Refrigeration and HVAC

Geothermal Heat Pump Systems

Job Sheets - Courseware Sample

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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
	Caution, lifting hazard
	Caution, hand entanglement hazard
	Notice, non-ionizing radiation
⎓	Direct current
~	Alternating current
≂	Both direct and alternating current
3~	Three-phase alternating current

Safety and Common Symbols

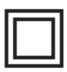
Symbol	Description
	Earth (ground) terminal
	Protective conductor terminal
	Frame or chassis terminal
	Equipotentiality
	On (supply)
	Off (supply)
	Equipment protected throughout by double insulation or reinforced insulation
	In position of a bi-stable push control
	Out position of a bi-stable push control

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Table of Contents

Preface

Geothermal heat pump systems, also known as ground source heat pumps, are among the most energy efficient systems available today for HVAC applications. Depending on geographical location, typical energy savings from a geothermal heat pump system are from 25% to 70%.

The Geothermal Training System, Model 46126, allows you to develop knowledge in heat transfer, refrigeration, and air conditioning. The topics covered in the job sheets are designed to help you gain the skills required during installation, operation, and troubleshooting of geothermal heat pump systems.

The tools and instruments commonly used with geothermal heat pump systems are also introduced and, when applicable, are used during hands-on activities.

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

Description

The topics covered in this manual are presented in the form of job sheets. Each job sheet consists of a theoretical section named *Information Job Sheet* followed by a series of tasks required to attain the learning objectives.

Safety considerations

Safety symbols that may be used in this manual and on the equipment are listed in the Safety 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.

Systems of units

Units are expressed using the International System of Units (SI) followed by the units expressed in the U.S. customary system of units (between parentheses).

Appendices

The appendices included in this manual are:

Appendix A - Conversion Table: Factors to apply to convert US customary units to SI units and vice versa.

Appendix B - Pressure-Enthalpy Diagrams: Pressure-enthalpy diagrams of the refrigerant used in the training system.

Appendix C - Psychrometric Charts: Standard air psychrometric charts.

Appendix D - Anemometer Instructions: Operating instructions of the anemometer supplied with the training system.

Appendix E - Thermo-Fusion Joints on Geothermal Pipes: Explains how to make joints on geothermal pipes.

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.

Important note about the training system. The results obtained with the geothermal training system correspond to a picture of the system when an experiment was performed. Each experiment is done under conditions (ambient temperature, temperature of the water in the tank, humidity…) which can vary tremendously from a location to the other and as time goes by. Those operating conditions have a large impact on the performance of the system as well as on the measurements obtained and on the calculations based upon those measurements. Consequently, the results given in this instructor manual are far from absolute: they are merely examples of results and calculations. The instructor must use care when interpreting the results herein and comparing them to results obtained by his/her students. **The intended phenomena and learning objectives will be met, but numerical results will inevitably vary.**

On the use of the digital thermometer. The digital thermometer provided with your training system may feature two channels. If this is the case, it is a good practice to use only a single channel (and always the same one) to perform the temperature measurements. This ensures better precision of the temperature measurements as the two channels may present different readings for a given thermocouple at a given temperature. Also, the calculations often make use of temperature differences. The accuracy is better if all readings come from the same channel as there is then no risk of conflicting offsets from two channels. The instructor should remind his students of this fact on a regular basis.

Sample
Extracted from
the Job Sheets Student
and the Job Sheets Instructor

Heat Exchangers

Heat exchangers

Introduction

Heat exchangers are devices that transfer energy from a warmer fluid to a colder one. The role of the exchanger is to optimize the transfer of heat by providing a space where the two fluids interact thermally as much as possible. The fluids do not mix together during the heat exchange process due to a physical barrier between them. The exchanger provides a surface area that allows the heat of the hot fluid to be transferred by conduction to the cold fluid through the thin, heat-conductive walls separating the fluids.

There are different devices that exchange heat that are not strictly considered heat exchangers. In general, devices that mix two fluids at different temperatures are considered mass and heat exchangers. Mixing chambers, such as a kitchen faucet that mixes hot and cold water together, are a good example of such devices. However, we will not discuss such exchangers in this manual.

The heat that is exchanged in a given fluid can be expressed by the following equation:

$$\dot{Q} = \dot{m} c_p (T_{in} - T_{out}) \tag{7-1}$$

where $\dot{Q}$ is the heat flow of the fluid in W (Btu/h)

$\dot{m}$ is the mass flow rate of the fluid in kg/s (lbs/h)

c_p is the constant pressure specific heat of the fluid (e.g., 4190 J/kg °C (1.00 Btu/lb °F) for water at room temperature) in J/kg·K (Btu/lb·°F)

T_{in} is the temperature of the fluid entering the heat exchanger in °C (°F)

T_{out} is the temperature of the fluid leaving the heat exchanger in °C (°F)

The fluids in a heat exchanger could be identified by a sub-index such as: "r" for the refrigerant, "w" for water, "h" for the hot fluid, and "c" the cold fluid. The equation for the hot fluid in an exchanger would then become: $\dot{Q}_h = \dot{m}_h c_{p,h} (T_{in,h} - T_{out,h})$.

Configurations of heat exchangers are available for different applications. One of the most common types of exchanger is the coaxial type shown in the bottom of Figure 105. In this exchanger, the fluids travel on the same axis on parallel trajectories. The coaxial type exchanger is used on your training system. Both the desuperheater and the geothermal heat pump ground-loop water/refrigerant heat exchanger are instances of coaxial exchangers.

Another type of heat exchanger is called the cross-flow heat exchanger. In this arrangement, instead of traveling in the same direction, both fluids meet at a ninety degree angle. The air/refrigerant heat exchanger found at the air intake of the heat pump is an example of a cross-flow exchanger.

Heat exchanger analysis

A heat exchanger analysis allows us to determine the amount of heat that is transferred from one fluid to another. A thorough analysis also permits us to determine the temperatures at the inlet and outlet of the fluids under certain conditions.

In a coaxial heat exchanger, fluids exchange heat using one of two flow configurations: the parallel-flow configuration (Figure 105a), where hot and cold fluids enter on the same side of the exchanger, and the counter-flow configuration (Figure 105b), where the fluids enter at opposite sides of the exchanger.

The fluids continue to exchange heat as long as there is a temperature difference between the fluids at a given position in the exchanger.

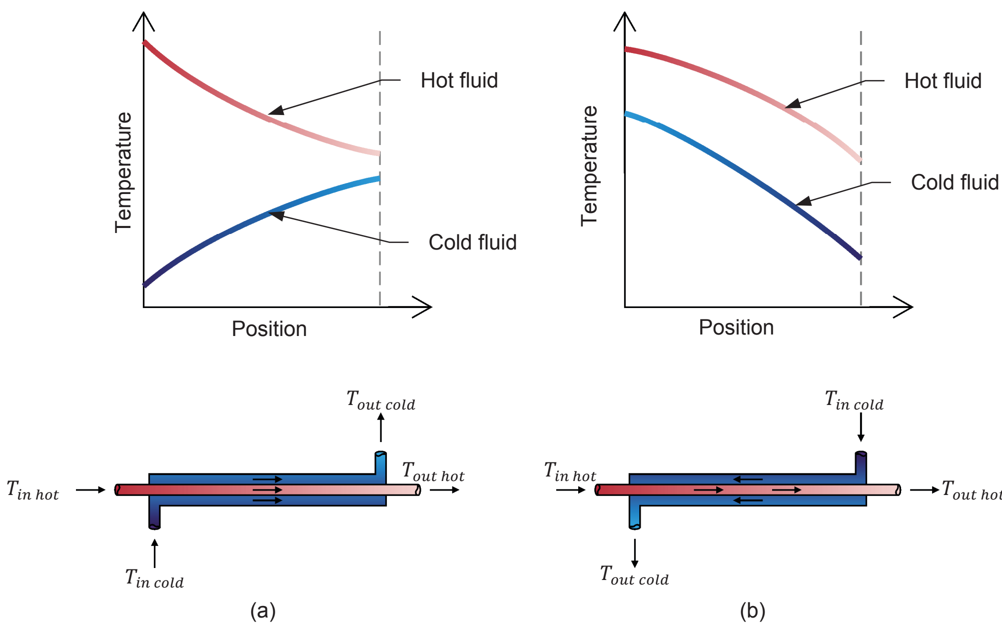


Figure 105. Heat exchanger flow.

Figure 105 shows that, when the flows are parallel, the temperatures of the hot and cold fluids merge until they either reach the same temperature or they exit the exchanger. When the fluids are flowing in a counter-flow configuration, the temperature lines have a tendency to "follow each other". Note that in the counter-flow configuration, the output temperature of the hot fluid can be colder than the output temperature of the cold water as shown in Figure 105b.

Several different heat exchangers play major roles in the geothermal heat pump HVAC installations.

- The ground loop is a heat exchanger that transfers heat between the thermal fluid and the ground.

- The **coaxial heat exchanger** in the heat pump exchanges heat between the ground loop and the refrigerant.

    - When the heat pump is set to work in heating mode, this exchanger works as an evaporator. The refrigerant evaporates as it takes the energy from the ground.

    - When the heat pump is working in cooling mode, the heat exchanger works as a condenser. As the refrigerant transfers heat to the ground, it is cooled and condensed into a liquid during the process.

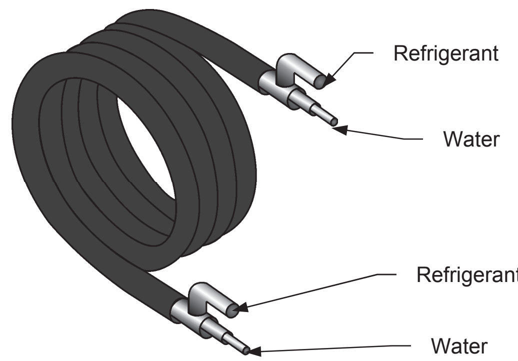


Figure 106. Coaxial heat exchanger.

- The desuperheater heat exchanger is a counter-flow heat exchanger. It exchanges heat from the refrigerant as it exits the compressor to the water in a domestic hot water (DHW) tank.

- The heat pump forced-air coil exchanges heat to warm the air when heating is needed. It can also cool and dehumidify the air when air conditioning is needed. In this case, the heat extraction cools the air and condensates the water. The air cooling and the water condensation have to be taken into account if an energy balance is performed.

The heat exchangers in a heat pump may work in counter-flow or parallel-flow mode, depending on the mode of operation (heating or cooling mode).

The evaporator and condenser coils

When a change in matter occurs inside a heat exchanger, latent heat is transferred. As long as only latent heat is exchanged, the fluid that condensates or evaporates stays at the same temperature from the inlet to the outlet.

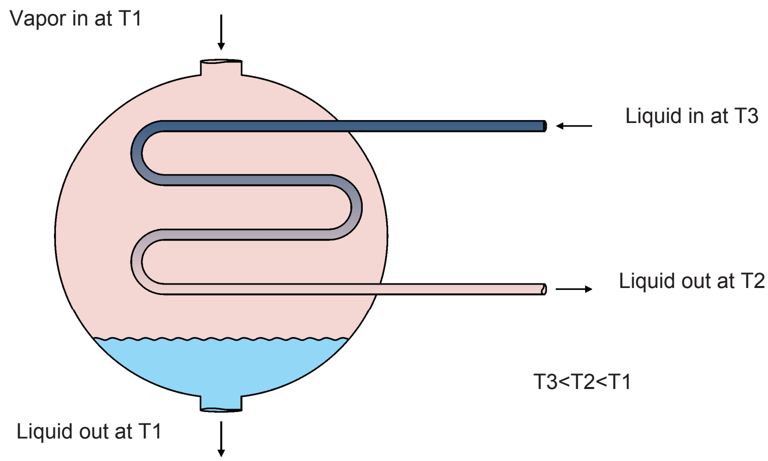


Figure 107. Condensation.

As shown in Figure 107, when condensation occurs in a heat exchanger, the temperature of the condensing fluid remains constant; but its state changes from vapor to liquid as it loses latent heat. The other fluid involved in the heat exchange gains sensible heat and its temperature rises. The state of the second fluid remains the same unless it reaches a state-change temperature (e.g., its boiling point).

When a fluid condensates on one side of the heat exchanger, the fluid on the other side absorbs heat and increases its temperature.

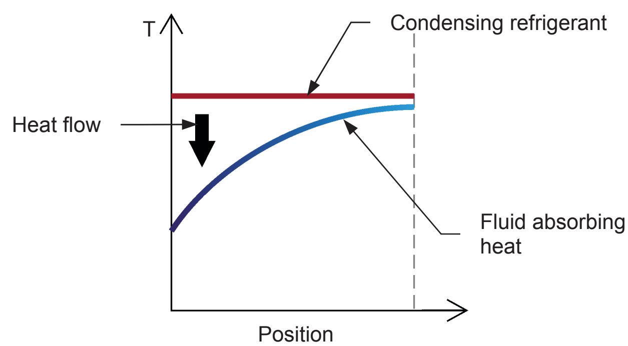


Figure 108. Condensation.

On the other hand, when a fluid is boiling on one side of the evaporator, the fluid on the other side cools down and releases energy.

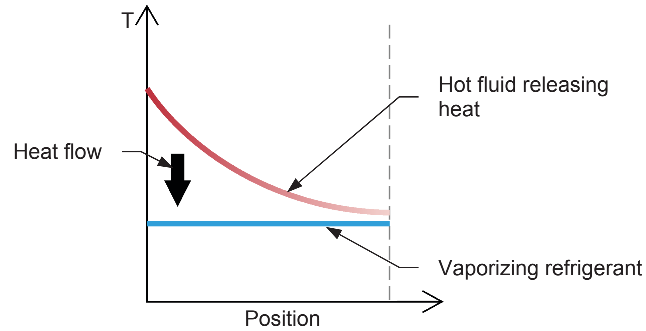


Figure 109. Vaporization.

In a typical heat pump, one of the flowing fluids is a refrigerant while the other fluid is either simple water or a water/antifreeze solution. Heat exchangers may work in parallel-flow or counter-flow and as either evaporators or condensers. This versatility of the heat exchanger is possible by using different valves to control the fluid flows. However, it makes this kind of heat exchangers more difficult to understand and the calculations are slightly less tractable.

The heat flow entering (evaporation) or leaving (condensation) the fluid undergoing a change of state is expressed by the equation:

$$\dot{Q} = \dot{m} \cdot h_{fg} \tag{7-2}$$

where $\dot{Q}$ is the heat flow in W (Btu/h)
$\dot{m}$ is the mass flow rate of the fluid in kg/s (lb/h)
h_{fg} is the enthalpy of vaporization or condensation in J/kg (Btu/lb)

The f and g indices in the h_{fg} variable refer to fluid and gas respectively. This indicates that the enthalpy refers to the vaporization/condensation.

In a typical installation, the analysis of Equation (7-1) and Equation (7-2) must be combined to reflect the multiple mechanisms at work in a geothermal heat exchanger.

The effectiveness of a heat exchanger

The effectiveness of a heat exchanger can be calculated as:

$$\epsilon = \frac{\dot{Q}}{\dot{Q}_{max}} \tag{7-3}$$

where ϵ is the effectiveness, a dimensional number such that $0 \leq \epsilon \leq 1$
$\dot{Q}$ is the heat flow taking place in the exchanger in W (Btu/h)
$\dot{Q}_{max}$ is the maximum heat transfer possible for the fluid parameters in W (Btu/h)

The maximum amount of heat transfer occurs when the temperature of the hot fluid drops to the temperature of the cold fluid at its inlet, or when the cold fluid reaches the temperature of the hot fluid at its inlet.

To compare the amount of heat each fluid is handling, we need to calculate the heat capacity of each fluid.

Formally, in SI units, the c_p would be expressed in units of J/kg·K, where K is the Kelvin temperature unit. This would imply the use of temperatures in K instead of °C in the equations in this page. However, temperatures differences in °C and K are the same, making this distinction irrelevant to our needs.

T [K] = T [°C] + 273.15

$$C_c = \dot{m}_c \cdot c_{p,c} \tag{7-4}$$

where C_c is the cold fluid heat capacity rate in W/°C (Btu/h·°F)
$\dot{m}_c$ is the mass flow rate of the cold fluid in kg/s (lb/h)
$c_{p,c}$ is the cold fluid specific heat in J/kg·°C (Btu/lb·°F)

$$C_h = \dot{m}_h \cdot c_{p,h} \tag{7-5}$$

where C_h is the hot fluid heat capacity rate in W/°C (Btu/h·°F)
$\dot{m}_t$ is the mass flow rate of the hot fluid in kg/s (lb/h)
$c_{p,h}$ is the hot fluid specific heat in J/kg·°C (Btu/lb·°F)

Keep the smallest value between C_c and C_h ($C_{min} = \min(C_c, C_h)$) and replace it in the following equation to obtain the maximum heat transfer:

$$\dot{Q}_{max} = C_{min.}(T_{in,h} - T_{in,c}) \tag{7-6}$$

where $\dot{Q}_{max}$ is the maximum heat transfer possible in W (Btu/h)
$C_{min.}$ is the minimum specific heat from the fluids in W/°C (Btu/h·°F)
$T_{in,h}$ is the temperature of the hot fluid entering the heat exchanger in °C (°F)
$T_{in,c}$ is the temperature of the cold fluid entering the heat exchanger in °C (°F)

The desuperheater

The **desuperheater** is a heat exchanger that extracts the sensible superheat stored in the refrigerant after the compression process. In the geothermal heat pump, the desuperheater is used to warm the water in a domestic hot water tank (DHW). This "free" energy saves part of the electric work that would otherwise be required to rise the water temperature in the tank.

The energy transferred to the water by the desuperheater is shown as a blue segment in Figure 110.

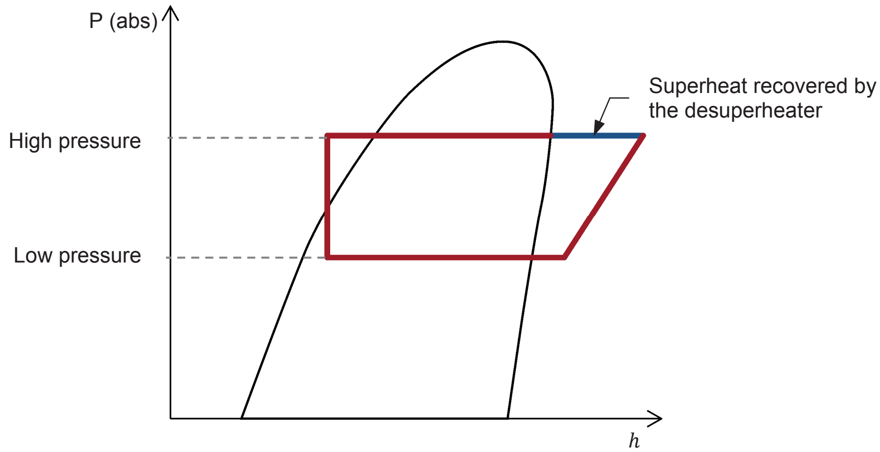


Figure 110. Desuperheater graph.

A double-tube heat exchanger is installed between the compressor exit and the four-way valve to transfer the superheat to the domestic hot water tank.

The goal of this heat exchanger is to cool down the superheated refrigerant as it exits the compressor to a temperature that is only slightly above the saturation temperature.

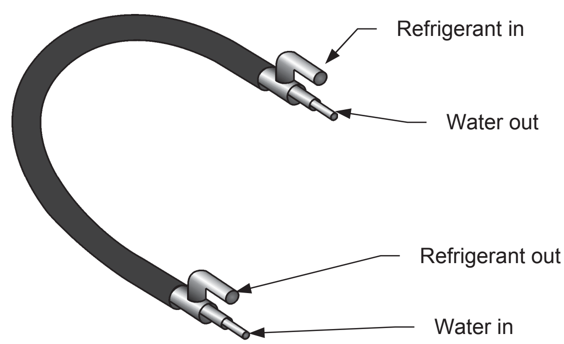


Figure 111. Desuperheater.

The pump that circulates the water through the desuperheater should work only when the temperature of the water in the tank is lower than the saturation temperature. The refrigerant should transfer heat to the water, but the water should never transfer heat to the refrigerant. If heat is transferred to the refrigerant, the pressure increases at the compressor exit, making the system less efficient.

In heating mode, the desuperheater circulation pump is usually turned off allowing all the available heat to warm the house.

Thermal efficiency

The ratio between the heat output and the heat input of any device is the theoretical **thermal efficiency**.

$$\eta_{th} = \frac{Q_{out}}{Q_{in}} \tag{7-7}$$

From the first law of thermodynamics, the energy output of a closed system cannot exceed its input. Consequently, the thermal efficiency is always in the range between:

$$0 \leq \eta_{th} \leq 1$$

When expressed as a percentage, the thermal efficiency must be between 0% and 100%. Due to inefficiencies, such as friction, heat loss, and other factors, the efficiency of any real-world thermal engine is typically much less than 100%.

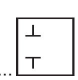
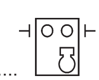
Heat Exchangers

OBJECTIVES

In this job sheet, you will determine the refrigerant mass flow rate circulating in the heat pump. You will also calibrate the water flow in the desuperheater to heat water in the domestic hot water tank (DHW) using the sensible heat from the hot, superheated refrigerant. You will determine the amount of money that could be saved with the use of a desuperheater.

PROCEDURE

1. Perform the following settings on your training system.

Main power switch	Off
Thermostat	Heating mode
Temperature set point	5°C (9°F) above room temperature
Valve HV-1	Open
Valve HV-2	Open
Valve HV-3	Open
Valve HV-4	Open
Valve HV-5	Open
Valve HV-6	Open
Valve HV-7	Open
Valve HV-8	Closed
Valve HV-9	No adjustments required
Valve HV-10	Handle in horizontal position
Valve HV-11	Open
Valve HV-12	Open
Valve HV-13	Open
Pressure gauge PI-1 selector switch	Right
Pressure gauge PI-2 selector switch	Right
Desuperheater On/Off switch	On
Priming tank three-way valves	
Pumping station three-way valves	
Air distribution register	Open

2. Set the main power switch to On.

3. Turn the valve HV-10 to the vertical position.

4. When the desuperheater indicator light turns on, adjust valve HV-9 to obtain a flow (FI-4) of 2 L/min (0.6 gal/min).

5. Locate the desuperheater heat exchanger on your training system. Complete Table 27 using the following labels: Refrigerant out, Water in, Water out, and Desuperheater pump.

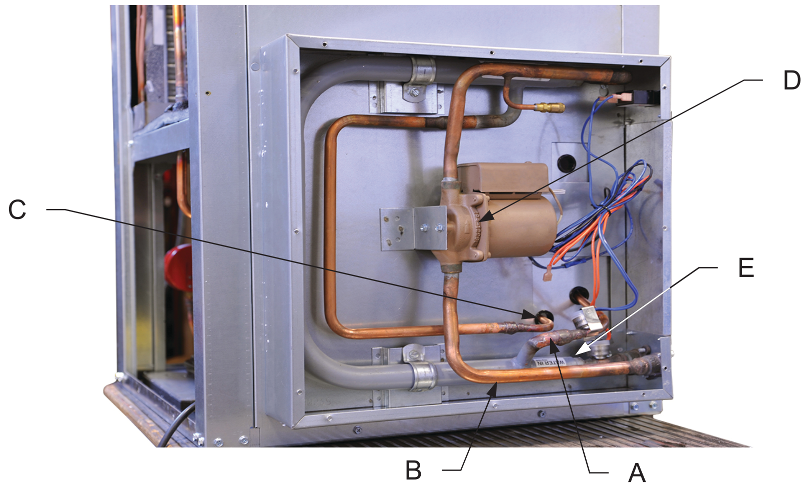


Figure 112. Desuperheater.

Table 27. Desuperheater element identification.

Location	Name
A	
B	
C	Refrigerant in
D	
E	

The domestic hot water tank of your training system has a capacity of 9.5 L (2.5 gal).

Desuperheater element identification.

Location	Name
A	Refrigerant out
B	Water in
C	Refrigerant in
D	Desuperheater pump
E	Water out

6. What type of configuration (parallel-flow or counter-flow) is used for the heat exchanger of the desuperheater?

The heat exchanger of the desuperheater uses the counter-flow configuration.

7. Turn valve HV-10 to the horizontal position.

8. Measure the temperatures and pressures shown in Table 28. Wait for fifteen minutes and repeat your measurements. Complete Table 28.

Table 28. Domestic hot water data.

	$t_{0\ min}$	$t_{15\ min}$
T_{TC-8}		
T_{TC-9}		
T_{TC-10}		
T_{TC-11}		
T_{TC-15}		
T_{TC-16}		
LP		
HP		

DHW data (SI units).

	$t_{0\ min}$	$t_{15\ min}$
T_{TC-8} (°C)	8.5	3.4
T_{TC-9} (°C)	67.4	69.7
T_{TC-10} (°C)	42.1	46.9
T_{TC-11} (°C)	32.9	31.1
T_{TC-15} (°C)	21.4	36.5
T_{TC-16} (°C)	26.5	39.4
LP (bar)	8.3	7.0
HP (bar)	24.0	24.0

DHW data (US customary units).

	$t_{0\ min}$	$t_{15\ min}$
T_{TC-8} (°F)	47	40
T_{TC-9} (°F)	130	153
T_{TC-10} (°F)	109	111.6
T_{TC-11} (°F)	95.8	89.3
T_{TC-15} (°F)	68.6	89.7
T_{TC-16} (°F)	87.7	95.9
LP (psia)	125	110
HP (psia)	350	375

9. Using a pressure-enthalpy diagram included at the end of this job sheet, find the saturation temperature T_{sat} for the value of HP found after fifteen minutes (remember that HP is a gauge pressure).

Saturation temperature T_{sat}: ________

Saturation temperature (T_{sat}): 40°C (115°F)

10. Turn valve HV-10 to the vertical position and let the water run for one minute. Turn valve HV-10 to the horizontal position and measure TC-10.

Temperature measured by TC-10: ________

Temperature measured at TC-10: 46.9°C (111.6°F)

The temperature must be adjusted to 42°C (119°F) for the operating conditions of the system given in this example. Results may vary.

11. Next, adjust valve HV-9 to obtain a temperature measured by TC-10 that is 2°C (4°F) over the saturation temperature found in step 0.

Set the thermostat operating mode to Off.

12. Calculate the energy gained by the water from $t_{0\,min}$ to $t_{15\,min}$ using Equation (7-8) and the temperatures measured at TC-15:

$$Q = m_w\, c_{p,w}\, (T_{15\,min} - T_{0\,min}) \tag{7-8}$$

where Q is the heat gained by the water in J (Btu)
m_w is the mass of water in kg (lb)
A 9.5 liter (2.5 gallon) water heater corresponds to 9.5 kg (20.875 lb) of water.
$c_{p,w}$ is the constant pressure specific heat of water in J/kg·°C (Btu/lb·°F)
$T_{15\,min}$ is the temperature of the water after fifteen minutes of running the system in °C (°F)
$T_{0\,min}$ is the temperature of water at the beginning of the experiment in °C (°F)

SI units

Q = 9.5 × 4.18 × (36.5 - 21.4) = 599.6 kJ

US customary units

Q = 20.875 × 1.0 × (89.7 - 68.6) = 440.5 Btu

13. The heat flow rate of the process corresponds to the total heat gained by the water in the tank (calculated at step 12) divided by the number of seconds in fifteen minutes or 0.25 hours.

$$\dot{Q}_w = \frac{Q_w}{t} \tag{7-9}$$

where $\dot{Q}_w$ is the heat flow rate in W (Btu/h)
Q_w is the total heat gained by water in J (Btu)
t is the time elapsed in seconds (SI units) or hours (US units)

Calculate the heat flow rate of the process:

SI units

Heat flow rate of the process = $\dot{Q} = \frac{599.6\text{ kJ}}{15\text{ min} \times 60\text{ s/min}} = \frac{599.6}{900} = 0.666\text{ kW}$

US customary units

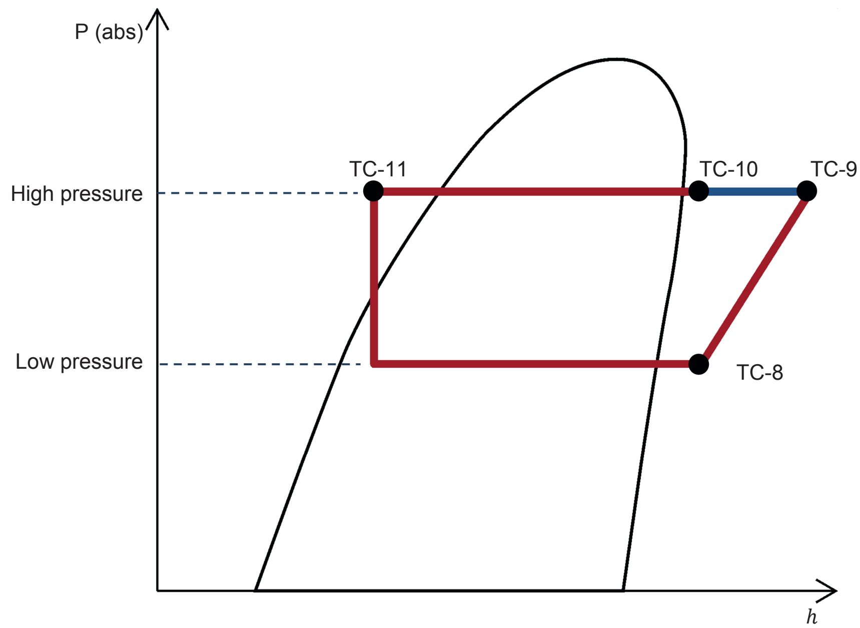
Heat flow of the process = $\dot{Q} = \frac{440.5\text{ Btu}}{0.25\text{ h}} = 440.5 \times 4 =$ 1762 Btu/h

14. Plot the compression cycle in a pressure-enthalpy diagram (Figure 117 or Figure 118) and fill in Table 29.

Table 29. Temperature-enthalpy.

	Enthalpy
TC–$9_{15\ min}$	
TC–$10_{15\ min}$	

The compression cycle is given in the graph below.



Compression cycle.

Table 29. Temperature-enthalpy (SI units).

	Enthalpy (kJ/kg)
TC – $9_{15\ min}$	470
TC – $10_{15\ min}$	438

Table 29. Temperature-enthalpy (US customary units).

	Enthalpy (Btu/lb)
TC – $9_{15\ min}$	136
TC – $10_{15\ min}$	123

15. Locate the TC-10 point on the pressure-enthalpy diagram. Is the desuperheater working in its ideal range of operation? Why?

No. To be in its ideal range, the desuperheater should operate in such a way that the TC-10 point is located precisely on the boundary of sensible enthalpy for the gaseous state. The actual position of TC-10 is slightly to the right of the boundary.

16. What would be the effect on the temperature read by TC-10 if you were to modify the desuperheater flow rate?

Increasing the flow rate into the desuperheater would move the TC-10 point to the left to the boundary and into the latent enthalpy region of the cycle. Decreasing the flow rate would move the TC-10 point to the right, leaving more heat available to heat the room.

17. Explain why it is preferable that the temperature at TC-10 does not drop below the saturation temperature?

If TC-10 drops below the saturation pressure, too much heat is transferred to the DHW. This does not have much impact if the system is in cooling mode. However, in heating mode, the system may simply be unable to heat the house as needed.

18. To calculate the refrigerant mass flow that circulates, compare the heat flow absorbed by the water with the enthalpy difference corresponding to the temperatures $TC-9_{15\,min}$ and $TC-10_{15\,min}$.

$$\dot{m}_r = \frac{\dot{Q}_w}{(h_{TC-9} - h_{TC-10})} \tag{7-10}$$

where
$\dot{Q}_w$ is the water heat flow in W (Btu/h) measured in step 13
$\dot{m}_r$ is the refrigerant mass flow rate in kg/s (lbs/h)
h_{TC-10} is the enthalpy corresponding to TC-10 in J/kg (Btu/lb)
h_{TC-9} is the enthalpy corresponding to TC-9 in J/kg (Btu/lb)

SI units

$$\dot{m}_r = \frac{\dot{Q}_w}{(h_{TC-9} - h_{TC-10})} = \frac{0.666}{470 - 438} = 0.0208 \text{ kg/s}$$

US customary units

$$\dot{m}_r = \frac{\dot{Q}_w}{(h_{TC-9} - h_{TC-10})} = \frac{1762}{136 - 123} = 135.5 \text{ lb/hour}$$

19. Calculate the amount of money the desuperheater saves in heating costs for one hour of continuous work. Assume one kWh costs $0.08 (U.S.).

Electric work (W_e) $= \dot{m}_r(h_{TC-9} - h_{TC-10}) = \dot{Q}_w$.

SI units

$W_e = \dot{Q}_w = 0.666$ kW

Savings = $0.666 \text{ kW} \times 0.08 \frac{\$}{\text{kWh}}$ = 0.053 $ per hour

US customary units

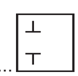
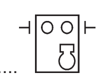
$W_e = \dot{Q}_w =$ 1762 Btu/h = 1762 Btu/h ÷ 3.413 Btu/h·W = 0.516 kW

Savings = $0.516 \text{ kW} \times 0.08 \frac{\$}{\text{kWh}}$ = 0.041 $ per hour

Coaxial coil heat exchanger

The following exercise is optional and explores the characteristics of the heat pump coaxial heat exchanger. You will calculate the refrigerant mass flow using the coaxial heat exchanger in heating mode and in cooling mode. You will also determine how the heat exchanger works in each mode.

20. Perform the following adjustments to the settings of your training system.

Main power switch	On
Thermostat	Heating mode
Temperature set point	5°C (9°F) above room temperature
Valve HV-1	Open
Valve HV-2	Open
Valve HV-3	Open
Valve HV-4	Open
Valve HV-5	Open
Valve HV-6	Open
Valve HV-7	Open
Valve HV-8	Closed
Valve HV-9	No adjustments required
Valve HV-10	Handle in horizontal position
Valve HV-11	Open
Valve HV-12	Open
Valve HV-13	Open
Pressure gauge PI-1 selector switch	Right
Pressure gauge PI-2 selector switch	Right
Desuperheater On/Off switch	Off
Priming tank three-way valves	
Pumping station three-way valves	
Air distribution register	Open

21. Allow your training system to run for ten minutes. Complete Table 30.

Table 30. Temperature, pressure, and flow in heating mode.

T_{TC-8}	
T_{TC-12}	
T_{TC-13}	
T_{TC-14}	
LP	
Ground loop water flow	

Temperature, pressure, and flow in heating mode (SI units).

T_{TC-8} (°C)	16
T_{TC-12} (°C)	14.2
T_{TC-13} (°C)	22.1
T_{TC-14} (°C)	18.4
LP (bar)	10.6
Ground loop water flow (L/min)	11

Temperature, pressure, and flow in heating mode (US customary units).

T_{TC-8} (°F)	60.8
T_{TC-12} (°F)	57.6
T_{TC-13} (°F)	71.8
T_{TC-14} (°F)	65.1
LP (psi)	154
Ground loop water flow (gal/min)	2.9

22. Fill in the blanks with your temperature readings and draw arrows to show the fluid flow in Figure 113.

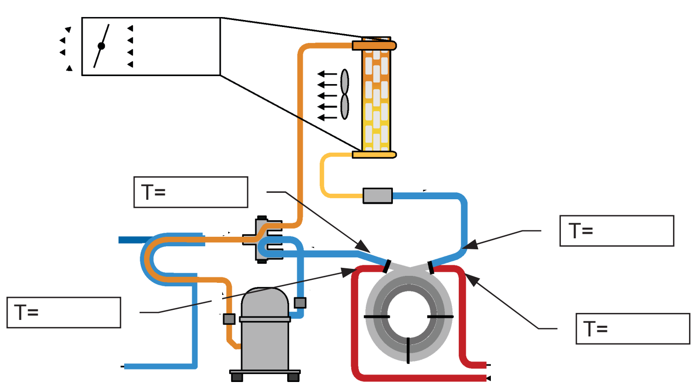
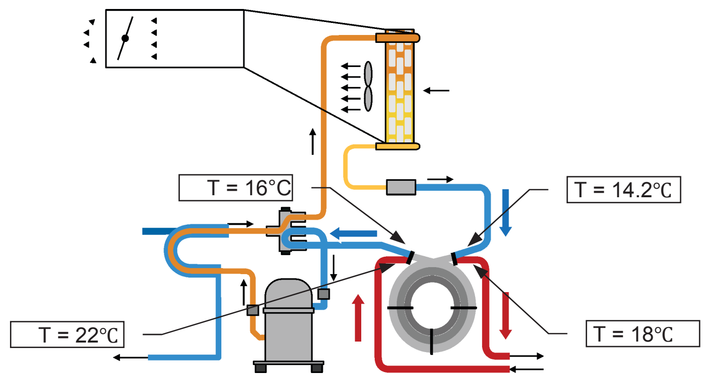


Figure 113. Heating mode heat exchanger analysis.



Heating mode heat exchange analysis.

23. Plot a simple graph to show how the temperature of each fluid varies as they flow through the system (as shown in Figure 109).

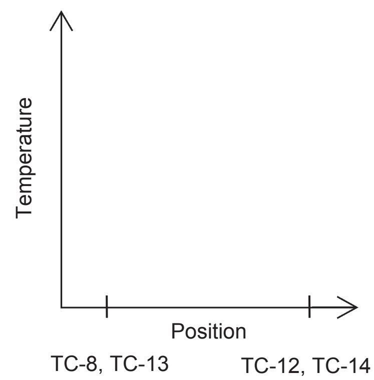
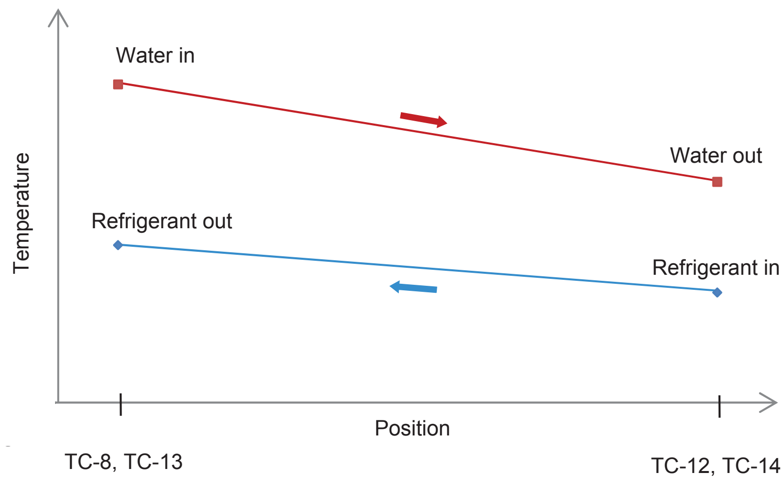


Figure 114. Heat exchanger temperature tendency in heating mode.

The evolution of the temperature looks like this in the exchanger:



Heat exchanger temperature tendency in heating mode.

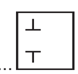
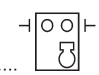
24. In heating mode, does the heat exchanger work in parallel-flow or counter-flow mode?

The heat exchanger works in counter-flow mode.

25. Is the heat exchanger working as an evaporator or a condenser?

The heat exchanger works as an evaporator.

26. Perform the following adjustments to your training system.

Main power switch	On
Thermostat	Cooling mode
Temperature set point	5°C (9°F) below room temperature
Valve HV-1	Open
Valve HV-2	Open
Valve HV-3	Open
Valve HV-4	Open
Valve HV-5	Open
Valve HV-6	Open
Valve HV-7	Open
Valve HV-8	Closed
Valve HV-9	No adjustments required
Valve HV-10	Handle in horizontal position
Valve HV-11	Open
Valve HV-12	Open
Valve HV-13	Open
Pressure gauge PI-1 selector switch	Right
Pressure gauge PI-2 selector switch	Right
Desuperheater On/Off switch	Off
Priming tank three-way valves	
Pumping station three-way valves	
Air distribution register	Open

27. Allow your training system to run for ten minutes. Complete Table 31.

Table 31. Temperature, pressure, and flow in cooling mode.

T_{TC-10}	
T_{TC-12}	
T_{TC-13}	
T_{TC-14}	
HP	
Ground loop water flow	

Cooling mode (SI units).

T_{TC-10} (°C)	35.2
T_{TC-12} (°C)	32.9
T_{TC-13} (°C)	28.6
T_{TC-14} (°C)	32.2
HP (bar)	20
Ground loop water flow (L/min)	11

Cooling mode (US customary units).

T_{TC-10} (°F)	95.4
T_{TC-12} (°F)	91.2
T_{TC-13} (°F)	83.5
T_{TC-14} (°F)	90.0
HP (psi)	290
Ground loop water flow (gal/min)	2.9

28. Set the thermostat operating mode to Off.

29. Complete the next figure by filling the measured temperatures in the blanks and draw arrows to show the fluid flows.

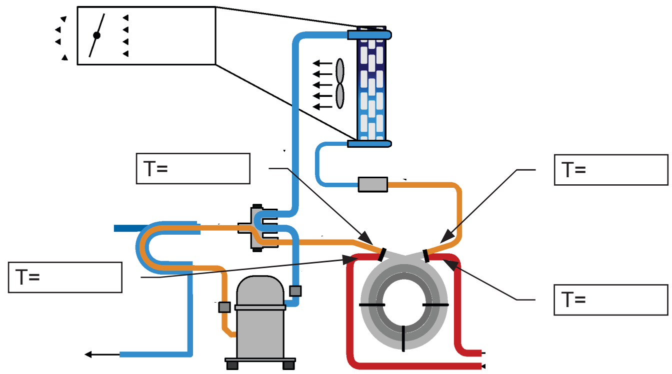
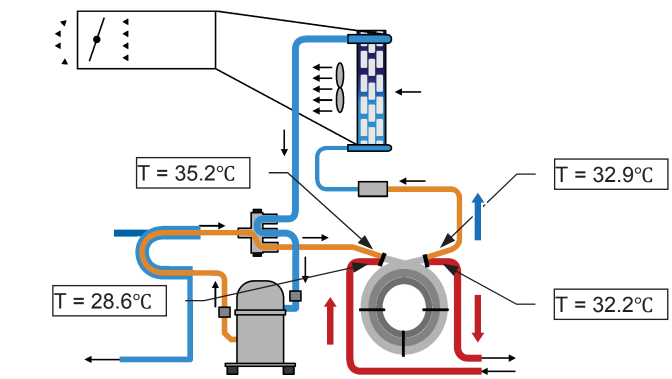


Figure 115. Cooling mode heat exchange analysis.



Cooling mode heat exchange analysis.

30. Plot a simple graph to show the drop in temperature as the fluid progresses in the heat exchanger (Use Figure 108 as a reference).

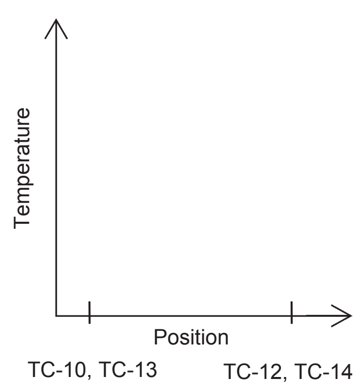
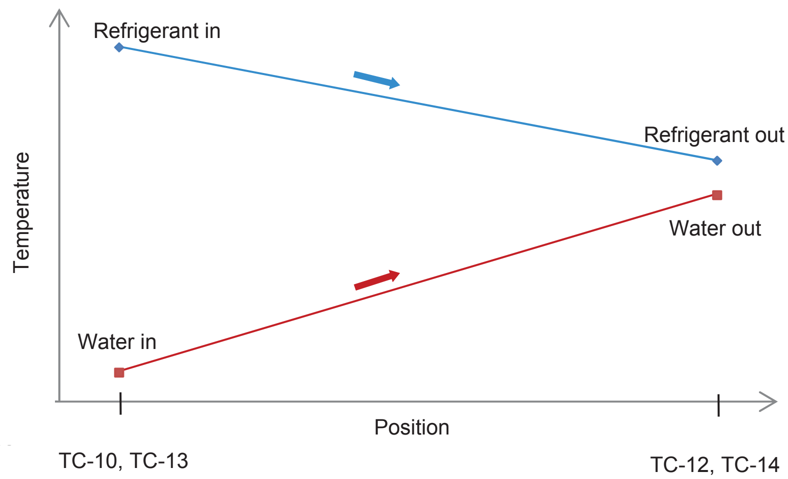


Figure 116. Heat exchanger temperature tendency in cooling mode.

The evolution of the temperature looks like this in the exchanger:



Heat exchanger temperature tendency in cooling mode.

31. In cooling mode, does the heat exchanger work in parallel-flow or counter-flow mode?

The heat exchanger works in parallel-flow mode.

32. Set the main power switch to Off.

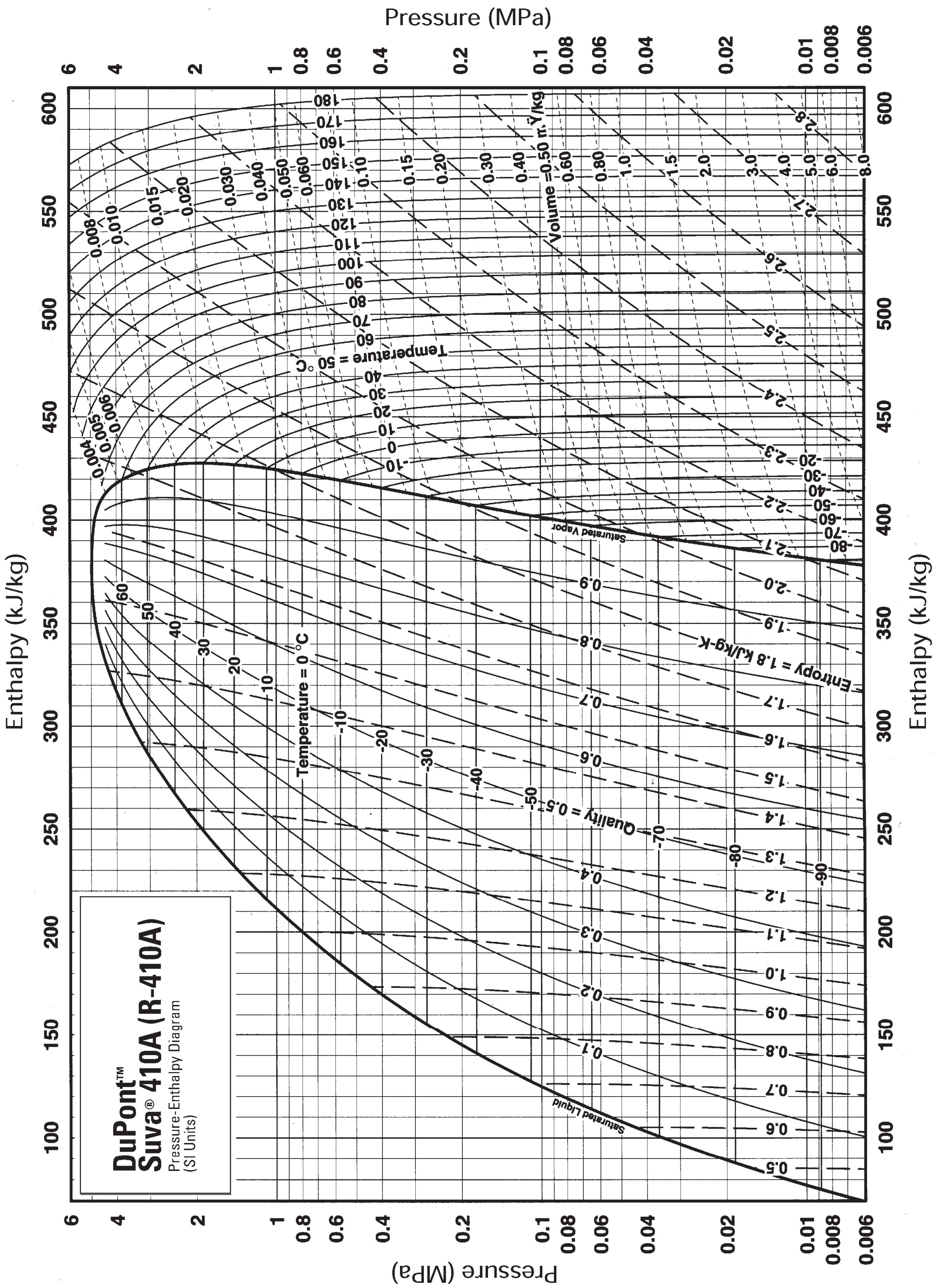


Figure 117. Pressure enthalpy diagram, SI units.

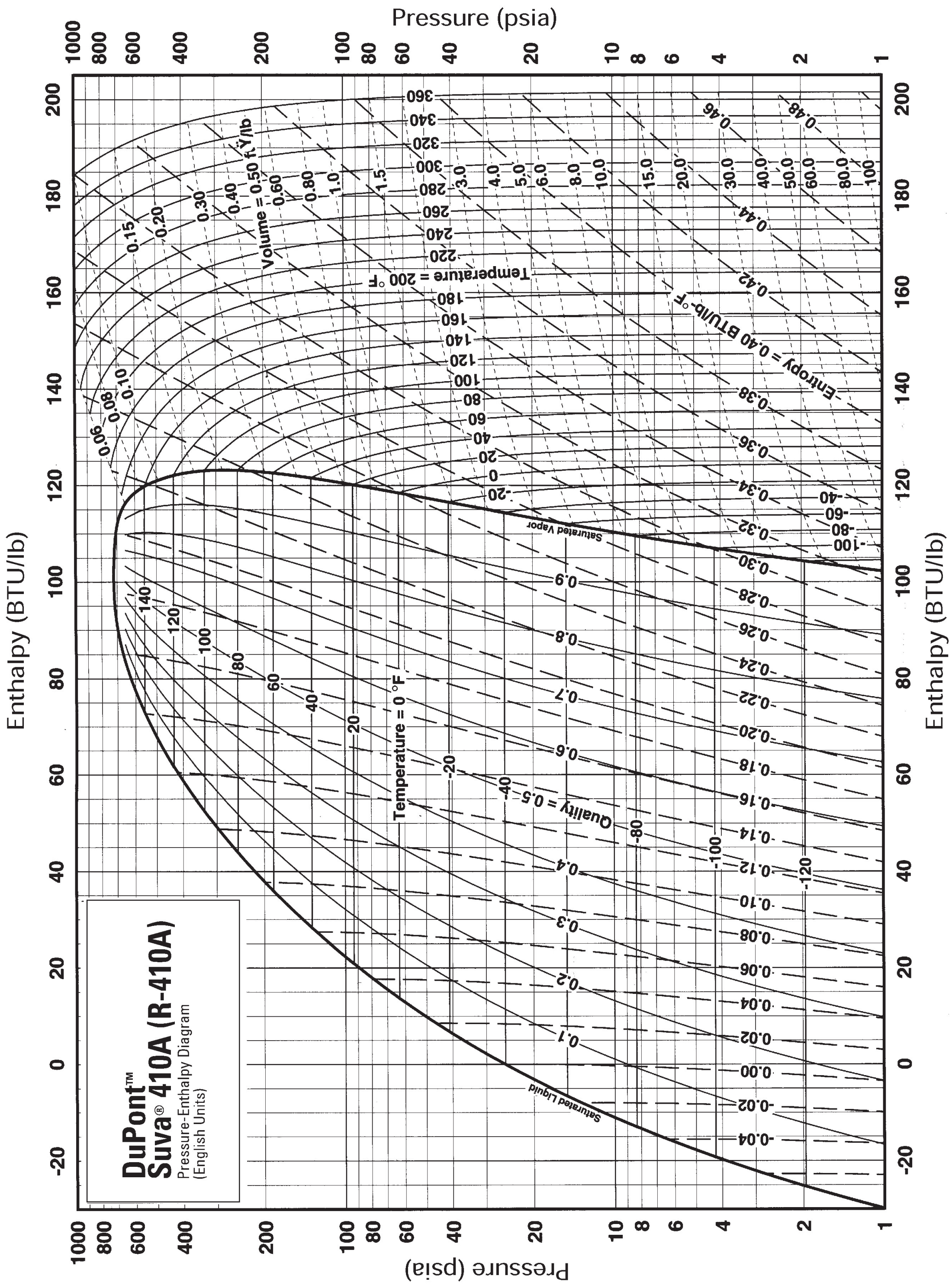


Figure 118. Pressure enthalpy diagram, English units.

Name: ______________________________ Date: ____________________

Instructor's approval: ____