APPENDIX B

EXPERIMENTAL

OPERATING

AND

MAINTENANCE PROCEDURES

OPTIONAL PLATE HEAT EXCHANGER

H100B

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INDEX

SYMBOLS AND UNITS

Symbol		Units
V_{cold}	Cold stream flow rate	litre s^{-1}
V_{hot}	Hot stream flow rate	litre s^{-1}
T1	Hot fluid inlet temperature	°C
T2	Hot fluid outlet temperature	°C
T3	Cold fluid inlet temperature	°C
T4	Cold fluid outlet temperature	°C
Δt_{hot}	Decrease in hot fluid temperature	K
Δt_{Cold}	Increase in cold fluid temperature	K
dT hot	Decrease in hot fluid temperature	K
dT cold	Increase in cold fluid temperature	K
N	Number of heat transfer plates with hot and cold fluid on both sides	-
T_{mean}	Mean temperature	°C
ρ	Density of stream fluid	kg litre
Cp	Specific Heat of stream fluid	$kJkg^{-1}K^{-1}$
$\dot{Q}$ e	Heat flow rate from hot stream	Watts
$\dot{Q}$ a	Heat flow rate to cold stream	Watts
$\dot{Q}$ f	Heat loss to surroundings	Watts
LMTD	Logarithmic mean temperature difference	K
F	LMTD correction factor for plate heat exchanger	-
A	Heat transfer surface area	m^2
a	Projected area of each heat transfer plate	m^2
U	Overall heat transfer coefficient	$Wm^{-2}K^{-1}$
$\eta_{Thermal}$	Thermal efficiency	%
η_{hot}	Temperature efficiency hot stream	%
η_{cold}	Temperature efficiency cold stream	%
η_{mean}	Mean temperature efficiency	%
dTmax	Maximum temperature difference across heat exchanger	K
dTmin	Minimum temperature difference across heat exchanger	K

FIGURE B1.

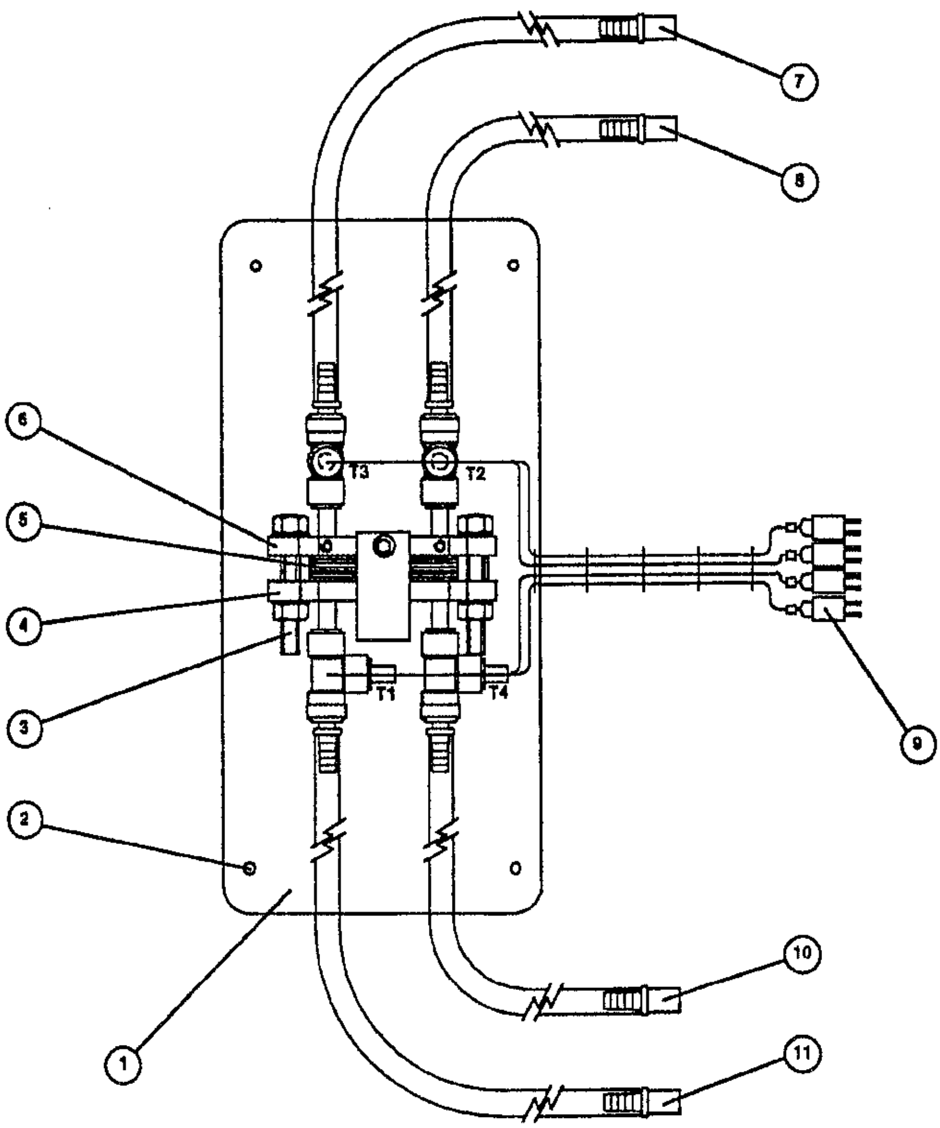
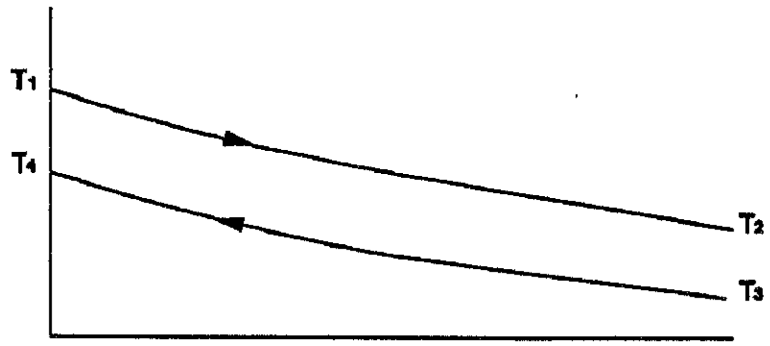
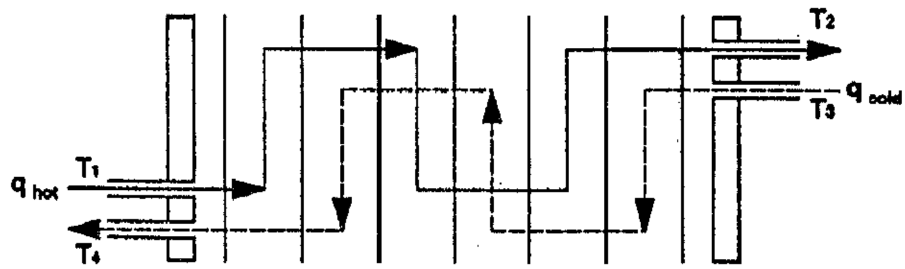


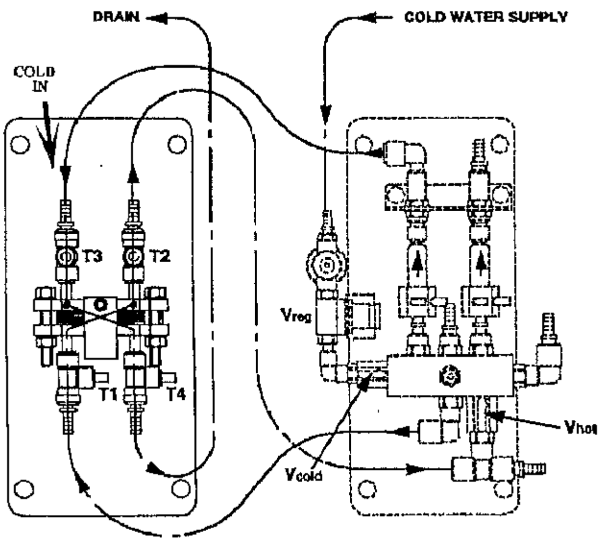
PLATE HEAT EXCHANGER H100B

Figure B2



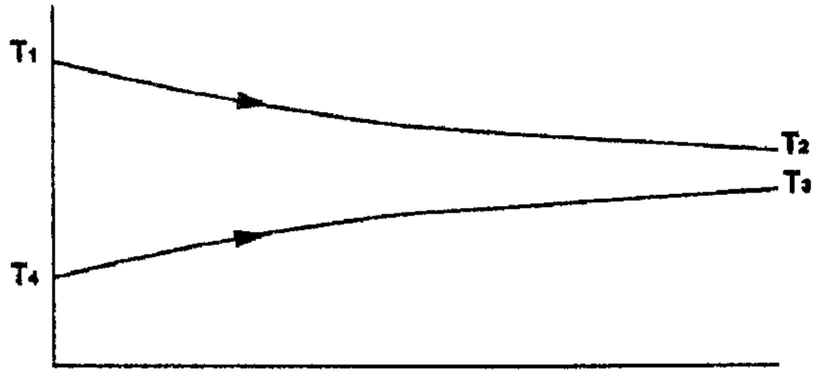


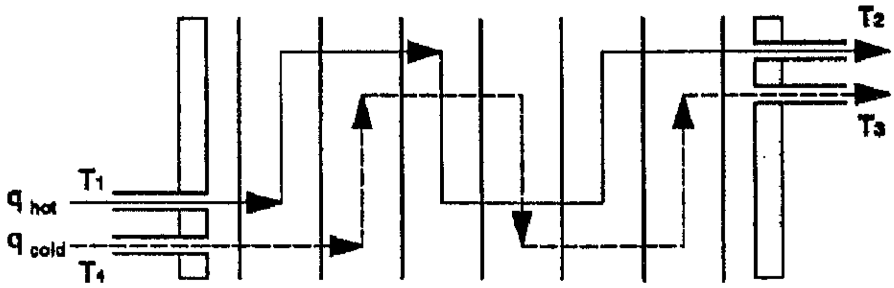
COUNTER-CURRENT OPERATION



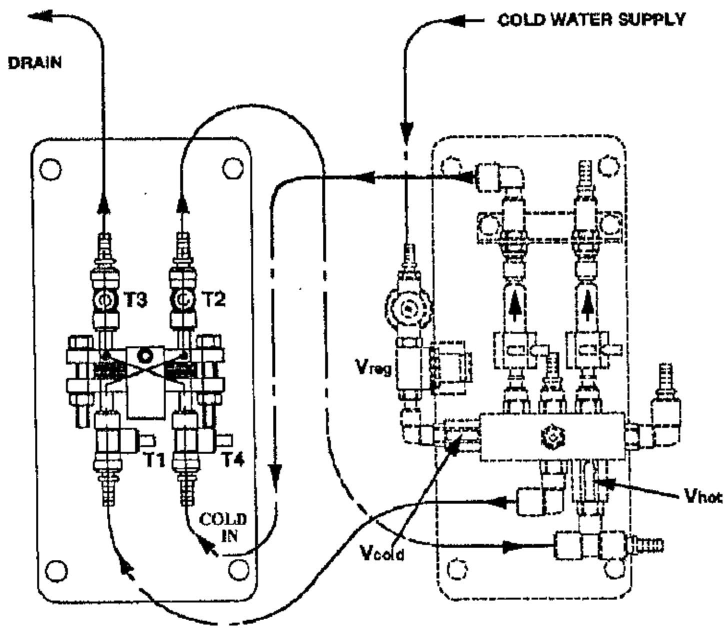
COUNTER-CURRENT PIPE ARRANGEMENT

Figure B3





CO-CURRENT PIPE OPERATION



CO-CURRENT PIPE ARRANGEMENT

DESCRIPTION
PLATE HEAT EXCHANGER H100B
(Figure Notation)
In this section of the manual figures are referenced with **"B"** prefix to identify them as relating to the H100**"B"** unit. For example Figure **B1** on page B1. Numbered items on the figures are referenced as follows **B1(2)**, this refers to Item **2** (the mounting holes) on the base board of Figure **B1** on page B1. This follows the similar procedure used in the main manual.

Please refer to figure B1 on page B1.
The plate heat exchanger is extremely versatile and exhibits one of the most efficient heat exchanger designs in terms of its capacity relative to its volume. In addition the design can allow on site variation of capacity by the addition or removal of plate combinations.

The plate heat exchanger finds application in the food processing and chemical industries where different combinations of plates and gaskets can be arranged to suit a particular application.
In addition certain welded designs are also used within the refrigeration industry where compact evaporation or condensation of refrigerant is required in association with heating or cooling of some other medium.

An example of the use of a plate heat exchanger occurs in the **Hilton Air and water Heat Pump R831 and the Computer Linked Air and Water Heat Pump RC831.** Details are available from P.A.Hilton Ltd or their local agent on request.

The H100B Plate Heat exchanger is a simple model that demonstrates the basic principles of heat transfer. The H100B is designed to be used with the Heat Exchanger Service Module H100.

The miniature The heat exchanger is mounted on a white PVC base plate **B1(1)** which incorporates four mounting holes **B1(2).** These locate on studs on the base unit and are secured with knurled nuts.

The miniature heat exchanger supplied consists of a pack of heat transfer plates with sealing gaskets between **B1(5)**, held together in a frame between a fixed end plate **B1(6)** and a moving end plate **B1(4).** Two bolts and nuts **B1(3)** pass through the end plates and compress the heat exchanger plates and gaskets together.

The detailed design of the components are shown in Figure B4 on page B6. Each plate is corrugated to promote turbulence and is perforated to allow the hot and cold streams to remain in sealed passages on opposite sides of the plates and allow the transfer of heat. It is the combination of turbulence, low volume, high surface area and high fluid velocities that give the high heat transfer capacity in a small volume.

In normal operation hot water from the heater/circulator passes into the end plate **B1(4)** from the flexible coupling **B1(11).** Its temperature at entry to the heat exchanger is measured by a thermocouple sensor **T1** located in a T fitting as shown in the diagram. It then flows through the heat exchanger and leaves via flexible hose **B1(8).** Its temperature on exit is measured by a similar thermocouple **T2.**

The general arrangement of the hot water flow passages is given in Figure B2 on page B2 and figure B3 on Page B3.

Cold water flows through the alternate passage between the alternate plates shown by the dotted lines in Figures B2 and B3. The cold water is fed into the heat exchanger by flexible couplings **B1(7)** ad **B1(10).**

Identical T fittings to those on the hot stream contain thermocouples T3 and T4 that measure the cold water inlet and exit temperatures.

The four thermocouple sensor points are labelled T1 to T4 on Figure B1 and each lead is terminated with a miniature thermocouple plug **B(9)** designed to be plugged into the first four numbered sockets on the base unit H100.

Flexible tubing attached to each fluid inlet/outlet is terminated in a male spigot that is designed to push into the quick release sockets on the Heat Exchanger Service unit H100. The flow direction of the cold stream relative to the hot stream can be reversed by changing the location of the inlet and exit tubes.

The sockets on the Heat Exchanger Service Unit H100 are colour coded **RED for Hot Water** and **BLUE for Cold Water.**

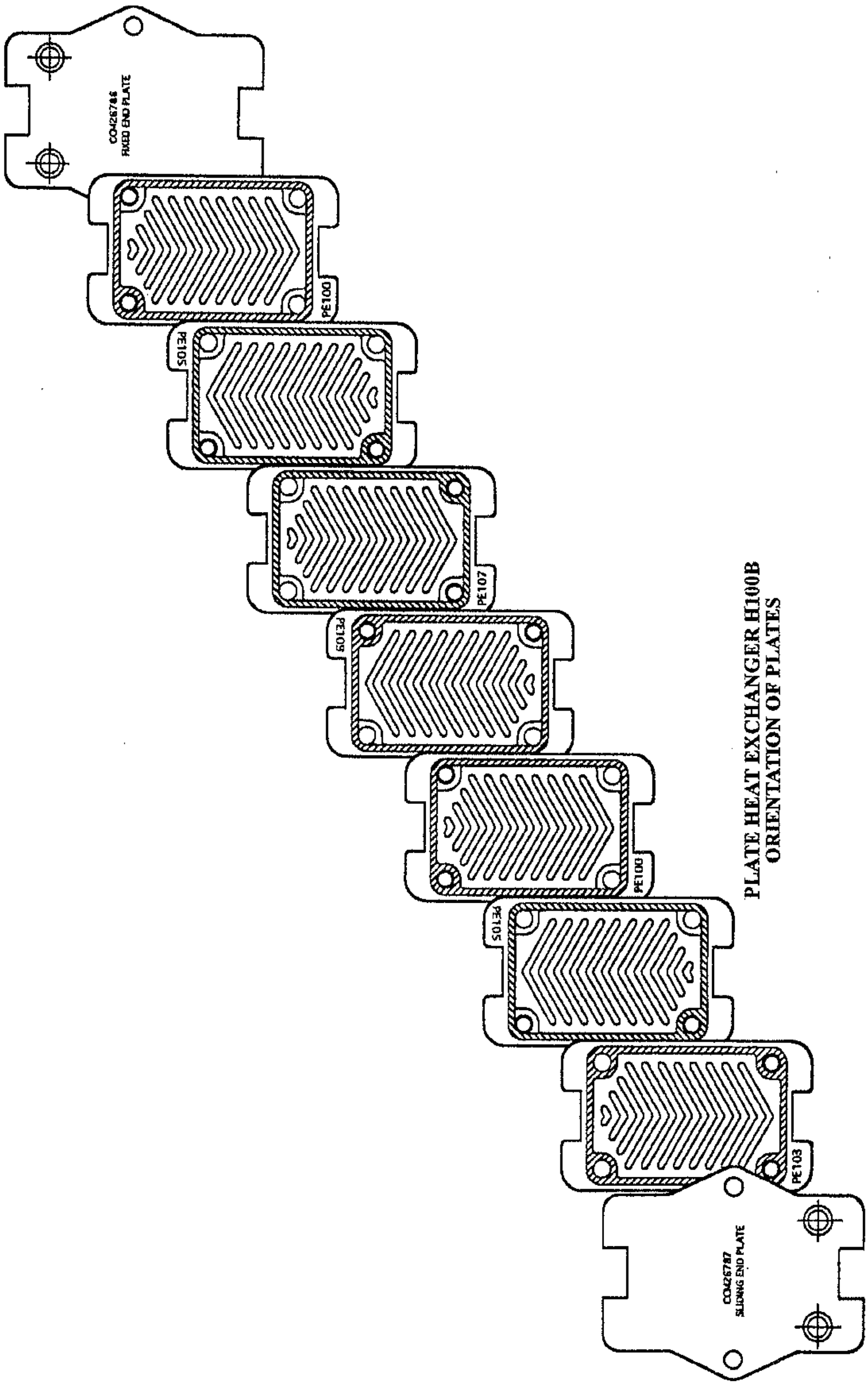


PLATE HEAT EXCHANGER H100B
ORIENTATION OF PLATES
FIXED END PLATE
PE100
PE105
PE107
PE109
PE100
PE105
PE103
SLIDING END PLATE

Figure B4

INSTALLATION

Heat Exchanger Installation H100B

Refer to Figure B1 on page B1, Figure B2 on page B2, Figure B3 on page B3.

It is assumed that the basic INSTALLATION AND COMMISSIONING procedures for the Heat Exchanger Service unit H100 have been completed as detailed in the main manual on pages 5 to 6. Locate the base **B1(1)** of the heat exchanger onto the studs on the base unit in the orientation shown in Figure B2 or B3 relative to the valve plate. Secure the base plate with the knurled nuts provided.

Temperature Sensors

Each of the four temperature sensors is terminated with a miniature plug and has an identification number. Connect the numbered plugs to the numbered sockets on the control console **2(8)**. Figure 2 page 3 of the main manual.

Note that the plugs have pins of different widths to ensure correct orientation.

Hot Water Circuit

This is **always** connected in the following manner.
Connect the flexible tube **B1(11)** from the front left tapping on the sliding end plate (adjacent to sensor T1) to the hot water outlet socket shown in Figure B2 and fitted with a red collar.

Connect the flexible tube **B1(8)** from the rear **right** hand (looking from the front of the unit) tapping on the fixed end plate (adjacent to sensor T2) to the hot water return socket shown in Figure B2 and fitted with a red collar.

The connection of the hot water circuit is common for all experiments and all configurations. However the cold water circuit may be configured in one of two directions according to the directions in the experimental procedure.

Cold Water Circuit Counter-current Flow

Refer to Figure B1 on page B1 and B2 on page B2.

In **counter-current flow** the hot and cold water streams flow in essentially opposing directions through the heat exchanger.

The cold water circuit is connected for **counter current** flow as shown in Figure B2 on page B2.

Connect the flexible tube **B1(7)** from the rear **left** hand tapping (looking from the front of the unit) on the fixed end plate (adjacent to sensor T3) to the cold water outlet socket shown in figure B2 and coloured blue.

Connect the flexible tube **B1(10)** from the front **right** hand tapping on the sliding end plate (adjacent to sensor T4) to a suitable drain.

Once the connections have been made the hot water circuit must be re-filled and the system started according to the **OPERATING PROCEDURE** in the main manual on pages 16 to 19.

Cold Water Circuit Co-current Flow

Refer to Figure B1 on page B1 and B3 on page B3.

In co-current flow the hot and cold water streams flow in essentially the same directions through the heat exchanger.

The cold water circuit is connected for co-current flow as shown in Figure B3 on page B3.

Connect the flexible tube **B1(8)** from the rear **left** hand tapping (looking from the front of the unit) on the fixed end plate (adjacent to sensor T3) to the drain hose provided using the adapter provided. The drain hose is reinforced nylon with a brass stub pipe at the end. This fits into the adapter provided and the adapter couples to the overflow flexible pipe. **The drain hose should be arranged so that it travels in a continuously downward direction to the drain.**

Connect the flexible tube **B1(10)** from the front **right** hand tapping on the sliding end plate (adjacent to sensor T4) to the cold water outlet socket shown in figure B3 and coloured blue.

Once the connections have been made the hot water circuit must be re-filled and the system started according to the **OPERATING PROCEDURE** in the main manual on pages 16 to 19.

USEFUL DATA
PLATE HEAT EXCHANGER H100B

Plate Material 316 Stainless steel
Plate overall dimensions 0.075m x 0.115m
Diameter of an equivalent tube having the same flow area as the inter plate flow passage 0.003m
Plate material thickness 0.0005m
Wetted perimeter 0.153m
Projected heat transmission area (This does not take into account the increase in area due to the corrugations in the plates) 0.008m^2 per plate

Table 1 Specific Heat capacity Cp of Water in kJ kg^{-1}

°C	0	1	2	3	4	5	6	7	8	9
0	4.1274	4.2138	4.2104	4.2074	4.2054	4.2019	4.1996	4.1974	4.1954	4.1936
10	4.1919	4.1904	4.189	4.1877	4.1866	4.1855	4.1864	4.1837	4.1829	4.1822
20	4.1816	4.181	4.1805	4.1801	4.1797	4.1793	4.1790	4.1787	4.1785	4.1783
30	4.1782	4.1781	4.1780	4.1780	4.1779	4.1779	4.1780	4.1780	4.1781	4.1782
40	4.1783	4.1784	4.1786	4.1788	4.1789	**4.1792**	4.1794	4.1796	4.1799	4.180
50	4.1804	4.1807	4.1811	4.1814	4.1817	4.1821	4.1825	4.1829	4.1833	4.1837
60	4.1841	4.1846	4.1850	4.1855	4.1860	4.1865	4.1871	4.1876	4.1882	4.1887
70	4.1893	4.1899	4.1905	4.1912	4.1918	4.1925	4.1932	4.1939	4.1964	4.1954

To use the table the vertical columns denote whole degrees and the Horizontal rows denote tens of degrees. For example the bold value 4.1792 kJ kg-1 is at 40 + 5 = 45 °C.

Alternatively the equation $\mathbf{Cp = 6x10^{-6}\, t^4 - 1.0x10^{-6}\, t^3 + 7.0487x10^{-5}\, t^2 - 2.4403x10^{-3}\, t + 4.2113}$
may be used if the data is to be calculated using a spreadsheet.

Table 2 Density of Water in kg $Litre^{-1}$

°C	0	2	4	6	8
0	0.9998	0.9999	0.9999	0.9999	0.9999
10	0.9997	0.9995	0.9992	0.9989	0.9986
20	0.9982	0.9978	0.9973	0.9968	0.9962
30	0.9957	0.9950	0.9944	0.9937	0.9930
40	0.9922	0.9914	**0.9906**	0.9898	0.9889
50	0.9880	0.9871	0.9862	0.9852	0.9842
60	0.9832	0.9822	0.9811	0.9800	0.9789
70	0.9778	0.9766	0.9754	0.9742	0.9730

To use the table the vertical columns denote degrees and the Horizontal rows denote tens of degrees. For example the bold value 0.9906 kg is at 40 + 4 = 44 °C.

Alternatively the equation $\rho = \mathbf{-4.582x10^{-6}\, t^2 - 4.0007x10^{-5}\, t + 1.004}$
may be used if the data is to be calculated using a spreadsheet.

CAPABILITIES OF THE PLATE EXCHANGER H100A WITH THE HEAT EXCHANGER SERVICE UNIT H100

1. To demonstrate indirect heating or cooling by transfer of heat from one fluid stream to another when separated by a solid wall (fluid to fluid heat transfer).

2. To perform an energy balance across a plate heat exchanger and calculate the overall efficiency at different fluid flow rates

3. To demonstrate the differences between counter-current flow (flows in opposing directions) and co-current flows (flows in the same direction) and the effect on heat transferred, temperature efficiencies and temperature profiles through a plate heat exchanger.

4. To determine the overall heat transfer coefficient for a plate heat exchanger using the logarithmic mean temperature difference to perform the calculations (for counter-current and co-current flows).

5. To investigate the effect of changes in hot fluid and cold fluid flow rate on the temperature efficiencies and overall heat transfer coefficient.

6. To investigate the effect of driving force (difference between hot stream and cold stream temperature) with counter-current and co-current flow.

1. Demonstration Of Indirect Heating Or Cooling By Transfer Of Heat From One Fluid Stream To Another When Separated By A Solid Wall (Fluid To Fluid Heat Transfer).

The following procedure demonstrates heat transfer from one fluid stream to another when separated by a solid wall.

NOTE that the observations from experiment No 2 may be used for the calculations in this procedure in order to save experimental time

It is assumed that the basic INSTALLATION AND COMMISSIONING procedures for the Heat Exchanger Service Unit H100 have been completed as detailed in the main manual on pages 5 to 7

Procedure

Install the Plate Heat Exchanger H100B as detailed in **INSTALLATION / Heat Exchanger Installation H100B** on page B7 and connect the cold water circuit to give Counter-Current flow as detailed in the same section.

Follow the **OPERATING PROCEDURE** detailed in the main manual on page 16 onwards in order to establish the following operating conditions.

> Fill the hot water circuit, set the cold water pressure regulator, and turn on the power to the unit. Then set the hot water temperature controller to 60°C and turn on the circulating pump.
>
> **Set the cold water flow rate V_{cold} to 1 litre min^{-1} and the hot water flow rate V_{hot} to between 2 to 2.5 litre min^{-1}.**

If the optional Computer Interface HC100 and software is being used:

> *It is assumed that the Installation and commissioning of both the hardware and software has been carried out according to the procedures on page 5 of the main manual. Ensure that the power lead to the Hilton data logger is connected, that the serial lead from the computer to the data logger is connected and that the ribbon cable from the interface to the base unit is also connected.*
>
> *It is assumed that the computer is already running in Windows™ mode. Click on the H100 icon to start the software.*

Language Screen:

> *The first screen will show the language section. If this option has been purchased then the preferred language may be selected.*

H100 Main Menu:

> *The next screen is the main menu for the H100 series of optional units. Select* ***the H100B Plate heat exchanger*** *(Note that only one option can be selected and that if the wrong unit is selected the procedure may be repeated.)*
>
> *It is assumed that the data is to be captured on disc and therefore this option should be selected in the lower box. When all selections have been made click OK.*

Communications Test:

> *As the user has selected to collect data the next screen carries out a communications test with the H100 base unit. Select the serial port of the computer that the unit is connected to and then click the Go button with the mouse pointer.*
>
> *Assuming communications is confirmed the next screen will show the H100B Plate Heat Exchanger Main Menu.*
>
> *If communications fails for any reason check the parameters indicated on the screen and repeat the test. If communications cannot be established for any reason the Cancel button may be used and the cause investigated.*

H100B Plate Heat Exchanger Main Menu:

> *This lists the optional experiments that may be carried out with the H100B Plate Heat Exchanger. To continue with the above experiment select 1.* ***To demonstrate indirect heating or cooling by transfer of heat from one fluid stream to another when separated by a solid wall (fluid to fluid heat transfer)*** *and then click OK.*

H100B Experiment Number 1:

Assuming that the above procedure is being followed select the Counter-Current flow option and check the Instructions on the screen have been observed. If data is to be recorded to disc then select the Store data on disc for later review option. Then click OK.

If the user DOES select to record data to disc then a file name will be requested. Note that a partially fixed file name is used together with a fixed file suffix. This enables the software to recognise data during the review option that is compatible with the review mode selected. The user is required to enter the remaining digits that will be of relevance to them in the future. Once a valid file name is entered the Recording data screen is displayed.

Recording data:

The next screen shows three tabs Flow, Temperature and Data Point. The Flow and Temperature graphs may be used to set the hot and cold stream flow rates to the desired values and the temperature graph used to determine when the unit has reached a stable condition.

Once stable conditions have been established the Data point tab may be clicked and the Record button clicked to record and display a captured data point. Note that data may be sent to a printer (If a printer is connected) if required. The option of Raw (end results not calculated) or Calculated data may be selected for the printing option.

The results shown in the table are updated each time the record button is clicked. NOTE that if no changes are made to the H100B settings of flow rate and hot stream temperature the captured results will all be similar.

The software should be utilised to automate the data recording procedures detailed as follows in the manual procedure.

To return to the H100B Plate Heat Exchanger Main Menu click the End button on the Data capture screen.

Monitor the stream temperatures and the hot and cold flow rates to ensure these too remain close to the original setting. Then record the following:

T1, T2, T3, T4, V_{hot} and V_{cold}

Then set the flow indicator to Fcold and adjust the cold water flow valve so that Vcold is approximately 2 litre min^{-1}. Maintain the Hot water flow rate at approximately 2 to 2.5 litre min^{-1} (the original setting).

If the optional Computer Interface HC100 and software is being used then the Flow screen and Temperature screen may again be used to adjust the hot and cold flow rates and to monitor the system for stability.

Allow the conditions to stabilise and repeat the above observations.

The procedure may be repeated with different hot and cold flow rates and different hot water inlet temperature if required.

OBSERVATIONS

Flow Direction: Counter-Current

Sample No.	T1	T2	T3	T4	V_{hot}	V_{cold}
----	°C	°C	°C	°C	L min^{-1}	L min^{-1}
1	51.8	41.5	15.0	37.4	2.54	0.96
2						
3						
4						
5						

Calculated Data

Sample No.	Δt_{hot}	Δt_{cold}
---	K	K
1	10.3	22.4

If the optional Computer Interface HC100 and software is being used then it will be seen that the tabular displays are similar to those used on screen.

CALCULATIONS

For the example result the calculations are as follows.

Reduction in Hot fluid temperature $\quad \Delta t$ hot $= T1 - T2$

$= 51.8 - 41.5$

$= \underline{10.3\ K}$

Increase in Cold fluid temperature $\quad \Delta t$ cold $= T4 - T3$

$= 37.4 - 15.0$

$= \underline{22.4\ K}$

Note that if the system is set up for **Co-Current flow** the hot stream temperature difference will remain the same but the cold stream temperature difference will become:

Δt cold $= T3 - T4$

The test results show the effect upon the temperature differences when the flow rates through a simple heat exchanger are varied.

The results from this experiment may also be used in experiment **No 2 To perform an energy balance across a plate heat exchanger and calculate the overall efficiency at different fluid flow rates.**

If the optional Computer Interface HC100 and software is being used then the user can return to the H100B Plate Heat Exchanger Main Menu by clicking the End and Back keys.

Once back at the main menu the user can opt to record more data in another experiment on the same heat exchanger or review the data recorded during the preceding experiment. Alternatively the user can return to the H100 Main Menu by continuing to click the Back key and the select to use another optional heat exchanger if available.

2. To perform an energy balance across a plate heat exchanger and calculate the overall efficiency at different fluid flow rates

The following procedure demonstrates heat transfer from one fluid stream to another when separated by a solid wall and shows that the heat release rate of the hot stream should equal the heat absorption rate of the cold stream.

NOTE that the observations from experiment No 1 may be used for the calculations in this procedure in order to save experimental time.

I It is assumed that the basic **INSTALLATION AND COMMISSIONING** procedures for the Heat Exchanger Service Unit H100 have been completed as detailed in the main manual on pages 5 to 7.

Procedure

Install the Plate Heat Exchanger H100B as detailed in **INSTALLATION / Heat Exchanger Installation H100B** on page B7 and connect the cold water circuit to give Counter-Current flow as detailed in the same section.

Follow the **OPERATING PROCEDURE** detailed in the main manual on page 16 onwards in order to establish the following operating conditions.

> Fill the hot water circuit, set the cold water pressure regulator, and turn on the power to the unit. Then set the hot water temperature controller to 60°C and turn on the circulating pump.
>
> **Set the cold water flow rate V_{cold} to 1 litre/ minute and the hot water flow rate V_{hot} to between 2.0 to 2.5 litre/minute.**

If the optional Computer Interface HC100 and software is being used:

> *It is assumed that the Installation and commissioning of both the hardware and software has been carried out according to the procedures on page 5 of the main manual. Ensure that the power lead to the Hilton data logger is connected, that the serial lead from the computer to the data logger is connected and that the ribbon cable from the interface to the base unit is also connected.*
>
> *It is assumed that the computer is already running in Windows™ mode. Click on the H100 icon to start the software.*

Language Screen:

> *The first screen will show the language section. If this option has been purchased then the preferred language may be selected.*

H100 Main Menu:

> *The next screen is the main menu for the H100 series of optional units. Select **the H100B Plate heat exchanger** (Note that only one option can be selected and that if the wrong unit is selected the procedure may be repeated.)*
>
> *It is assumed that the data is to be captured on disc and therefore this option should be selected in the lower box. When all selections have been made click OK.*

Communications Test:

> *As the user has selected to collect data the next screen carries out a communications test with the H100 base unit. Select the serial port of the computer that the unit is connected to and then click the Go button with the mouse pointer.*
>
> *Assuming communications is confirmed the next screen will show the H100B Plate Heat Exchanger Main Menu.*
>
> *If communications fails for any reason check the parameters indicated on the screen and repeat the test. If communications cannot be established for any reason the Cancel button may be used and the cause investigated.*

H100B Plate Heat Exchanger Main Menu:

> *This lists the optional experiments that may be carried out with the H100B Plate Heat Exchanger. To continue with the above experiment select 2 **To perform an energy balance across a plate heat exchanger and calculate the overall efficiency at different fluid flow rates**, and then click OK.*

H100B Experiment Number 2:

Assuming that the above procedure is being followed select the Counter-Current flow option and check the Instructions on the screen have been observed. If data is to be recorded to disc then select the Store data on disc for later review option. Then click OK.

If the user DOES select to record data to disc then a file name will be requested. Note that a partially fixed file name is used together with a fixed file suffix. This enables the software to recognise data during the review option that is compatible with the review mode selected. The user is required to enter the remaining digits that will be of relevance to them in the future.

Once a valid file name is entered the Recording data screen is displayed.

Recording data:

The next screen shows three tabs Flow, Temperature and Data Point. The Flow and Temperature graphs may be used to set the hot and cold stream flow rates to the desired values and the temperature graph used to determine when the unit has reached a stable condition.

Once stable conditions have been established the Data point tab may be clicked and the Record button clicked to record and display a captured data point. Note that data may be sent to a printer (If a printer is connected) if required. The option of Raw (end results not calculated) or Calculated data may be selected for the printing option.

The results shown in the table are updated each time the record button is clicked. NOTE that if no changes are made to the H100B settings of flow rate and hot stream temperature the captured results will all be similar.

The software should be utilised to automate the data recording procedures detailed as follows in the manual procedure.

To return to the H100B Plate Heat Exchanger Main Menu click the End button on the Data capture screen.

Monitor the stream temperatures and the hot and cold flow rates to ensure these too remain close to the original setting. Then record the following:

T1, T2, T3, T4, V_{hot} and V_{cold}

Then set the flow indicator to Fcold and adjust the cold water flow valve so that V_{cold} is approximately 2 litres/minute. Maintain the Hot water flow rate at approximately2.0 to 2.5 litres/minute (the original flow rate).

If the optional Computer Interface HC100 and software is being used then the Flow screen and Temperature screen may again be used to adjust the hot and cold flow rates and to monitor the system for stability.

Allow the conditions to stabilise and repeat the above observations.

The procedure may be repeated with different hot and cold flow rates and different hot water inlet temperature if required.

<u>OBSERVATIONS</u>

Flow Direction: Counter-Current

Sample No.	T1	T2	T3	T4	V_{hot}	V_{cold}
----	°C	°C	°C	°C	L min^{-1}	L min^{-1}
1	51.8	41.5	15.0	37.4	2.54	0.96
2						
3						
4						
5						

Calculated Data

Sample No.	Δt_{hot}	Δt_{cold}	$\dot{Q}e$	$\dot{Q}a$	$\eta_{Thermal}$
---	K	K	W	W	%
1	10.3	22.4	1804	1493	82.7

If the optional Computer Interface HC100 and software is being used then it will be seen that the tabular displays are similar to those used on screen.

CALCULATIONS
For the example the calculations are as follows.

It is necessary to convert the volume flow rates to mass flow rates using the conversion factors in table 1 and 2 on page B9. The water density ρ (kg $litre^{-1}$) and specific heat capacity Cp (kJ kg^{-1} K^{-1}) is dependant upon the temperature and the mean fluid temperature Tmean

$$T_{mean} = \frac{T_{inlet} + T_{outlet}}{2}$$

is used to calculate the relevant temperature.

For the Hot stream:
T_{mean} = (51.8 +41.5) / 2 = 46.6 K
From table 1 and 2 at T_{mean} = 46.6 °C ρ_{hot} = 0.9895 kg $litre^{-1}$
Cp = 4.1796 kJ kg^{-1} k^{-1}

Hence the power emitted from the hot stream $\dot{Q}$ e

$$Q_e = V_{hot}\ \dot{Q}e = \frac{V_{hot}}{60}\ \rho_{hot}\ Cp_{Hot}\,(T1 - T2) \times 1000 \quad \text{Watts}$$

$$= \frac{2.54}{60} \times 0.9895 \times 4.179 \times (51.8 - 41.5) \times 1000$$

$$= 1804 \text{ Watts}$$

For the cold stream :
T_{mean} = (15.0 + 37.4) / 2 = 26.6 K
From table 1 and 2 at T_{mean} = 26.6 °C °C ρ_{hot} = 0.9970 kg $litre^{-1}$
Cp = 4.185 kJ kg^{-1} k^{-1}

The power absorbed by the cold stream $\dot{Q}$ a

$$\dot{Q}a = \frac{V_{cold}}{60}\ \rho_{cold}\ Cp_{cold}\,(T4 - T3) \times 1000 \quad \text{Watts}$$

$$= \frac{0.96}{60} \times 0.9968 \times 4.179 \times (37.4 - 15.0) \times 1000$$

$$= 1493 \text{Watts}$$

The overall thermal efficiency

$$\eta_{Thermal} = \frac{\dot{Q}a}{\dot{Q}e} \times 100(\%)$$

Hence

$$\eta_{\text{Thermal}} = \frac{1493}{1804} \times 100(\%)$$
$$= 82.7\%$$

Note that as the plates are not insulated in order to allow student examination of the components heat will be lost or gained depending upon the ambient temperature. In extreme cases this can result in an *apparent* thermal efficiency greater than 100%.

If the optional Computer Interface HC100 and software is being used then the user can return to the H100B Plate Heat Exchanger Main Menu by clicking the End and Back keys.
Once back at the main menu the user can opt to record more data in another experiment on the same heat exchanger or review the data recorded during the preceding experiment. Alternatively the user can return to the H100 Main Menu by continuing to click the Back key and the select to use another optional heat exchanger if available.

3. To demonstrate the differences between counter-current flow (flows in opposing directions) and co-current flows (flows in the same direction) and the effect on heat transferred, temperature efficiencies and temperature profiles through a Plate heat exchanger

---

The following procedure demonstrates the effect of changing the direction of fluid flow on the heat transfer and temperature distribution in a Plate heat exchanger.

NOTE that the observations from experiment No 4 may be used for the calculations in this procedure in order to save experimental time.

I It is assumed that the basic INSTALLATION AND COMMISSIONING procedures for the Heat Exchanger Service Unit H100 have been completed as detailed in the main manual on pages 5 to 7.

Procedure

Install the Concentric tube Heat Exchanger H100A as detailed in **INSTALLATION / Heat Exchanger Installation H100B** on page B7 and connect the cold water circuit to give **Counter-Current** flow as detailed in the same section.

Follow the **OPERATING PROCEDURE** detailed in the main manual on page 16 onwards in order to establish the following operating conditions.

Fill the hot water circuit, set the cold water pressure regulator, and turn on the power to the unit. Then set the hot water temperature controller to 60°C and turn on the circulating pump.

Set the cold water flow rate V_{cold} to 1 litre min^{-1} and the hot water flow rate V_{hot} to 2 litre min^{-1}.

If the optional Computer Interface HC100 and software is being used:

It is assumed that the Installation and commissioning of both the hardware and software has been carried out according to the procedures on page 5 of the main manual. Ensure that the power lead to the Hilton data logger is connected, that the serial lead from the computer to the data logger is connected and that the ribbon cable from the interface to the base unit is also connected.

It is assumed that the computer is already running in Windows™ mode. Click on the H100 icon to start the software.

Language Screen:

The first screen will show the language section. If this option has been purchased then the preferred language may be selected.

H100 Main Menu:

The next screen is the main menu for the H100 series of optional units. Select ***the H100B Plate heat exchanger*** *(Note that only one option can be selected and that if the wrong unit is selected the procedure may be repeated.)*

It is assumed that the data is to be captured on disc and therefore this option should be selected in the lower box. When all selections have been made click OK.

Communications Test:

As the user has selected to collect data the next screen carries out a communications test with the H100 base unit. Select the serial port of the computer that the unit is connected to and then click the Go button with the mouse pointer.

Assuming communications is confirmed the next screen will show the H100B Plate Heat Exchanger Main Menu.

If communications fails for any reason check the parameters indicated on the screen and repeat the test. If communications cannot be established for any reason the Cancel button may be used and the cause investigated

H100B Plate Heat Exchanger Main Menu:

*This lists the optional experiments that may be carried out with the H100B Plate Heat Exchanger. To continue with the above experiment select **3 To demonstrate the differences between counter-current flow (flows in opposing directions) and co-current flows (flows in the same direction) and the effect on heat transferred, temperature efficiencies and temperature profiles through a plate heat exchanger** and then click OK.*

H100B Experiment Number 3:

*Assuming that the above procedure is being followed select the **Counter-Current** flow option initially and check the Instructions on the screen have been observed. If data is to be recorded to disc then select the Store data on disc for later review option. Then click OK.*

If the user DOES select to record data to disc then a file name will be requested. Note that a partially fixed file name is used together with a fixed file suffix. This enables the software to recognise data during the review option that is compatible with the review mode selected. The user is required to enter the remaining digits that will be of relevance to them in the future. Once a valid file name is entered the Recording data screen is displayed.

Recording data:

The next screen shows four tabs Flow, Temperature, Data Point and Temp. distribution. The Flow and Temperature graphs may be used to set the hot and cold stream flow rates to the desired values and the temperature graph used to determine when the unit has reached a stable condition.

Once stable conditions have been established the Data point tab may be clicked and the Record button clicked to record and display a captured data point. Note that data may be sent to a printer (If a printer is connected) if required. The option of Raw (end results not calculated) or Calculated data may be selected for the printing option.

The results shown in the table are updated each time the record button is clicked. NOTE that if no changes are made to the H100B settings of flow rate and hot stream temperature the captured results will all be similar.

If the Temp Distribution tab is clicked then a simple line diagram graph will be displayed showing the temperature distribution of the last sample.

The software should be utilised to automate the data recording procedures detailed as follows in the manual procedure.

To return to the H100B Plate Heat Exchanger Main Menu click the End button on the Data capture screen.

Monitor the stream temperatures and the hot and cold flow rates to ensure these too remain close to the original setting. Then record the following:

T1, T2, T3, T4, V_{hot} and V_{cold}

This completes the basic Counter-Current flow experiment observations.

Next connect the cold water circuit to give **Co-Current flow** as detailed in the **INSTALLATION / Heat Exchanger Installation H100B** on page B7. Note that there is no need to disconnect the hot water circuit or to turn off the hot water pump during this operation.

Set the flow indicator to Fcold and adjust the cold water flow valve so that V_{cold} is approximately 1 litre min^{-1}. Select Fhot and adjust the hot water flow rate V_{hot} to approximately 2 litre min^{-1}. Set the hot water temperature to 60 °C if this has been adjusted.

*If the optional Computer Interface HC100 and software is being used then, from the H100B Plate Heat Exchanger Main Menu, select **3 To demonstrate the differences between counter-current flow (flows in opposing directions) and co-current flows (flows in the same direction) and the effect on heat transferred, temperature efficiencies and temperature profiles through a Plate heat exchanger** and then click OK.*

H100B Experiment Number 3:

*Assuming that the above procedure is being followed select the **Co-Current** flow option initially and check the Instructions on the screen have been observed. If data is to be recorded to disc then select the Store data on disc for later review option. Then click OK.*

If the user DOES select to record data to disc then a file name will be requested. Note that a partially fixed file name is used together with a fixed file suffix. This enables the software to recognise data during the review option that is compatible with the review mode selected. The user is required to enter the remaining digits that will be of relevance to them in the future. Once a valid file name is entered the Recording data screen is displayed. The data display and capture procedure is the same as above in the Counter-current flow procedure.

Monitor the stream temperatures and the hot and cold flow rates to ensure these remain close to the original setting. Then record the following:

T1, T2, T3, T4, V_{hot} and V_{cold}

This completes the basic Co-Current flow experiment observations

OBSERVATIONS

Flow Direction: Counter-Current

Sample No.	T1	T2	T3	T4	V_{hot}	V_{cold}
----	°C	°C	°C	°C	L min^{-1}	L min^{-1}
1	56.1	41.3	14.3	36.2	2.00	1.10
2						
3						
4						
5						

Calculated Data

Sample No.	Δt_{hot}	Δt_{cold}	$\dot{Q}e$	$\dot{Q}a$	$\eta_{Thermal}$	η_{Cold}	η_{Hot}	η_{Mean}
---	K	K	W	W	%	%	%	%
1	14.8	21.9	2039	1675	82.5	52.4	35.4	43.9
2								
3								
4								
5								

If the optional Computer Interface HC100 and software is being used then it will be seen that the tabular displays are similar to those used on screen.

Flow Direction: Co-Current

Sample No.	T1	T2	T3	T4	V_{hot}	V_{cold}
----	°C	°C	°C	°C	L min^{-1}	L min^{-1}
1	59.2	44.7	39.2	13.2	2.02	1.01
2						
3						
4						
5						

Calculated Data

Sample No.	Δt_{hot}	Δt_{cold}	$\dot{Q}$ e	$\dot{Q}$ a	$\eta_{Thermal}$	η_{Cold}	η_{Hot}	η_{Meanl}
---	K	K	W	W	%	%	%	%
1	14.5	26.0	2015	1823	90.5	56.5	31.5	44.0
2								
3								
4								
5								

If the optional Computer Interface HC100 and software is being used then it will be seen that the tabular displays are similar to those used on screen.

CALCULATIONS

For the examples the calculations are as follows.

Counter-Current Flow

It is necessary to convert the volume flow rates to mass flow rates using the conversion factors in table 1 and 2 on page B9. The water density ρ (kg litre^{-1}) and specific heat capacity Cp (kJ kg^{-1} K^{-1}) is dependant upon the temperature and the mean fluid temperature T_{mean}

$$T_{mean} = \frac{T_{inlet} + T_{outlet}}{2}$$

is used to calculate the relevant temperature.

For the Hot Stream:

T_{mean} = (56.1 +41.3) / 2 = 48.7 °C

From table 1 and 2 at T_{mean} = 48.7 °C

ρ_{hot} = 0.988 kg litre^{-1}

Cp = 4.180 kJ kg^{-1} k^{-1}

Hence the power emitted from the hot stream $\dot{Q}$ e

$$\dot{Q}e = \frac{V_{hot}}{60}\ \rho_{hot}\ Cp_{Hot}\left(T1 - T2\right)\times 1000 \quad \text{Watts}$$
$$= \frac{2.00}{60}\times 0.988\times 4.180\times\left(56.1 - 41.3\right)\times 1000$$
$$= 2039 \ \text{Watts}$$

For the Cold stream:

T_{mean} = (36.2 + 14.3) / 2 = 25.3 °C

From table 1 and 2 at T_{mean} = 25.3 °C

ρ_{hot} = 0.997 kg litre^{-1}

Cp = 4.179 kJ kg^{-1} k^{-1}

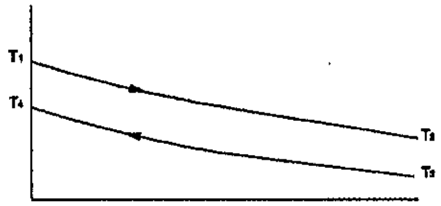
Hence the power absorbed by the cold stream $\dot{Q}$ a

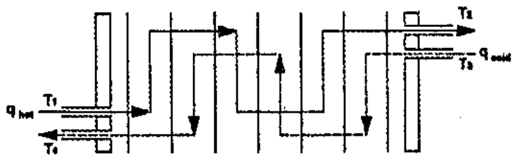
$$\dot{Q}a = \frac{V_{cold}}{60}\ \rho_{cold}\ Cp_{Cold}\left(T4 - T3\right)\ 1000 \quad \text{Watts}$$
$$= \frac{1.10}{60}\times 0.997\times 4.1793\times\left(36.2 - 14.3\right)\times 1000$$
$$= 1675 \quad \text{Watts}$$

Reduction in Hot fluid temperature $\quad \Delta t_{hot} = T1 - T2 = 56.1 - 41.3 = 14.8\ K$

Increase in Cold fluid temperature $\quad \Delta t_{cold} = T4 - T3 = 36.2 - 14.3 = 21.9\ K$

A useful measure of the heat exchanger performance is the temperature efficiency.





COUNTER-CURRENT OPERATION

The temperature change in each stream(hot and cold) is compared with the maximum temperature difference between the two streams. This could only occur in a perfect heat exchanger of infinite size with no external losses or gains.

The temperature efficiency of the hot stream from the above diagram

$$\eta_{Hot} = \frac{T1 - T2}{T1 - T3} \times 100\%$$
$$= \frac{56.1 - 41.3}{56.1 - 14.3} \times 100\%$$
$$= 35.4\%$$

The temperature efficiency of the cold stream from the above diagram

$$\eta_{Cold} = \frac{T4 - T3}{T1 - T3} \times 100\%$$
$$= \frac{36.2 - 14.3}{56.1 - 14.3} \times 100\%$$
$$= 52.4\%$$

The mean temperature efficiency

$$\eta_{Mean} = \frac{\eta_{Hot} + \eta_{Cold}}{2}$$
$$= \frac{35.4 + 52.4}{2}$$
$$= 43.9\%$$

Co-Current Flow

For the co-current flow system the calculation procedure is similar but the formulae are as follows

The power emitted from the hot stream $\dot{Q}e$

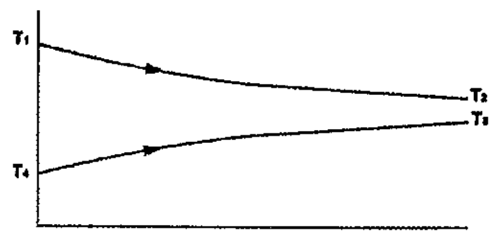
$$\dot{Q}e = \frac{V_{hot}}{60}\rho_{hot}\ Cp_{Hot}(T1 - T2) \times 1000 \quad \text{Watts}$$

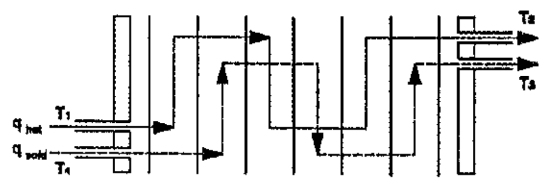
The power absorbed by the cold stream $\dot{Q}a$

$$\dot{Q}a = \frac{V_{cold}}{60}\rho_{cold}\ Cp_{Cold}(T3 - T4) \times 1000 \quad \text{Watts}$$

Reduction in Hot fluid temperature $\Delta t\ hot = T1 - T2\ K$

Increase in Cold fluid temperature $\Delta t\ cold = T3 - T4\ K$





CO-CURRENT PIPE OPERATION

The temperature efficiency of the hot stream from the above diagram

$$\eta_{Hot} = \frac{T1 - T2}{T1 - T4} \times 100\%$$

The temperature efficiency of the cold stream from the above diagram

$$\eta_{Cold} = \frac{T3 - T4}{T1 - T4} \times 100\%$$

The mean temperature efficiency

$$\eta_{Mean} = \frac{\eta_{Hot} + \eta_{Cold}}{2}$$

The tabulated and calculated results show the differences between Counter-Current flow and Co-Current flow and the effect upon temperature efficiency and Δt for the hot and cold streams.

4. To determine the overall heat transfer coefficient for a plate heat exchanger using the logarithmic mean temperature difference to perform the calculations (for the counter-current and co-current flows).

The following procedure demonstrates the effect of changing the direction of fluid flow on the overall heat transfer coefficient. The Logarithmic mean temperature difference is used to calculate the overall heat transfer coefficient.

NOTE that the observations from experiment No 3 may be used for the calculations in this procedure in order to save experimental time.

It is assumed that the basic INSTALLATION AND COMMISSIONING procedures for the Heat Exchanger Service Unit H100 have been completed as detailed in the main manual on pages 5 to 7.

Procedure

Install the Concentric tube Heat Exchanger H100B as detailed in **INSTALLATION / Heat Exchanger Installation H100B** on page B7 and connect the cold water circuit to give **Counter-Current** flow as detailed in the same section.

Follow the **OPERATING PROCEDURE** detailed in the main manual on page 16 onwards in order to establish the following operating conditions.

Fill the hot water circuit, set the cold water pressure regulator, and turn on the power to the unit. Then set the hot water temperature controller to 60°C and turn on the circulating pump.

Set the cold water flow rate V_{cold} to 1 litre min^{-1} and the hot water flow rate V_{hot} to 2 litre min^{-1}.

If the optional Computer Interface HC100 and software is being used:

It is assumed that the Installation and commissioning of both the hardware and software has been carried out according to the procedures on page 5 of the main manual. Ensure that the power lead to the Hilton data logger is connected, that the serial lead from the computer to the data logger is connected and that the ribbon cable from the interface to the base unit is also connected.

It is assumed that the computer is already running in Windows™ mode. Click on the H100 icon to start the software.

Language Screen:

The first screen will show the language section. If this option has been purchased then the preferred language may be selected.

H100 Main Menu:

*The next screen is the main menu for the H100 series of optional units. Select **the H100B Plate heat exchanger** (Note that only one option can be selected and that if the wrong unit is selected the procedure may be repeated.)*

It is assumed that the data is to be captured on disc and therefore this option should be selected in the lower box. When all selections have been made click OK.

Communications Test:

As the user has selected to collect data the next screen carries out a communications test with the H100 base unit. Select the serial port of the computer that the unit is connected to and then click the Go button with the mouse pointer.

Assuming communications is confirmed the next screen will show the H100B Plate Heat Exchanger Main Menu.

If communications fails for any reason check the parameters indicated on the screen and repeat the test. If communications cannot be established for any reason the Cancel button may be used and the cause investigated.

H100B Plate Heat Exchanger Main Menu:

This lists the optional experiments that may be carried out with the H100 Plate Heat Exchanger. To continue with the above experiment select 4 ***To determine the overall heat transfer coefficient for a Plate heat exchanger using the logarithmic mean temperature difference to perform the calculations*** *and then click OK.*

H100B Experiment Number 4:

Assuming that the above procedure is being followed select the ***Counter-Current*** *flow option initially and check the Instructions on the screen have been observed. If data is to be recorded to disc then select the Store data on disc for later review option. Then click OK.*

If the user DOES select to record data to disc then a file name will be requested. Note that a partially fixed file name is used together with a fixed file suffix. This enables the software to recognise data during the review option that is compatible with the review mode selected. The user is required to enter the remaining digits that will be of relevance to them in the future. Once a valid file name is entered the Recording data screen is displayed.

Recording data:

The next screen shows four tabs Flow, Temperature, Data Point and Temp. distribution. The Flow and Temperature graphs may be used to set the hot and cold stream flow rates to the desired values and the temperature graph used to determine when the unit has reached a stable condition.

Once stable conditions have been established the Data point tab may be clicked and the Record button clicked to record and display a captured data point. Note that data may be sent to a printer (If a printer is connected) if required. The option of Raw (end results not calculated) or Calculated data may be selected for the printing option.

The results shown in the table are updated each time the record button is clicked. NOTE that if no changes are made to the H100B settings of flow rate and hot stream temperature the captured results will all be similar.

If the Temp Distribution tab is clicked then a simple line diagram graph will be displayed showing the temperature distribution of the last sample.

The software should be utilised to automate the data recording procedures detailed as follows in the manual procedure.

To return to the H100B Plate Heat Exchanger Main Menu click the End button on the Data capture screen.

Monitor the stream temperatures and the hot and cold flow rates to ensure these too remain close to the original setting. Then record the following:

T1, T2, T3, T4, V_{hot} and V_{cold}

This completes the basic Counter-Current flow experiment observations.

Next connect the cold water circuit to give **Co-Current flow** as detailed in the **INSTALLATION / Heat Exchanger Installation H100B** on page B7. Note that there is no need to disconnect the hot water circuit or to turn off the hot water pump during this operation.

Set the flow indicator to Fcold and adjust the cold water flow valve so that V_{cold} is approximately 1 litre min^{-1}. Select Fhot and adjust the hot water flow rate V_{hot} to approximately 2 litre min^{-1}. Set the hot water temperature to 60 °C if this has been adjusted.

If the optional Computer Interface HC100 and software is being used then from the H100B Plate Heat Exchanger Main Menu select 4 ***To determine the overall heat transfer coefficient for a Plate heat exchanger using the logarithmic mean temperature difference to perform the calculations (for counter-current and co-current)*** *and then click OK.*

H100A Experiment Number 4:

*Assuming that the above procedure is being followed select the **Co-Current** flow option initially and check the Instructions on the screen have been observed. If data is to be recorded to disc then select the Store data on disc for later review option. Then click OK.*

If the user DOES select to record data to disc then a file name will be requested. Note that a partially fixed file name is used together with a fixed file suffix. This enables the software to recognise data during the review option that is compatible with the review mode selected. The user is required to enter the remaining digits that will be of relevance to them in the future. Once a valid file name is entered the Recording data screen is displayed. The data display and capture procedure is the same as above in the Counter-current flow procedure.

Monitor the stream temperatures and the hot and cold flow rates to ensure these remain close to the original setting. Then record the following:

T1, T2, T3, T4, V_{hot} and V_{cold}

This completes the basic Co-Current flow experiment observations

OBSERVATIONS

Flow Direction: Counter-Current

Sample No.	T1	T2	T3	T4	V_{hot}	V_{cold}
----	°C	°C	°C	°C	L min^{-1}	L min^{-1}
1	56.1	41.3	14.3	36.2	2.00	1.10
2						
3						
4						
5						

Calculated Data

Sample No.	Δt_{hot}	Δt_{cold}	$\dot{Q}$ e	$\dot{Q}$ a	$\eta_{Thermal}$	η_{Cold}	η_{Hot}	η_{Mean}
---	K	K	W	W	%	%	%	%
1	14.8	21.9	2039	1675	82.1	52.4	35.4	43.9
2								
3								
4								
5								

Sample	LMTD	U
---	K	Wm^2K^{-1}
1	23.2	2312.8
2		
3		
4		
5		

If the optional Computer Interface HC100 and software is being used then it will be seen that the tabular displays are similar to those used on screen.

Flow Direction: Co-Current

Sample No.	T1	T2	T3	T4	V_{hot}	V_{cold}
----	°C	°C	°C	°C	L min^{-1}	L min^{-1}
1	59.2	44.7	39.2	13.2	2.02	1.01
2						
3						
4						
5						

Calculated Data

Sample No.	Δt_{hot}	Δt_{cold}	$\dot{Q}e$	$\dot{Q}a$	$\eta_{Thermal}$	η_{Cold}	η_{Hot}	η_{Meanl}
---	K	K	W	W	%	%	%	%
1	14.5	26.0	2015	1823	90.5	56.5	31.5	44.0
2								
3								
4								
5								

Sample	LMTD	U
---	K	Wm^2K^{-1}
1	19.06	2782
2		
3		
4		
5		

If the optional Computer Interface HC100 and software is being used then it will be seen that the tabular displays are similar to those used on screen.

CALCULATIONS

For the examples the calculations are as follows.

Counter-Current Flow

It is necessary to convert the volume flow rates to mass flow rates using the conversion factors in table 1 and 2 on page B9. The water density ρ (kg $litre^{-1}$) and specific heat capacity Cp (kJ kg^{-1} K^{-1}) is dependant upon the temperature and the mean fluid temperature

$$T_{mean} = \frac{T_{inlet} + T_{outlet}}{2}$$

is used to calculate the relevant temperature the Hot Stream:

T_{mean} = (56.1 +41.3) / 2 = 48.7 °C

From table 1 and 2 at T_{mean} = 48.7 °C ρ_{hot} = 0.988 kg $litre^{-1}$

Cp = 4.180 kJ kg^{-1} k^{-1}

Hence the power emitted from the hot stream $\dot{Q}e$

$$\dot{Q}e = \frac{V_{hot}}{60}\,\rho_{hot}\,Cp_{Hot}\,(T1 - T2) \times 1000 \quad \text{Watts}$$

$$= \frac{2.00}{60} \times 0.988 \times 4.180 \times (56.1 - 41.3) \times 1000$$

$$= 2039 \ \text{Watts}$$

T_{mean} = (36.2 + 14.3) / 2 = 25.3 °C

From table 1 and 2 at T_{mean} = 25.3 °C

ρ_{Cold} = 0.9978 kg litre^{-1}
Cp_{Cold} = 4.179 kJ kg^{-1} k^{-1}

Hence the power absorbed by the cold stream $\dot{Q}$ a

$$\dot{Q}a = \frac{V_{cold}}{60}\,\rho_{cold}\,Cp_{Cold}\,(T4 - T3) \times 1000 \quad \text{Watts}$$
$$= \frac{1.10}{60} \times 0.997 \times 4.179 \times (36.2 - 14.3) \times 1000$$
$$= 1675 \quad \text{Watts}$$

Reduction in Hot fluid temperature

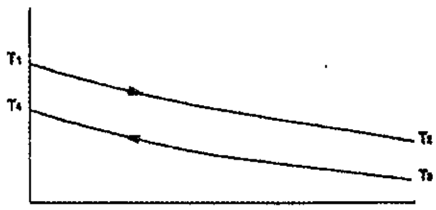
$$\Delta t\ hot = T1 - T2 = 56.1 - 41.3 = 14.8\ K$$

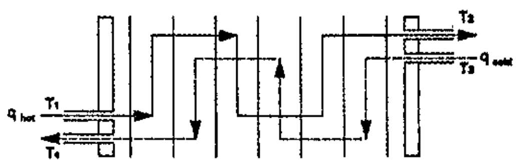
Increase in Cold fluid temperature

$$\Delta t\ cold = T4 - T3 = 36.2 - 14.3 = 21.9\ K$$

A useful measure of the heat exchanger performance is the temperature efficiency.

The temperature change in each stream (hot and cold) is compared with the maximum temperature difference between the two streams. This could only occur in a perfect heat exchanger of infinite size with no external losses or gains.





COUNTER-CURRENT OPERATION

The temperature efficiency of the hot stream from the above diagram

$$\eta_{Hot} = \frac{T1 - T2}{T1 - T3} \times 100\%$$
$$= \frac{56.1 - 41.3}{56.1 - 14.3} \times 100\%$$
$$= 35.4\%$$

The temperature efficiency of the cold stream from the above diagram

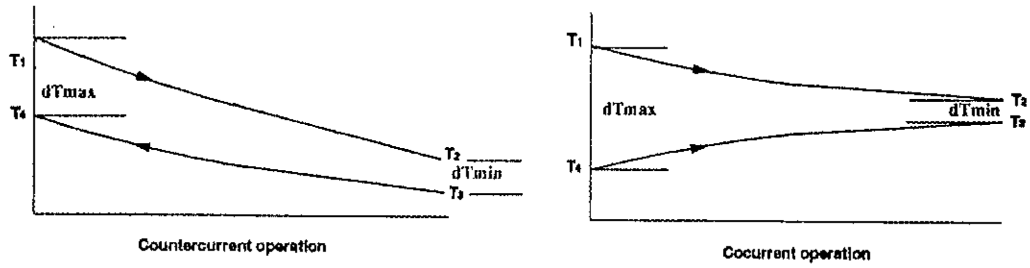
$$\eta_{Cold} = \frac{T4 - T3}{T1 - T4} \times 100\%$$
$$= \frac{32.2 - 14.3}{56.1 - 14.3} \times 100\%$$
$$= 52.4\%$$

The mean temperature efficiency

$$\eta_{Mean} = \frac{\eta_{Hot} + \eta_{Cold}}{2}$$
$$= \frac{35.4 + 52.4}{2}$$
$$= 43.9\%$$

As the temperature difference between the hot and cold fluids vary along the length of the heat exchanger it is necessary to derive a suitable mean temperature difference that may be used in heat transfer calculations. These calculations are not only of relevance in experimental procedures but also more importantly to be used in the design of heat exchangers to perform a particular duty.

The derivation and application of the Logarithmic Mean temperature Difference (LMTD) may be found in most thermodynamics and heat transfer text books.



The LMTD is defined as

$$LMTD = \frac{dTmax - dTmin}{\ln\left(\frac{dTmax}{dTmin}\right)}$$

Hence from the above diagrams of temperature distribution

$$LMTD = \frac{(T1 - T4) - (T2 - T3)}{\ln\left(\frac{(T1 - T4)}{(T2 - T3)}\right)}$$

Note that as the temperature measurement points are fixed on the heat exchanger the LMTD is the same formula for both Counter-current flow and Co-current flow.

Hence for the Counter-current example

$$\begin{aligned} \text{LMTD} &= \frac{(56.1-36.2)-(41.3-14.3)}{\ln\left(\frac{(56.1-36.2)}{(41.3-14.3)}\right)} \\ &= \frac{-7.1}{\ln(0.7370)} \\ &= \frac{-7.1}{-0.3051} \\ &= 23.2\,\text{K} \end{aligned}$$

The flow through the plate heat exchanger is not consistently either counter-current or co-current due to the nature of the plate arrangement and the flow passages. Therefore a correction factor F must be applied to the overall heat transfer coefficient as follows:

$$U = \frac{\dot{Q}_e}{A \times \text{LMTD} \times F}$$

Where

A Heat transfer area of heat exchanger (m^2)

$\dot{Q}$ e Heat emitted from hot stream (Watts)
LMTD Logarithmic mean temperature difference (K)
F Correction factor (Non-dimensional)
For the Hilton plate heat exchanger the factor F is 0.95

When applying the equations to a typical industrial heat exchanger the appropriate factor should be obtained from the manufacturer's data sheets.

The heat transfer area A may be calculated from:-

$A = N \times a$

Where

N Number of plates with hot AND cold fluid on opposing faces (Non-dimensional)
a Projected heat transfer area of each plate (m^2)

Note that 7 pressed plates are installed between the end plates only the central 5 plates have hot AND cold fluid on opposing faces and therefore contribute to the heat transfer process.
Therefore N= 5 for the plate heat exchanger.

Hence for the heat exchanger from the **USEFUL DATA** section on page B9.

$$\begin{aligned} A &= N \times a \\ &= 5 \times 0.008 \\ &= 0.04\,\text{m}^2 \end{aligned}$$

Hence for the test conditions the overall heat transfer coefficient:-

$$U = \frac{\dot{Q}_e}{A \times LMTD \times F}$$
$$= \frac{2039}{0.04 \times 23.2 \times 0.95}$$
$$= 2312.8\ Wm^{-2}K^{-1}$$

Co-Current Flow

For the co-current flow system the calculation procedure is similar but the formulae are as follows

The power emitted from the hot stream $\dot{Q}$ e

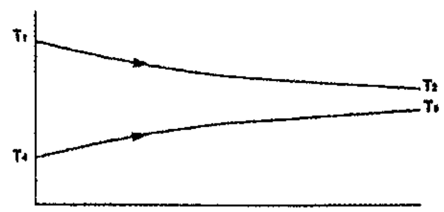
$$\dot{Q}e = \frac{V_{hot}}{60}\ \rho_{hot}\ Cp_{Hot}\,(T1 - T2) \times 1000 \quad \text{Watts}$$

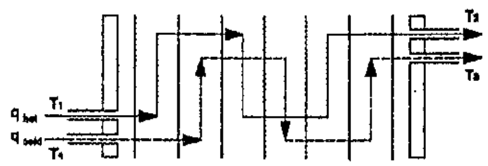
The power absorbed by the cold stream $\dot{Q}$ a

$$\dot{Q}a = \frac{V_{cold}}{60}\ \rho_{cold}\ Cp_{Cold}\,(T3 - T4)\ 1000 \quad \text{Watts}$$

Reduction in Hot fluid temperature Δt hot = T1 – T2 K

Increase in Cold fluid temperature Δt cold = T3 – T4 K





CO-CURRENT PIPE OPERATION

The temperature efficiency of the hot stream from the above diagram

$$\eta_{Hot} = \frac{T1 - T2}{T1 - T4} \times 100\%$$

The temperature efficiency of the cold stream from the above diagram

$$\eta_{Cold} = \frac{T3 - T4}{T1 - T4} \times 100\%$$

The mean temperature efficiency

$$\eta_{Mean} = \frac{\eta_{Hot} + \eta_{Cold}}{2}$$

The logarithmic mean temperature difference LMTD

$$LMTD = \frac{(T1 - T4) - (T2 - T3)}{\ln\left(\frac{(T1 - T4)}{(T2 - T3)}\right)}$$

The Overall heat transfer coefficient U

$$U = \frac{\dot{Q}_e}{A \times LMTD \times F}$$

The tabulated and calculated results show the differences between Counter-Current flow and Co-Current flow and the effect upon temperature efficiency , Δt , and the overall heat transfer coefficient.

If the optional Computer Interface HC100 and software is being used then the user can return to the H100B Plate Heat Exchanger Main Menu by clicking the End and Back keys.
Once back at the main menu the user can opt to record more data in another experiment on the same heat exchanger or review the data recorded during the preceding experiment. Alternatively the user can return to the H100 Main Menu by continuing to click the Back key and the select to use another optional heat exchanger if available.

5. To investigate the effect of changes in hot fluid and cold fluid flow rate on the temperature efficiencies and overall heat transfer coefficient.

The following procedure demonstrates the effect of changing the flow rate of both the hot and cold streams on the overall heat transfer coefficient. The Logarithmic mean temperature difference is used to calculate the overall heat transfer coefficient.

It is assumed that the basic INSTALLATION AND COMMISSIONING procedures for the Heat Exchanger Service Unit H100 have been completed as detailed in the main manual on pages 5 to 7.

Procedure

Install the Plate Heat Exchanger H100B as detailed in **INSTALLATION / Heat Exchanger Installation H100B** on page B7 and connect the cold water circuit to give **Counter-Current** flow as detailed in the same section.

Follow the **OPERATING PROCEDURE** detailed in the main manual on page 16 onwards in order to establish the following operating conditions.

Fill the hot water circuit, set the cold water pressure regulator, and turn on the power to the unit. Then set the hot water temperature controller to 40°C and turn on the circulating pump.

Set the cold water flow rate V_{cold} to 1 litre min^{-1} and the hot water flow rate V_{hot} to 1.0 litre min^{-1}.

If the optional Computer Interface HC100 and software is being used:

It is assumed that the Installation and commissioning of both the hardware and software has been carried out according to the procedures on page 5 of the main manual. Ensure that the power lead to the Hilton data logger is connected, that the serial lead from the computer to the data logger is connected and that the ribbon cable from the interface to the base unit is also connected.

It is assumed that the computer is already running in Windows™ mode. Click on the H100 icon to start the software.

Language Screen:

The first screen will show the language section. If this option has been purchased then the preferred language may be selected.

H100 Main Menu:

*The next screen is the main menu for the H100 series of optional units. Select **the H100B Plate heat exchanger** (Note that only one option can be selected and that if the wrong unit is selected the procedure may be repeated).*

It is assumed that the data is to be captured on disc and therefore this option should be selected in the lower box. When all selections have been made click OK.

Communications Test:

As the user has selected to collect data the next screen carries out a communications test with the H100 base unit. Select the serial port of the computer that the unit is connected to and then click the Go button with the mouse pointer.

Assuming communications is confirmed the next screen will show the H100B Plate Heat Exchanger Main Menu.

If communications fails for any reason check the parameters indicated on the screen and repeat the test. If communications cannot be established for any reason the Cancel button may be used and the cause investigated.

H100B Plate Heat Exchanger Main Menu:

*This lists the optional experiments that may be carried out with the H100B Plate Heat Exchanger. To continue with the above experiment select **5 To investigate the effect of changes in hot fluid and cold fluid flow rate on the temperature efficiencies and overall heat transfer coefficient,** and then click OK.*

H100B Experiment Number 5:

*Assuming that the above procedure is being followed select the **Counter-Current** flow option initially and check the Instructions on the screen have been observed. If data is to be recorded to disc then select the Store data on disc for later review option. Then click OK.*

If the user DOES select to record data to disc then a file name will be requested. Note that a partially fixed file name is used together with a fixed file suffix. This enables the software to recognise data during the review option that is compatible with the review mode selected. The user is required to enter the remaining digits that will be of relevance to them in the future. Once a valid file name is entered the Recording data screen is displayed.

Recording data:

The next screen shows four tabs Flow, Temperature and Data Point. The Flow and Temperature graphs may be used to set the hot and cold stream flow rates to the desired values and the temperature graph used to determine when the unit has reached a stable condition.

Once stable conditions have been established the Data point tab may be clicked and the Record button clicked to record and display a captured data point.

A dialogue box will be displayed where the user must enter the nominal hot stream flow rate to the nearest 0.5 litre min^{-1}. This is then used to group data points even though the ACTUAL hot stream flow recorded may deviate slightly from the original set value.

Note that data may be sent to a printer (If a printer is connected) if required. The option of Raw (end results not calculated) or Calculated data may be selected for the printing option. The results shown in the table are updated each time the record button is clicked. NOTE that if no changes are made to the H100B settings of flow rate and hot stream temperature the captured results will all be similar.

The software should be utilised to automate the data recording procedures detailed as follows in the manual procedure.

Monitor the stream temperatures and the hot and cold flow rates to ensure these too remain close to the original setting. Then record the following:

T1, T2, T3, T4, V_{hot} and V_{cold}

The hot and cold flows should then be adjusted according to the following suggested values and the procedure repeated.

V_{hot} (Litre min^{-1})	V_{cold} (Litre min^{-1})
1.0	1.0
1.0	2.0
1.0	3.0
1.0	1.0
2.0	2.0
2.0	3.0
Max	1.0
Max	2.0
Max	3.0

If time permits the increments between the hot and cold stream flow rates may be made smaller to 0.5 litre min^{-1} if required.

If the optional Computer Interface HC100 and software is being used:

All of the observations may be carried out without leaving the experiment 5 Recording data screens. The water flow rate tab and temperature tabs should be used to check the required flow rates and temperature stability and the Recording data procedures used to collect each data point. Note that for each reading a Nominal hot flow will be required and the user must select the nearest nominal hot flow value.

This completes the basic Counter-Current flow experiment observations.

If the optional Computer Interface HC100 and software is being used then the user can return to the H100B Plate Heat Exchanger Main Menu by clicking the End and Back keys.

Next connect the cold water circuit to give **Co-Current flow** as detailed in the **INSTALLATION / Heat Exchanger Installation H100B** on page B7. Note that there is no need to disconnect the hot water circuit or to turn off the hot water pump during this operation.

If the optional Computer Interface HC100 and software is being used:

Select H100B Experiment Number 5:

Assuming that the above procedure is being followed select the ***Co-Current*** *flow option and check the Instructions on the screen have been observed. If data is to be recorded to disc then select the Store data on disc for later review option. Then click OK.*

If the user DOES select to record data to disc then a file name will be requested. Note that a partially fixed file name is used together with a fixed file suffix. This enables the software to recognise data during the review option that is compatible with the review mode selected. The user is required to enter the remaining digits that will be of relevance to them in the future. Once a valid file name is entered the Recording data screen is displayed.

Recording data:

The next screen shows four tabs Flow, Temperature and Data Point. The Flow and Temperature graphs may be used to set the hot and cold stream flow rates to the desired values and the temperature graph used to determine when the unit has reached a stable condition.

Once stable conditions have been established the Data point tab may be clicked and the Record button clicked to record and display a captured data point.

A dialogue box will be displayed where the user must enter the nominal hot stream flow rate to the nearest 0.5 litre min^{-1}. This is then used to group data points even though the ACTUAL hot stream flow recorded may deviate slightly from the original set value.

Note that data may be sent to a printer (If a printer is connected) if required. The option of Raw (end results not calculated) or Calculated data may be selected for the printing option. The results shown in the table are updated each time the record button is clicked. NOTE that if no changes are made to the H100B settings of flow rate and hot stream temperature the captured results will all be similar.

The software should be utilised to automate the data recording procedures detailed as follows in the manual procedure.

Monitor the stream temperatures and the hot and cold flow rates to ensure these remain close to the original setting. Then record the following:

T1, T2, T3, T4, V_{hot} and V_{cold}

The hot and cold flows should then be adjusted according to the following suggested values and the procedure repeated.

V_{hot} (Litre min^{-1})	V_{cold} (Litre min^{-1})
1.0	1.0
1.0	2.0
1.0	3.0
2.0	1.0
2.0	2.0
2.0	3.0
Max	1.0
Max	2.0
Max	3.0

This completes the basic Co-Current flow experiment observations.

OBSERVATIONS

Flow Direction: Counter-Current

Sample No.	T1	T2	T3	T6	V_{hot}	V_{cold}
----	°C	°C	°C	°C	L min^{-1}	L min^{-1}
1	62.1	37.2	14.0	36.5	1.05	0.97
2						
3						
4						
5						

Calculated Data

Sample No.	Δt_{hot}	Δt_{cold}	$\dot{Q}e$	$\dot{Q}a$	η_{Cold}	η_{Hot}	η_{Mean}
---	K	K	W	W	%	%	%
1	24.9	22.5	1800	1516	46.8	51.8	49.3
2							
3							
4							
5							

Sample No.	LMTD	U	Nominal Hot Flow
---	K	W m^2K^{-1}	litre min^{-1}
1	24.4	2049	1.0
2			
3			
4			
5			

If the optional Computer Interface HC100 and software is being used then it will be seen that the tabular displays are similar to those used on screen.

Flow Direction: Co-Current

Sample No.	T1	T2	T3	T4	V_{hot}	V_{cold}
----	°C	°C	°C	°C	L min^{-1}	L min^{-1}
1	61.5	38.4	34.0	13.0	1.08	1.02
2						
3						
4						
5						

Calculated Data

Sample No.	Δt_{hot}	Δt_{cold}	$\dot{Q}e$	$\dot{Q}a$	η_{Cold}	η_{Hot}	η_{Meanl}
---	K	K	W	W	%	%	%
1	23.1	21.0	1590	1489	76.4	84.0	80.2
2							
3							
4							
5							

Sample No.	LMTD	U
---	K	$W\ m^2K^{-1}$
1	32.1	1303
2		
3		
4		
5		

CALCULATIONS
For the examples the calculations are as follows.

Counter-Current Flow
It is necessary to convert the volume flow rates to mass flow rates using the conversion factors in table 1 and 2 on page B9. The water density ρ (kg $litre^{-1}$) and specific heat capacity Cp (kJ kg^{-1} K^{-1}) is dependant upon the temperature and the mean fluid temperature Tmean

$$T_{mean} = \frac{T_{inlet} + T_{outlet}}{2}$$

is used to calculate the relevant temperature of the Hot stream.
For the Hot stream:
T_{mean} = (62.1 + 37.2) / 2 = 49.6 °C
From table 1 and 2 at T_{mean} = 49.6 °C

ρ_{hot} = 0.988 kg $litre^{-1}$
Cp = 4.180 kJ kg^{-1} k^{-1}

Hence the power emitted from the hot stream $\dot{Q}$ e

$$\dot{Q}e = \frac{V_{hot}}{60}\ \rho_{hot}\ Cp_{Hot}(T1 - T2)\ 1000 \quad \text{Watts}$$
$$= \frac{1.05}{60} \times 0.988 \times 4.180 \times (62.1 - 37.2) \times 1000$$
$$= 1800 \text{ Watts}$$

For the Cold stream T_{mean}
T_{mean} = (36.5 + 14.0) / 2 = 25.3 °C

From table 1 and 2 at T_{mean} = 25.3 °C

ρ_{Cold} = 0.997 kg $litre^{-1}$
Cp_{Cold} = 4.179 kJ kg^{-1} k^{-1}

Hence the power absorbed by the cold stream $\dot{Q}$ a

$$\dot{Q}a = \frac{V_{cold}}{60}\ \rho_{cold}\ Cp_{Cold}(T4 - T3) \times 1000 \quad \text{Watts}$$
$$= \frac{0.97}{60} \times 0.997 \times 4.179 \times (36.5 - 14.0) \times 1000$$
$$= 1516 \quad \text{Watts}$$

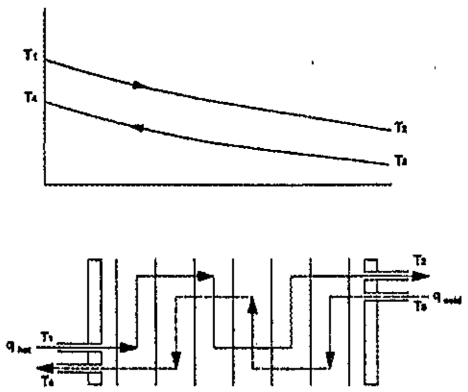
Reduction in Hot fluid temperature

Δt hot = T1 – T2
= 62.1 – 49.7
= 24.9 K

Increase in Cold fluid temperature Δt cold $= T4 - T3$
$= 36.5 - 14.0$
$= 22.5$ K

A useful measure of the heat exchanger performance is the temperature efficiency.

The temperature change in each stream (hot and cold) is compared with the maximum temperature difference between the two streams. This could only occur in a perfect heat exchanger of infinite size with no external losses or gains.



COUNTER-CURRENT OPERATION

The temperature efficiency of the hot stream from the above diagram

$$\eta_{Hot} = \frac{T1 - T2}{T1 - T3} \times 100\%$$
$$= \frac{62.1 - 37.2}{62.1 - 14.0} \times 100\%$$
$$= 51.8\%$$

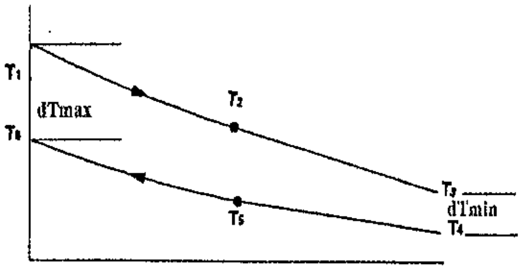
The temperature efficiency of the cold stream from the above diagram

$$\eta_{Cold} = \frac{T4 - T3}{T1 - T3} \times 100\%$$
$$= \frac{36.5 - 14.0}{62.1 - 14.0} \times 100\%$$
$$= 46.8\%$$

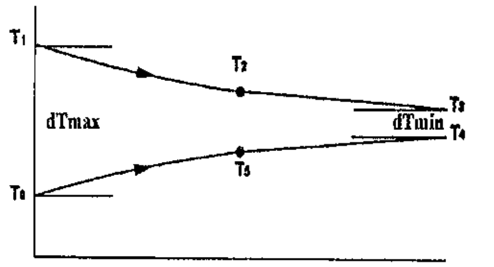
The mean temperature efficiency

$$\eta_{Mean} = \frac{\eta_{Hot} + \eta_{Cold}}{2}$$
$$= \frac{51.8 + 46.8}{2}$$
$$= 49.3\%$$

As the temperature difference between the hot and cold fluids vary along the length of the heat exchanger it is necessary to derive a suitable mean temperature difference that may be used in heat transfer calculations. These calculations are not only of relevance in experimental procedures but also more importantly to be used in the design of heat exchangers to perform a particular duty.
The derivation and application of the Logarithmic Mean temperature Difference (LMTD) may be found in most thermodynamics and heat transfer text books.



Countercurrent operation



Cocurrent operation

The LMTD is defined as

$$\text{LMTD} = \frac{\text{dTmax} - \text{dTmin}}{\ln\left(\dfrac{\text{dTmax}}{\text{dTmin}}\right)}$$

Hence from the above diagrams of temperature distribution

$$\text{LMTD} = \frac{(\text{T1} - \text{T4}) - (\text{T2} - \text{T3})}{\ln\left(\dfrac{(\text{T1} - \text{T4})}{(\text{T2} - \text{T3})}\right)}$$

Note that as the temperature measurement points are fixed on the heat exchanger the LMTD is the same formula for both Counter-current flow and Co-current flow.

Hence for the Counter-current example

$$\begin{aligned}\text{LMTD} &= \frac{(62.1 - 36.5) - (37.2 - 14.0)}{\ln\left(\dfrac{(62.1 - 36.5)}{(37.2 - 14.0)}\right)} \\ &= \frac{2.4}{\ln(1.103)} \\ &= \frac{2.4}{0.0984} \\ &= 24.4\,\text{K}\end{aligned}$$

The flow through the plate heat exchanger is not consistently either counter-current or co-current due to the nature of the plate arrangement and the flow passages. Therefore a correction factor F must be applied to the overall heat transfer coefficient as follows:

$$U = \frac{\dot{Q}_e}{A \times LMTD \times F}$$

Where

A	Heat transfer area of heat exchanger (m^2)
$\dot{Q}$ e	Heat emitted from hot stream (Watts)
LMTD	Logarithmic mean temperature difference (K)
F	Correction factor (Non-dimensional)

For the Hilton plate heat exchanger the factor F is 0.95

When applying the equations to a typical industrial heat exchanger the appropriate factor should be obtained from the manufacturer's data sheets.

The heat transfer area A may be calculated from:-

$$A = N \times a$$

Where

N	Number of plates with hot AND cold fluid on opposing faces (Non-dimensional)
a	Projected heat transfer area of each plate (m^2)

Note that 7 pressed plates are installed between the end plates only the central 5 plates have hot AND cold fluid on opposing faces and therefore contribute to the heat transfer process.
Therefore N= 5 for the plate heat exchanger.
Hence for the heat exchanger from the **USEFUL DATA** section on page B9.

$$\begin{aligned} A &= N \times a \\ &= 5 \times 0.008 \\ &= 0.04\ m^2 \end{aligned}$$

Hence for the test conditions the overall heat transfer coefficient:-

$$\begin{aligned} U &= \frac{\dot{Q}_e}{A \times LMTD \times F} \\ &= \frac{1800}{0.04 \times 24.4 \times 0.95} \\ &= 2049\ Wm^{-2}K^{-1} \end{aligned}$$

Co-Current Flow

For the co-current flow system the calculation procedure is similar but the formulae are as follows

The power emitted from the hot stream $\dot{Q}$ e

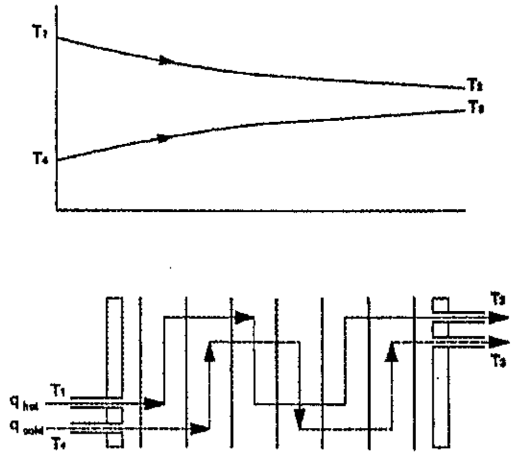
$$\dot{Q}e = \frac{V_{hot}}{60}\ \rho_{hot}\ Cp_{Hot}\left(T1 - T2\right)\ 1000 \quad \text{Watts}$$

The power absorbed by the cold stream $\dot{Q}$ a

$$\dot{Q}a = \frac{V_{cold}}{60}\,\rho_{cold}\;Cp_{Cold}\,(T3 - T4)\;\;1000 \quad \text{Watts}$$

Reduction in Hot fluid temperature $\Delta t\ hot = T1 - T2\ K$

Increase in Cold fluid temperature $\Delta t\ cold = T3 - T4\ K$



CO-CURRENT PIPE OPERATION

The temperature efficiency of the hot stream from the above diagram

$$\eta_{Hot} = \frac{T1 - T2}{T1 - T4} \times 100\%$$

The temperature efficiency of the cold stream from the above diagram

$$\eta_{Cold} = \frac{T3 - T4}{T1 - T4} \times 100\%$$

The mean temperature efficiency

$$\eta_{Mean} = \frac{\eta_{Hot} + \eta_{Cold}}{2}$$

The logarithmic mean temperature difference LMTD

$$LMTD = \frac{(T1 - T4) - (T2 - T3)}{\ln\left(\frac{(T1 - T4)}{(T2 - T3)}\right)}$$

The Overall heat transfer coefficient U

$$U = \frac{\dot{Q}_e}{A \times LMTD \times F}$$

In order to see the effect of the volume flow rate on the overall heat transfer coefficient the data should be plotted with overall heat transfer coefficient on the Y(vertical) axis and the Hot flow rate on the X (horizontal) axis.
If the optional Computer Interface HC100 and software is being used and the suggested procedure followed then the nominal flow rate column will group the data and allow the effect of varying hot flow rate to be seen.

If the optional Computer Interface HC100 and software is being used then the user can return to the H100B Plate Heat Exchanger Main Menu by clicking the End and Back keys.
Once back at the main menu the user can opt to record more data in another experiment on the same heat exchanger or review the data recorded during the preceding experiment. Alternatively the user can return to the H100 Main Menu by continuing to click the Back key and the select to use another optional heat exchanger if available.

6. To investigate the effect of driving force (difference between hot stream and cold stream temperature) with counter-current and co-current flow

The following procedure demonstrates the effect of changing the temperature difference (or driving force) between the hot and cold streams. The effect of this on the overall heat transfer coefficient and temperature efficiencies may be investigated for both counter-current and co-current flows.

I It is assumed that the basic INSTALLATION AND COMMISSIONING procedures for the Heat Exchanger Service Unit H100 have been completed as detailed in the main manual on pages 5 to 7

Procedure

Install the Concentric tube Heat Exchanger H100B as detailed in **INSTALLATION / Heat Exchanger Installation H100B** on page B7 and connect the cold water circuit to give **Counter-Current** flow as detailed in the same section.

Follow the **OPERATING PROCEDURE** detailed in the main manual on page 16 onwards in order to establish the following operating conditions.

Fill the hot water circuit, set the cold water pressure regulator, and turn on the power to the unit. Then set the hot water temperature controller to **40°C** and turn on the circulating pump .

Set the cold water flow rate V_{cold} to 1 litre min^{-1} and the hot water flow rate V_{hot} to 2.0 litre min^{-1}.

If the optional Computer Interface HC100 and software is being used:

It is assumed that the Installation and commissioning of both the hardware and software has been carried out according to the procedures on page 5 of the main manual. Ensure that the power lead to the Hilton data logger is connected, that the serial lead from the computer to the data logger is connected and that the ribbon cable from the interface to the base unit is also connected.

It is assumed that the computer is already running in Windows™ mode. Click on the H100 icon to start the software.

Language Screen:

The first screen will show the language section. If this option has been purchased then the preferred language may be selected.

H100 Main Menu:

*The next screen is the main menu for the H100 series of optional units. Select **the H100B Plate heat exchanger** (Note that only one option can be selected and that if the wrong unit is selected the procedure may be repeated).*

It is assumed that the data is to be captured on disc and therefore this option should be selected in the lower box. When all selections have been made click OK.

Communications Test:

As the user has selected to collect data the next screen carries out a communications test with the H100 base unit. Select the serial port of the computer that the unit is connected to and then click the Go button with the mouse pointer.

Assuming communications is confirmed the next screen will show the H100B Plate Heat Exchanger Main Menu.

If communications fails for any reason check the parameters indicated on the screen and repeat the test. If communications cannot be established for any reason the Cancel button may be used and the cause investigated.

H100B Plate Heat Exchanger Main Menu:

*This lists the optional experiments that may be carried out with the H100B Plate Heat Exchanger. To continue with the above experiment select 6 **To investigate the effect of driving force (difference between hot stream and cold stream temperature) with counter-current and co-current flow** and then click OK.*

H100B Experiment Number 6:

*Assuming that the above procedure is being followed select the **Counter-Current** flow option initially and check the Instructions on the screen have been observed. If data is to be recorded to disc then select the Store data on disc for later review option. Then click OK.*

If the user DOES select to record data to disc then a file name will be requested. Note that a partially fixed file name is used together with a fixed file suffix. This enables the software to recognise data during the review option that is compatible with the review mode selected. The user is required to enter the remaining digits that will be of relevance to them in the future. Once a valid file name is entered the Recording data screen is displayed.

Recording data:

The next screen shows four tabs Flow, Temperature and Data Point. The Flow and Temperature graphs may be used to set the hot and cold stream flow rates to the desired values and the temperature graph used to determine when the unit has reached a stable condition.

Once stable conditions have been established the Data point tab may be clicked and the Record button clicked to record and display a captured data point.

Note that data may be sent to a printer (If a printer is connected) if required The option of Raw (end results not calculated) or Calculated data may be selected for the printing option. The results shown in the table are updated each time the record button is clicked. NOTE that if no changes are made to the H100B settings of flow rate and hot stream temperature the captured results will all be similar.

The software should be utilised to automate the data recording procedures detailed as follows in the manual procedure.

Monitor the stream temperatures and the hot and cold flow rates to ensure these too remain close to the original setting. Then record the following:

T1, T2, T3, T4, V_{hot} and V_{cold}

Repeat the above procedure with the hot water temperature controller set to 50°, 60° and 70 °C.
If the optional Computer Interface HC100 and software is being used:
All of the observations may be carried out without leaving the experiment 6 Recording data screens. The water flow rate tab and temperature tabs should be used to check the required flow rates and temperature stability and the Recording data procedures used to collect each data point.

This completes the Counter-current observation procedures

If the optional Computer Interface HC100 and software is being used then the user can return to the H100B Plate Heat Exchanger Main Menu by clicking the End and Back keys.

Next connect the cold water circuit to give **Co-Current flow** as detailed in the **INSTALLATION / Heat Exchanger Installation H100B** on page B7. Note that there is no need to disconnect the hot water circuit or to turn off the hot water pump during this operation.
Follow the **OPERATING PROCEDURE** detailed in the main manual on page 16 onwards in order to establish the following operating conditions.

Fill the hot water circuit, set the cold water pressure regulator, and turn on the power to the unit. Then set the hot water temperature controller to 40°C and turn on the circulating pump.

Set the cold water flow rate V_{cold} to 1 litre min^{-1} and the hot water flow rate V_{hot} to 2.0 litre min^{-1}.

If the optional Computer Interface HC100 and software is being used:

Select H100B Experiment Number 6:

Assuming that the above procedure is being followed select the ***Co-Current*** *flow option and check the Instructions on the screen have been observed. If data is to be recorded to disc then select the Store data on disc for later review option. Then click OK.*

If the user DOES select to record data to disc then a file name will be requested. Note that a partially fixed file name is used together with a fixed file suffix. This enables the software to recognise data during the review option that is compatible with the review mode selected. The user is required to enter the remaining digits that will be of relevance to them in the future. Once a valid file name is entered the Recording data screen is displayed.

Recording data:

The next screen shows four tabs Flow, Temperature and Data Point. The Flow and Temperature graphs may be used to set the hot and cold stream flow rates to the desired values and the temperature graph used to determine when the unit has reached a stable condition.

Once stable conditions have been established the Data point tab may be clicked and the Record button clicked to record and display a captured data point.

Note that data may be sent to a printer (If a printer is connected) if required. The option of Raw (end results not calculated) or Calculated data may be selected for the printing option. The results shown in the table are updated each time the record button is clicked. NOTE that if no changes are made to the H100B settings of flow rate and hot stream temperature the captured results will all be similar.

The software should be utilised to automate the data recording procedures detailed as follows in the manual procedure.

Monitor the stream temperatures and the hot and cold flow rates to ensure these remain close to the original setting. Then record the following:

T1, T2, T3, T4, V_{hot} and V_{cold}

Repeat the above procedure with the hot water temperature controller set to 50°, 60° and 70° C.
If the optional Computer Interface HC100 and software is being used:
All of the observations may be carried out without leaving the experiment 6 Recording data screens. The water flow rate tab and temperature tabs should be used to check the required flow rates and temperature stability and the Recording data procedures used to collect each data point.

This completes the Co-current observation procedures

If the optional Computer Interface HC100 and software is being used then the user can return to the H100B Plate Heat Exchanger Main Menu by clicking the End and Back keys.
Once back at the main menu the user can opt to record more data in another experiment on the same heat exchanger or review the data recorded during the preceding experiment. Alternatively the user can return to the H100 Main Menu by continuing to click the Back key and the select to use another optional heat exchanger if available

OBSERVATIONS
Flow Direction: Counter-Current

Sample No.	T1	T2	T3	T4	V_{hot}	V_{cold}
----	°C	°C	°C	°C	L min^{-1}	L min^{-1}
1	39.3	31.1	15.0	28.1	2.01	1.07
2	49.8	38.2	15.1	33.6	2.01	1.07
3	58.6	43.7	15.0	38.6	2.01	1.07
4	59.9	44.5	15.1	38.8	2.01	1.06
5						

Calculated Data

Sample No.	Δt_{hot}	Δt_{cold}	$\dot{Q}$ e	$\dot{Q}$ a	η_{Cold}	η_{Hot}	η_{Mean}
---	K	K	W	W	%	%	%
1	8.2	13.1	1141	975	53.9	33.7	43.8
2	11.6	18.5	1609	1375	53.3	33.4	43.4
3	14.9	23.6	2102	1753	54.1	34.2	44.2
4	15.4	23.7	2130	1744	52.9	34.4	43.6
5							

Sample No.	LMTD	U
---	K	$W\ m^2K^{-1}$
1	13.5	2223
2	19.4	2177
3	24.1	2296
4	25.0	2240
5		

If the optional Computer Interface HC100 and software is being used then it will be seen that the tabular displays are similar to those used on screen.
Similar observations may be obtained for the Co-current configuration. The calculation procedures are shown below.

CALCULATIONS

Counter-Current Flow
For sample No 1 above:
It is necessary to convert the volume flow rates to mass flow rates using the conversion factors in table 1 and 2 on page B9. The water density ρ(kg litre^{-1}) and specific heat capacity Cp (kJ kg^{-1} K^{-1}) is dependant upon the temperature and the mean fluid temperature Tmean

$$T_{mean} = \frac{T_{inlet} + T_{outlet}}{2}$$

Is used to calculate the relevant temperature of the Hot stream.
For the Hot stream:
T_{mean} = (39.3 + 31.1) / 2 = 35.2 °C
From table 1 and 2 at T_{mean} = 35.2 °C

ρ_{hot} = 0.994 kg litre^{-1}
Cp = 4.180 kJ kg^{-1} k^{-1}

Hence the power emitted from the hot stream $\dot{Q}$ e

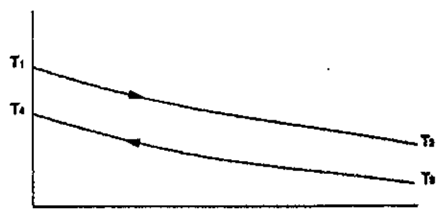
$$\dot{Q}e = \frac{V_{hot}}{60}\ \rho_{hot}\ Cp_{Hot}\left(T1 - T2\right) \times 1000 \quad \text{Watts}$$

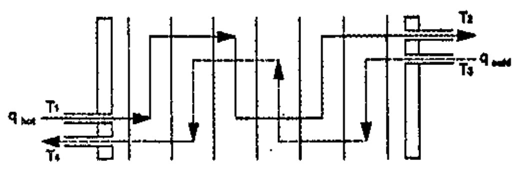
$$= \frac{2.01}{60} \times 0.994 \times 4.180 \times \left(39.3 - 31.1\right) \times 1000$$

$$= 1141 \text{ Watts}$$

A useful measure of the heat exchanger performance is the temperature efficiency.

The temperature change in each stream (hot and cold) is compared with the maximum temperature difference between the two streams. This could only occur in a perfect heat exchanger of infinite size with no external losses or gains.





COUNTER-CURRENT OPERATION

The temperature efficiency of the hot stream from the above diagram

$$\eta_{Hot} = \frac{T1 - T2}{T1 - T3} \times 100\%$$
$$= \frac{39.3 - 31.1}{39.3 - 15.0} \times 100\%$$
$$= 33.7\%$$

The temperature efficiency of the cold stream from the above diagram

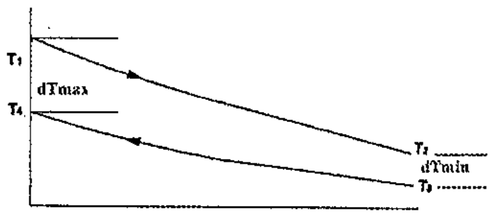
$$\eta_{Cold} = \frac{T4 - T3}{T1 - T3} \times 100\%$$
$$= \frac{28.1 - 15.0}{39.3 - 15.0} \times 100\%$$
$$= 53.9\%$$

The mean temperature efficiency

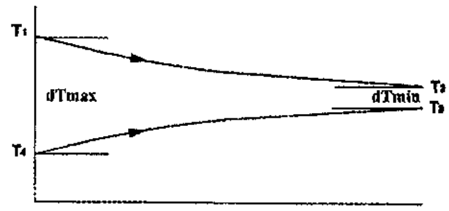
$$\eta_{Mean} = \frac{\eta_{Hot} + \eta_{Cold}}{2}$$
$$= \frac{33.7 + 53.9}{2}$$
$$= 43.8\%$$

As the temperature difference between the hot and cold fluids vary along the length of the heat exchanger it is necessary to derive a suitable mean temperature difference that may be used in heat transfer calculations. These calculations are not only of relevance in experimental procedures but also more importantly to be used in the design of heat exchangers to perform a particular duty.

The derivation and application of the Logarithmic Mean temperature Difference (LMTD) may be found in most thermodynamics and heat transfer text books.



Countercurrent operation



Cocurrent operation

The LMTD is defined as

$$LMTD = \frac{dTmax - dTmin}{\ln\left(\frac{dTmax}{dTmin}\right)}$$

Hence from the above diagrams of temperature distribution

$$LMTD = \frac{(T1 - T4) - (T2 - T3)}{\ln\left(\frac{(T1 - T4)}{(T2 - T3)}\right)}$$

Note that as the temperature measurement points are fixed on the heat exchanger the LMTD is the same formula for both Counter-current flow and Co-current flow.

Hence for the Counter-current example

$$\begin{aligned} LMTD &= \frac{(39.3 - 28.1) - (31.1 - 15.0)}{\ln\left(\frac{(39.3 - 28.1)}{(31.1 - 15.0)}\right)} \\ &= \frac{-4.9}{\ln(0.6956)} \\ &= \frac{-4.9}{-0.3629} \\ &= 13.5\,K \end{aligned}$$

The flow through the plate heat exchanger is not consistently either counter-current or co-current due to the nature of the plate arrangement and the flow passages. Therefore a correction factor F must be applied to the overall heat transfer coefficient as follows:

$$U = \frac{\dot{Q}_e}{A \times LMTD \times F}$$

Where

A	Heat transfer area of heat exchanger (m^2)
$\dot{Q}$ e	Heat emitted from hot stream (Watts)
LMTD	Logarithmic mean temperature difference (K)
F	Correction factor (Non-dimensional)

For the Hilton plate heat exchanger the factor F is 0.95

When applying the equations to a typical industrial heat exchanger the appropriate factor should be obtained from the manufacturer's data sheets.

The heat transfer area A may be calculated from:-

$$A = N \times a$$

Where

N	Number of plates with hot AND cold fluid on opposing faces (Non-dimensional)
a	Projected heat transfer area of each plate (m^2)

Note that 7 pressed plates are installed between the end plates only the central 5 plates have hot AND cold fluid on opposing faces and therefore contribute to the heat transfer process.
Therefore N= 5 for the plate heat exchanger.
Hence for the heat exchanger from the **USEFUL DATA** section on page B9.

$$\begin{aligned} A &= N \times a \\ &= 5 \times 0.008 \\ &= 0.04\,m^2 \end{aligned}$$

Hence for the test conditions the overall heat transfer coefficient:-

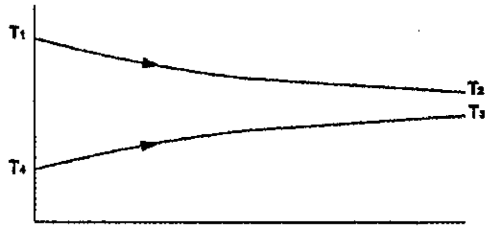
$$U = \frac{\dot{Q}_e}{A \times LMTD \times F}$$

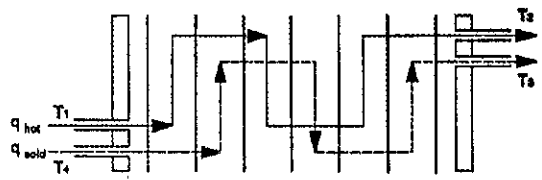
$$= \frac{1800}{0.04 \times 13.5 \times 0.95}$$

$$= 2223\ Wm^{-2}K^{-1}$$

Co-Current Flow

For the co-current flow system the calculation procedure is similar but the formulae are as follows





CO-CURRENT PIPE OPERATION

The power emitted from the hot stream $\dot{Q}\,e$

$$\dot{Q}e = \frac{V_{hot}}{60}\ \rho_{hot}\ Cp_{Hot}\left(T1 - T2\right) \times 1000 \quad \text{Watts}$$

The temperature efficiency of the hot stream from the above diagram

$$\eta_{Hot} = \frac{T1 - T2}{T1 - T4} \times 100\%$$

The temperature efficiency of the cold stream from the above diagram

The mean temperature efficiency

$$\eta_{Cold} = \frac{T3 - T4}{T1 - T4} \times 100\%$$

$$\eta_{Mean} = \frac{\eta_{Hot} + \eta_{Cold}}{2}$$

The logarithmic mean temperature difference LMTD

$$LMTD = \frac{(T1 - T4) - (T2 - T3)}{\ln\left(\frac{(T1 - T4)}{(T2 - T3)}\right)}$$

The Overall heat transfer coefficient U

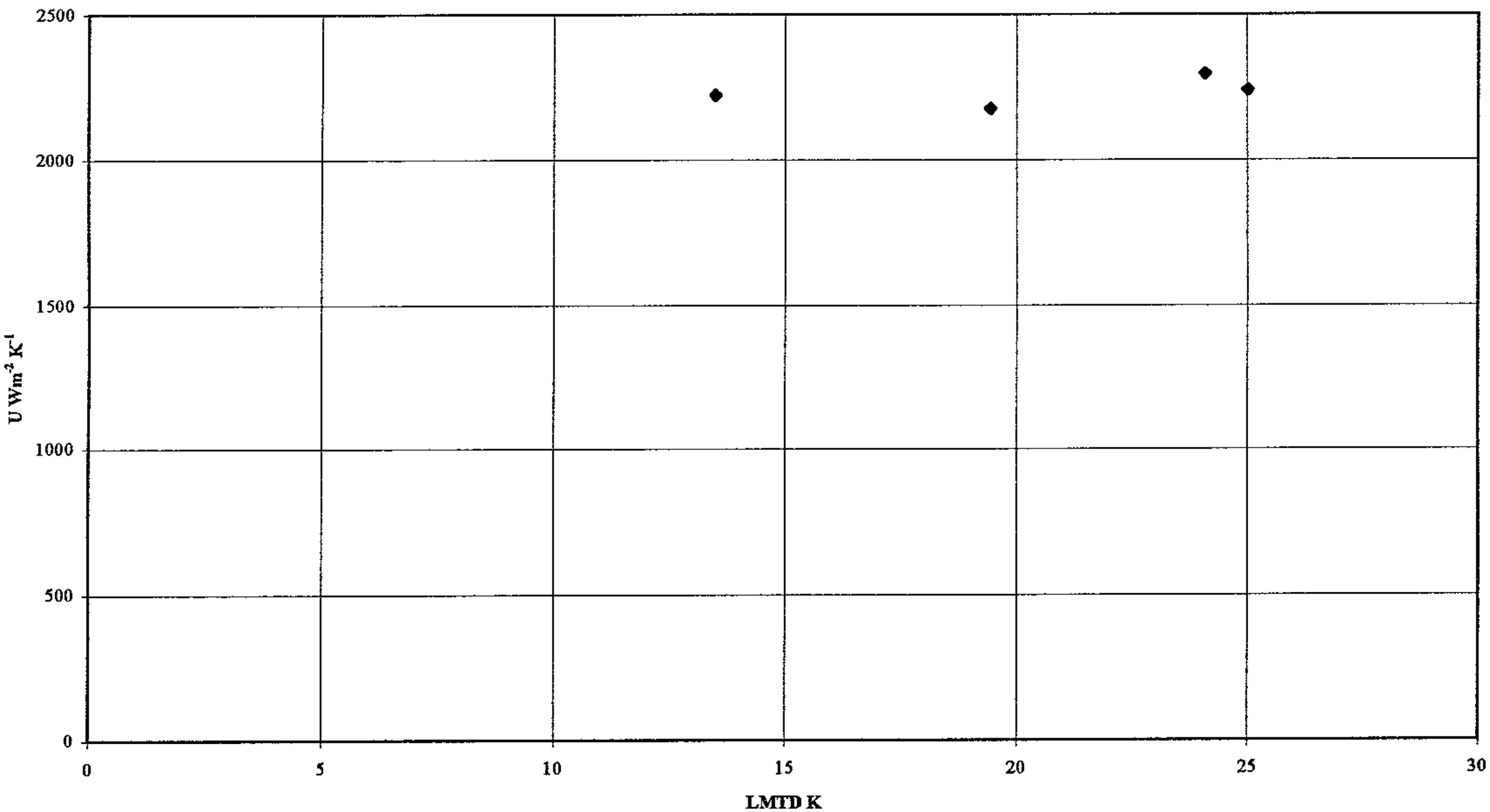
$$U = \frac{\dot{Q}_e}{A \times LMTD \times F}$$

In order to visualise the effect of temperature difference on the overall heat transfer coefficient the calculated data may be plotted against logarithmic mean temperature difference.
An example of this is given on page B52 for the Counter-current flow configuration.

If the optional Computer Interface HC100 and software is being used then the user can return to the H100B Plate Heat Exchanger Main Menu by clicking the End and Back keys.
Once back at the main menu the user can opt to record more data in another experiment on the same heat exchanger or review the data recorded during the preceding experiment. Alternatively the user can return to the H100 Main Menu by continuing to click the Back key and the select to use another optional heat exchanger if available.

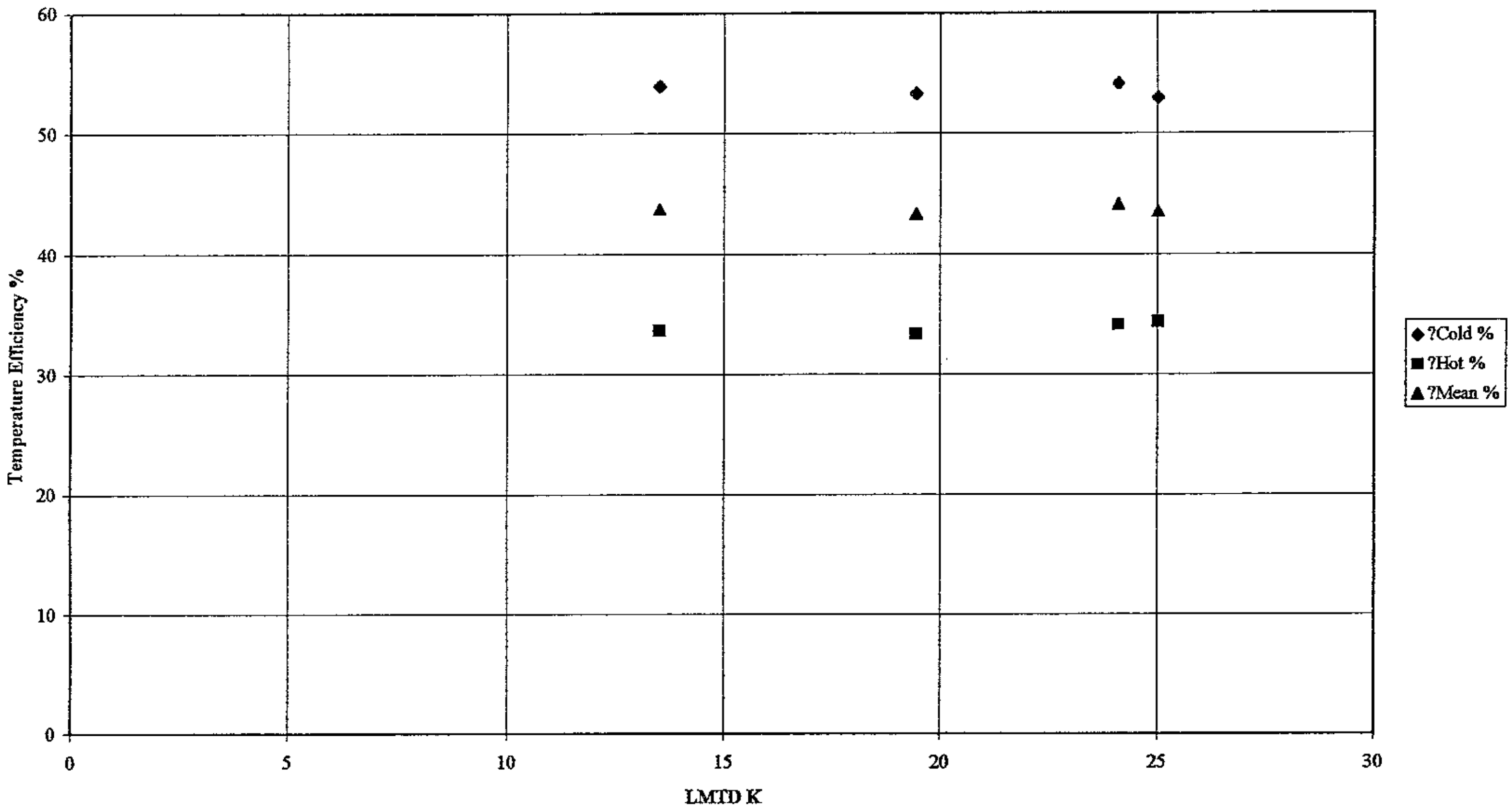
Example Data

Overall Heat Transfer Coefficient v Logarithmic Mean temperature Difference For a Plate Heat Exchanger H100B



B52

Temperature Efficiencies v Logarithmic Mean Temperature Difference For a Plate Heat Exchanger



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