Process Control

Heat Exchangers and Advanced Temperature Measurement

Temperature

Courseware Sample

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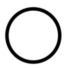
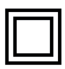
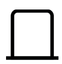
Safety and Common Symbols

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
⏚	Earth (ground) terminal

Safety and Common Symbols

Symbol	Description
	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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Preface

Automated process control offers so many advantages over manual control that the majority of today's industrial processes use it to some extent. Breweries, wastewater treatment plants, mining facilities, and the automotive industry are just a few industries that benefit from automated process control systems.

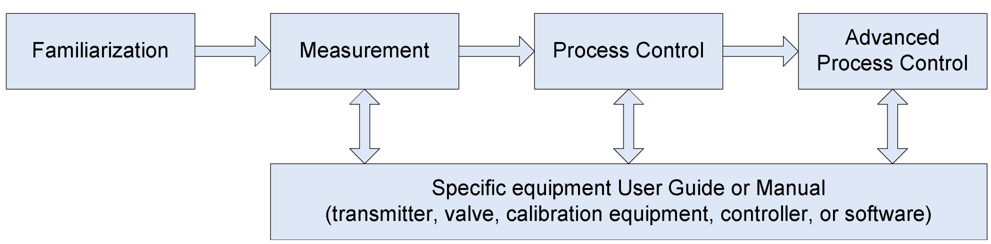
Maintaining process variables such as pressure, flow, level, temperature, and pH within a desired operating range is of the utmost importance when manufacturing products with a predictable composition and quality.

The Instrumentation and Process Control Training System, series 353X, is a state-of-the-art system that faithfully reproduces an industrial environment. Throughout this course, students develop skills in the installation and operation of equipment used in the process control field. The use of modern, industrial-grade equipment is instrumental in teaching theoretical and hands-on knowledge required to work in the process control industry.

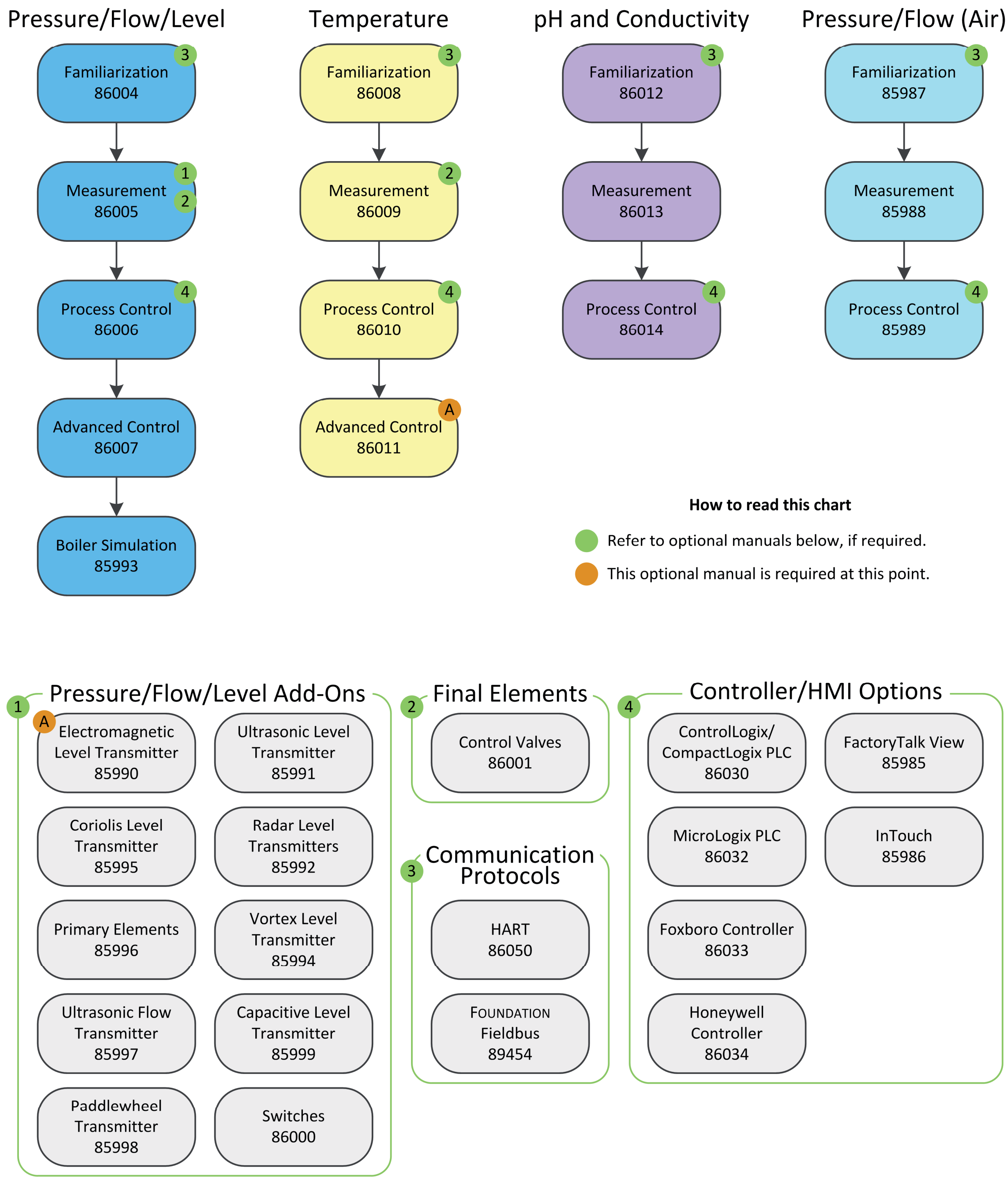
The modularity of the system allows the instructor to select the equipment required to meet the objectives of a specific course. Two mobile workstations, on which all of the equipment is installed, form the basis of the system. Several optional components used in pressure, flow, level, temperature, and pH control loops are available, as well as various valves, calibration equipment, and software. These add-ons can replace basic components having the same functionality, depending on the context. During control exercises, a variety of controllers can be used interchangeably depending on the instructor's preference.

We hope that your learning experience with the Instrumentation and Process Control Training System will be the first step toward a successful career in the process control industry.

Standard Learning Path



Manuals of the 353X Series



Preface

Do you have suggestions or criticism regarding this manual?

If so, send us an e-mail at did@de.festo.com.

The authors and Festo Didactic look forward to your comments.

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.

Equipment installation

In order for students to be able to perform the exercises in the Student Manual, the Process Control Training Equipment - Temperature must have been properly installed, according to the instructions given in the user guide Familiarization with the Instrumentation and Process Control System - Temperature, part number 86008-E.

Sample Exercise

Extracted from

the Student Manual

and the Instructor Guide

Gasketed Plate Heat Exchanger - Optional

EXERCISE OBJECTIVE

When you have completed this exercise, you will be familiar with the design and particularities of the gasketed plate heat exchanger and you will have gained experience characterizing such an exchanger using the energy manager.

DISCUSSION OUTLINE

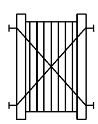
The Discussion of this exercise covers the following points:

- Description of a gasketed plate heat exchanger
- Characteristics of the gasketed plate heat exchanger
- Typical applications
- Using the gasketed plate heat exchanger
  Typical installation. Changing the number of plates.

DISCUSSION

Description of a gasketed plate heat exchanger

Equipment symbol



A gasketed plate heat exchanger is built on the same principles as the brazed plate heat exchanger: it features a series of thin, thermally conductive plates which are assembled together to create cavities or channels for each of the two fluids. By alternating the fluid which circulates in each channel between fluids 1 and 2, a multilayered and compact structure is created and allows an efficient heat transfer to take place. The main difference with respect to the brazed plate model is that the assembly can be modified by adding or removing a number of plates, thus changing the surface area where the heat exchange takes place.

This type of exchanger is typically made of two heavy end plates (one is fixed and is connected to the four inlet and outlet ports while the other plate at the back is mobile) and inner plates (see Figure 2-9). Each inner plate must be installed on the guiding rails with their gasketed surface towards the fixed end plate. A plate can be installed with its plastic tag to the right or to the left, indicating the side where the ports are blocked. The plate is identified as an *R* plate (tag to the right (or upwards)) when the right side is blocked, letting only the fluid flow from the leftmost ports. Rotating the plate by 180° makes the plate an *L* plate (tag to the left (or downwards)) which now blocks the left side and lets the fluid flow from the right ports.

Finally, three unique inner plates exist:

A flat plate of the same size as the inner plates is fixed to the front end plate. It should remain there at all times (this plate is not shown in Figure 2-9).

The type *B* plate must always be placed at the very beginning of the series of plates, just after the flat plate fixed to the heavy end plate at the front of the exchanger. The *B* plate blocks the access to its center to fluids from all four ports and is used to create a first corrugated wall between the fluids and the end plate.

The type *E* plate is like a standard plate, but no holes are punched into this plate to prevent the fluids from progressing further. The E plate must always be installed at the end of the series, just before the heavy end plate.

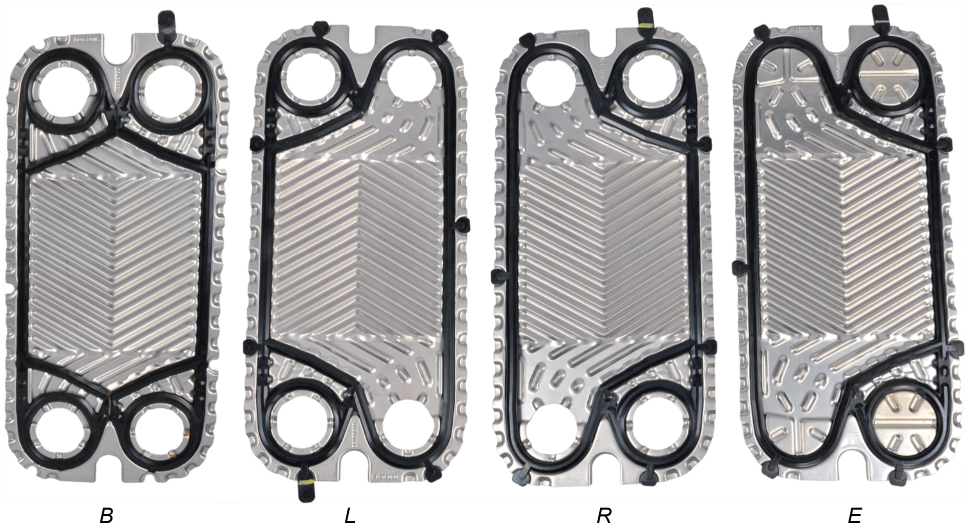


Figure 2-9. Types of inner plate for the gasketed plate heat exchanger.

The typical combination of plates would be to place in-between the two end plates: a *B* plate first (tag upwards), then a pattern made of an *L* plate followed by an *R* plate repeated as many times as desired, then an *L* plate and finally an *E* plate. In this exercise, the gasketed plate heat exchanger is used in a five-plate configuration and in a nine-plate configuration. These configurations will be described shortly.

One must visualize that a combination of a *B* and an *E* plate creates a single channel for one fluid. Each addition of an *L* or *R* plate in-between creates another channel. Consequently, there are four channels for a five-plate configuration and eight channels for a nine-plate configuration.

The number of exchange areas, or interfaces, is equal to the number of channels minus one. So, there are three exchange areas for a five-plate configuration and seven for a nine-plate configuration. It means that the total surface area will increase by a factor of 7/3 when you go from a five-plate to a nine-plate configuration.

Characteristics of the gasketed plate heat exchanger

The gasketed plate heat exchanger used in the experiment is shown in Figure 2-10.

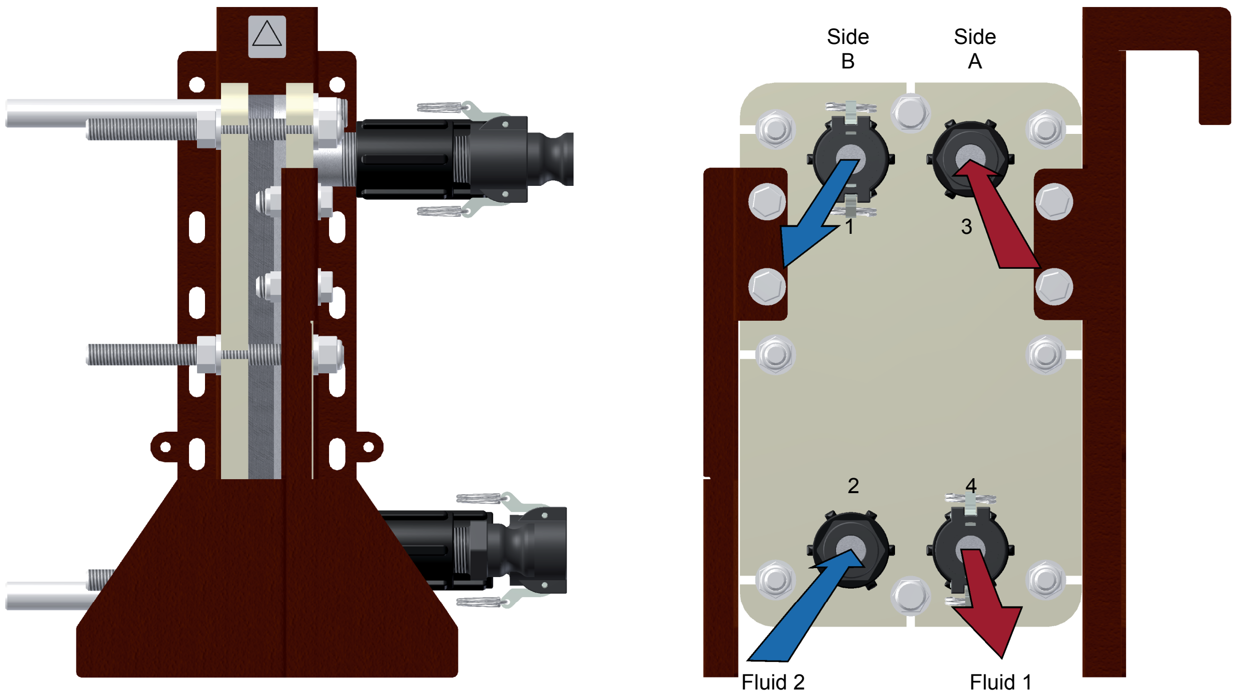


Figure 2-10. Gasketed plate heat exchanger in counter-flow mode, Model 46905-A.

Table 2-17 presents a summary of the main characteristics of the gasketed plate heat exchanger:

Table 2-17. Gasketed plate heat exchanger characteristics.

Gasketed plate heat exchanger				
Number of plates	5 plates		9 plates	
Nominal surface (A)	0.063 m^2 (0.678 ft^2)		0.147 m^2 (1.582 ft^2)	
Number of exchange surfaces	3		7	
Experimental overall heat transfer coefficient (U) for typical operating conditions: Fluid 1: T_{in} = 32°C (90°F) Fluid 2: T_{in} = 18°C (65°F) Flow of both fluids = 12 L/min (3 gaL/min)	3600 W/m^2·K (634 Btu/h·ft^2·°F)		2600 W/m^2·K (450 Btu/h·ft^2·°F)	
Experimental pressure drops (for the operating conditions stated above)	Side A	Side B	Side A	Side B
	6.3 kPa (0.8 psi)	4.8 kPa (0.6psi)	3.2 kPa (0.4 psi)	1.8 kPa (0.2 psi)
Number of channels	Side A	Side B	Side A	Side B
	2	2	4	4
Flow direction for counter-flow operation	See Figure 2-10			

⚠ CAUTION

This model is particularly heavy. Obtain assistance from another person to lift it and take the necessary precautions to install the exchanger securely on the workstation.

Make sure to install a strut to support the back of the exchanger at its lower end to avoid too much torsion on the upper strut. See Figure 2-11.

Bolt the exchanger securely in place at all time.

Typical applications

Gasketed plate heat exchangers were introduced in 1923 for the pasteurization of dairy products as they are easy to clean and allow a precise thermal control over the pasteurization process. Plate exchangers are now used in food processing, pharmaceutical industries, paper mills and so on.

Such exchangers develop high heat transfer coefficients and are unlikely to allow significant cold or hot spots in the exchangers. The gaskets must be periodically replaced when under heavy duty use. The material composition of the gaskets makes the use of this type of exchanger questionable in corrosive applications. Gaskets may develop pinhole leaks which are difficult to detect but fluid-to-fluid mixing is very unlikely unless a plate becomes pierced.

Using the gasketed plate heat exchanger

To ensure an efficient heat transfer as well as to extend the useful life of the heat exchanger, some precautions must be taken. Be sure to follow the guidelines presented in the following pages.

Typical installation

The following procedure describes the typical steps to install the heat exchanger for a counter-flow application.

1. Make sure to install a strut at the level shown in Figure 2-11 to support the back of the exchanger. You can use an extra strut or simply raise the unused strut which is located at a lower position in the basic setup.

2. Place the exchanger in place as indicated in Figure 2-11.

3. Using spring nuts and screws, secure the mounting bracket of the heat exchanger on the process workstation.

4. You may have to install elbow connectors on the ports of the heat exchanger to allow easy connection with other devices.

5. Install a strainer at the inlets to prevent dirt or impurities from clogging the heat exchanger (Ports 2 and 3 in Figure 2-10, while in counter-flow mode).

6. Connect the cold water source to port 2; this is the water that will be heated. The cold water comes from tank B.

7. Connect the hot water source to port 3. The warm water comes from tank A.

8. Connect hoses to port 1 and port 4 which are respectively the heated water outlet and cooled water outlet and make sure they return to the proper tank.

CAUTION

As shown in Figure 2-11, a strainer must be installed at the input port of both the cold and warm fluid inlets. This prevents impurities from clogging the heat exchanger.

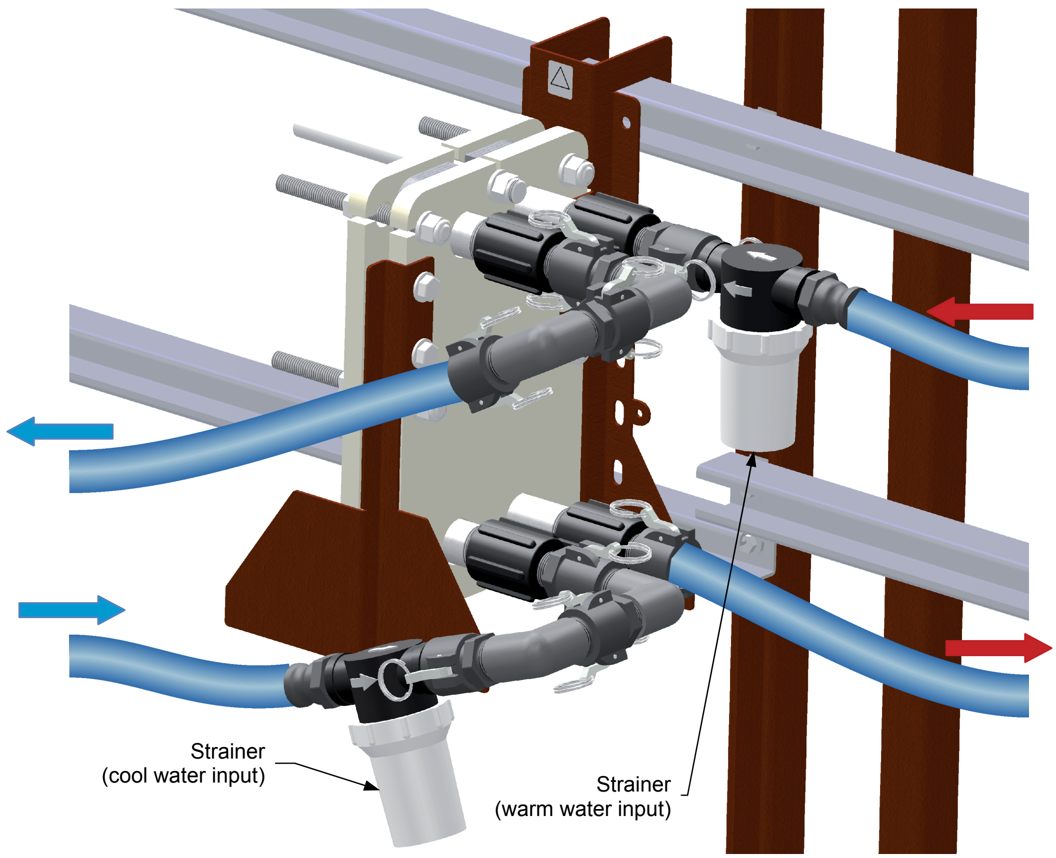


Figure 2-11. Typical installation of a gasketed plate heat exchanger.

Changing the number of plates

It is possible to change the number of plates of this heat exchanger to adjust it to the needs of a given process. The exchanger is used with a total of either five or nine plates in our experiments, but you can try out different configurations.

The following procedure describes the typical steps to adjust the number of plates. Work above the drip tray of the process workstation or on a floor able to withstand some water.

1. Make sure the hoses are disconnected from the exchanger (stop the pumps before disconnecting any hose!). The exchanger should be reasonably empty of water.

2. The heat exchanger should be securely fastened to the process workstation before you work on it. If the exchanger is not well located for you to work easily on it, unfasten it and place it on the ground. Use the assistance of another person to lift the exchanger as it is heavy.

3. Loosen the compression bolts sequentially. A few turns are sufficient at this point. It is suggested you start by the one in the upper left corner, then proceed to the one in the bottom right corner, then the one in the upper right corner and the one in the lower left corner. Finish with the ones in the center. Do not try to loosen the guide rods.

Figure 2-12. Loosening the compression bolts.

Once all compression bolts have been slightly loosened, you can finish loosening them and remove the compression bolts and the mobile end plate to gain access to the inner plates.

4. Insert or remove the appropriate plates in between plates *B* and *E* to obtain the required configuration. The suggested configurations from the static to the mobile end plates are:

   Five-plate configuration: *B L R L E*

   Nine-plate configuration: *B L R L R L R L E*

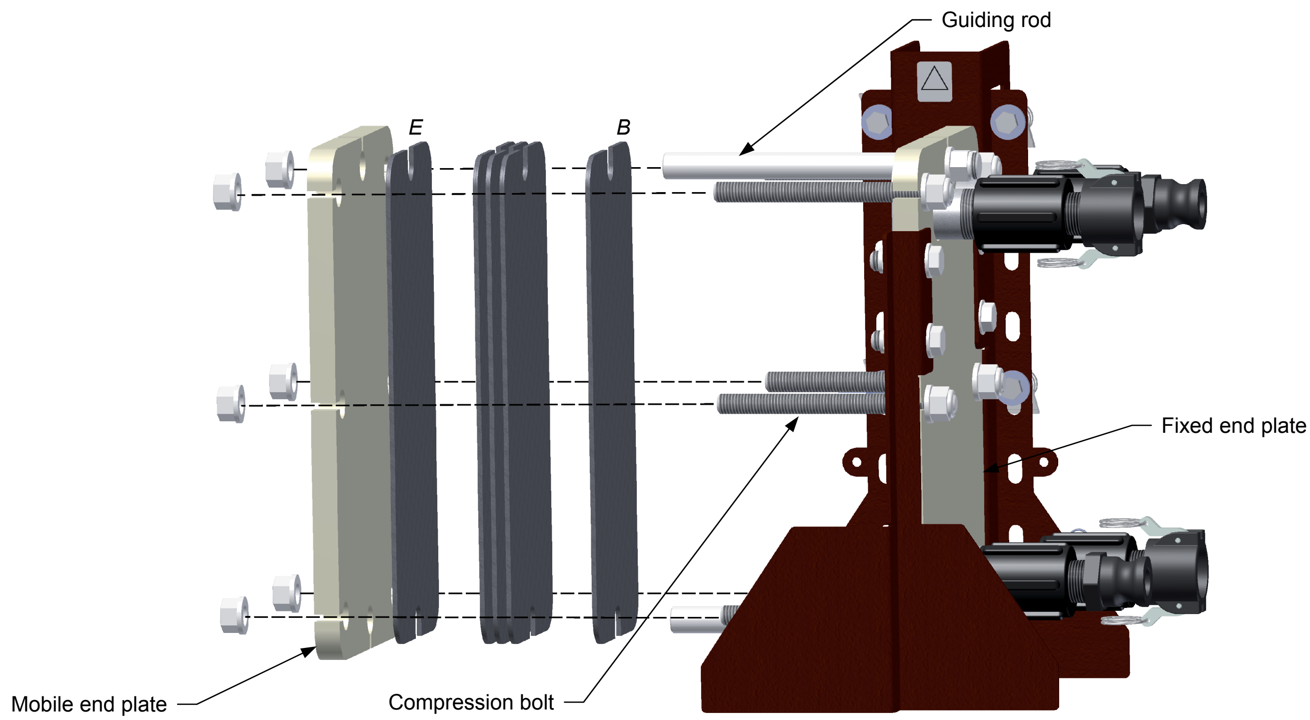


Figure 2-13. Configuration of the plates inside the exchanger.

5. Replace the back end plate and the compression bolts. Tighten the compression bolts lightly in the reverse order. Once all the compression bolts are in place, tighten them snugly.

   Do not tighten the rods too much with the ratchet: You should not need to use a large force to unscrew them later.

The exchanger is now ready to be used in a different configuration.

PROCEDURE OUTLINE

The Procedure is divided into the following sections:

- Set up and connections
- Counter-flow mode measurements
  Characterization with equal flow rates – Five plates. Characterization with equal flow rates – Nine plates. Comparison of the five-plate versus the nine-plate configuration. Characterization with a fixed flow rate and a variable flow rate. Characterization with a different input temperature for fluid 2.
- Parallel-flow mode measurements
  Characterization with equal flow rates – Nine plates. Characterization with equal flow rates – Five plates. Comparison of the nine-plate and five-plate configuration – parallel flow.

PROCEDURE

Set up and connections

1. Verify that the emergency push button is wired so as to be able to cut the power in case of emergency. The *Familiarization with the Training System* manual covers the security issues related to the use of electricity with the system as well as the wiring of the emergency push button.

2. Make sure the 3531 system is properly set up to use the Heating/Cooling unit.

3. Connect the equipment according to the piping and instrumentation diagram (P&ID) shown in Figure 2-14 and use Figure 2-15 to position the equipment correctly on the frame of the training system. To set up your system for this exercise, start with the basic setup (minus the control valve) presented in the *Familiarization with the Training System* manual and add the equipment listed in Table 2-18. Drives 3 and 4 and pumps 3 and 4 must be connected to the setup as explained in the *Familiarization with the Training System* manual even though they are not shown explicitly in Figure 2-14.

Table 2-18. Material to add to the basic setup for this exercise.

Name	Model	Identification
Gasketed plate heat exchanger	46905-A	-
4 Platinum RTDs	46917	TE A1, TE A2, TE B1 and TE B2
Electromagnetic flow transmitter	46922-0	FIT A
Electromagnetic flow transmitter	46922-1	FIT B
Paperless recorder (if wished)	46972	-
Energy manager	46974	UIY

Optionally, you may add the following equipment to measure pressure drops:

Name	Model	Identification
4 Pressure ports	70-85808	-
Differential pressure transmitter (high range)	46920	PDIT B
Differential pressure transmitter (low range)	46921	PDIT A

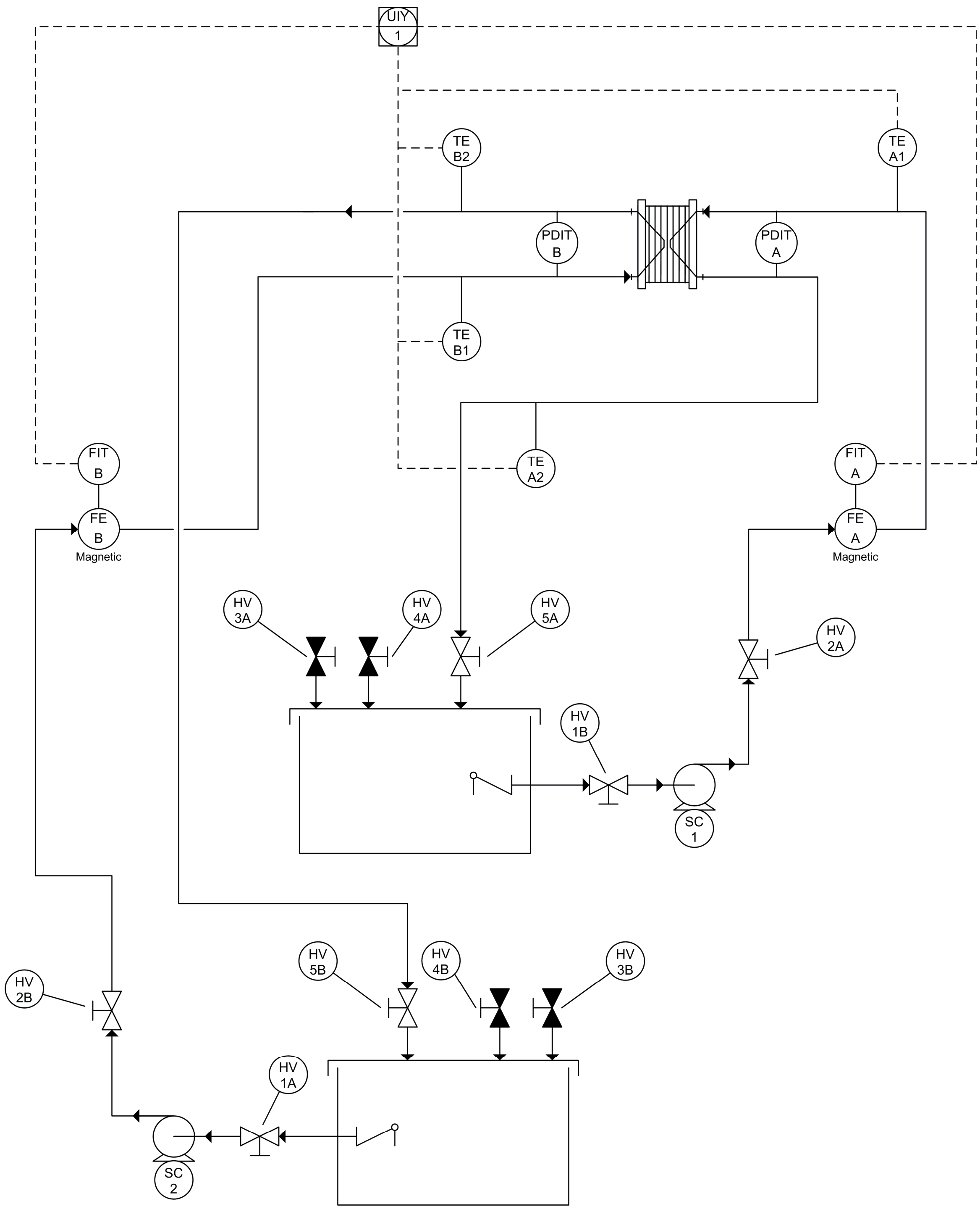


Figure 2-14. P&ID – Gasketed plate heat exchanger experiment.

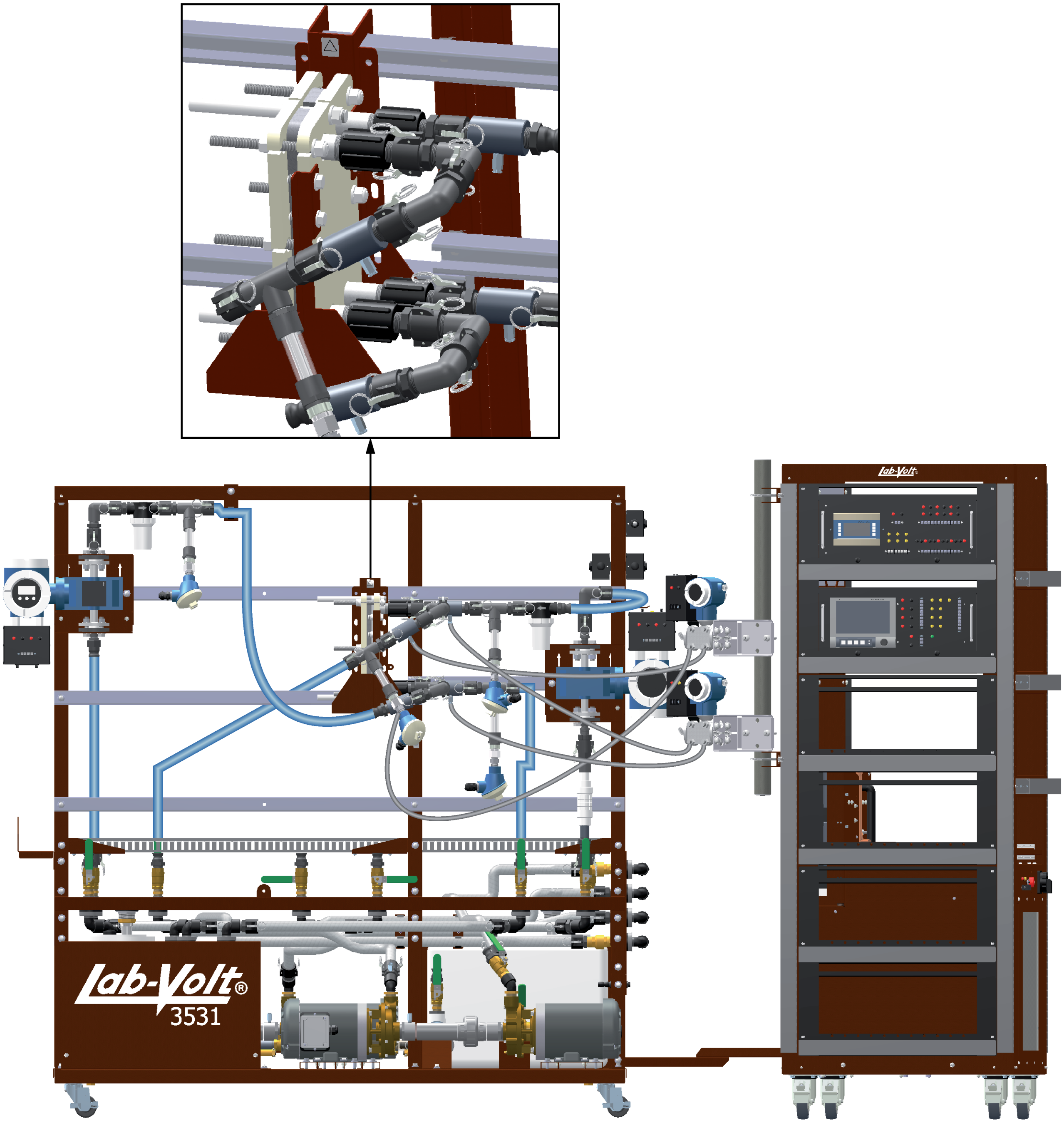


Figure 2-15. Setup – Gasketed plate heat exchanger experiment.

4. Do not power up the instrumentation workstation yet. Do not turn on the electrical panel or the heating/cooling unit before your instructor has validated your setup—that is not before step 7.

5. Before proceeding further, complete the following checklist to make sure you have set up the system properly. The points on this checklist are crucial elements for the proper completion of this exercise. This checklist is not exhaustive, so be sure to follow the instructions in the *Familiarization with the Training System* manual as well.

- Every piece of equipment used is secured to the station with the appropriate bolt-and-nut mechanism.
- The heat exchanger is properly installed on the station.
- The hand valves are in the positions shown in the P&ID:

  Open valves: HV1A, HV1B, HV2A, HV2B, HV5A, and HV5B.
  Closed valves: HV3A, HV3B, HV4A, and HV4B.
- The hand valves under the drip trays are in the positions specified in the *Familiarization with the Training System* manual:

  Open valves: HV1A, HV1B, HV8A, and HV8B.
  Closed valves: HV6A, HV6B, and HV7.

6. Ask your instructor to check and approve your setup.

7. Power up the electrical unit. This powers the different measurement devices. Engage the circuits to power the four drives.

8. Start drives 3 and 4 (pumps P3 and P4). These pumps make the water of the two tanks flow in the heating/cooling unit. Ensure the process fluid from each tank is circulating correctly, then power up the heating/cooling unit. Make sure valve HV7 is closed. Continue with the next steps while the water in each tank is respectively heating and cooling toward their temperature set points.

9. Test your system for leaks. Use drives 1 and 2 to make pumps P1 and P2 run at low speed to produce a small flow rate. Progressively increase the frequency output of drives 1 and 2 up to 30 Hz. Repair any leaks that may arise.

   Optional: Configure, bleed and adjust your differential-pressure transmitters so as to be able to measure the pressure drops across the heat exchanger for each fluid.

10. The temperatures in the two tanks should be stable and at their respective set points by now. If this is not the case, identify the problem or wait a few minutes until the temperatures of the tanks stabilize.

Counter-flow mode measurements

Characterization with equal flow rates – Five plates

11. Adjust the flow rates at 12 L/min (3 gpm) for the two fluids and let the temperature stabilize. Use the infrared thermometer to scan the heat exchanger. How does the temperature gradient look like?

The temperature distribution at the back of the exchanger is mostly constant, but varies slightly from point to point. You can measure the peak temperature behind the hot water inlet and the coldest temperature behind the cold water inlet. The heavy end plate does a good job of averaging the heat distribution.

12. Adjust the flow rates of the two fluids as prescribed in either Table 2-19 (SI units) or Table 2-20 (US customary units). Fill in the temperature and heat flow measurements as given by the energy manager. Wait until the readings are stable before recording the data.

Discontinue the measurements if the heat flows become larger than about 2 tons – 7 kW – 24 000 Btu/h, especially if you notice that the heating/cooling unit cannot keep the cold water close to its set point.

Optional: Record the pressure drops measured by the differential-pressure transmitters.

Table 2-19. Gasketed plate heat exchanger measurement – Counter-flow – Five plates – SI units.

Flow rate Fluid 1 (L/min)	Flow rate Fluid 2 (L/min)	$T_{1,in}$ (°C)	$T_{1,out}$ (°C)	$T_{2,in}$ (°C)	$T_{2,out}$ (°C)	Heat flow 1 (kW)	Heat flow 2 (kW)	ΔP_1 (kPa)	ΔP_2 (kPa)
4.0	4.0								
8.0	8.0								
12.0	12.0								
16.0	16.0								
20.0	20.0								
24.0	24.0								
28.0	28.0								
32.0	32.0								
36.0	36.0								

Table 2-20. Gasketed plate heat exchanger measurement – Counter-flow – Five plates – US customary units.

Flow rate Fluid 1 (gaL/min)	Flow rate Fluid 2 (gaL/min)	$T_{1,in}$ (°F)	$T_{1,out}$ (°F)	$T_{2,in}$ (°F)	$T_{2,out}$ (°F)	Heat flow 1 (Btu/h)	Heat flow 2 (Btu/h)	ΔP_1 (psi)	ΔP_2 (psi)
1.0	1.0								
2.0	2.0								
3.0	3.0								
4.0	4.0								
5.0	5.0								
6.0	6.0								
7.0	7.0								
8.0	8.0								
9.0	9.0								

The results for a five-plate counter-flow configuration of the gasketed plate heat exchanger are recorded in the following tables:

Gasketed plate heat exchanger measurement – Counter-flow – Five plates – SI units.

Flow rate Fluid 1 (L/min)	Flow rate Fluid 2 (L/min)	$T_{1,in}$ (°C)	$T_{1,out}$ (°C)	$T_{2,in}$ (°C)	$T_{2,out}$ (°C)	Heat flow 1 (kW)	Heat flow 2 (kW)	ΔP_1 (kPa)	ΔP_2 (kPa)
4	4	33.0	28.4	17.7	22.4	1.3	1.3	0.7	0.9
8	8	32.3	28.8	17.8	21.6	2.0	2.1	2.1	3.1
12	12	32.3	29.3	18.3	21.5	2.4	2.6	4.8	6.3
16	16	33.8	30.7	17.4	20.7	3.4	3.7	8.2	10.7
20	20	32.0	29.7	18.5	21.1	3.1	3.5	12.4	15.9
24	24	31.0	29.2	19.4	21.4	3.0	3.4	17.9	22.0
28	28	31.4	29.5	18.4	20.5	3.6	4.1	24.4	29.0
32	32	32.5	30.4	17.3	19.6	4.6	5.2	30.1	38.1
36	36	31.1	29.4	17.8	19.6	4.2	4.8	37.6	47.2

Gasketed plate heat exchanger measurement – Counter-flow – Five plates – US customary units.

Flow rate Fluid 1 (gaL/min)	Flow rate Fluid 2 (gaL/min)	$T_{1,in}$ (°F)	$T_{1,out}$ (°F)	$T_{2,in}$ (°F)	$T_{2,out}$ (°F)	Heat flow 1 (Btu/h)	Heat flow 2 (Btu/h)	ΔP_1 (psi)	ΔP_2 (psi)
1	1	91.9	83.5	63.0	72.0	4440	4440	0.1	0.1
2	2	90.7	84.0	64.6	71.8	6489	7172	0.3	0.4
3	3	92.1	85.8	62.4	69.4	9563	10246	0.6	0.8
4	4	90.7	86.0	64.9	70.3	10246	10929	1.1	1.4
5	5	90.0	85.8	66.9	71.2	9904	10929	1.6	2.1
6	6	89.8	85.8	65.1	69.6	11953	12978	2.3	2.9
7	7	88.3	84.9	64.9	68.9	11953	13661	3.2	3.8
8	8	89.6	86.4	65.1	68.9	13661	15368	3.9	5.0
9	9	88.3	85.1	65.7	69.1	13661	15027	4.9	6.2

13. Stop the pumps and use your results to perform the required calculations to complete either Table 2-21 or Table 2-22. The average heat flow is used in the calculations.

It is strongly suggested to use a spreadsheet software to perform the calculations quickly.

Table 2-21. Gasketed plate heat exchanger calculations – Counter-flow – Five plates – SI units.

Flow rate Fluid 1 (L/min)	Flow rate Fluid 2 (L/min)	$\Delta T_1 = T_{1,i} - T_{2,o}$ (°C)	$\Delta T_2 = T_{1,o} - T_{2,i}$ (°C)	ΔT_{lm} (°C)	Average Heat flow (kW)	U (kW/m²·°C)
4.0	4.0					
8.0	8.0					
12.0	12.0					
16.0	16.0					
20.0	20.0					
24.0	24.0					
28.0	28.0					
32.0	32.0					
36.0	36.0					

Table 2-22. Gasketed plate heat exchanger calculations – Counter-flow – Five plates – US customary units.

Flow rate Fluid 1 (gaL/min)	Flow rate Fluid 2 (gaL/min)	$\Delta T_1 = T_{1,i} - T_{2,o}$ (°F)	$\Delta T_2 = T_{1,o} - T_{2,i}$ (°F)	ΔT_{lm} (°F)	Average Heat flow (Btu/h)	U (Btu/h·ft²·°F)
1.0	1.0					
2.0	2.0					
3.0	3.0					
4.0	4.0					
5.0	5.0					
6.0	6.0					
7.0	7.0					
8.0	8.0					
9.0	9.0					

The calculations for the overall transfer coefficient are as follow:

Gasketed plate heat exchanger calculations – Counter-flow – Five plates – SI units.

Flow rate Fluid 1 (L/min)	Flow rate Fluid 2 (L/min)	$\Delta T_1 = T_{1,i} - T_{2,o}$ (°C)	$\Delta T_2 = T_{1,o} - T_{2,i}$ (°C)	ΔT_{lm} (°C)	Average Heat flow (kW)	U (kW/m²·°C)
4.0	4.0	10.6	10.7	10.65	1.3	1.9
8.0	8.0	10.7	11.0	10.85	2.1	3.0
12.0	12.0	10.8	11.0	10.90	2.5	3.6
16.0	16.0	13.1	13.3	13.20	3.6	4.3
20.0	20.0	10.9	11.2	11.05	3.3	4.7
24.0	24.0	9.6	9.8	9.70	3.2	5.2
28.0	28.0	10.9	11.1	11.00	3.9	5.6
32.0	32.0	12.9	13.1	13.00	4.9	6.0
36.0	36.0	11.5	11.6	11.55	4.5	6.2

Gasketed plate heat exchanger calculations – Counter-flow – Five plates – US customary units.

Flow rate Fluid 1 (gaL/min)	Flow rate Fluid 2 (gaL/min)	$\Delta T_1 = T_{1,i} - T_{2,o}$ (°F)	$\Delta T_2 = T_{1,o} - T_{2,i}$ (°F)	ΔT_{lm} (°F)	Average Heat flow (Btu/h)	U (Btu/h·ft²·°F)
1.0	1.0	20.0	20.5	20.25	4440	323
2.0	2.0	18.9	19.4	19.17	6830	526
3.0	3.0	22.7	23.4	23.04	9904	634
4.0	4.0	20.3	21.1	20.70	10587	754
5.0	5.0	18.7	18.9	18.81	10416	817
6.0	6.0	20.2	20.7	20.43	12465	900
7.0	7.0	19.4	20.0	19.71	12807	958
8.0	8.0	20.7	21.2	20.97	14515	1021
9.0	9.0	19.3	19.4	19.35	14344	1093

Characterization with equal flow rates – Nine plates

14. Make sure all the pumps are stopped and let the hoses and the exchanger empty themselves under the action of the gravity. Next, disconnect the hoses at the upper ports of the exchanger. Finally, carefully disconnect the hoses connected to the lower ports of the exchanger and let the water fall in the drip tray. This should allow the exchanger to be sufficiently empty of water to proceed.

Add the extra plates to obtain a nine-plate configuration. Follow the instructions given in page 53. Reconnect the hoses, restart the pumps and bleed your pressure transmitters if necessary.

15. Adjust the flow rates of the two fluids as prescribed in either Table 2-23 (SI units) or Table 2-24 (US customary units). Fill in the temperature and heat flow measurements as given by the energy manager. Wait until the readings are stable before recording the data.

Discontinue the measurements once the heat flows become larger than about 2 tons – 7 kW – 24 000 Btu/h, especially if you notice that the heating/cooling unit cannot keep the cold water close to its set point.

Optional: Record the pressure drops measured by the differential-pressure transmitters.

Table 2-23. Gasketed plate heat exchanger measurement – Counter-flow – Nine plates – SI units.

Flow rate Fluid 1 (L/min)	Flow rate Fluid 2 (L/min)	$T_{1,in}$ (°C)	$T_{1,out}$ (°C)	$T_{2,in}$ (°C)	$T_{2,out}$ (°C)	Heat flow 1 (kW)	Heat flow 2 (kW)	ΔP_1 (kPa)	ΔP_2 (kPa)
4.0	4.0								
8.0	8.0								
12.0	12.0								
16.0	16.0								
20.0	20.0								
24.0	24.0								
28.0	28.0								
32.0	32.0								
36.0	36.0								

Table 2-24. Gasketed plate heat exchanger measurement – Counter-flow – Nine plates – US customary units.

Flow rate Fluid 1 (gaL/min)	Flow rate Fluid 2 (gaL/min)	$T_{1,in}$ (°F)	$T_{1,out}$ (°F)	$T_{2,in}$ (°F)	$T_{2,out}$ (°F)	Heat flow 1 (Btu/h)	Heat flow 2 (Btu/h)	ΔP_1 (psi)	ΔP_2 (psi)
1.0	1.0								
2.0	2.0								
3.0	3.0								
4.0	4.0								
5.0	5.0								
6.0	6.0								
7.0	7.0								
8.0	8.0								
9.0	9.0								

The results for a nine-plate counter-flow configuration of the gasketed plate heat exchanger are recorded in the following tables:

Gasketed plate heat exchanger measurement – Counter-flow – Nine plates – SI units.

Flow rate Fluid 1 (L/min)	Flow rate Fluid 2 (L/min)	$T_{1,in}$ (°C)	$T_{1,out}$ (°C)	$T_{2,in}$ (°C)	$T_{2,out}$ (°C)	Heat flow 1 (kW)	Heat flow 2 (kW)	ΔP_1 (kPa)	ΔP_2 (kPa)
4	4	33.9	27.5	17.5	23.8	1.8	1.8	0.2	0.0
8	8	32.8	28.0	18.1	23.3	2.5	2.5	0.9	1.5
12	12	32.4	27.9	17.4	22.2	3.8	4.0	1.8	3.2
16	16	32.4	28.4	17.5	21.9	4.4	4.8	3.1	5.5
20	20	32.3	28.7	17.8	21.7	5.1	5.5	4.7	8.3
24	24	32.8	29.1	17.2	21.1	6.2	6.5	6.8	11.7
28	28	33.2	29.7	17.3	21.1	6.9	7.5	9.4	15.6
32	32	32.8	29.7	18.9	22.0	6.5	7.0	12.2	19.9
36	36	31.4	29.2	19.6	22.2	5.8	6.6	15.5	24.9

Gasketed plate heat exchanger measurement – Counter-flow – Nine plates – US customary units.

Flow rate Fluid 1 (gaL/min)	Flow rate Fluid 2 (gaL/min)	$T_{1,in}$ (°F)	$T_{1,out}$ (°F)	$T_{2,in}$ (°F)	$T_{2,out}$ (°F)	Heat flow 1 (Btu/h)	Heat flow 2 (Btu/h)	ΔP_1 (psi)	ΔP_2 (psi)
1	1	90.5	82.6	67.1	77.2	4440	5464	0.0	0.1
2	2	91.9	82.6	63.7	73.9	9563	10246	0.1	0.2
3	3	90.0	82.4	64.6	73.2	11612	12978	0.2	0.4
4	4	89.1	82.2	64.6	72.0	13319	14685	0.4	0.7
5	5	91.4	83.8	62.1	70.2	18783	20150	0.6	1.1
6	6	91.9	84.9	63.1	70.5	20491	22199	0.9	1.5
7	7	90.5	84.4	63.0	69.6	21857	23906	1.2	2.0
8	8	93.0	86.5	64.2	70.9	24931	26297	1.6	2.6
9	9	91.0	86.0	65.8	71.6	23223	25272	2.0	3.3

16. Stop the pumps and use your results to perform the required calculations to complete either Table 2-25 or Table 2-26. The average heat flow is used in the calculations.

It is strongly suggested to use a spreadsheet software to perform the calculations quickly.

Table 2-25. Gasketed plate heat exchanger calculations – Counter-flow – Nine plates – SI units.

Flow rate Fluid 1 (L/min)	Flow rate Fluid 2 (L/min)	$\Delta T_1 = T_{1,i} - T_{2,o}$ (°C)	$\Delta T_2 = T_{1,o} - T_{2,i}$ (°C)	ΔT_{lm} (°C)	Average Heat flow (kW)	U (kW/m²·°C)
4.0	4.0					
8.0	8.0					
12.0	12.0					
16.0	16.0					
20.0	20.0					
24.0	24.0					
28.0	28.0					
32.0	32.0					
36.0	36.0					

Table 2-26. Gasketed plate heat exchanger calculations – Counter-flow – Nine plates – US customary units.

Flow rate Fluid 1 (gaL/min)	Flow rate Fluid 2 (gaL/min)	$\Delta T_1 = T_{1,i} - T_{2,o}$ (°F)	$\Delta T_2 = T_{1,o} - T_{2,i}$ (°F)	ΔT_{lm} (°F)	Average Heat flow (Btu/h)	U (Btu/h·ft²·°F)
1.0	1.0					
2.0	2.0					
3.0	3.0					
4.0	4.0					
5.0	5.0					
6.0	6.0					
7.0	7.0					
8.0	8.0					
9.0	9.0					

The calculations for the overall transfer coefficient are as follow:

Gasketed plate heat exchanger calculations – Counter-flow – Nine plates – SI units.

Flow rate Fluid 1 (L/min)	Flow rate Fluid 2 (L/min)	$\Delta T_1 = T_{1,i} - T_{2,o}$ (°C)	$\Delta T_2 = T_{1,o} - T_{2,i}$ (°C)	ΔT_{lm} (°C)	Average Heat flow (kW)	U (kW/m²·°C)
4.0	4.0	10.1	10.0	10.05	1.8	1.2
8.0	8.0	9.5	9.9	9.70	2.5	1.8
12.0	12.0	10.2	10.5	10.35	3.9	2.6
16.0	16.0	10.5	10.9	10.70	4.6	2.9
20.0	20.0	10.6	10.9	10.75	5.3	3.4
24.0	24.0	11.7	11.9	11.80	6.4	3.7
28.0	28.0	12.1	12.4	12.25	7.2	4.0
32.0	32.0	10.8	10.8	10.80	6.8	4.3
36.0	36.0	9.2	9.6	9.40	6.2	4.5

Gasketed plate heat exchanger calculations – Counter-flow – Nine plates – US customary units.

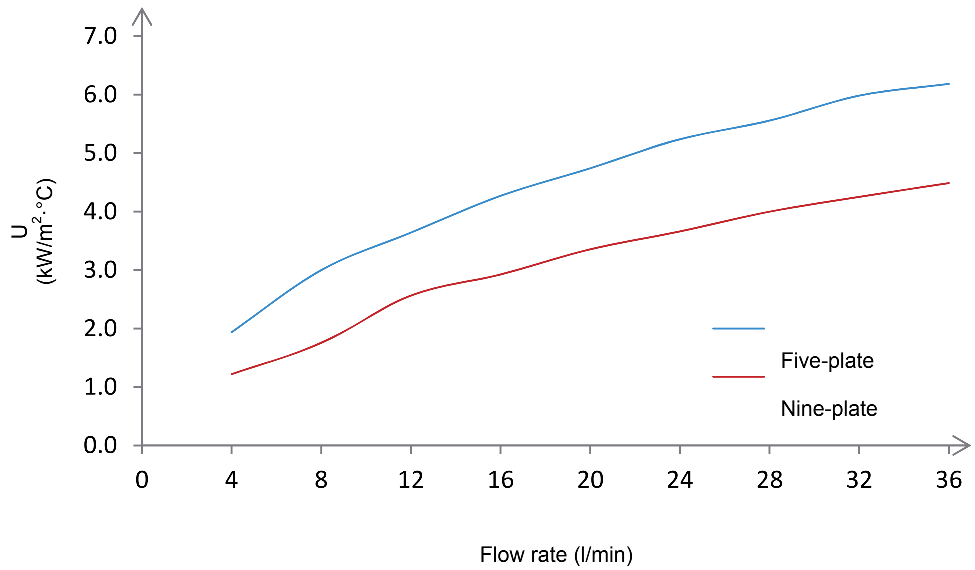
Flow rate Fluid 1 (gaL/min)	Flow rate Fluid 2 (gaL/min)	$\Delta T_1 = T_{1,i} - T_{2,o}$ (°F)	$\Delta T_2 = T_{1,o} - T_{2,i}$ (°F)	ΔT_{lm} (°F)	Average Heat flow (Btu/h)	U (Btu/h·ft²·°F)
1.0	1.0	13.3	15.5	14.37	4952	218
2.0	2.0	18.0	18.9	18.45	9904	339
3.0	3.0	16.7	17.8	17.27	12295	450
4.0	4.0	17.1	17.6	17.37	14002	510
5.0	5.0	21.2	21.8	21.51	19467	572
6.0	6.0	21.4	21.8	21.60	21345	625
7.0	7.0	20.9	21.4	21.15	22882	684
8.0	8.0	22.1	22.3	22.23	25614	728
9.0	9.0	19.4	20.2	19.80	24248	774

Comparison of the five-plate versus the nine-plate configuration

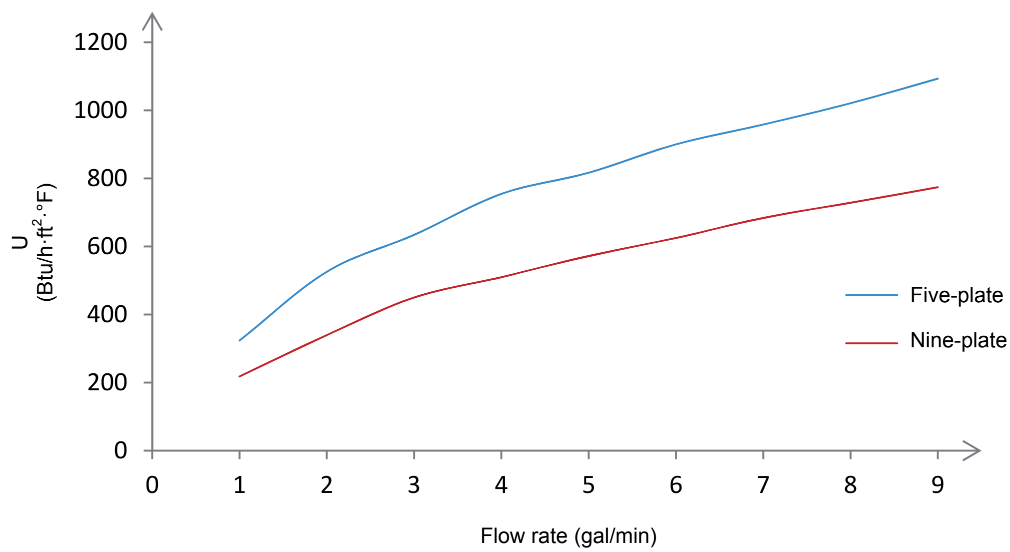
17. Finally, plot a graph of the average overall transfer coefficient as a function of the flow rate for both the five-plate and nine-plate counter-flow configurations.

Is it more efficient to use five plates or nine plates? Which configuration yields the larger heat flows?

The graphs for the overall transfer coefficient as a function of the flow rate in the case of both the five and nine-plate configurations look like this:



Overall transfer coefficient as a function of the flow rate – Counter-flow – SI units.



Overall transfer coefficient as a function of the flow rate – Counter-flow – US customary units.

The five-plate configuration has a higher overall transfer coefficient than the nine-plate one. A look at the tables of results shows that the nine-plate configuration yields higher average heat flows than the five-plate configuration.

Characterization with a fixed flow rate and a variable flow rate

18. Set the flow rate of fluid 1 to 16 L/min (4.0 gaL/min) and keep it fixed at this value. Next, adjust the flow rate of fluid 2 so as to fill either Table 2-27 or Table 2-28. Let the heat flow readings stabilize before recording the values.

Table 2-27. Gasketed plate heat exchanger measurement – Counter-flow – Flow rate of fluid 1 fixed – SI units.

Flow rate Fluid 1 (L/min)	Flow rate Fluid 2 (L/min)	Heat flow 1 (kW)	Heat flow 2 (kW)	Average heat flow (kW)
16.0	4.0			
16.0	8.0			
16.0	12.0			
16.0	16.0			
16.0	20.0			
16.0	24.0			
16.0	28.0			
16.0	32.0			
16.0	36.0			

Table 2-28. Gasketed plate heat exchanger measurement – Counter-flow – Flow rate of fluid 1 fixed – US customary units.

Flow rate Fluid 1 (gaL/min)	Flow rate Fluid 2 (gaL/min)	Heat flow 1 (Btu/h)	Heat flow 2 (Btu/h)	Average heat flow (Btu/h)
4.0	1.0			
4.0	2.0			
4.0	3.0			
4.0	4.0			
4.0	5.0			
4.0	6.0			
4.0	7.0			
4.0	8.0			
4.0	9.0			

The results are as follow for a constant fluid 1 flow rate:

Gasketed plate heat exchanger measurement – Counter-flow – Flow rate of fluid 1 fixed – SI units.

Flow rate Fluid 1 (L/min)	Flow rate Fluid 2 (L/min)	Heat flow 1 (kW)	Heat flow 2 (kW)	Average heat flow (kW)
16.0	4.0	2.2	2.5	2.4
16.0	8.0	3.6	4.0	3.8
16.0	12.0	3.8	4.1	4.0
16.0	16.0	3.9	4.3	4.1
16.0	20.0	4.5	4.9	4.7
16.0	24.0	4.2	4.4	4.3
16.0	28.0	4.8	5.0	4.9
16.0	32.0	5.2	5.5	5.4
16.0	36.0	4.9	5.0	5.0

Gasketed plate heat exchanger measurement – Counter-flow – Flow rate of fluid 1 fixed – US customary units.

Flow rate Fluid 1 (gaL/min)	Flow rate Fluid 2 (gaL/min)	Heat flow 1 (Btu/h)	Heat flow 2 (Btu/h)	Average heat flow (Btu/h)
4.0	1.0	7513	7172	7343
4.0	2.0	11270	11612	11441
4.0	3.0	13319	13319	13319
4.0	4.0	17076	17076	17076
4.0	5.0	17076	17759	17417
4.0	6.0	17076	17417	17247
4.0	7.0	17076	17076	17076
4.0	8.0	17417	17759	17588
4.0	9.0	17417	17417	17417

Characterization with a different input temperature for fluid 2

19. Change the temperature set point of fluid 2 (in tank B) to 24°C (75°F).

To do so: Locate the thermostat of the cooling circuit and press on the *menu* button. A blinking SP should appear on the screen. Press *menu* again to confirm. The current set point (18°C or 65°F) is displayed. Use the *arrows* to change the set point to 24°C or 75°F and press on the *menu* button to confirm. The set point is now adjusted.

Let fluid 2 warm up to its new set point before continuing. Allow fluids 1 and 2 to circulate at high flow rates in the heat exchanger to speed up the heating of the cold fluid.

20. Perform the manipulations as in step 18 with fluid 2 now at a higher temperature:

Table 2-29. Gasketed plate heat exchanger measurement – Counter-flow – Flow rate of fluid 1 fixed – Warmer fluid 2 – SI units.

Flow rate Fluid 1 (L/min)	Flow rate Fluid 2 (L/min)	Heat flow 1 (kW)	Heat flow 2 (kW)	Average heat flow (kW)
16.0	4.0			
16.0	8.0			
16.0	12.0			
16.0	16.0			
16.0	20.0			
16.0	24.0			
16.0	28.0			
16.0	32.0			
16.0	36.0			

Table 2-30. Gasketed plate heat exchanger measurement – Counter-flow – Flow rate of fluid 1 fixed – Warmer fluid 2 – US customary units.

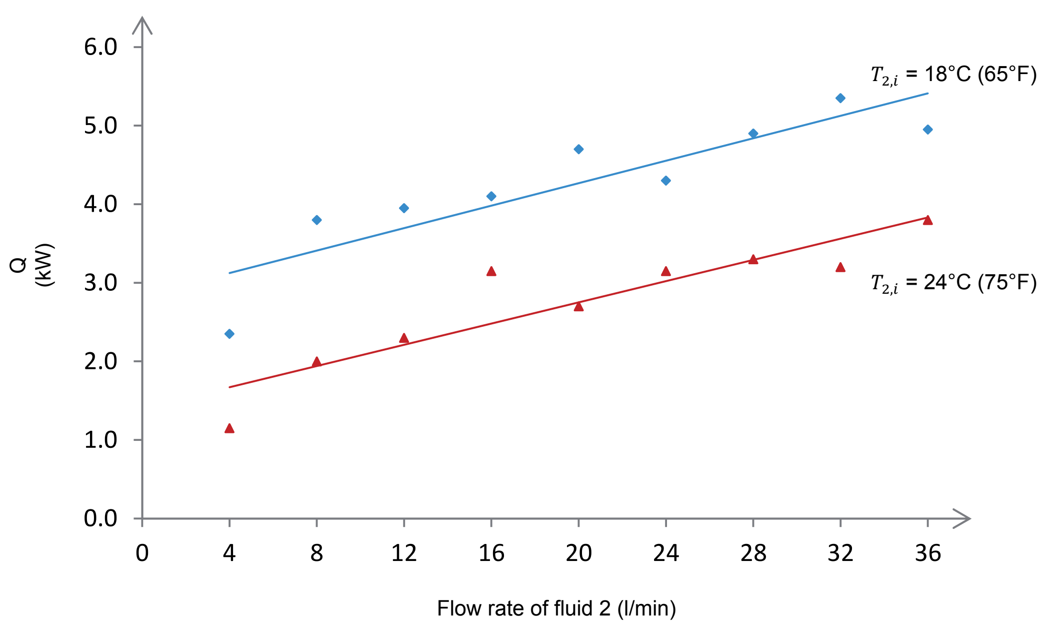
Flow rate Fluid 1 (gaL/min)	Flow rate Fluid 2 (gaL/min)	Heat flow 1 (Btu/h)	Heat flow 2 (Btu/h)	Average heat flow (Btu/h)
4.0	1.0			
4.0	2.0			
4.0	3.0			
4.0	4.0			
4.0	5.0			
4.0	6.0			
4.0	7.0			
4.0	8.0			
4.0	9.0			

How does the heat exchanger perform in the two cases? In which case is the heat exchange optimized?

The results are as follow for a constant flow rate for fluid 1 and a warmer set point temperature in the tank for fluid 2:

Gasketed plate heat exchanger measurement – Counter-flow – Flow rate of fluid 1 fixed – Warmer fluid 2 – SI units.

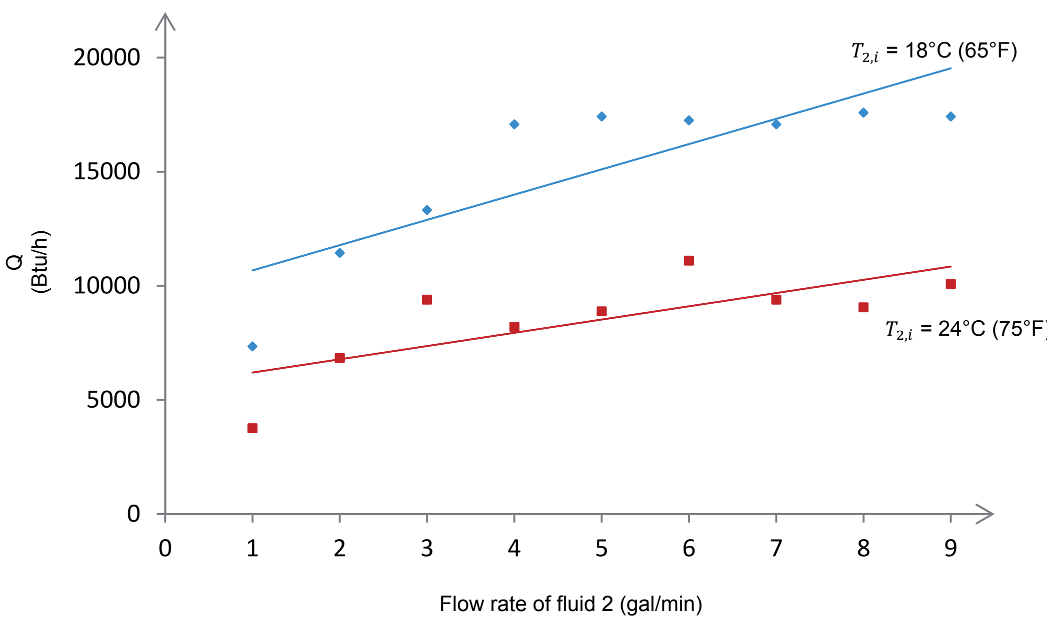
Flow rate Fluid 1 (L/min)	Flow rate Fluid 2 (L/min)	Heat flow 1 (kW)	Heat flow 2 (kW)	Average heat flow (kW)
16.0	4.0	1.1	1.2	1.2
16.0	8.0	1.9	2.1	2.0
16.0	12.0	2.2	2.4	2.3
16.0	16.0	3.1	3.2	3.2
16.0	20.0	2.5	2.9	2.7
16.0	24.0	3.1	3.2	3.2
16.0	28.0	3.2	3.4	3.3
16.0	32.0	3.0	3.4	3.2
16.0	36.0	3.7	3.9	3.8



Heat flow as a function of the flow rate of fluid 2 – Flow rate of fluid 1 fixed – SI units.

Gasketed plate heat exchanger measurement – Counter-flow – Flow rate of fluid 1 fixed – Warmer fluid 2 – US customary units.

Flow rate Fluid 1 (gaL/min)	Flow rate Fluid 2 (gaL/min)	Heat flow 1 (Btu/h)	Heat flow 2 (Btu/h)	Average heat flow (Btu/h)
4.0	1.0	3757	3757	3757
4.0	2.0	6830	6830	6830
4.0	3.0	9221	9563	9392
4.0	4.0	7513	8879	8196
4.0	5.0	8879	8879	8879
4.0	6.0	10929	11270	11099
4.0	7.0	9221	9563	9392
4.0	8.0	9904	8196	9050
4.0	9.0	9904	10246	10075



Heat flow as a function of the flow rate of fluid 2 – Flow rate of fluid 1 fixed – US customary units.

It can be seen, either by comparing the data or looking at the graphs, that the absolute heat flow is larger when the temperature difference between the two fluids is larger (i.e., when the set point of the water in tank B is lower, in our case at 18°C (65°F)).

21. Reset the set point of fluid 2 to its normal value of 18°C (65°F). Let the temperature of fluid 2 adjust while you perform the next step.

Parallel-flow mode measurements

Characterization with equal flow rates – Nine plates

22. Stop pumps 1 and 2. Modify the setup slightly to operate the exchanger in parallel-flow mode. Invert the inlet and the outlet of fluid 2 at the ports of the heat exchanger. You may need to change the elbow connectors.

    Make sure the strainer and the temperature probe TE B1 are located at the new input for fluid 2.

    The temperature of fluid 2 should be at its normal value of 18°C (65°F). If not, wait until it reaches its set point before continuing.

23. Adjust the flow rates at 12 L/min (3 gpm) for the two fluids and let the temperatures stabilize. Use the infrared thermometer to scan the heat exchanger. How does the temperature gradient look like?

    The temperature distribution at the back of the exchanger is mostly constant, but varies slightly from point to point. You can measure the peak temperature behind the hot water inlet and the coldest temperature behind the cold water inlet. The heavy end plate does a good job of averaging the heat distribution.

24. Adjust the flow rates of the two fluids as prescribed in either Table 2-31 or Table 2-32. Fill in the temperature and heat flow measurements as given by the energy manager.

    Optional: Record the pressure drops measured by the differential-pressure transmitters.

Table 2-31. Gasketed plate heat exchanger measurement – Parallel-flow – Nine plates – SI units.

Flow rate Fluid 1 (L/min)	Flow rate Fluid 2 (L/min)	$T_{1,in}$ (°C)	$T_{1,out}$ (°C)	$T_{2,in}$ (°C)	$T_{2,out}$ (°C)	Heat flow 1 (kW)	Heat flow 2 (kW)	ΔP_1 (kPa)	ΔP_2 (kPa)
4.0	4.0								
8.0	8.0								
12.0	12.0								
16.0	16.0								
20.0	20.0								
24.0	24.0								
28.0	28.0								
32.0	32.0								
36.0	36.0								

Table 2-32. Gasketed plate heat exchanger measurement – Parallel-flow – Nine plates – US customary units.

Flow rate Fluid 1 (gaL/min)	Flow rate Fluid 2 (gaL/min)	$T_{1,in}$ (°F)	$T_{1,out}$ (°F)	$T_{2,in}$ (°F)	$T_{2,out}$ (°F)	Heat flow 1 (Btu/h)	Heat flow 2 (Btu/h)	ΔP_1 (psi)	ΔP_2 (psi)
1.0	1.0								
2.0	2.0								
3.0	3.0								
4.0	4.0								
5.0	5.0								
6.0	6.0								
7.0	7.0								
8.0	8.0								
9.0	9.0								

The results for parallel-flow measurements are as follow.

Gasketed plate heat exchanger measurement – Parallel-flow – Nine plates – SI units.

Flow rate Fluid 1 (L/min)	Flow rate Fluid 2 (L/min)	$T_{1,in}$ (°C)	$T_{1,out}$ (°C)	$T_{2,in}$ (°C)	$T_{2,out}$ (°C)	Heat flow 1 (kW)	Heat flow 2 (kW)	ΔP_1 (kPa)	ΔP_2 (kPa)
4.0	4.0	32.9	27.7	17.6	23.2	1.5	1.6	0.3	0.5
8.0	8.0	32.2	27.8	17.7	22.5	2.5	2.7	0.9	1.6
12.0	12.0	32.2	28.3	17.8	22.2	3.3	3.7	1.8	3.2
16.0	16.0	33.2	29.3	18.0	22.2	4.3	4.7	3.1	5.6
20.0	20.0	33.1	29.7	18.6	22.4	4.8	5.3	4.8	8.5
24.0	24.0	31.5	28.8	19.4	22.3	4.5	5.0	6.8	11.8
28.0	28.0	31.4	28.6	18.4	21.4	5.4	5.9	8.7	16.1
32.0	32.0	30.8	28.1	17.9	20.7	5.8	6.3	11.6	20.7
36.0	36.0	31.1	28.5	17.7	20.5	6.4	7.2	15.0	25.9

Gasketed plate heat exchanger measurement – Parallel-flow – Nine plates – US customary units.

Flow rate Fluid 1 (gaL/min)	Flow rate Fluid 2 (gaL/min)	$T_{1,in}$ (°F)	$T_{1,out}$ (°F)	$T_{2,in}$ (°F)	$T_{2,out}$ (°F)	Heat flow 1 (Btu/h)	Heat flow 2 (Btu/h)	ΔP_1 (psi)	ΔP_2 (psi)
1.0	1.0	90.5	81.5	64.4	73.8	4440	4440	0.0	0.1
2.0	2.0	89.6	82.2	64.9	73.2	7513	8196	0.1	0.2
3.0	3.0	89.8	82.0	63.9	71.4	11270	11612	0.2	0.4
4.0	4.0	91.0	84.0	63.7	71.6	14344	15710	0.4	0.7
5.0	5.0	89.6	84.0	66.9	72.9	13661	15027	0.6	1.1
6.0	6.0	91.0	84.9	65.5	71.8	17417	18442	0.9	1.5
7.0	7.0	88.7	83.7	65.8	71.2	17417	18783	1.2	2.1
8.0	8.0	88.0	83.1	64.4	69.8	19808	21174	1.5	2.7
9.0	9.0	86.4	81.9	63.7	68.5	20150	21857	1.9	3.4

25. Stop the pumps and use your results to perform the required calculations to complete either Table 2-33 or Table 2-34. The average heat flow is used in the calculations.

It is strongly suggested to use a spreadsheet software to perform the calculations quickly.

Table 2-33. Gasketed plate heat exchanger calculations – Parallel-flow – Nine plates – SI units.

Flow rate Fluid 1 (L/min)	Flow rate Fluid 2 (L/min)	$\Delta T_1 = T_{1,i} - T_{2,i}$ (°C)	$\Delta T_2 = T_{1,o} - T_{2,o}$ (°C)	ΔT_{lm} (°C)	Average Heat flow (kW)	U (kW/m²·°C)
4.0	4.0					
8.0	8.0					
12.0	12.0					
16.0	16.0					
20.0	20.0					
24.0	24.0					
28.0	28.0					
32.0	32.0					
36.0	36.0					

Table 2-34. Gasketed plate heat exchanger calculations – Parallel-flow – Nine plates – US customary units.

Flow rate Fluid 1 (gaL/min)	Flow rate Fluid 2 (gaL/min)	$\Delta T_1 = T_{1,i} - T_{2,i}$ (°F)	$\Delta T_2 = T_{1,o} - T_{2,o}$ (°F)	ΔT_{lm} (°F)	Average Heat flow (Btu/h)	U (Btu/h·ft^2·°F)
1.0	1.0					
2.0	2.0					
3.0	3.0					
4.0	4.0					
5.0	5.0					
6.0	6.0					
7.0	7.0					
8.0	8.0					
9.0	9.0					

The calculations for the overall transfer coefficient in parallel mode are as follow:

Gasketed plate heat exchanger calculations – Parallel-flow – Nine plates – SI units.

Flow rate Fluid 1 (L/min)	Flow rate Fluid 2 (L/min)	$\Delta T_1 = T_{1,i} - T_{2,i}$ (°C)	$\Delta T_2 = T_{1,o} - T_{2,o}$ (°C)	ΔT_{lm} (°C)	Average Heat flow (kW)	U (kW/m^2·°C)
4.0	4.0	15.3	4.5	8.83	1.6	1.2
8.0	8.0	14.5	5.3	9.14	2.6	1.9
12.0	12.0	14.4	6.1	9.66	3.5	2.5
16.0	16.0	15.2	7.1	10.64	4.5	2.9
20.0	20.0	14.5	7.3	10.49	5.1	3.3
24.0	24.0	12.1	6.5	9.01	4.8	3.6
28.0	28.0	13.0	7.2	9.82	5.7	3.9
32.0	32.0	12.9	7.4	9.90	6.1	4.2
36.0	36.0	13.4	8.0	10.47	6.8	4.4

Gasketed plate heat exchanger calculations – Parallel-flow – Nine plates – US customary units.

Flow rate Fluid 1 (gaL/min)	Flow rate Fluid 2 (gaL/min)	$\Delta T_1 = T_{1,i} - T_{2,i}$ (°F)	$\Delta T_2 = T_{1,o} - T_{2,o}$ (°F)	ΔT_{lm} (°F)	Average Heat flow (Btu/h)	U (Btu/h·ft^2·°F)
1.0	1.0	26.1	7.7	15.10	4439.7	185.8
2.0	2.0	24.7	9.0	15.54	7854.9	319.6
3.0	3.0	25.9	10.6	17.15	11440.8	421.8
4.0	4.0	27.4	12.4	18.92	15026.8	502.1
5.0	5.0	22.7	11.2	16.24	14343.8	558.1
6.0	6.0	25.6	13.1	18.67	17929.7	607.2
7.0	7.0	22.9	12.4	17.11	18100.4	668.6
8.0	8.0	23.6	13.3	17.96	20491.1	721.0
9.0	9.0	22.7	13.3	17.59	21003.4	754.9

The graph shows the overall transfer coefficient as a function of the flow rates in the heat exchanger.

Characterization with equal flow rates – Five plates

26. Follow the procedure (see p.54 if required) to change the configuration of the exchanger to the five-plate configuration. Test your connections for leaks and operate the exchanger in parallel-flow mode.

27. Adjust the flow rates of the two fluids as prescribed in either Table 2-35 or Table 2-36. Fill in the temperature and heat flow measurements as given by the energy manager.

Optional: Record the pressure drops measured by the differential-pressure transmitters.

Table 2-35. Gasketed plate heat exchanger measurement – Parallel-flow – Five plates – SI units.

Flow rate Fluid 1 (L/min)	Flow rate Fluid 2 (L/min)	$T_{1,in}$ (°C)	$T_{1,out}$ (°C)	$T_{2,in}$ (°C)	$T_{2,out}$ (°C)	Heat flow 1 (kW)	Heat flow 2 (kW)	ΔP_1 (kPa)	ΔP_2 (kPa)
4.0	4.0								
8.0	8.0								
12.0	12.0								
16.0	16.0								
20.0	20.0								
24.0	24.0								
28.0	28.0								
32.0	32.0								
36.0	36.0								

Table 2-36. Gasketed plate heat exchanger measurement – Parallel-flow – Five plates – US customary units.

Flow rate Fluid 1 (gaL/min)	Flow rate Fluid 2 (gaL/min)	$T_{1,in}$ (°F)	$T_{1,out}$ (°F)	$T_{2,in}$ (°F)	$T_{2,out}$ (°F)	Heat flow 1 (Btu/h)	Heat flow 2 (Btu/h)	ΔP_1 (psi)	ΔP_2 (psi)
1.0	1.0								
2.0	2.0								
3.0	3.0								
4.0	4.0								
5.0	5.0								
6.0	6.0								
7.0	7.0								
8.0	8.0								
9.0	9.0								

The results for the five-plate parallel-flow measurements are as follow.

Gasketed plate heat exchanger measurement – Parallel-flow – Five plates – SI units.

Flow rate Fluid 1 (L/min)	Flow rate Fluid 2 (L/min)	$T_{1,in}$ (°C)	$T_{1,out}$ (°C)	$T_{2,in}$ (°C)	$T_{2,out}$ (°C)	Heat flow 1 (kW)	Heat flow 2 (kW)	ΔP_1 (kPa)	ΔP_2 (kPa)
4.0	4.0	32.1	27.5	15.6	20.4	1.3	1.4	0.7	0.8
8.0	8.0	31.8	28.3	16.0	20.0	2.0	2.3	2.4	2.8
12.0	12.0	32.4	29.1	16.3	19.8	2.7	2.9	4.9	5.8
16.0	16.0	32.3	29.7	17.0	20.0	3.0	3.4	8.1	9.6
20.0	20.0	32.2	29.8	18.2	20.8	3.1	3.4	12.0	14.3
24.0	24.0	32.0	30.2	19.4	21.5	3.0	3.5	16.9	19.6
28.0	28.0	31.8	30.2	20.0	21.8	3.1	3.6	22.9	25.9
32.0	32.0	30.8	29.4	19.2	20.9	3.2	3.8	30.0	33.2
36.0	36.0	32.5	30.7	17.9	19.9	4.5	5.1	42.5	35.1

Gasketed plate heat exchanger measurement – Parallel-flow – Five plates – US customary units.

Flow rate Fluid 1 (gaL/min)	Flow rate Fluid 2 (gaL/min)	$T_{1,in}$ (°F)	$T_{1,out}$ (°F)	$T_{2,in}$ (°F)	$T_{2,out}$ (°F)	Heat flow 1 (Btu/h)	Heat flow 2 (Btu/h)	ΔP_1 (psi)	ΔP_2 (psi)
1.0	1.0	90.7	82.0	59.4	68.2	4440	4440	0.1	0.1
2.0	2.0	88.7	82.0	61.0	68.0	6489	7172	0.3	0.4
3.0	3.0	91.6	85.1	59.7	66.7	9563	10587	0.7	0.8
4.0	4.0	89.1	84.0	62.6	68.0	9904	10587	1.1	1.3
5.0	5.0	91.4	86.7	63.0	68.2	11612	12636	1.6	1.9
6.0	6.0	88.3	85.5	67.3	70.9	9221	10587	2.2	2.6
7.0	7.0	90.7	87.3	66.9	70.9	11612	12978	3.0	3.4
8.0	8.0	89.8	86.4	65.1	68.7	12978	14685	3.9	4.3
9.0	9.0	88.7	86.2	65.5	68.9	12295	15368	4.9	5.4

28. Stop the pumps and use your results to perform the required calculations to complete either Table 2-37 or Table 2-38. The average heat flow is used in the calculations.

It is strongly suggested to use a spreadsheet software to perform the calculations quickly.

Table 2-37. Gasketed plate heat exchanger calculations – Parallel-flow – Five plates – SI units.

Flow rate Fluid 1 (L/min)	Flow rate Fluid 2 (L/min)	$\Delta T_1 = T_{1,i} - T_{2,i}$ (°C)	$\Delta T_2 = T_{1,o} - T_{2,o}$ (°C)	ΔT_{lm} (°C)	Average Heat flow (kW)	U (kW/m²·°C)
4.0	4.0					
8.0	8.0					
12.0	12.0					
16.0	16.0					
20.0	20.0					
24.0	24.0					
28.0	28.0					
32.0	32.0					
36.0	36.0					

Table 2-38. Gasketed plate heat exchanger calculations – Parallel-flow – Five plates – US customary units.

Flow rate Fluid 1 (gaL/min)	Flow rate Fluid 2 (gaL/min)	$\Delta T_1 = T_{1,i} - T_{2,i}$ (°F)	$\Delta T_2 = T_{1,o} - T_{2,o}$ (°F)	ΔT_{lm} (°F)	Average Heat flow (Btu/h)	U (Btu/h·ft²·°F)
1.0	1.0					
2.0	2.0					
3.0	3.0					
4.0	4.0					
5.0	5.0					
6.0	6.0					
7.0	7.0					
8.0	8.0					
9.0	9.0					

The calculations for the overall transfer coefficient in parallel mode for the five-plate configuration are as follow:

Gasketed plate heat exchanger calculations – Parallel-flow – Five plates – SI units.

Flow rate Fluid 1 (L/min)	Flow rate Fluid 2 (L/min)	$\Delta T_1 = T_{1,i} - T_{2,i}$ (°C)	$\Delta T_2 = T_{1,o} - T_{2,o}$ (°C)	ΔT_{lm} (°C)	Average Heat flow (kW)	U (kW/m²·°C)
4.0	4.0	16.5	7.1	11.15	1.4	1.9
8.0	8.0	15.8	8.3	11.65	2.2	2.9
12.0	12.0	16.1	9.3	12.39	2.8	3.6
16.0	16.0	15.3	9.7	12.29	3.2	4.1
20.0	20.0	14.0	9.0	11.32	3.3	4.6
24.0	24.0	12.6	8.7	10.53	3.3	4.9
28.0	28.0	11.8	8.4	10.00	3.4	5.3
32.0	32.0	11.6	8.5	9.97	3.5	5.6
36.0	36.0	14.6	10.8	12.60	4.8	6.0

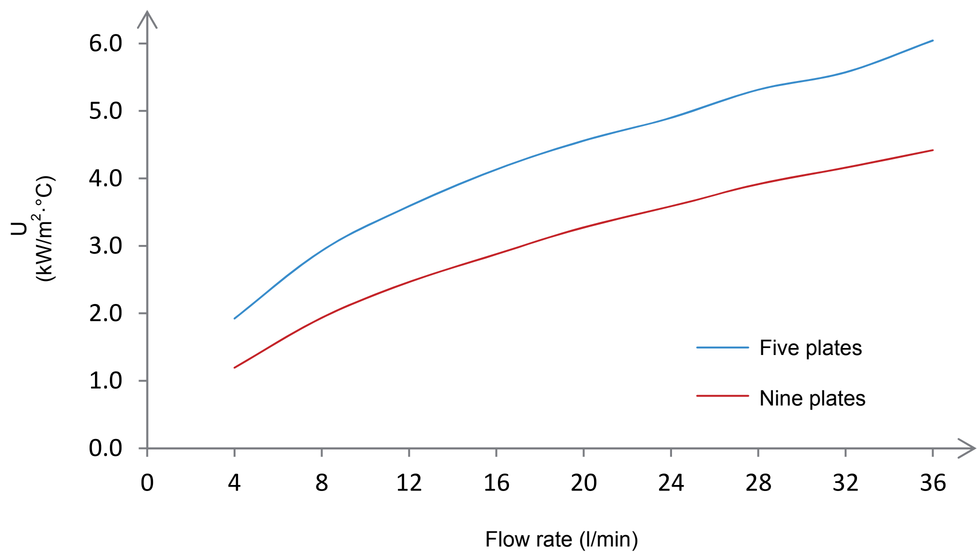
Gasketed plate heat exchanger calculations – Parallel-flow – Fives plates – US customary units.

Flow rate Fluid 1 (gaL/min)	Flow rate Fluid 2 (gaL/min)	$\Delta T_1 = T_{1,i} - T_{2,i}$ (°F)	$\Delta T_2 = T_{1,o} - T_{2,o}$ (°F)	ΔT_{lm} (°F)	Average Heat flow (Btu/h)	U (Btu/h·ft²·°F)
1.0	1.0	31.3	13.9	21.42	4439.7	305.8
2.0	2.0	27.7	14.0	20.11	6830.4	500.9
3.0	3.0	31.9	18.4	24.49	10074.8	606.7
4.0	4.0	26.5	16.0	20.81	10245.5	726.3
5.0	5.0	28.4	18.5	23.14	12123.9	772.8
6.0	6.0	21.1	14.6	17.62	9904.0	829.0
7.0	7.0	23.8	16.4	19.84	12294.6	913.9
8.0	8.0	24.7	17.6	20.95	13831.5	973.6
9.0	9.0	23.2	17.3	20.10	13831.5	1014.7

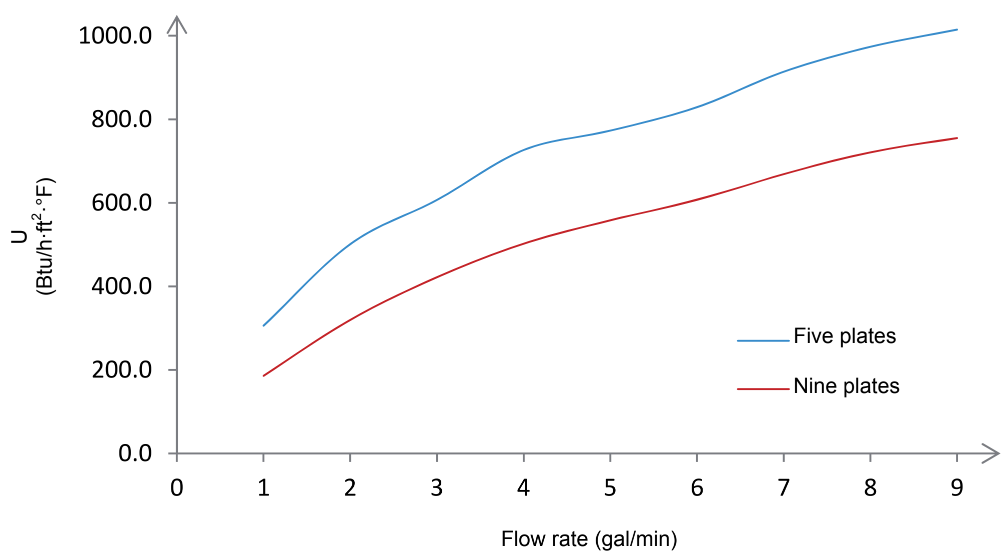
Comparison of the nine-plate and five-plate configuration – parallel flow

29. Finally, plot a graph of the average overall transfer coefficient as a function of the flow rate for both the five-plate and nine-plate configurations in parallel mode.

The overall transfer coefficient graphs for both the five-plate and nine-plate configurations in parallel look like this:



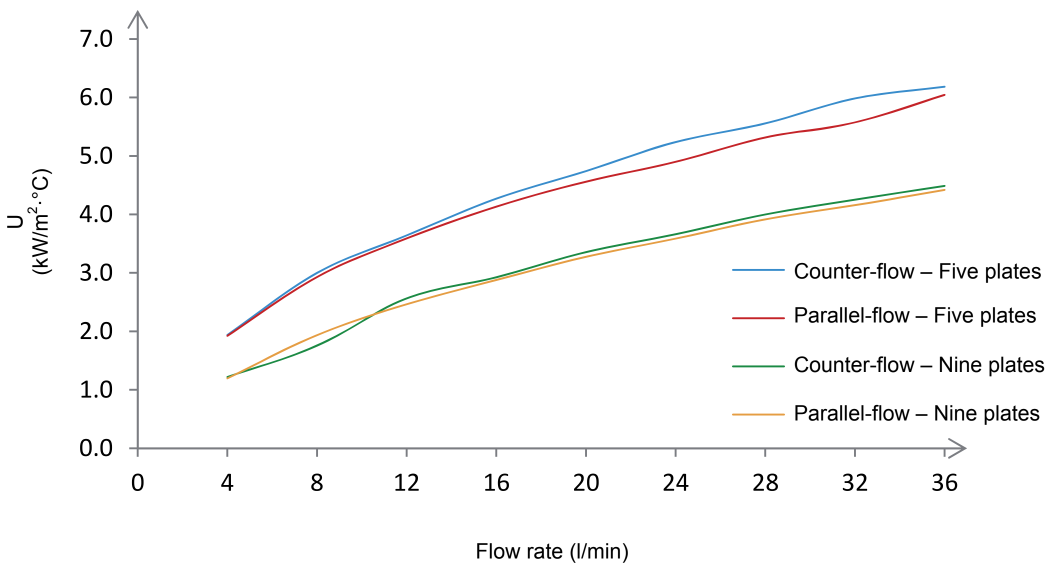
Comparison of the overall transfer coefficient as a function of the flow rate – Parallel-flow – SI units.



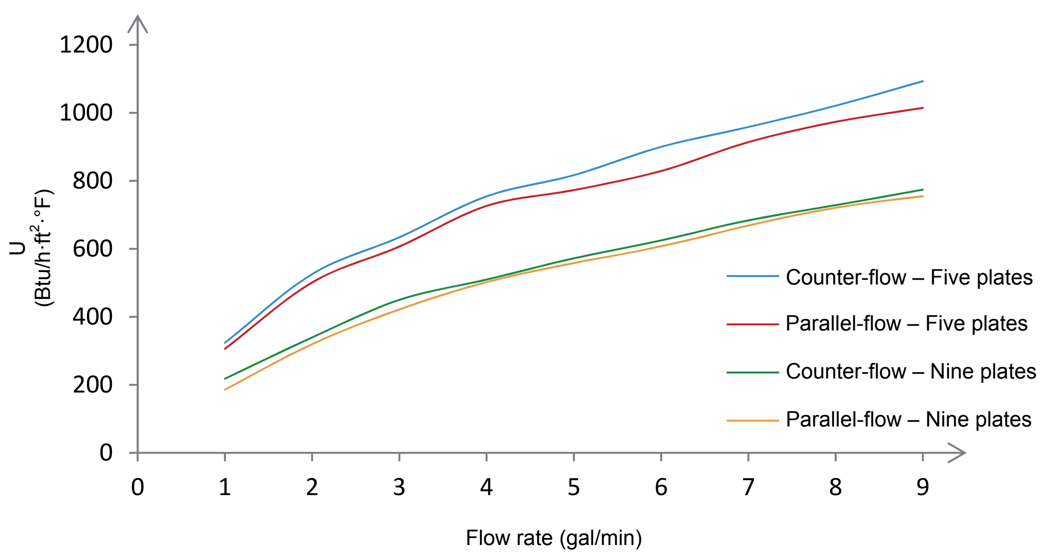
Comparison of the overall transfer coefficient as a function of the flow rate – Parallel-flow – US customary units.

30. Compare the graph obtained at step 29 for parallel-flow configuration with the one obtained at step 17 in counter-flow configuration. For which configuration is the heat exchanger more efficient?

As we can see from an analysis of the data or from the graphs below, the five-plate counter-flow configuration has the highest overall transfer coefficient. The difference for a given number of plates is slim between the counter-flow and the parallel-flow modes and this difference seems to diminish as the number of plates increases.



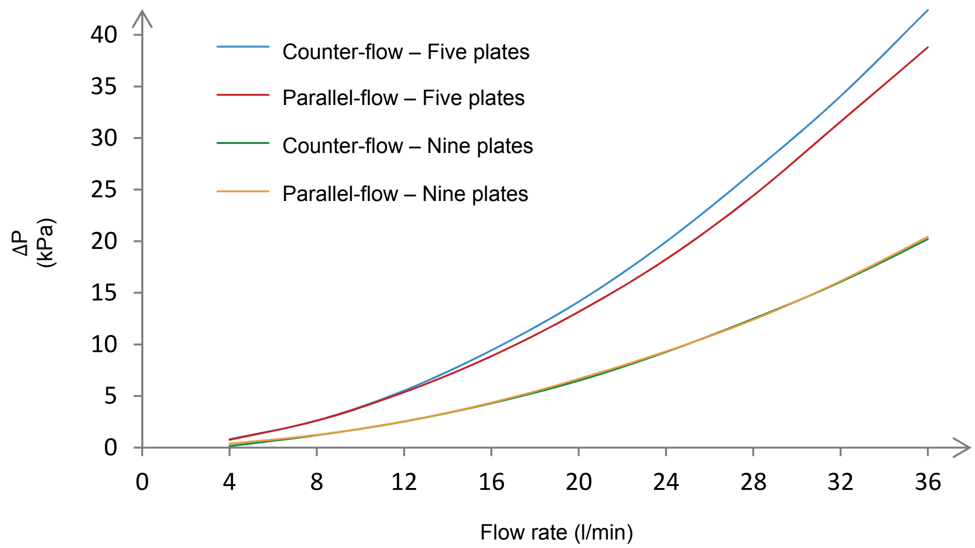
Overall transfer coefficient as a function of the flow rate – Comparison – SI units.



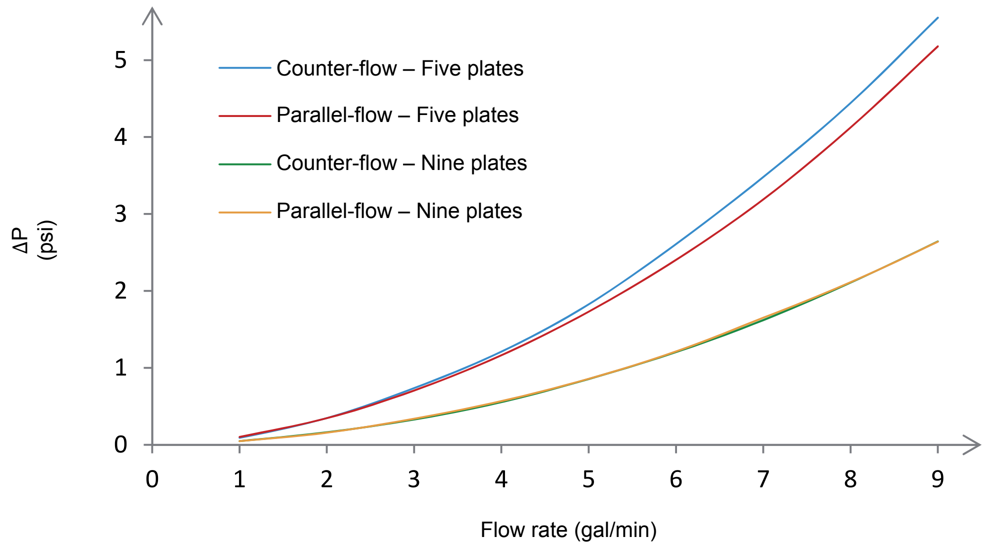
Overall transfer coefficient as a function of the flow rate – Comparison – US customary units.

31. *Optional*: Plot a graph of the average pressure drops as a function of the flow rate for both the counter-flow and parallel-flow modes. Trace a distinct curve for the five-plate and nine-plate cases.

The average pressure drop graphs for the gasketed plate heat exchanger look as shown below. Note how the pressure drops are the same for both the counter-flow and parallel-flow configurations in the case of the nine-plate exchanger. There is however a slight difference between the counter-flow and parallel-flow modes in the case of the five-plate exchanger. This is due to the different temperature distributions in the two modes which cause the viscosity of the fluids (and hence the pressure drops) to differ.



Average pressure drops as a function of the flow rate – SI units.



Average pressure drops as a function of the flow rate – US customary units.

32. Stop the system completely and turn off the power to the electrical panel and to the heating/cooling unit.

Store the equipment appropriately.

Conclusion

This exercise allowed to study how a gasketed plate heat exchanger is built and to learn on which principles it operates. You also learned to use such an exchanger in the course of characterization procedures designed to expose its behavior in response to different parameter changes (flow rates, exchange area, inlet temperature, modes of operation).

Review Questions

1. What is the result of increasing the number of plates in the heat exchanger?

   It increases the number of exchange surfaces between the two fluids and increases the total heat flow between them.

2. Based on your measurements, under which conditions of operation (number of plates, parallel flow or counter flow) is the **overall transfer coefficient** maximal? Is it coherent with the maximal **heat flow** observed?

   The **overall transfer coefficient** is at its maximum in the case of the five-plate counter-flow mode at high flow rates. The **heat flows** are typically larger for the nine-plate counter-flow mode (the input temperatures oscillate slightly and may affect the heat flow measured). This is coherent as the efficiency takes into account the total exchange area.

3. What are the different types of plate in this gasketed plate heat exchanger?

There is the *R* plate (which is the same as an *L* plate rotated by 180°), a *B* plate and an *E* plate. The flat plate can also be mentioned.

4. Name a main advantage of gasketed plate heat exchangers

One of the following answers is acceptable (others are possible as well):

They are typically very efficient (high overall transfer coefficient)

They can be cleaned relatively easily

The surface area can be modified (by changing the number of plates) to adapt the exchanger to a process.

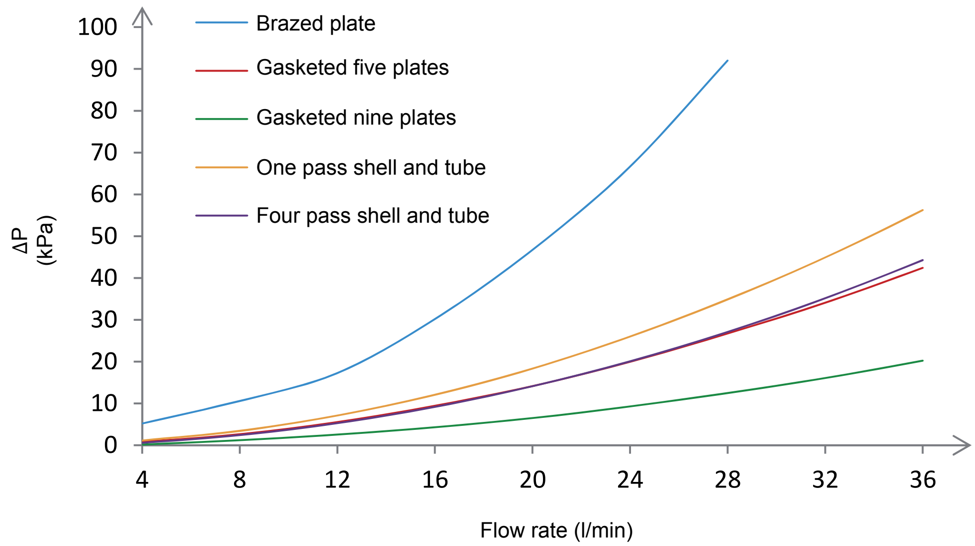
5. *Optional*: What is the maximum pressure drop recorded across the gasketed plate heat exchanger at a flow rate of 28 L/min (7 gaL/min)? Compare with the results obtained for the different exchangers in the other exercises if such results are available. Which exchanger causes the smallest pressure drops?

The pressure drop recorded at a flow rate of 28 L/min (7 gaL/min) is: 29.0 kPa (3.8 psi). This is for the case of a five-plate counter-flow gasketed heat exchanger.

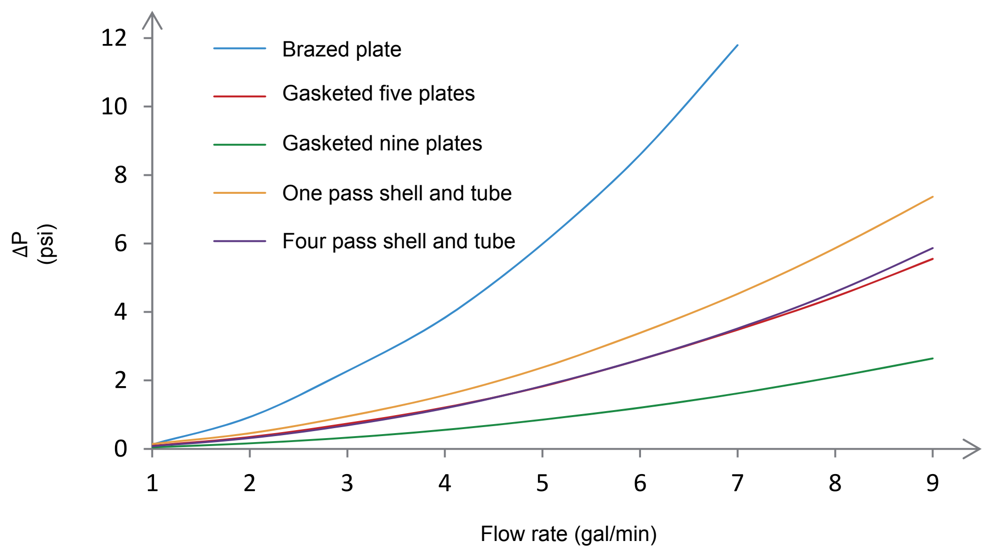
Comparison:

As can be seen in the graph, the brazed plate heat exchanger is the one causing the largest pressure drop, followed by the one-pass shell-and-tube heat exchanger, the four-pass exchanger, the five-plate gasketed plate exchanger and finally the nine-plate gasketed exchanger.

The smallest pressure drops are associated with the gasketed plate heat exchanger. The more plates are used, the less severe is the pressure drop.



Average pressure drops as a function of the flow rate – SI units.



Average pressure drops as a function of the flow rate – US customary units.

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