INSTRUCTION MANUAL

HT33

SHELL AND TUBE HEAT EXCHANGER

HT33

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THIS INSTRUCTION MANUAL SHOULD BE USED

IN CONJUNCTION WITH THE MANUAL SUPPLIED WITH THE

HT30X or HT30XC HEAT EXCHANGER SERVICE UNIT

This Manual provides the necessary information for operating the equipment in conjunction with the HT30X or HT30XC Service Unit, and for performing a range of Teaching Exercises designed to demonstrate the basic principles of Heat Exchanger theory and use.

IMPORTANT SAFETY INFORMATION

All practical work areas and laboratories should be covered by local safety regulations which must be followed at all times. If required Armfield can supply a typical set of standard laboratory safety rules.

Your HT33 Shell and Tube 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 may 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. Refer to the HT30X/HT30XC Heat Exchanger Service Unit for information on the use and testing of the Residual Current Device included as a safety measure on the service unit.

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 HT30X/HT30XC Heat Exchanger Service Unit product manual.

Waterborne 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. If water containing this bacterium is sprayed or splashed, the air-borne droplets created can transmit 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, i.e. 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.

ARMFIELD LIMITED

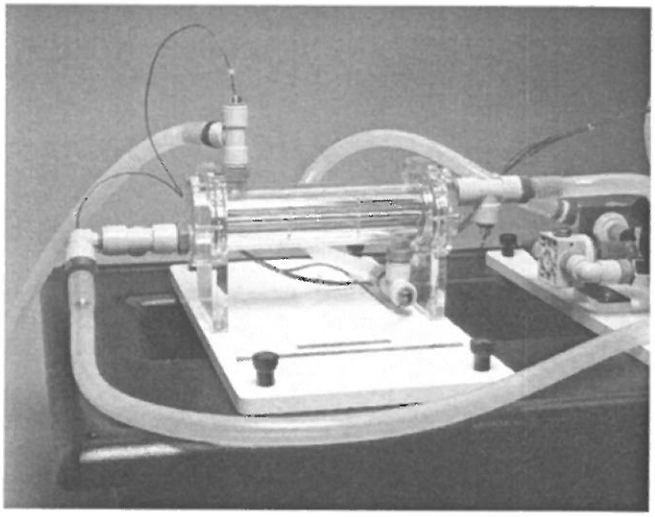
OPERATING INSTRUCTIONS AND EXPERIMENTS

HT33 SHELL AND TUBE HEAT EXCHANGER

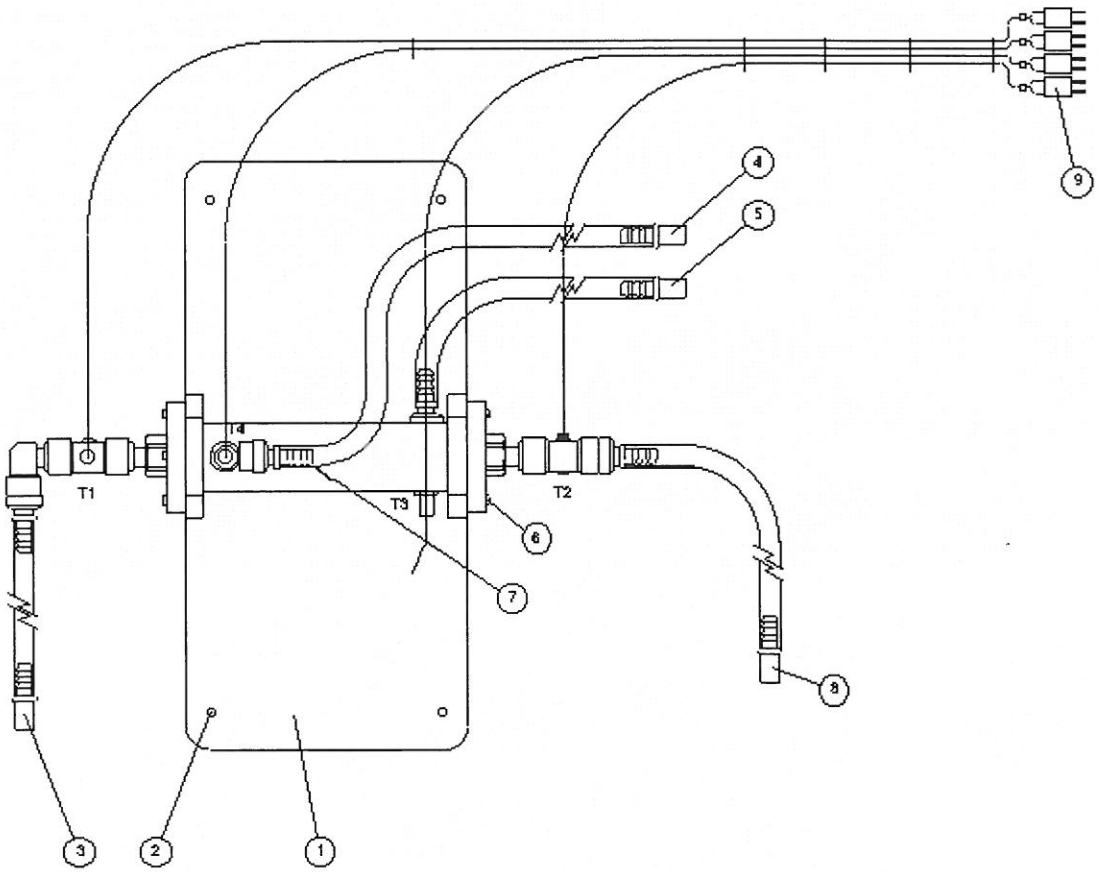
1 INTRODUCTION

This instruction manual describes the operation of the HT33 Shell and Tube Heat Exchanger which must be used in conjunction with the HT30X or 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 HT33 Shell and Tube Heat Exchanger is one model in a range of heat exchangers designed for use with the HT30X/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, the HT34 Jacketed Vessel with Coil and Stirrer, the HT36 Extended Tubular and HT37 Extended Plate with Regeneration. These modules are interchangeable on the service unit and each come with their own product manual.



HT33 SHELL AND TUBE HEAT EXCHANGER


T1
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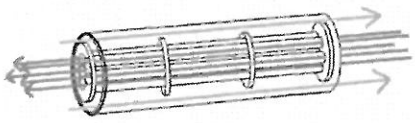
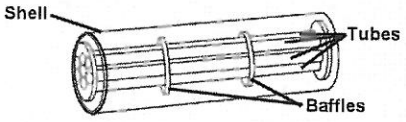
2 DESCRIPTION

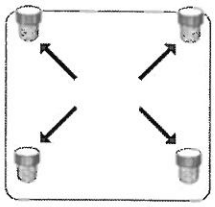
The shell and tube heat exchanger is commonly used in the food and chemical process industries. This type of exchanger consists of a number of tubes in parallel enclosed in a cylindrical shell. Heat is transferred between one fluid flowing through the tubes and another fluid flowing through the cylindrical shell around the tubes.

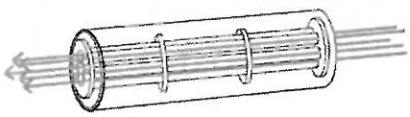




In this miniature exchanger, baffles inside the shell increase the velocity of the fluid and hence the rate of heat transfer. The exchanger has one shell and seven tubes with two transverse baffles in the shell.

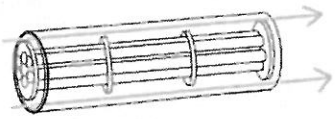
The exchanger is mounted on a PVC base plate which incorporates four holes, which locate it on four studs at the left hand end of the HT30X/HT30XC service unit. The PVC base plate is secured to the service unit using thumb nuts.



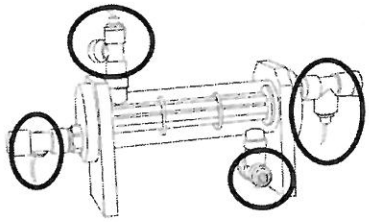


In normal operation the hot fluid from the hot water circulator enters the header at one end of the shell and passes through the bundle of stainless steel tubes.

The cold fluid from the cold water supply passes through the cylindrical shell. This arrangement minimises heat loss from the exchanger without the need for additional insulation and allows the construction of the exchanger to be viewed.



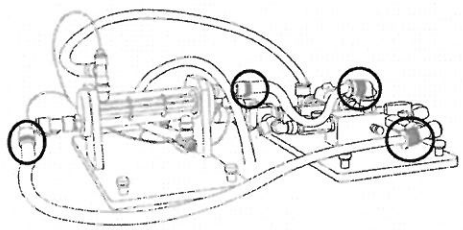
The outer annulus, caps and baffles are constructed from clear acrylic to allow visualisation of the heat exchanger construction and minimise thermal losses. These provide a liquid seal, accommodate differential expansion between the metal and plastic parts and allow the inner metal tubes to be removed for cleaning.



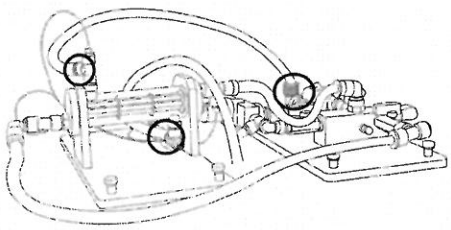
'O' ring seals allow differential expansion between the metal and plastic parts and allow the inner metal tubes to be removed for cleaning. The end housings incorporate the necessary fittings for sensors to measure the fluid temperatures and connections to the hot and cold water supplies.

The four thermocouple temperature sensors are labelled T1 to T4 for identification and each lead is terminated with a miniature thermocouple plug for connection to the appropriate socket on the side of the left hand side of the console on the service unit.

A length of flexible tubing is attached to each fluid inlet/outlet, terminated with a ferrule. This allows rapid connection to the appropriate fittings on the HT30X/HT30XC service unit, and conversion from countercurrent to cocurrent operation (the direction of water flow can be changed by reversing the appropriate connections). The fittings on the HT30X/HT30XC service unit and HT33 are colour coded red for hot water and blue for cold water to aid identification.



Red



Blue

Details of the connections are given in the Specifications and Operational Procedures sections of this manual, and in the Installation Guide (Appendix A in this manual).

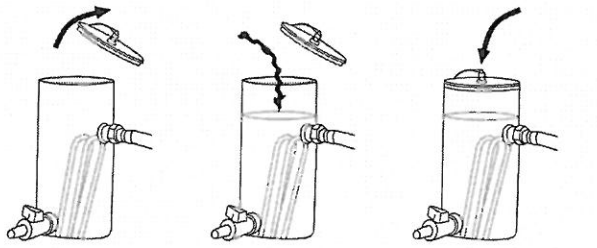
3 OPERATIONAL PROCEDURES

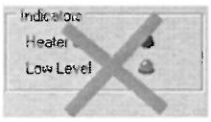
Before operating the equipment, ensure that the HT33 Heat Exchanger and the HT30X/HT30XC base unit have been assembled and installed as shown in the Installation Guide (Appendix A).

3.1 Priming the hot water circuit

(If using the older HT30X instead of the HT30XC, refer to the HT30X manual Operational Procedures section for the correct method of priming the hot water circuit, instead of using these instructions)

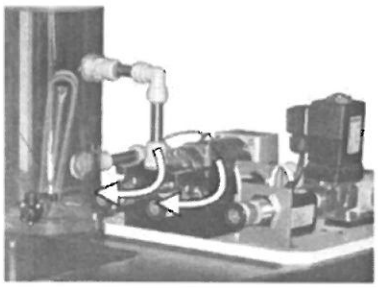
Remove the lid from the hot water vessel. Fill the vessel by pouring clean (preferably demineralised) water until the level is approximately 20 mm from the top.



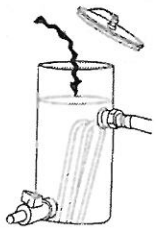


Check that the low-level indication in the software is not activated.

Check that the in-line isolating valves are both fully open.



Set the pump speed to 50% in the software and run the pump using counter-current operation until all air bubbles are displaced from the system into the hot water vessel.



Top up the level of this vessel as necessary to maintain the level above the tip of the level electrode (typically 20 mm from the top of the vessel).

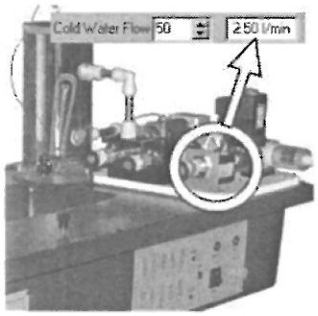
Note: Counter-current operation should always be selected when priming the hot water side of a heat exchanger for the first time.

3.2 Setting the cold water flow rate

(If using the older HT30X instead of the HT30XC, refer to the HT30X manual Operational Procedures section for the correct method of setting the cold water flow rate, instead of using these instructions)

The Cold Water Flow Valve can be controlled from the computer software. The valve can be driven from 0% (fully closed), to 100% (fully open) in steps of 1%.

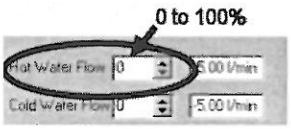
The actual flow rate achieved at any particular setting will be dependent on the water supply pressure, the pressure regulator setting, and the losses through the particular heat exchanger in use. This flow rate is measured by a flow meter and displayed in litres/min on the computer screen.



In normal use, the valve setting is adjusted until the desired flow rate is achieved.

Setting the hot water flow rate and direction

The hot water flow rate can be controlled from the computer software by varying the rotational speed of the re-circulation pump.



Again this can be set from 0% to 100%, with the actual flow rate being measured by a flow meter and displayed in L/min on the computer screen.

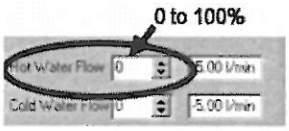
The hot water flow direction is set as a default value in the Armfield Software. If a counter-current exercise is chosen, the flow is in the direction indicated by the arrows adjacent to the two hot water connections. If a co-current exercise is chosen the direction of rotation of the pump and therefore the flow of water is reversed.

Note: A change in the temperature of the water will affect the viscosity of the water resulting in a small change in flowrate. It will therefore be necessary to adjust the hot water flow control in the software if it is required to perform tests at the same flowrate but different temperatures.

3.3 Setting the hot water flow rate and direction

(If using the older HT30X instead of the HT30XC please refer to the HT30X manual Operational Procedures section for the correct method of setting the hot water flow rate and direction, instead of using these instructions. Cocurrent or countercurrent flow is set by manually changing the plumbing of the HT30X, and cannot be controlled from the computer software)

The hot water flow rate can be controlled from the computer software by varying the rotational speed of the re-circulation pump.



Again this can be set from 0% to 100%, with the actual flow rate being measured by a flow meter and displayed in L/min on the computer screen.

The hot water flow direction is set as a default value in the Armfield Software. If a counter-current exercise is chosen, the flow is in the direction indicated by the arrows adjacent to the two hot water connections. If a co-current exercise is chosen the direction of rotation of the pump and therefore the flow of water is reversed.

Note: A change in the temperature of the water will affect the viscosity of the water resulting in a small change in flowrate. It will therefore be necessary to adjust the hot water flow control in the software if it is required to perform tests at the same flowrate but different temperatures.

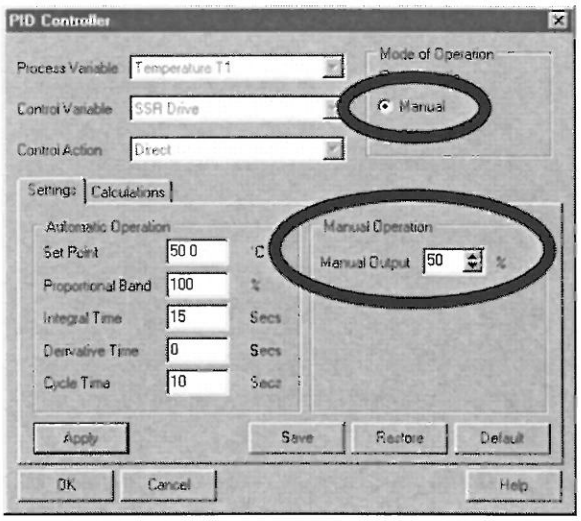
3.4 Setting the hot water temperature

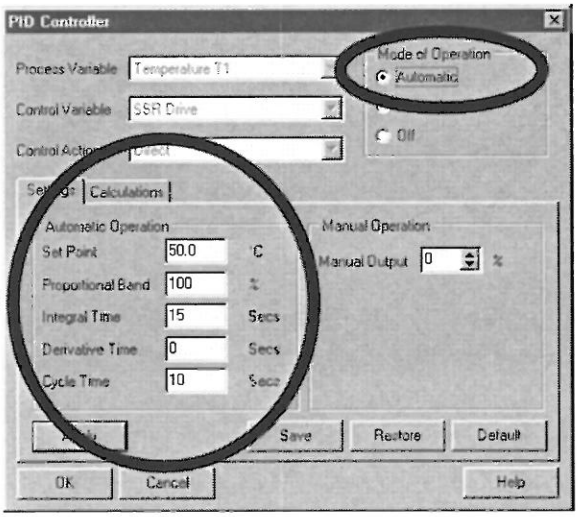
(If using the older HT30X instead of the HT30XC, refer to the HT30X manual Operational Procedures section for the correct method of setting the hot water temperature, instead of using these instructions)

Two modes are available for controlling the hot water temperature, a manual (or open loop) control mode to provide constant heater power and an auto (or closed loop) temperature control mode. Both modes are accessed via the software.

To access the heater control mode click the software 'control' button close to the appropriate sensor.

In manual mode, the heaters ('SSR Drive') are set to be on for a fixed proportion of time, operator selectable from 0% to 100%. This mode is useful when assessing energy balances or settling times.





In auto mode, the power to the heaters is modulated in accordance with a PID algorithm to achieve a stable temperature at one of the sensors (usually the hot water inlet to the heat exchanger). Advanced users may change the P, I and D parameters to perform process control investigations.

3.5 Measuring the water temperatures and flow rates

(If using the older HT30X instead of the HT30XC, and not using the HT30X software, then refer to the HT30X manual Operational Procedures section for the correct method of measuring the water temperatures and flow rates instead of using these instructions)

The temperature of the hot and cold fluids at the fluid inlet and outlet are measured using type 'k' thermocouples. The outputs from these sensors are displayed on the software mimic diagram screen, calibrated in °C. Sensor outputs may be monitored in X-Y graph format in real time by selecting the icon or bar graph format by selecting the icon. A snapshot of the sensor outputs may also be sent to a results table by selecting the icon and plotted on a graph via the icon, and may then be saved in native .vts format for later reference within the Armfield software, or exported in another spreadsheet format such as Microsoft™ Excel™ (not provided by Armfield).

The hot and cold flow rates are monitored using turbine-type flow sensors, calibrated in litres per minute. The outputs from these sensors may be monitored, logged and saved as for the temperature sensor outputs.

3.6 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.

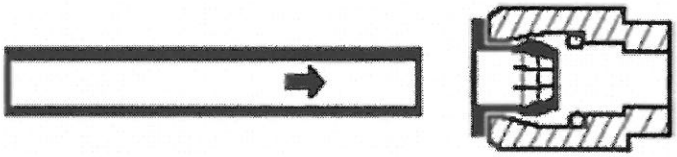
Some of the settings in the practical training exercises may be affected in this way. An excessively warm mains water supply will not present any problems since the temperature difference between the two fluid streams will be reduced. This would allow the hot water stream to be increased to even higher 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.

3.7 Operation of Guest push fittings

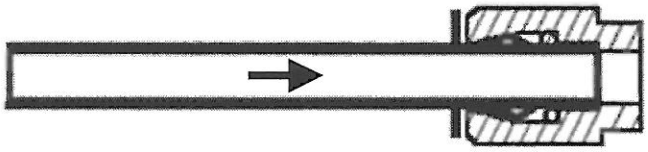
Guest push fittings are used on the equipment for convenience when changing the configuration or removing items for cleaning. The diagrams below show the simple operation of these fittings:-

To connect to a quick release fitting

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



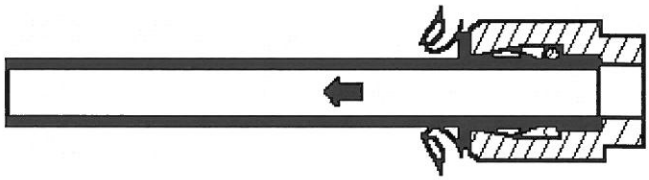
and push firmly until the tube stops.



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.

3.8 Connections to the I/O data port on HT30X

To allow access to the measurement signals in applications from the HT30X, other than when using an Armfield interface device, the connections to the 50 way connector are listed below for information:-

PIN NO	CHANNEL NO	SIGNAL FUNCTION
Analog Inputs (0-5Vdc):		
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 Outputs (0-5Vdc):		
22	Not used	
23	Ch 0	Hot water pump speed
24	Ch 1	Cold water valve setting
25	Not used	
Digital Inputs (0/5 Vdc):		
26-27	Not used	
30	Ch 2	Level Monitor
21-32	Not used	
33	Ch 4	Thermostat Monitor
34-37	Not used	
Digital Outputs (0/5 Vdc):		
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	

3.9 Connections to the USB port on HT30XC

To allow access to the measurement signals in applications other than the Armfield software when using the HT30XC, Armfield have provided a USB driver with the software installation disk. Armfield does not provide alternative software or instructions on using alternative software. The channel numbers for the USB port are listed below:-

CHANNEL NO SIGNAL FUNCTION

Analog Inputs (0-5Vdc):

Ch 0 signal	Temperatures 1 to 4 via analog switch (0-133°C)
Ch 0 return	
Ch 1 signal	Hot water flow Fhot (0-25 L/min)
Ch 1 return	
Ch 2 signal	Cold water flow (0-5 L/min)
Ch 2 return	
Not used	

Analog Outputs (0-5Vdc):
Not used

Digital Inputs (0/5 Vdc):
Not used

Digital Outputs (0/5 Vdc):

Ch 0	Analog switch
Ch 1	Analog switch
Ch 2	Analog switch
Ch 3	Analog switch
Digital ground	
Ch 4	Inhibit analog switch
Not used	
Digital ground	
Not used	

4 ROUTINE MAINTENANCE

To preserve the life and efficient operation of the equipment it is important that the equipment is properly maintained. Regular servicing/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.

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

1. The HT30X/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 HT33 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 HT30X/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

5 NOMENCLATURE FOR HT33

Name	Symbol	SI unit
ID of tube	d_i	m
OD of tube	d_o	m
Arithmetic mean diameter of tube	d_m	m
Heat transmission length	L	m
Heat transfer area	A	m^2
Specific Heat Capacity hot fluid	Cp_{hot}	kJ/kg°K
Specific Heat Capacity cold fluid	Cp_{cold}	kJ/kg°K
Hot fluid inlet temperature	T1	°C
Hot fluid outlet temperature	T2	°C
Cold fluid inlet temperature	T3	°C
Cold fluid outlet temperature	T4	°C
Decrease in hot fluid temperature	Δt_{hot}	°C
Increase in cold fluid temperature	Δt_{cold}	°C
Driving force, hot fluid inlet	Δt_1	°C
Driving force, hot fluid outlet	Δt_2	°C
Logarithmic Mean Temperature Difference	Δt_{lm}	°C
Volume flowrate (hot fluid)	qv_{hot}	m^3/s
Volume flowrate (cold fluid)	qv_{cold}	m^3/s
Density of hot fluid	ρ_{hot}	kg/m^3
Density of cold fluid	ρ_{cold}	kg/m^3
Mass flow rate hot fluid	qm_{hot}	kg/s
Mass flow rate cold fluid	qm_{cold}	kg/s
Heat power emitted from hot fluid	Q_e	W
Heat power absorbed by cold fluid	Q_a	W
Heat power lost (or gained)	Q_f	W
Overall Efficiency	η	%
Temperature Efficiency hot fluid	η_{hot}	%
Temperature Efficiency cold fluid	η_{cold}	%
Mean Temperature Efficiency	η_{mean}	%
Overall Heat Transfer Coefficient	U	$W/m^2°C$

6 REFERENCE TABLES

6.1 Table 1: Specific Heat Capacity of Water (Cp kJ/kg°K)

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

6.2 Table 2: Density of Water (ρ kg/m^3)

°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