoenix, Arizona, there is little humidity to turn to frost on freezer coils. Therefore, it is possible to use as few as two defrosts a day.

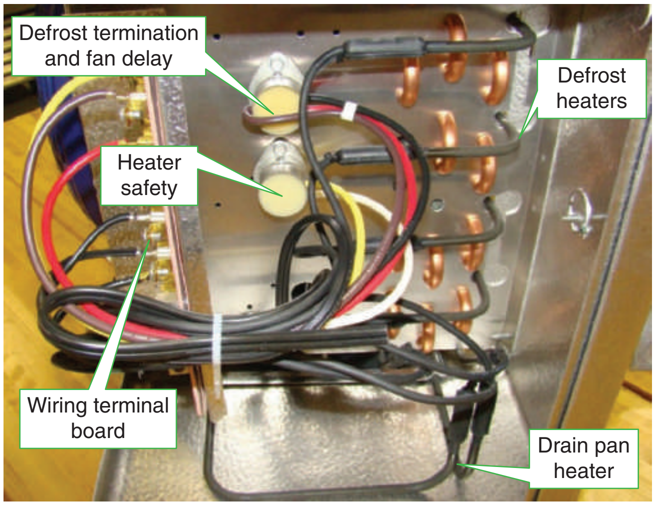
The freezer defrost sequence is as follows:

1. Defrost is initiated, or started, according to the time setting on the defrost clock.
2. The compressor and the evaporator fan(s) stop.
3. The electric heater (or hot gas) starts warming the coil.
4. When the coil reaches a temperature high enough to have melted all the frost, a temperature sensor, called the **defrost termination switch,** takes the coil out of defrost and returns it to refrigeration operation.
5. The compressor starts, but the fan(s) stay(s) off. The refrigerant now cooling the coil removes defrost heat and refreezes any remaining water droplets from defrost.
6. When the evaporator drops to approximately 25°F, the **fan delay switch** closes. The fans start and continue circulating air until the next defrost cycle.

NOTE: Usually the defrost termination and fan delay are combined into a single three-wire control designated by the letters DTFD (defrost termination/fan delay) (see Figure 2-17). The control has a common wire and two sets of contacts. One of the contacts is closed when warm, and the other set is closed when cold. The DTFD will be discussed in more detail later in this chapter.

The defrost cycle is also important for proper oil return. When the compressor is off, oil migrates to the coldest spot in the system, which, in a freezer, is usually the evaporator. During the freeze cycle, the cold oil thickens as it travels through the coil and tends to become trapped in the evaporator. Therefore, the heat during defrost warms the oil sufficiently to return it to the compressor on start-up.

FIGURE 2-17 Electric defrost heaters and controls on a freezer evaporator. *Photo by Dick Wirz.*



Freezer Defrost Clocks

Figure 2-18 is one of the more common 208- to 230-volt defrost clocks, the Paragon 8145-20. The face of the clock has the time of day on the outer ring. The black areas denote night from 6:00 P.M. to 6:00 A.M.

The screws on the face are defrost trip pins. The clock rotates slowly and continuously. When the tripper gets to the TIME pointer, the system is mechanically put into defrost. The clock in Figure 2-18 is set for four defrosts per day (6:00 A.M., noon, 6:00 P.M., and midnight).

The fail-safe setting is set on the center dial. The system is supposed to come out of defrost in response to the defrost termination temperature sensor in the evaporator. If it does not switch to refrigeration mode by the time the fail-safe time is reached, the clock will mechanically shift the contacts out of defrost and back into the freeze cycle. The clock in Figure 2-18 is set for a 45-minute fail-safe.

Setting the proper time of day, or manually turning the system into defrost, is accomplished by turning the center of the dial counterclockwise.

Freeze Cycle

On the clock in Figure 2-19, contacts 2 and 4 are closed, sending power to terminal 4 on the evaporator. Terminal 4 is connected to the freezer tstat solenoid and the evaporator fan.

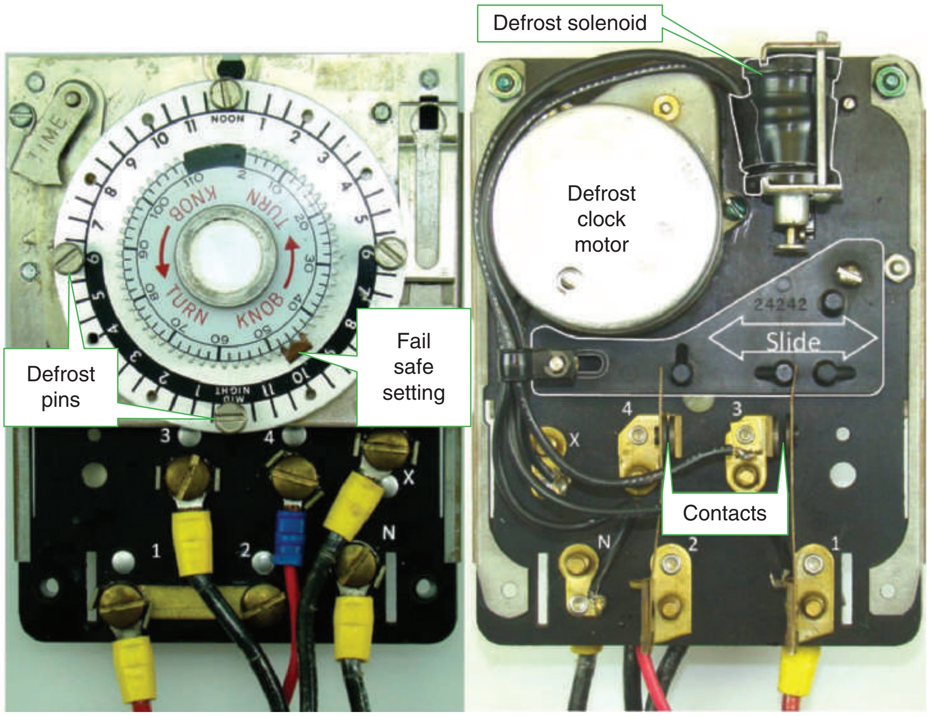
NOTE: N is used as the common wire.

Defrost Cycle

Defrost is time-initiated by the defrost clock. Following is the sequence of operation:

1. On the clock in Figure 2-20, contacts 2 and 4 are opened. This shuts off power to the tstat, solenoid, and fan.

FIGURE 2-18 **Paragon defrost time clock Model 8145-20.** *Photo by Dick Wirz.*



2. On the clock, contacts 1 and 3 are closed. This sends power to terminal 3 on the evaporator, energizing the defrost heater. When 3 on the clock is energized, it also sends power to one side of the defrost termination solenoid shown in the upper left corner of Figure 2-20. In an actual defrost timer, the solenoid is located behind the front panel of the clock, next to the clock motor (see Figure 2-18).

Defrost Termination

When the heaters warm up the evaporator to about 55°F, the defrost termination contacts close between **R** and **Brn** (brown) on the **DTFD** control (see Figure 2-21). This allows power to flow through the common wire from **N** through **X** and to the other side of the defrost solenoid. When energized, the defrost solenoid coil pulls a lever that moves the slide bar to the right. This mechanically changes the switch positions. Contacts 1 and 3 will open, and contacts 2 and 4 will close (see Figure 2-22).

The defrost clock runs continuously when the system is in freeze or defrost mode. If the defrost termination control does not bring the system out of defrost, the fail-safe switch will force the system back into freeze mode.

FIGURE 2-19 **Defrost clock in freeze cycle.** *Courtesy of Refrigeration Training Services.*

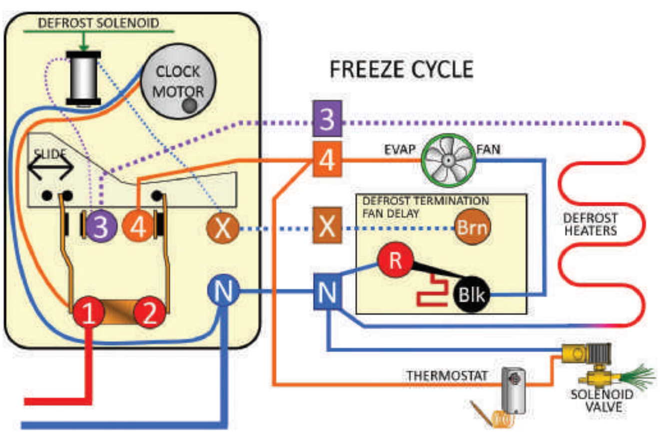
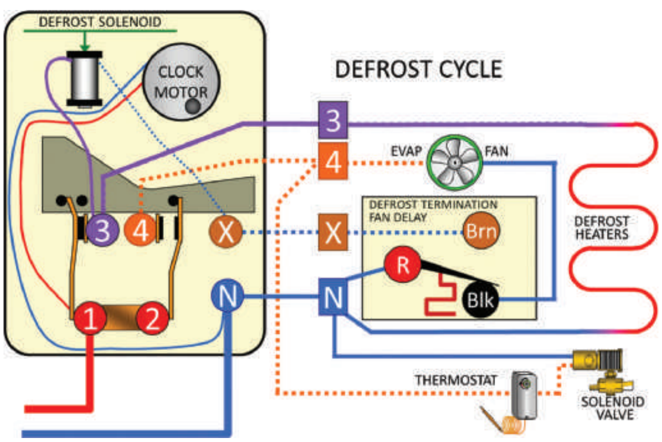


FIGURE 2-20 **Defrost clock in defrost cycle.** *Courtesy of Refrigeration Training Services.*



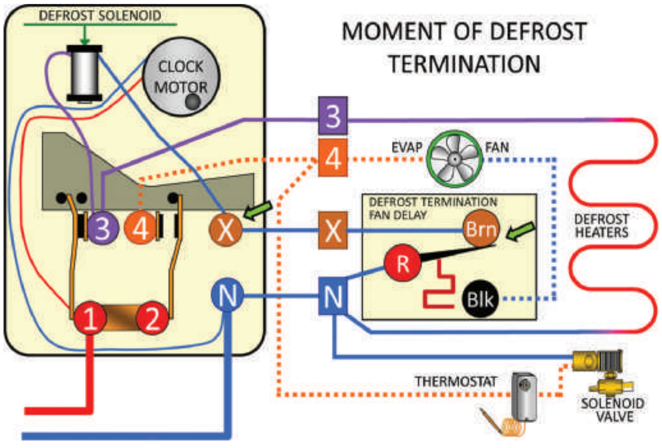


FIGURE 2-21 **Defrost clock at defrost termination.** *Courtesy of Refrigeration Training Services.*

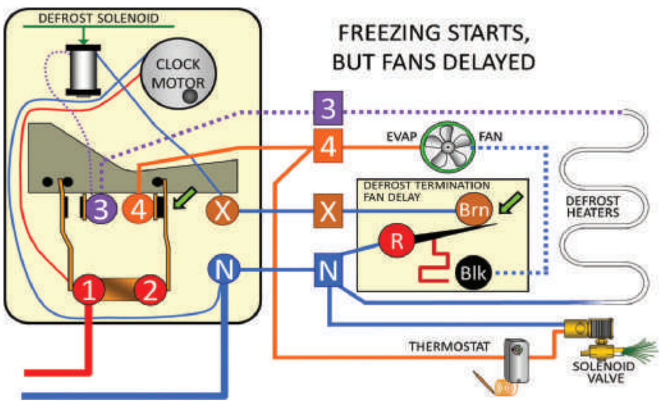


FIGURE 2-22 **Defrost clock returns to freeze cycle.** *Courtesy of Refrigeration Training Services.*

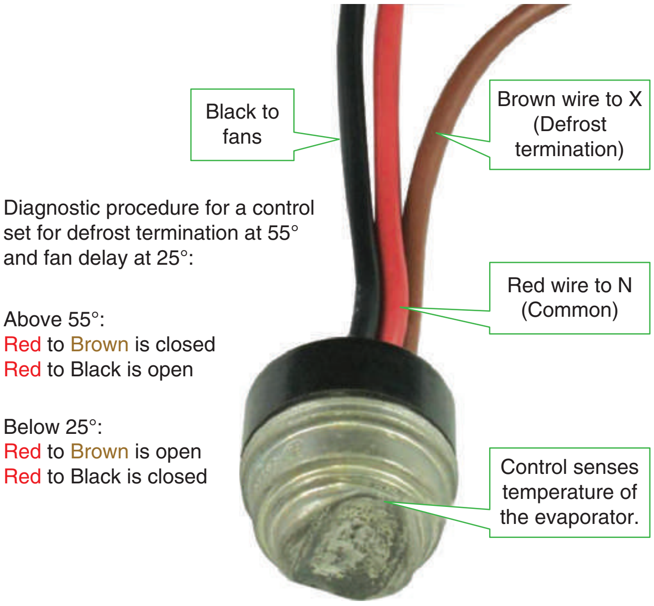
Return to Freeze Cycle

The closing of clock contacts 2 and 4 (see Figure 2-22) sends power to terminal 4 on the evaporator. This energizes the solenoid valve and one side of the evaporator fan.

Fan Delay

The evaporator fan stays off at the beginning of the freeze cycle because the fan delay contacts of the **DTFD** control are open between **R** and **Blk** (black) (see Figure 2-22). They will close when the evaporator cools down to **25**°F, delaying the fan until the evaporator is below freezing (see Figure 2-19). This ensures the heat from defrost is removed from the evaporator and the few droplets of water left after defrost are refrozen onto the evaporator fins. The fan delay control prevents both defrost heat and water droplets from being blown out into the box when the fan restarts. One indication of a bad fan delay would be icicles on the box ceiling and ice on the fan blades because closed contacts would allow the fan to start as soon as the unit is back in the freeze cycle.

FIGURE 2-23 **Three-wire defrost termination and fan delay.** *Photo by Dick Wirz.*



Check this type of DTFD control by putting it into another freezer until the temperature of the control is down to about 0°F. Then take it out and use an ohmmeter to measure continuity between the common wire and the wire that will go to the fan. Below 25°F, this circuit should be closed. As the control warms up, the contacts will open. At about 55°F, the contacts between the common wire and the wire that goes to the X terminal should close (see Figure 2-23).

When a warm freezer is starting up, the fans may seem to take a very long time to come on. In addition, the fans may cycle on and off a few times until the box temperature drops below 25°F. Some technicians jump out the control during start-up (see Figure 2-24).

Adjustable Defrost Termination

Some units have an adjustable defrost termination control mounted on the front of the evaporator coil, with the sensing bulb located in the evaporator compartment (Figure 2-25). The adjustable range to end defrost is between 60°F and 75°F depending on the control model. Although the defrost termination has some adjustment, the fan delay is usually fixed at about 25°F. However, the fan delay has an adjustment screw behind the control cover next to the duration adjustment. Each clockwise turn of the screw increases the fan delay by 3°F. The screw should not be adjusted more than four turns. Making this adjustment also increases the defrost temperature setting by a similar amount.

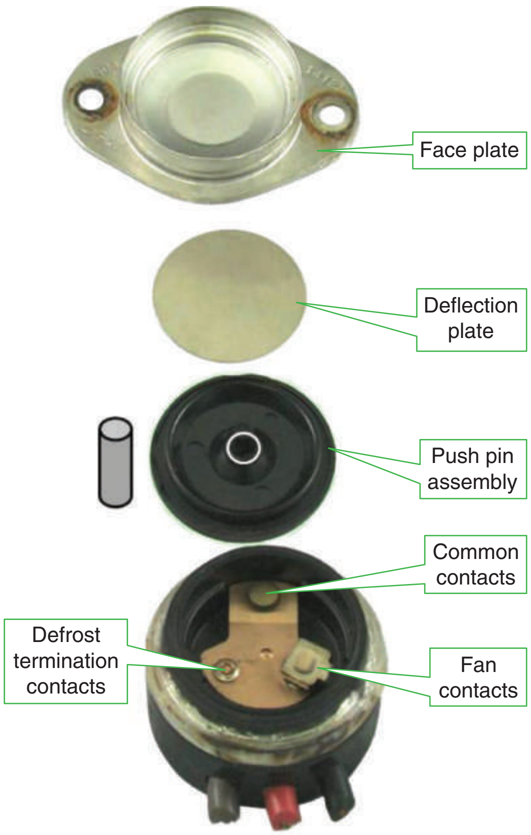


FIGURE 2-24 **Exploded view of DTFD.** *Photo by Dick Wirz.*

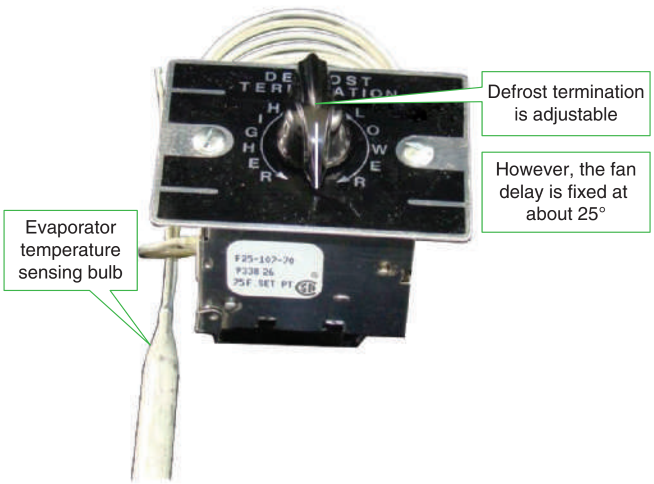


FIGURE 2-25 **Adjustable defrost termination control.** *Photo by Dick Wirz.*

Heater Safety

The heater safety control will break the circuit to the defrost heaters and pan heater if the evaporator overheats. The factory setting for most walk-ins is 70°F cut-out and 40°F cut-in.

Electronic Time Clocks

In the 1990s, a company called Grasslin came out with an electronic version of the old electro-mechanical time clocks (Figure 2-26). It was more accurate and easier to adjust, had battery backup available, and—most importantly—one clock could replace most of the older clocks. To make it easy to replace the Paragon with the Grasslin, the new company used a numbering system similar to Paragon. The idea caught on, and Paragon (later called Invensys) finally joined the movement about 5 years later with their own version (Figure 2-27).

Demand Defrost

In standard low-temperature refrigeration systems, the defrost clocks are set for a definite number of defrosts per day. Based only on time, the clock forces the unit to

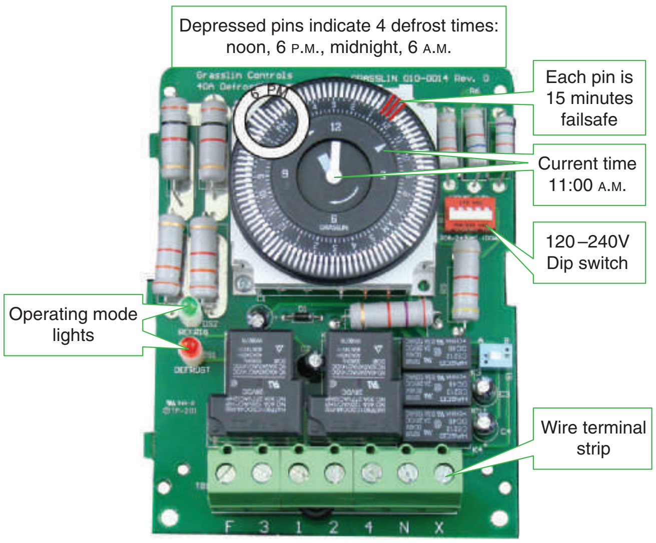


FIGURE 2-26 **Grasslin electronic defrost time clock.** *Photo by Dick Wirz.*

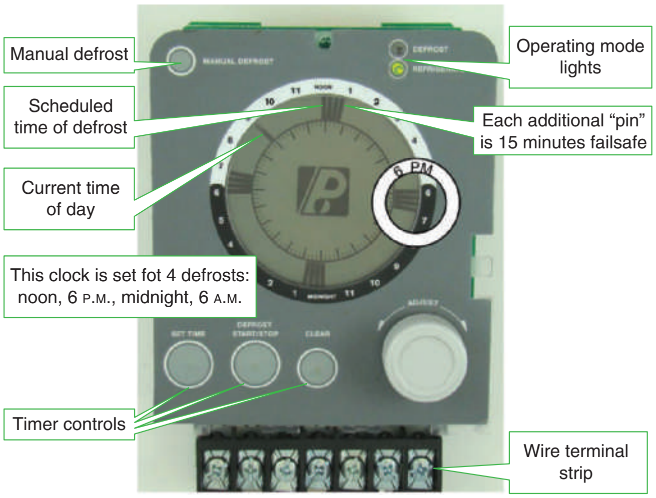


FIGURE 2-27 **Paragon electronic defrost time clock.** *Photo by Dick Wirz.*

FIGURE 2-28 **Pressure transducer.** *Photo by Dick Wirz.*

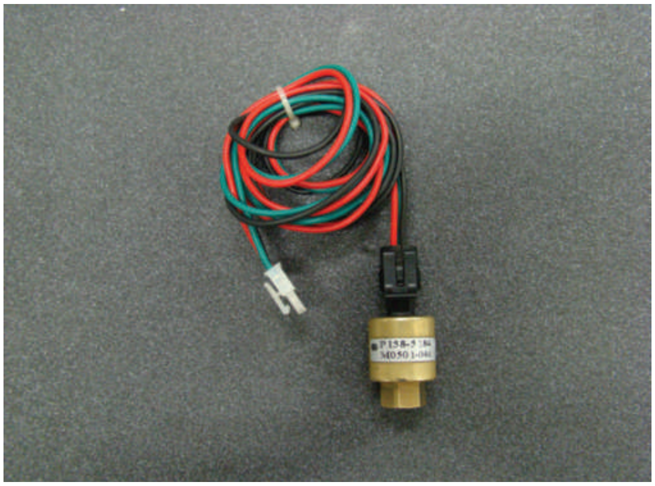


FIGURE 2-29 **Thermistors for temperature inputs.** *Photo by Dick Wirz.*

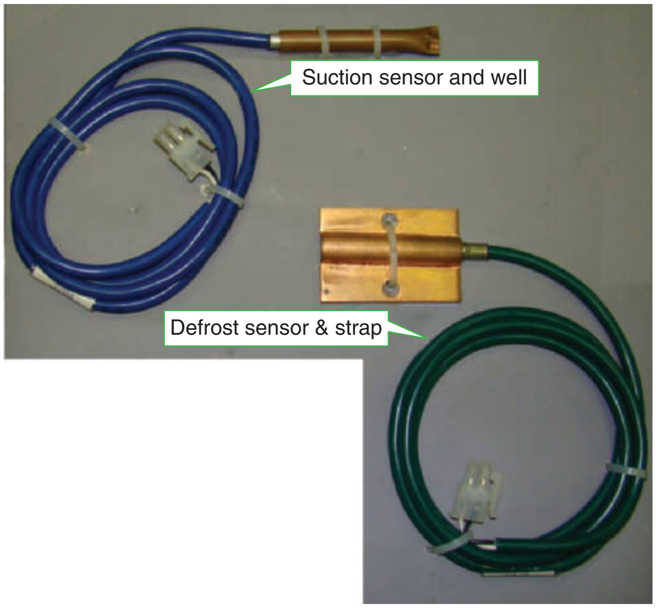


FIGURE 2-30 **Beacon controller mounted in evaporator.** *Courtesy of Heatcraft Worldwide Refrigeration.*

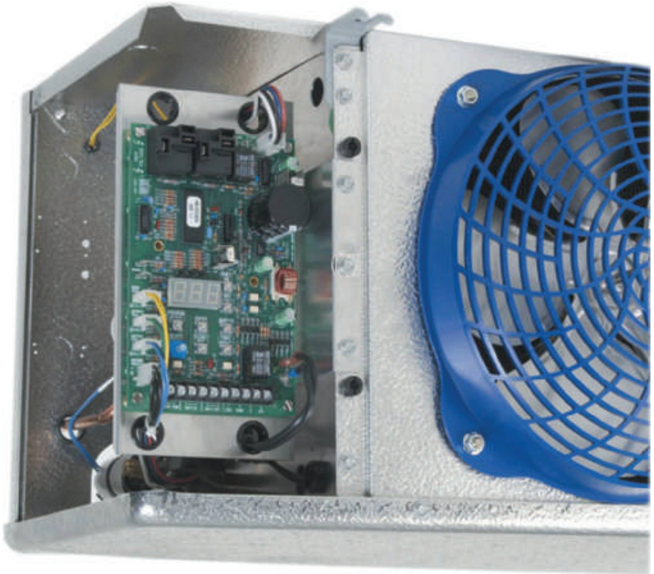


FIGURE 2-31 **Beacon II remote Smart Controller.** *Photo by Dick Wirz.*

defrost whether the evaporator has a substantial frost buildup or not. In the more advanced electronics-based refrigeration control systems, one of the many features is defrosting the coil only when needed. Because defrost is based on demand, it is sometimes referred to as demand defrost. Based on electronic inputs of pressure (using transducers; see Figure 2-28), temperature (using thermistors; see Figure 2-29), run cycle times (the amount of time for each cycle from the start of one cycle to the start of the next cycle), and other data, the controller determines when and if defrost is necessary. Heatcraft claims its factory-installed Beacon II (Figure 2-30) and aftermarket Smart Defrost Kit (Figure 2-31) can easily reduce defrost requirements by 40 percent. Fewer defrosts means less energy consumption for defrosting as well as for the refrigeration needed to remove the heat added to the coil during defrost. In addition, box and product temperatures are more stable.

SUMMARY

The evaporator's function is to absorb heat from the refrigerated space. There is a difference in the evaporator temperature for different applications from AC to very-low-temperature freezing.

TD is a function of the difference between air entering the evaporator and the temperature of the refrigerant inside the evaporator tubing. The greater the TD, the more moisture is removed from the air by the evaporator, thus lowering the relative humidity.

There are several types of evaporators, but the most common is the fan coil made of copper tubing with aluminum fins.

Three terms used to describe evaporator heat are the following:

- **Latent heat** is the heat absorbed in the evaporator by changing the state of the refrigerant, without a change in the temperature of the refrigerant.
- **Sensible heat** is the heat absorbed in the evaporator after all refrigerant has been evaporated. There is a change in refrigerant temperature as sensible heat is absorbed.
- **Superheat** is a measurement of the sensible heat after all the refrigerant has boiled off. It is an indication of the efficiency of the coil and whether the evaporator is starving or flooding.

Evaporators must have some type of defrost if the coil temperature is below freezing. In commercial refrigeration, all coils develop frost. They may only need some time while the compressor is off for the air in the box to defrost them, or they may need supplemental electric or hot gas to remove the frost. Electronic defrost clocks, temperature thermistors, pressure transducers, and electronic controllers have made refrigeration operation more precise and energy efficient.

REVIEW QUESTIONS

1. What is considered to be the "evaporator temperature"?
   a. The temperature of the refrigerant inside the evaporator tubing
   b. The temperature of the air entering the evaporator
   c. The temperature of the air leaving the evaporator
2. How do you calculate evaporator temperature from the suction pressure?
   a. Use a thermometer to check the air temperature
   b. Use a P/T chart
   c. Use an incline manometer to measure the pressure difference
3. How is evaporator TD calculated for a walk-in cooler?
   a. Subtract the entering air temperature from the leaving air
   b. Find the head pressure and add the box temperature
   c. Subtract the SST from the box temperature
4. What is hot pull-down?
   a. When the evaporator is subject to higher temperatures and loads than under normal operating conditions
   b. The defrost period of a freezer
   c. The head pressure a system experiences during pump-down
5. During hot pull-down, what is the evaporator experiencing?
   a. Flooding from the TEV being wide open
   b. Starving because the refrigerant is boiling off quickly
   c. Excessive frost because the evaporator is very cold
6. What is the approximate humidity in a walk-in refrigerator with a 10°F TD evaporator?
   a. 50 percent
   b. 65 percent
   c. 85 percent
7. As TD increases, how does it affect box humidity?
   a. Increases humidity
   b. Decreases humidity
   c. Humidity stays the same
8. If airflow across an evaporator is decreased, what effect does it have on evaporator temperatures and suction pressure?
   a. Evaporator temperature increases, and suction pressure increases
   b. Evaporator temperature decreases, but suction pressure increases
   c. Evaporator temperature and suction pressure both decrease

9. Why are multiple circuits used on larger evaporator coils?
   a. They provide less pressure drop than a long single-circuit evaporator.
   b. They cost less to produce than a single-circuit evaporator.
   c. They allow use of multiple TEVs on one evaporator.
10. If the suction pressure of an R22 unit is 55 psig, what is the approximate evaporator temperature? Refer to Appendix P/T chart.
   a. 25°F
   b. 30°F
   c. 35°F
11. If the suction pressure of an R404A unit is 21 psig, what is the approximate evaporator temperature? Refer to Appendix P/T chart.
   a. −14°F
   b. −4°F
   c. +14°F
12. How do you determine the evaporator superheat of a refrigeration system?
   a. Subtract head pressure from suction pressure
   b. Subtract evaporator temperature from the temperature of the suction line at the expansion valve bulb
   c. Add the evaporator temperature to the suction line temperature
13. A −10°F walk-in freezer using R404A has a suction pressure of 15 psig. The suction line temperature at the TEV bulb is −20°F. What is the evaporator superheat? Refer to Appendix P/T chart.
   a. 2°F
   b. 10°F
   c. 20°F
14. A superheat below 5°F indicates the evaporator is experiencing which of the following conditions?
   a. Flooding
   b. Normal
   c. Starving
15. Within how many degrees of the design box temperature can you check evaporator superheat?
   a. Any temperature is good for checking superheat.
   b. 25°F
   c. 5°F
16. What are the two main categories of evaporator problems?
   a. Airflow and refrigerant problems
   b. Evaporator choice and installation problems
   c. Evaporator sizing and defrosting problems
17. Why is it necessary for the fin spacing in a freezer evaporator to be wide?
   a. Frost buildup will not occur as fast if the fin spacing is wide.
   b. It helps to move more air because more space means less resistance.
   c. Defrost heat needs to get through the fin openings.
18. What is the basic sequence of operation at the beginning of a freezer defrost?
   a. Compressor shuts off, evaporator fans run, and heaters come on
   b. Evaporator fans shut off, compressor shuts off, and heaters come on
   c. Fans and heaters are delayed until the compressor cycles off
19. Which freezer defrost system is more efficient, hot gas or electric? Why?
   a. Hot gas, because it quickly warms tubing inside the evaporator
   b. Electric, because it is attached to the fins where frost forms
   c. Neither—they are equally efficient.
20. If a walk-in is operating at a box temperature of 35°F, what type of defrost should it have?
   a. Heated defrost: a defrost clock and electric heat or hot gas
   b. Planned defrost: a defrost clock only
   c. Random defrost: no clock or heaters, just off-cycle defrost with tstat
21. What is an effective way to check a DTFD control?
   a. Clip the common wire on the control and see if it goes into defrost
   b. Replace it with a new one from the factory and see if doing so corrects the problem
   c. Freeze the control in another freezer, then measure the continuity of the contacts with an ohmmeter

CONDENSERS

3

CHAPTER OVERVIEW

This chapter begins with an explanation of what a condenser does and how it is designed to accomplish its functions. The concepts of condensing temperature and condenser split are introduced to help explain the performance of a condenser.

The practice of subcooling measurement is shown as a reliable means of determining condenser performance and system charge. Understanding these key concepts and conditions is essential to solving the complex system troubleshooting problems in later chapters.

Different types of condensers are described, as well as their operation and proper maintenance. Because most commercial refrigeration remote condensers have to operate in cold ambient conditions, head pressure controls are covered in detail.

OBJECTIVES

After completing this chapter, you should be able to

- Describe the functions of a condenser
- Explain how a condenser operates
- Describe the three phases of a condenser
- Describe flash gas
- Describe condenser split
- Describe air-cooled condenser maintenance
- Describe low-ambient controls
- Describe condenser flooding
- Explain floating head pressure
- Describe types of water-cooled condensers
- Explain flow rates of water-cooled condensers
- Describe condensing temperatures of water-cooled condensers
- Describe water-cooled condenser maintenance

KEY TERMS

Mirror image
Discharge gas or hot gas
Superheated vapor
Condensing temperature
Flash gas
Condenser split
Compression ratios
Hunt
Differential
Variable frequency drive (VFD)
Electronically commutated motor (ECM)
Prevailing winds
Floating head pressure
Balanced port
Tube-in-tube
Shell-and-tube
Water-regulating valve (WRV)
Wastewater systems
Microchannel coil

FUNCTIONS OF THE CONDENSER

Condensers are the **mirror image** of evaporators. Whereas the function of the evaporator is to absorb heat from the refrigerated space, the condenser must reject that heat outside the refrigerated space.

In addition to evaporator heat and suction line superheat, the condenser must also reject the heat of compression and motor heat picked up by the suction vapor on its way through the compressor. This additional heat can be as much as one-third more than that absorbed by the evaporator. For example, a 36,000-Btuh system must reject about 48,000 Btuh of heat. To accomplish this, there must be more effective condensing coil surface than evaporator surface. Airflow through condensers is also an important factor. AC air handlers move about 400 cubic feet per minute per ton (cfm/ton), whereas condenser fans move about 1,000 cfm/ton. Most condenser coils are designed to have airflow across them of about 1,000 cfm/ton of refrigeration. This is two and a half times the airflow of most AC evaporators, which is 400 cfm/ton.

CONDENSER OPERATION

Those new to the trade may find it difficult to understand how the system could absorb so much heat into the evaporator yet still have a cold suction line. This strange condition is due to the fact that the heat absorbed is almost entirely latent heat. This type of heat does not change the temperature of the cool suction vapor. Latent heat is trapped inside the refrigerant vapor as the liquid droplets boil off in the evaporator. The temperature of this vapor remains the same throughout the evaporator. After the refrigerant has become fully saturated with latent heat, any additional heat (superheat) is sensible heat and is measurable with a thermometer.

Before the evaporator can reuse the refrigerant, two things must happen in the condenser:

1. The heat in the suction vapor must be removed.
2. The vapor must change to liquid before entering the metering device.

When a vapor condenses, it releases a tremendous amount of latent heat as a result of its change of state from a vapor to a liquid. In theory, the 35°F vapor in the suction line could condense if it were recooled sufficiently. However, in reality, the suction vapor is almost always exposed to temperatures higher than itself; therefore, it is nearly impossible to discharge the heat contained in the cool suction vapor into an ambient that is warmer.

Assuming an outdoor temperature of 95°F, how can a 35°F vapor be condensed back into a liquid? Somehow, the temperature of this vapor must be raised high enough that 95°F ambient air is cool enough to condense the vapor.

According to the laws of thermodynamics, the temperature of a vapor can be increased by raising its pressure. This process is accomplished in refrigeration with the help of a compressor. The mechanical operation of compression is covered in detail in Chapter 4, "Compressors." This chapter concentrates on the pressure–temperature relationship of compression as it aids the process of heat removal, eventually returning suction vapor to liquid.

EXAMPLE: 1

R22 vapor at 25°F and 49 psig is compressed until it reaches 185 psig. Based on the pressure/temperature (P/T) chart, the higher-pressure-vapor temperature is now 96°F. Theoretically, if the vapor is cooled by one degree, down to 95°F, it will no longer be totally saturated and should begin condensing back into a liquid.

With only a one-degree difference between the vapor and the ambient air, the cooling process is fairly slow. In Example 2, the difference between the temperature of the warm vapor in the condenser and the temperature of the ambient air is increased to 30°F. The greater the temperature difference between two substances, the faster the transfer of heat.

EXAMPLE: 2

R22 vapor at 25°F and 49 psig is compressed until it reaches 278 psig. At this pressure, the saturated vapor is 125°F and will condense much more quickly when cooled by 95°F ambient air.

The two preceding examples were theoretical and did not take into account the addition of several other sources of sensible heat that are part of an actual compression process. However, the intent is to show that increasing pressure increases heat and that temperature difference affects the rate of heat transfer.

THREE PHASES OF THE CONDENSER

Following are three phases of the condenser:

1. De-superheat
2. Condense
3. Subcool

De-superheat Phase

The **discharge gas,** or **hot gas,** leaving the compressor contains much more heat than it did when it entered the compressor and is at a much higher temperature.

As stated earlier, the suction vapor picks up motor heat and the heat of compression as it undergoes the compression process. The hot gas is called **superheated vapor.** Just like in the evaporator, if the temperature of a vapor is above its saturation temperature, it is superheated.

EXAMPLE: 3

Refer to Figure 3-1. The temperature of the hot gas leaving the compressor is 175°F, but the condensing temperature of R22 at 278 psig is only 125°F. The vapor must be cooled by 50°F in the first part of the condenser before condensation can begin.

Condensing Phase

The **condensing temperature** is the temperature at which a vapor returns to a liquid state.

Condensing is a process, not an action that happens all at once. Condensing starts when the condensing temperature is reached and continues throughout most of the condensing coil until the vapor has fully condensed into a liquid. At this point, the refrigerant is a saturated liquid at a temperature corresponding to the condensing pressure listed on a P/T chart.

Subcooling Phase

Cooling the saturated liquid below the condensing temperature is known as subcooling. The amount of subcooling is determined by subtracting the temperature of the liquid leaving the condenser from the condensing temperature.

EXAMPLE: 4

Refer to Figure 3-1. The condensing temperature (and saturation temperature) of R22 at 278 psig is 125°F. The liquid line temperature at the condenser outlet is 115°F.

- 125°F condensing temperature − 115°F liquid line temperature = 10°F subcooling

Why check for subcooling? By knowing the amount of subcooling, a technician can tell a lot about the system they are troubleshooting. For instance:

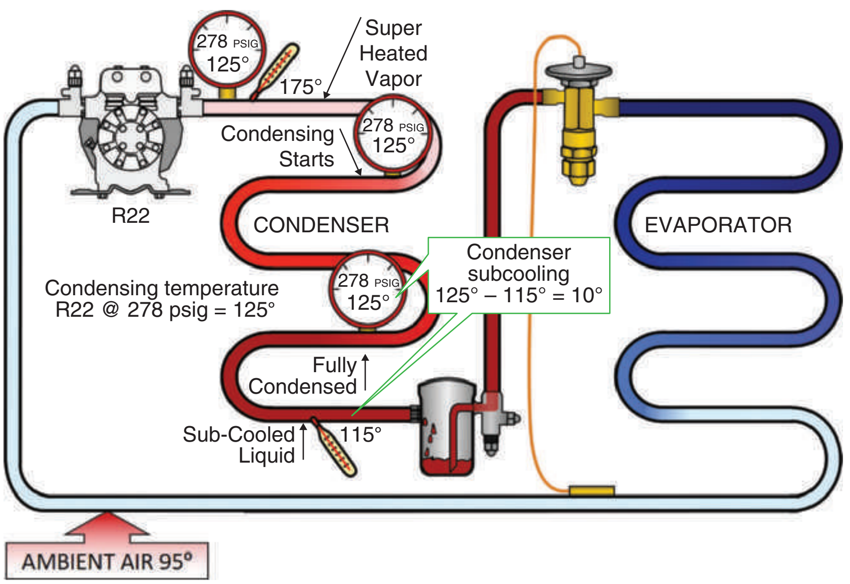
- No subcooling (0°F) means there is not enough refrigerant in the system to condense into a liquid.
- Low subcooling (less than 5°F) may mean there is flashing of refrigerant before it reaches the metering device.
- High subcooling (greater than 20°F) may mean there is too much refrigerant in the system.

NOTE: Although many systems operate properly between 5°F and 20°F subcooling, it is dangerous to make a diagnosis based entirely on measurements outside this range. Other factors should be considered, and they are covered in Chapter 7, "Refrigeration System Troubleshooting."

CAUTION

If you cannot measure any subcooling at the condenser outlet, but you are fairly certain the unit has enough refrigerant, then check the temperature of the liquid line leaving the receiver. Some manufacturers (Heatcraft, for one) use the condensing unit receiver as the subcooler rather than adding tubing to the condenser coil. ●

FIGURE 3-1 **Phases of a condenser.** *Courtesy of Refrigeration Training Services.*



FLASH GAS

Flash gas is liquid refrigerant boiling off into vapor. Flashing of saturated liquid occurs if its temperature rises or if its pressure is lowered.

EXAMPLE: 5

Refer to Figure 3-1. Liquid R22 at 278 psig is saturated at 125°F. It will flash if:

1. Its temperature is increased by one degree to 126°F.
2. Its pressure is lowered to 277 psig.

Pressure drop is the primary cause of flash gas and is a desirable event when the refrigerant passes through the metering device. The refrigerant drops from the liquid line temperature to the evaporator temperature as it flashes off.

However, flashing in the liquid line before the refrigerant enters the metering device can cause the device to behave erratically. This flash gas can sometimes be seen as bubbles in the sight glass, a good reason to install the sight glass just before the thermostatic expansion valve (TEV).

NOTE: Bubbles in the sight glass caused by low refrigerant charge or pressure drop may be corrected simply by adding refrigerant. However, bubbles will form in the sight glass during low load conditions and may occur when using blended refrigerants. With these conditions, adding refrigerant will cause more problems than it will solve.

Using Subcooling to Prevent Flash Gas

If the liquid in the previous example had a temperature drop equivalent to the pressure drop, then the liquid would have remained totally saturated, or in a liquid state. Therefore, subcooling a liquid can prevent it from flashing from a pressure drop. The amount of subcooling determines how much pressure drop the liquid can endure before it flashes into a vapor.

EXAMPLE: 6

If R22 at 278 psig drops to 277 psig, it will start flashing at 125°F.

If the liquid is subcooled to 120°F, it will still be in a liquid state if the pressure drops to 260 psig.

Proper liquid line pipe sizing is important in preventing a decrease in liquid pressure on long piping runs. Pressure drop is the result of friction between the inside of the pipe and the fluid flow. If the pipe size is too small or the length of run is too long, the pressure drop will increase. This is similar to rolling friction on the wheels of a car. If a car is coasting on level ground, the friction will slow the car, using up its forward momentum.

TROT

SUBCOOLING

Subcooling in most refrigeration systems is 10°F.

Vertical lift, or the opposing pressure of the weight of liquid being pushed straight up, results in a large pressure drop. A 3/8-inch vertical liquid line will experience a pressure drop of about 1/2 psig per foot of rise.

EXAMPLE: 7

A walk-in refrigerator is located in a third-floor cafeteria. Its condensing unit is located on the ground 30 feet below. The 3/8-inch liquid line will experience a 1/2-psig pressure drop per foot of vertical rise. The 15-pound pressure drop (30 feet × 0.5 psig/ft = 15 psig) on an R22 system will require about 4°F subcooling to prevent the liquid refrigerant from flashing before it enters the ceiling space (Figure 3-2).

Following are the calculations for the 4°F subcooling needed to prevent flashing in the liquid line riser piping in Figure 3-2.

According to the P/T chart, R22 at 278 psig will flash above its saturation temperature of 125°F. The 15-psig pressure drop from the liquid line riser will reduce the condensing pressure from 278 to 263 psig. The saturated temperature of R22 at 263 psig is about 121°F. Therefore, the condensing unit needs to subcool the liquid at least 4°F (125°F − 121°F) to prevent the liquid from flashing before it enters the ceiling space.

EXAMPLE: 8

In the same example in Figure 3-2, the liquid line turns horizontally into the attic. There is no pressure drop, but now the liquid line is exposed to heat in the attic space. The heat in the attic raises the liquid temperature an additional 5°F. Liquid will flash off as soon as the temperature rises above its condensing, or saturation, temperature. Therefore, to prevent flashing, there will have to be one degree of subcooling for every degree of heat added to the liquid above its condensing temperature. If the attic heat adds 5°F to the heat of the liquid, it will need 5°F of subcooling to prevent flashing.

The units in the previous two examples will need at least a total of 9°F of subcooling to prevent flashing before the liquid enters the TEV. To increase the subcooling, simply add refrigerant. Most split systems are designed to have about 10°F to 15°F of subcooling when properly charged. Detailed charging procedures will be covered in Chapter 9, "Retrofitting, Recovery, Evacuation, and Charging."

NOTE: A sight glass and liquid line pressure tap near the TEV would help the technician make sure there is no flashing at the TEV. Also, insulating the liquid line in the ceiling space may help prevent some of the attic heat from entering the liquid line. In addition, a heat exchanger in the suction line near the TEV will cool the liquid line and return any vapor to a liquid.

FIGURE 3-2 **Subcooling is required for pressure drop and added heat.** *Courtesy of Refrigeration Training Services.*

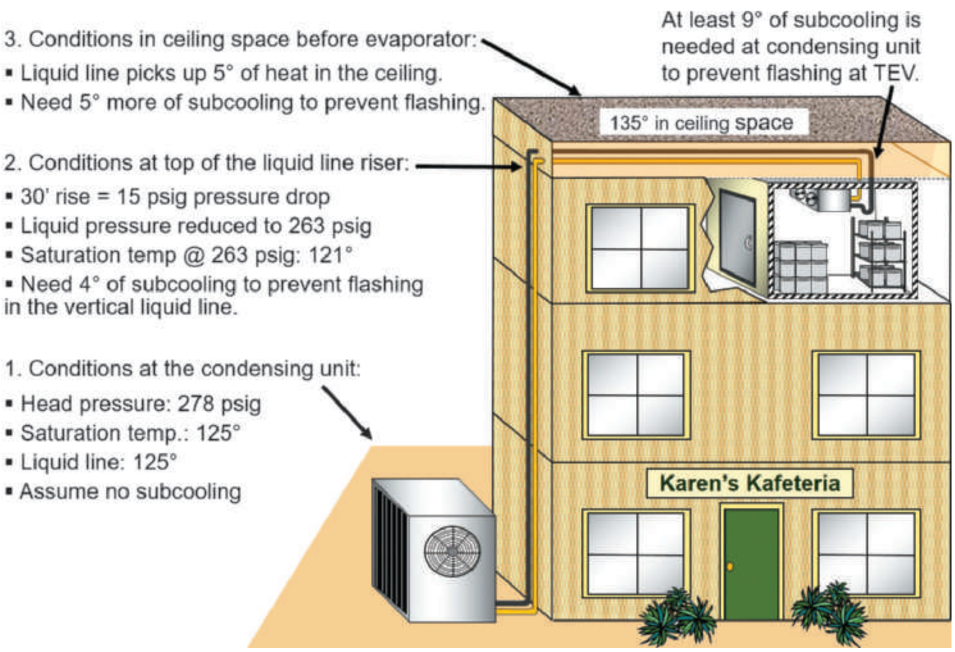
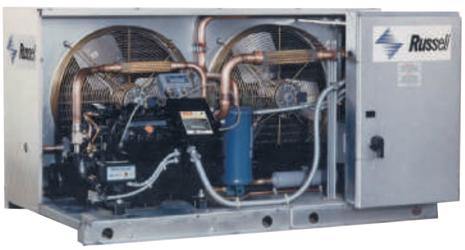


FIGURE 3-3 **Different condenser splits for different applications.** *Courtesy of Master-Bilt Products, Russell Heat Transfer Products Group, Heatcraft Worldwide Refrigeration, and York.*

Master Bilt medium temp 30° split



Russell freezer 25° split

Heatcraft remote 10° to 30° split

York high efficiency 20° split

TROT

CONDENSER SPLIT

Most CSs are designed for 30°F at a 95°F ambient temperature.

This applies to standard medium-temperature refrigeration condensing units and AC systems 10 seer and lower. Manufacturers have determined this split is a good balance between the cost of production and the cost of operation. However, high-efficiency units and freezers will have a CS closer to 20. See examples in Figure 3-3 ●

CONDENSER SPLIT

Condenser split (CS) is the temperature difference between a unit's condensing temperature and the temperature of the ambient air entering the condenser.

EXAMPLE: 9

If the condensing temperature of the refrigerant is 125°F and the ambient is 95°F, the CS is 30°F (125°F – 95°F = 30°F).

The system manufacturer determines the CS of a unit at a given ambient temperature. Many newer microchannel units are designed with a single size condenser and platform that can accommodate several different size compressors. Depending on the application, the CS may be 30ºF if a 2-hp compressor is used but closer to 20ºF for a 1-hp. One size condenser may be cost effective for the manufacturer, but the spec sheets will not have the CS listed. If the technician does not know the design CS of the unit, it may make diagnosis a little more difficult.

NOTE: The CS will vary slightly with ambient temperatures and evaporator loads.

EXAMPLE: 10

Consider a unit designed for a CS of 30°F at 95°F ambient:

- At a 70°F ambient, the CS could drop to about 25°F. A condenser is more efficient at temperatures below its maximum design conditions.
- Low evaporator loads do not require as much CS. The less heat absorbed by the evaporator, the less heat there is to be rejected by the condenser, and the lower the CS needed to reject that heat.
- High evaporator loads (such as during hot pull-down) will require higher CS to reject the additional heat picked up in the evaporator.

A lower split means a more energy-efficient system. The compressor does not have to work as hard (using less power) because the condensing temperature and pressure are lower.

Manufacturers can lower the CS by simply making the condensers larger. However, there are two reasons that all units do not have large condensers:

- The cost of the unit is higher because of increased production costs.
- Larger condensers require more space, which limits where the units can be located.

Fortunately, cost and size are not always factors. Following are several instances where the cost of a larger condenser is justified:

- High-efficiency AC units

The 13-SEER units have a CS of 20°F at a 95°F ambient.

- Freezer condensers

Freezer compressors are exposed to high **compression ratios** because they operate at very low suction pressures. This ratio can be lowered if the CS is lowered. Most low-temperature compressors have a 20°F to 25°F CS. (Compression ratios are discussed in detail in Chapter 4, "Compressors.")

- Remote condensers

Manufacturers of remote condensers justify the cost of larger condensers because lower CSs can lower the total horsepower requirements of a system. This reduces not only the initial cost of the total equipment package but also the customer's operating costs. The manufacturers of remote condensers offer a range of optional CSs as low as 10°F. However, the majority of remote condensers are the standard 30°F split.

EXAMPLE: 11

A supermarket may require a compressor rack with three 40-hp compressors if the CS is 30°F. Using a larger condenser can lower the split to 10°F. The lower CS may allow the same box load to be handled by only three 30-hp compressors. This results in savings of 25 percent in equipment costs and similar savings in operation. (NOTE: This is just an example; actual figures vary.)

CLEANING AND MAINTAINING AIR-COOLED CONDENSERS

A dirty condenser prevents the rejection of heat from the condenser and results in higher condensing pressures and temperatures. A condenser may look clean because the fins do not have dust or dirt on them. However, the only way a technician can be sure a condenser is clean all the way through is to clean it themselves. The technician should use a pump sprayer to soak the condenser with a good cleaning solution. On outdoor units, use as much water as possible to flush out the condenser. If possible, use a hose connected to a water faucet or hose bib to get the water pressure and volume needed for a good cleaning. Cooking grease buildup on condenser fins may require hot water, or even steam cleaning, to remove the deposits.

Clean the condenser fan blades to make sure they are moving the proper air quantities. Dirty fan blades move less air, raising the condensing pressures.

Air-cooled condensers inside the customer's building, especially kitchens, present special problems. A technician must try to not interfere with the customer's operation, make a mess in their work area, or damage their equipment with chemicals.

The technician should place towels around the base of the condensing unit to prevent water and cleaner from dripping down the side of the reach-in. Some cleaners can streak the box's metal surface, especially aluminum. The technician should be prepared to go through a lot of towels and rags.

Two products available on the Internet can help reduce the mess of coil cleaning: CoilPod and CoilBoss.

They cover the unit to trap the spray and dust yet provide access for a pressure hose and a wet–dry vacuum to clean the coil.

REALITY CHECK 1

Some equipment is so inaccessible that it must be moved outside for proper cleaning. If the unit cannot be moved, you may need to cut the condensing unit loose and take it outside. All Environmental Protection Agency (EPA) guidelines for recovery must be observed. •

Small portable steam cleaning machines can also be used to clean condensers. The high-temperature steam is very effective in melting accumulated cooking grease, yet it uses very little water. In addition, the use of a steam cleaner cuts down on the need for harsh cleaning chemicals.

GOOD BUSINESS TIP: **Proper cleaning can be very time consuming and expensive. Give your customer a quote first; they may choose to try cleaning the units themselves. After their first attempt, most will be happy to pay you to clean their equipment the next time.**

GOOD BUSINESS TIP: **When the customer is aware of the expense involved in cleaning, they may be more receptive to a quote on a maintenance contract. Periodic maintenance is much easier and less expensive than major cleanings as necessary. Also, a breakdown due to a dirty condenser has the added expense of lost product and the customer's inconvenience of working without the piece of refrigeration.**

Coil Cleaners

Use an alkaline (not acid) cleaner that will handle both the dirt and the grease found on most refrigeration equipment condensers. Two popular choices are Triple "D" by DiversiTech and CalClean by Nu-Calgon (Figure 3-4). These cleaners are concentrates and must be properly mixed at a ratio of one part cleaner to six parts water. The undiluted cleaner does not clean well. It would be like trying to clean your car with car wash soap without mixing it with a bucket of water first.

Another important tip is to allow enough time for the cleaner to work before rinsing—usually about 5 to 10 minutes.

Do not use foaming cleaners. The foaming action is hydrogen gas released as the chemical reacts with the aluminum, not with dirt or grease. They do not clean better than nonfoaming cleaners, they eat away the aluminum fins, and they etch the aluminum so that dirt and grease collects faster than it would on the original smooth aluminum surface.

Acid cleaners are good only for removing saltwater spray or drywall dust residue. Acid will not clean grease off a condenser coil.

Always wear eye protection and gloves when using chemicals of any kind. Use a mask or breathing apparatus if the cleaner you are using gives off any fumes.

Maintenance Inspections

Once the equipment is thoroughly cleaned and the customer is on a periodic maintenance schedule, the technician should install a filter on every indoor condensing unit. This will make inspections easier and faster because the filters are changed without having to reclean each condenser (Figure 3-5).

NOTE: **Condenser fans cannot handle much resistance to airflow. They will slow down, causing the head pressure to rise. To prevent this, use the inexpensive type of fiberglass filter material found in 1-inch disposable furnace filters. It is sold by the roll and can be cut to the size needed.**

FIGURE 3-4 **CalClean and Triple "D" coil cleaners.** *Photos by Dick Wirz.*

FIGURE 3-5 **Filters on condensers.** *Photos by Dick Wirz.*

Metal mesh condenser air filter on ice machine

1" fiberglass material allows good airflow

Fiberglass air filter on reach-in condenser

This filter material has wide spaces between the fibers to allow air to pass but will collect a lot of dust and grease. Hang it on the back of the condenser using two S-hooks fashioned from a piece of wire coat hanger.

Make sure the inspection intervals are frequent enough to prevent a heavy buildup on the filters. Some customers may require monthly inspections of filters on condensers in one section of their business, like the cooking area or a loading dock, whereas the rest of the unit filters may need to be changed only every 3 months.

Ice machine manufacturers have had fewer service problems since they began installing filters on their condensers. They usually use a thin, but dense, mesh of plastic or aluminum. To overcome the air resistance of these types of filters, the manufacturers had to upgrade to larger condenser fan motors.

LOW-AMBIENT CONTROLS FOR AIR-COOLED CONDENSERS

Most standard condensing units are designed to operate satisfactorily in ambient conditions between 60°F and 100°F. Below 60°F, the condensing pressure is too low for the metering device to operate properly. Standard expansion valves require a minimum pressure drop between the high-pressure liquid entering the valve and the low-pressure fluid leaving. When the inlet pressure is too low, the valve does not throttle properly, and erratic operation results. This causes the valve to **hunt** for its equilibrium point, starving the evaporator one minute and flooding it the next.

EXAMPLE: 12

R22 head pressure is at 168 psig; condensing temperature is 90°F. The evaporator temperature of a medium-temperature walk-in is 25°F at 49 psig. The pressure drop across the TEV is approximately 119 psig (168 pisg − 49 psig = 119 psig). Therefore, a pressure drop less than 119 psig may cause erratic TEV operation.

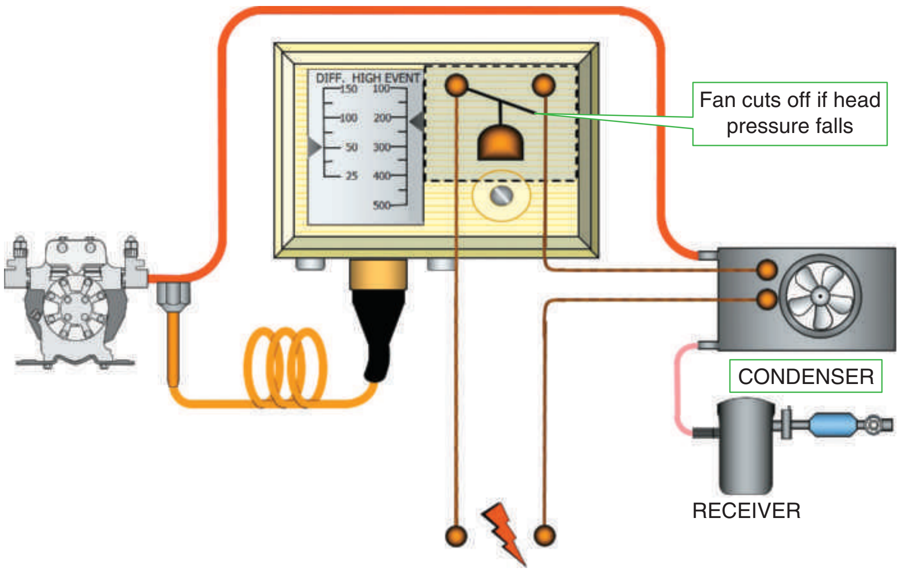
The solution is to keep the head pressure above the minimum, usually equivalent to a 90°F condensing temperature. For example, if the unit uses R22, the minimum pressure allowed would be 168 psig. The following sections describe three of the most common methods for keeping the head pressure up in low-ambient conditions:

- Cycling the condenser fans
- Using dampers to control the airflow through the condenser
- Flooding the condenser with refrigerant to decrease its effective condensing surface

Fan Cycle Controls

Fan cycle controls can help manage head pressure by monitoring one of two conditions, the discharge pressure or the ambient temperature (Figure 3-6). Most fan cycle controls stop the condenser fan when the head pressure drops to a minimum pressure cut-out setting. Without the fan pulling cool air through the condenser, the system cannot readily reject heat. As a result, the head pressure rises. The fan starts when the pressure reaches the control's higher cut-in setting.

FIGURE 3-6 **Fan cycle for low-ambient conditions.** *Courtesy of Refrigeration Training Services.*



EXAMPLE: 13

An R22 condensing unit is operating in an ambient of 50°F. When the head pressure drops to the equivalent of 90°F condensing temperature (168 psig for R22), the fan shuts off. This is called the control's cut-out pressure.

The cut-in pressure is usually set about 40 psig above the cut-out, or 208 psig (168 psig + 40 psig = 208 psig) in this example. The condenser fan cut-out is equivalent to an ambient of 60°F, and the cut-in is equivalent to a 74°F ambient. The unit will be operating in an average ambient condition of about 67°F, midway between 60°F and 74°F. The pressures will remain high enough for proper operation of the metering device.

The **differential** (difference between cut-in and cut-out) should be between 30 and 50 psig. If it is lower than 30 psig, the fan motor will short cycle, resulting in premature motor failure. If the cut-in is greater than a 50 psig differential, the fan will be off too long. Long off cycles cause wide swings in head pressure, which can result in erratic operation of the expansion valve.

On remote condensers with multiple fans, the manufacturer may use a combination of temperature and pressure fan controls. For instance, the first fan may be set to shut off at 70°F ambient, the second at 60°F ambient, and the last fan closest to the condenser outlet may be operating on condensing temperature. Check with the manufacturer for their recommendations.

Limitations to Using Fan Cycle Head Pressure Controls

On condensing units with air-cooled compressors, the condenser fan has the important function of providing the airflow needed to cool the air-cooled compressor motor. When the fan is cycled off, the lack of air movement could cause the compressor's motor to overheat, even in very cold weather.

Copeland does not recommend fan cycle controls on its single-fan condensing units equipped with an air-cooled compressor. However, if the unit has multiple condenser fans, the control can cycle all but one of the fans. The remaining fan ensures compressor motor cooling.

Fan cycle controls are most effective in the southern United States where winter temperatures are normally above freezing.

Fan Speed Controls

Variable frequency drive (VFD) and **electrically commutated motors (ECM)** allow condenser motors to modulate motor speed in order to maintain a more consistent head pressure. Unlike standard fan cycle controls that vary the head pressure by 30 to 50 psig, motors that vary their speed can keep the head pressure nearly constant. Although more expensive, these fan motors are gaining acceptance because they increase system performance and efficiency, which lowers operating costs.

Air Dampers

Shutters, or dampers, are occasionally used on large remote condensers to keep head pressure up. Similar to fan cycling, dampers limit the airflow across the condenser surface. The dampers have multiple positions and close in stages. Some damper systems respond to the head pressure of the unit, whereas others respond to ambient air temperatures. Fan cycle controls are often used in conjunction with the dampers for more complete head pressure control.

Dampers are also used to prevent low-ambient conditions based on **prevailing winds,** or winds that are blowing from the same direction most of the time. Wind blowing through a condenser can drop the condensing temperature, even if the fan has cycled off. A good rule to follow when installing air-cooled condensers is to place them 90 degrees to the prevailing wind.

CONDENSER FLOODING

Condenser flooding is like overcharging a unit; it increases the head pressure. Manufacturers of units with condenser flooding use a type of head pressure regulating (HPR) valve to restrict the liquid leaving the condenser. Backing up in the condenser, the liquid refrigerant fills condenser tubing, leaving less space for the discharge gas from the compressor to condense. As a result, the head pressure is elevated to a minimum pressure based on the HPR valve setting. The temperatures and pressures in the condenser rise as if there is warm ambient air going through the condenser.

Most HPR valves are actually three-port valves that close down the liquid leaving the condenser during low-ambient conditions to increase the head pressure equivalent to a 90°F condensing temperature. At the same time, the discharge pressure port opens to bypass hot discharge vapor to maintain a warm refrigerant temperature in the receiver (see Figures 3-7 and 3-8).

NOTE: Manufacturers of flooded condenser systems have calculated the proper charging procedures to ensure adequate refrigerant to flood the condenser during low-ambient conditions. If the unit does not have the information, the technician will have to contact the factory in order to properly charge the system. Also, the unit should have a receiver large enough to contain the total refrigerant charge during high-ambient conditions. See Chapter 9 for more information on charging flooded condensers and standard remote refrigeration systems.

Troubleshooting HPR Valves

To properly troubleshoot an HPR valve (Figure 3-9), the technician must know the following:

- Pressure setting of the HPR valve
- Current head pressure
- Liquid line temperature
- Ambient air temperature entering the condenser

As in all troubleshooting, the technician must determine what is currently happening in the system and compare it to how the system is supposed to be operating. Some technicians believe it would be nice if all refrigeration tubing were clear glass so that they could see the flow of refrigerant in all parts of the unit. However, it is actually better to rely on gauges and thermometers than to trust one's eyes. Correct temperature and pressure determination is the most accurate method of diagnosing a refrigeration system.

When the HPR is working properly, the head pressure is equal to the valve setting, and the liquid line is warm (about 90°F).

FIGURE 3-7 **Cutaway of an HPR valve.** *Courtesy of Refrigeration Training Services.*

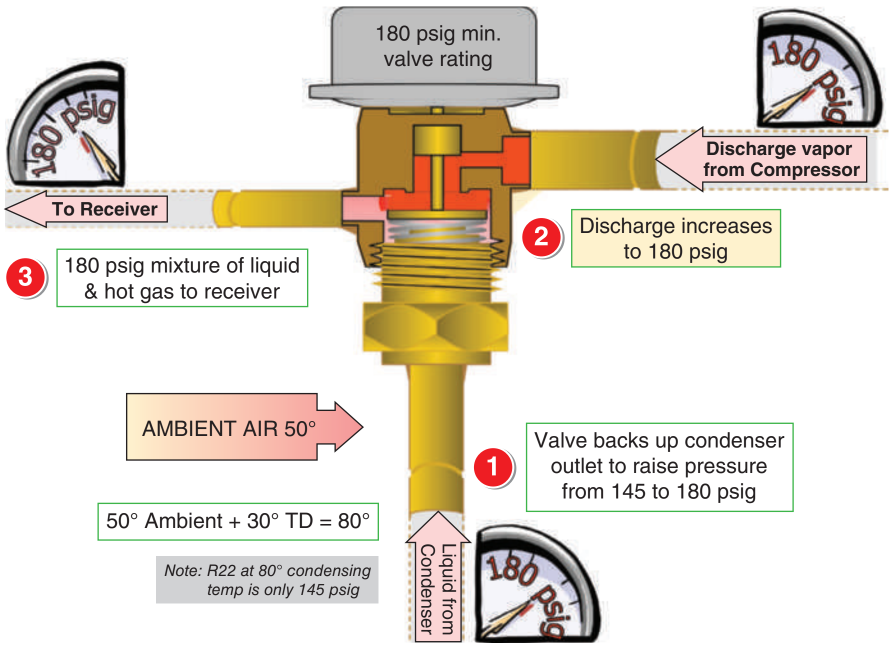


FIGURE 3-8 **HPR valve in a refrigeration system.** *Courtesy of Refrigeration Training Services.*

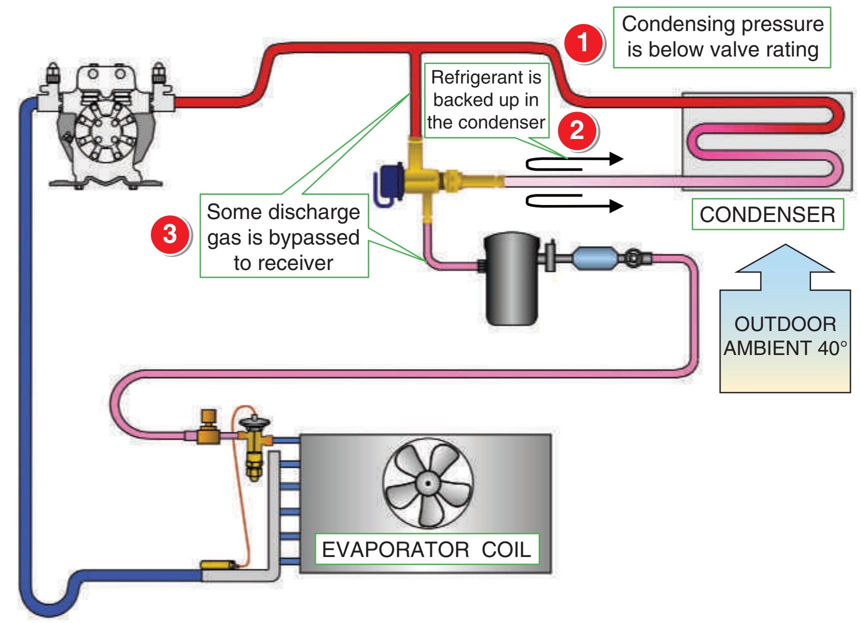


FIGURE 3-9 **A diagnostic chart for HPR valve problems.** *Courtesy of Refrigeration Training Services.*

DIAGNOSIS OF HEAD PRESSURE REGULATING VALVES (HPR's)

INFORMATION NEEDED:

HEAD PRESSURE **(HP)** ____________

LIQUID LINE TEMPERATURE **(LLT)** ____________

PRESSURE RATING OF HPR VALVE ____________

AIR TEMP. ENTERING THE CONDENSER ____________

NOTES

APPLICATION	REFRIGERANT	RATING
High pressure valves	R502, R404A, HP81, & R22	180 psig = 90° condensing temp
Low pressure valves	R12, R134a, MP39, R414B	100 psig = 90° condensing temp

Summer (ABOVE 60°)	Winter (BELOW 60°)	REASON	DIAGNOSIS
HP - NORMAL LLT - NORMAL	HP - LOW LLT - COLD	HPR IS NOT BACKING UP REFRIGERANT IN CONDENSER. NORMAL FLOW THROUGH THE CONDENSER. NO HOT GAS BYPASSING.	HPR STUCK OPEN OR HEAD HAS LOST CHARGE. **REPLACE HPR**
HP - HIGH LLT - HOT	HP - HIGH LLT - WARM/HOT	HPR TOTALLY BLOCKING CONDENSER OUTLET. NO LIQUID LEAVING CONDENSER. HOT GAS REPLACES LIQUID IN LL.	HPR STUCK CLOSED. **REPLACE HPR**
HP - LOW LLT - HOT	HP - LOW LLT - WARM/HOT	NOT ENOUGH GAS FOR GOOD HP, HOT GAS REPLACES LIQUID IN LL. *Note: a remote unit that requires 18 pounds of refrigerant for low ambient conditions may operate properly on only 8 pounds in warm weather.*	LOW CHARGE **ADD REFRIGERANT** *Not charged properly for low ambient conditions or there is a refrigerant leak.*

Following are two HPR problems during low-ambient operation:

- If the head pressure is low and the liquid line is cold, the HPR valve port at the condenser outlet is stuck open. It is not backing up refrigerant in the condenser or bypassing hot gas.
- If the head pressure is high and the liquid line is warm or hot, it means the HPR valve port at the condenser outlet is stuck closed. It has closed off the outlet to the condenser and is bypassing only hot gas into the liquid line.

NOTE: A low charge can fool you into condemning a good HPR valve. If the liquid line is warm (or hot) but the head pressure is low, the unit is low on refrigerant.

The valve is doing its job by shutting down the condenser outlet. However, there is not enough refrigerant backing up in the condenser to raise the head pressure. No liquid is coming through the valve inlet to mix with the discharge gas in the bypass line. Therefore, it is just hot gas entering the liquid line.

A technician who observes these symptoms can verify their diagnosis by adding a few pounds of refrigerant. If the pressures return to normal, the technician is justified in their assumptions.

NOTE: This situation often occurs during the first cold days of the fall or winter. If the unit was originally charged during the summer, it is not uncommon for the technician to have forgotten to add enough refrigerant for condenser flooding during cold weather operation.

FLOATING HEAD PRESSURE

Floating head pressure describes the practice of allowing a system's head pressure to drop as the ambient drops. The main reason for the use of low-ambient controls is to keep the liquid pressure high enough for conventional expansion valves to operate properly. However, several manufacturers have introduced **balanced port** expansion valves that operate correctly even as the liquid line pressure drops. Russell Coil Company uses these valves on its Sierra remote refrigeration system installed in many convenience stores. Russell has designed the system to operate efficiently and correctly down to a 30°F ambient without low-ambient controls. Below that temperature, condenser fan cycling is usually the only low-ambient control necessary.

WATER-COOLED CONDENSERS

Air-cooled units rely on ambient air to transfer the heat from inside the condenser to the air outside the air-conditioned space. The rate of heat transfer can be increased in several ways, including moving a greater quantity of air through the condenser.

Water is denser than air; therefore, it can absorb heat more efficiently than air can. Water-cooled condensers are physically smaller than air-cooled condensers and are designed to operate at a consistent condensing temperature of only about 105°F. The only time an air-cooled unit operates at this temperature is on a mild 75°F day.

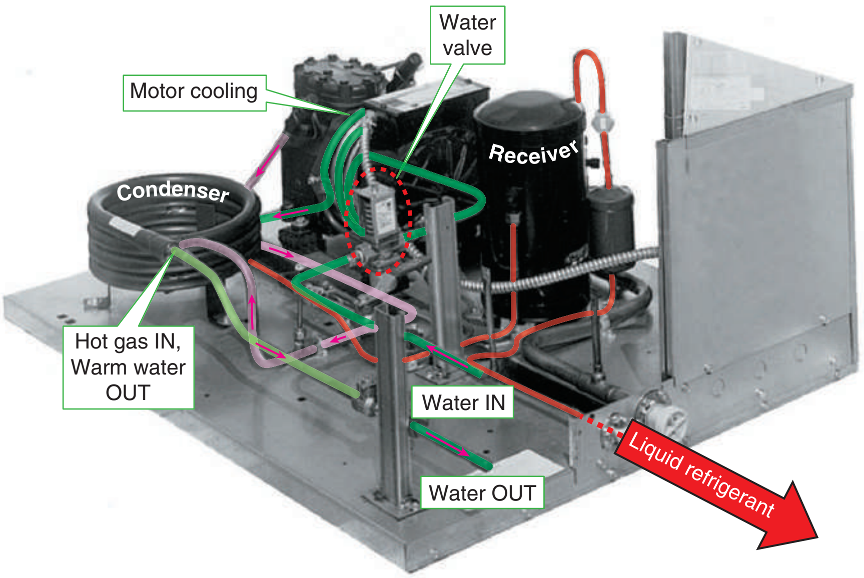
Water-cooled units are used indoors where the ambient air is hot or contains flour, dust, or grease, like in a commercial kitchen. Another application is when the condensing unit is located in an unventilated area. Ice machines situated in small vending areas are often water cooled. If they were air cooled, they would recirculate their own air and eventually go out on high head pressure.

The most popular water-cooled condensers for commercial refrigeration are:

- Tube-in-tube condensers like the coiled water-cooled condensers used in small condensing units and ice machines (Figure 3-10)
- Shell-and-tube condensers like the condenser-receivers used on larger condensing units and centrifugal chillers

Tube-in-tube condensers have the water circulating through an inner pipe, which is surrounded by an outer pipe that contains the refrigerant. In this configuration,

FIGURE 3-10 **Water-cooled condensing unit with tube-in-tube condenser.** *Courtesy of Russell Heat Transfer Products Group.*



the refrigerant can be cooled by both the inner water tube and the ambient air in contact with the exterior surface of the refrigerant pipe. (See Figure 3-11 for an interior view of this type of condenser.) A tube-in-tube condenser is designed so that the incoming water enters where the subcooled condensed liquid leaves the condenser. This counterflow configuration maintains a relatively constant rate of heat exchange throughout the entire condenser. In addition, if cold entering water comes in contact with the hot gas line, the thermal shock of the great temperature difference between the two fluids can cause metal fatigue and cracking. Furthermore, the greater the temperature difference between the two fluids, the more mineral buildup at that point in the system.

Tube-in-tube condensers are most often in a coil configuration and are relatively inexpensive. Another version is the flange type that has straight runs of stacked tube-in-tubes with removable flanges or plates on either end for cleaning.

Shell-and-tube condensers utilize a large tank, or shell, for the purpose of condensing and holding the refrigerant. The hot gas entering the shell comes in contact with cool water pipes, or tubes, that run through the tank. Another way to describe the configuration is that it looks like a liquid receiver with interior water tubes. In fact, some technicians call these units condenser-receivers. The end plates can be removed for cleaning the water tubes (see Figures 3-12 and 3-15).

FIGURE 3-11 **Flange-type condenser.** *Photo by Dick Wirz.*

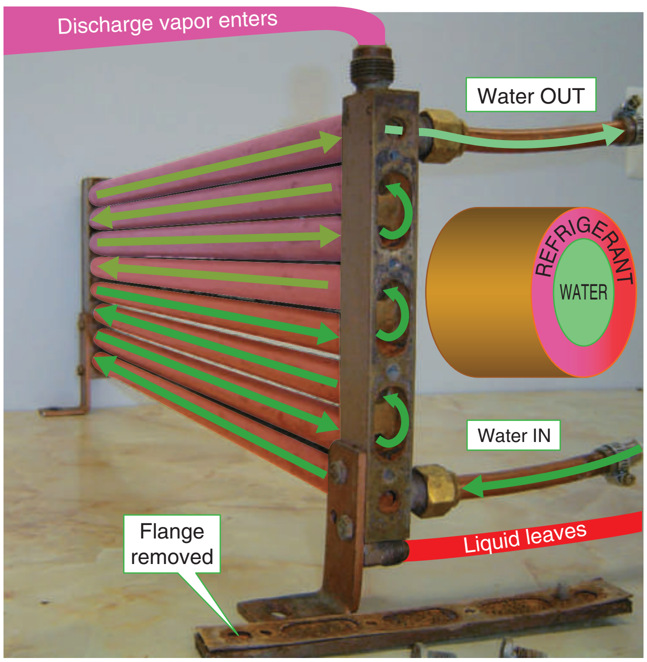
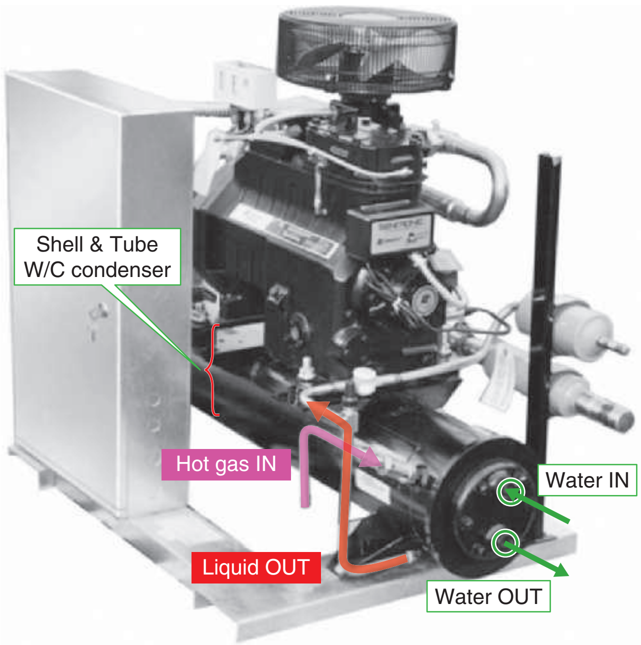


FIGURE 3-12 **Water-cooled condensing unit with shell-and-tube condenser.** *Courtesy of Russell Heat Transfer Products Group.*

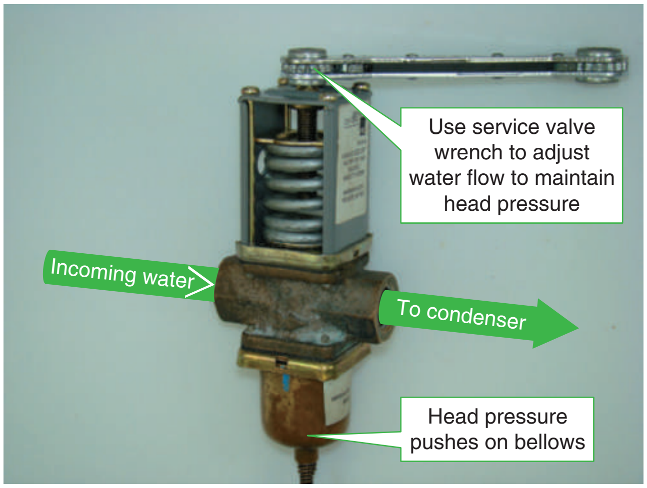


Water-regulating Valves

Most water-cooled units use **water-regulating valves (WRV)** to modulate the water flow entering the condenser in response to head pressure (see Figure 3-13). When the compressor is off, spring pressure pushes down on the valve's internal flange to shut off the flow of water into the condenser. When the compressor starts, the head pressure rises, pushing up on the bellows, which puts opening pressure on the valve. The two pressures equalize to allow only enough water into the condenser to maintain the head pressure for which the valve is adjusted (see Figure 3-13). When adjusting the WRV, use a gage wrench. Turning the shaft with a pair of pliers or a screwdriver often results in damaging the end of the adjuster. Turning the shaft counterclockwise (looking down on the end of the adjuster) increases the head pressure.

Proper selection of a WRV is based on flow rate, not pipe size. If the WRV is too large, it may cause the water lines to shake or hammer when the unit cycles. Instead of modulating the water flow, the valve is opening fully then slamming shut. As you will see in the next two sections, water-cooled condensers only require 1.5 to 3.0 gallons per minute (gpm) per ton of refrigeration. If it is not practical to replace the WRV with the proper size, install a water pressure–reducing valve to slow the amount of water going through the valve.

FIGURE 3-13 **Water-regulating valve.** *Photo by Dick Wirz.*



TROT
The cost of installing a cooling tower is usually justified when the combined water-cooled equipment capacities reach about 24,000 to 36,000 Btuh.

Cooling Towers

Cooling towers used in refrigeration are the same as those used for comfort cooling. However, it is important to remember that towers must be chemically treated to lower the scale buildup in condenser tubes. Also, they require some type of constant bleed-off or "blow-down" of the sump water to prevent excessive mineral concentration in that reservoir.

Operations large enough for cooling towers usually employ professional water treatment companies to maintain tower water quality. Without proper tower maintenance, the efficiency of the refrigeration systems will decrease as the cost of operation and service rises. Cooling towers recirculate their water at the rate of approximately 3 gpm per ton of refrigeration (12,000 Btuh) at an 85°F sump water temperature.

Wastewater Systems

Wastewater systems are water-cooled units that use tap water to cool the condenser and then drain the wastewater. This method uses about 1.5 gpm per ton at an incoming water temperature of 75°F.

NOTE: The flow rate of water depends on the temperature of the entering water. The colder the incoming water, the less the flow of water needed to condense the refrigerant. The higher the temperature of incoming water, the greater the flow of water needed for condensing.

When suggesting a water-cooled system, the technician should make the customer aware of the increase that will occur in their water and sewer bills.

EXAMPLE: 14

Assume a 1-ton (12,000-Btuh) unit runs an average of 16 hours (960 minutes) out of every 24 hours. The water use will be 1,440 gallons per day (1.5 gpm × 1 ton × 960 minutes). The customer's monthly water bill will reflect the water-cooled condenser usage of 43,200 gallons. If the charges are $3 per 1,000 gallons used, the water-cooled unit's portion of the bill will be $130 per month, or $1,560 annually. Multiple units, dirty condensers, or leaking HPR valves can make this figure rise considerably. Although the installed cost of water-cooled units using wastewater is cheaper initially, a cooling tower or even a remote air-cooled unit may be less expensive in the long run.

NOTE: Check with the local building inspector before installing a wastewater system. Many municipalities do not allow this type of refrigeration system, primarily due to its water usage but also because of the added load on the waste treatment facilities.

Service and Maintenance of Water-Cooled Equipment

Whether it is personal health or refrigeration equipment, periodic inspection and maintenance makes more sense than waiting until something goes wrong (Figures 3-14 and 3-15). Following are some guidelines:

1. What is the temperature of the water leaving the condenser?

   Tip: Take the temperature of the leaving water or strap and insulate an electronic thermometer probe to the condenser drain line. The pipe temperature should be very close to the actual water temperature.

2. What is the condensing temperature?

   Tip: Use gauges to determine the head pressure. Use a P/T chart to determine the condensing temperature.

FIGURE 3-14 **Mineral buildup in tube-in-tube condenser.** *Photo by Dick Wirz.*

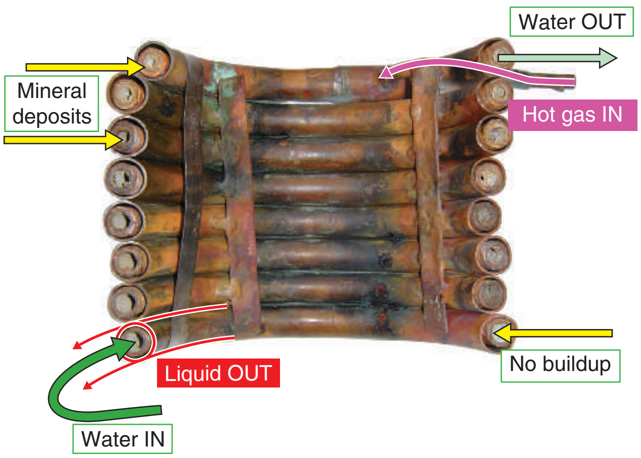
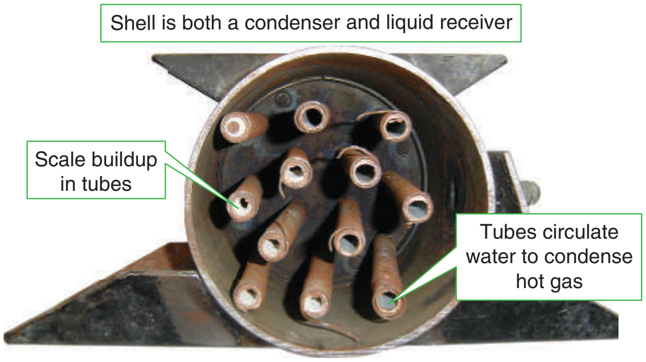


FIGURE 3-15 **Mineral buildup in shell-and-tube condenser.** *Photo by Dick Wirz.*



3. What is the flow rate of the leaving water?

   Tip: Use a measurable container, like a 1-gallon bucket. Put it under the condenser outlet and determine how long it takes to fill. For instance, if it takes 30 seconds to fill a 1-gallon bucket, the flow rate is 2 gpm.

If the condenser is piped into a larger drain pipe, cut the drain line from the water-cooled condenser that you are checking. Measure the flow as previously described. Install a union or compression coupling not only to reconnect the main drain but to make it easy to check the flow again during the next inspection.

Proper Operating Conditions of a Water-Cooled Unit on a Wastewater System

The CS of most water-cooled condensers is designed for 30°F above an average entering water temperature of 75°F. Therefore, the condensing temperature should be about 105°F (75°F + 30°F = 105°F). The leaving water temperature of a water-cooled unit should be 10ºF below the condensing temperature. In this case, it should be 95°F (105°F – 10°F = 95°F).

Following is why it is so important to check the water flow of the condenser outlet: The WRV is on the inlet water line of the condenser (see Figure 3-13). It regulates the flow of water to maintain the proper head pressure. When the condenser tubes become coated with a mineral buildup, the head pressure starts to rise. As the head pressure increases, the regulating valve opens wider, allowing more water to flow through the tubing to bring the head pressure back down to its original setting. If the technician checked only the head pressure, they would not realize the tubing was already starting to be coated with minerals.

EXAMPLE: 15

A technician checks the flow rate of a 12,000-Btuh unit and finds the condensing temperature at 95°F but a flow rate of 2 gpm instead of the normal 1.5 gpm. The technician would know they are starting to have a problem. They can schedule a convenient time to clean the unit and will probably have a relatively easy job of it.

If the technician depends only on seeing high head gauge pressure to signal the need for cleaning, it will be too late. The water-regulating valve keeps opening more and more to allow greater water flow to compensate for the insulating effect of the mineral buildup. Only when the water valve is fully open and the scale is thick enough to prevent proper heat transfer will high head pressure show up, probably tripping the high-pressure reset. At this point, the condenser has developed a very thick coating of minerals, making it more difficult to clean. In addition, the technician has an emergency situation on their hands.

CLEANING WATER-COOLED CONDENSERS

As mentioned earlier, the ends on a flange-type condenser can be removed for cleaning. Special brushes and drill-powered rods can be used to clean the minerals from the water tubing.

Some technicians first try removing the mineral deposits from flanged condensers with chemicals. This may prevent having to disassemble the condenser and clean it with rods and brushes. The next paragraph explains chemical cleaning of water-cooled condensers (see Figure 3-16).

FIGURE 3-16 **Acid cleaning illustration on a water-cooled condenser.** *Photo by Dick Wirz.*

REALITY CHECK 2

Planning in advance is very important. The technician should have flange gaskets, spare bolts, and a bolt extractor before starting the work. Occasionally, the bolts snap off in the process of removing the flange. The gaskets usually need to be replaced before reinstalling the flanges. •

REALITY CHECK 3

Cleaning water-cooled condensers is easy if the scale deposits on the tubes are not too thick. However, cleaning condensers that have a heavy buildup is not always successful. The cleaner may not be able to remove enough of the minerals to lower the head pressure. In some cases, the cleaning can dislodge chunks of minerals, resulting in a complete blockage of the condenser tubing. •

The only way to clean coil-type condensers is to circulate a strong cleaning solution through them that is specifically made for this purpose. The refrigeration supply house that has the cleaner should also be able to furnish the small epoxy-coated submersible pump needed just for this task. Following is a brief description of the cleaning procedure:

1. Cut the water inlet and outlet pipes.
2. Install unions in the cut pipes. This allows an easy means of hooking up the hoses for cleaning the condenser as well as reconnecting the piping upon completion of the cleaning process.
3. Attach a hose from the outlet of the acid pump to the inlet of the condenser.
4. Run a hose from the outlet of the condenser back to the bucket.
5. Mix the proper amount of cleaning solution in the bucket, then put the pump into the bucket of cleaner.
6. Turn on the pump and circulate the acid solution until the condenser is clean.

Follow the directions that come with the cleaner to determine when the condenser is clean. Or simply reconnect the condenser's inlet water and check the head pressure along with the outlet water flow rate.

For units in very bad condition, it may be advisable to give the customer two quotes. One quote is to attempt acid cleaning of the existing unit. The other quote includes an additional charge to replace the condenser if cleaning is unsuccessful. The customer may just decide to replace the condenser and be sure of the results, and the quote.

CAUTION

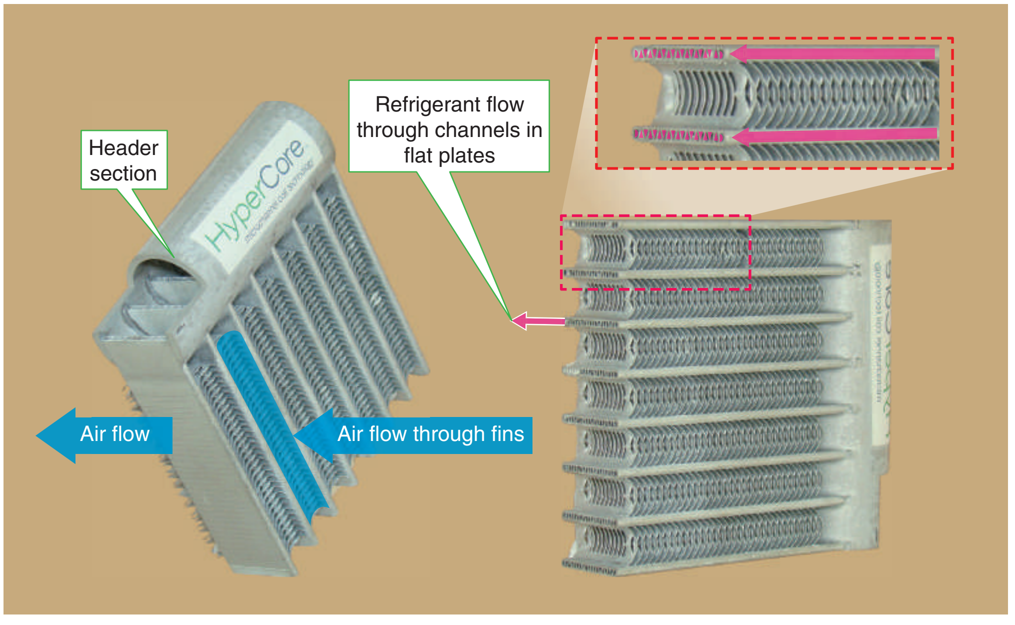
Safety note: Some cleaning solutions are caustic acid that can burn skin and even cause blindness. Make sure to use thick rubber gloves and eye protection. Also, cleaning solutions can damage the condenser if they are circulated too long (for instance, overnight). Always read and follow the manufacturer's instructions. •

BUSINESS TIP: It is best to provide customers with alternatives, whenever possible. If there is more than one way to perform a service, you should give your customer the appropriate information and then let them make the final decision.

Microchannel Technology

The fin and tube condenser coils may be a thing of the past. **Microchannel coil** is the term used for the type of condenser and evaporator coils being introduced in some units by Trane, York, Heatcraft, and other manufacturers (see 17). The new configuration produces smaller coils with higher efficiency. The design is similar to that currently being used by the auto industry in radiators.

FIGURE 3-17 **Microchannel coil technology.** *Photo by Dick Wirz.*



SUMMARY

Refrigerant boils in the evaporator as it absorbs heat. The compressor pumps the refrigerant and raises its pressure and temperature before discharging it to the condenser. The condenser rejects the heat and condenses the vapor back into a liquid.

Being able to measure condenser subcooling helps the technician determine if all refrigerant vapor has condensed into a liquid. Subcooling is also beneficial in preventing flash gas in the liquid line.

Low-ambient conditions require controls to maintain a minimum of 90°F condensing temperature in air-cooled condensers. On water-cooled condensers, the water-regulating valve automatically adjusts the water flow to maintain the proper head pressure.

The best way to be sure a condenser is clean is to clean it. There are proper procedures for cleaning both air- and water-cooled condensers. A consistent maintenance program is beneficial to the business of both the customer and the servicing technician.

REVIEW QUESTIONS

1. What is the primary function of the condenser?
    a. Absorb heat from the refrigerated space.
    b. Reject heat from the refrigerated space.
    c. Cool the air-cooled compressor with the condenser fan.
2. Why does the suction vapor have to be increased in temperature before it can be condensed?
    a. So that the condensing temperature is above the ambient.
    b. So that the ambient temperature will be warmer than the refrigerant.
    c. So that the suction vapor will not damage the compressor valves.
3. How can the temperature of refrigerant be increased without adding excessive heat?
    a. Raise the temperature going through the condenser.
    b. Lower the pressure of the refrigerant.
    c. Raise the pressure of the refrigerant.
4. What are the three phases of the condenser?
    a. Subcool, supercool, and condense.
    b. De-superheat, condense, and subcool.
    c. Superheat, condense, and subcool.
5. Where does the superheat in discharge gas come from?
    a. Suction vapor superheat.
    b. Compressor motor heat.
    c. Heat of compression.
    d. All of these choices.
6. When does condensing start?
    a. When the discharge gas is cooled to its condensing temperature.
    b. As soon as the discharge gas enters the condenser.
    c. After the refrigerant leaves the condenser.
7. What is subcooling, and what does it indicate?
    a. The difference between the condensing and suction temperatures indicates compression efficiency.
    b. The difference between condensing and liquid line temperatures indicates if the vapor has condensed to a liquid.
    c. The difference between ambient and condensing temperatures indicates if liquid is returning to the compressor.
8. After the vapor has been condensed to a liquid, what are two causes for the liquid to flash back into vapor before it reaches the metering device?
    a. A rise in temperature with a rise in pressure.
    b. A fall in temperature with a fall in pressure.
    c. A rise in temperature or a fall in pressure.
9. If a 3/8-inch liquid line has a vertical lift of 40 feet, how much pressure drop is there?
    a. 10 psig
    b. 20 psig
    c. 30 psig
    d. 40 psig