# 7 INDEX TO PRACTICAL TRAINING EXERCISES

## 7.1 Practical Training Exercise HT33A

### 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 bundle and outer shell of a shell and tube heat exchanger

### Equipment Required

HT30X/HT30XC Heat Exchanger Service Unit

HT33 Shell and Tube Heat Exchanger

### Equipment set-up

Before proceeding with the exercise ensure that the equipment has been set up and the accessory installed as described in this manual, with a cold water supply connected and the pressure regulator adjusted. The apparatus should be switched on, and if using the HT30XC the service unit should be connected to a suitable PC on which the software has been installed. Computer operation is optional with the HT30X.

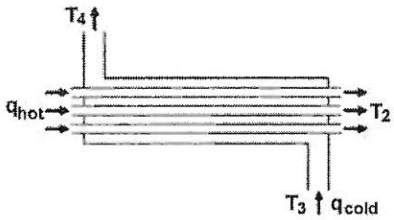
Prime the hot and cold water circuits using the cold water supply (Refer to the Operational Procedures on page 3-1 if you need details on how to prime the equipment).

If using the HT30XC, or the HT30X with the optional software, run the HT33 software for the service unit used (HT30XC software must be used with the HT30XC and HT30X software with the HT30X, as the calibration for the sensors differs between the two service units). If using the HT30XC, select the Countercurrent exercise. If using the HT30X, select Exercise A and then select Countercurrent Operation on the software display option box.

### 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 bundle will be cooled and the cold water flowing through the outer shell will be heated.

**Note:** For this demonstration the heat exchanger is configured with the two streams flowing in opposite directions (countercurrent flow). The cold fluid flowing through the shell is forced to flow over and under baffles in the shell which force the fluid to flow across the tube bundle to improve the heat exchange.




## Procedure

(Refer to the Operational Procedures on page 3-1 if you need details of the instrumentation and how to operate it. The mains supply should be switched on before starting this experiment.)

Set the temperature controller to 60°C. If using the HT30X then switch on the hot water circulator.

Adjust the cold water control valve setting to give a cold water flow rate of 1 litre/min.

If using HT30X, adjust the hot water control valve setting $V_{hot}$ to give a hot water flow of 3 litres/min. If using HT30XC, click on the button for the hot water flow rate controller, set the controller to Automatic and enter a Set Point value of 3 litres/min. Apply and click 'OK'.

Allow the temperatures to stabilise (monitor the temperatures using the sensor display on the software screen or control console).

When the temperatures are stable select the GO icon to record the following, or manually note the values: T1, T2, T3, T4, $F_{hot}$, $F_{cold}$.

Adjust the cold water control valve to give 2 litres/min.

Allow the heat exchanger to stabilise then repeat the above readings.

If using the software, save the logged data by selecting 'Save' or 'Save As' from the 'File' menu. Browse to the location you wish to place the saved data and give the results a meaningful name (e.g. HT33A).

## Results and Calculations

The software records all sensor outputs and also calculates several derived figures, and presents the recorded data in tabular form. The following columns are relevant to this exercise, and are suggested as suitable column headings if recording values manually:

| | | | |
|---|---|---|---|
| Hot fluid volume flowrate | $qv_{hot}$ | ($m^3/s$) | Multiply $F_{hot}$ (litres/min) by $1.667 \times 10^{-5}$ |

| | | | |
|---|---|---|---|
| Hot fluid inlet temperature | T1 | (°C) | |
| Hot fluid outlet temperature | T2 | (°C) | |
| Cold fluid volume flowrate | $qv_{cold}$ | ($m^3/s$) | Multiply $F_{cold}$ (litres/min) by $1.667 \times 10^{-5}$ |
| Cold fluid inlet temperature | T3 | (°C) | |
| Cold fluid outlet temperature | T4 | (°C) | |

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

For each set of readings, the relevant derived results are calculated and presented with the following headings:

| | | |
|---|---|---|
| Reduction in hot fluid temperature | $\Delta T_{hot} = T1 - T2$ | (°C) |
| Increase in cold fluid temperature | $\Delta T_{cold} = T4 - T3$ | (°C) |

These values should be calculated manually if not using the software.

A graph may be plotted of the results. The software graph facility may be used for this.

Estimate the cumulative influence of the experimental errors on your calculated values for $\Delta T_{hot}$ and $\Delta T_{cold}$.

Compare the changes in temperature at the different flowrates. If time permits try different combinations of hot and cold fluid flowrate.

## Conclusions

You have demonstrated how, using a simple shell and tube 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 $\Delta T_{hot}$ and $\Delta T_{cold}$ when the flow of cold water is increased. The consequence of these changes will be investigated in a later exercise.

**Note:** To save time exercise **HT33B** can be carried out using the readings obtained from this exercise.

## 7.2 Practical Training Exercise HT33B

### Objective

To perform an energy balance across a Shell and Tube 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 shell and tube heat exchanger and calculating the heat energy transferred to/from each stream to determine the Overall Efficiency.

### Equipment Required

As exercise HT33A.

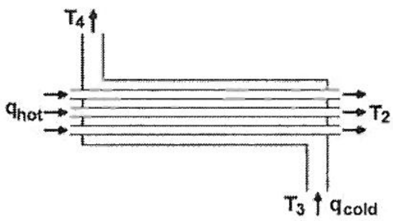
### Equipment set-up

If using the results from exercise HT33A then the equipment is not required.

If previous results are not available refer to the Set-up and Procedure sections of exercise HT33A.

### Theory/Background

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




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

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

Therefore:

Heat power emitted from hot fluid $Q_e = qm_h . Cp_h (T1 - T2)$ (W)

Heat power absorbed by cold fluid $Q_a = qm_c . Cp_c (T4 - T3)$ (W)

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

Overall Efficiency $\eta = \frac{Q_a}{Q_e} \times 100$ (%)

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 shell, if the average cold fluid temperature is above the ambient air temperature then heat will be lost to the surroundings resulting in $\eta<100\%$. If the average cold fluid temperature is below the ambient temperature then heat will be gained resulting in $\eta>100\%$.

## Procedure

Use the results obtained from exercise HT33A.

## Results and Calculations

The software records all sensor outputs and also calculates several derived figures, and presents the recorded data in tabular form. The following columns are relevant to this exercise, and are suggested as suitable column headings if recording values manually:

| | | | |
|---|---|---|---|
| Hot fluid volume flowrate | $qv_{hot}$ | ($m^3$/s) | Multiply $F_{hot}$ (litres/min) by $1.667\times10^{-5}$ |
| Hot fluid inlet temperature | T1 | (°C) | |
| Hot fluid outlet temperature | T2 | (°C) | |
| Cold fluid volume flowrate | $qv_{cold}$ | ($m^3$/s) | Multiply $F_{cold}$ (litres/min) by $1.667\times10^{-5}$ |
| Cold fluid inlet temperature | T3 | (°C) | |
| Cold fluid outlet temperature | T4 | (°C) | |

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

For each set of readings, the software calculates the average hot fluid temperature (from T1 and T2) and the average cold fluid temperature (from T3 and T4) and then automatically provides values for the following variables. If recording data manually, calculate these values and obtain the variables from the tables on page 6-1:

| | | |
|---|---|---|
| Specific heat of hot fluid | $Cp_h$ | kJ/kg°K (From table 1) |
| Specific heat of cold fluid | $Cp_c$ | kJ/kg°K (From table 1) |
| Density of hot fluid | $\rho_h$ | $kg/m^3$ (From table 2) |
| Density of cold fluid | $\rho_c$ | $kg/m^3$ (From table 2) |

For each set of readings, the relevant derived results are calculated and presented with the following headings:

| | | |
|---|---|---|
| Mass flowrate (hot fluid) | $qm_h$ | (kg/s) |
| Mass flowrate (cold fluid) | $qm_c$ | (kg/s) |
| Heat power emitted | $Q_e$ | (W) |
| Heat power absorbed | $Q_a$ | (W) |
| Heat power lost | $Q_f$ | (W) |
| Overall Efficiency | $\eta$ | (%) |

These values should be calculated manually if not using the software.

A graph may be plotted of the results. The software graph facility may be used for this.

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.

## Conclusions

Explain any difference between $Q_e$ and $Q_a$ in your results.

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

Exercise **HT33C** should be carried out on completion of this exercise.

## 7.3 Practical Training Exercise HT33C

### Objective

To demonstrate the differences between cocurrent flow (flows in same direction) and countercurrent flow (flows in the opposite direction) and the effect on heat transferred and temperature efficiencies.

### Method

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

### Equipment Required

HT30X/HT30XC Heat Exchanger Service Unit

HT33 Shell and Tube Heat Exchanger

### Equipment set-up

Before proceeding with the exercise ensure that the equipment has been set up and the accessory installed as described in this manual, with a cold water supply connected and the pressure regulator adjusted. The apparatus should be switched on, and if using the HT30XC the service unit should be connected to a suitable PC on which the software has been installed. Computer operation is optional with the HT30X.

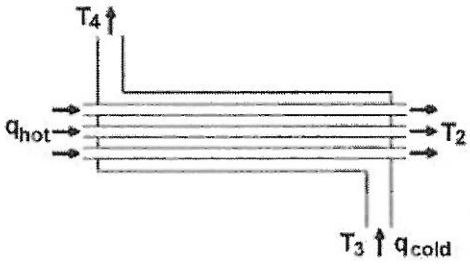
Prime the hot and cold water circuits using the cold water supply (Refer to the Operational Procedures on page 3-1 if you need details on how to prime the equipment).

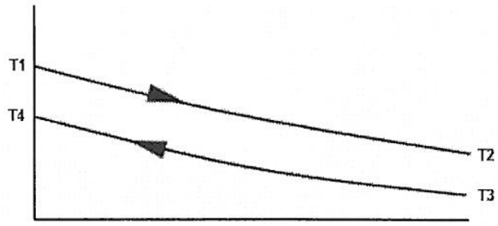
If using the HT30XC, or the HT30X with the optional software, run the HT33 software for the service unit used (HT30XC software must be used with the HT30XC and HT30X software with the HT30X, as the calibration for the sensors differs between the two service units). If using the HT30XC, select the Countercurrent exercise. If using the HT30X, select Exercise C and then select Countercurrent Operation on the software display option box.

### Theory/Background

***Countercurrent operation***

When the heat exchanger is connected for countercurrent operation 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). The hot fluid passes through the seven tubes in parallel, the cold fluid passes across the tubes three times, directed by the baffles inside the shell.




From the previous exercises:

Reduction in hot fluid temperature $\Delta T_{hot} = T1 - T2$ (°C)

Increase in cold fluid temperature $\Delta T_{cold} = T4 - T3$ (°C)

Heat power emitted from hot fluid $Q_e = qm_h.(Cp)_h (T1 - T2)$ (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.

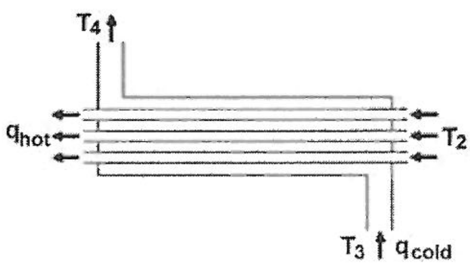
Temperature efficiency for hot fluid $\eta_h = \frac{T1 - T2}{T1 - T3}.100$ (%)

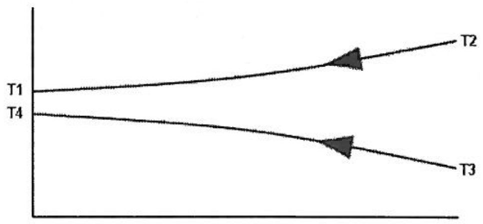
Temperature efficiency for cold fluid $\eta_c = \frac{T4 - T3}{T1 - T3}.100$ (%)

Mean Temperature Efficiency $\eta_m = \frac{\eta_h + \eta_c}{2}$ (%)

***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).




From the previous exercises:

Reduction in hot fluid temperature $\Delta T_{hot} = T2 - T1$ (°C)

Increase in cold fluid temperature $\Delta T_{cold} = T4 - T3$ (°C)

Heat power emitted from hot fluid $Q_e = qm_h.(Cp)_h (T2 - T1)$ (W)

Temperature efficiency for hot fluid $\eta_h = \dfrac{T2 - T1}{T2 - T3}.100$ (%)

Temperature efficiency for cold fluid $\eta_c = \dfrac{T4 - T3}{T2 - T3}.100$ (%)

Mean Temperature Efficiency $\eta_m = \dfrac{\eta_h + \eta_c}{2}$ (%)

## Procedure

(Refer to the Operational Procedures on page 3-1 if you need details of the instrumentation and how to operate it. The mains supply should be switched on before starting this experiment.)

Set the temperature controller to 60°C. If using the HT30X then switch on the hot water circulator.

Adjust the cold water control valve setting to give a cold water flow rate of 1 litre/min.

If using HT30X, adjust the hot water control valve setting $V_{hot}$ to give a hot water flow of 2 litres/min. If using HT30XC, click on the button for the hot water flow rate controller, set the controller to Automatic and enter a Set Point value of 2 litres/min. 'Apply' and select 'OK'.

Allow the temperatures to stabilise (monitor the temperatures using the sensor display on the software screen or control console).

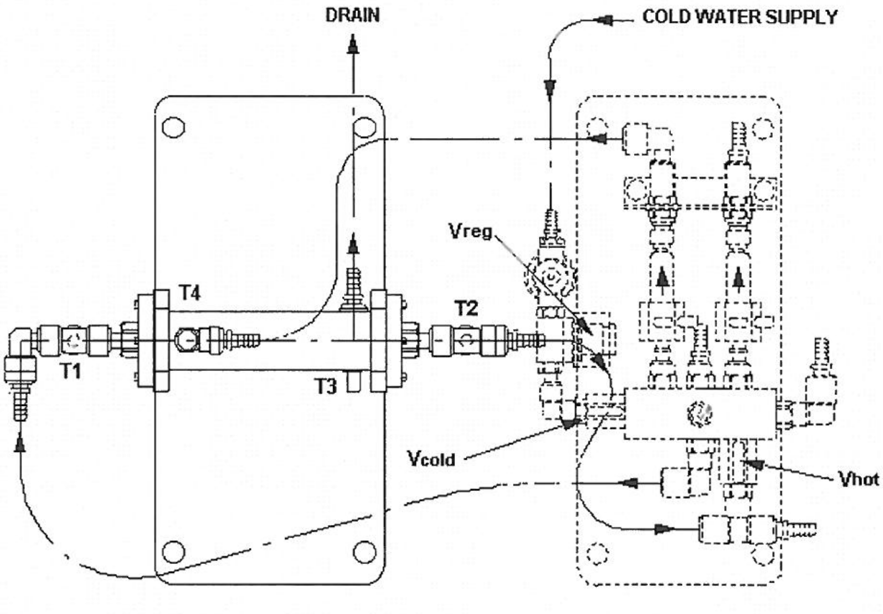
When the temperatures are stable select the GO icon to record the following, or manually note the values: T1, T2, T3, T4, $F_{hot}$, $F_{cold}$

Close the cold water flow control valve.

If using the HT30XC, save the logged data by selecting 'Save' or 'Save As' from the 'File' menu. Browse to the location you wish to place the saved data and give the results a meaningful name (e.g. HT33C Countercurrent Operation). If using HT30X software, create a new results sheet using the icon.

Change the system to cocurrent operation:

If using the HT30X, select the 'Cocurrent' radio button on the software mimic diagram, and change the connections to the hot water inlet and outlet as follows:




HT33 SHELL & TUBE HEAT EXCHANGER
(CONNECTED IN COCURRENT OPERATION)

If using the HT30XC, select 'Load New Experiment...' from the 'File' menu, clicking on the Cocurrent Operation exercise radio button then select the 'Load' button.

The connections to the heat exchanger are now configured for cocurrent operation where 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).

Adjust the cold water flow control valve to give a cold water flow rate reading of 1 litre/min (Hot and cold water flowrates the same as before).

When the temperatures are stable select the GO icon to record the following, or manually note the values: T1, T2, T3, T4, $F_{hot}$, $F_{cold}$

If using the software, save the logged data by selecting 'Save' or 'Save As' from the 'File' menu. Browse to the location you wish to place the saved data and give the results a meaningful name (e.g. HT33C Cocurrent Operation).

## Results and Calculations

The software records all sensor outputs and also calculates several derived figures, and presents the recorded data in tabular form. The following columns are relevant to this exercise, and are suggested as suitable column headings if taking readings manually:

| | | | |
|---|---|---|---|
| Hot fluid volume flowrate | $qv_{hot}$ | ($m^3/s$) | Multiply $F_{hot}$ (litres/min) by $1.667 \times 10^{-5}$ |
| Hot fluid inlet | T1 | (°C) | |

temperature

| | | | |
|---|---|---|---|
| Hot fluid outlet temperature | T2 | (°C) | |
| Cold fluid volume flowrate | $qv_{cold}$ | ($m^3/s$) | Multiply $F_{hot}$ (litres/min) by $1.667 x 10^{-5}$ |
| Cold fluid inlet temperature countercurrent flow | T3 | (°C) | |
| Cold fluid outlet temperature countercurrent flow | T4 | (°C) | |

**Note:** In cocurrent flow T2 is the hot fluid outlet temperature and T1 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 average hot fluid temperature (from T1 and T2) and the average cold fluid temperature (from T3 and T4) and then automatically provides values for the following variables. If recording data manually, calculate these values and obtain the variables from the tables on page 6-1:

| | | | |
|---|---|---|---|
| Specific heat of hot fluid | $Cp_h$ | kJ/kg°K | (From table 1) |
| Density of hot fluid | $\rho_h$ | $kg/m^3$ | (From table 2) |

For each set of readings, the relevant derived results are calculated and presented with the following headings:

| | | |
|---|---|---|
| Reduction in hot fluid temperature | $\Delta T_{hot}$ | (°C) |
| Increase in cold fluid temperature | $\Delta T_{cold}$ | (°C) |
| Heat power emitted from hot fluid | $Q_e$ | (W) |
| Temperature efficiency for hot fluid | $\eta_h$ | (%) |
| Temperature efficiency for cold fluid | $\eta_c$ | (%) |
| Mean temperature efficiency | $\eta_m$ | (%) |

These values should be calculated manually if not using the software.

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.

## Conclusions

Your results from this exercise should indicate clearly the basic differences between Cocurrent and Countercurrent flow through the shell and tube 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 $\Delta T_{hot}$ and $\Delta T_{cold}$ 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 **HT33D** can be carried out using the readings obtained from this exercise.

## 7.4 Practical Training Exercise HT33D

### 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

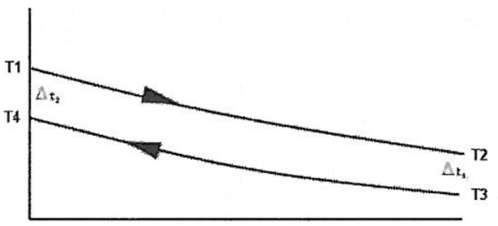
As exercise HT33C.

### Equipment set-up

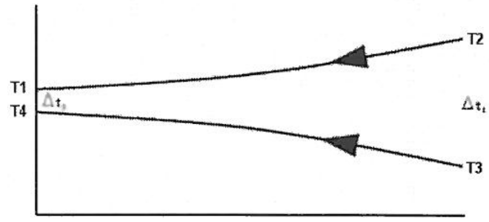
If using the results from exercise HT33C then the equipment is not required.

If previous results are not available refer to the Set-up and Procedure sections of exercise HT33C.

### Theory/Background




Countercurrent operation




Cocurrent operation

Heat power emitted from hot fluid $Q_e = qm_h.\ (Cp)_h\ (T1 - T2)$ (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) $\Delta t_{lm}$.

$$\text{LMTD } \Delta t_{lm} = \frac{\Delta t_1 - \Delta t_2}{\ln(\Delta t_1 / \Delta t_2)}$$

where $\Delta t_l = (T2 - T3)$ (°C)

and $\Delta t_2 = (T1 - T4)$ (°C)

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

LMTD $$\Delta t_{lm} = \frac{(T2 - T3) - (T1 - T4)}{\ln((T2 - T3)/(T1 - T4))} \quad (°C)$$

In this example the equation for LMTD is the same for both countercurrent and cocurrent operation.

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

Arithmetic mean diameter $$d_m = \frac{d_o + d_i}{2} \quad (m)$$

Heat transmission length $L = n.l$ (m)

where n = number of tubes $= 7$

l = heat transmission length of each tube $= 0.144$ (m)

$L = 1.008$

Heat transmission area $= A = \pi.d_m.L$ ($m^2$)

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

Overall Heat Transfer Coefficient $$U = \frac{Q_e}{A.\Delta t_{lm}} \quad (W/m^2K)$$

## Procedure

Use the results obtained from exercise HT33C.

## Results and Calculations

Technical data:

| | | |
|---|---|---|
| Tube inside diameter | $d_i = 0.00515$ | (m) |
| Tube outside diameter | $d_o = 0.00635$ | (m) |
| Heat transmission length | L = 1.008 (total) | (m) |

The software records all sensor outputs and also calculates several derived figures, and presents the recorded data in tabular form. The following columns are relevant to this exercise, and are suggested as suitable column headings if recording data manually:

| | | | |
|---|---|---|---|
| Hot fluid volume flowrate | $qv_{hot}$ | $(m^3/s)$ | Multiply $F_{hot}$ (litres/min) by $1.667x10^{-5}$ |
| Hot fluid inlet temperature | T1 | (°C) | |
| Hot fluid outlet temperature | T2 | (°C) | |
| Cold fluid volume flowrate | $qv_{cold}$ | $(m^3/s)$ | Multiply $F_{hot}$ (litres/min) by $1.667x10^{-5}$ |
| Cold fluid inlet temperature countercurrent flow | T3 | (°C) | |
| Cold fluid outlet temperature countercurrent flow | T4 | (°C) | |
| Arithmetic mean diameter | $d_m$ | (m) | |
| Heat transmission area | A | $(m^2)$ | |

You should estimate the experimental errors for these measurements.

**Note:** In cocurrent flow T2 is the hot fluid outlet temperature and T1 is the hot fluid inlet temperature.

For each set of readings, the software calculates the average hot fluid temperature (from T1 and T2) and the average cold fluid temperature (from T3 and T4) and then automatically provides values for the following variables. If recording data manually, calculate these values and obtain the variables from the tables on page 6-1:

| | | |
|---|---|---|
| Specific heat of hot fluid | $Cp_h$ | kJ/kg°K (From table 1 using T2 as the average temperature) |
| Density of hot fluid | $\rho_h$ | $kg/m^3$ (From table 2 using T2 as the average temperature) |

For each set of readings, the relevant derived results are calculated and presented with the following headings:

| | | |
|---|---|---|
| Temperature difference | $\Delta t_1$ | (°C) |

| | | |
|---|---|---|
| Temperature difference | $\Delta t_2$ | (°C) |
| Mass flowrate (hot fluid) | $qm_h$ | (kg/s) |
| Heat power emitted from hot fluid | $Q_e$ | (W) |
| LMTD | $\Delta t_{lm}$ | (°C) |
| Overall heat transfer coefficient | U | ($W/m^2K$) |

These values should be calculated manually if not using the software.

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

## Conclusions

You have now been introduced to the method for calculating the Overall Heat Transfer Coefficient for a shell and tube 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 $\Delta t_1$ and $\Delta t_2$ when the heat exchanger is configured for cocurrent and countercurrent flow. Comment on the resulting values for $\Delta t_{lm}$ 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 tubular heat exchanger (HT31 or HT36) or plate heat exchanger (HT32 or HT37) compare the performances and comment on the differences.

Exercise **HT33E** should be carried out on completion of this exercise.

## 7.5 Practical Training Exercise HT33E

### Objective

To investigate the effect of changes in hot and cold fluid flowrate 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 Heat Exchanger Service Unit

HT33 Shell and Tube Heat Exchanger

### Equipment set-up

Before proceeding with the exercise ensure that the equipment has been set up and the accessory installed as described in this manual, with a cold water supply connected and the pressure regulator adjusted. The apparatus should be switched on, and if using the HT30XC the service unit should be connected to a suitable PC on which the software has been installed. Computer operation is optional with the HT30X.

Prime the hot and cold water circuits using the cold water supply (Refer to the Operational Procedures on page 3-1 if you need details on how to prime the equipment).

If using the HT30XC, or the HT30X with the optional software, run the HT33 software for the service unit used (HT30XC software must be used with the HT30XC and HT30X software with the HT30X, as the calibration for the sensors differs between the two service units). If using the HT30XC, select the Countercurrent exercise. If using the HT30X, select Exercise E and then select Countercurrent Operation on the software display option box.

### Theory/Background

Refer to training 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 Operational Procedures on page 3-1 if you need details of the instrumentation and how to operate it. The mains supply should be switched on before starting this experiment.)

Set the temperature controller to 60°C. If using the HT30X then switch on the hot water circulator.

Adjust the cold water control valve setting to give a cold water flow rate of 1 litre/min.

If using HT30X, adjust the hot water control valve setting $V_{hot}$ to give a hot water flow of 1 litre/min. If using HT30XC, click on the button for the hot water flow rate controller, set the controller to Automatic and enter a Set Point value of 1 litre/min.

Allow the temperatures to stabilise (monitor the temperatures using the sensor display on the software screen or control console).

When the temperatures are stable select the icon to record the following, or manually note the values: T1, T2, T3, T4, $F_{hot}$, $F_{cold}$

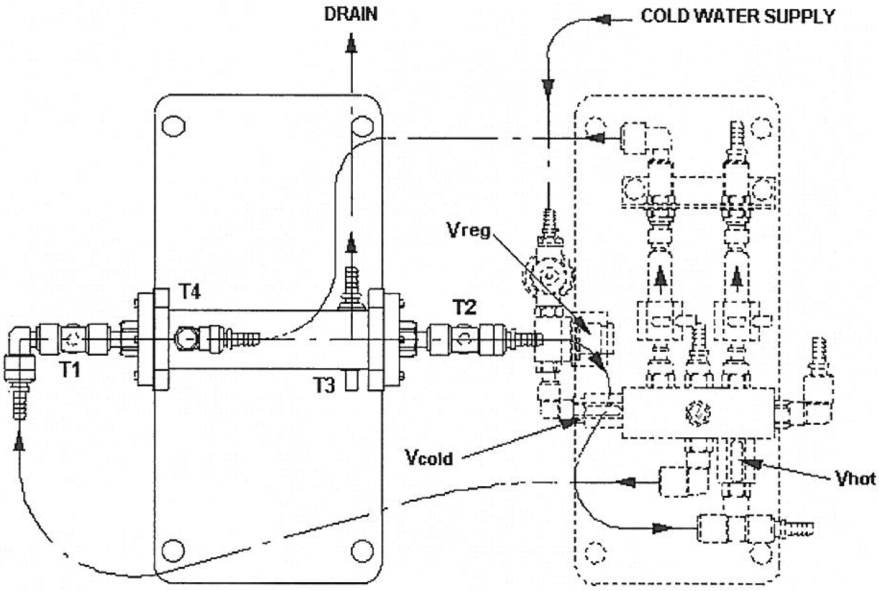
Repeat the above for different settings of the hot and cold fluid volume flowrate as follows:

| $F_{hot}$ (litres/min), | $F_{cold}$ (litres/min) |
|---|---|
| 2 | 1 |
| 3 | 1 |
| 2 | 2 |
| 1 | 2 |
| 1 | 3 |

If using the HT30XC, save the logged data by selecting ‘Save’ or ‘Save As’ from the ‘File’ menu. Browse to the location you wish to place the saved data and give the results a meaningful name (e.g. HT33E Countercurrent Operation). If using the HT30X software then create a new results sheet using the icon.

Change to cocurrent operation:

If using the HT30X, select the ‘Cocurrent’ radio button on the software mimic diagram and change the connections to the hot water inlet and outlet as follows:




HT33 SHELL & TUBE HEAT EXCHANGER
(CONNECTED IN COCURRENT OPERATION)

If using the HT30XC, select 'Load New Experiment...' from the 'File' menu and click on the Cocurrent Operation exercise radio button then select the 'Load' button.

The connections to the heat exchanger are now configured for cocurrent operation where 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).

Adjust the cold water flow control valve to give a cold water flow rate of 1 litre/min.

If using HT30X, adjust the hot water control valve setting $V_{hot}$ to give a hot water flow of 1 litre/min. If using HT30XC, click on the button for the hot water flow rate controller, set the controller to Automatic and enter a Set Point value of 1 litre/min.

Allow the temperatures to stabilise (monitor the temperatures using the sensor display on the software screen or control console).

When the temperatures are stable select the GO icon to record the following, or manually note the values: T1, T2, T3, T4, $F_{hot}$, $F_{cold}$

Repeat the above for different settings of the hot and cold fluid volume flowrate as follows:

| $F_{hot}$ (litres/min), | $F_{cold}$ (litres/min) |
|---|---|
| 2 | 1 |

| | |
|---|---|
| 3 | 1 |
| 2 | 2 |
| 1 | 2 |
| 1 | 3 |

If using the HT30XC or HT30X software, save the logged data by selecting 'Save' or 'Save As' from the 'File' menu. Browse to the location you wish to place the saved data and give the results a meaningful name (e.g. HT33E Cocurrent Operation).

## Results and Calculations

***Technical data:***

| | | |
|---|---|---|
| Inner tube inside diameter | $d_i = 0.00515$ | (m) |
| Inner tube outside diameter | $d_o = 0.00635$ | (m) |
| Heat transmission length | L = 1.008 (total) | (m) |

The software records all sensor outputs and also calculates several derived figures, and presents the recorded data in tabular form. The following columns are relevant to this exercise, and are suggested as suitable column headings of recording data manually:

| | | | |
|---|---|---|---|
| Hot fluid volume flowrate | $qv_{hot}$ | ($m^3/s$) | Multiply $F_{hot}$ (litres/min) by $1.667x10^{-5}$ |
| Hot fluid inlet temperature | T1 | (°C) | |
| Hot fluid outlet temperature | T2 | (°C) | |
| Cold fluid volume flowrate | $qv_{cold}$ | ($m^3/s$) | Multiply $F_{cold}$ (litres/min) by $1.667x10^{-5}$ |
| Cold fluid inlet temperature countercurrent flow | T3 | (°C) | |
| Cold fluid outlet temperature countercurrent flow | T4 | (°C) | |

**Note:** In cocurrent flow T2 is the hot fluid outlet temperature and T1 is the hot fluid inlet temperature.

You should estimate the experimental errors for these measurements.

For each set of readings, the software calculates the average hot fluid temperature (from T1 and T2) and the average cold fluid temperature (from T3 and T4) and then automatically provides values for the following variables. If recording data manually, calculate these values and obtain the variables from the tables on page 6-1:

| | | |
|---|---|---|
| Specific heat of hot fluid | $Cp_h$ | kJ/kg°K (From table 1 using T2 as the average temperature) |
| Density of hot fluid | $\rho_h$ | $kg/m^3$ (From table 2 using T2 as the average temperature) |

For each set of readings, the relevant derived results are calculated and presented with the following headings:

| | | |
|---|---|---|
| Mass flowrate (hot fluid) | $Qm_h$ | (kg/s) |
| Heat power emitted from hot fluid | $Q_e$ | (W) |
| LMTD | $\Delta t_{lm}$ | (°C) |
| Overall Heat Transfer Coefficient | U | ($W/m^2{}^\circ C$) |
| Temperature efficiency for hot fluid | $\eta_h$ | (%) |
| Temperature efficiency for cold fluid | $\eta_c$ | (%) |
| Mean temperature efficiency | $\eta_m$ | (%) |

These values should be calculated manually if not using the software.

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

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

## Conclusions

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 you have conducted a similar exercise using a tubular exchanger (HT31 or HT36) or plate heat exchanger (HT32 or HT37) compare the performances and comment on the differences.

Exercise **HT33F** should be carried out on completion of this exercise.

## 7.6 Practical Training Exercise HT33F

### 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

HT30X/HT30XC Heat Exchanger Service Unit

HT33 Shell and Tube Heat Exchanger

### Equipment set-up

Before proceeding with the exercise ensure that the equipment has been set up and the accessory installed as described in this manual, with a cold water supply connected and the pressure regulator adjusted. The apparatus should be switched on, and if using the HT30XC the service unit should be connected to a suitable PC on which the software has been installed. Computer operation is optional with the HT30X.

Prime the hot and cold water circuits using the cold water supply (Refer to the Operational Procedures on page 3-1 if you need details on how to prime the equipment).

If using the HT30XC, or the HT30X with the optional software, run the HT33 software for the service unit used (HT30XC software must be used with the HT30XC and HT30X software with the HT30X, as the calibration for the sensors differs between the two service units). If using the HT30XC, select the Countercurrent exercise. If using the HT30X, select Exercise F and then select Countercurrent Operation on the software display option box.

### Theory/Background

Refer to training 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 Operational Procedures on page 3-1 if you need details of the instrumentation and how to operate it. The mains supply should be switched on before starting this experiment.)

Set the temperature controller to 40°C. If using the HT30X then switch on the hot water circulator.

Adjust the cold water control valve setting to give a cold water flow rate of 1 litre/min.

If using HT30X, adjust the hot water control valve setting $V_{hot}$ to give a hot water flow of 2 litres/min. If using HT30XC, click on the button for the hot water flow rate controller, set the controller to Automatic and enter a Set Point value of 2 litres/min.

Allow the temperatures to stabilise (monitor the temperatures using the sensor display on the software screen or control console).

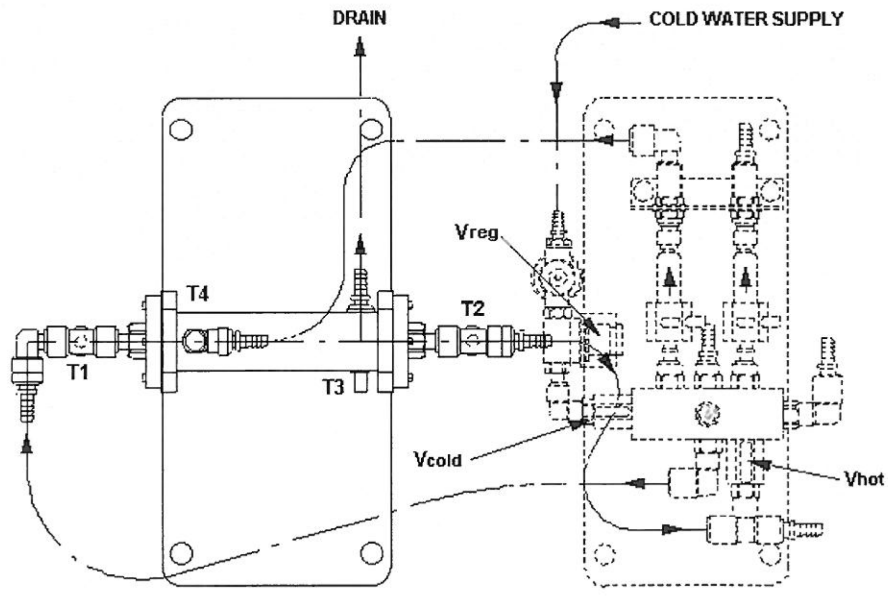
When the temperatures are stable select the GO icon to record the following, or manually note the values: T1, T2, T3, T4, $F_{hot}$, $F_{cold}$

Repeat the above for different settings of the hot water temperature controller as follows: 50°C, 60°C & 70°C

If using the HT30XC, save the logged data by selecting 'Save' or 'Save As' from the 'File' menu. Browse to the location you wish to place the saved data and give the results a meaningful name (e.g. HT33F Countercurrent Operation).

Change the system to cocurrent operation:

If using the HT30X, create a new results sheet in the software using the icon, select the 'Cocurrent' radio button on the software mimic diagram, and change the connections to the hot water inlet and outlet as follows:




HT33 SHELL & TUBE HEAT EXCHANGER
(CONNECTED IN COCURRENT OPERATION)

If using the HT30XC, select 'Load New Experiment...' from the 'File' menu and click on the Cocurrent Operation exercise radio button then select the 'Load' button.

The connections to the heat exchanger are now configured for cocurrent operation where 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).

Adjust the cold water flow control valve to give a flow rate reading of 1 litre/min.

If using HT30X, adjust the hot water control valve setting $V_{hot}$ to give a hot water flow of 2 litres/min. If using HT30XC, click on the button for the hot water flow rate controller, set the controller to Automatic and enter a Set Point value of 2 litres/min.

Set the temperature controller to 40 °C.

Allow the temperatures to stabilise (monitor the temperatures using the sensor display on the software screen or control console).

When the temperatures are stable, select the  icon to record the following or record the values manually: T1, T2, T3, T4, $F_{hot}$, $F_{cold}$

Repeat the above for different settings of the hot water temperature controller as follows: 50°C, 60°C & 70°C

If a supply of cold water is available at variable temperature the exercise can be repeated for different cold water inlet temperatures. Remember to create a new results sheet for each set of results, and to configure the hardware and/or software for countercurrent or cocurrent operation as required. The software will not correctly calculate the derived values if it has not been properly configured.

If using the HT30X or HT30XC software, save the logged data by selecting 'Save' or 'Save As' from the 'File' menu. Browse to the location you wish to place the saved data and give the results a meaningful name (e.g. HT33F Cocurrent Operation).

## Results and Calculations

Technical data:

| | | |
|---|---|---|
| Inner tube inside diameter | $d_i = 0.00515$ | (m) |
| Inner tube outside diameter | $d_o = 0.00635$ | (m) |
| Heat transmission length | $L = 1.008$ (total) | (m) |

The software records all sensor outputs and also calculates several derived figures, and presents the recorded data in tabular form. The following columns are relevant to this exercise, and are suggested as suitable column headings if recording data manually:

| | | | |
|---|---|---|---|
| Hot fluid volume flowrate | $qv_{hot}$ | ($m^3$/s) | Multiply $F_{hot}$ (litres/min) by $1.667 \times 10^{-5}$ |
| Hot fluid inlet temperature | T1 | (°C) | |
| Hot fluid outlet temperature | T2 | (°C) | |
| Cold fluid volume flowrate | $qv_{cold}$ | ($m^3$/s) | Multiply $F_{cold}$ (litres/min) by $1.667 \times 10^{-5}$ |
| Cold fluid inlet temperature countercurrent flow | T3 | (°C) | |
| Cold fluid outlet temperature countercurrent flow | T4 | (°C) | |

You should also estimate the experimental errors for these measurements.

**Note:** In cocurrent flow T2 is the hot fluid outlet temperature and T1 is the hot fluid inlet temperature.

For each set of readings, the software calculates the average hot fluid temperature (from T1 and T2) and the average cold fluid temperature (from T3 and T4) and then automatically provides values for the following variables. If recording data manually, calculate these values and obtain the variables from the tables on page 6-1:

| | | |
|---|---|---|
| Specific heat of hot fluid | $Cp_h$ | kJ/kg°K (From table 1) |
| Density of hot fluid | $\rho_h$ | kg/$m^3$ (From table 2) |

For each set of readings, the relevant derived results are calculated and presented with the following headings:

| | | |
|---|---|---|
| Mass flowrate (hot fluid) | $Qm_h$ | (kg/s) |
| Heat power emitted from hot fluid | $Q_e$ | (W) |
| LMTD | $\Delta t_{lm}$ | (°C) |
| Overall Heat Transfer Coefficient | U | (W/$m^2$°C) |

| | | |
|---|---|---|
| Temperature efficiency for hot fluid | $\eta_h$ | (%) |
| Temperature efficiency for cold fluid | $\eta_c$ | (%) |
| Mean temperature efficiency | $\eta_m$ | (%) |

These values should be calculated manually if not using the software.

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

Compare your derived results at the various differential fluid temperatures.

## Conclusions

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 tubular heat exchanger (HT31 or HT36) or plate heat exchanger (HT32 or HT37) compare the performances and comment on the differences.

## 7.7 Exercise HT33G: Project Work

### To investigate heat loss from the Shell and Tube Heat Exchanger

Practical training exercises HT33A to HT33F are performed with hot water flowing through the inner tubes 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 thorough 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 form the exchanger to the surroundings can be determined. Details of the necessary measurements and calculations are given in practical training 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 surfaced 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 inside which the surface has been pre-fouled.

Seven metal tubes 6.35mm (¼") outside diameter, 0.6mm wall thickness and 166mm 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 tubes from the heat exchanger, disconnect the quick release fittings from the exchanger, then carefully remove the headers (end plates) from the exchanger assembly (sealed using 'O' ring seals) before pushing out the individual metal tubes. If the tubes do not move easily a small amount of wetting agent should be poured into the 'O' ring housings at the end of each tube to prevent damage to the 'O' ring seals.

Before re-inserting the metal tubes, or installing alternative tubes with fouling on the inner surface, lubricate the 'O' ring seals with a small amount of wetting agent.

## 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 HT33 Shell and Tube Heat Exchanger, then the fittings used on the HT33 may be transferred directly, complete with the temperature sensors fitted. The alternative heat exchanger can then be connected directly to the HT30X/HT30XC service unit for evaluation.

The inlet and outlet tubes should be 9.5mm (3/8") outside diameter to allow direct connection to the fitting supplied with the HT33 Shell and Tube Heat Exchanger. If using the temperature sensors only from the HT33 then the tappings for the temperature sensors should be 9.5mm (3/8") inside diameter.

Practical training exercises HT33A to HT33F may be applied to the students' own design of heat exchanger as appropriate.

Typical projects might include:

A Shell and Tube Heat Exchanger constructed with different internal dimensions, e.g. different tube diameter/shell diameter.

A Shell and Tube Heat Exchanger constructed using different materials, e.g. tube bundle manufactured from copper.

A Shell and Tube Heat Exchanger with different tube bundle geometry (spacing of tubes or different pattern/number of tubes).

A Shell and Tube Heat Exchanger with the tubes arranged for multi-pass operation (ends of tube bundle connected to allow hot fluid to flow through the tubes in series instead of parallel).

# 8 Appendix A: Installation Guide

The HT33 Shell and Tube Heat Exchanger must be used in conjunction with the HT30X or HT30XC Heat Exchanger Service Unit.

Before mounting the HT33 Shell and Tube Heat Exchanger on a HT30X/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 service unit.

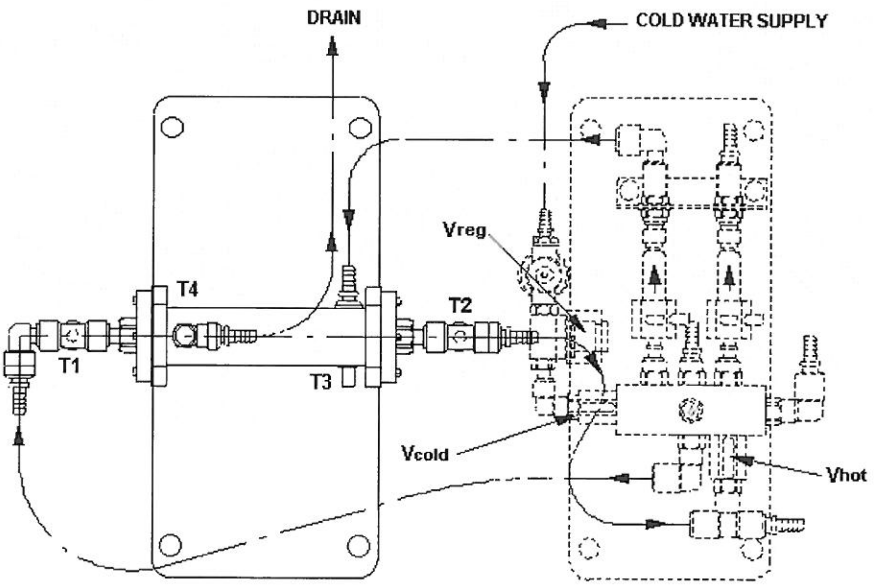
1 Check that the HT30X/HT30XC service unit and the Armfield HT30 range software has been installed as described in the HT30X/HT30XC product manual (provided with the service unit). If used, the PC on which the software has been installed should be located close to the service unit (a compatible PC is required if using the HT30XC).

2 Remove the HT33 accessory from any packaging and position the accessory on the HT30X/HT30XC plinth so that the holes in the HT33 baseplate are located over the studs on the plinth top.

3 Secure the HT33 to the plinth using the thumb nuts provided.

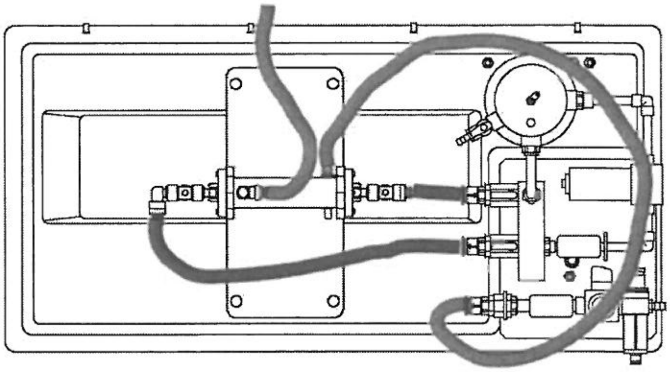
4 Connect the flexible tubing on the HT33 to the quick-release fittings on the service unit as shown:

If using the HT30X:




HT33 SHELL & TUBE HEAT EXCHANGER
(CONNECTED IN COUNTERCURRENT OPERATION)

If using the HT30XC:



5 Direct the tubing carrying the cold water out of the exchanger into a suitable drain.

6 Check that the HT30X/HT30XC service unit is connected to suitable mains water and mains electricity supplies (as described in the manual supplied with the service unit), and that the water and electricity supplies are switched on.

7 If using the HT30XC, check that the 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.

If using the HT30X with optional interface device and software, check that the interface device is connected to the service unit and to the PC. Check that the PC is switched on, and that the red and green indicator lights on the interface device are illuminated.

8 Switch on the service unit (using the mains switch on the front of the unit). If using the HT30XC, check that the Emergency Stop button is released (pulled out).

9 If using the HT30X with software, or the HT30XC, run the HT33 software and select Exercise A (HT30X) or the Countercurrent Exercise (HT30XC). Check that the software reads 'IFD OK' in the bottom right-hand corner of the screen.

10 If using a PC, select the mimic diagram in the software by clicking on the  icon.

11 If using the HT30XC, select the 'Power On' switch on the software mimic diagram.

12 If using the HT30X, switch on the hot water circulating pump then fully open the hot water flow control valve. Run the pump until all air bubbles have been expelled from the hot water circuit. Top up the priming vessel with clean (preferably de-ionised or de-mineralised) water if the level drops more than a centimetre or so below the top. Switch off the pump.

If using the HT30XC, 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. Set the Hot Water Pump Speed back to 0%. The pump should cease operation. Close the controller window.

13 Fully close the pressure regulator at the cold water inlet. Set the Cold Water Valve to fully open (100%), either manually (if using the HT30X) or using the software (if using the HT30XC). 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 the flow rate reaches 4.9 L/min then lock the regulator setting. Allow water to flow until any bubbles have been eliminated, then close the cold water valve again (set the valve back to 0%).

The HT33 accessory is now installed and primed ready for use.

Refer to the HT30X/HT30XC manual for further information on the service unit and its operation.

Refer to the Operational Procedures and Laboratory Teaching Exercises in this manual for more information on the operation of the HT33 and the investigations that can be performed using this Heat Exchanger. The Teaching Exercises are also available from within the HT33 software Help Text.