Refrigeration and HVAC

Refrigeration Training System

Job Sheets - Courseware Sample

54223-F0

Order no.: 54223-30
First Edition
Revision level: 07/2017

By the staff of Festo Didactic

Internet: www.festo-didactic.com
e-mail: did@de.festo.com

Printed in Canada

ISBN 978-2-89747-940-4 (Printed version)
ISBN 978-2-89747-942-8 (CD-ROM)
Legal Deposit – Bibliothèque et Archives nationales du Québec, 2017
Legal Deposit – Library and Archives Canada, 2017

Safety and Common Symbols

The following safety and common symbols may be used in this manual and on the equipment:

Symbol	Description
⚠ DANGER	**DANGER** indicates a hazard with a high level of risk which, if not avoided, will result in death or serious injury.
⚠ WARNING	**WARNING** indicates a hazard with a medium level of risk which, if not avoided, could result in death or serious injury.
⚠ CAUTION	**CAUTION** indicates a hazard with a low level of risk which, if not avoided, could result in minor or moderate injury.
CAUTION	**CAUTION** used without the *Caution, risk of danger* sign ⚠, indicates a hazard with a potentially hazardous situation which, if not avoided, may result in property damage.
	Caution, risk of electric shock
	Caution, hot surface
	Caution, risk of danger. Consult the relevant user documentation.
	Caution, lifting hazard
	Caution, belt drive entanglement hazard
	Caution, chain drive entanglement hazard
	Caution, gear entanglement hazard
	Caution, hand crushing hazard
	Notice, non-ionizing radiation
	Consult the relevant user documentation.

Safety and Common Symbols

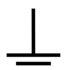
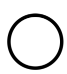
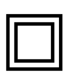
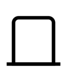
Symbol	Description
	Direct current
	Alternating current
	Both direct and alternating current
	Three-phase alternating current
	Earth (ground) terminal
	Protective conductor terminal
	Frame or chassis terminal
	Equipotentiality
	On (supply)
	Off (supply)
	Equipment protected throughout by double insulation or reinforced insulation
	In position of a bi-stable push control
	Out position of a bi-stable push control

Table of Contents

Preface

The Refrigeration Training System provides the student with theoretical and practical knowledge in the operation and maintenance of typical refrigeration components and systems. Practical experience is gained by the student through procedure steps contained in each job sheet.

The courseware starts by introducing the student to the fundamentals of physics related to refrigeration. Then the basic refrigeration cycle is studied. Typical refrigeration components are studied. The student is then familiarized with system startup, inspection, and troubleshooting.

The topics covered in this manual are provided in the form of job sheets. Each job sheet includes a brief description of the task to perform, drawing(s) related to this task when necessary, as well as a step-by-step procedure of the task.

The Refrigeration Training System is intended for use with the Heat, Ventilating, and Air Conditioning (LVHVAC) software, a powerful learning tool that allows the real-time monitoring of the temperature and pressure sensed at critical points of the system. The software automatically calculates and refreshes the system variables, including the refrigeration capacity, the coefficient of performance, and the superheat. Moreover, a plotting function displays in real-time the pressure-enthalpy diagram, constantly changing as the refrigeration cycle evolves toward equilibrium. Furthermore, a trend recorder provides a graph over time of the data acquired on the pressure, temperature, and compressor.

In order for students to be able to perform the job sheets in this manual, therefore, the LVHVAC software must have been previously installed on the student's computer. The material covered in this manual is intended to provide a level of refrigeration knowledge that will enable the student to enter more specialized areas of study in this field. The answers to all procedural questions in this student manual can be found in the Instructor Guide.

We invite readers of this manual to send us their tips, feedback, and suggestions for improving the book.

Please send these to did@de.festo.com.

The authors and Festo Didactic look forward to your comments.

About This Manual

Manual objectives

When you have completed this manual, you will know the fundamentals of physics related to refrigeration. You will be familiar with the refrigeration cycle. You will be able to describe the operation of typical refrigeration systems using industrial and commercial devices. You will know the basic principles used to startup, inspect, and troubleshoot refrigeration systems.

Safety considerations

Safety symbols that may be used in this manual and on the equipment are listed in the Safety and Common Symbols table at the beginning of the manual.

Safety procedures related to the tasks that you will be asked to perform are indicated in each exercise.

Make sure that you are wearing appropriate protective equipment when performing the tasks. You should never perform a task if you have any reason to think that a manipulation could be dangerous for you or your teammates.

Reference material

Complementary information to the information sheets in this manual can be found in the reference books listed in the Bibliography at the end of this manual.

Systems of units

Units are expressed using the metric system and International System (SI) of units. They are also expressed (between parentheses) in the U.S. customary system of units when the operating voltage is 120 V, 60 Hz.

To the Instructor

You will find in this Instructor Guide all the elements included in the Student Manual together with the answers to all questions, results of measurements, graphs, explanations, suggestions, and, in some cases, instructions to help you guide the students through their learning process. All the information that applies to you is placed between markers and appears in red.

Accuracy of measurements

The numerical results of the hands-on exercises may differ from one student to another. For this reason, the results and answers given in this manual should be considered as a guide. Students who correctly performed the exercises should expect to demonstrate the principles involved and make observations and measurements similar to those given as answers.

Sample

Extracted from

Job Sheets - Instructor

Refrigeration Components (Part II) and Enthalpy Diagram

INTRODUCTION

In the previous job sheet, you familiarized yourself with part of the components that make up a basic refrigeration system. In this job sheet, you will study the remainder of the components: the condenser, the expansion (metering) device, and the evaporator, as Figure 21 shows. You will then familiarize yourself with the pressure/enthalpy diagram of a refrigerant. You will learn how this diagram can be used to graphically represent the refrigeration cycle of a system.

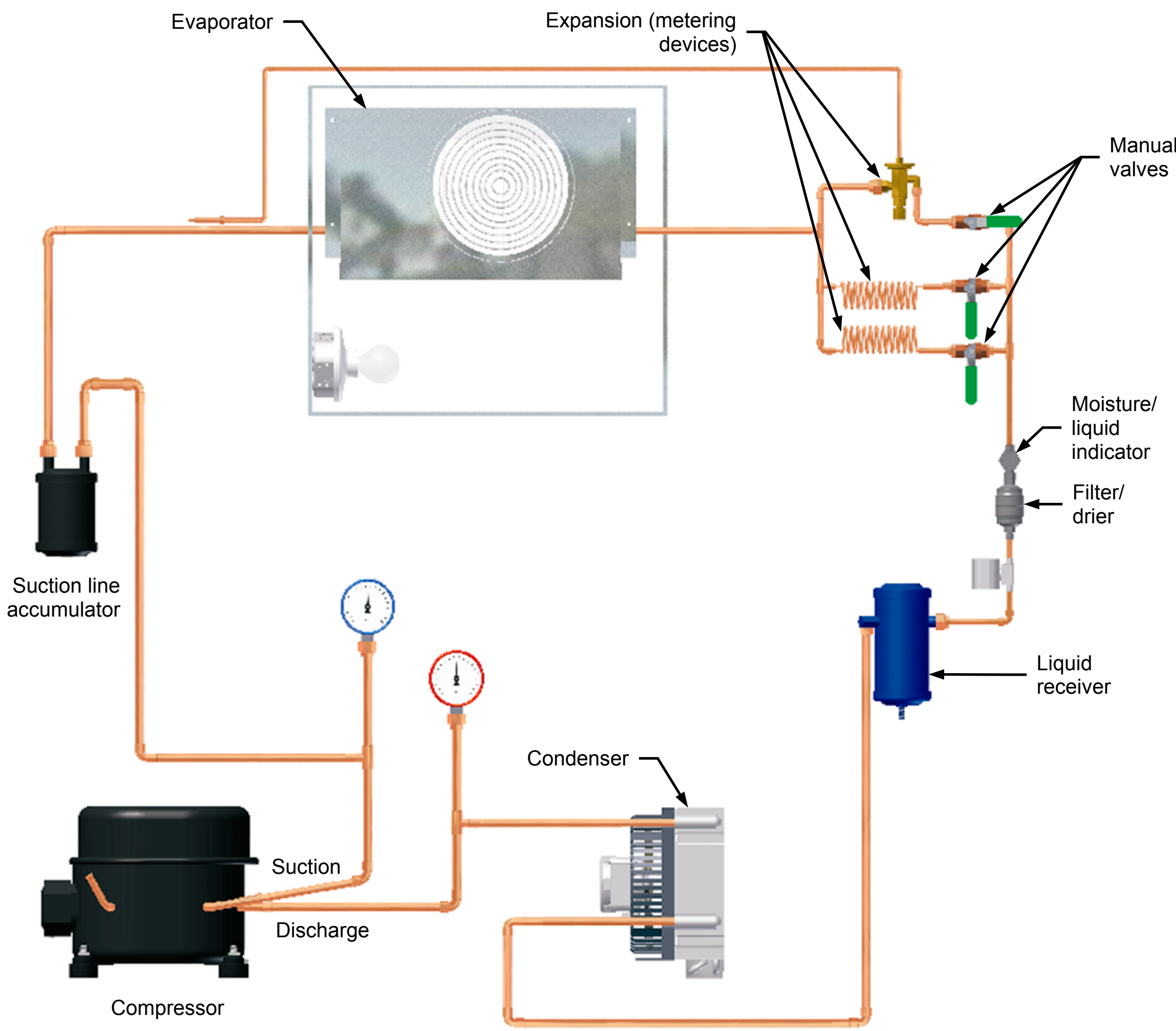


Figure 21. Refrigeration components of the system.

Condenser

The condenser **removes thermal energy** from the superheated vapor discharged by the compressor, turning it into a saturated liquid. At the outlet of the condenser, this liquid, because it has lost all its latent energy, is said to be **subcooled**.

The thermal energy removed by the condenser is transferred to the surrounding air, as long as the temperature of the air stays lower than the condensing temperature of the refrigerant.

- As Figure 22 shows, a condenser consists of copper or aluminum tubing bent in a serpentine shape through which the refrigerant is conducted.

- AsFigure 22 shows, the refrigerant flows through the tubing, thermal energy from the refrigerant transfers to the coils by **forced convection** and by **conduction**.

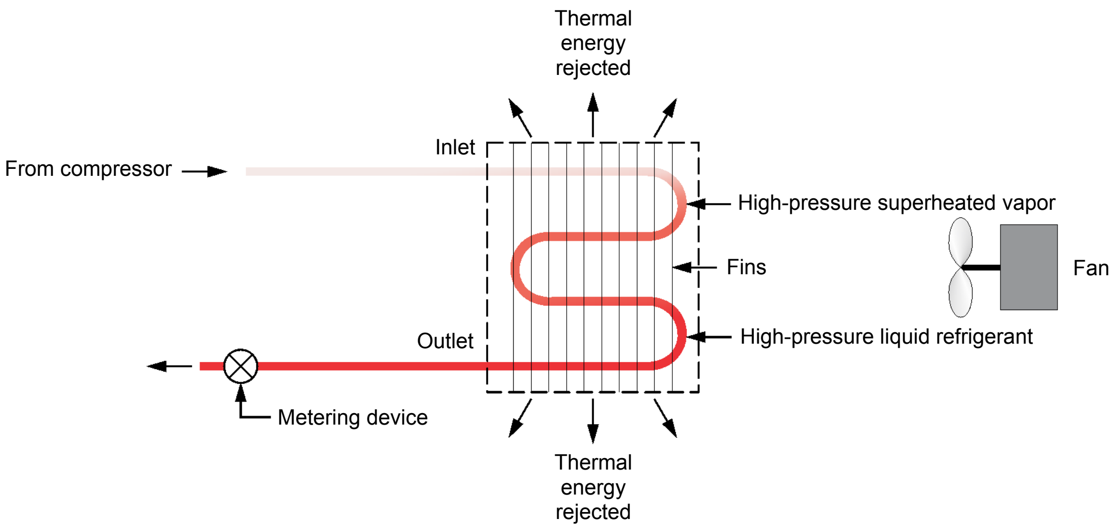
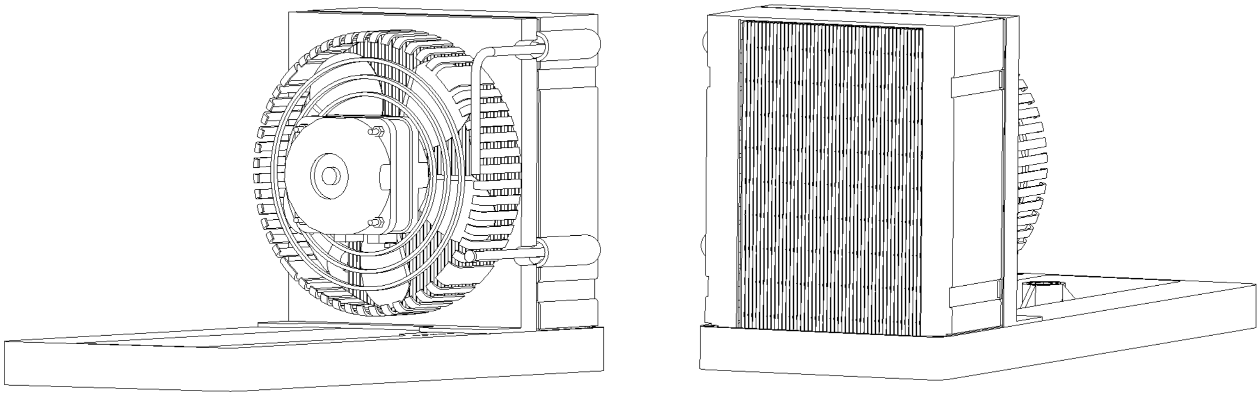


Figure 22. Removal of thermal energy through the condenser tubing.

- Thermal energy from the tubing then transfers to the air flowing across the coils by **convection**, causing the temperature of the refrigerant to decrease. The convection is forced by a fan. The higher the rotation speed of the fan is, the faster the circulation of fresh air across the tubing and, therefore, the higher the rate of thermal energy transfer between the tubing and the air.

- Attached to the tubing is a web of thin metallic fins that increase the surface of thermal energy transfer between the tubing and the surrounding air, which further increases the rate of thermal energy transfer by **forced convection**.

Figure 23 shows the condenser used on the Refrigeration Training System.



(a) Rear view (b) Front view

Figure 23. Condenser used on the Refrigeration Training System.

Expansion (metering) device

The expansion (metering) device is connected between the condenser and the evaporator. It makes the **breakpoint** between the **high-** and **low-pressure** sides of the system.

The expansion device consists of a **restriction** or **small orifice**, through which the liquid refrigerant from the condenser is forced to flow. This creates a **drop in the pressure** of the refrigerant, thereby **decreasing its boiling point** accordingly. This in turn causes part of the liquid to turn into **vapor**, and the temperature of the **remaining liquid** to decrease.

Due to its **high resistance** to the flow of refrigerant, the expansion device regulates (**meters**) this flow to the evaporator.

The Refrigeration Training System has two types of expansion (metering) devices:

– **capillary tubes**, which have a **fixed** restriction (orifice size);

– a **thermostatic expansion valve**, whose restriction can be **adjusted**.

Capillary tube

A **capillary tube** is a simple length of tubing having an inside diameter smaller than that of the main refrigerant line, as Figure 24 shows. Because of this, the capillary tube restricts and meters the liquid refrigerant.

The **friction** and **evaporation** of the refrigerant that takes place within the capillary tube are responsible for the pressure drop created across it. The longer the capillary tube, the greater the created pressure drop, for any given inside diameter of the tube. Also, the smaller the inside diameter of the capillary tube, the greater the created pressure drop, for any given length of the tube.

The Refrigeration Training System comes with **two** capillary tubes, mounted on the front panel, just ahead of the evaporator. These tubes create differing pressure drops, allowing you to test the effect that this difference makes on the operation of the system. Since capillary tubes offer a fixed restriction to refrigerant flow, they do not have the ability of thermostatic expansion valves (TEV's) to adapt to significant changes in the heat load.

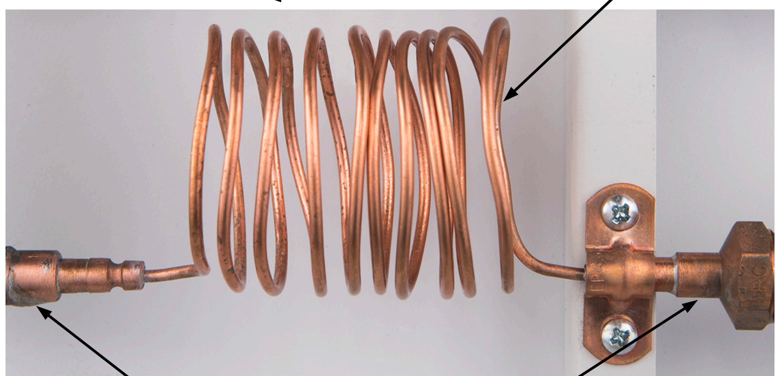


Figure 24. Capillary tube operation.

Thermostatic expansion valve (TEV)

A **thermostatic expansion valve** (**TEV**) is a device that meters the flow rate of refrigerant going to the evaporator by adapting it to any changes in the heat load. It allows more refrigerant to flow when the evaporator warms up and, conversely, it allows less refrigerant to flow when the evaporator cools down.

Figure 25 (a) shows the internal construction a thermostatic expansion valve (TEV) with its main components. As this figure shows, a TEV consists of a diaphragm with a needle valve and a spring that is adjusted to obtain the desired level of superheat. An external **thermal bulb**, partly filled with liquid refrigerant, is used to sense the temperature of the refrigerant at the outlet of the evaporator.

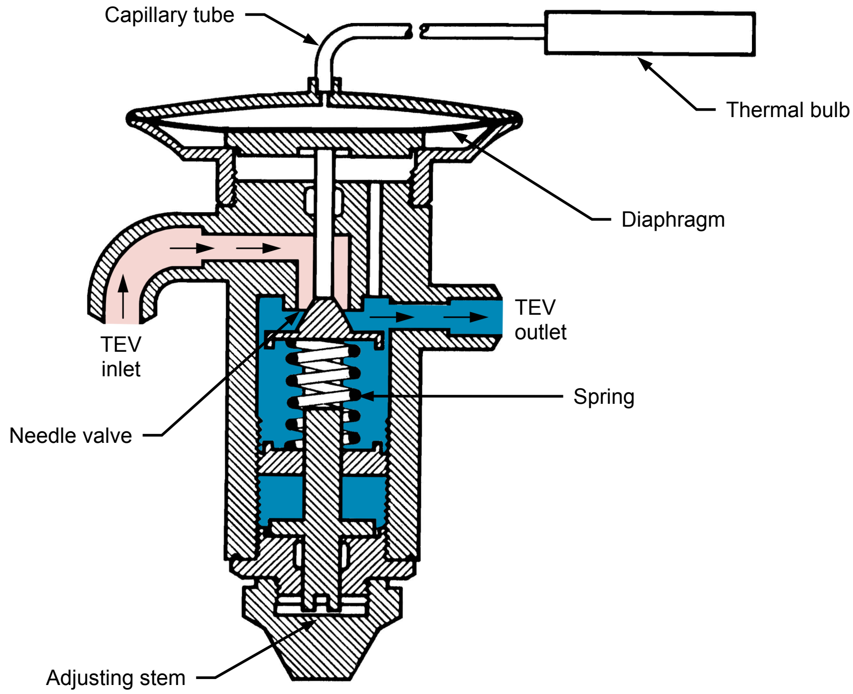
Figure 25 (b) shows control of an evaporator using a TEV.

> On the Refrigeration Training System, the TEV is mounted on the front panel of the trainer, just ahead of the cooling chamber. The thermal bulb of the TEV is attached to the suction line of the system.

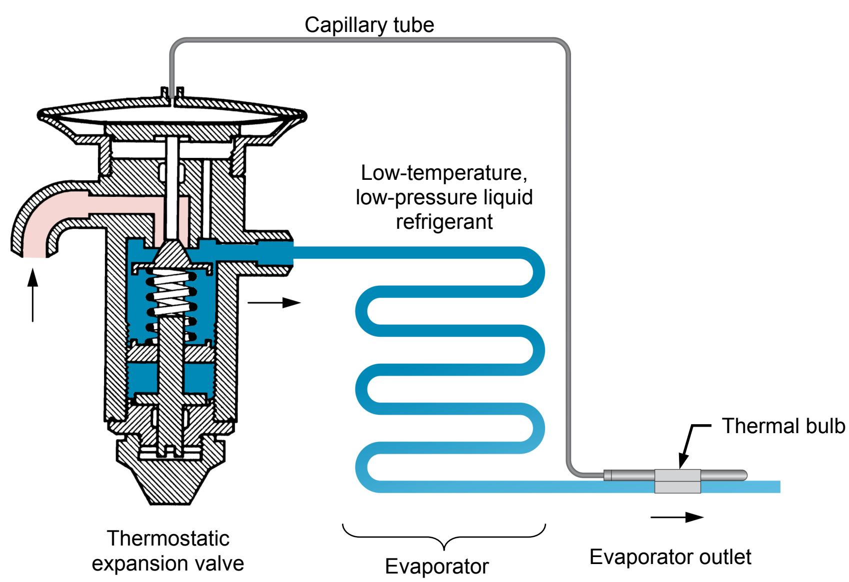
– The difference between the temperature of the refrigerant sensed by the bulb at the evaporator outlet and the temperature of the refrigerant at the evaporator inlet results in a pressure difference that acts on the spring of the TEV to modify the TEV opening accordingly.

– Thus, when this temperature difference is high, the TEV opening is larger to increase the flow of refrigerant entering the evaporator compared to when this temperature difference is low.

– When the compressor is stopped, the valve is automatically closed to stop the flow of refrigerant to the evaporator.



(a) Thermostatic expansion valve construction



(b) Control of an evaporator using a TEV

Figure 25. Thermostatic expansion valve.

Evaporator

The evaporator, located within the cooling chamber, turns the mixture of liquid and gas refrigerant coming out of the expansion device into a **low-pressure superheated vapor**. In the process, the evaporator **removes thermal energy** from the cooling chamber.

An evaporator is basically constructed the same as a condenser. As Figure 26 shows, the evaporator consists of copper or aluminum tubing bent in a serpentine shape through which the refrigerant is conducted.

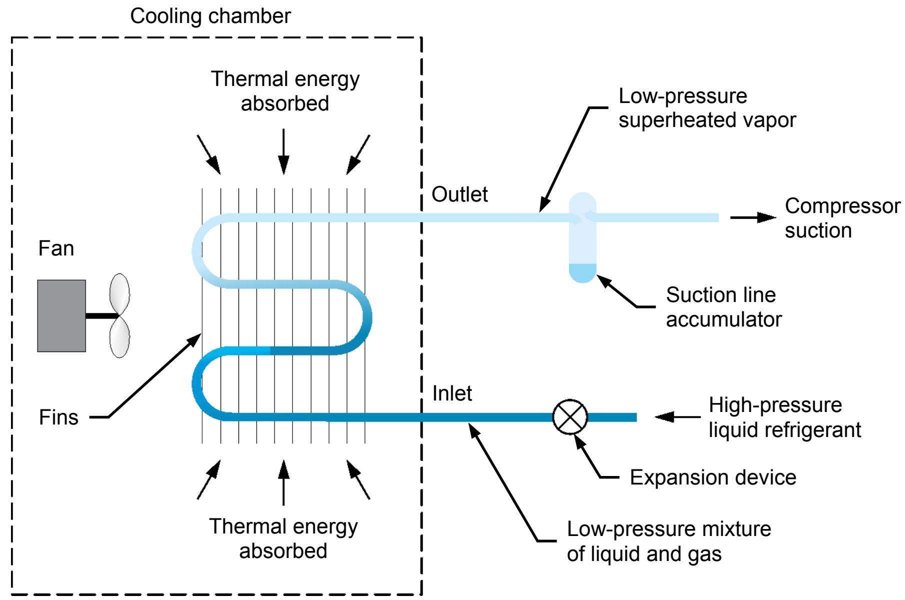


Figure 26. Absorption of thermal energy through the evaporator tubing.

– As the refrigerant (mixture of gas and liquid) flows through the evaporator, thermal energy from the warmer air in the cooling chamber transfers to the refrigerant, through the evaporator tubing, by **conduction**, and through air recirculation by the **forced convection** created by the evaporator fan.

– The higher the rotation speed of the fan is, the faster the recirculation created by the fan and, therefore, the higher the rate of thermal energy transfer between the surrounding air and the refrigerant.

– Attached to the tubing is a web of thin metallic fins that increase the surface of thermal energy transfer between the tubing and the surrounding air, which further increases the rate of thermal energy transfer by **forced convection**.

As it flows through the tubing of the evaporator, the refrigerant absorbs **thermal energy** (**sensible heat**). This increases its temperature to the boiling point. As it further absorbs **thermal energy** (latent heat), the refrigerant turns into vapor. The vapor then flows from the evaporator outlet to the suction side of the compressor.

Figure 27 shows the evaporator of the Refrigeration Training System. This evaporator is of the forced-circulation type, and is enclosed, along with an electric fan, in a compact metal housing.

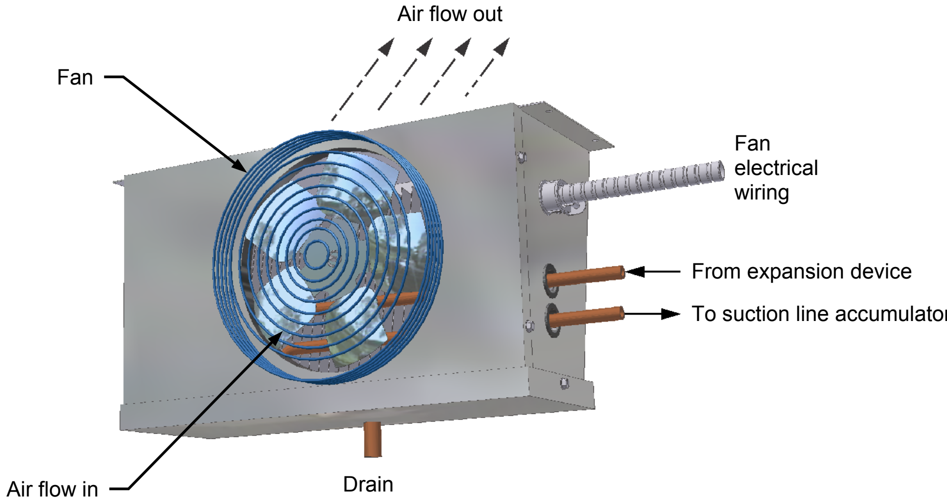


Figure 27. Evaporator used on the Refrigeration Training System.

Enthalpy table

The amount of thermal energy per unit of mass of a refrigerant is called **enthalpy** (or **heat content**).

Enthalpy can be measured in different units, such as

– **metric** or **S.I.** units of kilojoules per kilogram ($\mathbf{kJ/kg}$);

– **U.S. custom** units of British thermal units per pound-mass ($\mathbf{Btu/lbm}$).

As it flows through the evaporator to refrigerate the space, the refrigerant absorbs thermal energy. Consequently, the enthalpy of the **vapor** at the outlet of the evaporator is **greater** than that of the liquid at the inlet of the expansion device. The thermal energy absorbed per unit of mass of the refrigerant is called the **refrigeration effect**.

Refrigerant manufacturers normally provide tables indicating the enthalpy of their refrigerants at various temperatures. Appendix D for example, is a table indicating the enthalpy of saturated liquid and vapor for the R-134a refrigerant, at different temperatures. Take a look at this table.

Pressure-enthalpy diagrams

In addition to tables, refrigerant manufacturers provide diagrams that show the enthalpy of their refrigerant as a function of absolute pressure. A simplified version of a **pressure-enthalpy diagram** is shown in Figure 28.

– The horizontal axis of the diagram is graduated in enthalpy units, while the vertical axis is graduated in absolute pressure units.

– Two curves on the diagram indicate the changes in state between **saturated vapor** (right-hand curve) and **saturated liquid** (left-hand curve).

– Between these two curves are horizontal lines of **constant temperature**.

A point representing the current refrigerant properties (pressure, enthalpy, and temperature) that is located on a horizontal line indicates that the refrigerant is a mixture of liquid and vapor. If this point is located on or to the right of the saturated vapor curve, the refrigerant is superheated. If this point is located on or to the left of the saturated liquid curve, the refrigerant is subcooled.

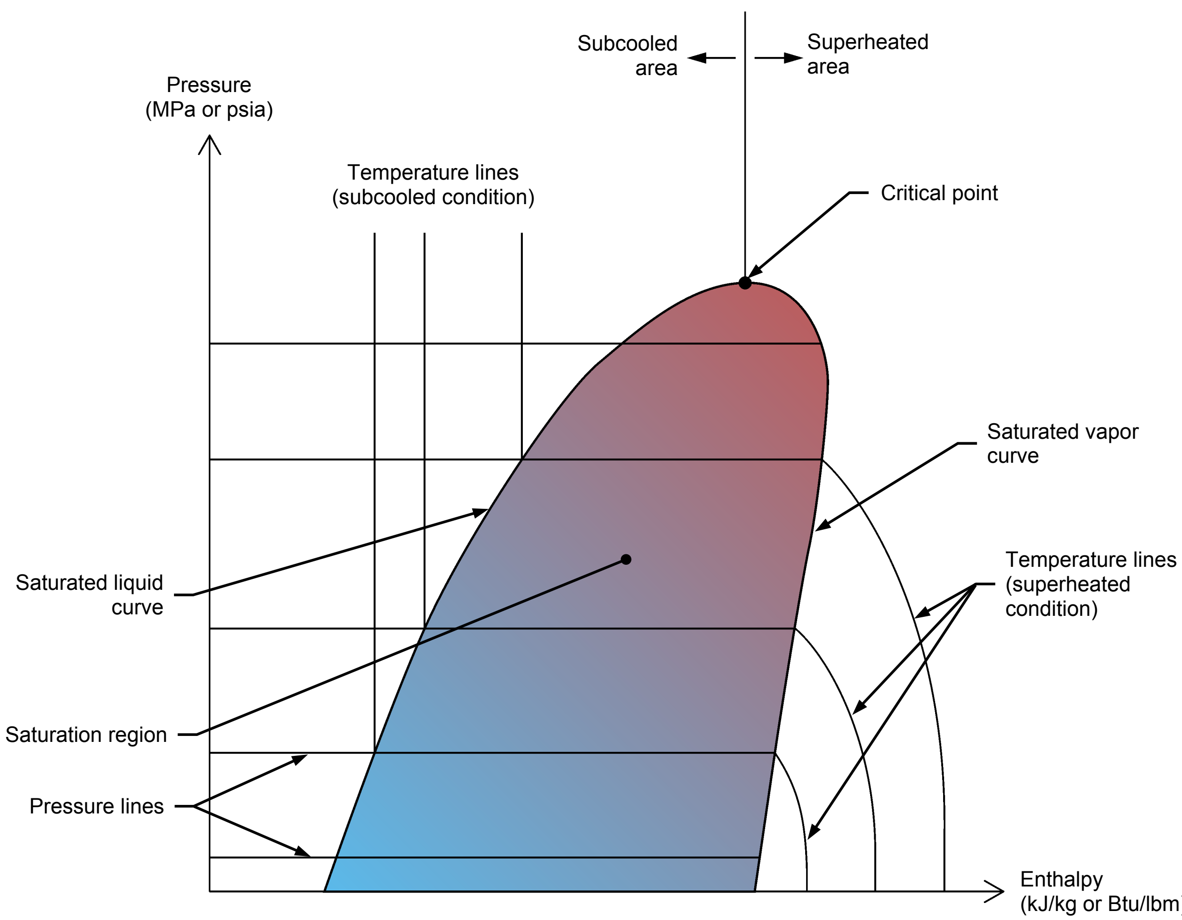


Figure 28. Pressure-enthalpy diagram.

The pressure-enthalpy diagram of a refrigerant can be used to determine the amount of thermal energy absorbed or removed by the refrigerant between two points.

Graphical representation of the refrigeration cycle

The refrigeration cycle of a system can be represented by a simplification of the pressure-enthalpy diagram of the refrigerant it uses. The refrigerant cycle is a quadrilateral representing the refrigerant properties (pressure, temperature, enthalpy) at any point of the cycle.

Figure 29, for example, shows a refrigeration cycle of the Refrigeration Training System, displayed in the LVHVAC software. Icons indicate the typical equipment associated with each phase of the refrigeration cycle.

– The horizontal line ❶ ← ❺ corresponds to a change of state from **vapor to liquid**, as the refrigerant flows through the condenser. The temperature and absolute pressure of the refrigerant stay constant, but the enthalpy decreases from right to left. The pressure is at the compressor discharge (HP) level.

– At point ❶, **high-pressure subcooled liquid** reaches the inlet of the expansion device.

– Between points ❶ and ❷, the refrigerant flows through the expansion device: its absolute pressure drops, while its enthalpy stays constant. Part of the liquid turns into vapor.

– The horizontal line ❷ → ❸ corresponds to a change of state from **liquid to vapor**, as the refrigerant flows through the evaporator. The temperature and absolute pressure of the refrigerant stay constant, but the enthalpy increases from left to right. The pressure is at the compressor suction (LP) level.

– At point ❸, **low-pressure superheated** vapor reaches the compressor suction inlet.

– Between points ❸ and ❹, the compressor compresses the vapor, causing the absolute pressure of the refrigerant to rise, and its enthalpy to also rise.

– At point ❹, **high-pressure superheated vapor** is expelled from the compressor discharge outlet.

– At point ❺, the discharged vapor reaches the condenser inlet, and a new refrigeration cycle begins.

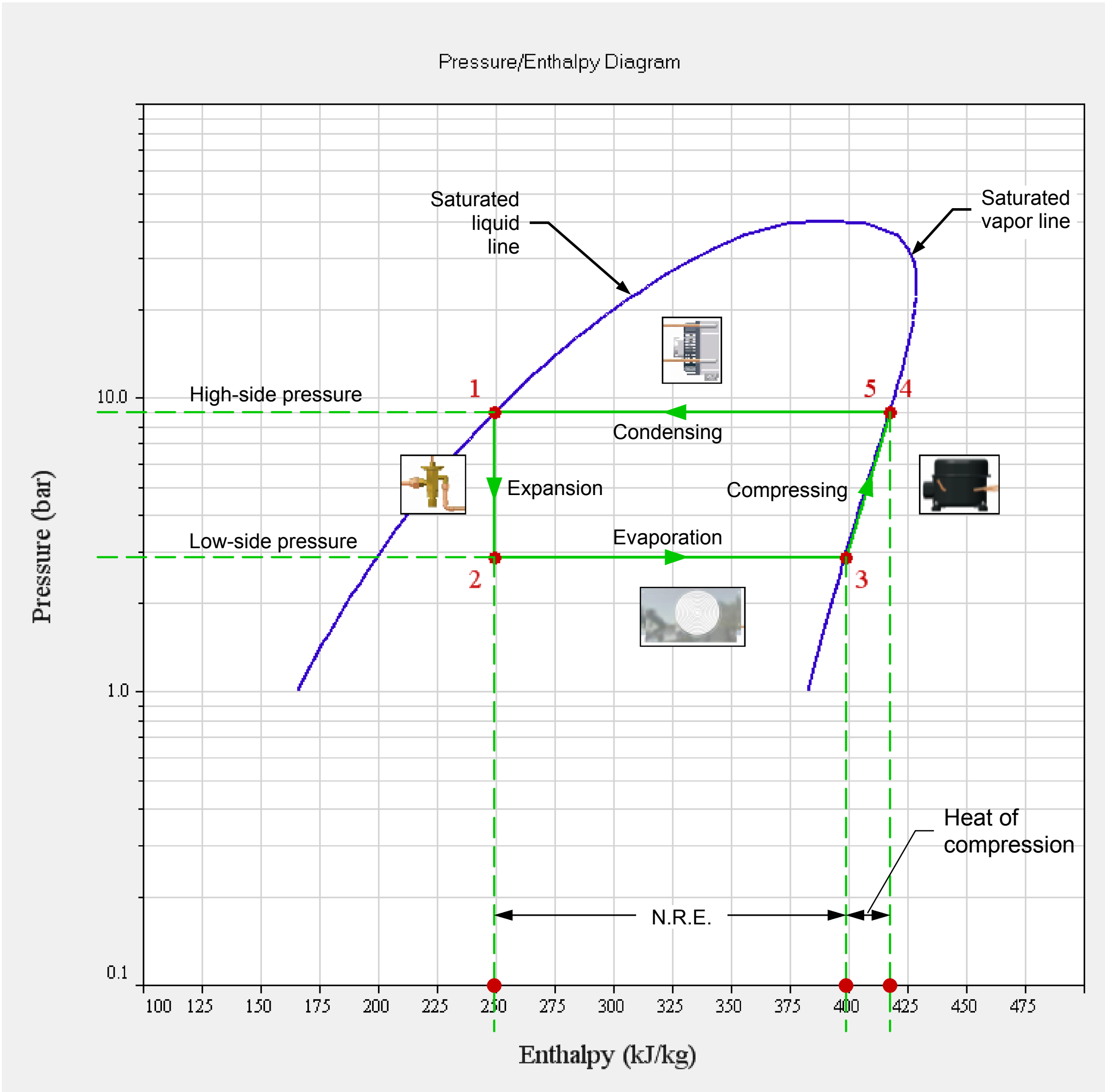


Figure 29. Pressure/enthalpy diagram for the R-134a (metric units).

N.R.E., heat of compression, and coefficient of performance

Important characteristics of a refrigeration system are: the net refrigeration effect, the heat of compression, and the coefficient of performance. These properties can be determined graphically by using the system's refrigeration cycle (refer to Figure 29.)

– The **net refrigeration effect (N.R.E.)** is the enthalpy removed by evaporation. It is determined by drawing vertical lines downward from points ❷ and ❸. The difference on the enthalpy (horizontal) axis where the lines cross this axis is equal to the N.R.E.

– The heat of compression is the enthalpy added to the vapor, mainly by the work done by the compressor. It is determined by drawing vertical lines downward from points ❸ and ❹. The difference on the enthalpy (horizontal) axis where the lines cross this axis is equal to the heat of compression.

– The **coefficient of performance (COP)** is a pure number indicating the efficiency of the refrigeration cycle. It corresponds to the ratio of the enthalpy removed by evaporation (or N.R.E.) to the enthalpy added to the vapor during the compressing phase. In equation form:

$$\text{Coefficient of performance} = \frac{\text{net refrigeration effect (N.R.E.)}_{\text{(kJ/kg or Btu/lbm)}}}{\text{heat of compression}_{\text{(kJ/kg or Btu/lbm)}}}$$

The higher the coefficient of performance, the better the efficiency of the system.

The COP of refrigeration systems varies according to the conditions under which they operate and the components constituting them. Therefore, this figure should not be used to compare the performance of two refrigeration systems that operate under differing conditions and/or that are not entirely made up of the same components.

Refrigeration Components (Part II) and Enthalpy Diagram

OBJECTIVE

In this job, you will learn how to observe the system temperatures and pressures over time at various points of the Refrigeration Training System, using the Trend Recorder of the LVHVAC software. You will then use an enthalpy table to determine the values required to plot the refrigeration cycle of the system. You will then observe the refrigeration cycle of the system and measure the coefficient of performance, using a Pressure/Enthalpy diagram.

PROCEDURE

Observing the system temperatures and pressures over time

1. On the control panel of the Refrigeration Training System, make sure that the COMPRESSOR switch is set to O (Off). Set the main POWER switch to On (I).

   Connect the Refrigeration Training System to the computer used to run the LVHVAC software, via a USB cable. Turn on the computer and then run the LVHVAC software.

2. Activate the Trend Recorder of the LVHVAC software: in the menu bar of this software, select the *Tools* menu, and then select the *Trend Recorder* option. This brings up the Trend Recorder, as Figure 30 shows (without the signals displayed in this figure, since the recorder has not been started yet):

   – Locate the section *General* of the Settings panel in the right section of the Trend Recorder. Set the *Scale* (*min*) field of this section to 30. This sets the display time (range of observation of the variables) of the Trend Recorder to 30 minutes.

   – Locate the section *Data* of the Settings panel in the right section of the Trend Recorder. Select the following variables only (deselect the other variables if they are selected);

     - Pressure 1;
     - Pressure 2;
     - Temperature 3;
     - Temperature 7;
     - Compressor current.

   – In the menu bar of the Trend Recorder, select *Acquisition*, and then *Start* to start the display of the selected variables.

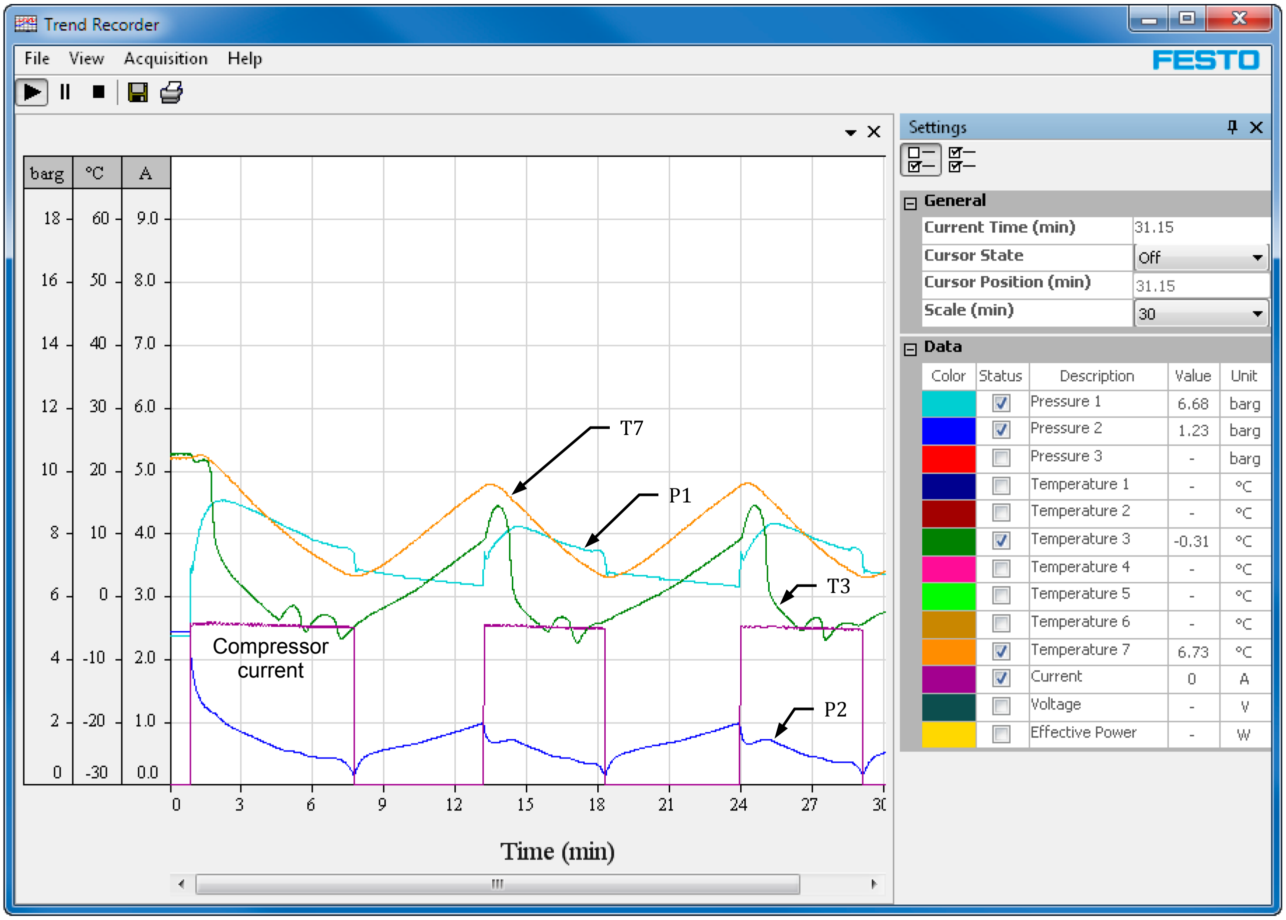


Figure 30. Trend Recorder of the LVHVAC software displaying selected variables as a function of time.

The setting of the CONDENSER FAN SPEED control knob is given as a guide for a typical room temperature of 22˚C (72˚F) approximately. You may need to slightly readjust this knob setting if your results differ significantly from the expected results.

3. On the Refrigeration Training System, make the following settings:

COMPRESSOR switch .... Off (O)
EVAPORATOR-FAN SPEED knob .... HIGH
CONDENSER-FAN SPEED knob .... Half of HIGH
HEAT LOAD switch .... Off (O)
Thermostat setpoint .... 5˚C (41˚F)

Manually-operated valves

V1 .... Open (handle turned fully counterclockwise)
V2 .... Closed (handle turned fully clockwise)
V3 .... Closed (handle turned fully clockwise)

4. Turn on the compressor. Let the system run for about 20 minutes.

5. On the Trend Recorder, examine the signal of Temperature 3 (temperature at the evaporator outlet), and fill in the following sentences.

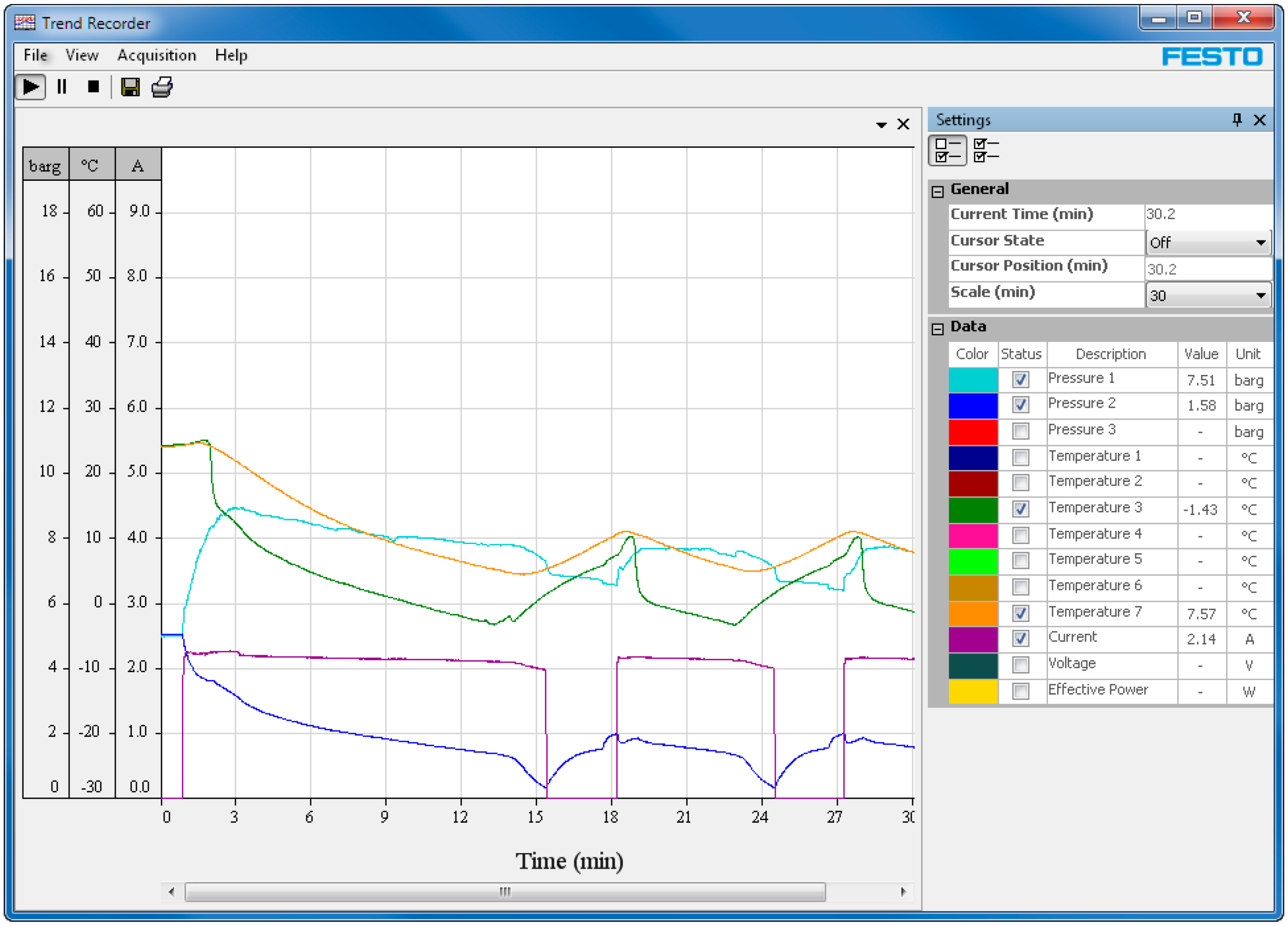
Immediately after power up, the temperature sensed by the thermal bulb of the TEV at the evaporator outlet is ______________ (higher/lower) than the thermostat setpoint of 5°C (41°F). This causes the opening of the thermostatic expansion valve (TEV) to be maximum to allow the full refrigerant flow to enter the evaporator. As a result, Temperature 3 ______________ (increases/decreases).

As the evaporator cools down, the TEV opening is reduced to decrease the flow of refrigerant entering the evaporator, causing Temperature 3 to ______________ (increase/decrease). As more refrigerant is allowed into the evaporator, the superheat sensed by the TEV sensing bulb ______________ (increases/decreases). This causes the TEV opening to ______________ (increase/decrease), causing the superheat to increase. This phenomena can repeat, cyclically or not, until thermal equilibrium is reached.

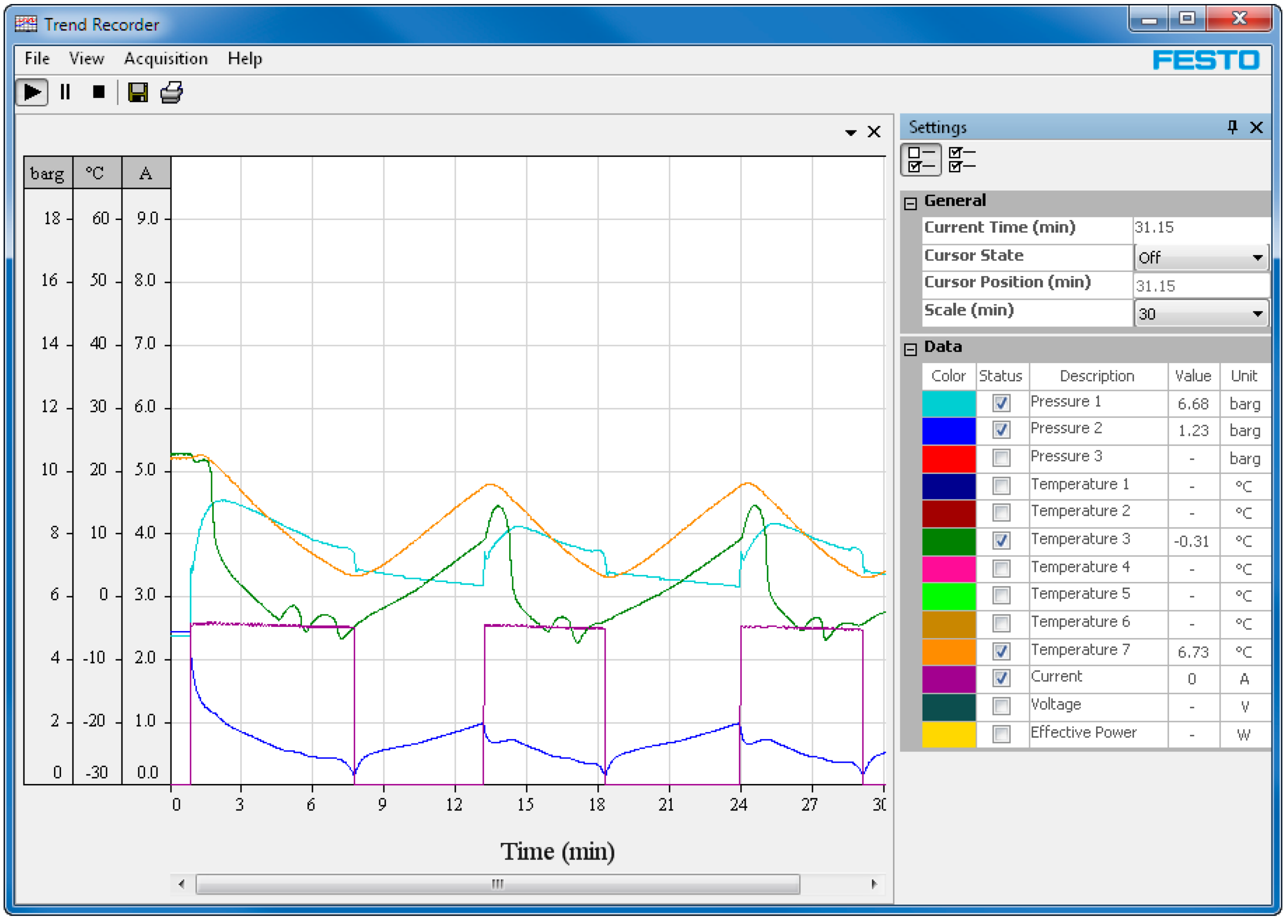
Immediately after power up, the temperature sensed by the thermal bulb of the TEV at the evaporator outlet is higher than the refrigerant temperature at the evaporator inlet. This causes the opening of the thermostatic expansion valve (TEV) to be maximum to allow the full refrigerant flow to enter the evaporator. As a result, Temperature 3 decreases.

As the evaporator cools down, the TEV opening is reduced to decrease the flow of refrigerant entering the evaporator, causing Temperature 3 to increase. As more refrigerant is allowed into the evaporator, the superheat sensed by the TEV sensing bulb decreases. This causes the TEV opening to decrease, causing the superheat to increase. This phenomena can repeat, cyclically or not, until thermal equilibrium is reached.

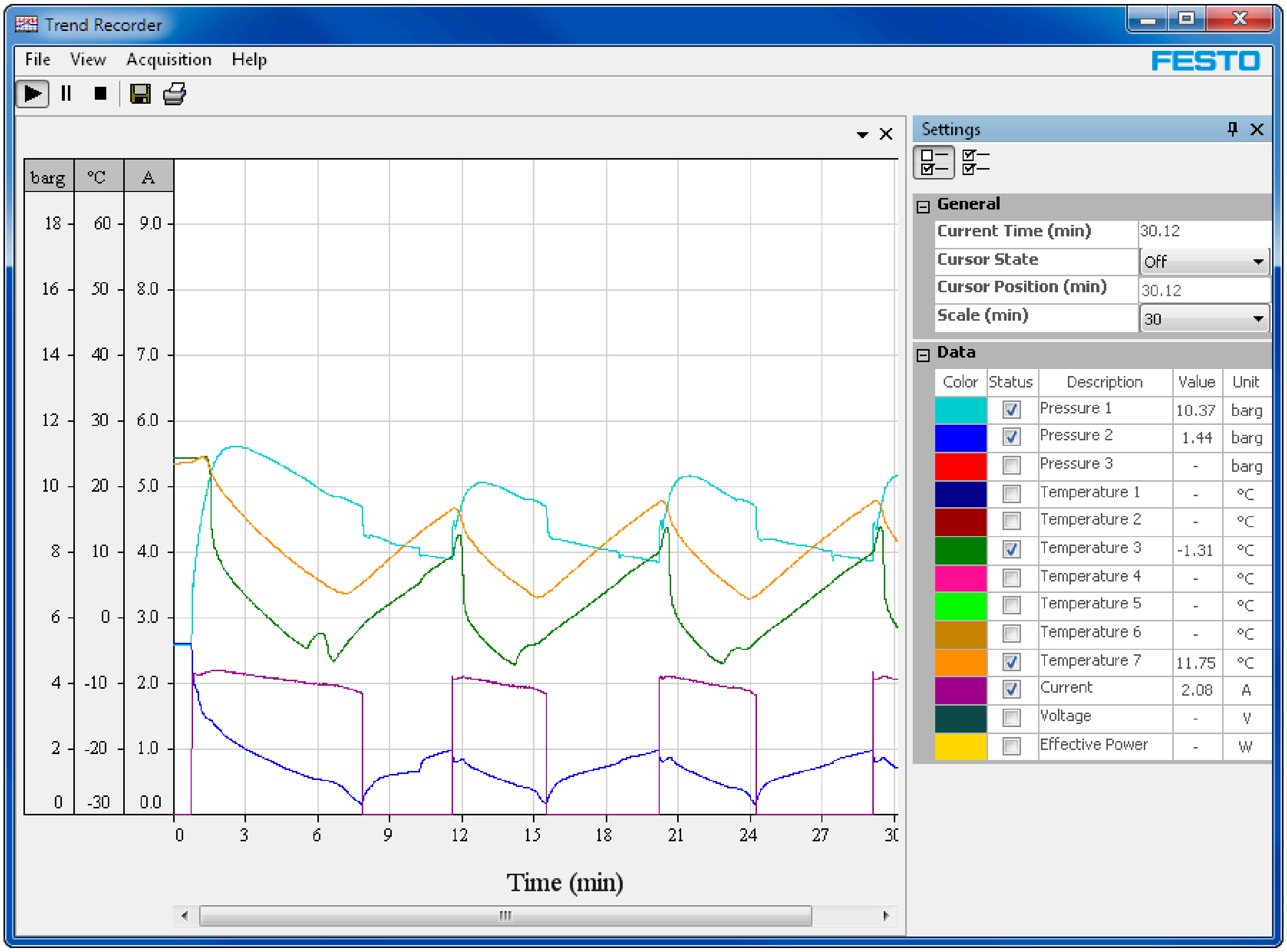
The following figures show examples of the signals displayed on the Trend Recorder as a function of time, for different operating voltages.



Example of the signals displayed on the Trend Recorder as a function of time for an operating voltage of 120 V, 60 Hz.



Example of the signals displayed on the Trend Recorder as a function of time for an operating voltage of 220-240 V, 50 Hz.



Example of the signals displayed on the Trend Recorder as a function of time for an operating voltage of 220 V, 60 Hz.

6. (Refer to the signals on the Trend Recorder). While Temperature 3 varies, does Temperature 7 (temperature in the cooling chamber) slowly decrease in a steady way until it becomes close to the thermostat setpoint of 5°C (41°F), causing the compressor to stop?

❑ Yes ❑ No

Yes.

7. (Refer to the recorded signals). When the compressor stops, Temperatures 3 and 7 both start to _______________ (increase/decrease) in a steady way. Once Temperature 7 has risen by a certain amount, the compressor restarts to begin a new cycle.

When the compressor stops, Temperatures 3 and 7 both start to increase in a steady way. Once Temperature 7 has risen by a certain amount, the compressor restarts to begin a new cycle.

8. Leave the Trend Recorder open for the rest of the exercise, but minimize this window. You should now see the Refrigeration Diagram of the LVHVAC software.

Determining refrigerant enthalpy at different pressures and temperatures

9. Figure 31 shows an example of the temperatures and pressures that can be read at the various test points of the Refrigeration Diagram, under the current operating conditions. Using the temperatures and pressures in this figure, fill in Table 16—once complete, this table contains all the data required to plot the refrigeration cycle of the system.

   – In the first (leftmost) column, record the gauge pressures indicated at PS1 and PS2 of the figure. Convert these pressures into absolute pressures and record your results in the second column.

   – In the third column, record the temperatures indicated at T1 through T5 of the figure.

   – In the fourth and fifth columns, record the enthalpy corresponding to each recorded temperature (T1 through T5), according to the enthalpy table for the R134-a in Appendix D of this manual.

Table 16. Pressure, temperature, and enthalpy data required to plot the refrigeration cycle.

Gauge pressure (barg/psig)	Absolute pressure (bar abs./psia)	Temperature (°C / °F)	Enthalpy (kJ/kg or Btu/lbm)	
			Liquid	Vapor
HP side (PS1):	HP side:	T1:		*
		T4:		*
		T5:		*
LP side (PS2)	LP side:	T2:	*	
		T3:	*	

* Not applicable

Pressure, temperature, and enthalpy data required to plot the refrigeration cycle. Refer to Figure 31.

Gauge pressure (barg/psig)	Absolute pressure (bar abs./psia)	Temperature (°C / °F)	Enthalpy (kJ/kg or Btu/lbm)	
			Liquid	Vapor
HP side (PS1): 7.6 barg (110.2 psig)	HP side: 8.61 bar abs. (124.9 psia)	T1: 33.9°C (93.0°F)	247.6 kJ/kg (42.7 Btu/lbm)	*
		T4: 52.2°C (126.0°F)	275.7 kJ/kg (54.7 Btu/lbm)	*
		T5: 41.8°C (107.2°F)	259.3 kJ/kg (47.7 Btu/lbm)	*
LP side (PS2): 1.6 barg (23.2 psig)	LP side: 2.61 bar abs. (37.9 psia)	T2: – 0.9°C (30.4°F)	*	398.3 kJ/kg (107.5 Btu/lbm)
		T3: – 0.6°C (30.9°F)	*	398.4 kJ/kg (107.6 Btu/lbm)

* Not applicable

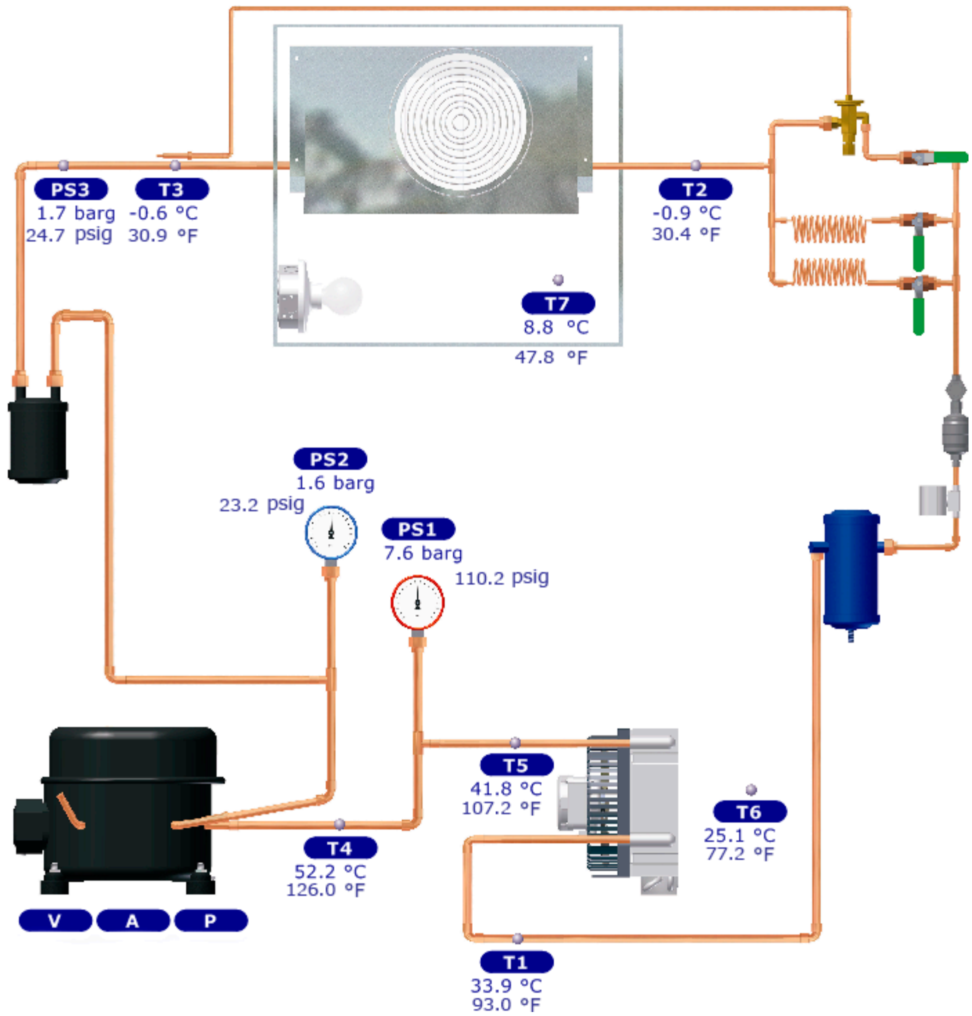


Figure 31. Example of the temperatures and pressures read at the various test points of the system.

10. According to the data recorded in Table 16, the temperature of the high-pressure liquid refrigerant is at a minimum at test point _______________ (T1/T4/T5). At that point, the enthalpy of the refrigerant is _______________ (minimum/maximum), the refrigerant being _______________ (superheated/subcooled) when it reaches the inlet of the expansion device.

Conversely, the temperature of the low-pressure vapor refrigerant is maximum at test point _______________ (T2/T3). At that point, the enthalpy of the refrigerant is _______________ (minimum/maximum), the refrigerant being _______________ (superheated/subcooled) at the evaporator outlet.

According to the data recorded in Table 16, the temperature of the high-pressure liquid refrigerant is at a minimum at test point T1. At that point, the enthalpy of the refrigerant is **minimum**, the refrigerant being **subcooled** when it reaches the inlet of the expansion device.

Conversely, the temperature of the low-pressure vapor refrigerant is maximum at test point T3. At that point, the enthalpy of the refrigerant is **maximum**, the refrigerant being **superheated** at the evaporator outlet.

Observing the refrigeration cycle and measuring the coefficient of performance

11. In the LVHVAC software, locate the **Refrigeration Training System** panel to the right of the **Refrigeration Diagram**. The *System Information* section of this panel allows you to enter the current settings of the system. Enter the current temperature controller setpoint, and the settings of the fan speeds and heat load.

Now locate the *Temperature Test Points* section of the **Refrigeration Training System** panel. This section indicates the current temperature, absolute pressure, and enthalpy at test points T1 through T5 of the Refrigeration Diagram. This data is continuously refreshed.

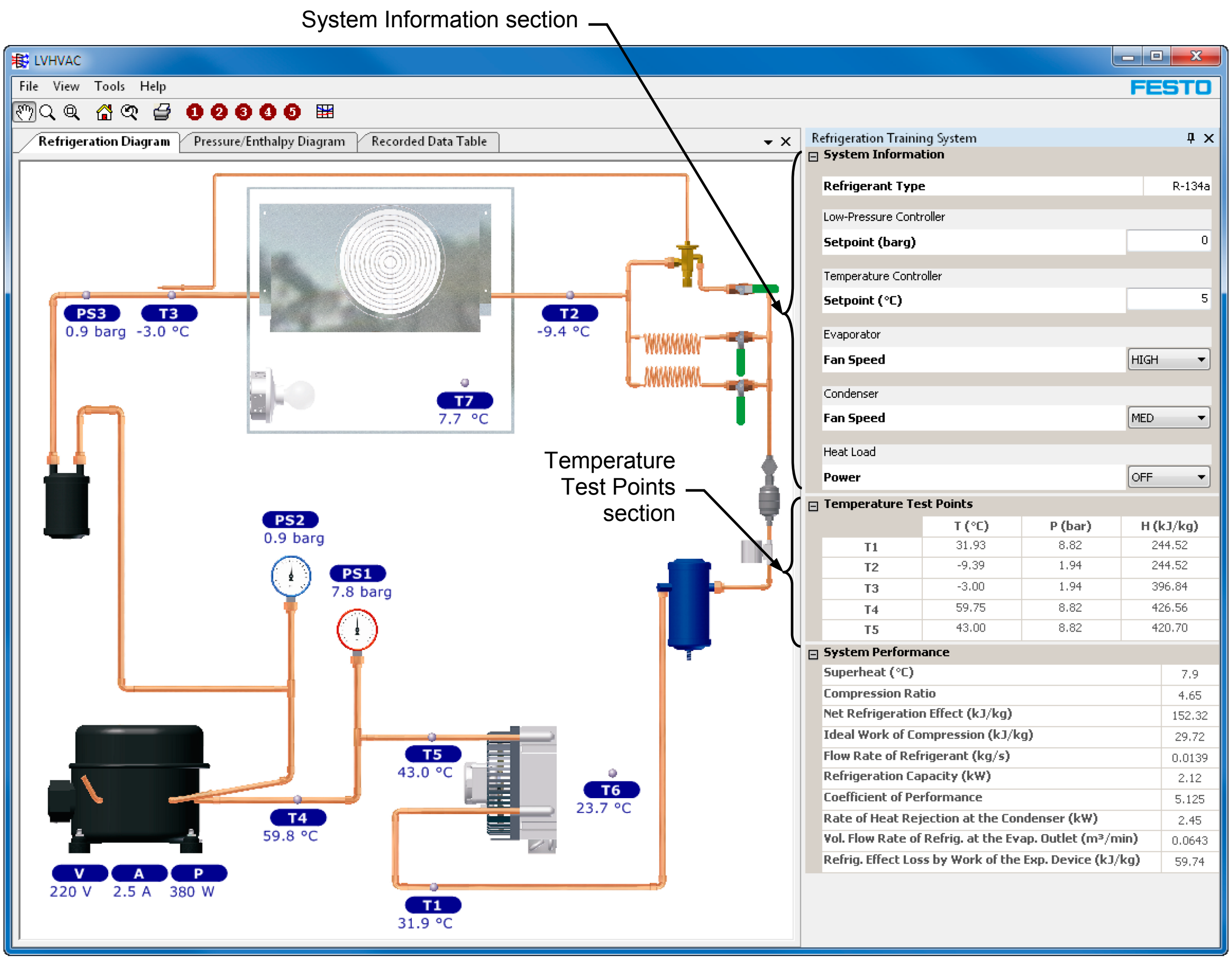


Figure 32. *System Information* and *Temperature Test Points* sections of the Refrigeration Training System panel.

12. While the compressor is running, make the following observations in the *Temperature Test Points* section of the **Refrigeration Training System** panel.

    – The pressures at T1, T4, and T5 are approximately equal. They correspond to the absolute pressure on the HP side of the system.

    – The pressures at T2 and T3 are approximately equal. They correspond to the absolute pressure on the LP side of the system.

13. In the menu bar of the LVHVAC software, select the *Tools* menu, and then click on *Options*..., which brings up the *Options* dialog box. Make sure that the *Display the Cycle Icons* check box is selected, and then click *OK* to close the *Options* dialog box.

14. Activate the **Pressure/Enthalpy Diagram** of the LVHVAC software.

The **Pressure/Enthalpy Diagram** shows the refrigeration cycle of the system, plotted by using the temperatures and absolute pressures at T1 through T5 of the system (as displayed in the *Temperature Test Points* section of the **Refrigeration Training System** panel).

The display of the refrigeration cycle is continuously refreshed to reflect any changes that may occur in the measured temperatures and pressures.

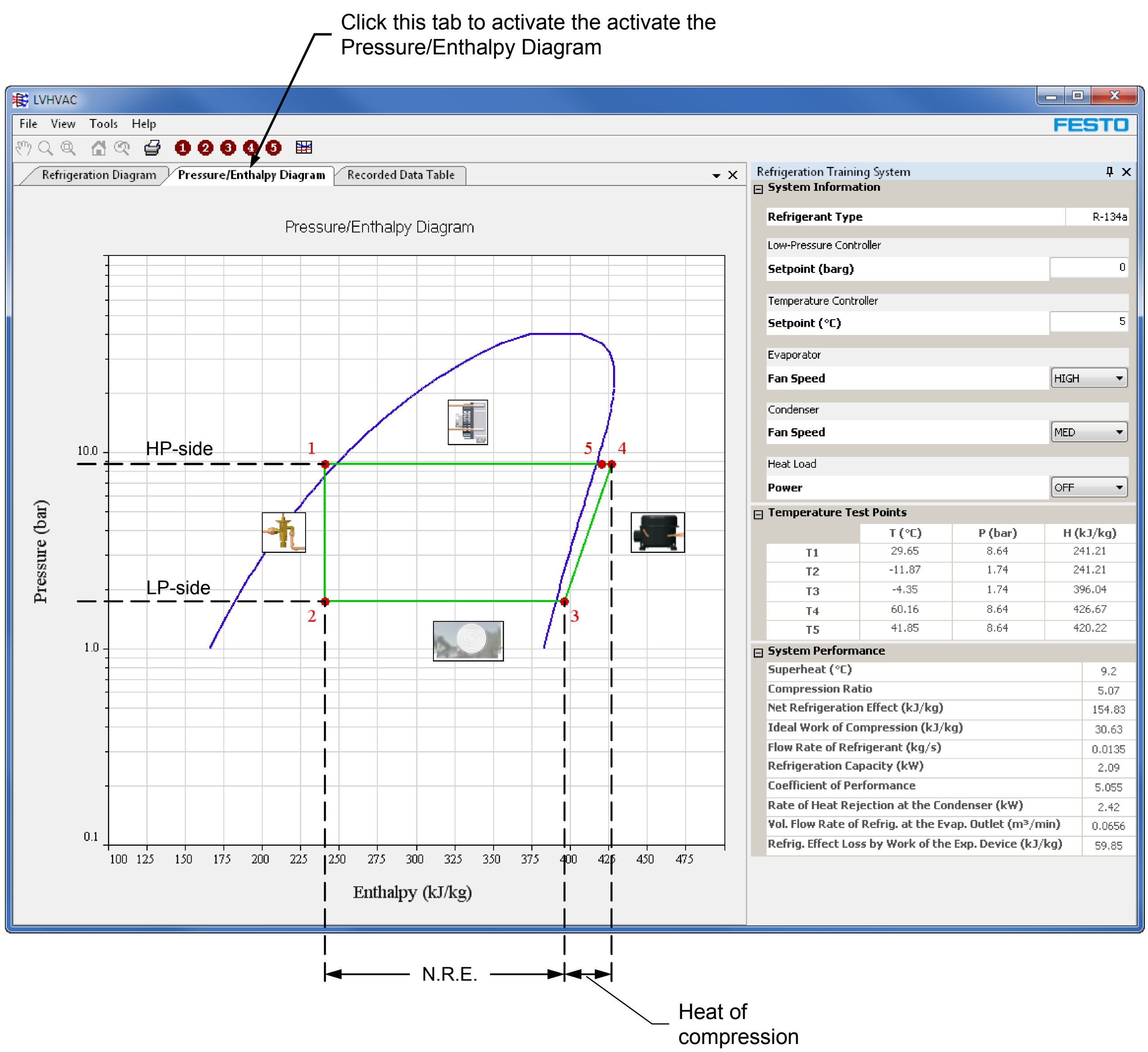


Figure 33. Pressure/enthalpy diagram with normal heat load when the TEV is used.

15. Allow the compressor to stop, then wait until it restarts to begin a new cycle. 3 minutes later, print the **Pressure/Enthalpy Diagram** and **Refrigeration Training System** panels.

16. Determine the net refrigeration effect (N.R.E.) graphically on your printed diagram. To do so, draw vertical lines downward from points ❷ and ❸ until they cross the enthalpy (horizontal) axis, as shown in Figure 33. The difference on the enthalpy axis where the lines cross this axis is equal to the N.R.E. Record your result below.

Compare your result to the value displayed in the field *Net Refrigeration Effect* of the *System Performance* section on your printed **Refrigeration Training System** panel. Are these values approximately equal?

❑ Yes ❑ No

Your result should be approximately equal to the value displayed in the field *Net Refrigeration Effect* of the *System Performance* section on your printed **Refrigeration Training System** panel:

- For an operating voltage of 120 V, 60 Hz, the net refrigeration effect should be around 150 kJ/kg (40.5 Btu/lbm).
- For an operating voltage of 220-240 V, 50 Hz, the net refrigeration effect should be around 155 kJ/kg.
- For an operating voltage of 220 V, 60 Hz, the net refrigeration effect should be around 139 kJ/kg.

Yes.

17. Determine the heat of compression graphically on your printed diagram. To do so, draw vertical lines downward from points ❸ and ❹ until they cross the enthalpy (horizontal) axis, as shown in Figure 33. The difference on the enthalpy axis where the lines cross this axis is equal to the heat of compression. Record your result below.

Compare your result to the value displayed in the field *Ideal Work of Compression* of the *System Performance* section on your printed **Refrigeration Training System** panel. Are these values approximately equal?

❑ Yes ❑ No

Your result should be approximately equal to the value displayed in the field *Ideal Work of Compression* of the *System Performance* section on your printed **Refrigeration Training System** panel:

- For an operating voltage of 120 V, 60 Hz, the heat of compression should be around 26 kJ/kg (6.98 Btu/lbm).

- For an operating voltage of 220-240 V, 50 Hz, or 220 V, 60 Hz, the heat of compression should be around 31 kJ/kg.

Yes.

18. Based on the N.R.E. and heat of compression obtained in the previous steps, calculate the coefficient of performance of the system. Record your result.

$$\text{Coefficient of performance} = \frac{\text{Net refrigeration effect}_{\ (\text{kJ/kg or Btu/lbm})}}{\text{Heat of compression}_{\ (\text{kJ/kg or Btu/lbm})}}$$

Compare your result to the value displayed in the field *Coefficient of Performance* of the *System Performance* section on your printed **Refrigeration Training System** panel. Are these values approximately equal?

❑ Yes ❑ No

Your result should be approximately equal to the value displayed in the field *Coefficient of Performance* of the *System Performance* section on your printed **Refrigeration Training System** panel:

- For an operating voltage of 120 V, 60 Hz, the coefficient of performance should be around 5.8.

- For an operating voltage of 220-240 V, 50 Hz, the coefficient of performance should be around 5.1.

- For an operating voltage of 220 V, 60 Hz, the coefficient of performance should be around 4.5.

19. Turn off the trainer and close the LVHVAC software.

Name: ______________________________ Date: ___________________

Instructor's approval: ____