EXPERIMENTAL

OPERATING

AND

MAINTENANCE PROCEDURES

OPTIONAL JACKETED VESSEL WITH COIL AND STIRRER

H100D

(i)

This page is intentionally blank

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	Vessel Contents temperature	°C
T2	Hot fluid into jacket temperature	°C
T3	Hot fluid out of jacket temperature	°C
T4	Hot fluid into coil temperature	°C
T5	Hot fluid out of coil temperature	°C
T6	Cold fluid into vessel 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
H	Overflow height above floor of vessel	m
di	Inside diameter of vessel wall	m
do	Outside diameter of vessel wall	m
dmean	Mean diameter	m
V	Volume	m^3
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
A	Heat transfer surface area	m^2
U	Overall heat transfer coefficient	Wm^{-2}K^{-1}
$\eta_{Thermal}$	Thermal efficiency	%
$d_{coil}i$	Submerged coil tube inside diameter	m
$d_{coil}o$	Submerged coil tube outside diameter	m
$d_{coil}m$	Submerged coil tube mean diameter	m
L	Submerged coil tube effective length	m
dTmax	Maximum temperature difference across heat exchanger	K
dTmin	Minimum temperature difference across heat exchanger	K

FIGURE D1

View From
Above

T3

Side View

T1

Front View

T6

T4   T5

JACKETED VESSEL WITH COIL
AND STIRRER H100D

Figure D2

COLD WATER SUPPLY

DRAIN

Vreg

Vcold

Vhot

T1

T6
Cold
In

T2
Hot
In

T3
Hot
Out
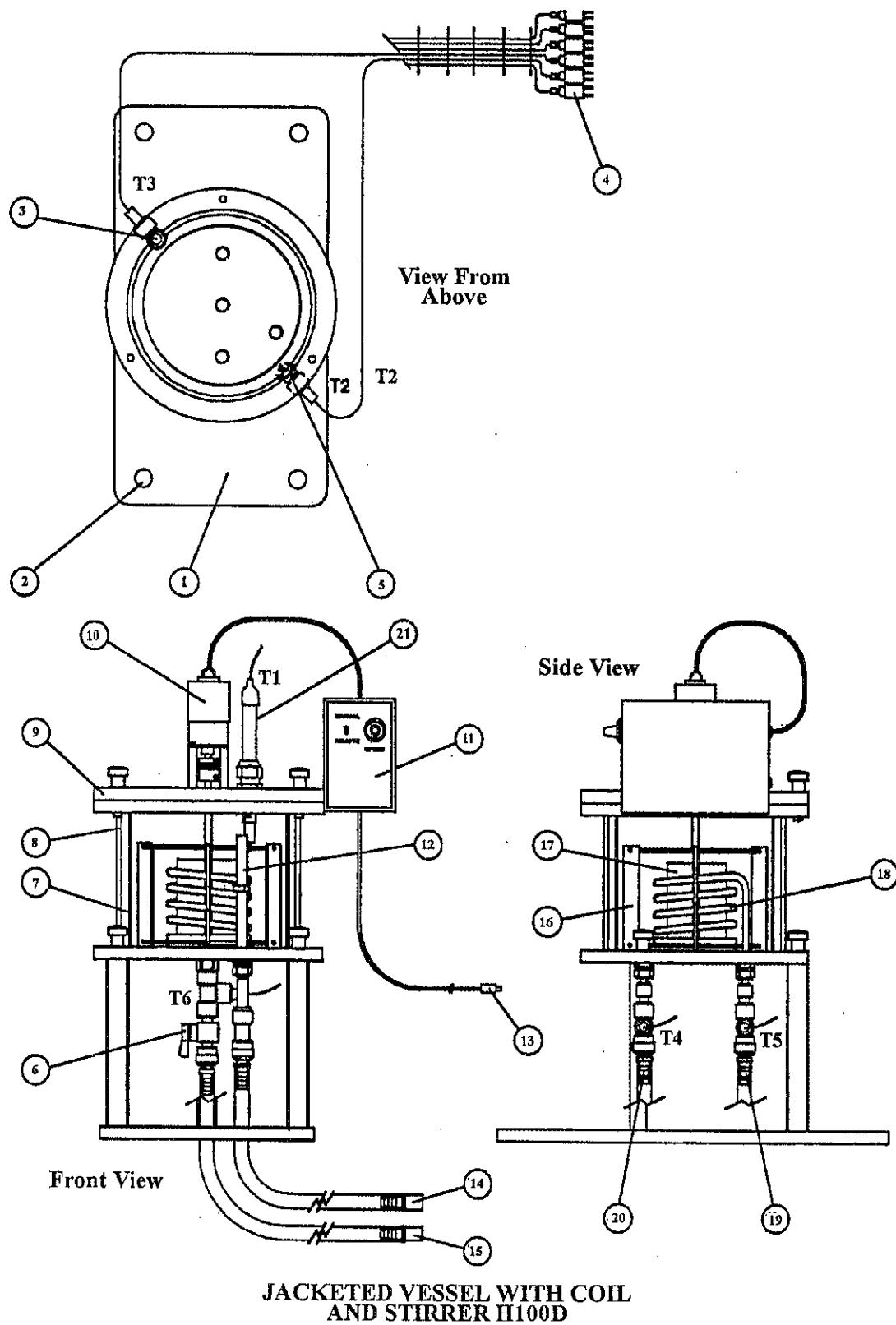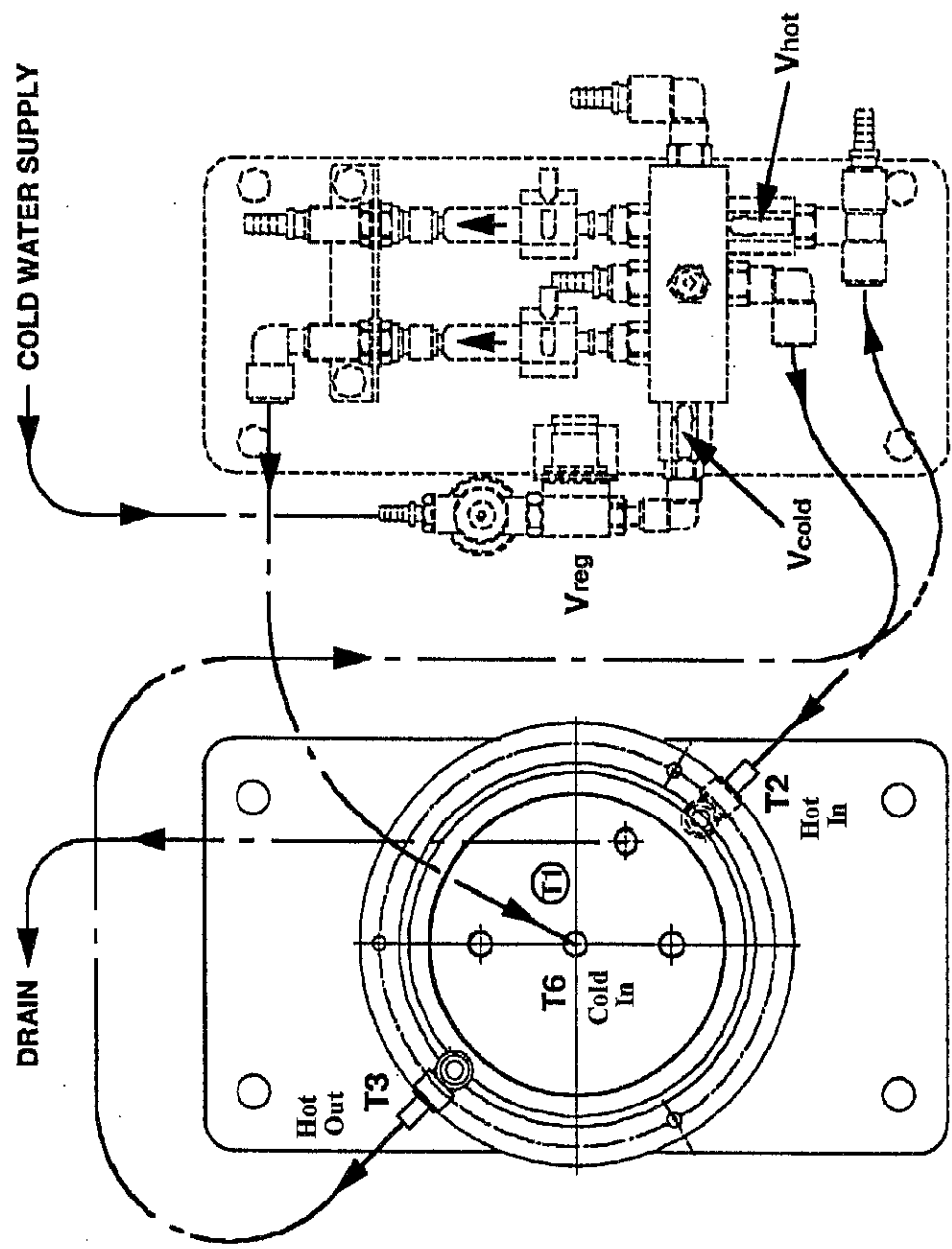
JACKETED VESSEL H100D
(Connected For Operation Using the Jacket)

Figure D3

COLD WATER SUPPLY

DRAIN

Hot
Out

Cold T6
In

T5

T4

Hot
In

Vreg

Vcold

Vhot
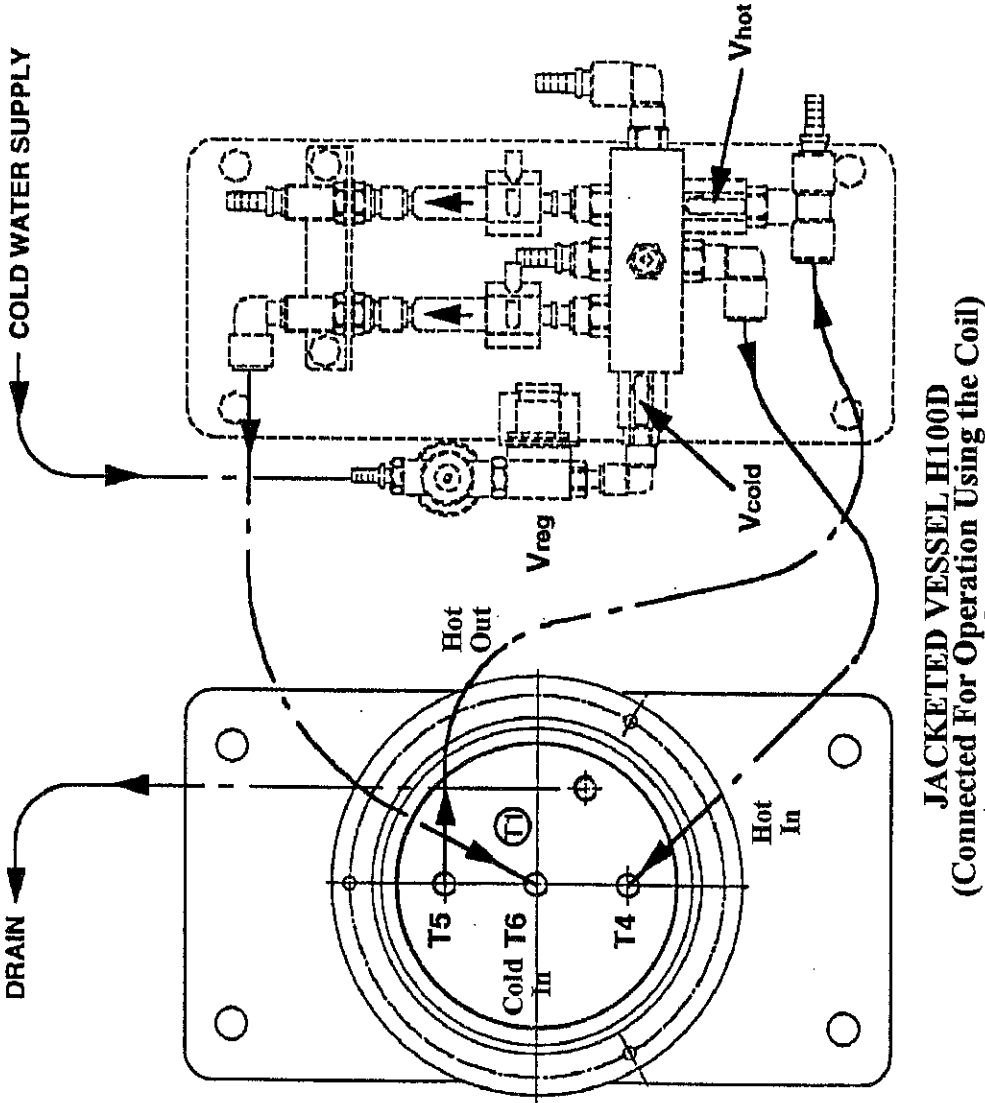
JACKETED VESSEL H100D
(Connected For Operation Using the Coil)

DESCRIPTION
JACKETED VESSEL WITH COIL AND STIRRER H100 D
(Figure Notation)

In this section of the manual figures are referenced with "D" prefix to identify them as relating to the H100 "D" unit. For example Figure **D1** on page D1. Numbered items on the figures are referenced as follows **D1(2)** , this refers to Item 2 (The mounting holes) on the base board of Figure **D1** on page D1. This follows the similar procedure used in the main manual.

Please refer to figure D1 on page D1.
Heating or cooling of process liquid within a stirred tank or vessel is common throughout industry. The fluid may be heated as a batch (a fixed volume) or as a flow process depending upon the processes occurring in the vessel.
The heating or cooling fluid may be brought into contact with the process material by having a hollow jacket surrounding the vessel through which the heating or cooling material passes. This allows the vessel to be easily cleaned after each batch is removed.
Alternatively a coil may be immersed within the vessel and the heating or cooling medium passed through this.

The H100D Jacketed Vessel with Coil and Stirrer allows batch and flow processes to be examined with and without the use of a stirrer. In addition both jacket and coil heating methods may be investigated.

The H100D 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 **D1(1)** which incorporates four mounting holes **C1(2)**. These locate on studs on the base unit and are secured with knurled nuts.

The vessel consists of a stainless steel cylinder **D1(7)** with a PVC base and clear acrylic top ring. A larger heat resistant glass cylinder **D1(8)** surrounds the stainless steel cylinder forming an annular jacket . Seals at the top and bottom of the glass and stainless steel cylinders allow the annular space to be filled with hot fluid for indirect heating of the vessel contents.

Alternatively a stainless steel coil **D1(18)** submerged beneath the contents of the vessel may be used to indirectly heat the contents by passing hot fluid through the coil.

An adjustable overflow pipe **D1(12)** allows the level of the contents of the vessel to be controlled and hence the contained volume to be adjusted between approximately 1 and 2 litres. The vessel can be operated in a fixed volume mode by simply filling to the top of the overflow pipe. Alternatively the vessel may be operated in a flow situation by continuously feeding water to the vessel and allowing the excess to flow through the overflow pipe.

A height adjustable temperature sensor **D1(21)** allows the temperature T1 at any depth in the fluid batch to be measured.

Flexible hoses allow the hot and cold streams from the base unit to be coupled to the jacket, the coil and the vessel.

When using the outer jacket to heat the vessel the connections are as follows:-
Refer to Figure D1 on page D1 and D2 on page D2.
Hot water inlet to the bottom of the jacket **D1(5)** adjacent to temperature sensor T2
Hot water outlet from the top of the jacket **D1(3)** adjacent to temperature sensor T3
Cold water inlet to bottom of the vessel **D1(15)** adjacent to temperature sensor T6
Cold water outlet from liquid surface **D1(14)** via adjustable overflow **D1(12)**

When using the submerged coil to heat the vessel contents the connections are as follows:-
Refer to Figure D1 on page D1 and D3 on page D2.
Hot water inlet to the bottom of the coil **D1(20)** adjacent to temperature sensor T4
Hot water outlet from the top of the coil **D1(19)** adjacent to temperature sensor T5
Cold water inlet to bottom of the vessel **D1(15)** adjacent to temperature sensor T6
Cold water outlet from liquid surface **D1(14)** via adjustable overflow **D1(12)**

The six thermocouple sensor points are labelled T1 to T6 on Figure D1 and each lead is terminated with a miniature thermocouple plug **D1(4)** designed to be plugged into the six 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 sockets on the Heat Exchanger Service Unit H100 are colour coded **RED for Hot Water** and **BLUE for Cold Water**.

The vessel incorporates a variable speed stirrer **D1(17)** and baffle arrangement to allow thorough mixing of the vessel contents as required . The drive motor **D1(10)** is connected directly to the stirrer paddle via a flexible coupling. The speed of the motor is varied by adjustment of the potentiometer on the front of the speed controller **D1(11)** with the selector switch set to the "manual" position.

Temperatures are measured using K type thermocouples at the following locations.

Vessel contents (adjustable depth)	T1
Hot fluid inlet to jacket	T2
Hot fluid outlet from jacket	T3
Hot fluid inlet to coil	T4
Hot fluid outlet from coil	T5
Cold fluid inlet to vessel	T6

INSTALLATION
Jacketed Vessel with Coil and Stirrer H100D
Refer to Figure D1 on page D1, Figure D2 on page D2, Figure D3 on page D3.

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. Locate the base D1(1) of the heat exchanger onto the studs on the base unit in the orientation shown in Figure D2 or D3 relative to the valve plate. Secure the base plate with the knurled nuts provided.

Temperature Sensors
Each of the six 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 main manual. Note that the plugs have pins of different widths to ensure correct orientation.

The temperature of vessel contents is measured by a thermocouple T1 on an adjustable rod **D1(21)**. This should be adjusted in conjunction with the overflow **D1(12)** so that the thermocouple is approximately 10 – 15mm below the water surface. As the vessel is stirred thermocouple is most likely to measure the bulk fluid temperature in this position.

Hot Water Circuit Using the Outer Jacket
Refer to Figure D1 on page D1 and Figure D2 on page D2.

Hot Water Inlet
Connect the flexible tube **D1(5)** from the base of the outer jacket (adjacent to sensor T2) to the hot water outlet socket shown in Figure C2 and fitted with a red collar.

Hot Water outlet
Connect the flexible tube **D1(3)** from the top of the outer jacket (adjacent to sensor T3) to the hot water return socket shown in Figure C2 and fitted with a red collar.

Hot Water Circuit Using the Submerged Coil
Refer to Figure D1 on page D1 and Figure D3 on page D3.

Hot water Inlet
Connect the flexible tube **D1(20)** from the base of the submerged coil (adjacent to sensor T4) to the hot water outlet socket shown in Figure C2 and fitted with a red collar.

Hot Water outlet
Connect the flexible tube **D1(19)** from the base of the submerged coil (adjacent to sensor T5) to the hot water return socket shown in Figure C2 and fitted with a red collar.

Cold Water Circuit
Refer to Figure D1 on page D1, D2 on page D2 and D3 on page D3.

The connection of the cold water circuit is common for all experiments. However in the case of batch (fixed volume) experiments the cold water flow is zero and the cold water source is only used to fill the vessel to the desired volume. The volume is controlled by the height of the adjustable overflow **D1(12)**. The valve D1(6) may be used to admit the necessary volume of water to the vessel and then closed to retain the volume.

Cold Water inlet
Connect the flexible tube **D1(15)** from the underside of the vessel (adjacent to sensor T6) to the cold water outlet connector shown in Figure D2 and D3 and fitted with a blue collar.

Cold Water Outlet
Connect the flexible tube **D1(14)** from the adjustable overflow **D1(12)** to the drain hose provided using the adapter provided. **The drain hose should be arranged so that it travels in a continuously downward direction to the drain. If any U shaped bends or kinks are formed in the drain tube then an air lock will result and the vessel will overflow.**

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
JACKETED VESSEL WITH COIL AND STIRRER H100D

Vessel wall inside diameter	0.1524m
Vessel wall outside diameter	0.1542m
Coil tube outside diameter	0.0063m
Coil tube bore diameter	0.0049m
Effective length of coil tube	1.15m

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 $Cp = 6 \times 10^{-9} t^4 - 1.0 \times 10^{-6} t^3 + 7.0487 \times 10^{-5} t^2 - 2.4403 \times 10^{-3} t + 4.2113$
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 $\rho = -4.582 \times 10^{-6}\, t^2 - 4.0007 \times 10^{-5}\, t + 1.004$
may be used if the data is to be calculated using a spreadsheet.

CAPABILITIES OF THE SHELL AND TUBE HEAT EXCHANGER H100D 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 investigate the heating characteristics of a stirred vessel containing a fixed batch of liquid when heated using hot fluid circulating through a submerged coil.

3. To investigate the heating characteristics of a stirred vessel containing a fixed batch of liquid when heated using hot fluid circulating through an outer jacket.

4. To investigate the change in overall heat transfer coefficient and logarithmic mean temperature difference as a batch of fluid in the vessel changes temperature.

5. To perform an energy balance, calculate the overall efficiency and determine the overall heat transfer coefficient for a continuous flow in a stirred vessel when heated using a submerged coil.

6. To perform an energy balance, calculate the overall efficiency and determine the overall heat transfer coefficient for a continuous flow in a stirred vessel when heated using an outer jacket.

7. To investigate the effect of stirring on the heat transfer characteristics of a stirred vessel.

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).**

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

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
Refer to Figure D1 on page D1 and D2 page D2.
Install the Jacketed Vessel with Coil and Stirrer H100D as detailed in **INSTALLATION Jacketed Vessel with Coil and Stirrer H100D** on page D6 and connect the hot water circuit according to the instructions in **Hot Water Circuit Using the Outer Jacket** as detailed in the same section.

Adjust the overflow in the vessel to the **minimum height.** Open the drain valve at the base of the vessel **D1(6).**
Configure the cold water side of the system according to the **Cold Water Circuit** instructions in the same section.
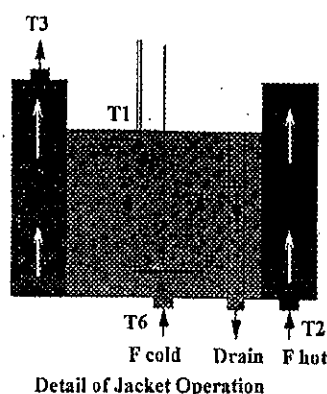
Follow the **OPERATING PROCEDURE** detailed in the main manual on page 16 onwards in order to establish the following operating conditions.

> 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 70°C and turn on the circulating pump.

Set the cold water flow rate V_{cold} to 0.5 litre min^{-1} and the hot water flow rate V_{hot} to approximately 2.0 litre min^{-1}.

Note that the vessel will first have to fill to the point where the water level reaches the top of the overflow. The unit will be operated with the cold water continuously flowing into the vessel and it is ESSENTIAL that the overflow and drain are free flowing to prevent the vessel overfilling and flooding. Examine the unit closely at the above cold water flow rate and ensure that the incoming flow and outgoing flow balance and the vessel level remains constant.

If the level tends to rise due to the limitations of the local drain or drain hose route it will be necessary

Detail of Jacket Operation

to adjust the drain to rectify the problem.
A schematic arrangement of the configuration is given in the diagram above.

Switch the stirrer control **D1(11)** to the manual position and adjust the speed control to maximum.

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 onwards 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^{TM} 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 H100D Jacketed Vessel** (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 H100D Jacketed Vessel 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.

H100D Jacketed Vessel Main Menu:

*This lists the optional experiments that may be carried out with the H100D Jacketed Vessel. 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.*

H100D Experiment Number 1:

Assuming that the above procedure is being 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.

*The Temperature and Data point screen also include a Stirrer% control. By switching the stirrer control **D1(11)** on the vessel to **Remote** the Stirrer% control on the computer screen may be used to remotely set the stirrer speed.*

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 H100D 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, T6, V_{hot} and V_{cold}

Then set the flow indicator to F_{cold} and adjust the cold water flow valve so that V_{cold} is approximately 1 litre min^{-1}. Maintain the Hot water flow rate at approximately 2.5 to 3.0 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	T6	V_{hot}	V_{cold}
----	°C	°C	°C	°C	L min^{-1}	L min^{-1}
1	32.5	70.2	64.2	14.1	2.0	0.52
2						
3						
4						
5						

Calculated Data

Sample No.	Δt_{hot}	Δt_{cold}
---	K	K
1	6.0	18.4

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

Δt hot $= T2 - T3$
$= 70.2 - 64.2$
$= 6.0 K$

Increase in Cold fluid temperature

Δt cold $= T1 - T6$
$= 32.5 - 14.1$
$= 18.4 K$

It can be seen that the increase in temperature of the cold stream is accompanied by a reduction in temperature of the hot stream. The effect of increasing the cold stream flow rate will be observed if the recommended tests are performed.

If time permits different combinations of hot and cold fluid flow rates may be compared

If the optional Computer Interface HC100 and software is being used then the user can return to the H100D jacketed Vessel 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 investigate the heating characteristics of a stirred vessel containing a fixed batch of liquid when heated using hot fluid circulating through a submerged coil

The following procedure investigates heat transfer to a stirred fixed volume of fluid when heated by a submerged coil. The procedure involves monitoring the temperature rise of the fixed volume with time and with a constant heating rate from the submerged coil.

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
Refer to Figure D1 on page D1 and D3 on page D3.
Install the Jacketed Vessel H100D as detailed in **INSTALLATION Jacketed Vessel with Coil and Stirrer H100D** on page D6 and connect the hot water circuit according to the instructions in **Hot Water Circuit Using the Submerged Coil** in the same section.

Adjust the overflow in the vessel to the maximum height and measure this height **H** (m) and record it for future reference. Do not fill the vessel at this stage.
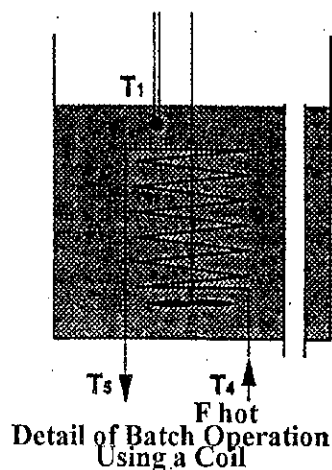
Follow the **OPERATING PROCEDURE** detailed in the main manual on page 16 onwards in order to establish the following operating conditions.

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 70°C and turn on the circulating pump.

Set the hot water flow rate V $_{hot}$ to 2. 0 litre/minute and allow the hot water circuit to reach the 70°C set point. Then turn off the circulating pump.

Open the valve at the base of the chamber **D1(6)** and slowly open the cold water valve to begin filling the vessel. When the water level reaches to top of the overflow pipe and just begins to overflow close the cold water valve. When the excess water has drained down the overflow close the valve **D1(6)** at the base of the vessel.
Switch the stirrer control **D1(11)** to the manual position and adjust the speed control to maximum.

Detail of Batch Operation
Using a Coil

A schematic arrangement of the configuration is given in the diagram above.
Record the temperature of the vessel contents T1 prior to starting the heating process.

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 **H100D Jacketed Vessel** (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 H100D jacketed Vessel 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.*

H100D jacketed Vessel Main Menu:

> *This lists the optional experiments that may be carried out with the H100D jacketed Vessel. To continue with the above experiment select 2, **To investigate the heating characteristics of a stirred vessel containing a fixed batch of liquid when heated using hot fluid circulating through a submerged coil** and then click OK.*

H100D Experiment Number 2:

> *Assuming that the above procedure is being followed 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 Numeric. The Flow graph may be used to set the hot stream flow rate to the desired value and to check that this remains constant.*
>
> *The Temperature and Numeric tabs allow data to be collected at a constant rate with respect to time. The Sample Interval has a default value that may be increased by the user. The user cannot set the value below the minimum as this limitation is set by the data capture hardware.*
>
> *The Temperature and Numeric screen also include a Stirrer% control. By switching the stirrer control D1(11) on the vessel to **Remote** the Stirrer% control on the computer screen may be used to remotely set the stirrer speed.*
>
> *On both the Temperature and Numeric screens when the operator clicks the Record Start button data will be recorded at the Sample interval (seconds) set by the user. The operator can start and stop the data capture if necessary but once started the sample interval is locked until the user finishes the experiment procedure. The Temperature screen gives a graphical representation of the data as it is collected and the Numerical screen gives the data in a tabular form.*

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

The procedure for collecting data is to record the temperatures

T1, T4, T5 and V_{hot}

at regular time intervals. The first reading should be taken before turning on the hot water circulating pump. There after the same readings should be taken at typically 30 second intervals.

If the optional Computer Interface HC100 and software is being used then start the Record procedure (in either the Numerical or Temperature screen) to allow the first data point to be recorded THEN turn on the hot water circulating pump. There after the data will be captured automatically at the set Sample Interval.

Continue recording data at the same interval until T1 the vessel contents reach a constant value.

If the optional Computer Interface HC100 and software is being used Stop the Record procedure when T1 the vessel contents reach a constant value. To return to the H100D Jacketed Vessel Main Menu click the End button on the Data capture screen.

The procedure may be repeated with the overflow set to maximum height and the new height H(m) recorded. Note that it will be necessary to drain and cool the vessel before repeating the experiment.

OBSERVATIONS

Heater in Use:- Submerged Coil
Stirrer Setting%:- 100%
Overflow Height (H) :- 0.060m

Sample No.	T1	T2	T3	T4	T5	T6	V_{hot}	V_{cold}
----	°C	°C	°C	°C	°C	°C	L min^{-1}	L min^{-1}
1	19.5	-	-	-	-		2.0	-
2	30.4			61.5	53.8		2.0	
3	40.5			62.5	57.3		2.0	
4	47.7			65.1	60.9		2.0	
5	53.6			68.5	65.0		2.0	
6	58.9			71.6	68.5		2.0	
7	63.3			73.4	71.0		2.0	
8	67.0			74.1	72.0		2.0	
9	69.1			73.9	73.0		2.0	
10	70.4			73.1	72.9		2.0	
11	71.2			72.3	72.6		2.0	
12								
13								
14								
15								
16								
17								
18								
19								
20								

Calculated Data

Sample No.	dT_{hot}
----	K
1	0.0
2	7.7
3	5.2
4	4.2
5	3.5
6	3.1
7	2.4
8	2.1
9	0.9
10	0.2
11	-0.3
12	
13	
14	
15	
16	
17	
18	
19	
20	

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.

The volume V of the water being heated can be calculated from

$$V = \frac{\left(\pi \times d^2_i\right) \times H}{4}$$

Where:-

V	Heated volume (m³)
d_i	Inside diameter of vessel (m)
H	Vertical height of overflow above vessel base (m)

For the vessel from the USEFUL data section on page D8
D_i 0.1524m
For the above test:
H   0.060m
Hence for the above example

$$V = \frac{\left(\pi \times 0.1524^2\right) \times 0.060}{4}$$

$$= 1.094 \times 10^{-3} \text{ m}^3$$

The temperature difference between the water entering the submerged coil and that leaving is simply

$$dT \text{ hot} = T4 - T5 \text{ K}$$

For the second reading above

$$dT\ hot\ =\ 61.5 - 53.8$$
$$=\ 7.7\ K$$

All of the data is calculated in a similar manner.

The calculated data may be presented in graphical form as shown in the following graph.

If the optional Computer Interface HC100 and software is being used then the user can return to the H100D jacketed Vessel 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.

Sample Data

Jacketed Vessel T1 and dT hot v Time for a fixed batch of 0.060m height (1.094 x 10^{-3} m^3)
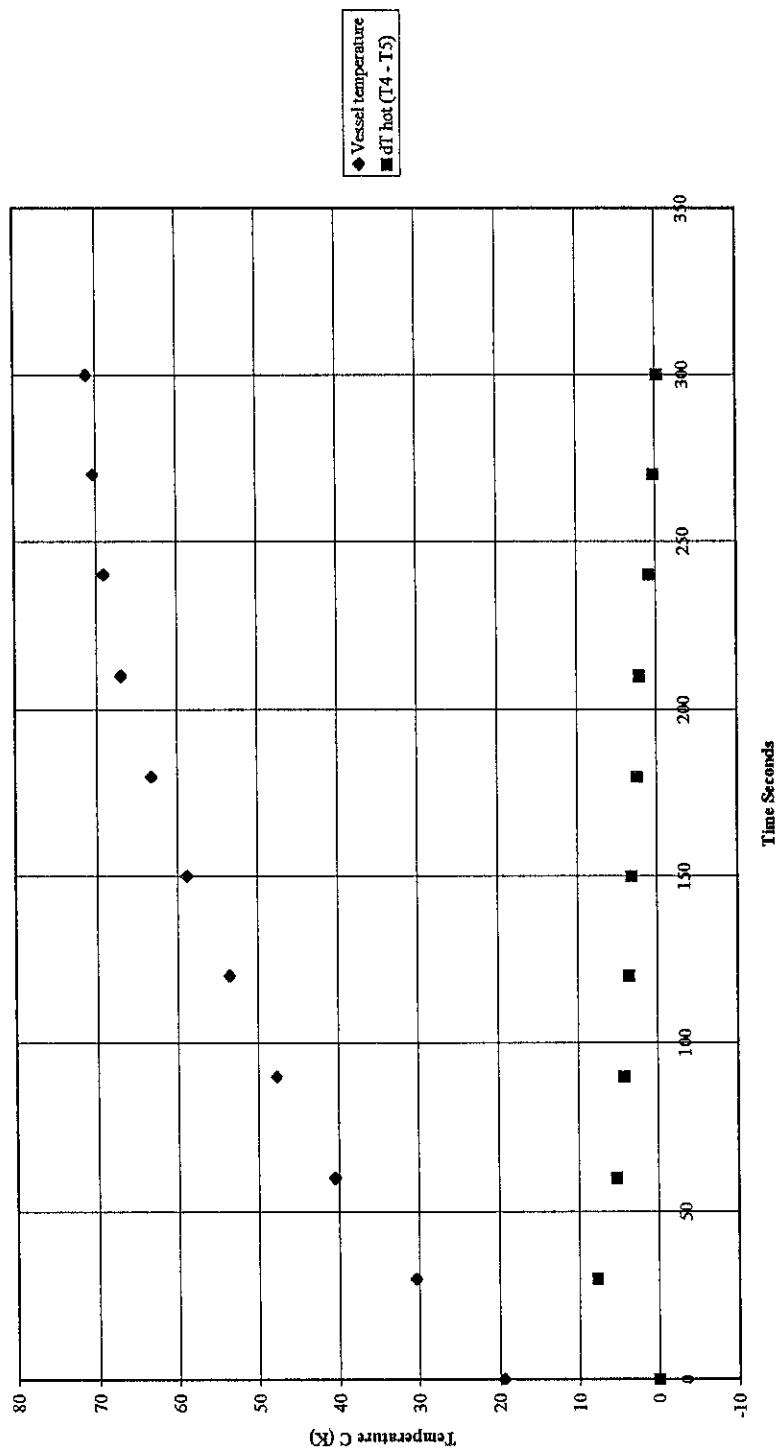
3. **To investigate the heating characteristics of a stirred vessel containing a fixed batch of liquid when heated using hot fluid circulating through an outer jacket**

The following procedure investigates heat transfer to a stirred fixed volume of fluid when heated by fluid flowing in an outer jacket. The procedure involves monitoring the temperature rise of the fixed volume with time and with a constant heating rate from the jacket.

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.

<u>Procedure</u>
Refer to Figure D1 on page D1 and D2 on page D2.
Install the Jacketed Vessel H100D as detailed in **INSTALLATION Jacketed Vessel with Coil and Stirrer H100D** on page D6 and connect the hot water circuit according to the instructions in **Hot Water Circuit Using the Outer Jacket** in the same section.

Adjust the overflow in the vessel to the minimum height and measure this height **H** (m) and record it for future reference. Do not fill the vessel at this stage.
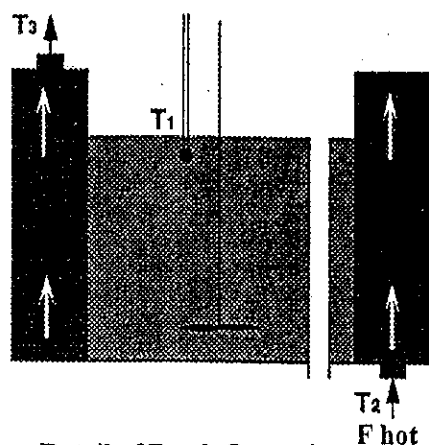
Follow the **OPERATING PROCEDURE** detailed in the main manual on page 16 onwards in order to establish the following operating conditions.

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 70°C and turn on the circulating pump.

Set the hot water flow rate V $_{hot}$ to 2. 0 litre/minute and allow the hot water circuit to reach the 70°C set point. Then turn off the circulating pump.

Open the valve at the base of the chamber **D1(6)** and slowly open the cold water valve to begin filling the vessel. When the water level reaches to top of the overflow pipe and just begins to overflow close the cold water valve. When the excess water has drained down the overflow close the valve **D1(6)** at the base of the vessel.
Switch the stirrer control **D1(11)** to the manual position and adjust the speed control to maximum.

Detail of Batch Operation
Using the Jacket

A schematic arrangement of the configuration is given in the diagram above
Record the temperature of the vessel contents T1 prior to starting the heating process.

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^{TM} 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 **H100D Jacketed Vessel** (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 H100D jacketed Vessel 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.*

H100D jacketed Vessel Main Menu.

> *This lists the optional experiments that may be carried out with the H100D jacketed Vessel. To continue with the above experiment select 3. **To investigate the heating characteristics of a stirred vessel containing a fixed batch of liquid when heated using hot fluid circulating through an outer jacket** and then click OK.*

H100D Experiment Number 3:

> *Assuming that the above procedure is being followed 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 Numeric. The Flow graph may be used to set the hot stream flow rate to the desired value and to check that this remains constant.*
>
> *The Temperature and Numeric tabs allow data to be collected at a constant rate with respect to time. The Sample Interval has a default value that may be increased by the user. The user cannot set the value below the minimum as this limitation is set by the data capture hardware.*
>
> *The Temperature and Numeric screen also include a Stirrer% control. By switching the stirrer control **D1(11)** on the vessel to **Remote** the Stirrer% control on the computer screen may be used to remotely set the stirrer speed.*
>
> *The user will be required to enter the height H of the overflow pipe (in meters, m) that is being used for the experiment. The software will not proceed from this point until a positive value has been entered. Entry of an incorrect value will result in incorrect calculation of the jacket heat transfer surface area.*

On both the Temperature and Numeric screens when the operator clicks the Record Start button data will be recorded at the Sample interval (seconds) set by the user. The operator can start and stop the data capture if necessary but once started the sample interval is locked until the user finishes the experiment procedure. The Temperature screen gives a graphical representation of the data as it is collected and the Numerical screen gives the data in a tabular form.

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

The procedure for collecting data is to record the temperatures

T1, T2, T3 and V_{hot}

at regular time intervals. The first reading should be taken before turning on the hot water circulating pump. There after the same readings should be taken at typically 60 second intervals.

If the optional Computer Interface HC100 and software is being used then start the Record procedure (in either the Numerical or Temperature screen) to allow the first data point to be recorded THEN turn on the hot water circulating pump. There after the data will be captured automatically at the set Sample Interval.

Continue recording data at the same interval until T1 the vessel contents reach a constant value.

If the optional Computer Interface HC100 and software is being used Stop the Record procedure when T1 the vessel contents reach a constant value. To return to the H100D Jacketed Vessel Main Menu click the End button on the Data capture screen.

The procedure may be repeated with the overflow set to maximum height and the new height H(m) recorded. Note that it will be necessary to drain and cool the vessel before repeating the experiment.

OBSERVATIONS

Heater in Use:-   **Vessel Jacket**
Stirrer Setting%:-   **100%**
Overflow Height (H) :-   **0.060m**

Sample No.	T1	T2	T3	T4	T5	T6	V_{hot}	V_{cold}
----	°C	°C	°C	°C	°C	°C	L min⁻¹	L min⁻¹
1	17.5	-	-				0	
2	18.0	29.3	26.3				1.96	
3	20.1	39.8	36.0				2.0	
4	23.7	49.2	44.5				2.0	
5	28.4	57.8	52.6				2.02	
6	34.6	65.6	59.8				2.03	
7	41.2	72.6	66.7				2.02	
8	47.8	75.7	70.5				2.02	
9	53.6	76.1	72.2				2.03	
10	58.3	74.2	71.6				2.0	
11	61.5	73.2	71.2				2.04	
12	63.7	72.5	71.1				2.04	
13	65.4	72	71.1				2.05	
14	66.6	71.5	70.8				2.07	
15	67.4	71.3	70.8				2.07	
16	68.0	71.2	70.8				2.09	
17	68.4	70.6	70.2				2.09	
18	68.6	70.6	70.3				2.08	
19	68.9	70.8	70.5				2.06	
20	69.1	71.1	70.7				2.08	

Calculated Data

Sample No.	dT$_{hot}$
----	K
1	-
2	3
3	3.8
4	4.7
5	5.2
6	5.8
7	5.9
8	5.2
9	3.9
10	2.6
11	2
12	1.4
13	0.9
14	0.7
15	0.5
16	0.4
17	0.4
18	0.3
19	0.3
20	0.4

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 the calculations are as follows.

The volume V of the water being heated can be calculated from

$$V = \frac{(\pi \times d^2{}_i) \times H}{4}$$

Where:-

V   Heated volume (m^3)
d$_i$ Inside diameter of vessel (m)
H   Vertical height of overflow above vessel base (m)

For the vessel from the USEFUL data section on page D8.
d$_i$ 0.1524m
For the above test:
H   0.060m
Hence for the above example

$$V = \frac{(\pi \times 0.1524^2) \times 0.060}{4}$$
$$= 1.094 \times 10^{-3} \text{ m}^3$$

The temperature difference between the water entering the surrounding jacket and that leaving is simply
         dT hot   = T3 − T2   K

For the second reading above

$$dT \text{ hot} = 29.3 - 26.3$$

$$= 3.0 \text{ K}$$

All of the data is calculated in a similar manner.

The calculated data may be presented in graphical form as shown in the following graph.

If the optional Computer Interface HC100 and software is being used then the user can return to the H100D jacketed Vessel 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.

Sample Data

Jacketed Vessel T1 and dT hot v Time for a fixed batch 0f 0.060m height (1.094 x 10-3 m3) Heated Using The Surrounding Jacket
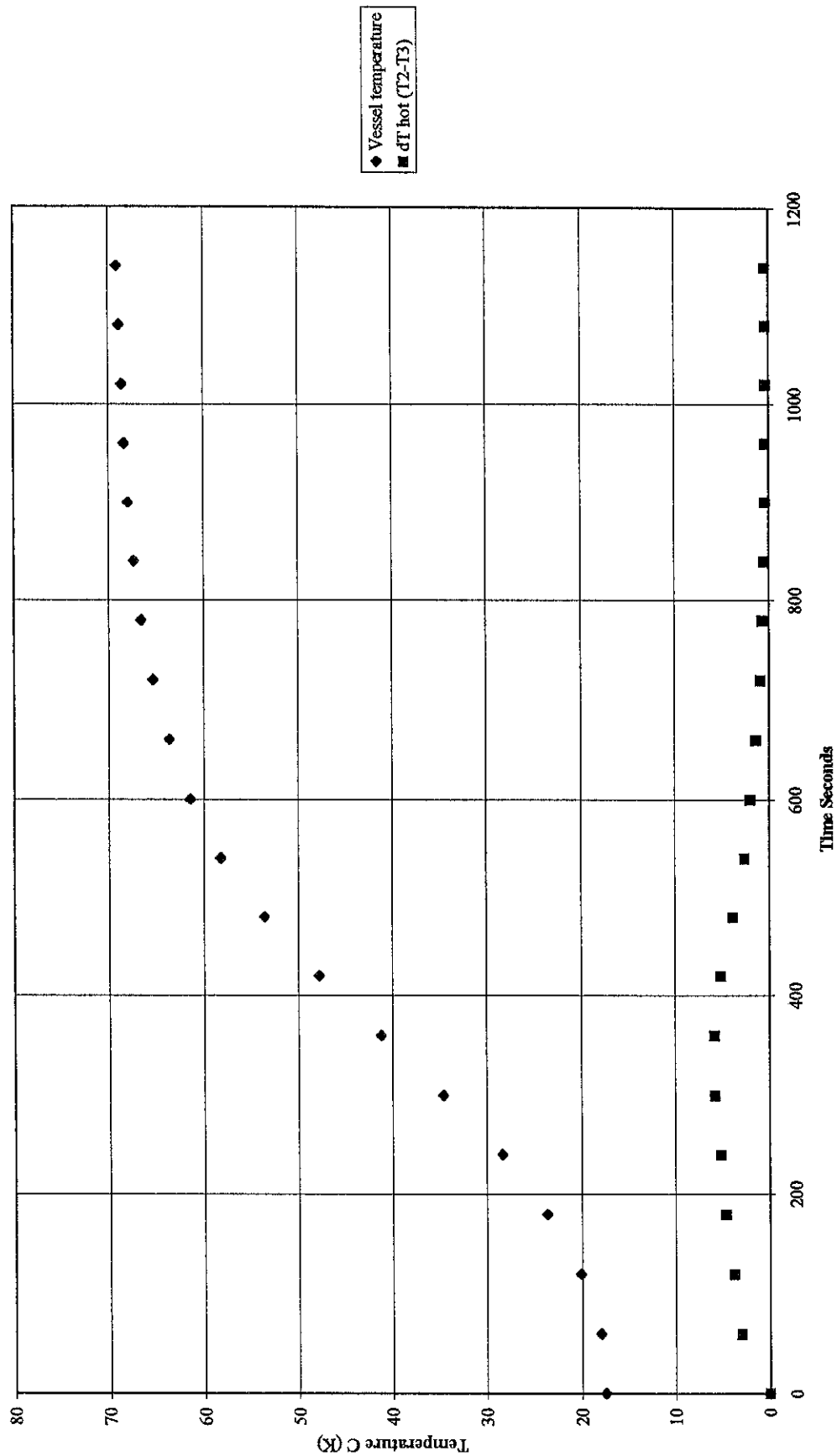
4. **To investigate the change in overall heat transfer coefficient and logarithmic mean temperature difference as a batch of fluid in the vessel changes temperature**

The following procedure examines how the overall heat transfer coefficient changes with time as a batch of liquid is heated. 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
Refer to Figure D1 on page d1 and D2 on page D2.
Install the Jacketed Vessel H100D as detailed in **INSTALLATION Jacketed Vessel with Coil and Stirrer H100D** on page d6 and connect the hot water circuit according to the instructions in **Hot Water Circuit Using the Outer Jacket** in the same section.

Adjust the overflow in the vessel to the minimum height and measure this height **H** (m) and record it for future reference. Do not fill the vessel at this stage.
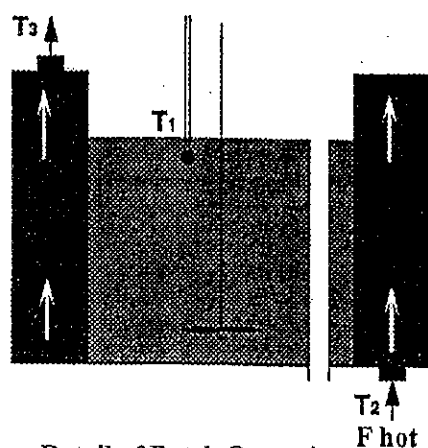
Follow the **OPERATING PROCEDURE** detailed in the main manual on page 16 onwards in order to establish the following operating conditions.

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 70°C and turn on the circulating pump.

Set the hot water flow rate V $_{hot}$ to 2. 0 litre/minute and allow the hot water circuit to reach the 70°C set point. Then turn off the circulating pump.

Open the valve at the base of the chamber D1(6) and slowly open the cold water valve to begin filling the vessel. When the water level reaches to top of the overflow pipe and just begins to overflow close the cold water valve. When the excess water has drained down the overflow close the valve D1(6) at the base of the vessel.
Switch the stirrer control D1(11) to the manual position and adjust the speed control to maximum.

Detail of Batch Operation
Using the Jacket

A schematic arrangement of the configuration is given in the diagram above.
Record the temperature of the vessel contents T1 prior to starting the heating process.

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 H100D Jacketed Vessel** (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 H100D jacketed Vessel 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.*

H100D jacketed Vessel Main Menu:

> *This lists the optional experiments that may be carried out with the H100D jacketed Vessel. To continue with the above experiment select 4. **To investigate the change in overall heat transfer coefficient and logarithmic mean temperature difference as a batch of fluid in the vessel changes temperature** and then click OK.*

H100D Experiment Number 4:

> *Assuming that the above procedure is being followed 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 Numeric. The Flow graph may be used to set the hot stream flow rate to the desired value and to check that this remains constant.*

> *The Temperature and Numeric tabs allow data to be collected at a constant rate with respect to time. The Sample Interval has a default value that may be increased by the user. The user cannot set the value below the minimum as this limitation is set by the data capture hardware.*

> *The Temperature and Numeric screen also include a Stirrer% control. By switching the stirrer control D1(11) on the vessel to **Remote** the Stirrer% control on the computer screen may be used to remotely set the stirrer speed.*

> *The user will be required to enter the height H of the overflow pipe (in meters, m) that is being used for the experiment. The software will not proceed from this point until a positive value has been entered. Entry of an incorrect value will result in incorrect calculation of the jacket heat transfer surface area.*

On both the Temperature and Numeric screens when the operator clicks the Record Start button data will be recorded at the Sample interval (seconds) set by the user. The operator can start and stop the data capture if necessary but once started the sample interval is locked until the user finishes the experiment procedure. The Temperature screen gives a graphical representation of the data as it is collected and the Numerical screen gives the data in a tabular form.

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

The procedure for collecting data is to record the temperatures

T1, T2, T3 and V_{hot}

at regular time intervals. The first reading should be taken before turning on the hot water circulating pump. There after the same readings should be taken at typically 60 second intervals.

If the optional Computer Interface HC100 and software is being used then start the Record procedure (in either the Numerical or Temperature screen) to allow the first data point to be recorded THEN turn on the hot water circulating pump. There after the data will be captured automatically at the set Sample Interval.

Continue recording data at the same interval until T1 the vessel contents reach a constant value.

If the optional Computer Interface HC100 and software is being used Stop the Record procedure when T1 the vessel contents reach a constant value. To return to the H100D Jacketed Vessel Main Menu click the End button on the Data capture screen.

The procedure may be repeated with the overflow set to maximum height and the new height H(m) recorded. Note that it will be necessary to drain and cool the vessel before repeating the experiment.

OBSERVATIONS

Heater in Use:-   **Vessel Jacket**
Stirrer Setting%:-   **100%**
Overflow Height (H) :-   **0.060m**

Sample No.	T1	T2	T3	T4	T5	T6	V_{hot}	V_{cold}
----	°C	°C	°C	°C	°C	°C	L min^{-1}	L min^{-1}
1	17.5	-	-				0	
2	18.0	29.3	26.3				1.96	
3	20.1	39.8	36.0				2.0	
4	23.7	49.2	44.5				2.0	
5	28.4	57.8	52.6				2.02	
6	34.6	65.6	59.8				2.03	
7	41.2	72.6	66.7				2.02	
8	47.8	75.7	70.5				2.02	
9	53.6	76.1	72.2				2.03	
10	58.3	74.2	71.6				2.0	
11	61.5	73.2	71.2				2.04	
12	63.7	72.5	71.1				2.04	
13	65.4	72	71.1				2.05	
14	66.6	71.5	70.8				2.07	
15	67.4	71.3	70.8				2.07	
16	68.0	71.2	70.8				2.09	
17	68.4	70.6	70.2				2.09	
18	68.6	70.6	70.3				2.08	
19	68.9	70.8	70.5				2.06	
20	69.1	71.1	70.7				2.08	

Calculated Data

Sample No.	dT$_{hot}$	$\dot{Q}$ e	LMTD	U
----	K	W	K	W m^{2}K^{-1}
1	-			
2	3	409.4	9.7	1457.2
3	3.8	527.1	17.7	1028.7
4	4.7	649.4	23.1	974.2
5	5.2	722.9	26.7	936.4
6	5.8	807.3	28.0	997.8
7	5.9	814.5	28.3	994.3
8	5.2	716.7	25.2	983.9
9	3.9	540.0	20.5	912.1
10	2.6	354.8	14.6	843.3
11	2	278.5	10.7	903.4
12	1.4	195.0	8.1	835.2
13	0.9	126.0	6.1	710.2
14	0.7	99.0	4.5	754.1
15	0.5	70.7	3.6	671.2
16	0.4	57.1	3.0	659.6
17	0.4	57.1	2.0	991.5
18	0.3	42.6	1.8	799.2
19	0.3	42.2	1.7	836.9
20	0.4	56.8	1.8	1097.1

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

The temperature difference between the water entering the surrounding jacket and that leaving is simply

$$dT \text{ hot } = T2 - T3 \text{ K}$$

For the Hot stream in sample No.5

$$dT \text{ hot } = 57.8 + 52.6$$

$$= 5.2 \text{ K}$$

It is necessary to convert the volume flow rates to mass flow rates using the conversion factors in table 1 and 2 on page D8. 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 of the Hot stream.

For the Hot stream in sample No 5:
$T_{mean} = (57.8 + 52.6) / 2 = 55.2 °C$
From table 1 and 2 at $T_{mean} = 55.2 °C$
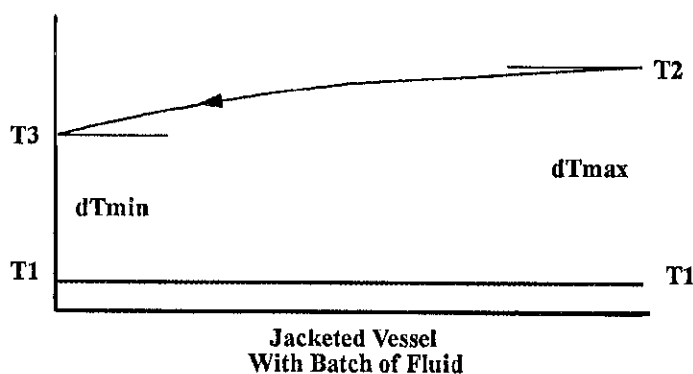
$$\rho_{hot} = 0.988 \text{ kg litre}^{-1}$$
$$Cp = 4.180 \text{ kJ kg}^{-1} \text{k}^{-1}$$

$$\dot{Q}e = \frac{V_{hot}}{60} \; \rho_{hot} \; Cp_{Hot} \left(T2 - T3\right) \times 1000 \quad \text{Watts}$$

$$= \frac{2.03}{60} \times 0.988 \times 4.180 \times \left(57.8 - 52.6\right) \times 1000$$

$$= 936 \; \text{Watts}$$

It can be assumed that at any instant in time the temperature of the batch of fluid in the vessel is uniform due to the high degree of mixing applied by the stirrer. However as the temperature difference between the hot and cold fluids varies across the height of the vessel jacket it is necessary to derive an average 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.

Jacketed Vessel
With Batch of Fluid

The LMTD is defined as

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

Hence from the above diagrams of temperature distribution

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

Hence for the example above:

$$LMTD = \frac{(57.8 - 28.4) - (52.6 - 28.4)}{\ln\left(\frac{(57.8 - 28.4)}{(52.6 - 28.4)}\right)}$$

$$= \frac{5.2}{\ln(1.215)}$$

$$= \frac{5.2}{0.1946}$$

$$= 26.7 \, K$$

In order to calculate the overall heat transfer coefficient the following parameters must be used with consistent units:-

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

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)

The heat transfer area may be calculated from:-

$$d_m = \frac{d_o + d_i}{2}$$

And

$$A = \pi \, d_m \, H$$

Where
do   Vessel wall outside diameter (m)
di   Vessel wall inside diameter (m)
dm   Vessel wall mean diameter (m)
H   Height of vessel contents (m)

Hence for the heat exchanger from the **USEFUL DATA** section on page D8.
And for the test conditions where H = 0.060m

$$d_m = \frac{0.1542 + 0.1524}{2}$$

$$= 0.1533 \, m$$

$$A = \pi \times 0.1533 \times 0.060$$

$$= 0.0289 \, m^2$$

Hence for the test conditions the overall heat transfer coefficient for sample No 5:-

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

$$= \frac{722.9}{0.0289 \times 26.7}$$

$$= 936.4 \, Wm^{-2}K^{-1}$$

Due to the changing conditions in the vessel as the batch heats up the LMTD will change with time as will the overall heat transfer coefficient.
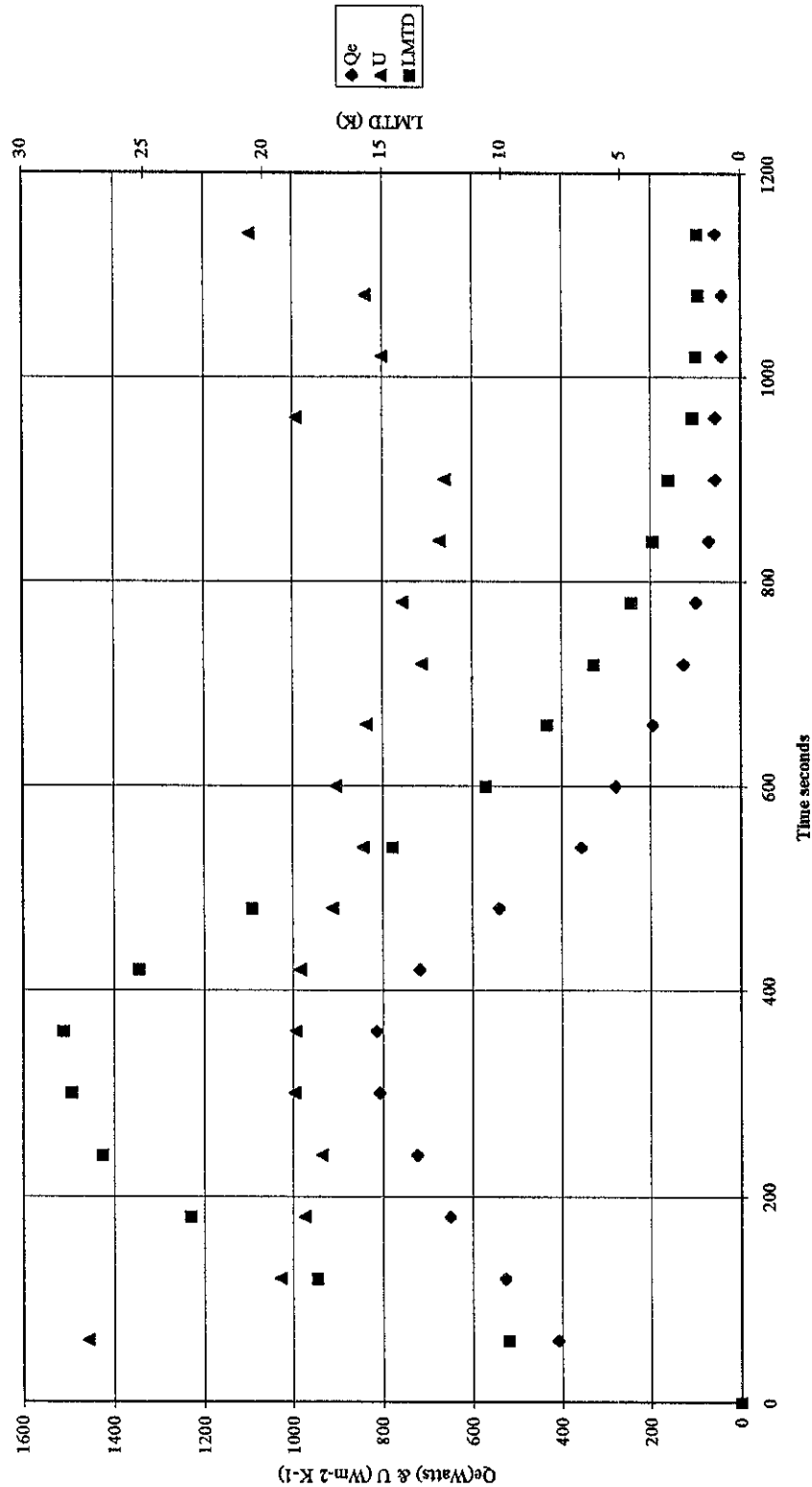
The above example is shown plotted against time as an example of typical performance.

If the optional Computer Interface HC100 and software is being used then the user can return to the H100D jacketed Vessel 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.

D34

Example Data

Variation of Heat emitted, LMTD and U (Overall Heat Transfer Coefficient) in a Stirred vessel batch with Time

5. **To perform an energy balance, calculate the overall efficiency and determine the overall heat transfer coefficient for a continuous flow in a stirred vessel when heated using a submerged coil**

The following procedure examines the heat transfer occurring in a stirred vessel in a flow situation when heated by a submerged coil.

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
Refer to Figure D1 on page D1 and D3 on page D3.
Install the Jacketed Vessel H100D as detailed in **INSTALLATION Jacketed Vessel with Coil and Stirrer H100D** on page D6 and connect the hot water circuit according to the instructions in **Hot Water Circuit Using the Submerged Coil** in the same section.

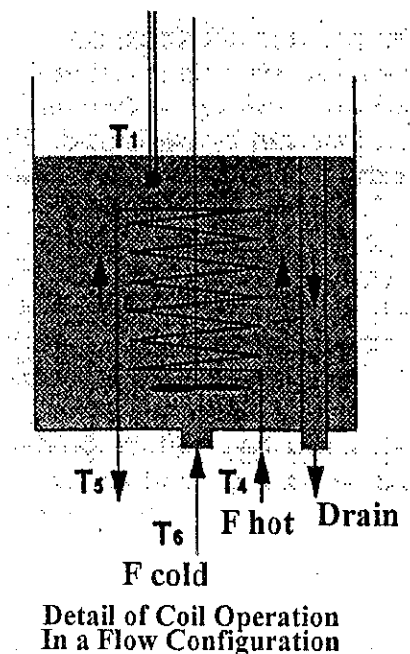Adjust the overflow in the vessel to the minimum height.
Follow the **OPERATING PROCEDURE** detailed in the main manual on page 16 onwards in order to establish the following operating conditions.

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 70°C and turn on the circulating pump.

Set the cold water flow rate V_{cold} to 0.5 litre min^{-1} and the hot water flow rate V_{hot} to approximately 2.0 litre min^{-1}.

Note that the vessel will first have to fill to the point where the water level reaches the top of the overflow. The unit will be operated with the cold water continuously flowing into the vessel and it is ESSENTIAL that the overflow and drain are free flowing to prevent the vessel overfilling and flooding. Examine the unit closely at the above cold water flow rate and ensure that the incoming flow and outgoing flow balance and the vessel level remains constant.

If the level tends to rise due to the limitations of the local drain or drain hose route it will be necessary to adjust the drain to rectify the problem.

Detail of Coil Operation
In a Flow Configuration

A schematic arrangement of the configuration is given in the diagram above.

Switch the stirrer control D1(11) to the manual position and adjust the speed control to maximum.

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^TM 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 **H100D Jacketed Vessel** (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 H100D jacketed Vessel 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.

H100D jacketed Vessel Main Menu.

*This lists the optional experiments that may be carried out with the H100D jacketed Vessel. To continue with the above experiment select 5. **To perform an energy balance, calculate the overall efficiency and determine the overall heat transfer coefficient for a continuous flow in a stirred vessel when heated using a submerged coil** and then click OK.*

H100D Experiment Number 5:

Assuming that the above procedure is being followed 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 graph may be used to set the hot and cold stream flow rates to the desired values and to check that this remains constant.

The Temperature and Numeric screen also include a Stirrer% control. By switching the stirrer control D1(11) on the vessel to Remote the Stirrer% control on the computer screen may be used to remotely set the stirrer speed.

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 H100D 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, T4, T5, T6, V_{hot} and V_{cold}

The hot flow should then be adjusted to 1 litre min^{-1} and the procedure repeated if time permits.

OBSERVATIONS
Heater in Use:-   **Submerged Coil**
Stirrer Setting%:-   **100%**
Overflow Height (H) :-   **0.060m**

Sample No.	T1	T2	T3	T4	T5	T6	V_{hot}	V_{cold}
----	°C	°C	°C	°C	°C	°C	L min^{-1}	L min^{-1}
1	49.2			68.8	60.5	17.9	2.12	0.53
2								
3								
4								
5								

Calculated Data

Sample No.	$\dot{Q}e$	$\dot{Q}a$	$\dot{Q}f$	$\eta_{Thermal}$	LMTD	U
----	W	W	W	%	K	$W\,m^2K^{-1}$
1	1204	1142	62	94.9	15.1	3928
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
It is necessary to convert the volume flow rates to mass flow rates using the conversion factors in table 1 and 2 on page D8. 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:
$T_{mean} = (68.8 + 60.5) / 2 = 64.6\ °C$
From table 1 and 2 at $T_{mean} = 64.6\ °C$

$$\rho_{hot} = 0.981\ kg\ litre^{-1}$$
$$Cp = 4.186\ kJ\ kg^{-1}\ k^{-1}$$

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

$$\dot{Q}e = \frac{V_{hot}}{60}\,\rho_{hot}\,Cp_{Hot}\,(T4 - T5) \times 1000 \quad Watts$$

$$= \frac{2.12}{60} \times 0.980 \times 4.186 \times (68.8 - 60.5) \times 1000$$

$$= 1204\ Watts$$

For the Cold stream T_{mean}

$T_{mean} = (49.2 + 17.9) / 2 = 33.6$ °C

From table 1 and 2 at $T_{mean} = 33.6$ °C $\quad\quad \rho_{Cold} \quad = 0.988$ kg litre^{-1}

$\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad$ $Cp_{Cold} \quad = 4.180$ kJ kg^{-1} k^{-1}

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

$$\dot{Q}a = \frac{V_{cold}}{60} \rho_{cold} \; Cp_{Cold} \left(T1 - T6\right) \times 1000 \quad \text{Watts}$$

$$= \frac{0.53}{60} \times 0.988 \times 4.180 \times \left(49.2 - 17.9\right) \times 1000$$

$$= 1142 \quad \text{Watts}$$

The difference between the heat emitted $\dot{Q}$ e and the heat absorbed $\dot{Q}$ a represent the losses or gains to the surroundings. As the vessel is not insulated these may be positive or negative due to temperature differences between the vessel, the hot stream and the surroundings.

Heat lost to surroundings $\dot{Q}$ f

$$\dot{Q}_f = \dot{Q}_e - \dot{Q}_a$$
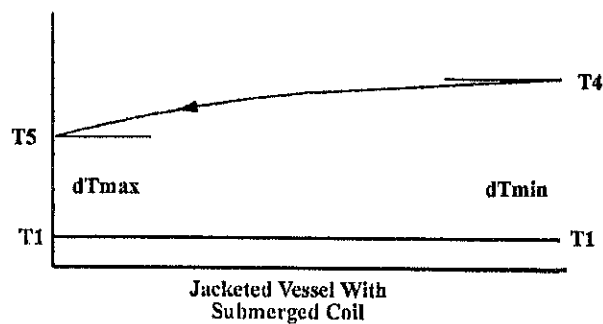
Hence for the example

$$\dot{Q}_f = 1204 - 1142$$

$$= 62 \text{ Watts}$$

The overall thermal efficiency η $_{Thermal}$ is a non dimensional measure of the heat losses (or gains) from the system and the effectiveness of the system as a means of transferring heat to the fluid being heated.

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

$$= \frac{1142}{1204} \times 100\%$$

$$= 94.9\%$$

It can be assumed that at any instant in time the temperature of the batch of fluid in the vessel is uniform due to the high degree of mixing applied by the stirrer. However as the temperature difference between the hot and cold fluids varies across the submerged coil it is necessary to derive an average 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.

Jacketed Vessel With
Submerged Coil

The LMTD is defined as

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

Hence from the above diagrams of temperature distribution

$$LMTD = \frac{(T4 - T1) - (T5 - T1)}{\ln\left(\dfrac{(T4 - T1)}{(T5 - T1)}\right)}$$

Hence for the example

$$LMTD = \frac{(68.8 - 49.2) - (60.5 - 49.2)}{\ln\left(\dfrac{(68.8 - 49.2)}{(60.5 - 49.2)}\right)}$$

$$= \frac{8.3}{\ln(1.7345)}$$

$$= \frac{8.3}{0.5507}$$

$$= 15.1\,K$$

In order to calculate the overall heat transfer coefficient the following parameters must be used with consistent units:-

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

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)

The heat transfer area may be calculated from:-

$$dm = \frac{d_{Coil\,i} + d_{Coil\,o}}{2}$$

And

$$A = \pi\, d_m\, L$$

Where

d_{CoilO}	Heat exchanger tube outside diameter (m)
d_{Coili}	Heat exchanger tube inside diameter (m)
dm	Heat exchanger tube mean diameter (m)
L	Effective length of heat exchanger tube (m)

Hence for the heat exchanger from the **USEFUL DATA** section on pageD8.
And for the test conditions where H = 0.060m

$$d_m = \frac{0.00635 + 0.00493}{2}$$

$$= 0.00564 \, m$$

$$A = \pi \times 0.00564 \times 1.15$$

$$= 0.0203 \, m^2$$

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

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

$$= \frac{1204}{0.0203 \times 15.1}$$

$$= 3928 \, Wm^{-2}K^{-1}$$

If the optional Computer Interface HC100 and software is being used then the user can return to the H100D jacketed Vessel 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 perform an energy balance, calculate the overall efficiency and determine the overall heat transfer coefficient for a continuous flow in a stirred vessel when heated using an outer jacket.

The following procedure examines the heat transfer occurring in a stirred vessel in a flow situation when heated by an outer jacket.

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
Refer to Figure D1 on page D1 and D2 on page D2.
Install the Jacketed Vessel H100D as detailed in **INSTALLATION Jacketed Vessel with Coil and Stirrer H100D** on page D6 and connect the hot water circuit according to the instructions in **Hot Water Circuit Using the Outer Jacket** in the same section.

Adjust the overflow in the vessel to the minimum height and record this height H (m).
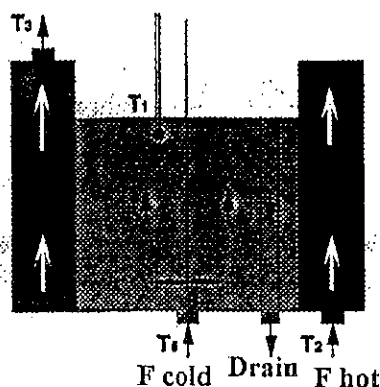
Follow the **OPERATING PROCEDURE** detailed in the main manual on page 16 onwards in order to establish the following operating conditions.

        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 70°C and turn on the circulating pump.

Set the cold water flow rate V_{cold} to 0.5 litre min^{-1} and the hot water flow rate V_{hot} to approximately 2.0 litre min^{-1}.

Note that the vessel will first have to fill to the point where the water level reaches the top of the overflow. The unit will be operated with the cold water continuously flowing into the vessel and it is ESSENTIAL that the overflow and drain are free flowing to prevent the vessel overfilling and flooding. Examine the unit closely at the above cold water flow rate and ensure that the incoming flow and outgoing flow balance and the vessel level remains constant.

If the level tends to rise due to the limitations of the local drain or drain hose route it will be necessary to adjust the drain to rectify the problem.

**Detail of Jacket Operation
In a Flow Configuration**

A schematic arrangement of the configuration is given in the diagram above.

Switch the stirrer control **D1(11)** to the manual position and adjust the speed control to maximum.

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 **H100D Jacketed Vessel** (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 H100D jacketed Vessel 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.*

H100D jacketed Vessel Main Menu.

> *This lists the optional experiments that may be carried out with the H100D jacketed Vessel. To continue with the above experiment select 6. **To perform an energy balance, calculate the overall efficiency and determine the overall heat transfer coefficient for a continuous flow in a stirred vessel when heated using an outer jacket** and then click OK.*

H100D Experiment Number 6:

> *Assuming that the above procedure is being followed 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 graph may be used to set the hot and cold stream flow rates to the desired values and to check that this remains constant.*

> *The Temperature and Data Point tabs allow data to be collected at a constant rate with respect to time. The Sample Interval has a default value that may be increased by the user. The user cannot set the value below the minimum as this limitation is set by the data capture hardware.*

> *The Temperature and Numeric screen also include a Stirrer% control. By switching the stirrer control D1(11) on the vessel to **Remote** the Stirrer% control on the computer screen may be used to remotely set the stirrer speed.*

> *The user will be required to enter the height H of the overflow pipe (in meters, m) that is being used for the experiment. The software will not proceed from this point until a positive value has been entered. Entry of an incorrect value will result in incorrect calculation of the jacket heat transfer surface area.*

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 H100D 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, T6, V_{hot} and V_{cold}

The hot flow should then be adjusted to 1 litre min^{-1} and the procedure repeated if time permits

OBSERVATIONS

Heater in Use:-   **Outer Jacket**
Stirrer Setting%:-   **100%**
Overflow Height (H) :-   **0.060m**

Sample No.	T1	T2	T3	T4	T5	T6	V_{hot}	V_{cold}
----	°C	°C	°C	°C	°C	°C	L min^{-1}	L min^{-1}
1	35.9	70.9	65.8			17.3	2.0	0.47
2								
3								
4								
5								

Calculated Data

Sample No.	$\dot{Q}e$	$\dot{Q}a$	$\dot{Q}f$	$\eta_{Thermal}$	LMTD	U
----	W	W	W	%	K	W m^{-2}K^{-1}
1	696	605	92	86.8		
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.

CALCULATIONS

It is necessary to convert the volume flow rates to mass flow rates using the conversion factors in table 1 and 2 on page D8. 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:
$T_{mean} = (70.9 + 65.8) / 2 = 68.4$ °C
From table 1 and 2 at $T_{mean} = 68.4$ °C

$$\rho_{hot} = 0.978 \text{ kg litre}^{-1}$$
$$C_p = 4.188 \text{ kJ kg}^{-1} \text{ k}^{-1}$$

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

$$\dot{Q}e = \frac{V_{hot}}{60} \rho_{hot} \ Cp_{Hot} (T2 - T3) \times 1000 \quad \text{Watts}$$

$$= \frac{2.00}{60} \times 0.978 \times 4.188 \times (70.9 - 65.8) \times 1000$$

$$= 696 \text{ Watts}$$

For the Cold stream T_{mean}
$T_{mean} = (35.9 + 17.3) / 2 = 26.6$ °C

From table 1 and 2 at $T_{mean} = 26.6$ °C
$$\rho_{Cold} = 0.993 \text{ kg litre}^{-1}$$
$$Cp_{Cold} = 4.179 \text{ kJ kg}^{-1} \text{ k}^{-1}$$

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

$$\dot{Q}a = \frac{V_{cold}}{60} \rho_{cold} \ Cp_{Cold} (T1 - T6) \times 1000 \quad \text{Watts}$$

$$= \frac{0.47}{60} \times 0.993 \times 4.179 \times (35.9 - 17.3) \times 1000$$

$$= 604 \quad \text{Watts}$$

The difference between the heat emitted $\dot{Q}e$ and the heat absorbed $\dot{Q}a$ represent the losses or gains to the surroundings. As the vessel is not insulated these may be positive or negative due to temperature differences between the vessel, the hot stream and the surroundings.
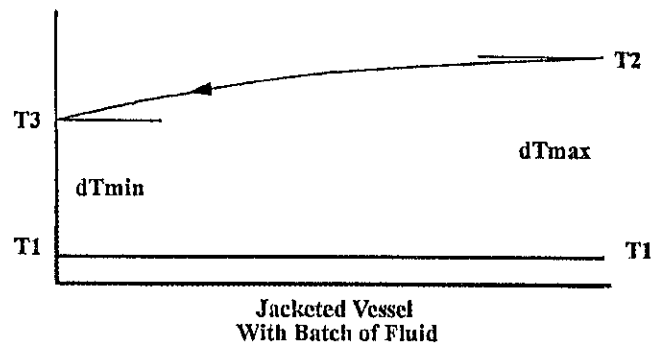
Heat lost to surroundings $\dot{Q}s$

$$\dot{Q}_s = \dot{Q}_e - \dot{Q}_a$$

Hence for the example

$$\dot{Q}_s = 696 - 604$$

$$= 92 \text{ Watts}$$

It can be assumed that at any instant in time the temperature of the batch of fluid in the vessel is uniform due to the high degree of mixing applied by the stirrer. However as the temperature difference between the hot and cold fluids varies across the heated jacket it is necessary to derive an average 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.

**Jacketed Vessel
With Batch of Fluid**

The LMTD is defined as

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

Hence from the above diagrams of temperature distribution

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

Hence for the example

$$LMTD = \frac{(70.9 - 35.9) - (65.8 - 35.9)}{\ln\left(\dfrac{(70.9 - 35.9)}{(65.8 - 35.9)}\right)}$$

$$= \frac{5.1}{\ln(1.1705)}$$

$$= \frac{5.1}{0.1575}$$

$$= 32.4\,K$$

In order to calculate the overall heat transfer coefficient the following parameters must be used with consistent units:-

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

Where

A   Heat transfer area of heat exchanger (m²)

$\dot{Q}$ e   Heat emitted from hot stream (Watts)

LMTD   Logarithmic mean temperature difference (K)

The heat transfer area may be calculated from:-

$$d_m = \frac{d_o + d_i}{2}$$

And

$$A = \pi\, d_m\, H$$

Where
do   Vessel wall outside diameter (m)
di   Vessel wall inside diameter (m)
dm   Vessel wall mean diameter (m)
H   Height of vessel contents (m)

Hence for the heat exchanger from the **USEFUL DATA** section on page D8.
And for the test conditions where H = 0.060m

$$d_m = \frac{0.1542 + 0.1524}{2}$$

$$= 0.1533 \, m$$

$$A = \pi \times 0.1533 \times 0.60$$

$$= 0.0289 \, m^2$$

Hence for the test conditions the overall heat transfer coefficient for sample No 5:-

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

$$= \frac{696}{0.0289 \times 32.4}$$

$$= 743.3 \, Wm^{-2}K^{-1}$$

If the optional Computer Interface HC100 and software is being used then the user can return to the H100D jacketed Vessel 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.

7.   To investigate the effect of stirring on the heat transfer characteristics of a stirred vessel

---

The stirrer within the vessel ensures even mixing of the vessel contents and in addition adds to the turbulence between the vessel contents and the submerged coil (and the heated jacket when this is in use). This turbulence has the effect of increasing the overall heat transfer coefficient for the heat exchanger.

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.

<u>Procedure</u>
Refer to Figure D1 on page D1 and D3 on page D3.
Install the Jacketed Vessel H100D as detailed in **INSTALLATION Jacketed Vessel with Coil and Stirrer H100D** on page D6 and connect the hot water circuit according to the instructions in **Hot Water Circuit Using the Submerged Coil** in the same section.

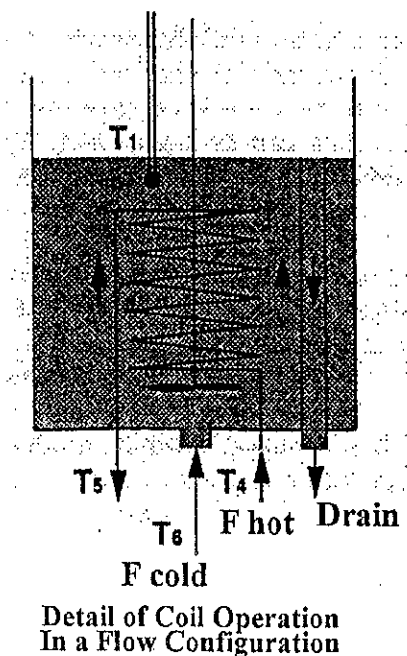Adjust the overflow in the vessel to the minimum height.
Follow the **OPERATING PROCEDURE** detailed in the main manual on page 16 onwards in order to establish the following operating conditions.

> 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 70°C and turn on the circulating pump.

Set the cold water flow rate V_{cold} to 0.5 litre min^{-1} and the hot water flow rate V $_{hot}$ to approximately 2.0 litre min^{-1}.

Note that the vessel will first have to fill to the point where the water level reaches the top of the overflow. The unit will be operated with the cold water continuously flowing into the vessel and it is ESSENTIAL that the overflow and drain are free flowing to prevent the vessel overfilling and flooding. Examine the unit closely at the above cold water flow rate and ensure that the incoming flow and outgoing flow balance and the vessel level remains constant.

If the level tends to rise due to the limitations of the local drain or drain hose route it will be necessary to adjust the drain to rectify the problem.

**Detail of Coil Operation
In a Flow Configuration**

A schematic arrangement of the configuration is given in the diagram above.

Switch the stirrer control **D1(11)** to the manual position and adjust the speed control to maximum.

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 H100D Jacketed Vessel** (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 H100D jacketed Vessel 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.*

H100D jacketed Vessel Main Menu:

> *This lists the optional experiments that may be carried out with the H100D jacketed Vessel. To continue with the above experiment select 7. **To investigate the effect of stirring on the heat transfer characteristics of a stirred vessel** and then click OK.*

H100D Experiment Number 7:

> *Assuming that the above procedure is being followed 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 graph may be used to set the hot and cold stream flow rates to the desired values and to check that this remains constant.*

> *The Temperature and Numeric screen also include a Stirrer% control. By switching the stirrer control D1(11) on the vessel to **Remote** the Stirrer% control on the computer screen may be used to remotely set the stirrer speed. In this instance the stirrer should be controlled via the computer and for the first reading the stirrer should be set to **Maximum (100%)**.*

> *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 H100D 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, T4, T5, T6, V_{hot} and V_{cold}

The stirrer speed should then be adjusted to 75% of full speed and the other conditions held constant. Allow the system to stabilise and then record the above parameters again.
The procedure may then be repeated for stirrer speeds of 50%, 25% and 0% (Stationary).

If the optional Computer Interface HC100 and software is being used then the adjustment of the stirrer speed setting in the Temperature and Data Point screens will result in the value of the setting being saved with the test data.

OBSERVATIONS
Heater in Use:-   **Submerged Coil**
Stirrer Setting%:-   **Varied**
Overflow Height (H) :- **0.060m**

Sample No.	T1	T3	T4	T5	T6	V_{hot}	V_{cold}	Stirrer
----	°C	°C	°C	°C	°C	L min⁻¹	L min⁻¹	%
1	48.6		69.7	60.6	15.3	2.2	0.55	100
2	46.6		69.3	60.3	14.6	2.1	0.54	75
3	45.5		69.1	60.8	15.0	2.05	0.53	50
4	43.0		68.7	61.3	15.6	2.05	0.52	25
5	40.2		69.0	61.3	14.2	2.04	0.53	0

Calculated Data

Sample No.	$\dot{Q}e$	$\dot{Q}a$	$\dot{Q}f$	$\eta_{Thermal}$	LMTD	U
----	W	W	W	%	K	W m⁻²K⁻¹
1	1371	1273	98	92.9	16.1	4173.0
2	1295	1202	93	92.8	17.8	3564.7
3	1165	1124	41	96.5	19.2	2986.4
4	1039	991	47	95.4	21.8	2340.0
5	1076	960	116	89.2	24.8	2133.1

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
It is necessary to convert the volume flow rates to mass flow rates using the conversion factors in table 1 and 2 on page D8. 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:
$T_{mean} = (69.7 + 60.6) / 2 = 65.15$ °C
From table 1 and 2 at $T_{mean} = 65.15$ °C

ρ_{hot} = 0.982 kg litre⁻¹
Cp   = 4.185 kJ kg⁻¹ k⁻¹

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

$$\dot{Q}e = \frac{V_{hot}}{60} \, \rho_{hot} \, Cp_{Hot} \, (T4 - T5) \times 1000 \quad \text{Watts}$$

$$= \frac{2.2}{60} \times 0.982 \times 4.185 \times (69.7 - 60.6) \times 1000$$

$$= 1371 \, \text{Watts}$$

For the Cold stream T_{mean}
$T_{mean} = (48.6 + 15.3) / 2 = 31.9 \, °C$

From table 1 and 2 at $T_{mean} = 31.9 \, °C$ 　　 ρ_{Cold} 　 $= 0.998 \, \text{kg litre}^{-1}$
　　　　　　　　　　　　　　　　　　　　 Cp_{Cold} 　 $= 4.179 \, \text{kJ kg}^{-1} \text{k}^{-1}$

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

$$\dot{Q}a = \frac{V_{cold}}{60} \, \rho_{cold} \, Cp_{Cold} \, (T1 - T6) \times 1000 \quad \text{Watts}$$

$$= \frac{0.55}{60} \times 0.998 \times 4.179 \times (48.6 - 15.3) \times 1000$$

$$= 1273 \quad \text{Watts}$$

The difference between the heat emitted $\dot{Q}$ e and the heat absorbed $\dot{Q}$ a represent the losses or gains to the surroundings. As the vessel is not insulated these may be positive or negative due to temperature differences between the vessel, the hot stream and the surroundings.

Heat lost to surroundings $\dot{Q}$ f
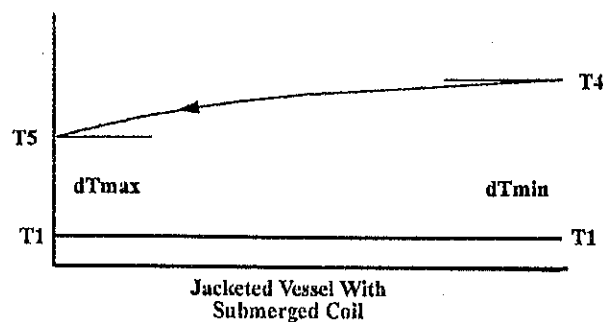
$$\dot{Q}f = \dot{Q}_e - \dot{Q}_a$$

Hence for the example

$$\dot{Q}f = 1371 - 1273$$

$$= 98 \, \text{Watts}$$

The overall thermal efficiency η Thermal is a non dimensional measure of the heat losses (or gains) from the system and the effectiveness of the system as a means of transferring heat to the fluid being heated.

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

$$= \frac{1273}{1371} \times 100\%$$

$$= 92.9\%$$

It can be assumed (apart from the case where the stirrer speed is zero) that at any instant in time the temperature of the batch of fluid in the vessel is uniform due to the high degree of mixing applied by the stirrer. However as the temperature difference between the hot and cold fluids varies across the submerged coil it is necessary to derive an average 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.

Jacketed Vessel With Submerged Coil

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

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

Hence from the above diagrams of temperature distribution

$$LMTD = \frac{(T4 - T1) - (T5 - T1)}{\ln\left(\dfrac{(T4 - T1)}{(T5 - T1)}\right)}$$

Hence for the example

$$LMTD = \frac{(69.7 - 48.6) - (60.6 - 48.6)}{\ln\left(\dfrac{(69.7 - 48.6)}{(60.6 - 48.6)}\right)}$$

$$= \frac{9.1}{\ln(1.7583)}$$

$$= \frac{9.1}{0.5643}$$

$$= 16.1 \, K$$

In order to calculate the overall heat transfer coefficient the following parameters must be used with consistent units:-

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

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)

The heat transfer area may be calculated from:-

$$d_m = \frac{d_{Coil}i + d_{Coil}o}{2}$$

And

$$A = \pi \, d_m \, L$$

Where

d $_{Coil}$o	Heat exchanger tube outside diameter (m)
d $_{Coil}$i	Heat exchanger tube inside diameter (m)
dm	Heat exchanger tube mean diameter (m)
L	Effective length of heat exchanger tube (m)

Hence for the heat exchanger from the **USEFUL DATA** section on page D8.

$$d_m = \frac{0.00635 + 0.00493}{2}$$

$$= 0.00564 \text{ m}$$

$$A = \pi \times 0.00564 \times 1.15$$

$$= 0.0203 \text{ m}^2$$

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

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

$$= \frac{1371}{0.0203 \times 16.1}$$

$$= 4194.8 \text{ Wm}^{-2}\text{K}^{-1}$$

In order to visualise the effect of the stirrer on the LMTD and the overall heat transfer coefficient the data may be plotted against the stirrer %.
Sample data is shown on the following page.

If the optional Computer Interface HC100 and software is being used then the user can return to the H100D jacketed Vessel 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

Effect of stirrer speed (%) on LMTD and Overall heat Transfer Coefficient in a vessel heated by a submerged coil