Experiment – 10 Concentric Tube Heat Exchanger

Aim of this Experiment

Concentric heat exchanger is the simplest form of heat exchanger and a design that may besuccessfully analysed and described by empirical equations. Concentrıc tube heat exchanger demonstrates the basıc prıncıples of heat transfer. Two separate concentric tubes are arranged in series in a U format to reduce the overall length andto provide a mid position measuring point.

Experimental Set – up

The concentric tube heat exchanger experiment set - up consists of two coaxial tubes one inside the other carryingfluids of different temperatures. Due to the temperature difference, heat will flow from the hotter stream to the cooler one. This is the simplest form of heat exchanger and a design that may be successfully analysed and described by empirical equations.

Concentrıc tube heat exchanger demonstrates the basıc prıncıples of heat transfer. Two separate concentric tubes are arranged in series in a U format to reduce the overall length andto provide a mid position measuring point.

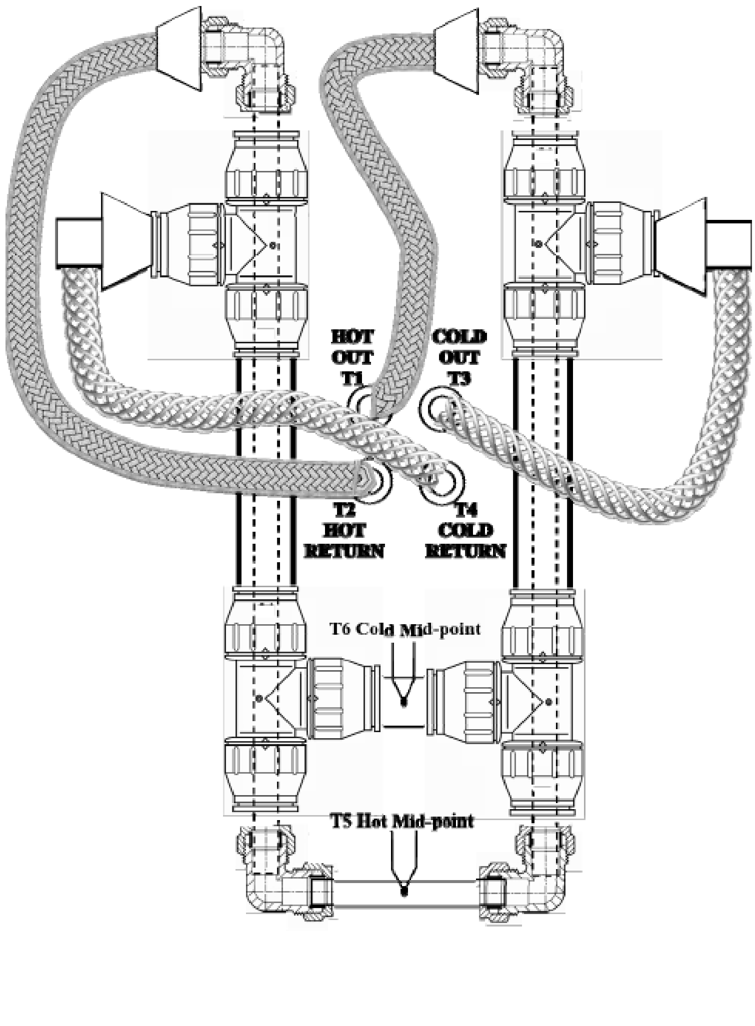
The heat exchanger is mounted on the H102 panel fascia and retained by locking pipe clips.In normal operation, hot water from the heating tank and pump passes through the 'HOT OUT'braided hose and self-sealing coupling into the inner stainless tube. It then flows through the heatexchanger and leaves via the 'HOT RETURN' braided hose**.** Cold water flows from the 'COLDOUT' hose through the annulus between the clear plastic tube and the inner stainless tube. With thehot water in the inner tube, losses from the system to the outside are minimised while still allowingstudents to see the construction of the unit. As the cold stream warms above the ambienttemperature however there will be some external losses.

12mm compression fittings provide a liquid seal between the stainless tubes and the outer annulus.This also allows the stainless tubes to be removed for cleaning if necessary.

The midway points of both hot and cold streams are fitted with type K thermocouple sensors tomeasure the stream temperatures. Miniature thermocouple plugs take these signals to thetemperature indicator and Data Logger (when HC102 upgrade fitted).

The hot hose terminates with a socket and the cold hose a plug to prevent cross-connection. Flowdirection may be arranged for co-current (parallel) or counter-current (opposite direction) of theHot/Cold streams. Self-sealing couplings retain the water in both the hoses and the heatexchangers. Changeover may be performed without stopping the pump or cold flow, but operatorsshould wear gloves for protection from hot surfaces. Reversing the cold flow is the safer option.

Schematic Representation of Linear Conduction Experiment Unit



Capabilities Of The Concentric Heat Exchanger Unit

1. To demonstrate indirect heating or cooling by transfer of heat from one fluid stream to another when separated by a solid wall (fluid to fluid heat transfer).
2. To perform an energy balance across a concentric tube heat exchanger and calculate the overall efficiency at different fluid flow rates.
3. To demonstrate the differences between counter-current flow (flows in opposing directions) and co-current flows (flows in the same direction) and the effect on heat transferred, temperature efficiencies and temperature profiles through a concentric tube heat exchanger.
4. To determine the overall heat transfer coefficient for a concentric tube heat exchanger using the logarithmic mean temperature difference to perform the calculations (for counter-current and cocurrent flows).
5. To investigate the effect of changes in hot fluid and cold fluid flow rate on the temperature efficiencies and overall heat transfer coefficient.
6. To investigate the effect of driving force (difference between hot stream and cold stream temperature) with counter-current and co-current flow.

Operating Procedure Of Concentric Heat Exchanger Unit

Starting

Fit the chosen heat exchanger and connect the Hot/Cold hoses to suit co-current or counter current flow.

Turn on the cooling water supply and open the cooling water flow control valve on the cooling water flowmeter(7) . Ensure that cooling water flows freely through the flowmeter and heat exchanger to the drain. Set the cooling water flow to a low value (10-25g/s depending upon water inlet temperature).

Supply power to the unit and turn on the main switch. The hot water flowmeter(8) should indicate a circulating flow.

Both the digital temperature indicator(6) and the digital water temperature control(5) will illuminate and carry out a self-test before displaying numeric values.

Setting the hot water temperature

The water temperature controller is a digital PID (Proportional Integral Derivative) controller that operates an internal solid state relay which in turn controls power to the 3.0kW water heater. The measured value (Upper display) is sensed at a point close to T1 (Hot Water to Heat Exchanger).

The water temperature controller has the following components.

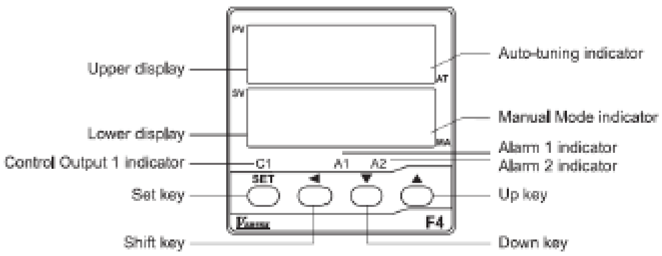


Figure 3. Front panel description

- PV (Upper display) : Display the process Value, parameter index code or error code
- SV (Lower display) : Display the set point value or the set value of parameter
- C1 : Control output 1 indicator
- A1 : Alarm 1 indicator
- A2 : Alarm 2 indicator
- AT : Auto-tuning indicator (The right-most decimal point of upper display)
- MA : Manual mode indicator (The right-most decimal point of lower display)

The Lower Display (shown in the diagram above) shows the SV set point value (the hot water temperature required).

The Upper Display (also shown above) shows Process Value PV (or the ACTUAL temperature of the hot water at the controller sensor). Note that there may be a difference between T1 (Hot Out) temperature and the temperature at the controller sensor. This is normal.

Note that the user has access to the SET, Shift, Up and Down keys. These have different uses.

Setting a New Temperature

To set a new hot water temperature press the Shift key. This will, cause one digit in the Lower display to highlight. The highlighted digit can be changed by using the up and down keys:-

Up Key to increase or Down key to decrease.

This procedure can be repeated for all of the digits in the display by pressing the Shift key repeatedly.

Note that the maximum value that can be set on the H102 unit is 100ºC and the maximum normal operating value is 70ºC and is limited by the safety cut out at 80ºC.

The SET key gives the user access to the following options.

Display	Description	Range
PVoF	Process value offset correction	-1000~1000 (dP =0000) -100.0~100.0 (dP =0000) -10.00~10.00 (dP =0000) -1.000~1.000 (dP =0000)
oUtL	Control output percentage	0.0~100.0%
rUn	Control mode	oFF : Off on : On At1 : AT1 At2 : AT2 mAn : Man

IMPORTANT NOTE that if rUn (the control mode) shows anything OTHER than on, then the PID controller is NOT necessarily controlling the heater.

Under normal running conditions when the set value SV (Lower display) is above the measured value MV the controller will indicate a heating demand by illuminating (or flashing) the white C1 LED Control Output 1 Indicator . When the set value is below the measured value the green C1 LED will be extinguished.

When the heater switch(3) is OFF even if the controller is indicating a heating demand the heater will be off.

Turn on the heater supply switch and if the temperature controller is demanding heat the Red ‘HEAT INPUT’ neon adjacent to the controller will illuminate or flash.

(Note:- A certain amount of air will come out of solution as the water is heated, but this will be automatically vented).

If this is the first time that the unit has been operated then it may need to run for approximately 15 minutes in order to ensure that the majority of dissolved air is released from the hot water circuit.

Note that there will be a slight difference between T1 and the value indicated on the water temperature controller due to sensor location.

Once the system is stable readings may be taken as required.

Shutting Down

1. Turn off the heater switch.
2. Turn the cooling water flow to a high value, and fully open the hot water flow control valves.
3. When the system has cooled to about 40°C, turn off the mains switch and isolate the unit from the mains.
4. Turn off the cold water supply.

Experiment -10.1

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

<u>Aim of This Experiment</u>

This experiment aimed to observe effect of heat transfer form one fluid stream to another one when fluids seperated by a solid wall.

<u>Procedure</u>

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

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

Install the Concentric tube Heat Exchanger H102A as detailed before and connect the cold water circuit to give Counter-Current flow.

Turn on the 'MAIN SWITCH' and 'HEATER SWITCH'

Set the hot water temperature controller to 60°C.
Set the cold water flow rate Vcold to 15g/sec
Set the hot water flow rate V hot to 50g/sec.

Monitor the stream temperatures and the hot and cold flow rates to ensure these too remain close tothe original setting. Then record the following: T1, T2, T3, T4, T5, T6, Vcold and Vhot

Then adjust the 'COOLING WATER FLOW CONTROL' so that Vcold is approximately 30g/sec.

Maintain the Hot water flow rate at approximately 50g/sec.

Allow the conditions to stabilise and repeat the above observations.

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

Sample Test Results

Sample No.	T1	T5	T2	T3	T6	T4	V_{cold}	V_{hot}
----	°C	°C	°C	°C	°C	°C	G/sec	G/sec
1	59.2	56.6	53.0	15.4	25.1	30.9	15	50
2								
3								
4								
5								

Experiment -10.2

To perform an energy balance across a concentric tube heat exchanger and calculate theoverall efficiency at different fluid flow rates

Aim of This Experiment

This experiment aimed to calculate overall heat transfer efficiency in concentric tube heat exchanger at different fluid flow rates.

Procedure

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

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

Install the Concentric tube Heat Exchanger H102A as detailed in INSTALLATION / HeatExchanger Installation H102A and connect the cold water circuit to give Counter-Current flow.

Turn on the 'MAIN SWITCH' and 'HEATER SWITCH'

Set the hot water temperature controller to 60°C.
Set the cold water flow rate Vcold to 15g/sec
Set the hot water flow rate V hot to 50g/sec.

Monitor the stream temperatures and the hot and cold flow rates to ensure these too remain close tothe original setting. Then record the following:T1, T2, T3, T4, T5, T6, Vcold and Vhot

Then adjust the 'COOLING WATER FLOW CONTROL' so that Vcold is approximately 30g/sec.

Maintain the Hot water flow rate at approximately 50g/sec.

Allow the conditions to stabilise and repeat the above observations.

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

Sample Test Results

Sample No.	T1	T5	T2	T3	T6	T4	V_{cold}	V_{hot}
----	°C	°C	°C	°C	°C	°C	G/sec	G/sec
1	59.2	56.6	53.0	15.4	25.1	30.9	17	50
2								
3								
4								
5								

Experiment -10.3

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

Aim of This Experiment

This experiment aimed to demonstrate differences between counter current and co-current flows through a concentric tube heat exchanger.

Procedure

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

Install the Concentric tube Heat Exchanger H102A as detailed in INSTALLATION / HeatExchanger Installation H102A and connect the cold water circuit to give Counter-Current flow.

Turn on the ‘MAIN SWITCH’ and ‘HEATER SWITCH’

Set the hot water temperature controller to 60°C.
Set the cold water flow rate Vcold to 17g/sec
Set the hot water flow rate V hot to 35g/sec.

Monitor the stream temperatures and the hot and cold flow rates to ensure these too remain close tothe original setting. Then record the following:T1, T2, T3, T4, T5, T6, Vhot and Vcold

This completes the basic Counter-Current flow experiment observations.

Next connect the cold water circuit to give **Co-Current flow.**Note that there is no need to disconnect the hot water circuitor to turn off the hot water pump during this operation.

Set the hot water temperature controller to 60°C.
Set the cold water flow rate Vcold to 17g/sec
Set the hot water flow rate V hot to 35g/sec.

Monitor the stream temperatures and the hot and cold flow rates to ensure these remain close to theoriginal setting. Then record the following:T1, T2, T3, T4, T5, T6, Vhot and Vcold

Sample Test Results

Sample No.	T1	T5	T2	T3	T6	T4	V_{hot}	V_{cold}
----	°C	°C	°C	°C	°C	°C	G/sec	G/sec
1	59.6	56.4	51.9	14.7	23.3	28.3	35	17
2								
3								
4								
5								

Theory of Experiments

Co-current and Counter current flow

Thermocouples sense the stream temperatures at the four fixed stations: -

T1 – Hot Water INLET to Heat Exchanger

T2 – Hot Water RETURN from Heat Exchanger

T3 – Cooling Water INLET to Heat Exchanger

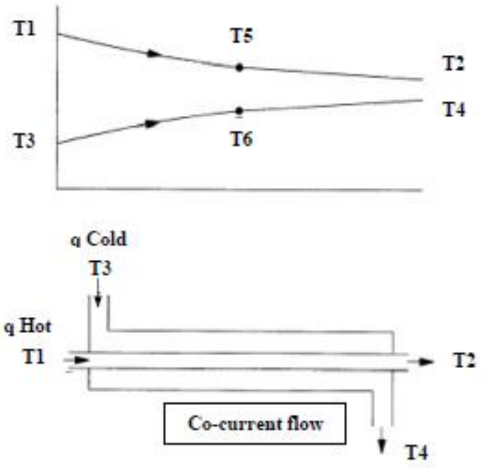
T4 – Cooling Water RETURN from Heat Exchanger

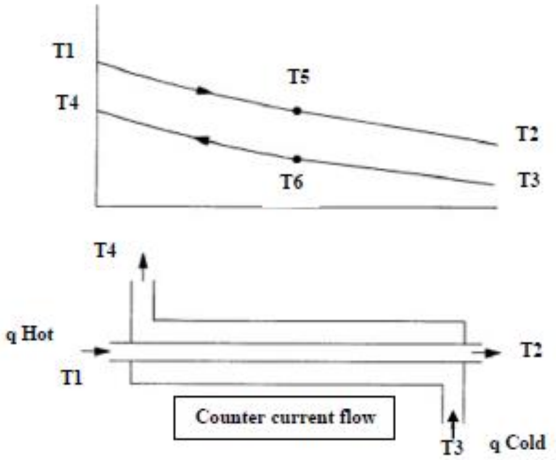
In addition, two plug-in stations: -

T5 – Hot Mid-position (for Concentric Tube)

T6 – Cold Mid-position (for Concentric Tube)

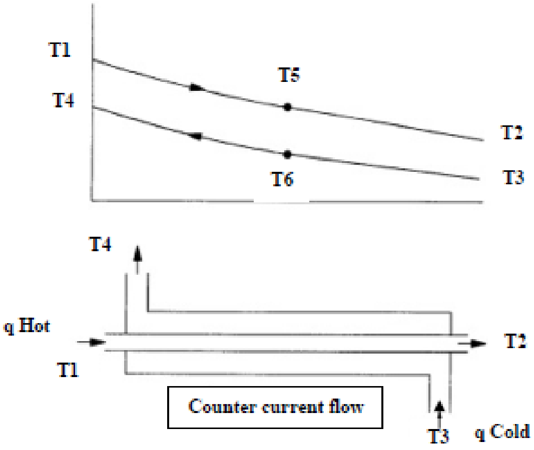
All thermocouples are duplex sensors, the spare sensor is utilised when HC102A Data Acquisition upgrade is fitted.





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

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



The temperature efficiency of the hot stream from the above diagram

$$\eta_{Hot} = \frac{T1\text{-}T2}{T1\text{-}T3} \times 100\%$$

The temperature efficiency of the cold stream from the above diagram

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

The temperature efficiency of the hot stream from the above diagram

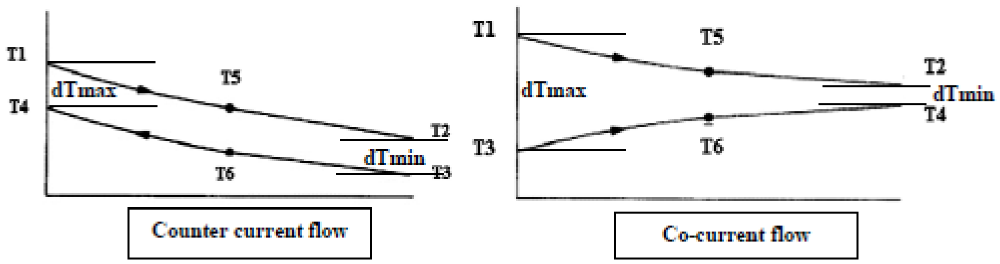
$$\eta_{Hot} = \frac{T1 - T3}{T1 - T4} \times 100\%$$

The mean temperature efficiency

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

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

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



The LMTD is defined as

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

Hence from the above diagrams of temperature distribution for Counter current flow

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

Note that as the temperature measurement points are not fixed on the heat exchanger the LMTD is not the same formula for both Counter-current flow and Co-current flow.

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

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

Where

A	Heat transfer area of heat exchanger (m2)
$\dot{Q}$ e	Heat emitted from hot stream (Watts)
LMTD	Logarithmic mean temperature difference (K)

The heat transfer area may be calculated from: -

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

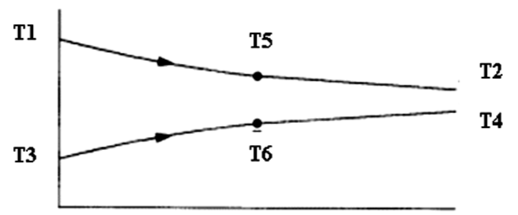
And

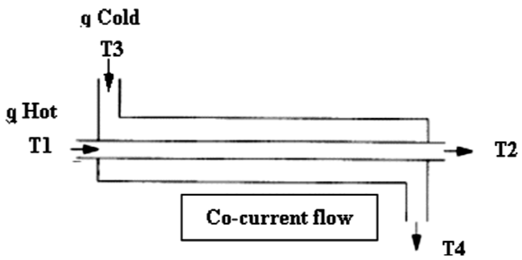
$$A = \pi \, d_m \, L$$

Where

do	Heat transfer tube outside diameter (m)
di	Heat transfer tube inside diameter (m)
dm	Heat transfer tube mean diameter (m)
L	Heat transfer tube effective length (m)

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





The temperature efficiency of the hot stream from the above diagram

$$\eta_{Hot} = \frac{T1\text{-}T2}{T1\text{-}T3} \times 100\%$$

The temperature efficiency of the cold stream from the above diagram

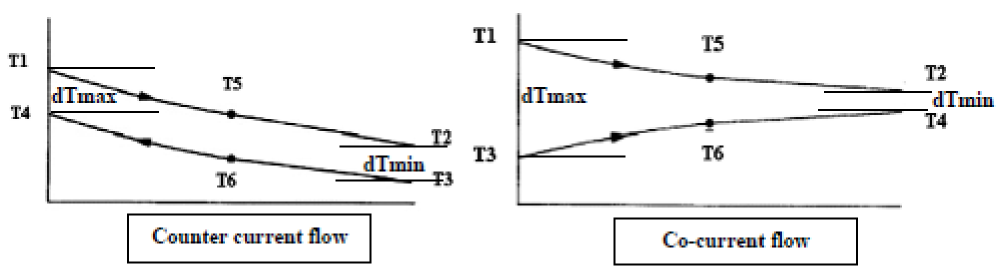
$$\eta_{Cold} = \frac{T4\text{-}T3}{T1\text{-}T3} \times 100\%$$

The mean temperature efficiency

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

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

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



The LMTD is defined as

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

Hence from the above diagrams of temperature distribution

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

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

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

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

Where

A Heat transfer area of heat exchanger (m^2)
Q e Heat emitted from hot stream (Watts)
LMTD Logarithmic mean temperature difference (K)

The heat transfer area may be calculated from:-

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

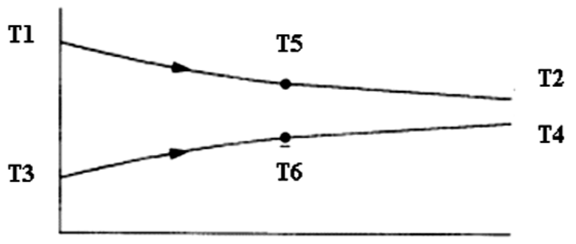
And

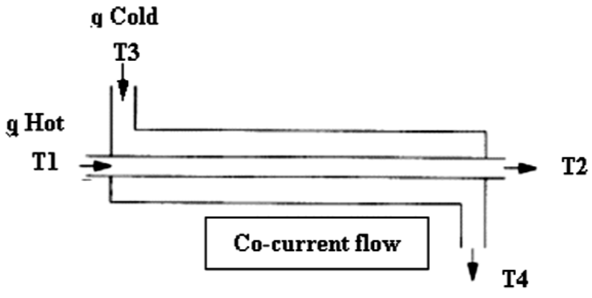
$$A = \pi\, d_m\, L$$

Where

do Heat transfer tube outside diameter (m)
di Heat transfer tube inside diameter (m)
dm Heat transfer tube mean diameter (m)
L Heat transfer tube effective length (m)

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





The power emitted from the hot stream Qe

$$\dot{Q}e = V_{hot}\,\rho_{hot}\;Cp_{Hot}\;(T1 - T2)\;\text{Watts}$$

The temperature efficiency of the hot stream from the above diagram

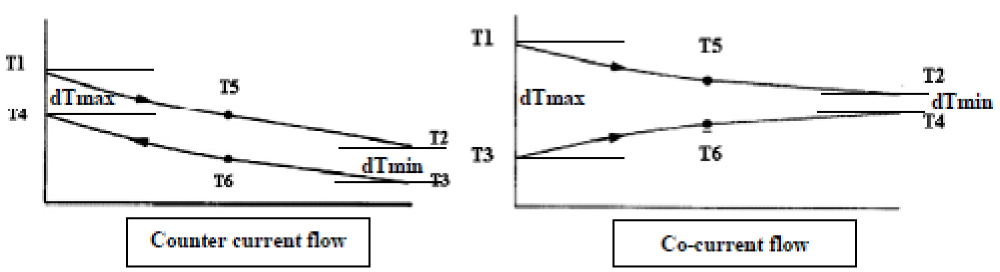
$$\eta_{Hot} = \frac{T1\text{-}T2}{T1\text{-}T4} \times 100\%$$

The temperature efficiency of the cold stream from the above diagram

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

The mean temperature efficiency

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



The logarithmic mean temperature difference LMTD (Co-current flow)

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

The Overall heat transfer coefficient U

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

In order to visualise the effect of temperature difference on the overall heat transfer coefficient the calculated data may be plotted against logarithmic mean temperature difference.

For the Hot stream:

$$\dot{Q}e = V_{hot}\,\rho_{hot}\;Cp_{Hot}\;(T1 - T3)\;\;\text{Watts}$$

For the Cold stream:

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

Appendix – I Symbolas and Units

Symbols and Units

Symbol		Units
V_{cold}	Cold stream flow rate	$g\ s^{-1}$
V_{hot}	Hot stream flow rate	$g\ s^{-1}$
T1	Hot fluid inlet temperature	°C
T2	Hot fluid outlet temperature	°C
T3	Cold fluid inlet temperature	°C
T4	Cold fluid outlet temperature	°C
T5	Hot fluid mid point temperature	°C
T6	Cold fluid mid point temperature	°C
Δt_{hot}	Decrease in hot fluid temperature	K
Δt_{Cold}	Increase in cold fluid temperature	K
dT hot	Decrease in hot fluid temperature	K
dT cold	Increase in cold fluid temperature	K
di	Inside diameter of hot tube	m
do	Outside diameter of hot tube	m
dmean	Mean diameter	m
T_{mean}	Mean temperature	°C
ρ	Density of stream fluid	kg litre
Cp	Specific Heat of stream fluid	$kJkg^{-1}K^{-1}$
$\dot{Q}$ e	Heat flow rate from hot stream	Watts
$\dot{Q}$ a	Heat flow rate to cold stream	Watts
$\dot{Q}$ f	Heat loss to surroundings	Watts
LMTD	Logarithmic mean temperature difference	K
A	Heat transfer surface area	m^2
U	Overall heat transfer coefficient	$Wm^{-2}\ K^{-1}$
$\eta_{Thermal}$	Thermal efficiency	%
η_{hot}	Temperature efficiency hot stream	%
η_{cold}	Temperature efficiency cold stream	%
η_{mean}	Mean temperature efficiency	%
L	Hot tube effective length	m
dTmax	Maximum temperature difference across heat exchanger	K
dTmin	Minimum temperature difference across heat exchanger	K

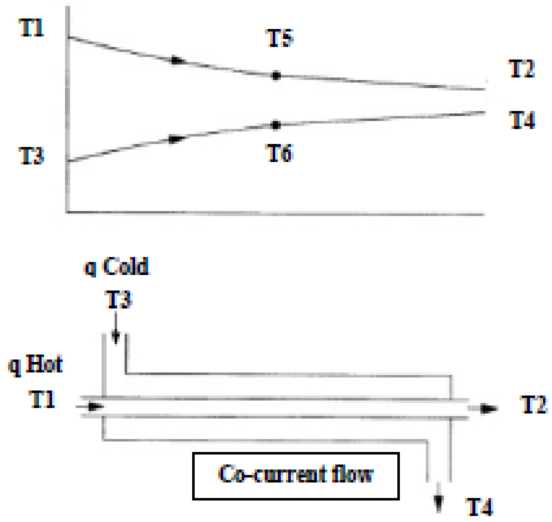
Appendix – II Some Useful Data

Thermocouple Stations

Co-current and Counter current flow

Thermocouples sense the stream temperatures at the four fixed stations: -
T1 – Hot Water INLET to Heat Exchanger
T2 – Hot Water RETURN from Heat Exchanger
T3 – Cooling Water INLET to Heat Exchanger
T4 – Cooling Water RETURN from Heat Exchanger
In addition, two plug-in stations: -
T5 – Hot Mid-position (for Concentric Tube)
T6 – Cold Mid-position (for Concentric Tube)

All thermocouples are duplex sensors, the spare sensor is utilised when HC102A Data Acquisition upgrade is fitted.



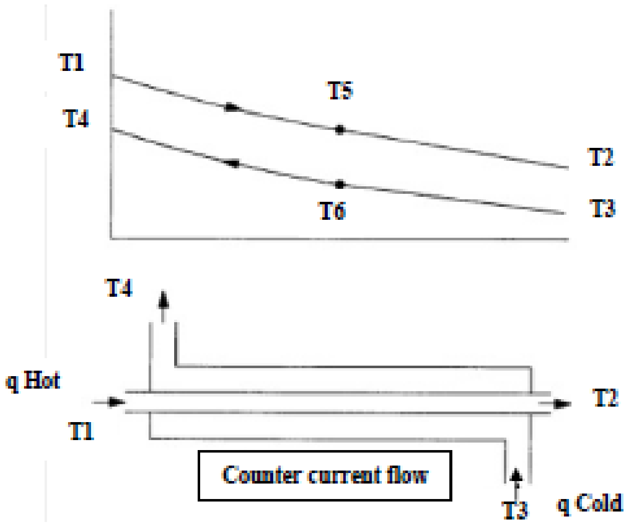


Table 1 Specific Heat capacity Cp of Water in kJ kg $^{-1}$

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

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

Alternatively the equation **$Cp = 6x10^{-9}\, t^4 - 1.0x10^{-6}\, t^3 + 7.0487x10^{-5}\, t^2 - 2.4403x10^{-3}\, t + 4.2113$**
may be used if the data is to be calculated using a spreadsheet.

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

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

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

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