

Extended Tubular Heat Exchanger

Instruction Manual

HT36

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Copyright and Trademarks	1
General Overview	2
Equipment Diagrams	3
Important Safety Information	6
Introduction	6
Electrical Safety	6
Hot Surfaces and Liquids	6
Water Borne Hazards	6
Description	8
Overview	8
Baseplate	8
End Housings	8
Cold Water Circuit Manual Configuration Valves	8
Thermocouples	9
Connections for Flexible Tubing	9
Installation 1	0
Advisory1	0
Installation Process 1	0
Operation 1	12
Operating the Software1	2
Operating the Equipment 2	22
Equipment Specifications	29
I/O Port Pin Connections	29
USB Channel Numbers	30
Environmental Conditions	31
Routine Maintenance	33
Responsibility	33
General	33
Laboratory Teaching Exercises	34

Table of Contents

Index to Exercises	34
Nomenclature	34
Reference Tables	36
Calculating Reynolds Number	37
Exercise A: Indirect Heating/Cooling Demonstration	39
Exercise B: Energy Balance and Overall Efficiency	45
Exercise C: Cocurrent and Countercurrent Flow	48
Exercise D: Overall Heat Transfer Coefficient	55
Exercise E: Effect of Flow Rate	59
Exercise F: Driving Force	65
Exercise G: Project Work	70
Contact Details for Further Information	72

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General Overview

This instruction manual should be used in conjunction with the manual supplied with the HT30XC Heat Exchanger Service Unit.

This Manual provides the necessary information for operating the equipment in conjunction with the HT30XC Service Unit and a connected PC running the Armfield HT36-304 software. It includes a range of Teaching Exercises designed to demonstrate the basic principles of Heat Exchanger theory and use.

This instruction manual describes the operation of the HT36 Extended Tubular Heat Exchanger which must be used in conjunction with the HT30XC Heat Exchanger Service Unit (supplied separately). Details of the service unit are given in a separate instruction manual, which is supplied with the unit. The service unit provides the hot and cold water streams for the heat exchanger along with flow and temperature measurement and control and the facility for computerised data logging of the results.

The HT36 Extended Tubular Heat Exchanger is one model in a range of heat exchangers designed for use with the HT30XC service unit. A full description of the exchanger is provided in the DESCRIPTION section of this manual (page 2-1). Other heat exchangers available in the range include the HT31 Tubular, HT32 Plate, HT33 Shell and Tube, HT34 Jacketed Vessel with Coil and Stirrer and HT37 Extended Plate with Regeneration. These modules are interchangeable on the service unit and each come with their own product manual.



HT36 Extended Tubular Heat Exchanger

Equipment Diagrams



Figure 1 Plan View of HT36



Figure 2 Side View of HT36



Figure 3 Diagram of Countercurrent Operation



Figure 4 Diagram of Cocurrent Operation

Important Safety Information

Introduction

All practical work areas and laboratories should be covered by local safety regulations **which must be followed at all times**.

It is the responsibility of the owner to ensure that all users are made aware of relevant local regulations, and that the apparatus is operated in accordance with those regulations. If requested then Armfield can supply a typical set of standard laboratory safety rules, but these are guidelines only and should be modified as required. Supervision of users should be provided whenever appropriate.

Your **HT36 Extended Tubular Heat Exchanger** has been designed to be safe in use when installed, operated and maintained in accordance with the instructions in this manual. As with any piece of sophisticated equipment, dangers exist if the equipment is misused, mishandled or badly maintained.

Electrical Safety

The equipment described in this Instruction Manual operates from a mains voltage electrical supply. It must be connected to a supply of the same frequency and voltage as marked on the equipment or the mains lead. If in doubt, consult a qualified electrician or contact Armfield.

The equipment must not be operated with any of the panels removed.

To give increased operator protection, the unit incorporates a Residual Current Device (RCD), alternatively called an Earth Leakage Circuit Breaker, as an integral part of this equipment. If through misuse or accident the equipment becomes electrically dangerous, the RCD will switch off the electrical supply and reduce the severity of any electric shock received by an operator to a level which, under normal circumstances, will not cause injury to that person.

At least once each month, check that the RCD is operating correctly by pressing the TEST button. The circuit breaker **MUST** trip when the button is pressed. Failure to trip means that the operator is not protected and the equipment must be checked and repaired by a competent electrician before it is used.

Hot Surfaces and Liquids

The heat exchanger is capable of producing temperatures that could cause burns. Do not touch the heat exchanger while it is in operation and allow sufficient time for it to cool after use before handling the exchanger or pipework. If the model needs to be changed it should be handled by the white base on which the exchanger is mounted. Do not open the circulator unit on the service unit except in accordance with the safety instructions included in the HT30XC Heat Exchanger Service Unit product manual.

Water Borne Hazards

The equipment described in this instruction manual involves the use of water, which under certain conditions can create a health hazard due to infection by harmful micro-organisms.

For example, the microscopic bacterium called Legionella pneumophila will feed on any scale, rust, algae or sludge in water and will breed rapidly if the temperature of water is between 20 and 45°C. Any water containing this bacterium which is sprayed or splashed creating air-borne droplets can produce a form of pneumonia called Legionnaires Disease which is potentially fatal.

Legionella is not the only harmful micro-organism which can infect water, but it serves as a useful example of the need for cleanliness.

Under the COSHH regulations, the following precautions must be observed:

- Any water contained within the product must not be allowed to stagnate, ie. the water must be changed regularly.
- Any rust, sludge, scale or algae on which micro-organisms can feed must be removed regularly, i.e. the equipment must be cleaned regularly.
- Where practicable the water should be maintained at a temperature below 20°C. If this is not practicable then the water should be disinfected if it is safe and appropriate to do so. Note that other hazards may exist in the handling of biocides used to disinfect the water.
- A scheme should be prepared for preventing or controlling the risk incorporating all of the actions listed above.

Further details on preventing infection are contained in the publication "The Control of Legionellosis including Legionnaires Disease" - Health and Safety Series booklet HS (G) 70.

Description

Where necessary, refer to the drawings in the Equipment Diagrams section.

Overview

The tubular heat exchanger is the simplest form of heat exchanger and in its basic form consists of two concentric (coaxial) tubes carrying the hot and cold fluids. Heat is transferred to/from one fluid in the inner tube from/to the other fluid in the outer annulus via the metal wall which separates the two fluids.



In this miniature version, four sets of concentric tubes are arranged in series in the form of a coil to reduce the overall length and allow the temperature mid way along both fluid streams to be measured.

In normal operation (see Figure 3 and 4) the hot fluid from the hot water circulator passes through the inner stainless steel tube and cold fluid from the cold water supply passes through the annulus created between each inner metal tube and clear acrylic outer tube. This arrangement minimises heat loss from the exchanger without the need for additional insulation and allows the construction of the exchanger to be viewed.

Baseplate

The tubular heat exchanger is mounted on a PVC base plate (1) which incorporates four holes (2) which locate it on four studs at the left hand end of the HT30X service unit. The PVC base plate is secured to the service unit using thumb nuts.

End Housings

PVC housings (3), bonded to each end of the clear acrylic outer tubes, incorporate 'O' rings between each inner tube and outer annulus. These provide a liquid seal, accommodate differential expansion between the metal and plastic parts and allow the inner metal tubes to be removed for cleaning. The end housings also incorporate the necessary fittings for sensors to measure the fluid temperatures and connections to the hot and cold water supplies.

Cold Water Circuit Manual Configuration Valves

The manual valves on the cold water circuit allow the cold water to be passed through one, two, three or four of the outer annuli, hence allowing active heat exchange through 1, 2, 3 or 4 sections of the Heat Exchanger. This allows the effect of differing heat exchanger lengths to be investigated.

Thermocouples

The ten thermocouple temperature sensors (4) are labelled T1 to T10 for identification and each lead is terminated with a miniature thermocouple plug (5) for connection to the appropriate socket on the front of the service unit.

Connections for Flexible Tubing

Flexible tubing attached to each fluid inlet/outlet is terminated with a ferrule (6). This allows rapid connection to the appropriate quick release fittings on the HT30XC service unit. The fittings on the HT30XC service unit and HT36 are colour coded red for hot water and blue for cold water to aid identification.

Details of the connections are given in the Installation and Operation sections of this manual.

Installation

Advisory

Before operating the equipment, it must be unpacked, assembled and installed as described in the steps that follow. Safe use of the equipment depends on following the correct installation procedure.

Installation Process

The HT36 Extended Tubular Heat Exchanger must be used in conjunction with the HT30X Heat Exchanger Service Unit.

Before mounting the HT36 Extended Tubular Heat Exchanger on a HT30XC Heat Exchanger Service Unit ensure that the service unit has been assembled and connected to the appropriate services as described in the instruction manual supplied with the HT30XC.

- 1. Check that the HT30XC service unit and the Armfield HT30 range software has been installed as described in the HT30XC product manual (provided with the service unit). The PC on which the software has been installed should be located close to the service unit.
- 2. Remove the HT36 accessory from any packaging and position the accessory on the HT30XC plinth so that the holes in the HT36 baseplate are located over the studs on the HT30XC.
- 3. Secure the HT36 to the plinth using the thumb nuts provided.
- 4. Connect the flexible tubing on the HT36 to the quick-release fittings on the service unit as shown in the following diagram:



- 5. Direct the tubing carrying the cold water out of the exchanger into a suitable drain.
- 6. Check that the HT30XC service unit is connected to suitable mains water and mains electricity supplies (as described in the HT30XC manual), and that the water and electricity supplies are switched on.

- Check that the HT30XC service unit is connected to the PC using the USB cable provided, and that the PC is switched on. Check that the red and green USB indicator lights on the front panel of the HT30XC are illuminated.
- 8. Switch on the HT30XC service unit (using the mains switch on the front of the unit), and check that the Emergency Stop button is released (pulled out).
- 9. Run the HT36 software and select the exercise required. Check that the software reads 'IFD OK' in the bottom right-hand corner of the screen.
- 10. Select the mimic diagram in the software by clicking on the \blacksquare icon.
- 11. Select the 'Power On' switch on the software mimic diagram.
- 12. Select the Hot Water Pump Control button. In the controller window, set the controller to Manual and then set the Hot Water Pump Speed to 100% using the Manual Control box in the right-hand pane of the window. The hot water pump should begin to operate. Run the pump until the hot water circuit of the heat exchanger has filled with water and all bubbles have been expelled from the circuit. Top up the hot water tank with clean (preferably de-ionised or de-mineralised) water if the level drops below the tip of the level sensor.
- 13. Set the Hot Water Pump Speed back to 0%. The pump should cease operation. Close the controller window.
- 14. Fully close the pressure regulator at the cold water inlet. On the mimic diagram screen, set the Cold Water Valve to 100%. The valve should be heard to operate. Gradually open the pressure regulator. Cold water should begin to flow through the cold water circuit. Open the pressure regulator until a flow rate of 4.9 L/min is reached, then lock the regulator setting. Allow water to flow until any bubbles have been eliminated, then set the cold water valve back to 0%.

The HT36 accessory is now installed and primed ready for use.

Refer to the HT30XC manual for further information on the service unit and its operation.

Refer to the Operation section and Laboratory Teaching Exercises for more information on the operation of the HT36 and the investigations that can be performed using this Heat Exchanger. The Teaching Exercises are also available from within the HT36 software Help Text.

Operation

Where necessary, refer to the drawings in the Equipment Diagrams section.

Operating the Software

Note: The diagrams in this section are included as typical examples and may not relate specifically to the individual product described in this instruction manual.

The Armfield Software is a powerful Educational and Data Logging tool with a wide range of features. Some of the major features are highlighted below, to assist users, but full details on the software and how to use it are provided in the presentations and Help text incorporated in the Software. Help on Using the Software or Using the Equipment is available by clicking the appropriate topic in the **Help** drop-down menu from the upper toolbar when operating the software as shown:



Before operating the software ensure that the equipment has been connected to the IFD5 Interface (where IFD5 is separate from the equipment) and the IFD5 has been connected to a suitable PC using a USB lead. For further information on these actions refer to the Operation manual.

Load the software and wait for the presentation screen to open fully as shown:



Before proceeding to operate the software ensure that **IFD: OK** is displayed at the bottom of the screen. If IFD:ERROR is displayed check the USB connection between the IFD5 and the PC and confirm that the red and green LED's are both illuminated. If the problem persists then check that the driver is installed correctly (refer to the Operation manual).

Presentation Screen - Basics and Navigation

As stated above, the software starts with the Presentation Screen displayed. The user is met by a simple presentation which gives them an overview of the capabilities of the equipment and software and explains in simple terms how to navigate around the software and summarizes the major facilities complete with direct links to detailed context sensitive 'help' texts.

To view the presentations click **Next** or click the required topic in the left hand pane as appropriate. Click **More** while displaying any of the topics to display a Help index related to that topic.

To return to the Presentation screen at any time click the View Presentation icon

from the main tool bar or click **Presentation** from the dropdown menu as shown:

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Sample D	Graph Table Presentation																
Ā	Show Gauge Show History																
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For more detailed information about the presentations refer to the **Help** available via the upper toolbar when operating the software.

Toolbar

A toolbar is displayed at the top of the screen at all times, so users can jump immediately to the facility they require, as shown:

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The upper menu expands as a dropdown menu when the cursor is placed over a name.

The lower row of icons (standard for all Armfield Software) allows a particular function to be selected. To aid recognition, pop-up text names appear when the cursor is placed over the icon.

Mimic Diagram

The Mimic Diagram is the most commonly used screen and gives a pictorial representation of the equipment, with continuously updated display boxes for all the various sensor readings, calculated variables etc. directly in engineering units.

To view the Mimic Diagram click the View Diagram icon	fro
or click Diagram from the View drop-down menu as shown:	

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A Mimic diagram is displayed, similar to the diagram as shown:



In addition to measured variables such as Temperature, Pressure and Flowrate (from a direct reading flowmeter), calculated data such as Motor Torque, Motor Speed and Discharge / Volume flowrate (from pressure drop across an orifice plate) are continuously displayed in data boxes with a white background. These are automatically updated and cannot be changed by the user.

Manual data input boxes with a coloured background allow constants such as Orifice Cd and Atmospheric Pressure to be changed by over-typing the default value, if required.

The data boxes associated with some pressure sensors include a **Zero** button alongside. This button is used to compensate for any drift in the zero value, which is an inherent characteristic of pressure sensors. Pressing the **Zero** button just before starting a set of readings resets the zero measurement and allows accurate pressure measurements to be taken referenced to atmospheric pressure. This action must be carried out before the motor is switched on otherwise the pressure readings will be offset. The mimic diagram associated with some products includes the facility to select different experiments or different accessories, usually on the left hand side of the screen, as shown:

Controls	
Watchdog Enabled	
Pump On	oi 🔰
Pump Speed 0	•
Brake Control 0	∃
PID - Pressure Mode: Manual S/P: -	
Accessory FM60 Impulse Turbine FM61 Reaction Turbin FM62 Pelton Turbine FM64 Pump Test	e dr
Diagram	Sample Mode - Manual

Clicking on the appropriate accessory or exercise will change the associated mimic diagram, table, graphs etc to suit the exercise being performed.

Control Facilities in the Mimic Diagram

A Power On button allows the motor to be switched off or on as required. The button always defaults to off at startup. Clicking this button switches the power on (1) and off (0) alternately.

A box marked **Motor Setting** allows the speed of the motor to be varied from 0 to 100% either stepwise, by typing in values, or using the up / down arrows as appropriate. It is usual to operate the equipment with the motor initially set to 100%, then reduce the setting as required to investigate the effect of reduced speed on performance of the equipment.

When the software and hardware are functioning correctly together, the green LED marked **Watchdog Enabled** will alternate On and Off. If the Watchdog stops alternating then this indicates a loss of communication between the hardware and software that must be investigated.

Details on the operation of any automatic PID Control loops in the software are included later in this section.

Data Logging Facilities in the Mimic Diagram

There are two types of sampling available in the software, namely Automatic or Manual. In **Automatic logging**, samples are taken regularly at a preset but variable interval. In **Manual logging**, a single set of samples is taken only when requested by the operator (useful when conditions have to be changed and the equipment allowed to stabilize at a new condition before taking a set of readings). The type of logging will default to manual or automatic logging as appropriate to the type of product being operated.

Manual logging is selected when obtaining performance data from a machine where conditions need to stabilize after changing appropriate settings. To record a set of set

of data values from each of the measurement sensors click the icon from the main toolbar. One set of data will be recorded each time the icon is clicked.

Automatic logging is selected when transients need to be recorded so that they can

be plotted against time. Click the icon from the toolbar to start recording, click

the eigen icon from the toolbar to stop recording.

The type of logging can be configured by clicking **Configure** in the **Sample** dropdown menu from the upper toolbar as shown:

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File Edit View Options	Sample Fotmat Window Help	
0 🗃 🖬 😂 🐰	Sample Now Next Results	1.40
	Configure	

In addition to the choice of Manual or Automatic sampling, the parameters for Automatic sampling can also be set. Namely, the time interval between samples can be set to the required number of minutes or seconds. Continuous sampling can be selected, with no time limit or sampling for a fixed duration can be set to the required number of hours, minutes or seconds as shown:

ample Configuratio	n		
Sampling Operation			
Manual			
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Sample Interval	10	secs	•
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C Continuous			
Fixed Duration	1	hrs	•
	- 1 ⁵		1
UK Ca	ncel		Help

Tabular Display

To view the Table screen click the View Table icon IIII from the main tool bar or click **Table** from the View dropdown menu as shown:

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0 📽 🛛	Diagram Graph	8 🖬 🖾 🎟 🏙 🕍 🔗 Ф2 🤣 🖚 🛛 🕲 🎰 🖗 📉 茶 蒜 なし 🖓	
Sample D	Table		
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The data is displayed in a tabular format, similar to the screen as shown:

1 918 100 200 121 237 171 0.407 0.474 0.909 2 901 00 200 122 240 1.70 0.455 1.499 0.309 3 901 100 200 122 240 1.70 0.455 1.499 0.309 4 901 100 200 122 240 1.70 0.259 2.72 0.309 5 901 100 200 122 242 1.582 0.257 3.447 0.389 5 901 100 200 113 242 1.582 0.354 4.384 0.380 6 901 100 200 103 242 1.690 0.354 5.970 0.388 1.990 1.36 5.970 0.386 5.970 0.386 5.970 0.380 1.970 0.19 5.94 0.380 0.980 0.980 0.980 0.980 0.980 0.980	000 000 000 120 22.5 1.73 0.407 9.476 0.909 000 000 2000 125 24.0 1.760 0.456 1.800 0.909 000 000 125 24.0 1.760 0.456 2.762 0.909 001 000 5000 7.22 24.0 1.760 0.356 2.072 0.909 001 901 900 5000 7.22 24.0 1.760 0.356 2.072 0.909 001 901 900 5000 7.22 24.0 1.760 0.356 2.072 0.909 001 901 900 5000 1.13 24.2 1.789 0.356 4.344 0.909 901 900 5200 1.01 24.2 1.789 0.356 0.806 0.806 901 900 5200 1.02 24.0 1.779 0.039 6.964.0 9800 901	NH NH<	018 000 2000 128 232 1778 0.005 0.444 0.995 019 010 2000 125 246 1.796 0.035 1.796 0.036 0.997 0.991 100 2000 113 2.42 1.790 0.005 0.991 0.00 0.00 100 2.000 103 2.42 1.790 0.006 6.922 0.960 0.91 0.00 100 2.000 1.91 1.91 0.00 1.91 1.91 1.92 0.92 2.41 1.790 0.068 6		Atmospheric Pressure (KPa)	Compressor Setting [%]	Compressar Spood n Jipmj	Bater Torque t (Nm)	iniet Temperature T [*C]	Density of Air [kg/m ²]	Orifice Biffecential Pressure [kPa]	Compressor Differential Pressure (kPa)	Discharge Ceofficies Cd
2 001 100 2000 121 210 1.700 0.359 2.076 0.369 4 001 100 2000 122 210 1.700 0.359 2.772 0.909 5 001 100 2000 122 210 1.700 0.259 2.772 0.909 5 001 100 2000 122 212 1.89 0.257 3.497 0.398 5 001 100 2000 111 2.42 1.89 0.355 4.344 0.398 6 001 100 2000 101 2.42 1.89 0.355 4.344 0.398 6 001 100 2000 101 2.42 1.89 0.355 5.970 0.369 6 001 100 2000 101 2.42 1.89 0.368 6.369 62 0301 100 2000 1.070 2.42 1.76 0.868 </td <td>2 901 100 3000 125 24.0 1.770 0.356 1.189 0.90 4 901 100 5000 122 24.0 1.770 0.356 2.772 0.980 5 901 100 5000 122 24.2 1.89 0.259 2.772 0.980 5 901 100 5000 122 24.2 1.89 0.259 2.772 0.980 5 901 100 5000 111 24.2 1.89 0.255 3.447 0.980 6 901 100 5000 111 24.2 1.89 0.356 2.970 0.980 6 901 100 5000 103 24.2 1.89 0.356 5070 0.980 6 901 100 5000 103 24.2 1.89 0.356 2.970 0.900 7 901 100 5000 103 24.2 1.80</td> <td>2 94 90 200 125 24.0 1.770 0.356 1.499 0.00 941 901 2000 122 24.0 1.770 0.358 2076 0.393 941 901 2000 122 24.0 1.770 0.358 2076 0.393 941 901 2000 122 24.0 1.770 0.358 2.072 0.936 941 901 2000 122 24.2 1.86 0.376 4.364 0.386 941 901 2000 113 24.2 1.86 0.376 4.364 0.386 941 900 2000 103 24.2 1.86 0.376 4.364 0.386 941 900 2000 103 24.2 1.86 0.376 0.376 0.376 0.376 0.376 0.376 0.376 0.376 0.376 0.376 0.376 0.376 0.376 0.376 0.376 0.376</td> <td>91 90 100 100 125 910 170 0.456 1.499 0.00 91 90 500 72 510 1.70 0.355 2.072 0.93 91 90 500 521 310 1.70 0.299 2.772 0.93 91 90 500 522 312 1.78 0.295 2.572 0.93 91 100 5500 1.9 3.42 1.89 0.355 4.34 0.93 91 100 5500 1.9 3.42 1.89 0.355 4.34 0.93 91 100 5500 1.06 2.44 1.78 0.196 5.94 0.95 91 100 5500 1.06 2.44 1.76 0.068 6.962 0.96 91 100 5500 2.91 2.44 1.76 0.060 7.16 0.96 91 100 5700 2.79 <</td> <td>t</td> <td> 101</td> <td>300</td> <td>3000</td> <td>1.28</td> <td>23.7</td> <td>1.171</td> <td>0.487</td> <td>0.474</td> <td>0.900</td>	2 901 100 3000 125 24.0 1.770 0.356 1.189 0.90 4 901 100 5000 122 24.0 1.770 0.356 2.772 0.980 5 901 100 5000 122 24.2 1.89 0.259 2.772 0.980 5 901 100 5000 122 24.2 1.89 0.259 2.772 0.980 5 901 100 5000 111 24.2 1.89 0.255 3.447 0.980 6 901 100 5000 111 24.2 1.89 0.356 2.970 0.980 6 901 100 5000 103 24.2 1.89 0.356 5070 0.980 6 901 100 5000 103 24.2 1.89 0.356 2.970 0.900 7 901 100 5000 103 24.2 1.80	2 94 90 200 125 24.0 1.770 0.356 1.499 0.00 941 901 2000 122 24.0 1.770 0.358 2076 0.393 941 901 2000 122 24.0 1.770 0.358 2076 0.393 941 901 2000 122 24.0 1.770 0.358 2.072 0.936 941 901 2000 122 24.2 1.86 0.376 4.364 0.386 941 901 2000 113 24.2 1.86 0.376 4.364 0.386 941 900 2000 103 24.2 1.86 0.376 4.364 0.386 941 900 2000 103 24.2 1.86 0.376 0.376 0.376 0.376 0.376 0.376 0.376 0.376 0.376 0.376 0.376 0.376 0.376 0.376 0.376 0.376	91 90 100 100 125 910 170 0.456 1.499 0.00 91 90 500 72 510 1.70 0.355 2.072 0.93 91 90 500 521 310 1.70 0.299 2.772 0.93 91 90 500 522 312 1.78 0.295 2.572 0.93 91 100 5500 1.9 3.42 1.89 0.355 4.34 0.93 91 100 5500 1.9 3.42 1.89 0.355 4.34 0.93 91 100 5500 1.06 2.44 1.78 0.196 5.94 0.95 91 100 5500 1.06 2.44 1.76 0.068 6.962 0.96 91 100 5500 2.91 2.44 1.76 0.060 7.16 0.96 91 100 5700 2.79 <	t	 101	300	3000	1.28	23.7	1.171	0.487	0.474	0.900
S 001 000 5000 121 210 1.700 0.389 2.076 0.389 5 001 100 5000 122 212 1.78 0.387 2.772 0.388 5 001 100 5000 122 212 1.78 0.377 3.447 0.388 6 001 100 5000 113 24.2 1.789 0.354 5.979 0.988 7 001 100 5000 103 24.2 1.789 0.354 5.979 0.988 901 100 5000 106 24.0 1.770 0.119 5.954 0.989 901 100 2500 106 24.1 1.769 0.088 6.982 0.980 901 100 2500 103 24.1 1.769 0.088 6.982 0.360 901 100 2500 103 24.1 1.769 0.086 5.922 0.300	9 001 000 5000 1.21 21.0 1.770 0.322 2.016 0.980 9 001 000 5000 1.22 24.0 1.770 0.329 2.772 0.380 9 001 5000 1.22 24.2 1.389 0.577 3.467 0.980 9 001 5000 1.13 24.2 1.389 0.795 4.342 0.980 9 001 100 5000 1.13 24.2 1.389 0.795 4.342 0.980 9 001 100 5000 1.01 24.2 1.389 0.795 4.342 0.980 9 001 100 2000 1.01 24.2 1.389 0.784 2.970 0.980 9 001 100 2000 1.02 24.1 1.770 0.068 6.962 0.960 1 001 100 2000 0.71 24.1 1.770 0.000	3 001 000 5000 121 210 1.770 0.324 2006 0.938 5 001 000 5000 122 210 1.770 0.254 2.72 0.988 5 001 000 5000 122 212 1.789 0.754 3.497 0.988 5 001 000 5200 1.13 24.2 1.789 0.756 3.487 0.988 5.970 0.988 5.970 0.988 5.970 0.988 5.970 0.988 5.970 0.988 5.972 0.988 5.970 0.988 5.970 0.988 5.970 0.988 5.970 0.988 5.972 0.988 5.972 0.988 5.972 0.988 5.972 0.988 5.972 0.988 5.972 0.988 5.972 0.988 5.972 0.988 5.972 0.988 5.972 0.988 5.972 0.930 1.979 0.908 5.962 0.989 2.21 1.790	NH NO 300 121 210 178 0.384 2078 0.384 910 NO 500 1.22 310 1.78 0.384 2078 0.384 910 NO 500 1.22 312 1.58 0.55 3.44 0.384 911 NO 500 1.31 312 1.58 0.55 3.44 0.384 911 NO 500 1.13 312 1.58 0.354 5070 0.384 911 NO 5500 1.01 312 1.59 0.354 5070 0.384 911 NO 5500 1.02 314 1.78 0.038 6.084 0.396 911 100 5500 1.63 241 1.79 0.038 6.642 0.960 911 100 5500 1.63 241 1.79 0.038 6.642 0.960 911 100 5500 1.63 241 <td>2</td> <td>101</td> <td>100</td> <td>3000</td> <td>1.25</td> <td>21.0</td> <td>1.178</td> <td>0.436</td> <td>1.189</td> <td>0.900</td>	2	101	100	3000	1.25	21.0	1.178	0.436	1.189	0.900
4 901 100 2000 122 210 1.700 0.289 2.722 0.380 5 903 100 2000 112 212 1.789 0.357 3.407 0.380 6 903 100 2000 113 212 1.789 0.757 3.407 0.380 7 903 100 2000 113 212 1.789 0.752 3.407 0.380 8 903 100 2000 106 240 1.770 0.19 5.954 0.380 9 901 100 2000 106 240 1.770 0.198 6.962 0.380 901 100 2000 103 241 1.770 0.068 6.962 0.360 903 100 2000 103 241 1.770 0.068 6.964 0.360 903 100 2000 103 241 1.770 0.069 7.277 <td< td=""><td>1 001 100 2000 122 210 1.170 0.257 2.722 0.380 5 001 100 500 122 242 1.180 0.157 3.414 0.380 3.84 0.380 5 3.94 0.380 0.385 4.384 0.386 4.384 0.386 4.384 0.386 4.384 0.386 4.384 0.386 5 0.391 100 5500 1.13 242 1.189 0.154 5.707 0.386 5 0.391 0.386 5 0.393 5.854 0.380 5 0.386 5.854 0.380 5 0.386 5.854 0.380 5 0.391 0.388 5.954 0.380 5 0.391 0.396 5.854 0.380 5 0.390 5.354 0.380 5.954 0.380 5.954 0.380 5.954 0.380 5.954 0.380 5.954 0.380 5.954 0.380 5.954 0.380 5.954 0.380</td><td>1 001 000 5000 122 210 1.70 0.279 2.72 038 5 001 000 5000 112 212 1.389 0.357 3.444 038 6 001 000 5000 113 242 1.389 0.354 5.457 0.386 4.384 0.386 4.384 0.386 4.384 0.386 4.384 0.386 4.384 0.386 4.384 0.386 4.384 0.386 4.384 0.386 4.384 0.386 6.386 0.386 6.386 0.386 6.386 0.386 6.386 0.386 6.386 0.386 6.386 0.386 6.382 0.386 6.382 0.386 6.382 0.386 6.382 0.386 6.382 0.386 6.382 0.386 6.382 0.386 6.382 0.386 6.382 0.386 6.382 0.386 6.382 0.386 6.382 0.386 6.382 0.386 6.382 0.386 6.382<</td><td>0 00 100 2000 122 210 1.170 0.257 2.722 0.986 001 100 2000 1.13 242 1.188 0.155 4.384 0.986 001 100 2000 1.13 242 1.189 0.155 4.384 0.986 001 100 2000 1.13 242 1.189 0.155 4.507 0.986 001 100 2000 1.03 242 1.179 0.195 5.54 0.986 001 100 2000 1.06 240 1.779 0.196 5.64 0.986 010 100 2000 1.079 0.196 6.964 0.980 011 100 2000 1.679 242 1.769 0.026 7.165 0.960 011 100 2000 1.679 243 1.779 0.026 7.165 0.960 011 100 2000 1.659</td><td>3</td><td>101</td><td>100</td><td>200</td><td>1.21</td><td>24.0</td><td>1,128</td><td>0.359</td><td>2.016</td><td>0.980</td></td<>	1 001 100 2000 122 210 1.170 0.257 2.722 0.380 5 001 100 500 122 242 1.180 0.157 3.414 0.380 3.84 0.380 5 3.94 0.380 0.385 4.384 0.386 4.384 0.386 4.384 0.386 4.384 0.386 4.384 0.386 5 0.391 100 5500 1.13 242 1.189 0.154 5.707 0.386 5 0.391 0.386 5 0.393 5.854 0.380 5 0.386 5.854 0.380 5 0.386 5.854 0.380 5 0.391 0.388 5.954 0.380 5 0.391 0.396 5.854 0.380 5 0.390 5.354 0.380 5.954 0.380 5.954 0.380 5.954 0.380 5.954 0.380 5.954 0.380 5.954 0.380 5.954 0.380 5.954 0.380	1 001 000 5000 122 210 1.70 0.279 2.72 038 5 001 000 5000 112 212 1.389 0.357 3.444 038 6 001 000 5000 113 242 1.389 0.354 5.457 0.386 4.384 0.386 4.384 0.386 4.384 0.386 4.384 0.386 4.384 0.386 4.384 0.386 4.384 0.386 4.384 0.386 4.384 0.386 6.386 0.386 6.386 0.386 6.386 0.386 6.386 0.386 6.386 0.386 6.386 0.386 6.382 0.386 6.382 0.386 6.382 0.386 6.382 0.386 6.382 0.386 6.382 0.386 6.382 0.386 6.382 0.386 6.382 0.386 6.382 0.386 6.382 0.386 6.382 0.386 6.382 0.386 6.382 0.386 6.382<	0 00 100 2000 122 210 1.170 0.257 2.722 0.986 001 100 2000 1.13 242 1.188 0.155 4.384 0.986 001 100 2000 1.13 242 1.189 0.155 4.384 0.986 001 100 2000 1.13 242 1.189 0.155 4.507 0.986 001 100 2000 1.03 242 1.179 0.195 5.54 0.986 001 100 2000 1.06 240 1.779 0.196 5.64 0.986 010 100 2000 1.079 0.196 6.964 0.980 011 100 2000 1.679 242 1.769 0.026 7.165 0.960 011 100 2000 1.679 243 1.779 0.026 7.165 0.960 011 100 2000 1.659	3	101	100	200	1.21	24.0	1,128	0.359	2.016	0.980
5 901 100 5000 122 24.2 1.89 0.364 5.484 0.380 7 901 100 5000 113 24.2 1.89 0.365 5.484 0.380 8 901 100 5000 103 24.2 1.89 0.365 5.894 0.380 9 901 100 5000 106 24.0 1.770 0.195 5.894 0.380 9 901 100 5000 103 24.1 1.769 0.088 6.986 0.898 101 100 5000 103 24.1 1.769 0.088 6.986 0.898 101 100 5000 103 24.1 1.709 0.088 6.986 0.898 102 901 100 5000 1.71 24.1 1.709 0.088 6.986 0.898 103 100 5000 1.71 24.1 1.709 0.089 7.279	5 001 100 5200 112 242 1180 0.257 3.407 0.380 9 001 100 5200 1.13 242 1.180 0.154 5370 0.380 9 001 100 5200 1.06 242 1.180 0.154 5370 0.380 9 001 100 5200 106 242 1.179 0.058 6.998 0.980 8 001 100 5200 106 242 1.179 0.058 6.998 0.980 9 100 5200 1.99 241 1.79 0.058 6.998 0.980 1 001 100 5200 1.99 241 1.79 0.058 6.998 0.980 1 001 100 5200 1.99 241 1.79 0.068 6.964 0.900 2 001 100 5200 1.92 1.170 0.002 7.290<	5 091 100 5200 112 242 1,369 0,357 3,497 0.988 9 091 100 5200 113 242 1,369 0,354 5,070 0,988 0,988 0,988 0,991 100 5200 106 242 1,369 0,354 5,070 0,988 6,988 0,988 6,988 0,988 6,988 0,988 6,988 0,988 6,988 0,988 6,988 0,988 6,988 0,988 6,988 0,988 6,988 0,988 6,988 0,988 6,988 0,988 6,988 0,988 6,988 0,988 6,988 0,988 6,988 0,988 6,982 0,900 1,179 0,006 6,642 0,900 1,179 0,006 6,642 0,900 1,179 0,006 6,642 0,900 1,179 0,000 7,16 0,300 1,179 0,000 7,16 0,300 1,179 0,000 7,16 0,300 1,179 0,0002	00 100 500 122 242 1380 0.257 3.497 0.981 001 100 5200 1.13 242 1.180 0.354 5340 0.981 001 100 5200 1.66 242 1.180 0.354 5470 0.981 001 100 5200 1.66 242 1.170 0.068 6.078 0.981 001 100 5200 1.06 242 1.170 0.068 6.078 0.981 011 100 5200 1.091 242 1.160 0.068 6.052 0.901 011 100 5200 1.091 242 1.170 0.068 6.052 0.900 1 011 100 5200 1.071 243 1.170 0.008 6.064 0.960 1 011 100 5200 1.91 1.70 0.000 7.16 0.900 1 101 100	4	101	100	3000	1.23	24.0	1.120	0.299	2.772	0.980
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				2	- 24	100	1200	0.01	24.5	1,100	0.000	7.517	0.500
					101	100	1200	0.58	24.5	1.170	0.002	7 290	0.000
					7764				100000		10000		

As the data is sampled, it is stored in spreadsheet format, updated each time the data is sampled. The table also contains columns for the calculated values.

New sheets can be added to the spreadsheet for different data runs by clicking the

icon from the main toolbar. Sheets can be renamed by double clicking on the sheet name at the bottom left corner of the screen (initially Run 1, Run 2 etc) then entering the required name.

For more detailed information about Data Logging and changing the settings within the software refer to the **Help** available via the upper toolbar when operating the software.

Graphical Display

When several samples have been recorded, they can be viewed in graphical format.

To view the data in Graphical format click the View graph icon from the main tool bar or click **Graph** from the **View** drop-down menu as shown:



The results are displayed in a graphical format as shown:



(The actual graph displayed will depend on the product selected and the exercise that is being conducted, the data that has been logged and the parameter(s) that has been selected).

Powerful and flexible graph plotting tools are available in the software, allowing the user full choice over what is displayed, including dual y axes, points or lines, displaying data from different runs, etc. Formatting and scaling is done automatically by default, but can be changed manually if required.

To change the data displayed on the Graph click **Graph Data** from the **Format** dropdown menu as shown:

2		- 🗆 🗙
File Edit View Options Sample	Format Window Help	
	Graph 🕨	
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The available parameters (Series of data) are displayed in the left hand pane as shown:

XAvis Context Compressor Discharge Qv [Va] Image: Compressor Discharge Qv [Va] Available Series Series on Primary Y Avis Fun 1 Mechanical Power Pm [V/] Run 1 Predicted Compressor Dever Run 2 Mechanical Power Pm [V/] Run 2 Predicted Compressor Flictory Run 2 Mechanical Power Pm [V/] Run 2 Compressor Flictory Run 2 Predicted Compressor Flictory Run 2 Predicted Compressor Power Run 2 Predicted Compressor Flictory Run 2 Run 2	te		
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Build 2 Medical Compressor Price Sinite on Secondary Y Akis Run 2 Compressor Total Pressure p(L) Sinite on Secondary Y Akis Run 2 Compressor Total Pressure p(L) Image: Sinite on Secondary Y Akis Run 2 Predicted Compressor Durb Puil Image: Sinite on Secondary Y Akis Run 2 Predicted Total Pressure p(L) Image: Sinite on Secondary Y Akis Run 2 Predicted Total Pressure p(L) Image: Sinite on Secondary Y Akis Run 2 Predicted Total Pressure p(L) Image: Sinite on Secondary Y Akis Run 2 Predicted Total Pressure p(L) Image: Sinite on Secondary Y Akis Run 2 Predicted Total Pressure p(L) Image: Sinite on Secondary Y Akis Run 2 Predicted Compressor Efficien Image: Sinite on Secondary Y Akis Image: Sinite on Secondary Y Akis Image: Sinite on Secondary Y Akis Image: Sinite on Secondary Y Akis Image: Sinite on Secondary Y Akis Image: Sinite on Secondary Y Akis Image: Sinite on Secondary Y Akis Image: Sinite on Secondary Y Akis Image: Sinite on Secondary Y Akis Image: Sinite on Secondary Y Akis Image: Sinite on Secondary Y Akis Image: Sinite on Secondary Y Akis Image: Sinite on Secondary Y Akis Image: Sinite on Secondary Y Akis Image: Sinite on Secondary Y Akis Image: Sinite on Secondary Y Akis Image: Sinite on Secondary Y Akis Image: Sinite on Secondary Y Akis Image: Sinite	un 1 Mechanical Power Pm [W] lun 1 Congressor Power Output Pu lun 1 Predicted Compressor Power I lun 1 Predicted Total Pressure pIC2 un 1 Predicted Compressor Filling	Bun 1 Compressor Total Pressur	
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Two axes are available for plotting, allowing series with different scaling to be presented on the same x axis.

To select a series for plotting, click the appropriate series in the left pane so that it is highlighted then click the appropriate right-facing arrow to move the series into one of the windows in the right hand pane. Multiple series with the same scaling can be plotted simultaneously by moving them all into the same window in the right pane.

To remove a series from the graph, click the appropriate series in the right pane so that it is highlighted then click the appropriate left-facing arrow to move the series into the left pane.

The X-Axis Content is chosen by default to suit the exercise. The content can be changed if appropriate by opening the drop down menu at the top of the window.

The format of the graphs, scaling of the axes etc. can be changed if required by clicking **Graph** in the **Format** drop-down menu as shown:

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For more detailed information about changing these settings refer to the **Help** available via the upper toolbar when operating the software.

PID Control

Where appropriate, the software associated with some products will include a single or multiple PID control loops whereby a function on the product can be manually or automatically controlled using the PC by measuring an appropriate variable and varying a function such as a heater power or pump speed.

The PID loop can be accessed by clicking the box labelled **PID** or **Control** depending on the particular software:



A PID screen is then displayed as shown:

B. W. W. DEDE		Mode of Operation
Process Variable Iniet Pressure	<u>+</u>	C Automatic
Control Variable Pump Speed	*	
Control Action Reverse	+	(• Manual
Settings Calculations		
Time Since Last Calculation:	0.250 secs	
Calculated Error:	300.0 kPa	[22 % measured full span
Proportional Portion of PID output:	21.6 %	[17.8 % of output]
Integral Portion of PID output:	100.0 %	[82.2 % of output]
Derivative Portion of PID output:	0.0 %	[0.0 % of output]
Gain:	0.1	
Calculated PID output:	122.0 %	
Output at Zero Error:	39.0 %	
Actual PID Output:	100.0 %	

The Mode of operation always defaults to **Manual** control and 0% output when the software is loaded to ensure safe operation of the equipment. If appropriate, the operator can retain manual operation and simply vary the value from 0 to 100% in the **Manual Output** box, then clicking **Apply**.

Alternatively, the PID loop can be changed to Automatic operation by clicking the **Automatic** button. If any of the PID settings need to be changed from the default values then these should be adjusted individually before clicking the **Apply** button.

The controller can be restored to manual operation at any time by clicking the **Manual** button. The value in the **Manual Output** box can be changed as required before clicking the **Apply** button.

Settings associated with Automatic Operation such as the **Setpoint**, **Proportional Band**, **Integral Time**, **Derivative Time** and **Cycle Time** (if appropriate) can be changed by the operator as required before clicking the **Apply** button.

Clicking **Calculations** displays the calculations associated with the PID loop to aid understanding and optimization of the loop when changing settings as shown:

Process Variable Inlet Pressure		Mode of Operation
Control Variable Pump Speed	*	C Manual
Control Action Reverse	4	
Settings Calculations		
Time Since Last Calculation:	0.250 secs	
Calculated Error:	300.0 kPa	[22 % measured full span]
Proportional Portion of PID output:	21.6 %	[74.0 % of output]
Integral Portion of PID output:	7.6 %	[26.0 % of output]
Derivative Portion of PID output	0.0 %	[0.0 % of output]
Gain:	0.1	
Calculated PID output	29.2 %	
Output at Zero Error:	0.0 %	
Actual PID Output:	29.2 %	

Clicking **Settings** returns the screen to the PID settings.

Clicking **OK** closes the PID screen but leaves the loop running in the background.

In some instances the **Process Variable, Control variable** and **Control Action** can be varied to suit different exercises, however, in most instances these boxes are locked to suit a particular exercise. Where the variables can be changed the options available can be selected via a drop-down menu.

Advanced Features

The software incorporates advanced features such as the facility to recalibrate the sensor inputs from within the software without resorting to electrical adjustments of the hardware. For more detailed information about these advanced functions within the software refer to the **Help** available via the upper toolbar when operating the software.

Operating the Equipment

Before operating the equipment, ensure that the HT36 Extended Tubular Heat Exchanger and the HT30XC base unit have been assembled and installed as shown in the separate Installation section.

Connecting the heat exchanger to the service unit

The connections required are as follows:



The connectors are colour coded on both the service unit and the heat exchanger accessory, with blue for cold water and red for hot water.

Configuring the heat exchanger for countercurrent and cocurrent flow

The cold water supply always enters the heat exchanger at the same end. The hot water supply may be configured to enter at the same end as the cold water flow (cocurrent flow), or at the opposite end (countercurrent flow). The direction of the hot water flow is set by the direction of the hot water pump. This is controlled by the software, and thus countercurrent flow may be set by selecting a 'Countercurrent' software exercise and cocurrent flow by selecting a 'Cocurrent' exercise.

Configuring the number of active heat exchanger tubes

The heat exchanger may be used with one, two, three or four active sections. To configure the exchanger, close each manual valve on the heat exchanger (but NOT the valves on the HT30XC service unit) by turning the handle at right-angles to the tube. Then open the appropriate valve as follows:

4 tubes

Open the lower right valve on the exchanger (turn handle in line with tube)



3 tubes

Open the lower left valve on the exchanger



2 tubes

Open the upper right valve on the exchanger



1 tube

Open the upper left valve on the exchanger



If you are uncertain as to the correct valve settings, run the software and select the number of active tubes you require. The software will then show an image with the correct valve settings on the display screen.

Configuring the software to match the number of active tubes

The cocurrent and countercurrent exercises in the software (not the Project Work exercises) include a panel on the left when the number of active sections may be selected. When one of these options is selected, the software screen displays the manual valve settings for the cold water circuit, and the inactive outer annuli (i.e. those through which the cold water does not flow) are dimmed on the display.

Priming the hot water circuit

The hot water circuit should be filled with deionised or demineralised water if possible, to minimise scale and reduce the need for cleaning. If this is not available then the water used should be clean. To prime the hot water circuit, fill the hot water vessel on the HT30XC service unit with water by carefully removing the lid (without damaging the level sensor attached to it) and pouring in the water. The vessel should be filled until it covers the tip of the level sensor mounted on the lid of the vessel.

Check that the accessory has been connected to the service unit as described above, and that the service unit is connected to a suitable PC. Switch on the service unit using the mains switch on the front of the unit.

Run the HT36 software (any exercise). Switch the service unit from standby to on by selecting the 'Power On' switch on the software mimic diagram screen.

Select the hot water flow rate control button. In the controller window, set the controller to 'Manual' and gradually increase the manual control setting to 100% using the arrow buttons. Check that the pump starts to operate and water begins to flow through the hot water system. The hot water vessel may need topping up as water enters the rest of the system, to keep the tip of the level sensor covered.

Select the heater control button, and set the controller to Automatic with a Set Point of 80°C (maximum operating temperature- do not operate at this temperature for more than a few minutes, as prolonged high temperatures may cause softening and warping of the acrylic outer heat exchanger tube). The heater should begin to operate. As the water heats, dissolved air will be released from the hot water. The resulting bubbles, along with any air still remaining in the system after the initial priming process, will be gradually flushed from the system and into the hot water vessel as hot water continues to flow through the system. They may be encouraged to move by gently squeezing the flexible tubing.

Controlling the cold water flow

DO NOT re-adjust the pressure regulator to vary the flow of cold water through the heat exchanger.



The cold water flow should be adjusted using the cold water flow control valve, which can be set using the control box on the software screen.

Controlling the hot water flow

The hot water flow rate can be controlled using the hot water pump, which can be set using the PID controller in the software. To adjust the controller Set Point or PID values, click on the hot water 'Flow' button on the software screen to open the controller window, and select 'Automatic'. For approximate default values of the controller settings, the Proportional Band may be set to 100%, with an Integral time of 3s and Derivative time of 0s (these values are set by default and in most cases the flow rate can be controlled by simply entering the required flow rate in the Set Point box). The settings required for the exercises included in this manual described in the individual Laboratory Teaching Exercises and in the software Help Text.

Setting the hot water temperature controller

The hot water temperature can be controlled using the heater (SSR drive) in the hot water vessel, which is operated using the 'Heater' controller in the software. Selecting this controller button opens the controller window, and the controller should then be set to Automatic. The Proportional Band should be set to 100%, with Integral and Derivative times of 0s. The Set Point value (i.e. the required temperature) should then be entered in the appropriate box.

By default, the heater controller compares the Set Point value to the inlet temperature of the hot water stream as it enters the heat exchanger, and adjusts the proportion of heating time until the inlet temperature matches the required Set Point.

The hot water stream always flows through every section of tubing, but depending on the configuration of the cold water supply, not every section of the heat exchanger will be part of the heat exchange process. In cocurrent flow, the point at which the hot water enters the active section of the heat exchanger will differ depending on the number of active tubes. By default, the controller is set to monitor the temperature T5 (the initial inlet point), which will give reasonable accuracy. However, for greater accuracy the controller may be reconfigured to monitor the inlet temperature for the active section of the heat exchanger. To change the temperature monitored, open the controller window and select the required thermocouple from the 'Process Variable' drop-down list.

Measuring the water temperatures

The water temperatures are displayed on the mimic diagram screen. The values displayed reflect the configuration selected, i.e. the number of tubes through which the hot and cold water streams are flowing. The correct number of tubes should be selected in order to display the relevant temperatures.

Prevention of bubbles in the hot water circuit

Before taking results, ensure that all air bubbles have been expelled from the water via the priming vessel. Note that as the water is heated for the first time the air dissolved in the water will continue to be released. It is therefore sensible to heat the water to the maximum intended operating temperature before carrying out tests at lower temperatures, as described in **Priming the Hot Water Circuit**.

The hot water vessel is equipped with a level sensor, which will cut electrical power to the heating element and pump until the system is primed.

Effect of cold water temperature on heat exchange

The temperature of the water entering the equipment from the mains cold water supply will affect the range of range of hot and cold water flowrates and/or the temperature of the hot water that can be achieved when using the equipment.

The heater in the hot water circulator has a nominal rating of 2 kW, limiting the heat exchange from the hot water stream to the cold water stream to this value. If the temperature of the hot water will not reach the value set on the PID controller with the controller providing full power to the heater then this indicates that the limit of the heater power has been reached. This is not a problem and simply requires an adjustment to the settings on the equipment.

To operate with the same flowrates then a lower hot water temperature must be accepted (reduced differential temperature between the two fluid streams). To operate with an elevated hot water temperature then one or both of the flowrates must be reduced until the demand on the heater is less than 2 kW.

Some of the settings in the practical training exercises may be affected in this way. An excessively warm mains water supply will not present any problems since the temperature difference between the two fluid streams will be reduced. This would allow the hot water stream to be increased to even higher temperatures than quoted. An excessively cold mains water supply may mean that the hot water temperature quoted cannot be achieved because of the increased temperature difference between the two fluid streams. Operation at reduced hot water temperature or reduced flowrate must then be accepted.

Connecting HT30X or HT30XC to a PC

The USB port on the right hand side of the console allows the voltage signals from the sensors, valve and pump to be sent to the USB port of a suitable PC. The Windows[™] based HT36 software allows control of the HT30XC service unit, and logging of the sensor outputs from the heat exchanger. The software should be installed on a PC running Windows[™] 98 or later, which must have an available USB port for connection to the Ht30XC. The software MUST be installed before connecting the PC to the service unit- installation is described in the product Installation section.

Once the software has been installed and the PC has been connected to the service unit with the HT36 accessory in place and connected as described in the Installation section, the HT36 software should be run (Select Armfield Heat Exchanger Software from your Start menu and select HT36). The software will then present a selection of exercises to choose from. The Laboratory Teaching Exercises provided in this manual describe the appropriate exercise to pick (either Countercurrent or Cocurrent). If performing independent study work or other project work that does not use a standard configuration then one of the two Project Work exercises may be chosen instead.

Use of the software for controlling the equipment and logging the sensor data is described in the Laboratory Teaching Exercises. This information is also available in the Software Help Text, accessible from within the software. It is recommended that students perform at least a representative selection of the Laboratory Teaching Exercises, to become familiar with the equipment and the use of the software, before attempting independent project work.

Operation of Guest push fittings

Guest push fittings are used on the equipment for convenience when changing the configuration or removing items for cleaning. The diagrams below show the simple operation of these fittings:

To connect to a quick release fitting

Align the parallel section of the rigid tube with the loose collet on the quick release fitting...



and push firmly until the tube stops.



An 'O' ring inside the fitting provides a leak-proof seal between the tube and the fitting. The collet grips the tube and prevents it from being pulled out from the fitting.

To disconnect from a quick release fitting

Push the loose collet against the body of the quick release fitting while pulling the tube firmly.



The tube will slide out from the fitting. The tube/fitting can be assembled and disassembled repeatedly without damage.

Equipment Specifications

I/O Port Pin Connections

To allow access to the measurement signals in applications other than when using the apparatus with an Armfield data logger interface and associated software, the connections to the 50 way connector are listed below for information:

Pin No	Channel No	Signal Function		
Analog Inputs (0-5 V dc):				
1	Ch 0	Temperature 1 (0-200°C)		
2	Ch 1	Temperature 2 (0-200°C)		
3	Ch 2	Temperature 3 (0-200°C)		
4	Ch 3	Temperature 4 (0-200°C)		
5	Ch 4	Temperature 5 (0-200°C)		
6	Ch 5	Temperature 6 (0-200°C)		
7	Ch 6	Temperature 7 (0-200°C)		
8	Ch 7	Temperature 8 (0-200°C)		
9	Ch 8	Temperature 9 (0-200°C)		
10	Ch 9	Temperature 10 (0-200°C)		
11	Ch 10	Flow F1 (0-3 L/min)		
12	Ch 11	Flow F2 (0-1.5 L/min)		
13-21	Not used			
Analog O	utputs (0-5V dc):			
22	Not used			
23	Ch 0	Hot water pump speed		
24	Ch 1	Cold water valve setting		
25	Not used			

Digital Inputs (0-5V dc):			
26-27	Not Used		
30	Ch 2	Level Monitor	
21-32	Not used		
33	Ch 4	Thermostat Monitor	
34-37	Not used		
Digital Outp	outs (0-5V dc):		
38	Ch 0	Power On	
39	Ch 1	Watchdog pulse	
40	Ch 2	SSR drive	
41	Ch 3	Pump direction	
42	Digital Ground		
43	Ch 4	Stirrer on	
44	Ch 5	Aux heater on	
47-48	Digital Ground		
49-50	Not Used		

USB Channel Numbers

The HT36 includes Windows[™]-compatible software for full remote operation of the equipment and data logging of all output signals. However, users may prefer to write their own software for control and data logging, and for the convenience of those wishing to do so, Armfield has provided additional USB drivers allowing operation of the equipment via the USB socket on the HT30XC console. The relevant channel numbers for the HT36 are as follows:

Channel No	Signal Function
Analog Inputs (0-	5 V dc):
Channel 0	Temperature T1 (0 to133°C = -5 to +5 V)
Channel 1	Temperature T2 (0 to133°C = -5 to +5 V)

Channel 2	Temperature T3 (0 to133°C = -5 to +5 V)		
Channel 3	Temperature T4 (0 to133°C = -5 to +5 V)		
Channel 4	Femperature T5 (0 to133°C = -5 to +5 V)		
Channel 5	Temperature T6 (0 to133°C = -5 to +5 V)		
Channel 6	Temperature T7 (0 to133°C = -5 to +5 V)		
Channel 7	Temperature T8 (0 to133°C = -5 to +5 V)		
Channel 8	Temperature T9 (0 to133°C = -5 to +5 V)		
Channel 9	Temperature T10 (0 to133°C = -5 to +5 V)		
Channel 10	Hot water flow F _{hot} (0 to 25 L/min = 0 to 5 V)		
Channel 11	Cold water flow F_{cold} (0 to 5 L/min = 0 to 5 V)		
Analog Outputs (0-5V dc):			
Channel 0	Hot water pump speed		
Channel 1	Cold water valve setting		
Digital Inputs (0-5	V dc):		
Channel 0	Not Used		
Channel 1	Not Used		
Channel 2	Level monitor		
Channel 4	Thermostat monitor		
Digital Outputs (0-5V dc):			
Channel 0	Power on required (1 = on)		
Channel 1	Watchdog pulse (1 pulse every 5 seconds)		
Channel 2	SSR drive (1 = on)		
Channel 3	Pump direction (1 = cocurrent)		

Environmental Conditions

This equipment has been designed for operation in the following environmental conditions. Operation outside of these conditions may result reduced performance, damage to the equipment or hazard to the operator.

- a. Indoor use;
- b. Altitude up to 2000 m;
- c. Temperature 5 °C to 40 °C;
- d. Maximum relative humidity 80 % for temperatures up to 31 °C, decreasing linearly to 50 % relative humidity at 40 °C;
- e. Mains supply voltage fluctuations up to ±10 % of the nominal voltage;
- f. Transient over-voltages typically present on the MAINS supply;

Note: The normal level of transient over-voltages is impulse withstand (over-voltage) category II of IEC 60364-4-443;

g. Pollution degree 2.

Normally only nonconductive pollution occurs.

Temporary conductivity caused by condensation is to be expected.

Typical of an office or laboratory environment
Routine Maintenance

Responsibility

To preserve the life and efficient operation of the equipment it is important that the equipment is properly maintained. Regular maintenance of the equipment is the responsibility of the end user and must be performed by qualified personnel who understand the operation of the equipment.

General

In addition to regular maintenance the following notes should be observed:

- 1. The HT30XC service unit should be disconnected from the electrical and water supplies when not in use.
- 2. Water should be drained from the inner tubes and outer annulus of the HT36 heat exchanger after use to minimise build up of scale or fouling on the heat exchange surfaces.

The water can be drained by simply disconnecting the four flexible tubes connecting the exchanger to the HT30XC service unit.

3. Any build up of scale inside the heat exchanger can be removed by passing a mild descaler through the exchanger then flushing thoroughly with clean water.

Any stubborn deposits can be eliminated by manual cleaning having carefully removed the inner tube from the outer annulus. To remove the metal tube for cleaning, disconnect the quick release fittings from each end of the metal tube then pull the tube out of the assembly taking care not to damage the 'O' ring seals. After cleaning, lubricate the 'O' ring seals with a small amount of wetting agent before re-inserting the metal tube and replacing the quick release fittings.

Note: The PVC housing at each end of the acrylic tube is bonded to the acrylic tube and cannot be removed.

If it is necessary to replace the 'O' ring seals the replacements should have the following specification:

Material Nitrile rubber

Diameter To suit 3/8" shaft

Section 0.103" section

For reference the Dowty part number is 200-110-4470

Laboratory Teaching Exercises

Index to Exercises

Exercise A - Indirect Heating/Cooling Demonstration

Exercise B - Energy Balance and Overall Efficiency

Exercise C - Cocurrent and Countercurrent Flow

Exercise D - Overall Heat Transfer Coefficient

Exercise E: Effect of Flow Rate

Exercise F: Driving Force

Exercise G: Project Work

Nomenclature

Name	Symbol	SI Unit	Notes/Calculation
ID of tube	di	m	0.0083
OD of tube	d _o	m	0.0095
ID of shell	d _s	m	0.014
Arithmetic mean diameter of tube	d _m	m	$d_{m} = \frac{d_{o} + d_{i}}{2}$
Heat transmission length	L	m	0.330 per tube
Heat transfer area	A	m²	π.d _m .L
Specific Heat Capacity hot fluid	Cp _{hot}	kJ/kg°K	From table 1
Specific Heat Capacity cold fluid	Cp _{cold}	kJ/kg°K	From table 1
Hot fluid inlet temperature	T1	(°C)	T5 Cocurrent
Hot fluid intermediate temperature 1	T2	(°C)	T4 Cocurrent
Hot fluid intermediate temperature 2	Т3	(°C)	
Hot fluid intermediate temperature 3	T4	(°C)	T2 Cocurrent

Hot fluid outlet temperature	Т5	(°C)	T1 Cocurrent
Cold fluid inlet temperature	Т6	(°C)	
Cold fluid intermediate temperature 1	T7	(°C)	
Cold fluid intermediate temperature 2	Т8	(°C)	
Cold fluid intermediate temperature 3	Т9	(°C)	
Cold fluid outlet temperature	T10	(°C)	
Decrease in hot fluid temperature	∆t _{hot}	°C	T1 – T5 (Counter)
Increase in cold fluid temperature	∆t _{cold}	°C	T6 – T10
Driving force, inlet	Δt ₁	°C	T1 – T10
Driving force, outlet	∆t ₂	°C	T5 – T6
Logarithmic Mean Temperature Difference	∆tım	°C	$\frac{\Delta t_1 - \Delta t_2}{\ln(\Delta t_1 / \Delta t_2)}$
Volume flowrate (hot fluid)	qv _{hot}	m³/s	From F _{hot} (litres/min)
Volume flowrate (cold fluid)	qv_{cold}	m³/s	From F _{cold} (litres/min)
Density of hot fluid	Phot	kg/m ³	From table 2
Density of cold fluid	$ ho_{cold}$	kg/m ³	From table 2
Mass flow rate hot fluid	qm _{hot}	kg/s	$qv_{hot} \ x \ \rho_{hot}$
Mass flow rate cold fluid	qm _{cold}	kg/s	$Qv_{cold} \ x \ \rho_{cold}$
Heat power emitted from hot fluid	Q _e	W	qm _h .(Cp) _h (T1 – T5)
Heat power absorbed by cold fluid	Q _a	W	qm _c .(Cp) _c (T6 – T10)
Heat power lost (or gained)	Q _f	W	Q _e - Q _a

Overall Efficiency	η	%	$\frac{Q_{a}}{Q_{e}} \times 100$
Temperature Efficiency hot fluid	η_{hot}	%	$\frac{T5-T1}{T5-T6}$.100
Temperature Efficiency cold fluid	η_{cold}	%	$\frac{T6-T10}{T5-T6}$.100
Mean Temperature Efficiency	η_{mean}	%	$\frac{\eta_{h}+\eta_{c}}{2}$
Overall Heat Transfer Coefficient	U	W/m²⁰C	Q _e A.∆t _{lm}

Reference Tables

Table 1

Specific Heat Capacity of Water (Cp kJ/kg°K)

°C	0	1	2	3	4	5	6	7	8	9
0										
10	4.1274	4.2138	4.2104	4.2074	4.2045	4.2019	4.1996	4.1974	4.1954	4.1936
20	4.1919	4.1904	4.1890	4.1877	4.1866	4.1855	4.1846	4.1837	4.1829	4.1822
30	4.1816	4.1810	4.1805	4.1801	4.1797	4.1793	4.1790	4.1787	4.1785	4.1783
40	4.1782	4.1781	4.1780	4.1780	4.1779	4.1779	4.1780	4.1780	4.1781	4.1782
50	4.1783	4.1784	4.1786	4.1788	4.1789	4.1792	4.1794	4.1796	4.1799	4.1801
60	4.1804	4.1807	4.1811	4.1814	4.1817	4.1821	4.1825	4.1829	4.1833	4.1837
70	4.1841	4.1846	4.1850	4.1855	4.1860	4.1865	4.1871	4.1876	4.1882	4.1887
	4.1893	4.1899	4.1905	4.1912	4.1918	4.1925	4.1932	4.1939	4.1946	4.1954

Table 2

Density of Water (ρ kg/m³)

°C	0	2	4	6	8
0	999.8	999.9	999.9	999.9	999.9
10	999.7	999.5	999.2	998.9	998.6
20	998.2	997.8	997.3	996.8	996.2
30	995.7	995.0	994.4	993.7	993.0
40	992.2	991.4	990.6	989.8	988.9
50	988.0	987.1	986.2	985.2	984.2
60	983.2	982.2	981.1	980.0	978.9
70	977.8	976.6	975.4	974.2	973.0

Calculating Reynolds Number

For tubular heat exchangers, when using Reynold's Number to describe the characteristics of the exchanger it is usual to calculate it for the process fluid, which is generally the fluid flowing through the inner tube. It is also possible to calculate a Reynold's Number for fluid flowing through the outer shell. This may sometimes be of interest, for example in systems where one fluid has a high viscosity, which may provide more efficient heat exchange when directed through the outer shell if the flow is sufficiently turbulent.

Reynold's Number for a tubular heat exchanger may be calculated as follows:

For the Inner Tube (hot fluid if configured as described in the manual):

$$Re = \frac{\rho_t u_t d_i}{\mu_t}$$

Where ρ_t = Density of fluid in inner tube at temp T_{tave} (kg/m³)

 u_t = Fluid velocity in the inner tube (m/s)

 d_i = Tube ID = Inner diameter of tube (m)

= 892.5×10^{-6} m (see dimensions below)

 μ_t = Dynamic viscosity of fluid in inner tube at temp T_{tave} (10⁻³ m²/s)

where T_{tave} = Average temperature of fluid within inner tube (K)

For the Outer Tube (cold fluid if configured as described in the manual):

$$Re = \frac{\rho_s u_s de}{\mu s}$$

Where ρ_s = Density of fluid in outer shell at temp T_{save} (kg/m³)

 u_s = Fluid velocity in the outer shell (m/s)

d_e = Equivalent diameter of shell (m)

 $= \frac{4 \times \text{cross-sectional area}}{\text{wetted perimeter}}$ $= \frac{4 \left(\frac{\pi (\text{shell ID})^2}{4} - \frac{\pi (\text{tube OD})^2}{4} \right)}{\pi (\text{tube OD}) + \pi (\text{shell ID})}$ $= \frac{4 \left(\frac{\pi (0.0014)^2}{4} - \frac{\pi (0.0009525)^2}{4} \right)}{\pi (0.0009525) + \pi (0.0014)} \text{ (see dimensions below)}$ $= 111.875 \times 10^{-6} \text{ m}$

 μ_t = Dynamic viscosity of fluid in outer shell at temp T_{save} (10⁻³ m²/s)

where T_{save} = Average temperature of fluid within outer shell (K)

For the HT36, exchanger dimensions are as follows:

Tube ID = 8.925 mm = 0.0008925 mTube OD = 9.525 mm = 0.0009525 mShell ID = 14 mm = 0.0014 m

The HT36 software calculates Reynold's number for the hot and cold streams using the above equation. The software also automatically calculates the density and kinematic viscosity of the hot and cold fluid streams using the temperature of the relevant stream averaged over the entire length of the heat exchanger.

Exercise A: Indirect Heating/Cooling Demonstration

Objective

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)

Method

By measuring the changes in temperature of two separate streams of water flowing through the inner tube and outer annulus of a tubular (concentric double pipe) heat exchanger

Equipment Required

HT30XC Computer Compatible Heat Exchanger Service Unit

HT36 Extended Tubular Heat Exchanger

PC running Microsoft[™] Windows 98 or XP with available USB port

Equipment set-up

Before proceeding with the exercise, ensure that the equipment has been prepared as follows:

Locate the HT36 Extended Tubular Heat Exchanger on the HT30XC Service Unit and secure it using the knurled fixings.

Connect the ten thermocouples on the heat exchanger to the appropriate sockets on the front of the HT30XC plinth (labelled T1 - T10).

Connect the hot and cold water supplies as follows:



Ensure that a cold water supply is connected to the inlet of the pressure regulating valve.

Ensure that the service unit is connected to an electrical supply.

Switch on the front Mains switch.

Ensure that the service unit is connected to a suitable PC, and run the HT36 software. Select the Countercurrent exercise.

Switch the service unit from Standby to On by selecting the Power On switch on the mimic diagram screen.

Prime the hot and cold water circuits as described in the Operation section.

Open the cold water configuration valve for 4 tube configuration.



To open the valve, turn the black valve handle in line with the tube/valve body. Close the other three cold water configuration valves. To close the valve, turn the black handle at 90° to the tube/valve body.

Theory/Background

Any temperature difference across the metal tube wall will result in the transfer of heat between the two fluid streams. The hot water flowing through the inner tube will be cooled and the cold water flowing through the outer annulus will be heated.

Note: For this demonstration the heat exchanger is configured with the two streams flowing in opposite directions (countercurrent flow).



Procedure

(Refer to the Operation section if you need details of the instrumentation and how to operate it.)

In the software, in the 'Number of Tubes' box on the left, select '4'.

Set a cold water flow rate of approximately 1 l/min by adjusting the arrows on the side of the cold water flow rate display box.

Check the cold water inlet temperature T6 (shown in a display box on the mimic diagram screen).

Set the temperature controller to a set point approximately 30°C above the cold water inlet temperature (e.g. if T6 is 15°C then choose a Set Point of 45°C). Check that the Proportional Band is set to 100, the Integral Time to 3 and the Derivative Time to 0, and change them accordingly if they do not match these values.

Click on the Heater control box. In the heater controller window, type in the required value for the Set Point, and then select Automatic control from the selection on the top right of the window. Check that the Proportional Band is set to 5, the Integral Time to 200 and the Derivative Time to 0, and change them accordingly if they do not match these values. Click on 'Apply' and then 'OK' to close the window.

Set the hot water flow controller to give 3 l/min: click on the 'Flow' controller box, and type the required Set Point (3.0 l/min) into the Set Point box. The Proportional Band should be 100% and the Integral time should be 3s. The Derivative time should be 0s. Select 'Automatic' in the top right of the controller window, then 'Apply'. Select 'OK' to close the controller window.

Allow the heat exchanger to stabilise (monitor the temperatures on the mimic diagram display).

When the temperatures are stable select the ¹⁰⁰ icon on the top toolbar to record the following:

T1, T2, T3, T4, T5, T6, T7, T8, T9, T10, F_{hot}, F_{cold}.

Adjust the cold water control valve to give 2 litres/min, using the arrow buttons on the side of the display box.

Create a new results sheet using the icon.

Check that the correct number of tubes is still selected on the mimic diagram.

Allow the heat exchanger to stabilise then repeat the above readings by selecting the icon.

If there is ample time in which to take results, then other combinations of hot and cold water flow rates may be investigated. Remember to create a new results sheet for each set of results by selecting the icon.

Open the heater controller window and adjust the controller from 'Automatic' to 'Off'. Open the hot water pump controller window and change the set point to 0 l/min. Set the cold water flow control valve to 0%.

Close the manual flow valve for four tube configuration and open the valve for three tube configuration:



In the 'Number of Tubes' box on the left of the software screen, select 3.

Repeat the above procedure with the heat exchanger configured for three tubes (leave the software set to 3 tubes).

Remember to create a new results sheet for each set of results. The software will record all ten thermocouple outputs, but will use only the sensors on the active sections for performing calculations.

Set the heater, hot water pump and cold water valve to 0. Close the manual flow valve for three tubes, and open the valve for two tubes:



Repeat the procedure as before, remembering to create a new results sheet and to select the correct number of tubes in the software.

Finally, configure the accessory for operation with a single tube:



Repeat the above procedure.

Set the heater, pump and cold water flow valve to 0, then select the Power On switch to set the HT30XC service unit to Standby.

Results and Calculations

For each set of readings your raw data is presented in a table using the following headings:

Hot fluid volume flowrate	qv _{hot}	(m³/s)	From F _{hot} (litres/min)
Hot fluid inlet temperature	T1	(°C)	
Hot fluid mid temperature 1	T2	(°C)	
Hot fluid mid temperature 2	Т3	(°C)	
Hot fluid mid temperature 3	T4	(°C)	
Hot fluid outlet temperature	T5	(°C)	
Cold fluid volume flowrate	qv _{cold}	(m³/s)	From F _{cold} (litres/min)
Cold fluid volume flowrate Cold fluid inlet temperature	qv _{cold} T6	(m ³ /s) (°C)	From F _{cold} (litres/min)
Cold fluid volume flowrate Cold fluid inlet temperature Cold fluid mid temperature 1	qv _{cold} T6 T7	(m ³ /s) (°C) (°C)	From F _{cold} (litres/min)
Cold fluid volume flowrate Cold fluid inlet temperature Cold fluid mid temperature 1 Cold fluid mid temperature 2	qv _{cold} T6 T7 T8	(m ³ /s) (°C) (°C) (°C)	From F _{cold} (litres/min)
Cold fluid volume flowrate Cold fluid inlet temperature Cold fluid mid temperature 1 Cold fluid mid temperature 2 Cold fluid mid temperature 3	qv _{cold} T6 T7 T8 T9	(m ³ /s) (°C) (°C) (°C) (°C)	From F _{cold} (litres/min)

You should also estimate and record the experimental errors for these measurements.

For each set of readings your derived results are also tabulated under the following headings:

Reduction in hot fluid temperature $^{\Delta t_{hot}} = T1 - T5$ (°C)

Increase in cold fluid temperature $\Delta t_{cold} = T10 - T6$ (°C)

Estimate the cumulative influence of the experimental errors on your calculated values for Δt_{hot} and Δt_{cold} .

Compare the changes in temperature at the different flowrates.

Conclusion

You have demonstrated how, using a tubular heat exchanger, a stream of cold fluid can be heated by indirect contact with another fluid stream at a higher temperature (the fluid streams being separated by a wall which conducts heat). This transfer of heat results in a cooling of the hot fluid.

Comment on the changes in Δt_{tot} and Δt_{cold} when the flow of cold water is increased. The consequence of these changes will be investigated in a later exercise.

Comment on the effect of differing numbers of tubes (and therefore differing lengths of tubular heat exchanger).

Note: To save time Exercise B can be carried out using the readings obtained from this exercise.

Exercise B: Energy Balance and Overall Efficiency

Objective

To perform an energy balance across a Tubular Heat Exchanger and calculate the Overall Efficiency at different fluid flowrates.

Method

By measuring the changes in temperature of the two separate fluid streams in a tubular heat exchanger and calculating the heat energy transferred to/from each stream to determine the Overall Efficiency.

Equipment Required

As Exercise A.

Optional Equipment

As Exercise A.

Equipment set-up

If using the results from Exercise A then the equipment is not required.

If previous results are not available refer to the Set-up and Procedure sections of Exercise A.

Theory/Background

Note: For this demonstration the heat exchanger is configured for countercurrent flow (the two fluid streams flowing in opposite directions).

Mass flow rate (qm) = Volume flow rate (qv) x Density of fluid (ρ) (kg/s)

Heat power (Q) = Mass flow rate (qm) x specific heat (Cp) x change in temperature (ΔT) (W)

Therefore:

Heat power emitted from hot fluid $Q_e = qm_h.(Cp)_h (T1 - T5) (W)$

Heat power absorbed by cold fluid $Q_a = qm_c.(Cp)_c (T6 - T10) (W)$

Heat power lost (or gained) $Q_f = Q_e - Q_a$ (W)

$$\eta = \frac{Q_{a}}{Q_{e}} \ge 100$$

Overall Efficiency

Theoretically Q_e and Q_a should be equal. In practice these differ due to heat losses or gains to/from the environment.

Note: In this exercise the cold fluid is circulated through the outer annulus, if the average cold fluid temperature is above the ambient air temperature then heat will be lost to the surroundings resulting in η <100%. If the average cold fluid temperature is below the ambient temperature then heat will be gained resulting in η >100%.

Procedure

Use the results obtained from Exercise A.

Results and Calculations

For each set of readings your raw data is presented in a table using the following headings:

Hot fluid volume flowrate	qv _{hot}	(m ³ /s)	From F _{hot} (litres/min)
Hot fluid inlet temperature	T1	(°C)	
Hot fluid mid temperature 1	T2	(°C)	
Hot fluid mid temperature 2	Т3	(°C)	
Hot fluid mid temperature 3	T4	(°C)	
Hot fluid outlet temperature	T5	(°C)	
Cold fluid volume flowrate	qv _{cold}	(m³/s)	From F _{cold} (litres/min)
Cold fluid volume flowrate Cold fluid inlet temperature	qv _{cold} T6	(m ³ /s) (°C)	From F _{cold} (litres/min)
Cold fluid volume flowrate Cold fluid inlet temperature Cold fluid mid temperature 1	qv _{cold} T6 T7	(m ³ /s) (°C) (°C)	From F _{cold} (litres/min)
Cold fluid volume flowrate Cold fluid inlet temperature Cold fluid mid temperature 1 Cold fluid mid temperature 2	qv _{cold} T6 T7 T8	(m ³ /s) (°C) (°C) (°C)	From F _{cold} (litres/min)
Cold fluid volume flowrate Cold fluid inlet temperature Cold fluid mid temperature 1 Cold fluid mid temperature 2 Cold fluid mid temperature 3	qv _{cold} T6 T7 T8 T9	(m ³ /s) (°C) (°C) (°C) (°C)	From F _{cold} (litres/min)

You should also estimate and record the experimental errors for these measurements.

For each set of readings, the software calculates the following variables. These may also be obtained from the <u>Reference Tables</u>:

Specific heat of hot fluid	Срһ	kJ/kg°K (From table 1 using average hot water temperature)
Specific heat of cold fluid	Ср _с	kJ/kg°K (From table 1 using average cold water temperature)
Density of hot fluid	ρ _h	kg/m ³ (From table 2 using average hot water temperature)
Density of cold fluid	ρ _c	kg/m ³ (From table 2 using average cold water temperature)

For each set of readings, your derived results are also tabulated under the following headings:

Mass flow rate (hot fluid)	qm _h	(kg/s)
Mass flow rate (cold fluid)	qm _c	(kg/s)
Heat power emitted	Q _e	(VV)
Heat power absorbed	Q _a	(VV)
Heat power lost	Q _f	(VV)
Overall Efficiency	η	(%)

Estimate the cumulative influence of the experimental errors on your calculated values for Q_e, Q_a, Q_f and $\eta.$

Compare the heat power emitted from/absorbed by the two fluid streams at the different flowrates.

Conclusion

Explain any difference between Qe and Qa in your results.

Comment on the effects of the increase in the cold fluid flowrate.

Exercise C should be carried out on completion of this exercise.

Exercise C: Cocurrent and Countercurrent Flow

Objective

To demonstrate the differences between cocurrent flow (hot and cold flows in same direction) and countercurrent flow (hot and cold flows in the opposite direction) and the effect on the heat transferred, temperature efficiencies and temperature profiles through a Tubular Heat Exchanger.

Method

By measuring the temperatures of the two fluid streams. Using the temperature changes and differences, to calculate the heat energy transferred and the temperature efficiencies.

Equipment Required

HT30XC Computer Compatible Heat Exchanger Service Unit

HT36 Extended Tubular Heat Exchanger

PC running Microsoft[™] Windows 98 or XP with available USB port

Equipment set-up

Before proceeding with the exercise, ensure that the equipment has been prepared as follows:

Locate the HT36 Extended Tubular Heat Exchanger on the HT30XC Service Unit and secure it using the knurled fixings.

Connect the ten thermocouples on the heat exchanger to the appropriate sockets on the front of the HT30XC plinth (labelled T1 - T10).

Connect the hot and cold water supplies as follows:



Ensure that a cold water supply is connected to the inlet of the pressure regulating valve.

Ensure that the service unit is connected to an electrical supply.

Switch on the front Mains switch.

Ensure that the service unit is connected to a suitable PC, and run the HT36 software. Select the Countercurrent exercise.

Switch the service unit from Standby to On by selecting the Power On switch on the mimic diagram screen.

Prime the hot and cold water circuits as described in the Operation section.

Open the cold water flow control valve to give a 4 tube configuration (turn the black valve handle in line with the tube/valve body).



Close the other three manual valves on the accessory configuration (turn the black valve handles at right angles to the tube/valve body).

Theory/Background

Countercurrent operation

When the heat exchanger is operated with countercurrent flow, the hot and cold fluid streams flow in opposite directions across the heat transfer surface (the two fluid streams enter the heat exchanger at opposite ends).



From the previous exercises:

Reduction in hot fluid temperature $\triangle t_{hot} = T1 - T5$ (°C)

Increase in cold fluid temperature $\Delta t_{cold} = T10 - T6$ (°C)

Heat power emitted from hot fluid $Q_e = qm_h.Cp_h (T1 - T5) (W)$

A useful measure of the heat exchanger performance is the temperature efficiency of each fluid stream. The temperature change in each fluid stream is compared with the maximum temperature difference between the two fluid streams giving a comparison with an exchanger of infinite size.

Temperature efficiency for hot fluid

$$\eta_{h} = \frac{T1 - T5}{T1 - T6} .100$$
 (%)

Temperature efficiency for cold fluid

$$\eta_{c} = \frac{T6 - T10}{T1 - T6} .100$$
(%)
$$- \eta_{h} + \eta_{c}$$

Mean Temperature Efficiency

$$\eta_{m} = \frac{\eta_{m} + \eta_{c}}{2}$$
(%)

Cocurrent operation

When the heat exchanger is connected for cocurrent operation the hot and cold fluid streams flow in the same direction across the heat transfer surface (the two fluid streams enter the heat exchanger at the same end).



Reduction in hot fluid temperature $\Delta t_{hot} = T5 - T1 (^{\circ}C)$ Increase in cold fluid temperature $\Delta t_{cold} = T10 - T6 (^{\circ}C)$

Heat power emitted from hot fluid $Q_e = qm_h.Cp_h (T5 - T1)(W)$

Temperature efficiency for hot fluid
$$\eta_{h} = \frac{T5 - T1}{T5 - T6} \cdot 100$$
 (%)

cold fluid
$$\eta_{c} = \frac{T6 - T10}{T5 - T6}.100$$
 (%)

Temperature efficiency for cold fluid

$$\eta_{m} = \frac{\eta_{h} + \eta_{c}}{2} \quad (\%)$$

Mean Temperature Efficiency

Procedure

(Refer to the Operation section if you need details of the instrumentation and how to operate it.)

In the software, in the 'Number of Tubes' box on the left, select '4'.

Set a cold water flow rate of 1 l/min by adjusting the arrows on the side of the cold water flow rate display box.

Check the cold water inlet temperature T10 (shown in a display box on the mimic diagram screen).

Set the temperature controller to a set point approximately 30°C above the cold water inlet temperature (e.g. if T10 is 15°C then choose a Set Point of 45°C):

Click on the Heater control box. In the heater controller window, type in the required value for the Set Point, and then select Automatic control from the selection on the top right of the window. Check that the Proportional Band is set to 5, the Integral Time to 200 and the Derivative Time to 0, and change them accordingly if they do not match these values. Click on 'Apply' and then 'OK' to close the window.

Set the hot water flow controller to give 2 l/min: click on the 'Flow' controller box, and type the required Set Point (2.0 l/min) into the Set Point box. The Proportional Band should be 100% and the Integral time should be 3s. The Derivative time should be 0s. Select 'Automatic' in the top right of the controller window, then 'Apply'. Select 'OK' to close the controller window.

Allow the heat exchanger to stabilise (monitor the temperatures on the mimic diagram display).

When the temperatures are stable select the ¹⁰ icon on the top toolbar to record the following:

T1, T2, T3, T4, T5, T6, T7, T8, T9, T10, F_{hot} , F_{cold} .

Open the heater controller window and adjust the controller from 'Automatic' to 'Off'. Open the hot water pump controller window and change the set point to 0 l/min. Set the cold water flow control valve to 0%.

Save your results sheet by selecting 'Save' from the 'File' menu of the software. Save it with a file name such as 'HT36 Exercise C Countercurrent'.

If a printer is available then you may find it useful to print a graph of the hot and cold water temperatures against the distance from the hot water inlet (the default graph

for the software). To print a graph, select the graph icon (\mathbb{E}^{1}), then the print icon.

Select 'Load New Experiment' from the 'File' menu, and select the Cocurrent exercise.

In the 'Number of Tubes' box on the left, select '4'.

Set a cold water flow rate of 1 l/min, a hot water flow rate of 2 l/min, and the same hot water temperature set point as for the countercurrent part of this exercise.

When the temperatures are stable select the ¹⁹⁹ icon on the top toolbar to record the following:

T1, T2, T3, T4, T5, T6, T7, T8, T9, T10, F_{hot} , F_{cold} .

Print a graph of the cocurrent results, and save your results sheet with a title such as 'HT36 Exercise C Cocurrent'.

If time permits, the exercise may be repeated with 3, 2 and 1 heat exchanger tubes by adjusting the manual flow valves (as described in the Operation section). Remember to select the correct number of tubes within the software to match the valve configuration on the hardware.

Results and Calculations

For each set of readings your raw data is presented in a table using the following headings:

Hot fluid volume flowrate	qv_{hot}	(m³/s)	From F _{hot} (I/min)
Hot fluid inlet temperature	T1	(°C)	(T5 Cocurrent)
Hot fluid intermediate temperature 1	T2	(°C)	(T4 Cocurrent)
Hot fluid intermediate temperature 2	Т3	(°C)	
Hot fluid intermediate temperature 3	T4	(°C)	(T2 Cocurrent)
Hot fluid outlet temperature	T5	(°C)	(T1 Cocurrent)
Cold fluid volume flowrate	qv_{cold}	(m³/s)	From F _{cold} (I/min)
Cold fluid inlet temperature	T6	(°C)	
Cold fluid intermediate temperature 1	T7	(°C)	
Cold fluid intermediate temperature 2	T8	(°C)	
Cold fluid intermediate temperature 3	Т9	(°C)	
Cold fluid outlet temperature	T10	(°C)	

Note: In cocurrent flow T1 is the hot fluid outlet temperature and T5 is the hot fluid inlet temperature.

You should also estimate the experimental errors for these measurements.

For each set of readings plot the temperatures at inlet, mid positions and outlet against position then estimate the profile of each stream through the exchanger.

For each set of readings, the software obtains the following variables. These may also be obtained from the <u>Reference Tables</u>:

Specific heat of hot fluid	Cph	kJ/kg ^o K (From table 1 using average temperature)
Density of hot fluid	$ ho_h$	kg/m ³ (From table 2 using average temperature)

For each set of readings your derived results are also tabulated; the following headings are used:

Reduction in hot fluid temperature	∆t _{hot}	(°C)	

Increase in cold fluid temperature	∆t _{cold}	(°C)
Heat power emitted from hot fluid	Q _e	(W)
Temperature efficiency for hot fluid	η _h	(%)
Temperature efficiency for cold fluid	η _c	(%)
Mean temperature efficiency	η _m	(%)

Estimate the cumulative influence of the experimental errors on your calculated values for each of the above temperature differences and efficiencies.

Compare each set of calculated values.

Conclusion

Your results from this exercise should indicate clearly the basic differences between Cocurrent and Countercurrent flow through the tubular heat exchanger. The selection of the best arrangement for a particular application depends on many parameters such as Overall Heat Transfer Coefficient, Logarithmic Mean Temperature Difference, Fluid Flowrate etc. These will be explained and investigated in later exercises.

Comment on the change in Δt_{tot} and Δt_{cold} when the heat exchanger is converted from cocurrent to countercurrent operation.

Comment on the differences between the hot and cold fluid temperature efficiency for any given configuration and explain the changes in efficiency when the configuration is changed from cocurrent to countercurrent operation.

Note: To save time Exercise D can be carried out using the readings obtained from this exercise.

Exercise D: Overall Heat Transfer Coefficient

Objective

To determine the Overall Heat Transfer Coefficient for a Tubular Heat Exchanger using the Logarithmic Mean Temperature Difference to perform the calculations (for cocurrent and countercurrent flow).

Method

By measuring the temperatures of the two fluid streams and calculating the LMTD from which the overall heat transfer coefficient can be calculated for each flow configuration.

Equipment Required

As Exercise C.

Optional Equipment

As Exercise C

Equipment set-up

If using the results from Exercise C then the equipment is not required.

If previous results are not available refer to the Set-up and Procedure sections of Exercise C.

Theory/Background



Countercurrent Flow



Cocurrent Flow

Heat power emitted from hot fluid $Q_e = qm_h.Cp_h (T1 - T5) (W)$

Note: To eliminate the effect of heat losses/gains in the cold water stream the heat emitted from the hot fluid stream will be used in the calculations.

Because the temperature difference between the hot and cold fluid streams varies along the length of the heat exchanger it is necessary to derive an average temperature difference (driving force) from which heat transfer calculations can be performed. This average temperature difference is called the Logarithmic Mean

Temperature Difference (LMTD) $^{\Delta t_{lm}}$.

LMTD

$$\Delta t_{lm} = \frac{\Delta t_1 - \Delta t_2}{\ln \left(\Delta t_1 / \Delta t_2 \right)} \text{ where}$$
$$\Delta t_1 = (T1 - T10)$$

Note: This equation cannot produce a result for the case where $\Delta t_1 = \Delta t_2$.

LM

(T1-T10) - (T5-T6)

In this example the equation for LMTD is the same for both countercurrent and cocurrent operation because the temperature measurement points are fixed on the exchanger. Two different equations will result if the temperature points are related to fluid inlets and outlets.

The heat transmission area in the exchanger must be calculated using the arithmetic mean diameter of the inner tube.

ean diameter
$$d_m = \frac{d_o + d_i}{2}$$
 (m)

Arithmetic me

Heat transmission length L (m)

Heat transmission area $A = \pi \cdot dm \cdot L (m^2)$

(d_m can be used since r2/r1<1.5 otherwise the logarithmic mean radius d_{im} must be used)

$$U = \frac{Q_{e}}{A \cdot \Delta t_{m}} \quad (W/m^{2}K)$$

Overall Heat Transfer Coefficient

Procedure

Use the results obtained from Exercise C.

Results and Calculations

Technical data:

Inner tube inside diameter	d _i = 0.0083	(m)
Inner tube outside diameter	d _o = 0.0095	(m)
Heat transmission length	L = 0.330 per tube(1.32 total)	(m)

Your raw data is presented in a table using the following headings:

Hot fluid volume flowrate	qv _{hot}	(m ³ /s)	From F _{hot} (I/min)
Hot fluid inlet temperature	T1	(°C)	(T5 Cocurrent)
Hot fluid intermediate temperature 1	T2	(°C)	(T4 Cocurrent)
Hot fluid intermediate temperature 2	Т3	(°C)	
Hot fluid intermediate temperature 3	T4	(°C)	(T2 Cocurrent)
Hot fluid outlet temperature	T5	(°C)	(T1 Cocurrent)
Cold fluid volume flowrate	qv _{cold}	(m ³ /s)	From F _{hot} (I/min)
Cold fluid inlet temperature	Т6	(°C)	
Cold fluid intermediate temperature 1	T7	(°C)	
Cold fluid intermediate temperature 2	Т8	(°C)	
Cold fluid intermediate temperature 3	Т9	(°C)	
Cold fluid outlet temperature	T10	(°C)	
Arithmetic mean diameter	d _m	(m)	
Heat transmission area	A	(m²)	

Note: In cocurrent flow T1 is the hot fluid outlet temperature and T5 is the hot fluid inlet temperature.

You should estimate the experimental errors for these measurements.

For each set of readings, the software calculates the following variables. These may also be obtained from the <u>Reference Tables</u>:

Specific heat of hot fluid	Cp_h	kJ/kg°K (From table 1 using average temperature)	
			L

Density of hot fluid	ρ_h	kg/m ³ (From table 2 using average temperature)

For each set of readings, your derived results are tabulated; the following headings are used:

Temperature difference	∆tı	(°C)
Temperature difference	∆t ₂	(°C)
Mass flow rate (hot fluid)	qm _h	(kg/s)
Heat power emitted from hot fluid	Q _e	(VV)
LMTD	∆t _{lm}	(°C)
Overall heat transfer coefficient	U	(W/m²K)

Estimate the cumulative influence of the experimental errors on your calculated values for Δt_{lm} and U.

Compare your calculated values for Δt_{lm} and U for each set of readings.

Conclusion

You have now been introduced to the method for calculating the Overall Heat Transfer Coefficient for a heat exchanger. This is the most important characteristic of a heat exchanger. The effect of fluid flowrates and temperature differences between the hot and cold fluid streams will be investigated in later exercises.

Comment on the differences in Δt_1 and Δt_2 when the heat exchanger is configured

for cocurrent and countercurrent flow. Comment on the resulting values for Δt_{lm} and its effect on U.

Comment on any difference between the Overall Heat Transfer Coefficient for the same heat exchanger in cocurrent and countercurrent flow (with all other variables the same).

If you have conducted a similar exercise using a plate heat exchanger (HT32) or shell and tube heat exchanger (HT33) compare the performances and comment on the differences.

Exercise E should be carried out on completion of this exercise.

Exercise E: Effect of Flow Rate

Objective

To investigate the effect of changes in hot and cold fluid flow rate on the Temperature Efficiencies and Overall Heat Transfer Coefficient.

Method

By measuring the fluid temperatures at different combinations of hot and cold fluid flowrate then calculating the corresponding Overall Heat Transfer Coefficient.

Equipment Required

HT30XC Computer Compatible Heat Exchanger Service Unit

HT36 Extended Tubular Heat Exchanger

PC running Microsoft[™] Windows 98 or XP with available USB port

Equipment set-up

Before proceeding with the exercise, ensure that the equipment has been prepared as follows:

Locate the HT36 Extended Tubular Heat Exchanger on the HT30XC Service Unit and secure it using the knurled fixings.

Connect the ten thermocouples on the heat exchanger to the appropriate sockets on the front of the HT30XC plinth (labelled T1 - T10).

Connect the hot and cold water supplies as follows:



Ensure that a cold water supply is connected to the inlet of the pressure regulating valve.

Ensure that the service unit is connected to an electrical supply.

Switch on the front Mains switch.

Ensure that the service unit is connected to a suitable PC, and run the HT36 software. Select the Countercurrent exercise.

Switch the service unit from Standby to On by selecting the Power On switch on the mimic diagram screen.

Prime the hot and cold water circuits as described in the Operation section.

Open the cold water flow control valve to give a 4 tube configuration (turn the black valve handle in line with the tube/valve body).



Close the other three manual valves on the accessory configuration (turn the black valve handles at right angles to the tube/valve body).

Theory/Background

Refer to Teaching Exercises C & D for details of the relevant theory relating to the calculation of the Temperature efficiencies and Overall Heat Transfer Coefficients.

Procedure

(Refer to the Operation section if you need details of the instrumentation and how to operate it.)

In the software, in the 'Number of Tubes' box on the left, select '4'.

Set a cold water flow rate of 1 l/min by adjusting the arrows on the side of the cold water flow rate display box.

Check the cold water inlet temperature T10 (shown in a display box on the mimic diagram screen).

Set the temperature controller to a set point approximately 30°C above the cold water inlet temperature (e.g. if T10 is 15°C then choose a Set Point of 45°C):

Click on the Heater control box. In the heater controller window, type in the required value for the Set Point, and then select Automatic control from the selection on the top right of the window. Check that the Proportional Band is set to 5, the Integral Time to 200 and the Derivative Time to 0, and change them accordingly if they do not match these values. Click on 'Apply' and then 'OK' to close the window.

Set the hot water flow controller to give 1 l/min: click on the 'Flow' controller box, and type the required Set Point (1.0 l/min) into the Set Point box. The Proportional Band should be 100% and the Integral time should be 3s. The Derivative time should be 0s. Select 'Automatic' in the top right of the controller window, then 'Apply'. Select 'OK' to close the controller window.

Allow the heat exchanger to stabilise (monitor the temperatures on the mimic diagram display).

When the temperatures are stable select the ¹⁹⁹ icon on the top toolbar to record the following:

T1, T2, T3, T4, T5, T6, T7, T8, T9, T10, F_{hot} , F_{cold} .

Select the icon to create a new results sheet.

Repeat the above for different settings of the hot and cold fluid volume flowrate as follows. Remember to create a new results sheet for each set of results, and to check that the software is still configured for the correct number of heat exchanger tubes.

F _{hot} (litres/min)	F _{cold} (litres/min)
2	1
3	1
2	2
1	2
1	3

Note: The above results are all obtained with turbulent flow through the heat exchanger (Reynolds number >2000). If time permits, the effect of laminar flow can be investigated by operating the heat exchanger with flowrates below 0.4 litres/min.

As the flow measurement will not be as accurate at these settings it is suggested that the volume flowrate is checked using a measuring cylinder and stopwatch (to intercept the flow to drain).

Open the heater controller window and adjust the controller from 'Automatic' to 'Off'. Open the hot water pump controller window and change the set point to 0 l/min. Set the cold water flow control valve to 0%.

Save your results sheet by selecting 'Save' from the 'File' menu of the software. Save it with a file name such as 'HT36 Exercise E Countercurrent'.

If a printer is available then you may find it useful to print a graph of the hot and cold water temperatures against the distance from the hot water inlet for each set of

results. To print a graph, select the graph icon (), then the graph configuration icon (). Highlight the results on the right and move them all to the left using the red arrow key. Select the first set of results (run 1 hot and cold), and move them back onto the y-axis plot with the arrow key. 'Apply' and close the print configuration window, then select the print icon. Repeat this process for each set of results.

Select 'Load New Experiment' from the 'File' menu, and select the Cocurrent exercise.

In the 'Number of Tubes' box on the left, select '4'.

Set a cold water flow rate of 1 l/min, a hot water flow rate of 1 l/min, and the same hot water temperature set point as for the countercurrent part of this exercise.

When the temperatures are stable select the ¹⁰⁰ icon on the top toolbar to record the following:

T1, T2, T3, T4, T5, T6, T7, T8, T9, T10, F_{hot} , F_{cold} .

Select the icon to create a new results sheet.

Repeat the above for different settings of the hot and cold fluid volume flowrate as follows. Remember to create a new results sheet for each set of results and to check that the software is still configured for the correct number of tubes.

F _{hot} (litres/min)	F _{cold} (litres/min)
2	1
3	1
2	2
1	2
1	3

Note: The above results are all obtained with turbulent flow through the heat exchanger (Reynolds number >2000). If time permits, the effect of laminar flow can be investigated by operating the heat exchanger with flowrates below 0.4 litres/min.

As the flow measurement will not be as accurate at these settings it is suggested that the volume flowrate is checked using a measuring cylinder and stopwatch (to intercept the flow to drain).

Open the heater controller window and adjust the controller from 'Automatic' to 'Off'. Open the hot water pump controller window and change the set point to 0 l/min. Set the cold water flow control valve to 0%. Set the HT30XC service unit back to Standby by selecting the Power On switch on the mimic diagram.

Save your results sheet by selecting 'Save' from the 'File' menu of the software. Save it with a file name such as 'HT36 Exercise E Cocurrent'.

Print your results as for the countercurrent section of this experiment.

If time permits, the exercise may be repeated with 3, 2 and 1 heat exchanger tubes by adjusting the manual flow valves (as described in the Operation section). Remember to select the correct number of tubes to match the configuration of the valves on the hardware.

Results and Calculations

Technical data:

Inner tube inside diameter	d _i = 0.0083	(m)
Inner tube outside diameter	d _o = 0.0095	(m)
Heat transmission length	L = 0.330 per tube (1.32 total)	(m)

For each set of readings your raw data is presented in a table using the following headings:

Hot fluid volume flowrate	qv _{hot}	(m³/s)	From F _{hot} (I/min)
Hot fluid inlet temperature	T1	(°C)	(T5 in cocurrent)
Hot fluid intermediate temperature 1	T2	(°C)	(T4 in cocurrent)
Hot fluid intermediate temperature 2	Т3	(°C)	
Hot fluid intermediate temperature 3	T4	(°C)	(T2 in cocurrent)
Hot fluid outlet temperature	T5	(°C)	(T1 in cocurrent)
Cold fluid volume flowrate	qv_{cold}	(m³/s)	From F _{cold} (I/min)
Cold fluid inlet temperature	Т6	(°C)	
Cold fluid intermediate temperature 1	T7	(°C)	
Cold fluid intermediate temperature 2	Т8	(°C)	
Cold fluid intermediate temperature 3	Т9	(°C)	
Cold fluid outlet temperature	T10	(°C)	

Note: In cocurrent flow T1 is the hot fluid outlet temperature and T5 is the hot fluid inlet temperature.

You should estimate the experimental errors for these measurements.

For each set of readings, the software calculates the following variables. These may also be obtained from the <u>Reference Tables</u>:

Specific heat of hot fluid	Срһ	kJ/kg°K (From table 1 using T2 as the average temperature)
Density of hot fluid	ρ _h	kg/m ³ (From table 2 using T2 as the average

	temperature)	

For each set of readings your derived results are also tabulated; the following headings are used:

Mass flow rate (hot fluid)	Qm _h	(kg/s)
Heat power emitted from hot fluid	Q _e	(W)
LMTD	∆t _{lm}	(°C)
Overall Heat Transfer Coefficient	U	(W/m²°C)
Temperature efficiency for hot fluid	η_h	(%)
Temperature efficiency for cold fluid	η _c	(%)
Mean temperature efficiency	η_m	(%)

Estimate the cumulative influence of the experimental errors on your calculated values for Δt_{lm} , U and the temperature efficiencies.

Compare the results for U and the temperature efficiencies at the different hot and cold fluid flowrates.

Conclusion

Your results from this exercise should indicate clearly the different effects of hot and cold flowrate on the Overall Heat Transfer Coefficient and temperature efficiencies.

Comment on the effects of changing the hot and cold fluid flowrates.

If additional results were obtained at very low cold fluid flowrate, comment on the effect of laminar flow through the annulus.

If additional results for 1, 2 and 3 tubes were obtained, compare the results for differing lengths of heat exchanger.

If you have conducted a similar exercise using a plate heat exchanger (HT32) or shell and tube heat exchanger (HT33) compare the performances and comment on the differences.

Exercise F should be carried out on completion of this exercise.

Exercise F: Driving Force

Objective

To investigate the effect of driving force with cocurrent and countercurrent flow.

Method

By measuring the fluid temperatures at different hot fluid inlet temperatures then calculating the corresponding Temperature Efficiencies and Overall Heat Transfer Coefficients to determine the effect of the driving force.

Equipment Required

HT30XC Computer Compatible Heat Exchanger Service Unit

HT36 Extended Tubular Heat Exchanger

PC running Microsoft[™] Windows 98 or XP with available USB port

Equipment set-up

Before proceeding with the exercise, ensure that the equipment has been prepared as follows:

Locate the HT36 Extended Tubular Heat Exchanger on the HT30XC Service Unit and secure it using the knurled fixings.

Connect the ten thermocouples on the heat exchanger to the appropriate sockets on the front of the HT30XC plinth (labelled T1 - T10).

Connect the hot and cold water supplies as follows:



Ensure that a cold water supply is connected to the inlet of the pressure regulating valve.

Ensure that the service unit is connected to an electrical supply.

Switch on the front Mains switch.

Ensure that the service unit is connected to a suitable PC, and run the HT36 software. Select the Countercurrent exercise.

Switch the service unit from Standby to On by selecting the Power On switch on the mimic diagram screen.

Prime the hot and cold water circuits as described in the Operation section.

Open the cold water flow control valve to give a 4 tube configuration (turn the black valve handle in line with the tube/valve body).



Close the other three manual valves on the accessory configuration (turn the black valve handles at right angles to the tube/valve body).

Theory/Background

Refer to Teaching Exercises C and D for details of the relevant theory relating to the calculation of the Temperature Efficiencies and Overall Heat Transfer Coefficients.

Procedure

(Refer to the Operational section if you need details of the instrumentation and how to operate it.)

In the software, in the 'Number of Tubes' box on the left, select '4'.

Set a cold water flow rate of 1 l/min by adjusting the arrows on the side of the cold water flow rate display box.

Check the cold water inlet temperature T10 (shown in a display box on the mimic diagram screen).

Set the temperature controller to a set point approximately 15°C above the cold water inlet temperature (e.g. if T10 is 15°C then choose a Set Point of 30°C):

Click on the Heater control box. In the heater controller window, type in the required value for the Set Point, and then select Automatic control from the selection on the top right of the window. Check that the Proportional Band is set to 5, the Integral Time to 200 and the Derivative Time to 0, and change them accordingly if they do not match these values. Click on 'Apply' and then 'OK' to close the window.

Set the hot water flow controller to give 2 l/min: click on the 'Flow' controller box, and type the required Set Point (2.0 l/min) into the Set Point box. The Proportional Band should be 100% and the Integral time should be 3s. The Derivative time should be 0s. Select 'Automatic' in the top right of the controller window, then 'Apply'. Select 'OK' to close the controller window.

Allow the heat exchanger to stabilise (monitor the temperatures on the mimic diagram display).

When the temperatures are stable select the ¹⁹⁹ icon on the top toolbar to record the following:

T1, T2, T3, T4, T5, T6, T7, T8, T9, T10, F_{hot} , F_{cold} .

Select the icon to create a new results sheet.

Repeat the above at different Set Points for the hot water temperature controller, increasing in steps of 5°C until the limit on the heater/controller is reached (Approximately 50°C depending on the cold fluid inlet temperature).

Open the heater controller window and adjust the controller from 'Automatic' to 'Off'. Open the hot water pump controller window and change the set point to 0 l/min. Set the cold water flow control valve to 0%.

Save your results sheet by selecting 'Save' from the 'File' menu of the software. Save it with a file name such as 'HT36 Exercise E Countercurrent'.

If a printer is available then you may find it useful to print a graph of the hot and cold water temperatures against the distance from the hot water inlet for each set of

results. To print a graph, select the graph icon (^{ED}), then the graph configuration

icon (^{yinx}). Highlight the results on the right and move them all to the left using the red arrow key. Select the first set of results (run 1 hot and cold), and move them back onto the y-axis plot with the arrow key. 'Apply' and close the print configuration window, then select the print icon. Repeat this process for each set of results.

If there is plenty of time then the procedure may be repeated for different flow rates, different hot water Set Point temperatures, and (if available) different cold water inlet flow temperatures. The maximum cold water outlet temperature achievable is limited by the maximum heater power input, and will depend on the combination of fluid flow rates, cold water inlet temperature, and the number of heat exchanger tubes used. With four tubes at maximum cold water flow rate, the maximum temperature gain in the cold fluid may be as low as 5 to 10°C.

Select 'Load New Experiment' from the 'File' menu, and select the Cocurrent exercise.

In the software, in the 'Number of Tubes' box on the left, select '4'.

Set a cold water flow rate of 1 l/min, a hot water flow rate of 2 l/min, and the same initial hot water temperature set point as for the countercurrent part of this exercise.

When the temperatures are stable select the ⁽¹⁾ icon on the top toolbar to record the following:

T1, T2, T3, T4, T5, T6, T7, T8, T9, T10, F_{hot} , F_{cold} .

Repeat the above for different settings of the hot water temperature controller, increasing in steps of 5° C until the limit on the heater controller is reached.

If there is plenty of time then the procedure may be repeated for different flow rates, different hot water Set Point temperatures, and (if available) different cold water inlet flow temperatures. Similar but not identical limitations apply to the maximum attainable heat exchange when operating under cocurrent flow. Students may wish to investigate how these limitations compare to those in countercurrent flow.

The exercise can also be repeated with 1, 2, and 3 heat exchanger tubes used. Remember to set the appropriate number of tubes within the software to suit the valve settings on the hardware.

Results and Calculations

Technical data:

Inner tube inside diameter $d_i = 0.0083$ (m)

Inner tube outside diameter $d_o = 0.0095$ (m)

Heat transmission length L = 0.330 per tube (1.32 total) (m)

For each set of readings your raw data is presented in a table using the following headings:

Hot fluid volume flowrate	qv _{hot}	(m³/s)	From F _{hot} (I/min)
Hot fluid inlet temperature	T1	(°C)	(T5 in cocurrent)
Hot fluid intermediate temperature 1	T2	(°C)	(T4 in cocurrent)
Hot fluid intermediate temperature 2	Т3	(°C)	
Hot fluid intermediate temperature 3	T4	(°C)	(T2 in cocurrent)
Hot fluid outlet temperature	T5	(°C)	(T1 in cocurrent)
Cold fluid volume flowrate	qv_{cold}	(m³/s)	From F _{cold} (I/min)
Cold fluid inlet temperature	Т6	(°C)	
Cold fluid intermediate temperature 1	Τ7	(°C)	
Cold fluid intermediate temperature 2	Т8	(°C)	
Cold fluid intermediate temperature 3	Т9	(°C)	
Cold fluid outlet temperature	T10	(°C)	

Note: In cocurrent flow T1 is the hot fluid outlet temperature and T5 is the hot fluid inlet temperature.

You should also estimate the experimental errors for these measurements.
For each set of readings, the software calculates the following variables. These may also be obtained from the <u>Reference Tables</u>:

Specific heat of hot fluid	Срь	kJ/kg°K (From table 1 using average hot water temperature)
Density of hot fluid	ρ _h	kg/m ³ (From table 2 using T2 average hot water temperature)

For each set of readings your derived results are also tabulated; the following headings are used:

Mass flow rate (hot fluid)	Qm _h	(kg/s)
Heat power emitted from hot fluid	Q _e	(VV)
LMTD	∆t _{lm}	(°C)
Overall Heat Transfer Coefficient	U	(W/m ^{2o} C)
Temperature efficiency for hot fluid	η_h	(%)
Temperature efficiency for cold fluid	η _c	(%)
Mean temperature efficiency	η _m	(%)

Estimate the cumulative influence of the experimental errors on your calculated values for ${}^{\underline{\Delta}t_{lm}}$, U and the temperature efficiencies.

Compare your derived results at the various differential fluid temperatures.

Conclusion

Your results from this exercise should indicate clearly the effect of driving force (temperature difference between the hot and cold fluid streams) on the Overall Heat Transfer Coefficient and Temperature Efficiencies.

If you have conducted a similar exercise using a plate heat exchanger (HT32) or shell and tube heat exchanger (HT33) compare the performances and comment on the differences.

Exercise G: Project Work

To Investigate Heat Loss from the Tubular Heat Exchanger

Practical Teaching Exercises A to F are performed with hot water flowing through the inner tube and cold water flowing through the outer annulus. This arrangement minimises the loss of heat from the heat exchanger because the temperature difference between the cold water stream and the ambient air is relatively small. (If the ambient air temperature is higher than the average temperature of the cold water stream then a small gain in heat can occur.)

An investigation of heat loss from the heat exchanger when the hot water flows through the outer annulus would provide a suitable project for students who have completed the previous training exercises. The quick release fittings between the heat exchanger and the service unit will allow the hot and cold fluid streams to be interchanged.

By comparing the heat power emitted from the hot water with the heat power absorbed by the cold water, the heat loss from the exchanger to the surroundings can be determined. Details of the necessary measurements and calculations are given in Teaching Exercise B.

Note: As the outer annulus of the heat exchanger is manufactured using clear acrylic tube, the hot water flowing through the outer annulus should be limited to 65°C to minimise softening of the tube. Similarly, the heat exchanger should not be operated with hot water in the outer annulus for long periods of time.

To Investigate Reduction in Heat Transfer Coefficient due to Fouling of the Heat Transfer Surfaces

The effect of fouling of the heat transfer surfaces can provide an interesting project for students who have completed the previous training exercises.

The construction of the heat exchanger using 'O' ring seals allows the inner tubes to be easily removed and replaced with alternative tubes, the inside surface of which the have been pre-fouled.

Metal tubes 9.5mm (3/8") outside diameter and 380 mm long (not supplied) should be provided for the student to foul by coating the inside diameter with a suitable insulating layer.

Note: The action of pushing the metal tube through an 'O' ring prevents the application of fouling to the outer surface of the metal tube.

If alternative tubing is not available then the existing tubes can be fouled but it will be necessary to remove the fouling before using the heat exchanger for normal measurements.

To remove the inner metal tube from the heat exchanger, disconnect the quick release fittings from each end of the tube then pull the tube out of the assembly taking care not to damage the 'O' ring seals. Before re-inserting the metal tube, or installing an alternative tube with fouling on the inner surface, lubricate the 'O' ring seals with a small amount of wetting agent.

Note: The PVC housing at each end of the acrylic tube is bonded to the acrylic tube and cannot be removed.

Designing an Alternative Heat Exchanger

An interesting project for students who have completed the previous training exercises is to build and test a heat exchanger of their own design. Provided that the alternative heat exchanger is constructed with inlet and outlet connections to suit the quick release fittings on the HT36 Extended Tubular Heat Exchanger, then the fittings used on the HT36 may be transferred directly, complete with the temperature sensors fitted. The alternative heat exchanger can then be connected directly to the HT30XC Service Unit for evaluation.

The inlet and outlet tubes should be 9.5mm (3/8") outside diameter to allow direct connection to the fittings supplied with the HT36 Extended Tubular Heat Exchanger. If using the temperature sensors only from the HT36 then the tappings for the temperature sensors should be 9.5mm (3/8") inside diameter.

Teaching Exercises A to F may be applied to the students'; own design of heat exchanger as appropriate.

Typical projects might include:

A tubular heat exchanger constructed with different internal dimensions.

A tubular heat exchanger constructed using different materials.

A tubular heat exchanger incorporating a helical spacer in the outer annulus to increase the local velocity of the cold water relative to the metal tube.

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