Refrigerants and Refrigerant Oils

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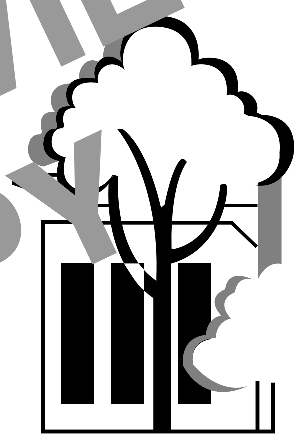
REFRIGERANTS AND REFRIGERANT OILS

Lesson One

Physical Properties of Refrigerants



TPC Training Systems

43201

Lesson

1 Physical Properties of Refrigerants

TOPICS

Refrigerant
Pressure-Temperature Relationships
Enthalpy
Pressure-Enthalpy Diagram
The Ideal Refrigeration Cycle
Using the P-H Diagram
Liquid Subcooling
A Practical Refrigeration Cycle

OBJECTIVES

After studying this Lesson, you should be able to…

- Explain the relationship between pressure and boiling point in a liquid.
- Define the term *enthalpy*, and differentiate between the enthalpy of saturated liquid, the enthalpy of evaporation, and the enthalpy of saturated vapor.
- Use a P-H diagram to show the process of evaporation, compression, condensation, and liquid metering.
- Calculate the *compression ratio*, *refrigerating effect*, *refrigerant flow rate*, *heat of compression*, *compressor horsepower*, and *coefficient of performance* for a system.
- Determine compressor discharge temperature, compressor volume displacement, superheat, subcooling, and total heat rejection in the condenser, using a P-H diagram.
- Explain the purpose and methods of liquid subcooling.

KEY TECHNICAL TERMS

Refrigerant 1.01 fluid that carries heat from one point to another in a mechanical refrigeration system

Saturation temperature 1.07 temperature at which any liquid boils

Enthalpy (EN-thul-pee) 1.10 property that represents the amount of thermal energy (heat) contained in a fluid

Critical point 1.18 maximum temperature at which a refrigerant can exist as a liquid

Compression ratio 1.33 absolute condensing pressure divided by absolute suction pressure

Refrigerating effect (RE) 1.34 useful cooling done (accomplished) by a refrigerant

Subcooling 1.47 process used to cool condensed refrigerant to a temperature lower than saturation temperature

In this Lesson you will study the heat-carrying properties of a refrigerant. There are a number of refrigerants commonly used in commercial and industrial applications. Each refrigerant has properties that differ from the others, including boiling point, specific heat, latent heat of vaporization, density, and other factors that affect the refrigerant's ability to transfer heat.

Effective maintenance of any mechanical refrigeration system depends largely on your understanding of the physical properties of refrigerants. The job of troubleshooting a problem becomes much easier when you know how the refrigerant reacts to changes in temperature and pressure. Refrigerant behavior is frequently the key to pinpointing the cause of trouble.

Refrigerant

1.01 *Refrigerant* is a fluid that carries heat from one point to another in a refrigeration system. It boils in the evaporator at low temperature as it absorbs heat from the air or from the substance that you want to cool. The refrigerant vapor is then drawn into the compressor, which increases pressure and temperature so that the vapor will condense at the higher temperature outside the refrigerated area. In condensing, the refrigerant rejects the heat that it absorbed during boiling. The condensed liquid refrigerant is then metered back to the refrigerated area to absorb more heat by boiling again.

1.02 When you think about this process carefully, some questions might come to mind. Why do refrigerants boil at "low" temperature? How much heat is absorbed as the refrigerant boils? What does the compressor actually do to the refrigerant in raising its temperature and pressure, and by how much are the temperature and pressure raised? What actually causes the vapor to condense at a higher temperature? How is the heat rejected? How much heat is rejected?

1.03 These are the kinds of questions you should be concerned with in working with refrigeration systems. If your job is to keep a refrigeration system running smoothly, the first thing you must know about is the refrigerant inside the system. A typical system has many indicators that tell you the exact condition of the refrigerant at various points in the system. It also has controls that enable you to make adjustments as the need arises. These control devices are used to maintain the desired conditions of the refrigerant as cooling demands change. However, if you do not know how the refrigerant responds to changes in temperature and pressure, the indicators and controls will not be very useful to you.

1.04 The purpose of this Lesson is to give you the kind of insight you need to answer basic questions, like those listed earlier, as they arise in your everyday work. The relationship between pressure and temperature, for example, is central to your understanding of refrigerants. How a refrigerant absorbs, carries, and rejects heat as it changes states from liquid to vapor and back to liquid is equally important to understanding and performing your work. These are the physical properties of refrigerants. They differ from one refrigerant to another.

Pressure-Temperature Relationships

1.05 At standard atmospheric pressure of 14.7 psia, water in an open container boils at 212°F (100°C). In a closed container, however, where you can control pressure, you can change the boiling point as you choose. As you increase the pressure in the container, you also increase the boiling temperature. If you decrease the pressure, you also decrease the boiling temperature. This principle applies to all liquids.

1.06 In refrigeration work, you are dealing with refrigerants in closed containers at varying pressures. By controlling these pressures, you control the temperature of the refrigerant at different points in the system. Therefore, you can cause the refrigerant to boil at a low temperature at one point, and then to condense at a high temperature at another point.

1.07 For any liquid, the temperature at which boiling takes place is called the *saturation temperature* and the corresponding pressure is called the *saturation pressure*. Table 1-1 on page 7 shows the saturation pressure/temperature relationships and other data for refrigerant R-22 within a narrow temperature range. Note in Table 1-1 that at 14.451 psia (near sea level atmospheric pressure), the saturation temperature of R-22 is -42°F (-41.1°C). To be more precise, the refrigerant's saturation temperature at 14.7 psia is -41.44°F (-40.8°C). This information tells you that R-22 will boil in an open container at -41.44°F.

1.08 Figure 1-1 shows the saturation curve for R-22. This curve is simply a plot of the values given in Table 1-1. Although the table is better for finding precise values, the curve is a visual aid to help you understand the relationship between temperature and pressure.

1.09 Any point on the curve in Fig. 1-1 represents a boiling point of R-22. Each point can also be called a *condensing point*. This is because a mixture of R-22 liquid and vapor at saturation temperature and pressure can be in any one of three states (boiling, condensing, or equilibrium) depending on whether any heat transfer is taking place. If you add heat, the liquid will boil. If you remove heat, the vapor will condense. If you neither add heat nor remove heat, the mixture remains in equilibrium.

Application 1-1

"Why should I bother to learn to read a pressure-temperature chart?" fumed the apprentice. "That's easy," said his buddy. "What if you have to calibrate your gauges? Here's a simple method. Submerge a tank of R-22 in a bucket of ice water. You'll see that a thermometer will read exactly 32°F. At 32°F on the P-T chart, R-22 has a pressure of 57.8 psig. Simply hook up your gauges and adjust the calibrating screw to exactly 57.8. You can do this with any refrigerant, but you need the proper chart and you have to know how to use it."

Enthalpy

1.10 One section in Table 1-1 is labeled ENTHALPY. *Enthalpy* is a property that represents the total amount of thermal energy or heat contained in a fluid. Enthalpy is expressed in Btu/lb. For most refrigerants, enthalpy is considered to be zero at a saturation temperature of -40°F (-40°C). Then, the heat added to or removed from the refrigerant from that point is considered to be its total enthalpy. In most heat transfer work, you will be concerned with the change in enthalpy that takes place during a process. There is usually no need to know the absolute energy content.

1.11 **Enthalpy of saturated liquid (h_f).** Looking at Table 1-1, you can see that the enthalpy of saturated liquid R-22 (h_f) at -40°F is 0. Notice, however, that its enthalpy at -35°F (-37.2°C) is 1.269 Btu/lb. These figures indicate that 1.269 Btu of heat is needed to raise the saturation temperature of R-22 from -40°F to -35°F.

1.12 **Enthalpy of evaporation (h_{fg}).** The next enthalpy column indicates the amount of heat required to change 1 lb of liquid to 1 lb of vapor at a constant temperature. Notice that at -35°F, this value is 99.536 Btu/lb. This number is the latent heat of vaporization of R-22 at a saturation temperature of -35°F. The enthalpy of evaporation is the latent heat of vaporization for any refrigerant.

1.13 **Enthalpy of saturated vapor (h_g).** The enthalpy of the saturated vapor, shown in the third enthalpy column in Table 1-1, is the sum of the enthalpy of the saturated liquid and the enthalpy of evaporation. For example, at -35°F, the enthalpy of saturated vapor is 1.269 Btu/lb + 99.536 Btu/lb = 100.805 Btu/lb, which rounds off to 100.8 Btu/lb.

1.14 Hopefully, you are beginning to understand why enthalpy values are so useful in making heat-transfer calculations. You can see that enthalpy involves the absorption of both sensible heat and latent heat. Furthermore, you know that different liquids have different specific heats and different latent heats of vaporization. They also have different boiling points. Enthalpy tables like Table 1-1 will save you a great deal of time when you must calculate heat-transfer loads using specific refrigerants. Entropy (the final column in the Table) will be explained later in this Lesson.

Pressure-Enthalpy Diagram

1.15 When the values given in refrigerant tables are plotted on a graph, the resulting diagram becomes a valuable tool for understanding and analyzing refrigeration system performance. The diagram most commonly used is the *pressure-enthalpy diagram*, also called a *Mollier diagram*. The pressure-enthalpy (P-H) diagram for R-22 is shown in Fig. 1-2 on page 8.

Table 1-1. Properties of saturated R-22

	Pressure		Density, lb/ft^3		Enthalpy, Btu/lb			Entropy, Btu/lb(°R)
Temp., °F	psia	psig	Liquid, $1/v_f$	Vapor, $1/v_g$	Liquid, h_f	Latent, h_{fg}	Vapor, h_g	Vapor, s_g
-45	13.354	2.732*	88.507	0.26851	-1.260	100.963	99.703	0.24046
-44	13.712	2.002*	88.407	0.27523	-1.009	100.823	99.814	0.24014
-43	14.078	1.258*	88.307	0.28207	-0.757	100.683	99.925	0.23982
-42	14.451	0.498*	88.207	0.28905	-0.505	100.541	100.036	0.23951
-41	14.833	0.137	88.107	0.29617	-0.253	100.399	100.147	0.23919
-40	15.222	0.256	88.006	0.30342	0.000	100.257	100.257	0.23888
-39	15.619	0.923	87.905	0.31082	0.253	100.114	100.367	0.23858
-38	16.024	1.328	87.805	0.31835	0.506	99.971	100.477	0.23827
-37	16.437	1.741	87.703	0.32602	0.760	99.826	100.587	0.23797
-36	16.859	2.163	87.602	0.33384	1.014	99.682	100.696	0.23767
-35	17.290	2.594	87.501	0.34181	1.269	99.536	100.805	0.23737
-34	17.728	3.032	87.399	0.34992	1.524	99.391	100.914	0.23707
-33	18.176	3.400	87.297	0.35818	1.779	99.844	101.003	0.23678

*Inches of mercury below one atmosphere

Although it looks complicated, it is not difficult to understand and use.

1.16 Figure 1-3 on page 9 shows a simplified P-H diagram that represents the data contained in Table 1-1. Putting it simply, the diagram represents the behavior of the refrigerant. The P-H diagram has three zones that correspond to the physical states of the refrigerant. The zone to the left of the saturated-liquid line is the *subcooled-liquid zone*. The zone in the middle is the *mixed liquid-vapor zone*. And the zone to the right of the saturated vapor line is the *superheated-vapor zone*.

1.17 At any given point on the saturated-liquid line, the liquid is at its boiling point. At this point, a liquid is at its boiling temperature, but no trace of vapor has formed. At any point on the saturated-vapor line, the liquid refrigerant is completely vaporized. In other words, the refrigerant vapor is at its condensing temperature and no trace of liquid is present.

1.18 As the pressure increases, the saturated-liquid and the saturated-vapor lines gradually come together at a point called the *critical point*. The critical point is the maximum temperature at which the refrigerant can exist as a liquid. The temperature at the critical point is called the *critical temperature*, and the pressure at the critical point is called the *critical pressure*. When the refrigerant temperature is above the critical temperature, it cannot be liquefied, even under the highest pressure available. At temperatures higher than criti-

Fig. 1-1. Pressure-temperature curve for R-22

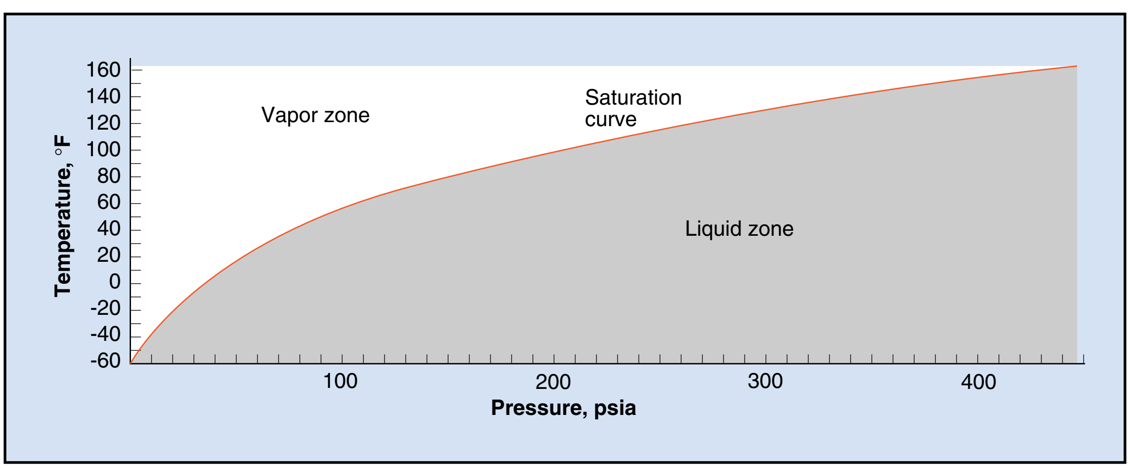


Fig. 1-2. Pressure-enthalpy diagram for R-22

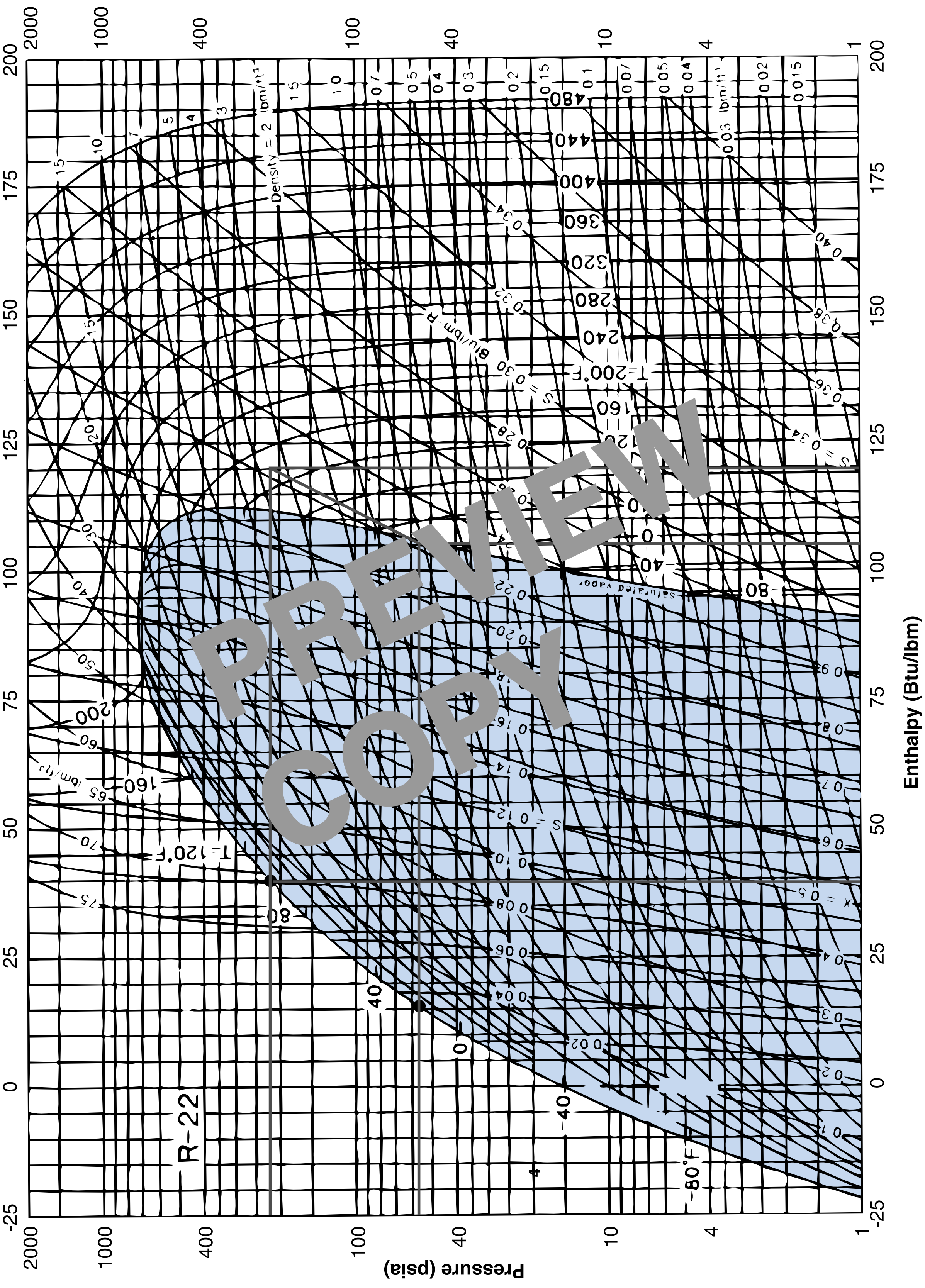
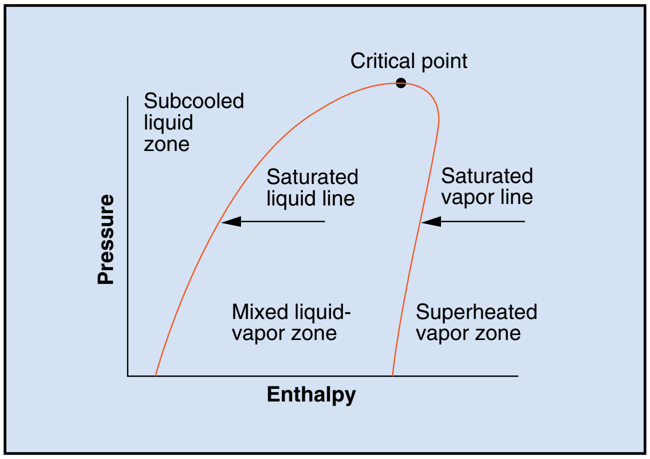


Fig. 1-3. Simplified P-H diagram



cal, the refrigerant can exist only as a gas. At temperatures below critical, it is frequently referred to as a *vapor* when at or near saturation. In the superheated region, the word *gas* is used.

1.19 The complete pressure-enthalpy diagram shown in Fig. 1-2 shows five basic properties of the refrigerant on one diagram. In Fig. 1-4, each property is shown separately so that you can see how to tell them apart.

1.20 **Pressure (psia).** Absolute pressure is plotted along the vertical scale in Fig. 1-2. Lines of constant pressure, therefore, run horizontally across the chart. If you compare Fig. 1-4A with Fig. 1-2, you can see that the scale intervals represent larger pressure changes as you get higher up the pressure scale. This spacing permits the plotting of large pressure values on a smaller diagram.

1.21 **Enthalpy (Btu/lb).** Enthalpy is plotted along the horizontal scale in Fig. 1-2. Lines of constant enthalpy, therefore, are vertical, as shown in Fig. 1-4B. As you read earlier in this Lesson, enthalpy represents the total heat energy in 1 lb of refrigerant.

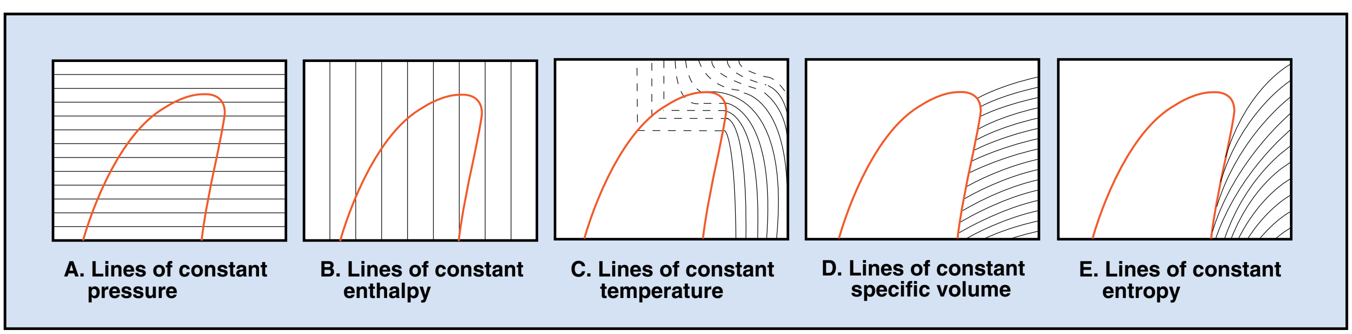
1.22 **Temperature (°F).** In the superheated vapor zone and the subcooled liquid zone, lines of constant temperature are nearly vertical. In the mixed liquid-vapor zone they run horizontally between the saturation curves. To simplify the diagram, lines of constant temperature are shown only in the superheated vapor zone, as shown in Fig. 1-4C.

1.23 **Specific volume (ft³/lb).** Lines of constant volume extend from the saturated vapor curve out into the superheated vapor zone (refer to Fig. 1-2 and Fig. 1-4D). They usually are not shown in the other zones.

1.24 **Entropy (Btu/lb × °R).** *Entropy* is an engineering term generally applied to a compression process. An ideal compression process would follow a constant entropy line on the pressure-enthalpy (P-H) diagram. In actual practice, however, heat is added during the compression process. The change of entropy is a measure of the unavailable energy resulting from a change in the properties of a refrigerant that occur during compression. Change in entropy is defined as the ratio of the heat quantity added or subtracted during a process to the absolute temperature at which this heat flow occurs. Lines of constant entropy are shown in Fig. 1-4E.

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

Fig. 1-4. How basic refrigerant properties are shown on a P-H diagram



1-1. The temperature at which a liquid will boil or condense is called its ________ temperature.	1-1. SATURATION Ref: 1.07
1-2. If you remove heat from a saturated mixture of liquid and vapor, the vapor will ________.	1-2. CONDENSE Ref: 1.09
1-3. Enthalpy is a measure of the total ________ contained in a fluid.	1-3. THERMAL ENERGY or HEAT Ref: 1.10
1-4. For most refrigerants, enthalpy is considered to be zero at a saturation temperature of ________.	1-4. -40°F (-40°C) Ref: 1.10
1-5. Enthalpy involves the absorption of both ________ heat and ________ heat.	1-5. SENSIBLE; LATENT Ref: 1.14
1-6. At any point on the saturated liquid line on a P-H diagram, refrigerant is at its ________ point, but no vapor has formed.	1-6. BOILING Ref: 1.17
1-7. The saturated liquid and saturated vapor lines on a P-H diagram come together at the ________.	1-7. CRITICAL POINT Ref: 1.18
1-8. On a P-H diagram, absolute pressure is plotted along the ________ scale and enthalpy is plotted along the ________ scale.	1-8. VERTICAL; HORIZONTAL Ref: 1.20, 1.21

The Ideal Refrigeration Cycle

1.25 The P-H diagram is very useful in showing what takes place during the four stages of the vapor-compression refrigeration cycle. Each stage for an ideal cycle is shown in Fig. 1-5.

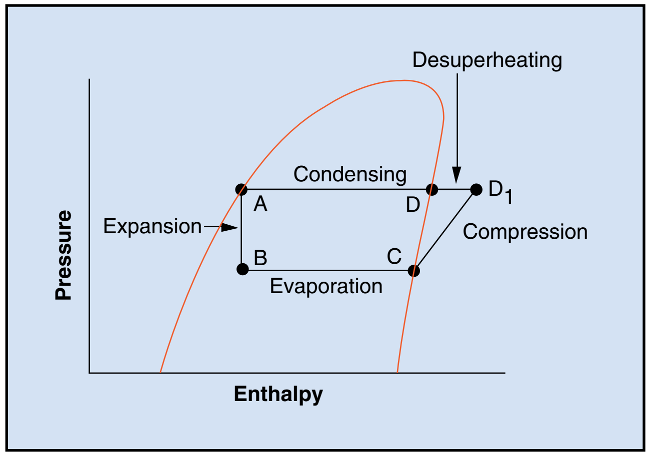
1.26 *Expansion* of liquid refrigerant takes place as the refrigerant moves through the thermostatic expansion valve from point A to point B. The expansion process is represented by line A-B (constant enthalpy). At point B, the refrigerant is a mixture of vapor and liquid, but is at a lower pressure than at A. (Notice that point B is in the mixed liquid-vapor zone.) Some liquid has boiled off to a vapor. The heat absorbed by the vapor came from the remaining liquid. This cooled the refrigerant from the condensing temperature to the evaporator temperature.

1.27 *Evaporation* of the remaining liquid takes place in the evaporator. The evaporation process is represented by line B-C. Note that line B-C also represents a considerable gain in enthalpy. This gain is the latent heat of vaporization of the refrigerant. At condition C, all of the liquid refrigerant is vaporized.

1.28 *Compression* of the refrigerant vapor by the compressor is represented by line C-D_1. The compressor adds energy to the refrigerant. This added energy is the gain in enthalpy from point C to point D_1, and is commonly called the *heat of compression*. The compressor raises the pressure of the refrigerant vapor to a level at which it can be condensed using readily available cooling media, such as surrounding air or cooling-tower water. Besides raising the pressure of the refrigerant vapor, the compressor also raises the refrigerant temperature. The temperature at point D_1 can be found using the constant temperature lines. It will be above the temperature corresponding to the saturation pressure at point D_1. Therefore, the refrigerant is superheated. (Point D_1 is in the superheated vapor zone.)

1.29 *Condensation and desuperheating* take place at constant pressure in the condenser. As superheat is removed from the refrigerant in the condenser, the enthalpy of the refrigerant decreases from D_1 to D. At point D the refrigerant is saturated vapor. Continued cooling in the condenser then causes the refrigerant vapor to condense until it is completely liquefied at point A. The condensing process is represented by line D-A. The loss in enthalpy as the condenser rejects heat is equal to the length of line D-A. The liquid then collects in a receiver tank, or is immediately metered back to the evaporator.

Fig. 1-5. Ideal vapor-compression cycle



Using the P-H Diagram

1.30 If you measure the evaporating and condensing temperatures of a particular refrigeration system, you can plot the entire refrigeration cycle on the P-H diagram. You then can read the values of the refrigerant properties at each point in the refrigerant cycle on the diagram, and follow the changes in these values through each process.

1.31 A refrigeration cycle has been drawn on Fig. 1-2 to demonstrate the use of the P-H diagram. The evaporating temperature is 20°F, with the suction gas leaving the evaporator in the saturated vapor condition. The condensing temperature is 100°F, with the liquid leaving the condenser as a saturated liquid.

1.32 **Pressures.** The temperature scale appears on both the saturated liquid and saturated vapor lines. Follow the horizontal line through those points, extending it to the vertical scales that show the saturation pressure. In this manner you will find:

	Temperature	Pressure
Condensing	100°F	211 psia
Evaporating	20°F	58 psia

1.33 **Refrigerating effect (RE).** The useful cooling done by the refrigerant, called the *refrigerating effect*, is represented by the change in enthalpy occurring in the evaporator. In Fig. 1-2, the enthalpy of the liquid entering the evaporator is 39 Btu/lb on the horizontal scale. As the refrigerant changes to vapor, its enthalpy increases to 106 Btu/lb, also on the horizontal scale. The change in enthalpy is the difference between 106 Btu/lb and 39 Btu/lb. Thus, the refrigerating effect is:

$$\text{RE} = 106 \text{ Btu/lb} - 39 \text{ Btu/lb} = 67 \text{ Btu/lb.}$$

1.34 **Ton of refrigeration.** The common unit of measure for refrigerating effect is the *ton of refrigeration*. One ton of refrigeration equals the heat absorbed in melting 1 ton (2000 lb) of ice in 24 hr. The latent heat of fusion of ice at sea level atmospheric pressure is 144 Btu/lb—that is, it takes 144 Btu to melt 1 lb of ice. Therefore, the amount of heat absorbed in melting 1 ton of ice is 144 × 2000, or 288,000 Btu. You can express 1 ton of refrigeration as 288,000 Btu/24 hr:

$$1 \text{ ton} = \frac{288{,}000 \text{ Btu}}{24 \text{ hr}} = 12{,}000 \text{ Btu/hr, or}$$

$$1 \text{ ton} = \frac{12{,}000 \text{ Btu}}{60 \text{ min}} = 200 \text{ Btu/min}$$

1.35 **Refrigerant flow rate (R).** The rate at which the refrigerant circulates through the system is called the *refrigerant flow rate*, and is expressed in lb/min. If you assume the refrigeration load (T) is 10 tons, you can find R as follows:

$$\text{T} = 10 \text{ tons} = 10 \times 200 \text{ Btu/min} = 2000 \text{ Btu/min}$$

$$\text{RE} = 67 \text{ Btu/lb}$$

$$\text{R} = \frac{\text{T}}{\text{RE}} = \frac{2000 \text{ Btu/min}}{67 \text{ Btu/lb}} = 29.8 \text{ lb/min}$$

1.36 **Compression ratio (CR).** If you divide the absolute condensing pressure by the absolute evaporating pressure, you have the *compression ratio* of the compressor. This number indicates the working strength the compressor must have. For this example, the compression ratio is:

$$\text{CR} = \frac{211 \text{ psia}}{58 \text{ psia}} = 3.6$$

1.37 **Heat of compression.** From the example in Fig. 1-2, you can see that a further increase in enthalpy occurs during compression—from 106 Btu/lb (at evaporating pressure) to 120.5 Btu/lb (at condensing pressure). The difference between these two values is the *heat of compression*, expressed as:

$$\text{Heat of compression} = h_{g\ (\text{discharge})} - h_{g\ (\text{suction})}$$

$$= 120.5 \text{ Btu/lb} - 106 \text{ Btu/lb}$$

$$= 14.5 \text{ Btu/lb.}$$

1.38 The heat of compression (14.5 Btu/lb) is the work done by the compressor for each pound of refrigerant circulated through the system. If you multiply this value by the number of pounds of refrigerant circulated per minute, you can find the heat flow rate in Btu/min:

$$\text{Heat flow rate} = \text{heat of compression} \times \text{refrigerant flow rate}$$

$$= 14.5 \text{ Btu/lb} \times 29.8 \text{ lb/min}$$

$$= 432 \text{ Btu/min.}$$

1.39 **Compressor horsepower.** The *horsepower* (hp) is a unit of power in the English measurement system. One horsepower is the power needed to do 33,000 ft-lb of work in one minute. When stated in terms of heat rather than mechanical work, 1 hp equals 42.4 Btu/min. You can find the power used by the compressor for the heat of compression as follows:

$$\text{Heat flow rate} = 432 \text{ Btu/min}$$

$$1 \text{ hp} = 42.4 \text{ Btu/min}$$

$$1 \text{ Btu/min} = \frac{1}{42.4} \text{ hp}$$

$$\text{Heat flow rate} = 432\left(\frac{1}{42.4} \text{ hp}\right)$$

$$= 10.2 \text{ hp} = \text{compressor power}$$

1.40 Sometimes you might need to find the power required per ton of refrigeration. In this case, you simply divide the compressor power by the number of tons of refrigeration load:

$$\text{power/ton} = \frac{\text{compressor power}}{\text{refrigeration load}}$$

$$= \frac{10.2\text{ hp}}{10\text{ ton}} = 1.02\text{ hp/ton}$$

1.41 **Coefficient of performance (COP).** The *coefficient of performance* is the ratio of the refrigerating effect to the work done by the compressor (heat of compression) for each pound of refrigerant. Assuming no friction loss occurs in the ideal system, the COP can be expressed as:

$$\text{COP} = \frac{\text{refrigerating effect}}{\text{heat of compression}}$$

$$= \frac{67\text{ Btu/lb}}{14.5\text{ Btu/lb}} = 4.6$$

1.42 **Compressor discharge temperature.** You can read the compressor discharge temperature at the end of the compression line shown in Fig. 1-2. In the example, the compressor discharge temperature is approximately 141°F.

1.43 **Compressor displacement.** You can read the specific volume of the vapor at the start of compression in Fig. 1-2. It is about 0.94 ft^3/lb. The system is circulating 29.8 lb of refrigerant per minute. Therefore, the compressor must handle 0.94 × 29.8, or 28 ft^3 of suction per minute.

1.44 **Heat rejection in condenser.** The heat rejected in the condenser equals the change in enthalpy occurring during the condensing process. In the Fig. 1-2 example, enthalpy decreases from 120.5 Btu/lb to 39 Btu/lb. The difference equals 81.5 Btu/lb. Because 29.8 lb of refrigerant is circulating per minute, the total heat rejected in the condenser is 29.8 lb/min × 81.5 Btu/lb, or 2428.7 Btu/min.

1.45 Notice that the heat rejected in the condenser equals the heat absorbed in the evaporator plus the energy supplied by the compressor:

$$2429\text{ Btu/min} = 1997\text{ Btu/min} + 432\text{ Btu/min.}$$

1.46 When you are working with a P-H diagram, the values you can read on the scales are only close approximations. If greater accuracy is required for some calculations, you can consult manufacturers' tables, like the one shown in Table l-l. These give enthalpy, pressure, and other values that are precise to three or four decimal places. The tables are often available in handy pocket-size form.

Liquid Subcooling

1.47 When the refrigerant vapor has condensed completely to liquid in the condenser, its condition point lies on the saturated liquid curve. At this point, the refrigerant liquid is *saturated*. If the saturated liquid is cooled to a temperature below its saturation temperature, so that its condition point lies in the subcooled liquid zone, the refrigerant is said to be subcooled. *Subcooling* is the process of cooling the condensed refrigerant to a temperature lower than the saturation temperature. Subcooling is used to increase system efficiency, and to ensure that only liquid (and no vapor) enters the metering device.

1.48 Subcooling can be accomplished in several ways. Two of the most common are the condenser method and the heat-exchanger method.

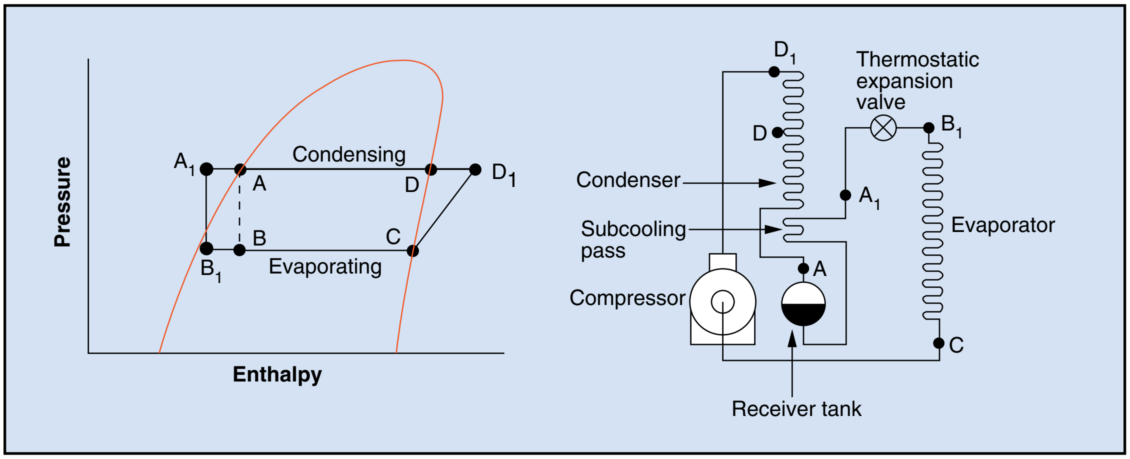
1.49 **Condenser method.** The condenser method of subcooling makes it possible to increase the refrigerating effect (evaporator capacity) with no increase in compressor power. Figure 1-6 on the following page shows a piping arrangement for condenser subcooling in which the liquid refrigerant is piped through a subcooling pass on its way to the expansion valve. The enthalpy drop due to subcooling is represented by the line A-A_1. Compare this figure to Fig. 1-2, and you will see the benefits of subcooling the refrigerant 20°F. The temperature of the liquid refrigerant drops from 100°F to 80°F. The enthalpy at 80°F is about 33 Btu/lb. The refrigerating effect—that is, the enthalpy change that takes place in the evaporator—is now greater:

$$\text{RE} = 106\text{ Btu/lb} - 33\text{ Btu/lb}$$

$$= 73\text{ Btu/lb.}$$

1.50 Without subcooling, the refrigerating effect was 67 Btu/lb. Thus, the increase in refrigerating effect with subcooling is 73 – 67, or 6 Btu/lb. Expressed as a percentage, the increase is 6 ÷ (67 × 100), or 8.9%. Notice that no increase in power is required to achieve this increase in capacity.

Fig. 1-6. Subcooling–condenser method



1.51 **Heat-exchanger method.** When a suction-line heat exchanger is used to subcool the refrigerant liquid from A to A_1, as shown in Fig. 1-7, the cold vapor from the evaporator is used to lower the temperature of the liquid refrigerant below the saturation temperature. At the same time, heat is transferred within the system to the cold vapor leaving the evaporator at C, so that it becomes superheated (C_1). Although this method increases the refrigerating effect, it does not always result in increased system capacity. With some refrigerants, the refrigerant flow rate (lb/min) is reduced, because the lower density of the superheated vapor reduces the pumping capacity of the compressor. For this reason, there is no overall increase in system capacity. With other refrigerants, however, this method of subcooling does increase system capacity.

1.52 A further difficulty sometimes experienced with the heat exchanger method is that the heat of compression added to the heat of the vapor entering the compressor at C_1 results in higher superheat temperatures at D_2. The temperature might be high enough to cause oil decomposition and even refrigerant burnout at the discharge valves. If the temperature is acceptable, however, the heat-exchanger method can be used to advantage.

A Practical Refrigeration Cycle

1.53 The *ideal* refrigeration cycle in Fig. 1-5 is based on the simplified assumption that no vapor superheating (except in compression), no liquid subcooling, no pressure losses (except in the thermostatic expansion valve), and no heat flow (except in the evaporator or condenser) occur. Of course, an actual refrigeration cycle is different from the ideal cycle in several ways:

- Superheating of suction gas is normal in actual cycles. In fact, some superheating is required to prevent liquid from entering the compressor. The evaporator, uninsulated suction lines, and hermetic motors are major sources of heat that produce superheat.
- Subcooling of the liquid refrigerant is normal, especially by the condenser method.
- Some pressure losses occur in every flow process.
- Some heat transfer always takes place between piping and surroundings.
- In an actual compressor, compression does not take place at constant entropy.
- Because reciprocating compressors require some clearance in the cylinders, some of the compressed gas re-expands as the piston moves through its suction stroke.

1.54 Pressure losses occur when high-velocity vapor is pushed through the compressor valve. To overcome these internal losses, the compressor must pump to pressures slightly above the condensing pressure and slightly below the evaporating pressure.

Fig. 1-7. Subcooling–heat-exchanger method

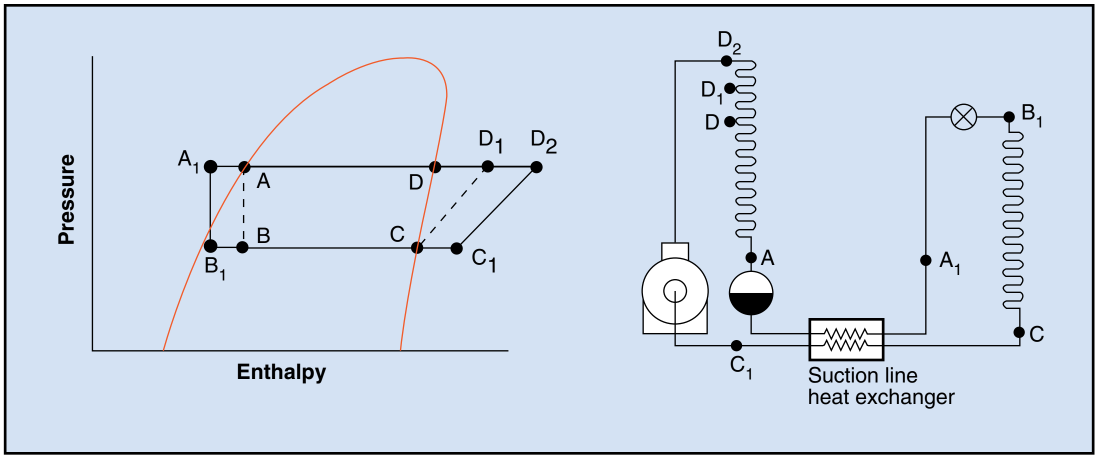
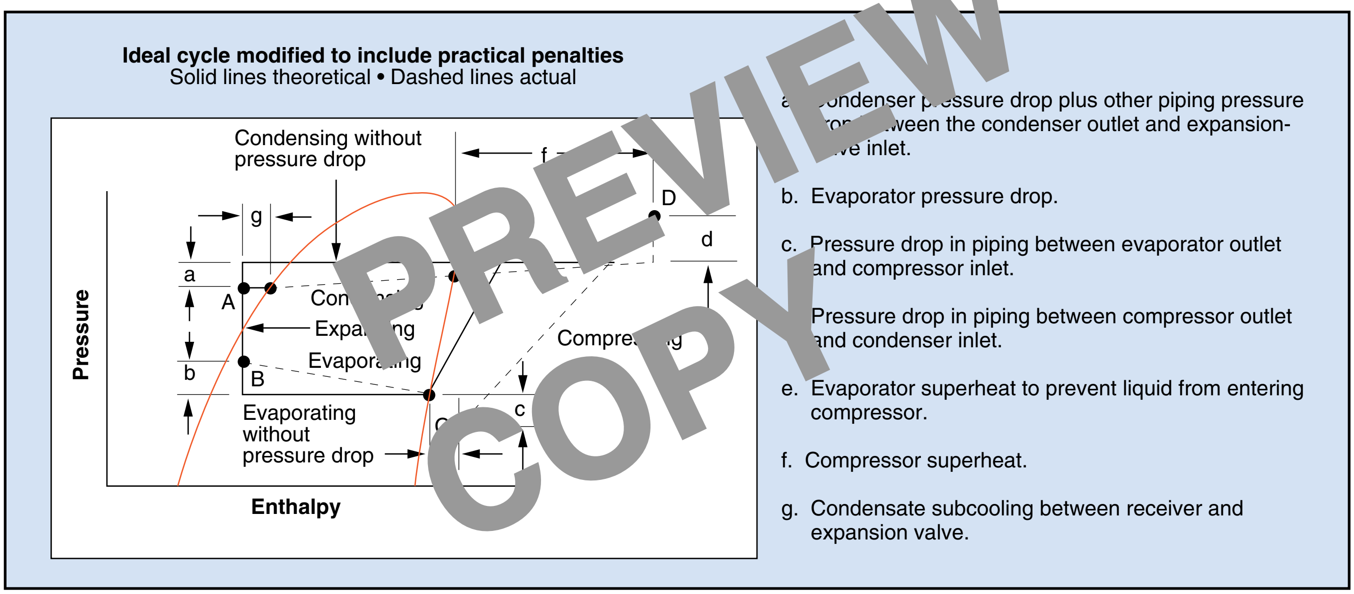


Fig. 1-8. Modified ideal cycle



1.55 The ideal refrigeration cycle shown in Fig. 1-5 is used for reference purposes. By studying the ideal cycle, you can approximate the conditions in an actual cycle. To picture the actual cycle accurately, however, you must measure the deviations from the ideal cycle and adjust the diagram accordingly. Having pressure taps at the inlet and outlet of each coil make exact computations possible. Figure 1-8 shows the ideal cycle modified to include practical deviations. As you progress through this course, you will be able to duplicate the work necessary to draw such a diagram.

1-9. What happens to the enthalpy of a refrigerant during compression?	1-9. IT INCREASES Ref: 1.28
1-10. Condensation appears as a horizontal line on a P-H diagram because _________ remains constant.	1-10. PRESSURE Ref: 1.29
1-11. The useful cooling done by a refrigerant is called the ________.	1-11. REFRIGERATING EFFECT Ref: 1.33
1-12. How is one ton of refrigeration defined?	1-12. THE HEAT ABSORBED IN MELTING 1 TON OF ICE IN 24 HR Ref: 1.34
1-13. Dividing the absolute condensing pressure by the absolute evaporating pressure results in the ________ of the compressor, an indication of the compressor's required working strength.	1-13. COMPRESSION RATIO Ref: 1.36
1-14. The increase in enthalpy that occurs during compression is called the ________.	1-14. HEAT OF COMPRESSION Ref: 1.37
1-15. To calculate the coefficient of performance, divide the _________ by the ________.	1-15. REFRIGERATING EFFECT; HEAT OF COMPRESSION Ref: 1.41
1-16. What are the two purposes of subcooling?	1-16. INCREASE SYSTEM EFFICIENCY; ENSURE THAT ONLY LIQUID ENTERS THE METERING DEVICE Ref: 1.47

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

1-1. As the pressure increases in a closed container of saturated liquid, the

- ☐ a. liquid starts to evaporate
- ☐ b. liquid's boiling point drops
- ☐ c. liquid's boiling point rises
- ☐ d. liquid's temperature drops

1-2. In refrigerant saturation tables, the symbol h_f represents the

- ☐ a. enthalpy of evaporation
- ☐ b. enthalpy of saturated liquid
- ☐ c. enthalpy of saturated vapor
- ☐ d. latent heat of vaporization

1-3. Which of the following equations represents the enthalpy of saturated vapor?

- ☐ a. $h_f = h_g + h_{fg}$
- ☐ b. $h_f = h_g \times h_{fg}$
- ☐ c. $h_{fg} = h_f + h_g$
- ☐ d. $h_g = h_f + h_{fg}$

1-4. The horizontal scale on a P-H diagram indicates

- ☐ a. enthalpy
- ☐ b. pressure
- ☐ c. temperature
- ☐ d. volume

1-5. When the refrigeration cycle is plotted on a P-H diagram, the lower horizontal line represents

- ☐ a. compression of the refrigerant vapor
- ☐ b. condensation of the refrigerant vapor
- ☐ c. evaporation of the liquid refrigerant
- ☐ d. metering of the liquid refrigerant

1-6. Which of the following takes place during the compression stage of the refrigeration cycle?

- ☐ a. Enthalpy increases
- ☐ b. Pressure decreases
- ☐ c. Temperature decreases
- ☐ d. Vapor increases in volume

1-7. On a P-H diagram, condensation and desuperheating are represented by a horizontal line because the process

- ☐ a. involves no change in volume
- ☐ b. takes place at constant enthalpy
- ☐ c. takes place at constant pressure
- ☐ d. takes place at constant temperature

1-8. Refrigerating effect is shown in a P-H diagram as the

- ☐ a. gain in enthalpy occurring in the compressor
- ☐ b. gain in enthalpy occurring in the evaporator
- ☐ c. gain in enthalpy occurring in the condenser
- ☐ d. loss in pressure occurring in the metering device

1-9. The coefficient of performance is the ratio of the refrigerating effect to the

- ☐ a. compressor horsepower
- ☐ b. heat flow rate
- ☐ c. heat of compression
- ☐ d. heat rejection in the condenser

1-10. One of the purposes of subcooling the liquid refrigerant is to

- ☐ a. cancel the effect of superheating
- ☐ b. ensure that only liquid enters the expansion valve
- ☐ c. reduce compressor discharge temperature
- ☐ d. reduce compressor overheating

SUMMARY

Refrigerant is a fluid that carries heat from one point to another in a refrigeration system. When you work with refrigeration systems, you are working with refrigerants in closed containers at varying pressures. You can control the temperature of the refrigerant at different points in the system by controlling the pressure.

You can use a pressure-enthalpy (P-H) diagram to analyze refrigeration system performance. The P-H diagram has various zones that correspond to the physical states of the refrigerant at different temperatures and pressures. You can measure certain values and use the results to plot the refrigeration cycle on the P-H diagram.

It is helpful to study an ideal refrigeration cycle so that you can approximate the conditions in an actual cycle. An actual cycle must take into account pressure drops in piping and other practical deviations from that ideal.

Answers to Self-Check Quiz

1-1. c. Liquid's boiling point rises. Ref: 1.05

1-2. b. Enthalpy of saturated liquid. Ref: 1.11

1-3. d. $h_g = h_f + h_{fg}$. Ref: 1.13

1-4. a. Enthalpy. Ref: 1.21, Fig. 1-2

1-5. c. Evaporation of the liquid refrigerant. Ref: 1.27, Fig. 1-5

1-6. a. Enthalpy increases. Ref: 1.28, Fig. 1-5

1-7. c. Takes place at constant pressure. Ref: 1.29, Fig. 1-5

1-8. b. Gain in enthalpy occurring in the evaporator. Ref: 1.33

1-9. c. Heat of compression. Ref: 1.41

1-10. b. Ensure that only liquid enters the expansion valve. Ref: 1.47

Contributions from the following sources are appreciated:

Table 1-1. E.I. DuPont de Nemours & Company
Figure 1-2. Reprinted with permission of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers