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HEAT EXCHANGERS

1. INTRODUCTION

Practically all the operations that are carried out by the chemical engineer involve the production of absorption of energy in the form of heat. The laws governing the transfer of heat and the types of apparatus that have for their main object to control of heat flow are therefore of great importance.

When two objects at different temperatures are brought into thermal contact, heat flows from the object at the higher temperature to that at the lower temperature. The net flow is always in the direction of the temperature decrease. The mechanisms by which the heat may flow are three; conduction, convection, radiation.

The flow of heat from a fluid through a solid wall to a cooler fluid is often encountered in chemical engineering practice. The heat transferred may be latent heat accompanying phase changes such as condensation or vaporization, or it may be sensible heat coming from increasing or decreasing the temperature of a fluid without phase change. Typical examples are reducing the temperature of a fluid by transfer of sensible heat to a cooler fluid, the temperature of which is increased thereby, condensing steam by cooling water; and vaporizing water from a solution at a given pressure by condensing steam at a higher pressure. All such cases require that heat be transferred by conduction and convection.

In industrial processes heat energy is transferred by a variety of methods, including conduction in electric-resistance heaters; conduction-convection in exchangers, boilers, and condensers; radiation in furnaces and radiant-heat dryers; and by special methods such as dielectric heating. Often the equipment operates under steady-state conditions, but in many processes it operates cyclically, as in regenerative furnaces and agitated process vessels.

Heat exchangers are so important and so widely used in the process industries that their design has been highly developed. Standards devised and accepted by the TEMA (Tubular Exchangers Manufacturers Association) are available covering in detail materials, methods of

construction, technique of design, and dimensions for heat exchangers. Most exchangers are liquid-to-liquid, but gases and non-condensing vapors can also be treated in them.
This experiment is dealing with concentric tube (double pipe) and shell and tube heat exchangers [1,2].

2. THEORY

In the process industries the transfer of heat between two fluids is generally done in heat exchangers. The most common type is one in which the hot and cold fluids do not come into direct contact with each other but are separated by a tube wall or a flat or curved surface. The transfer of heat from the hot fluid to the wall or tube surface is accomplished by convection, through the tube wall or plate by conduction, and then by convection to the cold fluid.
There are several criteria for heat exchangers classification: their geometry, the types of flow, the flow conditions, etc. There is a brief classification of heat exchangers below:

✓ <u>According to their geometry</u>

- Concentric tubes heat exchanger
- Shell and tube heat exchanger
- Plate heat exchanger
- Coil heat exchanger
- Jacketed heat exchanger with stirrer
- Bayonet tube heat exchanger

✓ <u>According to the type of flow</u>

- Parallel flow exchanger
- Countercurrent flow exchanger
- Cross flow heat exchanger

✓ <u>According to the flow conditions</u>

- Laminar flow exchanger
- Transient flow exchanger
- Turbulent flow exchanger

2.1. Types of flow in heat exchangers

There are different types of flow in a heat exchanger:

- Parallel flow
- Countercurrent flow
- Cross flow

In parallel flow, the hot and cold fluids enter and leave through the same end and circulate in the same direction. On the other hand, in countercurrent flow, the fluids enter and leave through opposite ends and circulate in opposite directions. Figure 1 shows both types of flow.

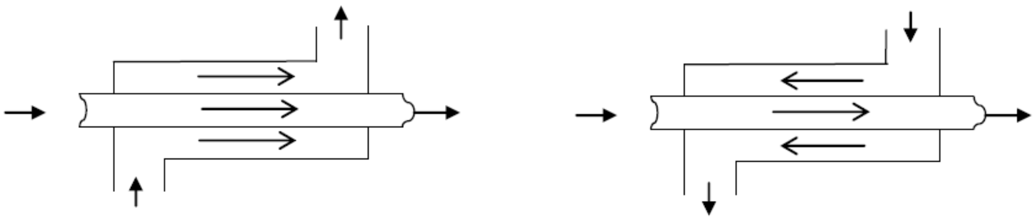
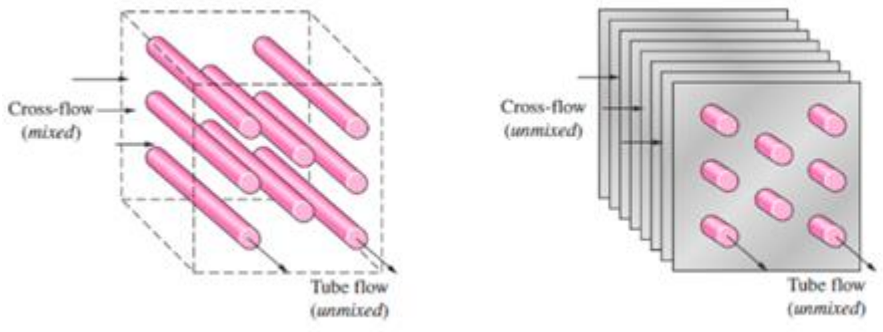


Figure 1: Parallel flow (left) and countercurrent flow (right)[3]

In cross flow, a gas passes perpendicularly through some fins or a bundle of tubes, where a hot fluid flows, as it is shown in Figure 2[3].



(a) **(b)**

Figure 2: Flow patterns of cross-flow heat exchangers: (a) one fluid mixed (gas) and one fluid unmixed; (b) both fluids unmixed

When a gas such as air is being heated or cooled, a common device used in the *cross-flow heat exchangers*. One of the fluids, which is a liquid, flows inside through the tubes, and the exterior gas flows across the tube bundle by forced or sometimes natural convection. The fluid inside the tubes is considered to be unmixed, since it is confined and can not mix with any other stream. The gas flow outside the tubes is mixed, since it can move about freely between the tubes, and there will be a tendency for the gas temperature to equalize in the direction normal to the flow. For the unmixed fluid inside the tubes, there will be a temperature gradient both parallel and normal to the direction of flow. A second type of cross-flow inside heat exchanger shown in Fig. 2b is typically used in air-conditioning and space-heating applications. In this type the gas flows across a finned-tube bundle and is unmixed, since it is confined in separate flow channels between the fins as it passes over the tubes. The fluid in the tubes is unmixed.

2.2. Temperature distribution in exchangers

The following figure (Figure 3) shows the temperature distribution of an exchanger in parallel and countercurrent flow:

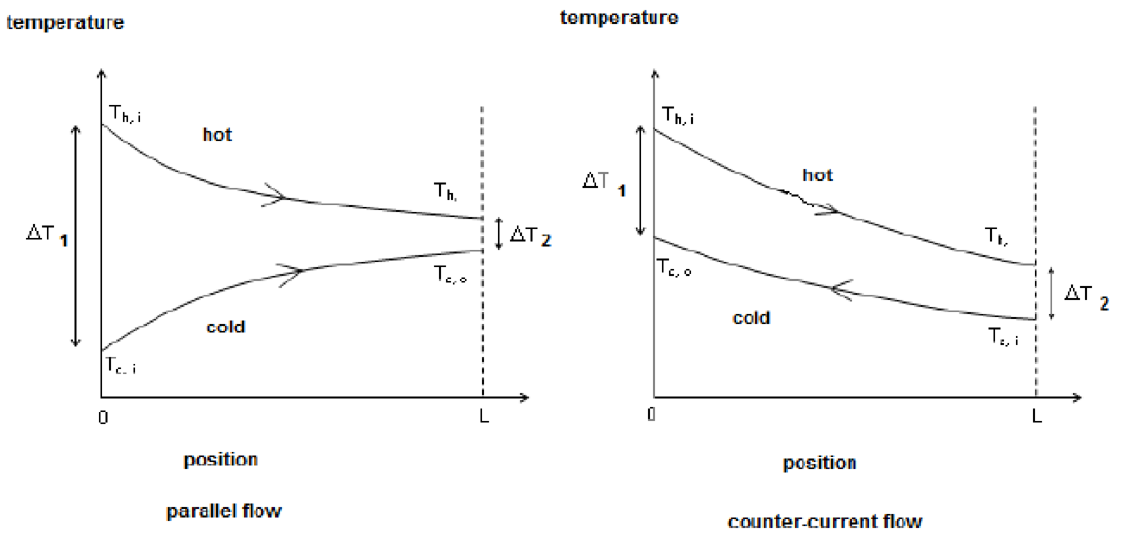


Figure 3: Temperature distribution in exchangers[3]

Where:

- Th,i = temperature of the hot fluid at the inlet of the exchanger
- Th,o = temperature of the hot fluid at the outlet of the exchanger
- Tc,i = temperature of the cold fluid at the inlet of the exchanger
- Tc,o = temperature of the cold fluid at the outlet of the exchanger

In the parallel flow exchanger, the hottest zone of the hot fluid exchanges heat with the coolest zone of the cold fluid at the inlet area. At the beginning the heat transfer is big, since the temperature difference is great; but this difference falls very quickly along the exchanger, approaching asymptotically to zero. It is important to say that, for this type of exchangers, the outlet temperature of the cold fluid never exceeds the outlet temperature of the hot fluid.

In countercurrent flow, the hottest zone of the hot fluid exchanges heat with the hottest zone of the cold fluid and the coldest zone of the hot fluid with the coldest zone of the cold fluid. This configuration gives a good heat transfer both between the hot parts of both fluids at one end and the cold parts at the other end. Besides, the outlet temperature of the cold fluid may exceed the outlet temperature of the hot fluid[3].

2.3. Types of heat exchangers

The simplest exchanger is the *double-pipe or concentric-pipe exchanger* which one fluid flows inside one pipe and the other fluid flows in the annular space between the two pipes. Double-pipe heat exchanger can be made from a pair of single lengths of pipe with fittings at the ends or from a number of pairs interconnected in series. This type of exchanger is useful mainly for small flow rates.

If larger flows are involved, *a shell-and-tube exchanger* is used, which is the most important type of exchanger in use in the process industries. In these exchangers the flows are continuous. Many tubes in parallel are used, where one fluid flows inside these tubes. The tubes, arranged in a bundle, are enclosed in a single shell and the other fluid flows outside the tubes in the shell side. The simplest shell-and-tube exchanger is shown in Figure 4.a for one shell pass and one tube pass, or a 1-1 counterflow exchanger. The cold fluid enters at the other end and flows counterflow across the outside of the tubes. Cross baffles are used so that the fluid is forced to flow perpendicular across the tune bank rather than parallel with it. The added turbulence generated by this cross-flow increases the shell-side heat-transfer coefficient. In Figure 4.b. a 1-2 parallel-counterflow exchanger is shown. The liquid on the tube side flows in two passes as shown and the shell-side liquid flows in one pass. In the first pass of the tube side, the cold fluid is flowing counterflow to the hot shell-side fluid; in the second pass of the tube side, the cold fluid flows in parallel with the hot fluid. Another type of exchanger has two shell-side passes and four tube passes. Other combinations of number of passes are also used sometimes, with the 1-2 and 2-4 types being the most common.

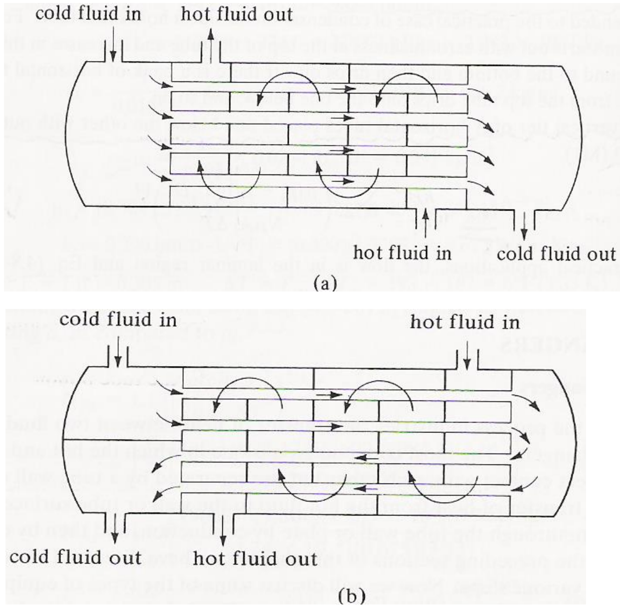


Figure 4. Shell-and-tube heat exchangers: (a) 1 shell pass 1 tube pass (1-1 exchanger); (b) 1 shell pass and 2 tube passes (1-2 exchanger) [4]

Plate heat exchanger allows for the study of heat transfer between hot and cold water flowing through alternate canals formed between parallel plates. A plate heat exchanger consists of a set of corrugated metal plates confined in a shell. Each metal plate has 4 ports or holes (Figure 5). The plates and the ports are sealed by joints at their edge to allow hot and cold fluids flowing through narrow alternate passages formed between the plates. Plates limit the flow of fluids through the path of the exchanger and provide the surface area for heat transfer. The surface is corrugated to improve heat transfer. Heat transfers through the thin plates, offering relatively low thermal resistance. Flow on both sides of the plates may be counter-current or parallel flow. The shell is the frame sustaining the whole unit[5].

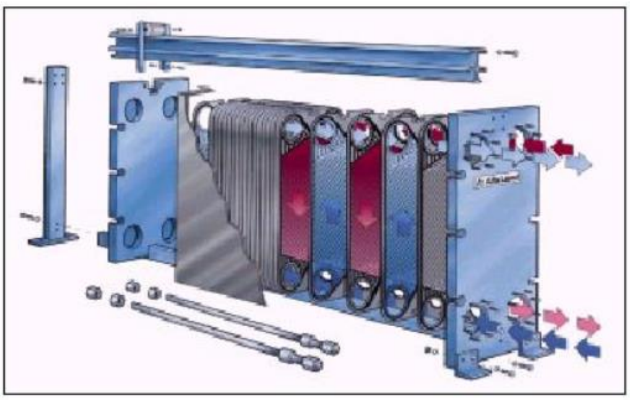


Figure 5. Plate heat exchanger[3]

For a heat exchanger, the heat transfer rate can be found by using the following equation;

$$q = UA\Delta T_{lm} \qquad (1)$$

Where q is heat transfer rate, U is the overall heat transfer coefficient, A is the heat transfer area, and ΔT_{lm} is the log mean temperature difference. The log mean temperature difference can be defined as;

$$\Delta T_{lm} = \frac{\Delta T_2 - \Delta T_1}{\ln\left(\Delta T_2 / \Delta T_1 \right)} \qquad (2)$$

where ΔT_2 is the temperature difference at one end of the exchanger and ΔT_1 at the other end. This ΔT_{lm} holds for a double-pipe heat exchanger and a 1-1 exchanger with 1 shell pass and 1 tube pass in parallel or counterflow. In the cases where multiple-pass heat exchanger is involved, it is necessary to obtain a different expression for the mean temperature difference to use, depending on the arrangement of the shell and tube passes.

Two important relations for the analysis of a heat exchanger are the overall energy balances, both of the hot fluid and the cold fluid. Neglecting the changes of potential and kinetic energy along the exchanger:

General heat transfer rate from the hot fluid:

Heat power emitted = qh = m_h Cp_h (Th,i - Th,o) (3)

General heat transfer rate from the cold fluid:

Heat power absorbed = qc = m_c Cp_c (Tc,o - Tc,i) (4)

Where *mh* and *mc* are the mass flows (kg/s), and *Cph* and *Cpc* are the specific heats of the hot and cold fluids.

Hence, heat power lost is;

$$\text{Heat power lost} = \text{Heat power emitted} - \text{heat power absorbed} \qquad (5)$$

Hence, overall all heat transfer coefficient can be calculated by using the equation (6);

$$U = \frac{\text{Heat power emitted}}{\text{Heat transfer area} * \Delta T_{lm}} = \frac{q}{A * \Delta T_{lm}} \qquad (6)$$

2.4. NTU-effectiveness method for the analysis of a heat exchanger

If the outlet temperatures of the exchanger are not known, to calculate the heat transfer rate from the logarithmic mean temperature difference the problem should be solved by iteration, starting from an approximate value of one of the temperatures. This method would be slow and expensive. In these cases the NTUeffectiveness method is preferred.

The effectiveness is defined as the ratio of the actual rate of heat transfer in a given exchanger to the maximum possible amount of heat transfer if an infinite heat transfer area were available.

$$\mathcal{E} = \frac{q_{real}}{q_{maximum}} \tag{7}$$

where $q_{maximum} = m_h\, Cp_h$ (Th,i - Tc,i) if $m_h\, Cp_h < m_c\, Cp_c$ because the cold fluid may experience the highest change in temperature and $q_{maximum} = m_c\, Cp_c$ (Th,i - Tc,i) if $m_c\, Cp_c < m_h\, Cp_h$ because the hot fluid may experience the highest temperature change. Being (Th,i - Tc,i) the highest possible difference in temperature that one of the fluids may experience. Therefore, effectiveness may be:

$$\mathcal{E} = \frac{mcxCpc\; x(T_{co}-T_{ci})}{mhxCph\; x\; (T_{hi}-T_{ci})} \qquad \text{if mh Cph < mc Cpc} \tag{8}$$

$$\mathcal{E} = \frac{mhxCph\; x(T_{hi}-T_{ho})}{mcxCpc\; x(T_{hi}-T_{ci})} \qquad \text{if mc Cpc < mh Cph} \tag{9}$$

The number of transmission units (NTU) is a dimensionless parameter widely used for heat exchanger analysis being defined as:

$$NTU = \frac{U.A}{(m.C_p)_{min}} \tag{10}$$

On the other hand, we may define Capacity Coefficient (C_R) as:

$$C_R = \frac{(m.C_p)_{min}}{(m.C_p)_{max}} \tag{11}$$

Expressing $\mathcal{E}$ as a function of C_R and NTU, the following plot is obtained (Figure 6):

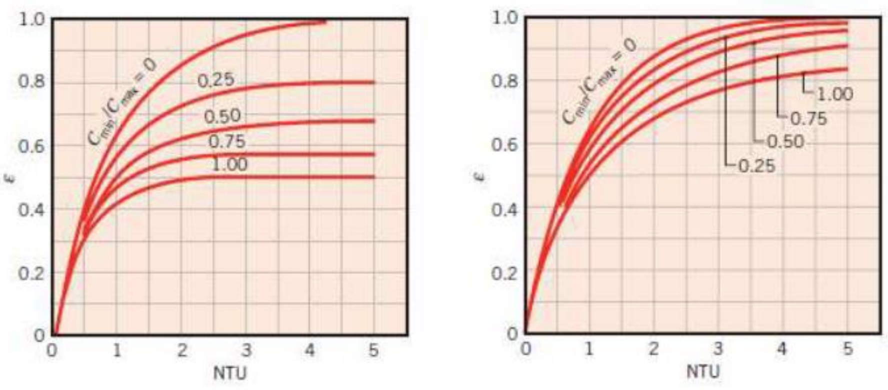


Figure 6: ε-NTU plots for parallel flow (left) and countercurrent flow (right)

2.5. Fouling Factors

In actual practice, heat-transfer surfaces do not remain clean. Dirt, soot, scale, and other deposits form on one or both sides of the tubes of an exchanger and on other heat transfer surfaces. These deposits form additional resistances to the flow of heat and reduce the overall heat-transfer coefficient U. In petroleum processes coke and other substances can deposit. Silting and deposits of mud and other materials can occur. Corrosion product may form on the surfaces which could form a serious resistance to heat transfer. Biological growth, such as algae can occur with cooling water in the biological industries.

To avoid or lessen these fouling problems chemical inhibitors are often added to minimize corrosion, salt deposition, and algae growth. Water velocities above 1 m/s are generally used to help reduce fouling. Large temperature differences may cause excessive deposition of solids on surfaces and should be avoided if possible. The effect of such deposits and fouling is usually taken care of in design by adding a term for the resistance of the fouling on the inside and outside of the tube [6].

3.DESCRIPTION OF APPARATUS

A heat exchanger is any device where a heat exchange between two fluids separated by a metal wall is verified. This metal wall represents the heat transfer surface and its geometry can be of any shape.

3.1. Concentric Tube Exchanger

The concentric tube heat exchanger allows to measure hot and cold water temperatures at different points of the exchanger. The base unit and the exchanger are connected by flexible tubes allowing hot and cold water to circulate.

The interface allows to visualize on a screen the measurements taken while performing a test: temperatures in the exchanger, temperature of the water in the heating tank and water flows.

The equipment consists of two parts: the base unit and the concentric tube exchanger.

3.1.1. Base Unit

- **TIUS unit**
- **TIUSB unit**

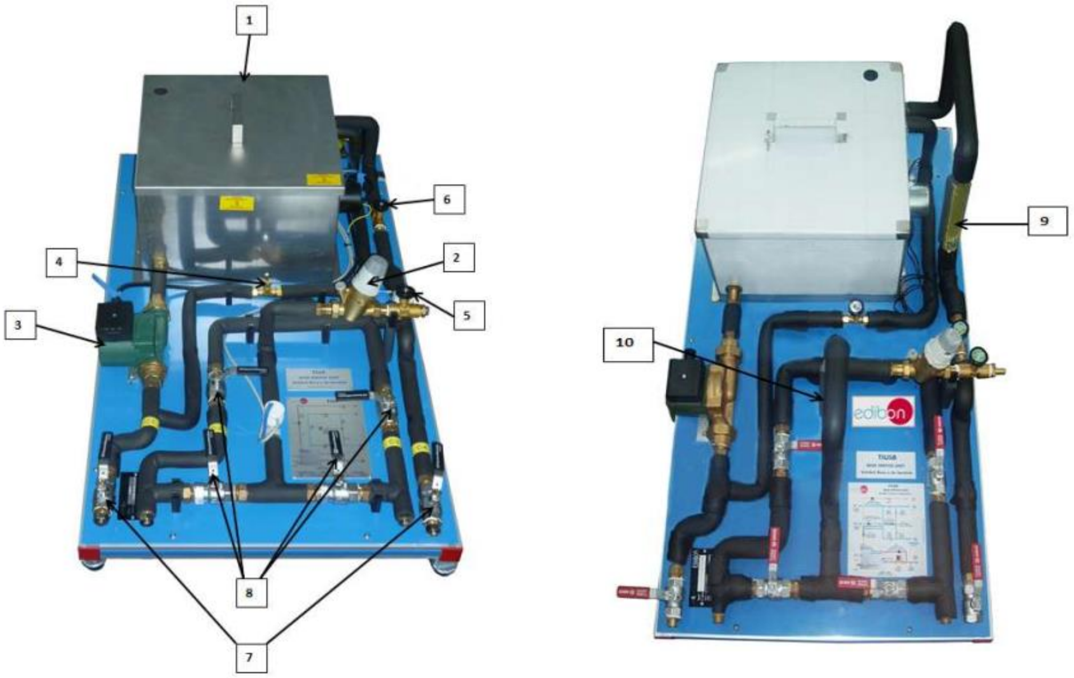


Figure 7: Experimental set-up of base unit

1. D-1: tank made of stainless steel to heat the fluid of the hot circuit. Inside it includes:

- Heating element, AR-1.
- Level sensor, AN-1, to guarantee a specific level in the tank.
- Temperature sensor, ST-16, of the water in the tank.

2. RP-1: pressure regulator. It allows to regulate the water inlet pressure. The unit is supplied with the regulator adjusted to 0.7 bars approx. to avoid overpressures in the unit it will supply.

3. AB-1: hot water impeller centrifugal pump that allows the variation of the flowrate that circulates through the hot circuit.

4. VR-1: regulation valve of the hot circuit water bypass. It is supplied already adjusted to a minimum flowrate, which is the one recommended by the manufacturer and the one that guarantees a good operation of the unit. It is sealed.

5. VR-2: regulation valve of the water flowrate of the cold circuit.

6. VR-3: regulation valve of the water flowrate of the hot circuit.

7. V-1 and V-6: passing ball valve and draining ball valve of the hot water circuit of the base unit.

8. V-2, V-3, V-4 and V-5: passing ball valves that allow to vary the direction of the flow of the cold circuit towards the exchanger.

Instrumentation:

- SC-1: flow sensor that measures the water flowrate of the hot circuit.
- SC-2: flow sensor that measures the water flowrate of the cold circuit.

- **Particularities of the TIUSB unit:**

9. C-1: flow meter that measures the water flow of the hot circuit.

10. C-2: flow meter that measures the water flow of the cold circuit.

3.1.2. TITC, concentric tube exchanger

Concentric tube exchanger consists of two concentric tubes with hot water flowing through the inner tube and cold water flowing through the ring-shaped area.

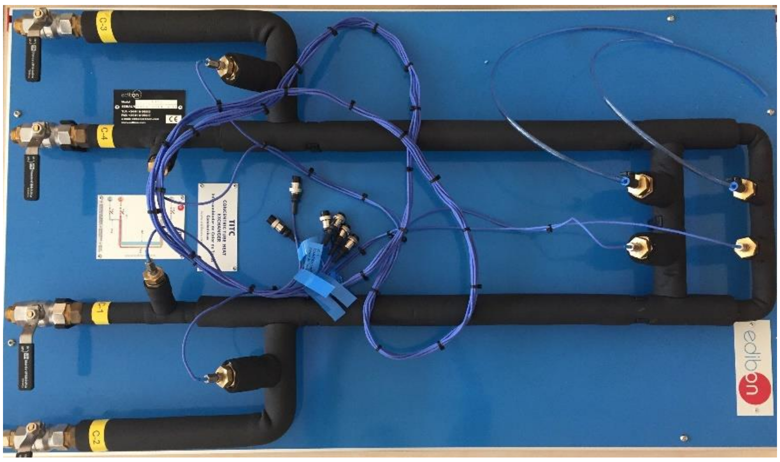


Figure 8: Experimental set-up of concentric tube exchanger

• Exchange length L = 2 x 0.5 = 1 m.
Heat transfer internal area: Ah = 0.0503 m^2
Heat transfer external area: Ac = 0.0565 m^2

3.2. Shell and Tube Heat Exchanger

The shell and tube heat exchanger is the most widely used in industry. It adapts to fluids at high and low pressures, high and low temperatures and constitutes the most important part of heat transfer equipment without combustion in chemical processes plants. Besides, they are compact and efficient, and their high velocities improve the heat transfer rate.

The shell and tube heat exchanger designed by EDIBON S.A. allows the study of heat transfer between the hot water that flows by an inner tube and the cold water that flows by the annular area between the inner tube and the outer tube, called shell. The unit allows to work under different flow conditions, from laminar to turbulent. At the same time, it can vary the flow direction to work either in countercurrent or in parallel.

3.2.1. TICT, shell and tube heat exchanger

The shell and tube heat exchanger, TICT, consists of 21 tubes arranged as a square through which a water flow from the hot circuit of the base unit TIUS (TIUSB) circulates. The cold circuit water flows by the annular side between the shell and the tubes.

The exchanger has 7 thermocouples (ST-1, ST-2, ST-3, ST4, ST5, ST-6 and ST-16) distributed between the hot and cold circuits, in which the temperature at the inlet, outlet and intermediate points of the exchanger are measured.

➢ Inner tube
• Inner diameter: Di = $8 \cdot 10^{-3}$ m
• Outer diameter: Do= $10 \cdot 10^{-3}$ m
➢ Shell
• Inner diameter: Dic, 0.148 m
• Outer diameter: Doc, 0.160 m
- Exchange length of each tube, L = 0.566 m.
- PT, distance from the center of one tube to the center of another tube (m). PT = 0.025 m.
- C, space between tubes (m). C = 0.015m.
- B, space between baffles (m). B= 0.100 m.

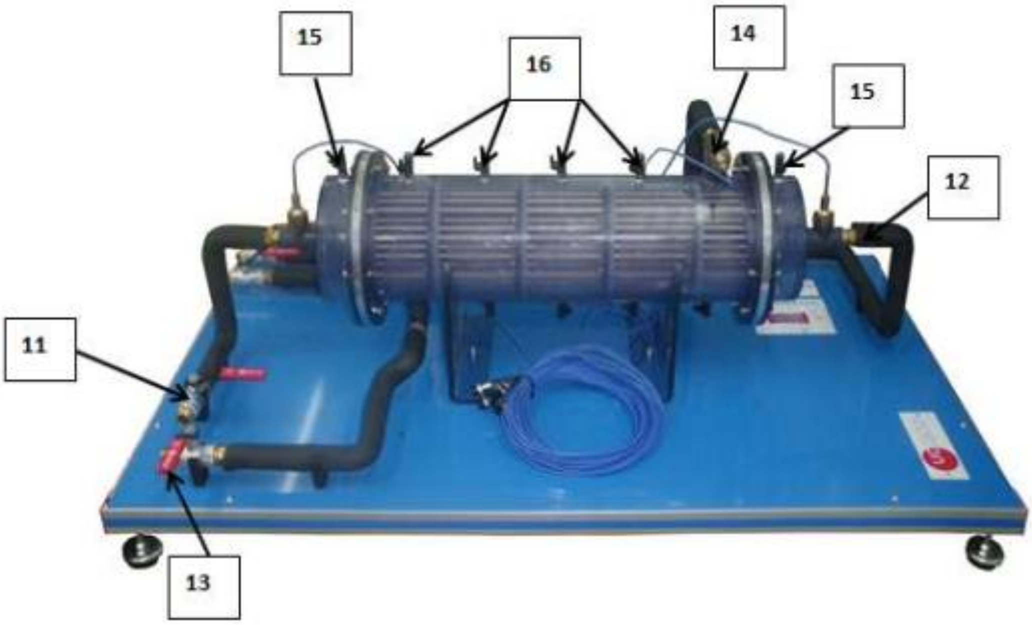


Figure 9: Experimental set-up of shell and tube heat exchanger

11. V-7: passing and draining valve of the water of the hot circuit at the inlet of the exchanger.

12. V-8: hot water outlet circuit. It ends in the passing and draining valve V-8.

13. V-9: passing and draining valve of the water of the cold circuit at the inlet of the exchanger (in parallel flow) and at the outlet of the exchanger (in countercurrent flow).

14. V-10: passing and draining valve of the water of the cold circuit at the inlet of the exchanger (in countercurrent flow) and at the outlet of the exchanger (in parallel flow).

15. P-1: two purge valves that allow to release air from the hot circuit.

16. P-2: four purge valves that allow to release air from the cold circuit.

<u>Instrumentation:</u>

- ST-1: temperature sensor of the hot water at the inlet of the exchanger.
- ST-2: temperature sensor of the hot water at the outlet of the exchanger.
- ST-3: temperature sensor of the water in the cold circuit at the inlet of the exchanger (in parallel flow) and outlet of the exchanger (in countercurrent flow).
- ST-4: temperature sensor of the water in the cold circuit at an intermediate point of the exchanger.
- ST-5: temperature sensor of the water in the cold circuit at an intermediate point of the exchanger.

- ST-6: temperature sensor of the water in the cold circuit at an intermediate point of the exchanger.
- ST-7: temperature sensor of the water in the cold circuit at the inlet of the exchanger (in countercurrent flow) and outlet of the exchanger (in parallel flow).

3.3. Main Instructions, Warnings and Precautions

- Avoid touching the heating tank, it reaches temperatures around 70ºC.
- Do not open the purge valve of the heating tank while the tank is full.
- Do not remove the cover of the tank during the performance of the practical exercises.
- Check the correct position of the valves before starting each practical exercise.
- Take into account that:

• For the TICC unit, the regulation valve VR-3 must be totally open and the flow of the hot fluid must be regulated with the control button of the AB-1 pump's flow, which varies from 0 to 100%.

• For the TICB unit, the flow of the hot fluid is regulated with the regulation valve VR-3, so that AB-1 pump's button must be set to ON position.

4. EXPERIMENTAL PROCEDURE

In the heat exchanger unit provided in Chemical Engineering Lab. II; the following will be practised:

❖ Overall energy balance in the concentric and shell and tube heat exchanger and study of heat losses in parallel and countercurrent flow.

❖ Obtainment and representation of the temperature distribution in the concentric and shell and tube exchanger for parallel and countercurrent flow.

❖ Calculation of the overall heat transfer coefficient (U) for parallel and countercurrent flow.

❖ Determination of the effectiveness of the exchanger. ε-NTU method for parallel and countercurrent flow.

❖ Demonstration the effect of flow rate variation on the performance characteristics of a concentric and shell and tube heat exchanger.

4.1. Concentric Tube Heat Exchanger

4.1.1. Study of heat transfer in counter current and parallel flow conditions and Determination of the exchanger effectiveness. NTU method

1. Verify that valves are open and parallel fluid configuration is set.
2. Verify that the heating tank is filled with water over the level switch.
3. Turn on the pump and the resistor (power supply of the unit).
4. Fix the tank temperature at **45 ºC** (ST16).
5. Set the hot water flow at about **1.5 l/min** (SC1) and adjust the cold water flow to stationary operating conditions keeping constant the temperature set in the tank.
6. Write down temperature and flow measurements on the experimental sheet.
7. Set the valves in the position required to invert the direction of cold water flow getting countercurrent flow disposition.
8. Make sure that the temperature is kept constant at 45 ºC in the tank and that the same cold and hot water flow values are those set previously in step 5.
9. Once the system is stabilized, write down temperatures and flow measurements on the experimental sheet.

It is important to compare the parallel flow and counter flow results and calculate the efficiency of the system for both parallel and counter flow. The following parts of the experiment will be performed at either parallel or counter flow according to their efficiencies. Theoretically counter flow efficiency is more than parallel flow efficiency; hence the procedure of the following parts will be explained according to the counter flow conditions.

4.1.2. Energy balance in the exchanger and losses study

1. Verify that valves are open and that countercurrent flow configuration has been set.
2. Verify that the heating tank is filled with water over the level switch.
3. Turn on the pump and the resistor (power supply of the unit).
4. Set the tank temperature in **45 ºC** (ST16).
5. Set the hot water flow in **1.0 l/min** approx. (SC1) and adjust the cold water flow so stationary operating conditions may be reached keeping the temperature in the tank constant.
6. Write down temperature and flow measurements on the experimental sheet.
7. Repeat steps 5 and 6 for different temperatures of the water tank: **50 ºC, 55ºC and 60 ºC**.

4.2. Shell and Tube Heat Exchanger

1. Check that the valves of the hot and cold circuit are correctly positioned for the performance of the practical exercise in paralel flow configuration, according to the operation section.

2. Check that the water heating tank is full of water above the level switch AN-1.

3. Switch on the heating element AR-1 and set the temperature of the heating tank ST-16, according to the operation section, to **45ºC.**

4. Set the hot water flow at about **1.5 l/min** (SC1) and adjust the cold water flow to stationary operating conditions keeping constant the temperature set in the tank.

5. Record the temperature measurements (ST-1, ST-2, ST-3, ST-4, ST-5, ST-6, ST-7, ST-16) and water flowrates SC-1 or (C-1) and SC-2 or (C-2) in the worksheet.

6. Set the hot water flow at about **1.5 l/min** (SC1) and switch the operation section in countercurrent flow configuration.

7. Then, repeat steps from 3 to 5, keeping constant the flow value SC-1 or (C-1) in **1 l/min** and the flow value SC-2 or (C-2) for different temperatures of the water in the tank, ST-16: **45ºC, 50ºC, 55ºC and 60ºC** for countercurrent flow configuration..

8. Record the temperature measurements (ST-1, ST-2, ST-3, ST-4, ST-5, ST-6, ST-7, ST-16) and water flowrates SC-1 or (C-1) and SC-2 or (C-2) in the worksheet.

5. CALCULATIONS

5.1 Calculations for Concentric Tube Heat Exchanger

• Considering the measures of Test 1 and Test 2, the following thermodynamic variables are calculated:

- Experimental effectiveness (Ɛ)
- Heat transferred by hot water (qh)
- Heat absorbed by the cold water (qc)
- Heat losses (ql)
- Log mean temperature difference between hot and cold water (ΔTlm)
- Parameters: U.A, NTU and C_R.
- Effectiveness obtained by the NTU method (ε_{NTU})

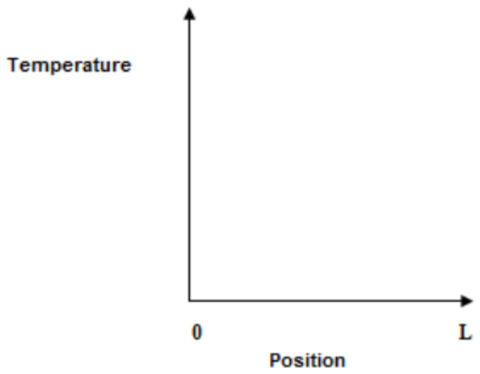
-Hot and cold water temperatures at the exchanger outlet obtained from experimental effectiveness (Th,o and Tc,o)

	TEST 1 Parallel Flow	TEST 2 Countercurrent Flow
ε		
qh (w)		
qc (w)		
ql (w)		
ΔTlm (k)		
U·A (w/k)		
NTU		
C_R		
ε_{NTU}		
Th,o (^{0}C)		
Tc,o (^{0}C)		

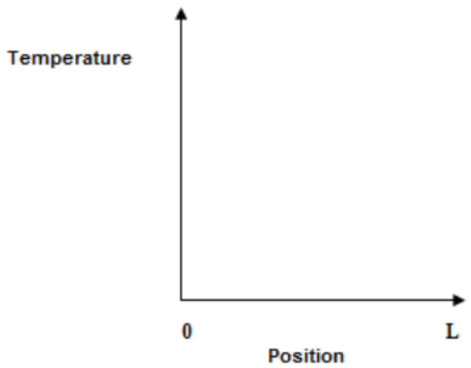
- Represent temperature distribution for countercurrent and parallel flows. Represent hot and cold water temperature values in ºC (T) on the y-axis; and represent the position along the exchanger in meters along the x-axis. Consider the exchange length to be 1m and that we have three measure points:

Cold water: ST_ in x=0, ST_ in x= 0.5m and ST_ in x=1m

Hot water: ST_ in x=0, ST_ in x= 0.5m and ST_ in x=1m



PARALLEL FLOW



COUNTERCURRENT FLOW

- From the measures of the Test 3, Test 4, Test 5 and Test 6, the following thermodynamic variables are calculated:

- Heat transferred by hot water (qh)
- Heat absorbed by the cold water (qc)
- Heat losses (ql)
- Log mean temperature difference between hot and cold water (ΔTlm)

- Overall heat transfer coefficient (U)

	Test 3	Test 4	Test 5	Test 6
qh (w)				
qc (w)				
ql (w)				
ΔTlm (K)				
U (w/m^2K)				

5.2 Calculations for Shell and Tube Heat Exchanger

• Considering the measures of Test 7 for parallel and Test 8 for counter current flow, the following thermodynamic variables are calculated:

	Test 7 (Parallel Flow)	Test 8 (Counter-Current Flow)
qh (w)		
C_{min} (J/sK)		
C_{max} (J/sK)		
Cr (dimensionless)		
A (m^2)		
ΔT_{lm} (K)		
U (W/m^2K)		
NTU		
ε		
Q_{max} (J/s)		
Q_{real} (J/s)		
Th,o (^{0}C)		
Tc,o (^{0}C)		

- Considering the measures of Test 9, Test 10, Test 11 and Test 12 the following thermodynamic variables are calculated:

	Test 9	Test 10	Test 11	Test 12
qh (w)				
qc (w)				
ql (w)				
ΔT_1 (K)				
ΔT_2 (K)				
ΔT_{lm} (K)				
A (m^2)				
U (W/m^2K)				

$$m = \frac{l}{min} \; x \; \rho \; \left(\frac{g}{l}\right) \text{x} \frac{1\, min}{60s}$$

- Considering the measures of Test 7 for parallel and Test 8 for counter current flow, plot the temperature distribution of the hot and cold circuits along the exchanger, taking into account that the distances between temperature sensors are:

➢ **Countercurrent flow**

Cold water:

- ST3 in L= 0
- ST4 in L= 0.125m
- ST5 in L= 0.25m
- ST6 in L= 0.375m
- ST7 in L= 0.5 m

Hot water:

- ST1 in L= 0
- ST2 in L= 0.5m

➢ **Parallel flow**

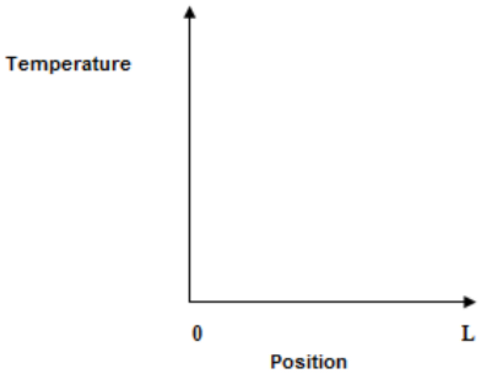
Cold water:

- ST3 in L= 0
- ST4 in L= 0.125m

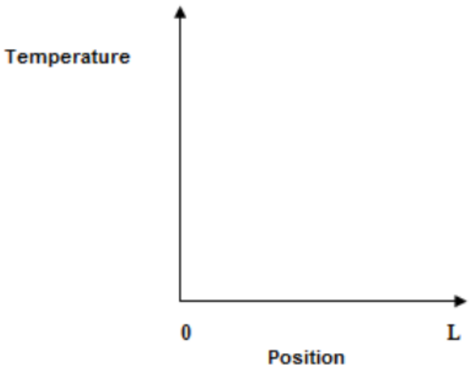
- ST5 in L= 0.25m
- ST6 in L= 0.375m
- ST7 in L= 0.5 m

Hot water:

- ST1 in L= 0
- ST2 in L= 0.5m



PARALLEL FLOW



COUNTERCURRENT FLOW

6. SYMBOLS

A Heat transfer area, m^2

C_p Specific heat, J/g^{o}C; C_{pc}, of cold fluid, C_{ph}, of hot fluid.

ε Efficiency of heat exchanger

q Heat transfer rate, W

Q Fluid flow rate, cc/min; Q_c, of cold fluid; Q_h, of hot fluid

ρ Density, kg/m^3; ρ_c, of cold fluid; ρ_c of hot fluid

T Temperature, ^{o}C; T_{ci} & T_{hi} of cold and hot fluids entering to the heat exchanger; T_{co} & T_{ho}, of cold and hot fluids leaving;

ΔT Temperature drop, ^{o}C; ΔT_{lm}, Logarithmic mean temperature differences, ^{o}C

U Overall heat transfer coefficient, W/m^2K

7. REFERENCES

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8. DATA SHEET

Group No :

Date :

HEAT EXCHANGERS

DATA SHEET

8.1. Concentric Tube Heat Exchanger

	TEST 1 Parallel Flow	**TEST 2 Counter-current Flow**	**TEST 3 Counter-current Flow**	**TEST 4 Counter-current Flow**	**TEST 5 Counter-current Flow**	**TEST 6 Counter-current Flow**
ST16 (ºC)	45	45	45	50	55	60
ST1 (ºC)						
ST2 (ºC)						
ST3 (ºC)						
ST4 (ºC)						
ST5 (ºC)						
ST6 (ºC)						
SC1 (l/min)						
SC2 (l/min)						

8.2. Shell and Tube Heat Exchanger

	TEST 7 Parallel Flow	**TEST 8 Counter-current Flow**	**TEST 9 Counter-current Flow**	**TEST 10 Counter-current Flow**	**TEST 11 Counter-current Flow**	**TEST 12 Counter-current Flow**
ST16 (ºC)	45	45	45	50	55	60
ST1 (ºC)						
ST2 (ºC)						
ST3 (ºC)						
ST4 (ºC)						
ST5 (ºC)						
ST6 (ºC)						
ST7 (ºC)						
SC1 (l/min)						
SC2 (l/min)						