

`Experiment Number -1-

Mixing of Powders

Objective:

To study the process of mixing and see how the properties of ingredients - the particle size distribution as example - will affect the process. Also investigate the effect of mixing time, and mixing speed on the state of mixing.

Equipment:

The unit is composed of a double-cone mixer, with a timer, and with a speed controller.

Samples can be analyzed by an ionselective meter, or by titration method.

Theory:

The mixing index is a measure of how far mixing has proceeded toward equilibrium.

For granular solids, the mixing index is defined as $\frac{\sigma_e}{S}$ the equilibrium standard deviation for complete mixing over standard deviation

$$I_s = \frac{\sigma_e}{S} = \sqrt{\frac{\mu_p \cdot (1 - \mu_p) \cdot (N - 1)}{n \sum_{i=1}^N (x_i - \bar{x})^2}}$$

where:

μ_p : is the overall fraction, by number of particles, of sand in the total mix.

N: is the number of spot samples.

n: is the number of particles in the sample.

x_i : Fraction of sand in each spot sample.

\bar{x} : Average fraction of sand in all spot samples.

Procedure:

1. Weigh certain amount of salt and sand as instructed, and load the material to the mixer.
2. Fix the speed of the mixer and run it.
3. After 5 minutes of running, stop the mixer and take 3-5 samples from different locations of the mixed material and place in sample bottles.
4. Start running the mixer again and repeat taking samples after 10, 15, 20, 30, 45, and 60 minutes.
5. Using the ionselective meter (or any analytical method), the weight of salt as well as sand in each sample taken can be found.
6. Repeat using one of the variables below:
 - a. Speed of rotation.
 - b. Moisture or liquid content of solids.
 - c. Relative amounts of components.

Calculation:

1. Calculate the mixing index for each spot sample.
2. Draw graph of mixing index against the variable selected.

References:

1. Coulson and Richardson, " Chemical Engineering ", Vol.II,Pergamon Press
2. McCabe and Smith," Unit Operation of Chemical Engineering ", 3rd edition.

Mixing of Powder Data Sheet

Weight of salt: _____ Particle size of salt: _____

Weight of sand: _____ Particle size of sand: _____

Time	Sample Location	Sample wt(g)	Vol. of AgNO ₃ (ml)
5 min	Top		
	Bottom		
	Right		
	Left		
10 min	Top		
	Bottom		
	Right		
	Left		
15 min	Top		
	Bottom		
	Right		
	Left		
20 min	Top		
	Bottom		
	Right		
	Left		
30 min	Top		
	Bottom		
	Right		
	Left		
45 min	Top		
	Bottom		
	Right		
	Left		
60 min	Top		
	Bottom		
	Right		
	Left		

Instructor signature: _____

Date: _____

Experiment Number -2-

Shell and Tube Heat Exchanger

Objective:

1. To determine the overall heat transfer coefficient using steam on the shell side and cooling water on the tube side.
2. To investigate the effect of flow pattern (co-current or counter current) on the heat transfer coefficient.
3. To establish energy balance in the heat exchanger.

Equipment:

The unit consists of 150mm diameter shell and tube heat exchanger with an effective heat transfer area of 3 m². It is supplied complete with all necessary instruments and valves for monitoring and controlling, pressure, temperature and flow rate within the unit.

Cooling water is fed into the exchanger via a rotameter to indicate the flow rate and control valve so that the flow pressures are indicated at the end of the pass. The steam is introduced in the shell from the main supply.

A series of baffles are fitted along the shell which increases the turbulence of flow, thus giving better heat transfer. These baffles are of the segmental form with about 25% cut.

Specification: Inside tube diameter is 12mm, outside tube diameter is 14mm, and tube length is 2030 mm. Number of tubes is 37. See figure (1)

Theory:

The overall coefficient of heat transfer required to fit the process conditions may be determined from the Fourier equation:

$$Q = U_D \cdot A \cdot \text{LMTD}$$

If the tubes from inside and outside are clean then the clean overall heat transfer coefficient (U_c) can be found from

$$U_c = \frac{h_{io} \cdot h_o}{h_{io} + h_o}$$

$h_o = 1500 \text{ Btu/hr.ft}^2 \cdot ^\circ\text{F}$ for condensed steam

$$h_{io} = h_i \times \frac{I \cdot D}{O \cdot D}$$

h_i can be found approximately from one of the two equations:

$$\frac{h_i \cdot D}{k} = 1.86 Re^{1/3} Pr^{1/3} \left(\frac{D}{L}\right)^{1/3} \left(\frac{\mu_b}{\mu_w}\right)^{0.14} \quad \text{For streamline flow.}$$

or

$$\frac{h_i \cdot D}{k} = 0.027 Re^{0.8} Pr^{1/3} \left(\frac{\mu_b}{\mu_w}\right)^{0.14} \quad \text{For turbulent flow.}$$

where :

D: pipe diameter in (m).

L: pipe length before mixing occurs in the pipe in (m).

μ_b : fluid viscosity at bulk average temperature in (Pa.s).

μ_w : viscosity at the wall temperature.

cp: heat capacity in (J/kg.K).

k: thermal conductivity in (W/m.K).

h_i : average heat- transfer coefficient in (W/m².K).

Re: dimensionless Reynolds number.

Pr: dimensionless Prandtl number.

The fluid properties expect for μ_w are evaluated at the mean bulk temperature.

The dirt factor or fouling factor can be found from:

$$R_d = \frac{U_c - U_D}{U_c \cdot U_D}$$

Procedure:

1. For all the experiments to be done: keep valves (4&5) always closed and valve (10) always open. See figure (1)
2. Open valve (8) very slowly to introduce the cold water in tube side. Regulate the flow rate as required.
 - For co-current experiment:
Open valves (2) & (7) and
Close valves (1) & (6).
 - For counter current experiment:
Open valves (1) & (6) and
Close valves (2) & (7).
3. Open valve (9) very slowly to introduce steam to the shell, and adjust the pressure as required. The steam goes through a trap to a collector and then to drain.
4. Allow sufficient time to reach steady state condition.
5. At steady state , record the following:

- Inlet and outlet water temperature.
- Inlet and outlet steam temperature.
- Inlet and outlet water pressure.
- Inlet and outlet steam pressure.
- Cooling water scale reading.
- The flow rate of the steam condensate.

At the end of the experiment, reduce the pressure of steam slowly. Then allow the heat exchanger to cool before reducing the cold water supply.

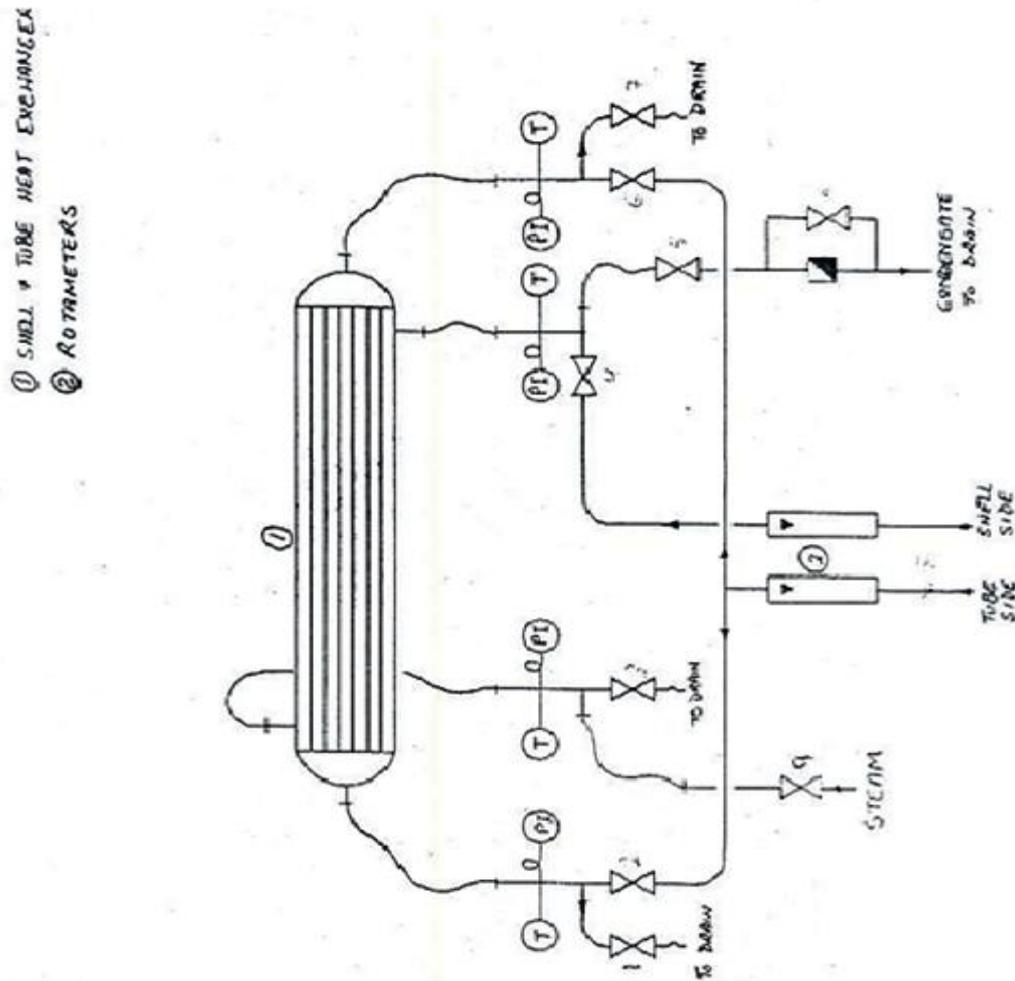


Figure (1): Schematic diagram for shell and tube heat exchanger.

Calculation:

1. Compare the overall heat transfer coefficient calculated with theoretical value.
2. Compare the results obtained for the co-current flow with those for the counter current flow.
3. Investigate the effect of changing water flow rate on heat the balance and the heat transfer coefficient.

References:

1. Coulson J.M. and Richardson J.F., "Chemical Engineering", Volume 1, 2nd Edition, Pergamon Press.
2. Kern D.Q., "Process Heat Transfer ", McGraw Hill.
3. Perry R.H., Chilton C.H., "Chemical Engineering Handbook". 5th Edition, MacGraw Hill.

Shell and Tube Heat Exchanger Data Sheet

	Run no.1	Run no.2	Run no.3	Run no.4	Run no.5
Inlet water temperature (°C)					
Outlet water temperature (°C)					
Inlet steam temperature (°C)					
Outlet steam temperature (°C)					
Inlet water pressure (bar)					
Outlet water pressure (bar)					
Inlet steam pressure (bar)					
Outlet steam pressure (bar)					
Cooling water scale reading					
The flow rate of the steam condensate					

Instructor signature:

Date:

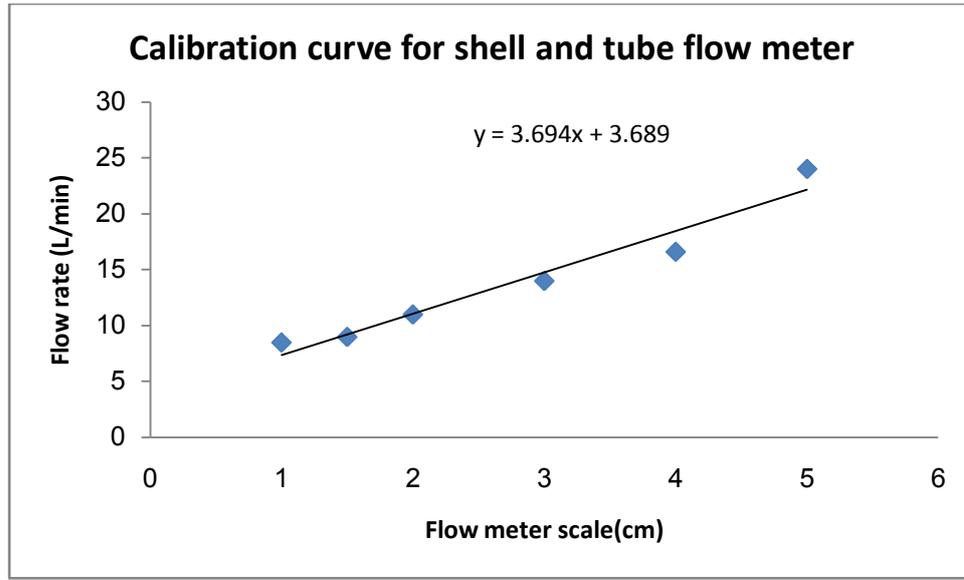


Figure (2): Calibration curve for shell and tube flow meter.

Experiment Number -3-

Climbing Film Evaporator

Objective:

1. To demonstrate the basic principles employed by a climbing film evaporator.
2. To determine the effect of process parameters such as feed flow rate on the overall heat transfer coefficient, vapour/liquid ratio and economy of the climbing film evaporators.
3. To investigate the two phase flow patterns at different feed flow rates.

Equipment:

The plant comprise of a steam heated, long tube calandria evaporator. Feed material enters at the base of the calandria and is partially evaporated. Vapour and liquid pass into the cyclone where the phases are separated, the vapour passing through a water cooled condenser and into a receiver whilst the liquid passes down into the concentrate receiver. The liquid may then be passed back to the base of the calandria and recirculated. In natural circulation mode, the evaporator is run flooded and concentrate continually passes back to the evaporator; evaporated product being replaced intermittently from the feed vessel.

Heating is carried out by the flow of steam through the jacket of the calandria. Steam from the main service line passes through a steam pressure reducer and is controlled at a certain pressure gauge by the pressure control valve PCV4, as shown in figure (3), the steam condensate from the boiler is removed by the action of the steam trap, ST.4, or during initial startup, through the bypass valve V.13. Steam pressure is monitored by the steam pressure gauge. PI.4.

The feed vessel is charged and the flow of process liquid to the calandria is monitored by the flow indicator FI.1 and control valve FCV.1. Process liquid pass up into the calandria and in so doing pulls a thin turbulent film of liquid up the calandria wall. The temperature at the inlet and outlet of the calandria are indicated by TI.1 and TI.2 respectively. Vapour and liquid pass into the cyclone where they are separated. Vapour passing through a condenser and into a receiver, whilst the liquid flows down and into the concentrate receiver, this can either be collected in the case of the once through process or it can be recycled by passing through valve V.4 back to the base of the calandria. This recirculation process can either be carried out as a batch process or with a continual feed.

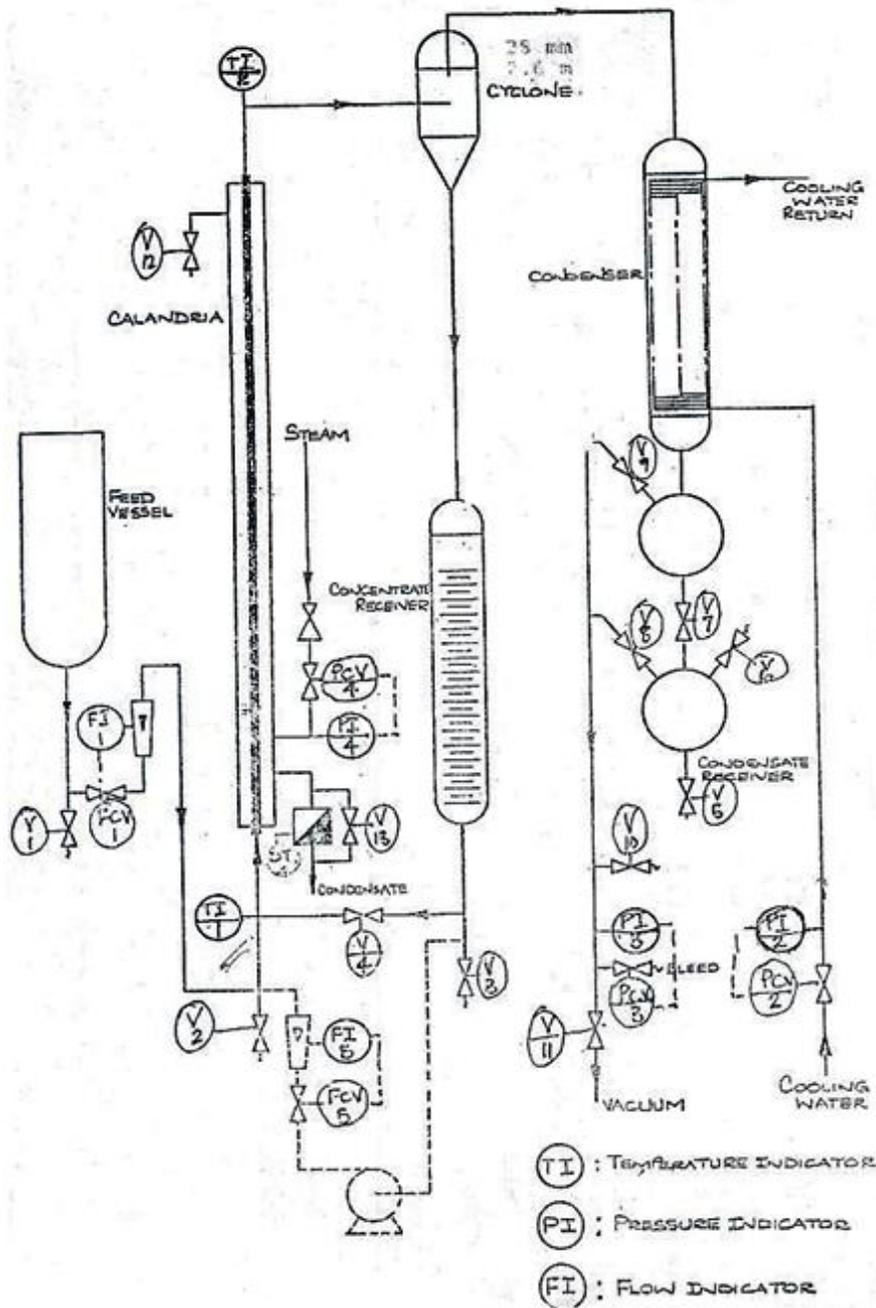


Figure (3): Schematic diagram for climbing evaporator

In case of forced circulation the liquid flows from the concentrate receiver and down through a pump which pumps it back up through the calandria. The flow rate being monitored by the flow indicator FI.5 and control valve FCV.5.

The operation pressure under vacuum is controlled by the pressure control valve PCV.3 and in monitored by the pressure indicator PI.3. The condensate receiver is arranged for removal of product when operating under vacuum.

Specification:

1. Calandria:
 - a. Diameter: 25mm.
 - b. Length: 2.6m.
 - c. Heat transfer area: 0.21m^2
2. Steam jacket:
 - a. Diameter: 50mm.
 - b. Operating steam pressure: 2.1 bar guage.
 - c. Steam consumption: 20kg/hr.
 - d. Length: 2.7m.
3. Cyclone separator:
 - a. Nominal diameter: 150mm.
4. Concentrate receiver:
 - a. Capacity: 7 liters.
 - b. Graduation increment: 50ml.
5. Condenser:
 - a. Heat transfer area: 1.5m^2 .
 - b. Maximum operating pressure: 2.7 bar gauge.
6. Condensate receiving vessels:
 - a. Top receiver:
 - Normal capacity: 5 Liters.
 - Working capacity: 5 Liters.
 - b. Bottom receiver:
 - Normal capacity: 5 Liters.
 - Working capacity: 5 Liters.

Theory:

The aim of any evaporation process is to produce a concentrated solution of a non-volatile solute and a volatile solvent, which in most operations is water.

Evaporators are operated in two modes:

1. Once-through operation, or
2. Circulation units.

In once through operation the feed liquor only once enters the evaporator tubes, in which the feed generates a vapour, and then leaves evaporator as a thick liquid.

In circulation operation the evaporator contains a pool or reservoir of liquid held within the equipment, the incoming feed is allowed to mix with the liquid in the reservoir, and then the mixture passes through the tubes. The un-evaporated liquid issuing from the tube returns to the reservoir, and only part of the evaporation is achieved in one pass. Such evaporators are operated under the condition where the liquor through the tubes is induced by differences in density, or the flow is provided by using a pump.

The rate of heat transfer Q , through the heating surface of an evaporator is product of three factors:

1. The heat transfer surface area, A (m^2).
2. The overall heat transfer coefficient, U ($W m^{-2} K^{-1}$).
3. The overall temperature driving force, ΔT ($^{\circ}C$)

Thus

$$Q = U \cdot A \cdot \Delta T \dots \dots \dots (1)$$

If the heat loss from the evaporator is not considered and the temperature of the steam in the steam chest is at its saturation temperature T_s , then the rate of heat transfer from the steam is:

$$Q_{st} = m_{st} \cdot \lambda_{st} \dots \dots \dots (2)$$

Where

Q_{st} : rate of heat transfer by steam condensation through the heating surface.

λ_{st} : latent heat of condensation of steam at the steam pressure inside the steam chest.

m_{st} : steam condensate rate.

However heat losses from the steam chest to the environment may not be negligible and thus:

$$Q_{st} = m_{st} \cdot \lambda_{st} + Q_R \dots \dots \dots (3)$$

Where Q_R is the rate of heat loss from the steam chest to the environment.

The rate of heat transfer by steam condensation in the steam chest is utilized to:

1. Heat the feed to its boiling point, namely the sensible heat load Q_{se} .
2. To vaporise water from the liquid feed, namely the evaporative heat load Q_e .

Thus:

$$Q_{st} = Q_{se} + Q_R \dots \dots \dots (4)$$

The rate of (thin) liquor feed to the evaporator is equal to the sum of (thick) liquor production (m_c), and the rate of (distillate) production (m). The specific heat (c_p) the liquor in the evaporator is constant and denoted by (c_p).

Thus:

$$Q_{se} = (m_c + m) * c_p * (T_{I,2} - T_{I,1}) \dots \dots \dots (5)$$

Where:

$T_{I,1}$: is the feed inlet temperature.

$T_{I,2}$: is the liquor temperature at the end of sensible heating zone ($T_{I,2}$ is equal to the liquor boiling temperature).

The overall temperature driving force for heat transfer at the evaporator feed inlet is ($T_s - T_{I,1}$) and ($T_s - T_{I,2}$) at the end of the sensible heating zone where vaporization of the feed commences. The height at which boiling commences is h_t , and the inside diameter of the evaporator tube is d . Defining the log mean temperature driving force ΔT_{Lmse} for sensible loading as:

$$\Delta T_{Lmse} = \frac{(T_s - T_{I,1}) - (T_s - T_{I,2})}{\ln \left(\frac{T_s - T_{I,1}}{T_s - T_{I,2}} \right)} \dots \dots \dots (6)$$

$$Q_{se} = U_{se} \cdot A_{se} \Delta T_{Lmse} \dots \dots \dots (7)$$

Where A_{se} : area available for the sensible heat load

$$A_{se} = \pi \cdot d \cdot h_t \dots \dots \dots (8)$$

Hence U_{se} is the overall sensible heat transfer coefficient based on the internal surface area of the exchanger in the sensible heating zone.

The evaporative section heat load $Q_e = m \cdot \lambda_e \dots \dots \dots (9)$

Where λ_e is the latent heat of vaporization of water at the pressure inside the separator. The overall temperature driving force throughout the evaporative section of the heat exchanger is ($T_s - T_{I,2}$), and thus:

$$Q_e = U_e \cdot A_e (T_s - T_{I,2}) \dots \dots \dots (10)$$

Where A_e is the area available for the evaporative heat load

$$A_e = \pi \cdot d \cdot (L - h_t) \dots \dots \dots (11)$$

Hence U_e is the overall evaporative heat transfer coefficient based on the internal surface area of the heat exchanger in the evaporative heating zone.

Neglecting heat losses from the steam chest to the environment, the overall heat balance equation is:

$$Q_{st} = m_{st} \cdot \lambda_{st} = (m_c + m) \cdot c_p \cdot (T_{I,2} - T_{I,1}) + m \cdot \lambda_e \dots \dots \dots (12)$$

$$Q_{st} = m_{st} \cdot \lambda_{st} = Q_{se} + Q_e \dots \dots \dots (13)$$

Or

$$Q_{st} = m_{st} \cdot \lambda_{st} = U_{se} \cdot A_{se} \Delta T_{Lmse} + U_e \cdot A_e \cdot (T_s - T_{I,1}) \dots \dots \dots (14)$$

$$Q_{st} = m_{st} \cdot \lambda_{st} = Q_{se} + Q_e \dots \dots \dots (15)$$

Capacity and economy are the principle measure of performance of steam heated tubular evaporators.

Capacity can be defined as the pounds of water vaporized per hour, whilst the economy is define as the number of pounds of water vaporized per pound of steam feed to the unit.

Procedure:

1. Check that the valves according to the following list: (refer to figure -2-)

	Open	Closed
FCV.1		X
V.1		X
V.2		X
V.3		X
V.4		X
V.5		X
V.6	X	
V.7		X
V.8		X
V.9		X
V.10	X	
V.11		X
V.12	X	
FCV.5		X
V.13	X	
PCV.2		X
PCV.3		X
PCV.4		X

2. Open the water flow control valve PCV.2 slowly and adjust to obtain the required pressure as indicated by PI.2.
3. Close vent valves V.6 and V.10.
4. Open vacuum valves V.8, V.9, and V.11, to apply vacuum to the system.

5. Monitor vacuum gauge PI.3 and adjust the vacuum control valve PCV.3 to obtain the required vacuum pressure.
6. Open valve FCV.1 and allow the calandria to fill up to a height of approximately 1m.
7. Close valve FCV.1.
8. Check steam trap by-pass valve V.13 is open.
9. Check vent valve V.12 is open.
10. Partially open steam pressure control valve PCV.4.
11. Following the initial surge of condensate and when a steady flow of steam issues from the condensate drain, close V.13.
12. When a steady flow of steam issues from the vent, close the vent valve V.12.
13. Monitor the steam pressure gauge PI.4 to obtain the required steam pressure gauge reading.
14. When the liquid in the calandria starts to vaporize and rise up the tube, open valve FCV.1 to set the flow rate of feed to 0.1.
15. Allow for equilibrium to be established.
16. Measure the condensate, concentrate, and the steam condensate rate over a 10 minute period.
17. Note TI.1, TI.2.
18. Measure height at which boiling occurs in the evaporator tube.
19. Repeat the experiment at flow rate FI.1 of 0.2, 0.3, 0.4, and 0.5.

Calculation:

1. Calculate the sensible heat load Q_{se} , and the evaporative heat load Q_e at different flow rates.
2. Calculate the overall sensible heat transfer coefficient U_{se} and the overall evaporative heat transfer coefficient U_e at different flow rates. Draw the two graphs and comment.
3. Draw a graph of Q_{se} , Q_e against feed rate.
4. Calculate the economy of the evaporator at various flow rates.
5. Describe the bubble formation and climbing film formation as a function of feed rate.

References:

1. J.M. Coulson and J.F. Richardson, "Chemical Engineering" Vol.1 and Vol.2, Pergamon Press.
2. D.Q.Kern, "Process Heat Transfer", McGraw Hill, 1982.

Climbing Film Evaporator Data Sheet

	Unit	Run # 1	Run # 2	Run # 3	Run # 4	Run # 5
Water flow rate						
Feed Inlet temperature ($T_{I,1}$)						
Liquor boiling temperature ($T_{I,2}$)						
Vacuum pressure						
Flow rate of process concentrated						
Flow rate of process condensate						
Height of sensible zone						
Steam pressure						
Flow rate of steam condensate						
Temperature of steam condensate						

Instructor signature:

Date:

Experiment Number -4-

Concentric Tube Heat Exchanger

Objective:

1. To demonstrate the working principles of a concentric tube heat exchanger operating under co-and counter flow arrangements.
2. To demonstrate the effect of hot water temperature variation, flow rate variation on the performance characteristics of a concentric tube heat exchanger.

Equipment:

A supply of hot water at temperature up to 80°C is maintained in a storage tank at the rear of the apparatus by an integral heating element. Power to the electric element is regulated by a controller, which is mounted on the front panel and incorporates a decade switch to set the desired water temperature, a deviation meter to indicate the deviation of the water temperature from the set point. Water is continuously recirculated through the tank by a pump.

Hot water for the exchanger is taken from the pump discharge and passes through the inner pipe of the concentric tube arrangement before returning to the tank for reheating. Flow through this circuit is regulated by a control valve (18) and indicated at the flow meter (19). Thermometer (15) and (17) installed at the inlet, midpoint and outlet of the exchanger hot water circuit indicate the respective water temperature. As shown in figure (4)

Cold water for the exchanger is supplied from an external source to the outer annulus of the concentric tube arrangement. Co-or counter-flow configuration may be obtained by appropriate setting of the selector valve (16). Valve (11) at the top of the exchanger permits air to be bled from the system and facilitate drainage.

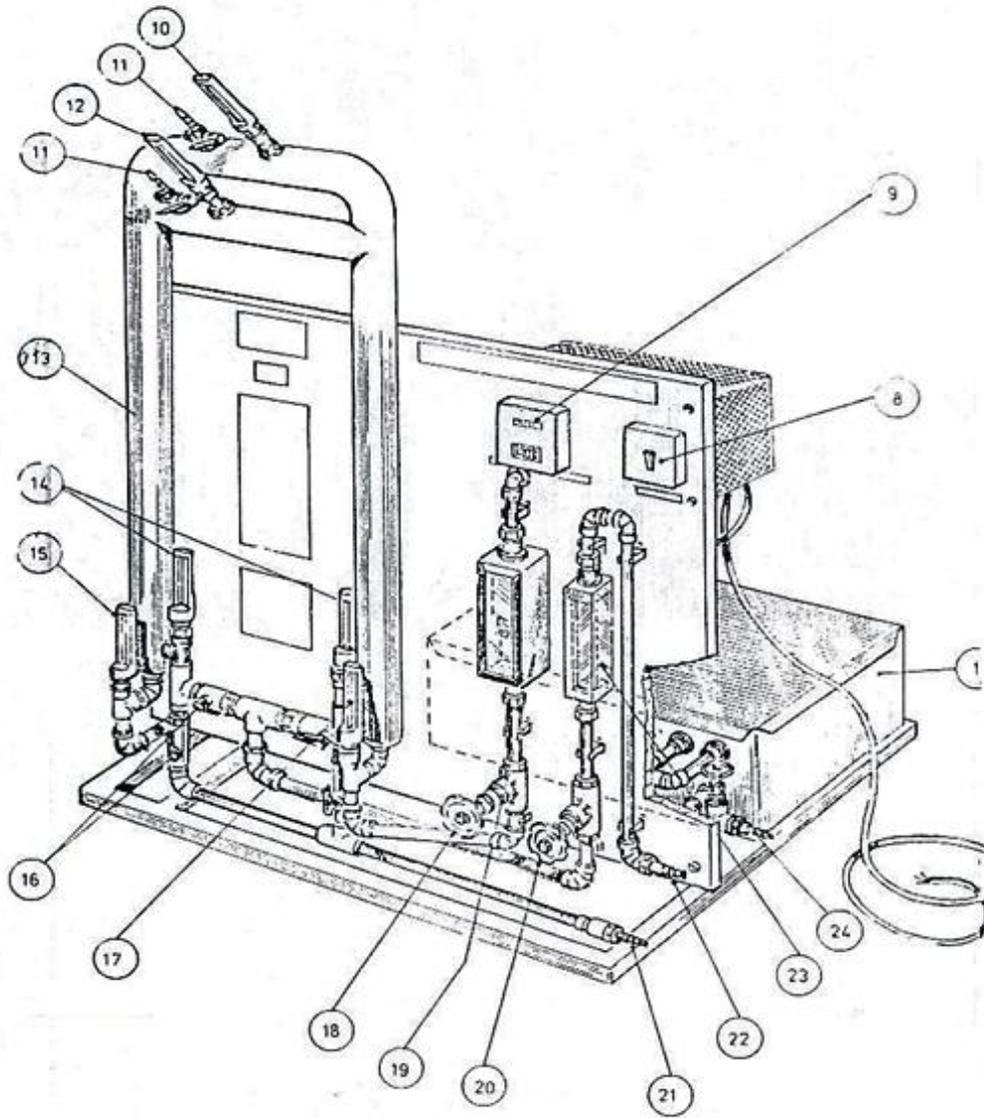


Figure (4): Schematic diagram for concentric tube heat exchanger.

Theory:

One of the simplest forms of heat exchanger is the so-called double-pipe exchanger. One of the fluids passes through the tube whilst the second fluid flows through the annular space. If the fluids flow through the exchanger in the same direction, then the unit is said to operate in parallel or co-current flow. Flow in opposite direction is called counter-current flow. The duty Q of the exchanger can be calculated from the change/unit time in sensible heat content of a fluid being heated or cooled, and/or the latent heat extracted or supplied in condensation or evaporation processes respectively.

In terms of heat transfer, the duty of the exchanger can be described by the simple equation:

$$Q=U.A. (L_{MTD})\dots\dots(1)$$

where:

U : the overall heat transfer coefficient referred to area A .

A : the heat transfer surface required in the exchanger.

L_{MTD} : the mean temperature difference between the two fluids.

The overall heat transfer efficiency can be calculated from equation:

$$\eta_{overall} = \frac{Q_{absorbed}}{Q_{emitted}} \dots \dots (2)$$

And the thermal efficiency for the cold side:

$$\eta_{cold} = \frac{\Delta T_{cold}}{\Delta T_{max}} \dots \dots (3)$$

And the thermal efficiency for hot side:

$$\eta_{hot} = \frac{\Delta T_{hot}}{\Delta T_{max}} \dots \dots (4)$$

Where:

$$\Delta T_{cold}=T_{c.out}-T_{c.in}$$

$$\Delta T_{hot}=T_{h.in}-T_{h.out}$$

$$\Delta T_{max}=T_{h.in}-T_{c.in}$$

Then the efficiency of exchanger equal $\frac{\eta_{cold} + \eta_{hot}}{2}$.

Procedure:

1. Fill the storage tank with clean water.
2. Close the air bleed valve (11) at the top of the heat exchanger.
3. Connect the cold water inlet to a source of cold water using flexible tubing.
4. Close the hot water flow control valve (18).
5. Set the selector switch on the side of the pump motor to the maximum setting.
6. Set the temperature controller to zero using the decade switches on the front panel.
7. Set the electrical supply switch on the ON position and observe operation of the pump.
8. Open the hot water flow control valve (18) to a medium value and allow water to flow through the exchanger until a steady flow of water is indicated on hot flowmeter (19).
9. Open the cold water flow control valve. Set the selector valves to co-current position. Allow water to flow through the exchanger until a steady flow of water is indicated on the cold flowmeter.
10. Set the temperature controller to 50°C.
11. Take the thermometers readings once they are stabilized as well as the flowrates on the flowmeters.
12. Increase the controller set point to 60°C, 70°C, 80°C and note the thermometers readings.
13. Set the controller temperature to 60°C and change the flowrate of hot water, making sure to note the readings of the thermometers for each flowrate.
14. The above procedure can be repeated for counter current.

Calculation:

1. Calculate the efficiency of the exchanger for both co-and counter arrangement.
2. Calculate the overall heat transfer coefficient.
3. Calculate the temperature efficiency of the heat exchanger.
4. Plot the temperature profile for both the co-current and counter current.

References:

1. D.Q. kern, "Process Heat Transfer ". McGraw Hill, 1982.
2. Coulson & Richardson, "Chemical Engineeringing ", Vol. 1.1980.

Concentric Tube Heat Exchanger Data Sheet

Heat transfer area: _____

Heat transfer length: _____

Cold water flow rate: _____

Co-current flow:

Hot water flow rate (cm ³ /min)	T _{hot,in} (°C)	T _{hot,out} (°C)	T _{cold,in} (°C)	T _{cold,out} (°C)

Counter-current flow:

Hot water flow rate (cm ³ /min)	T _{hot,in} (°C)	T _{hot,out} (°C)	T _{cold,in} (°C)	T _{cold,out} (°C)

Instructor signature: _____

Date: _____

Experiment Number -5-

Heat Conduction

Objective:

1. To measure the temperature distribution for steady state conduction of energy through a uniform cross-section and demonstrate the effect of a change in heat input.
2. To determine the thermal conductivity of a material and the effect of temperature on thermal conductivity.
3. To measure the application of poor thermal conductors and determine the thermal conductivity K of a poor thermal conductor.

Equipment:

The unit consists of a heat service unit, supplying a variable A.C. voltage to vary heater power. A heat conduction unit and 12 type K thermocouple sockets allow connection of this unit to the service unit. Three fixed thermocouples T₁, T₂, T₃, are positioned along the heated section at 15 mm intervals. Three fixed thermocouples T₆, T₇, T₈, are positioned along the cooled section at 15 mm intervals, and four intermediate sections are supplied to place between the heated and cooled sections. Water for the cooled section is supplied from the tap via a hose.

The specimens are brass or stainless steel of 30 mm and 25 mm diameter.

Theory:

The fundamental law of heat conduction is that of Fourier:

$$Q = -KA \frac{dT}{dx}$$

Q: is the rate of heat input.

K: is the thermal conductivity.

x: is the distance from the hot end.

T: is the temperature.

The negative sign being inserted because the heat is flowing towards the lower temperature face.

Integrating the above equation gives.

- a. For linear conduction through a uniform bar.

$$Q = -KA \frac{T_1 - T_2}{L}$$

- b. For radial conduction through a cylinder.

$$Q \ln \frac{R_2}{R_1} = 2\pi KL(T_1 - T_2)$$

where :

A: is the cross-sectional area of the bar.

L: is the length of the specimen.

R₁ and R₂: is the radius of the specimen at T₁ and T₂.

Procedure:

1. Ensure that the main switch is in the off position and the voltage controller is in the anti-clockwise position.
2. Make sure that the heat transfer unit is connected to the heat transfer service unit, and the specimen is installed in the heat transfer unit.
3. Open the water tap until the water flows through the drain.
4. Turn on the main switch and set the temperature selector switch to T₁.
5. Rotate the voltage controller clockwise to increase the voltage to the specified value, and observe the temperature T₁.
6. Allow the system to reach stability and take the reading of temperatures, voltage and current.
7. Repeat at different heat input or different specimens.
8. It is possible to connect the unit to the computer via the interface to monitor and record the temperature along the specimen, and have them on a printer paper. (You have to follow the instruction of your supervisor).

Calculation:

1. Draw graph of temperature gradient at steady state at different heat input.
2. Draw graph of temperature variation with time.
3. Calculate the thermal conductivity of the material under investigation and investigate the effect of changing heat transfer coefficient on the conductivity.

References:

Christie J. Geankolis, "Transport Processes and Unit Operation", 3rd Edition, Perntic Hall.

Experiment Number -6-

Fluidized Bed Heat Transfer Unit

Objective:

1. To calculate the heat transfer coefficient in fluidized bed.
2. To show the effect of fluid velocity on pressure drop through the fluidized bed.

Equipment:

The equipment consists of a glass cylinder through which a controllable flow of air is passed. It is mounted vertically with a diffuser/ filter at the lower end. A further filter at the upper end prevents solid particles suspended in the air stream from escaping. Air from a blower fan is produced controlled by a bleed control valve. This valve is progressively closed causing air to pass through two flow meters in turn and then the chamber at the lower end of the glass cylinder below the diffuser/filter before passing through the solid particles held above the filter.

Two flow meters is used, one having approximately one tenth the range of the other. This ensures that both the initial onset of fluidization can be measured as well as the full range which exceeds the Fluidization velocity. An electric heating element in mounted in such a manner that it can be held at any height within the glass cylinder, the surface area of the heating element is 20 cm^2 . The power input is controlled by a variable transformer and the surface temperature of the element is measured by a thermocouple located close under the surface of the thin copper cylinder which surrounds the heating element. By this means the cooling effect of the air and solid particle can be accurately measured.

Additional thermocouples are placed, one under the diffuser to measure air entry temperature and the other one on a movable probe to enable temperature measurement at any part in the cylinder. The thermocouple marked "X" is located close under the surface of the copper cylinder and is coupled directly to a high temperature cut out.

Pressure drop through the fluidized bed of solid particles is measured by tubular pressure probe which can be adjusted vertically to sense pressure just above the diffuser/filter. See figure (5).

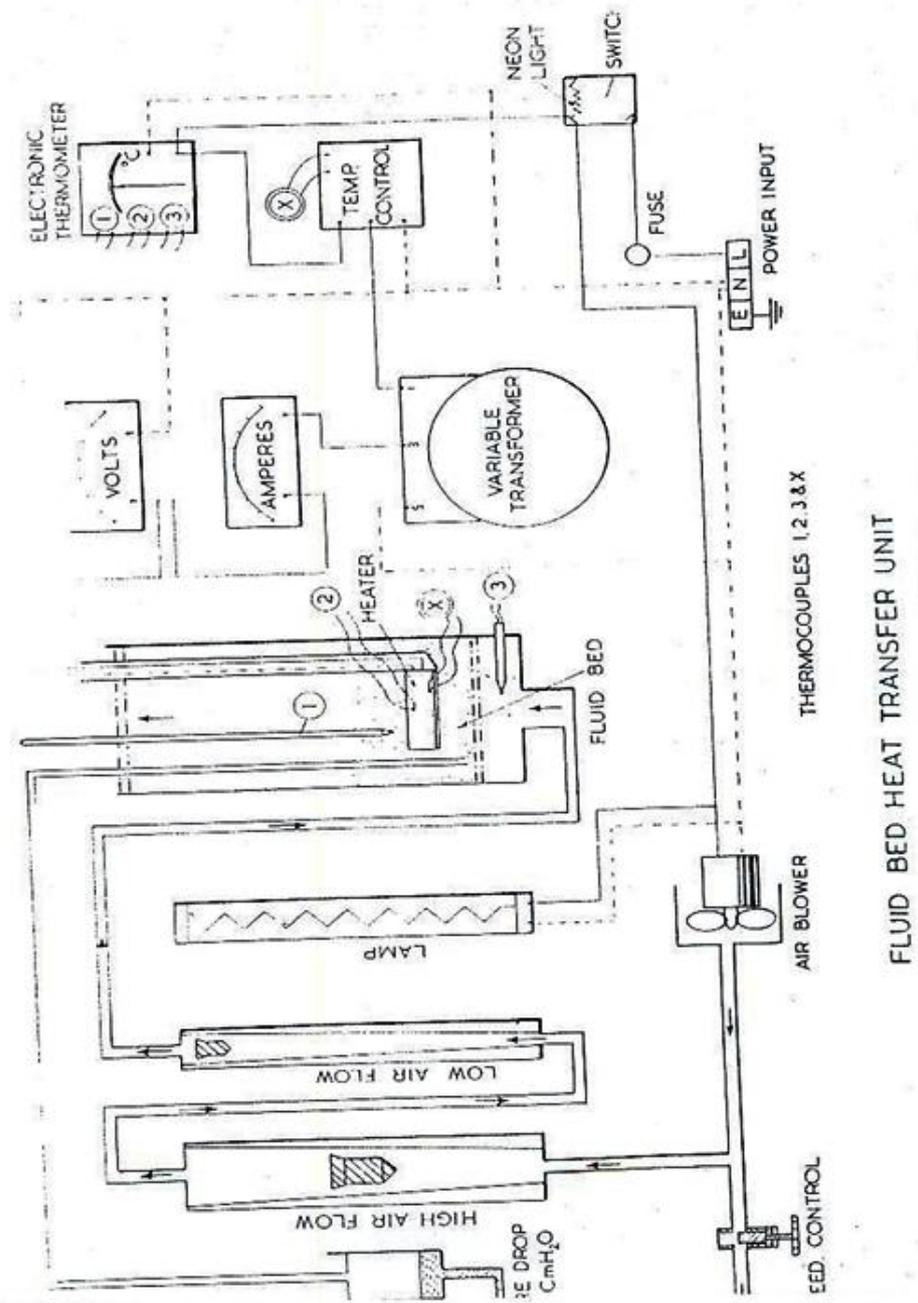


Figure (5): Schematic diagram for fluid bed heat transfer unit.

Theory:

Throughout the whole range of industry there can be found important processes which depend for their success upon good contact between fluid and a particulate solid. A major advantage of fluidized bed operation in heat transfer processes is that the rate of heat transfer is enhanced compared to similar conditions in traditional operations. Applications of fluidization include catalytic petroleum processes, ion exchange water treatment, separation processes and the combustion of solid fuels.

The heat transfer coefficient can be calculated by using the following equation for both (fixed and fluidized bed).

$$Q = h. A. (T_2 - T_1)$$

where:

Q: heat input (Q=V.I).

A: surface area of the heating element.

T₁: temperature of the bed.

T₂: Temperature of the heating element.

Procedure:

1. With the air bleed control opened fully, switch on the blower.
2. Immerse the heating element fully in the bed.
3. Adjust the variac to maintain the heating element at some predetermined temperature as controlled by the thermostat, and at the same time close the bleed control valve progressively so that the air is induced through the bed material causing the pressure to rise across the bed.
4. Wait for the steady state temperatures to be reached.
5. Record the flow rate, bed pressure drop, air temperature, element temperature, voltage and current at each air flow rate, and also record your observation.

Calculation:

1. Plot the bed pressure drop against air flow rate.
2. Plot the heat transfer coefficient against the air flow rate

References:

1. J.M. Coulson and J.F. Richardson, "Chemical Engineering", Vol.2, Third Edition, 1978, Pergamon Press.
2. D.Q. kern, "Process Heat Transfer ", McGraw Hill, 1982.

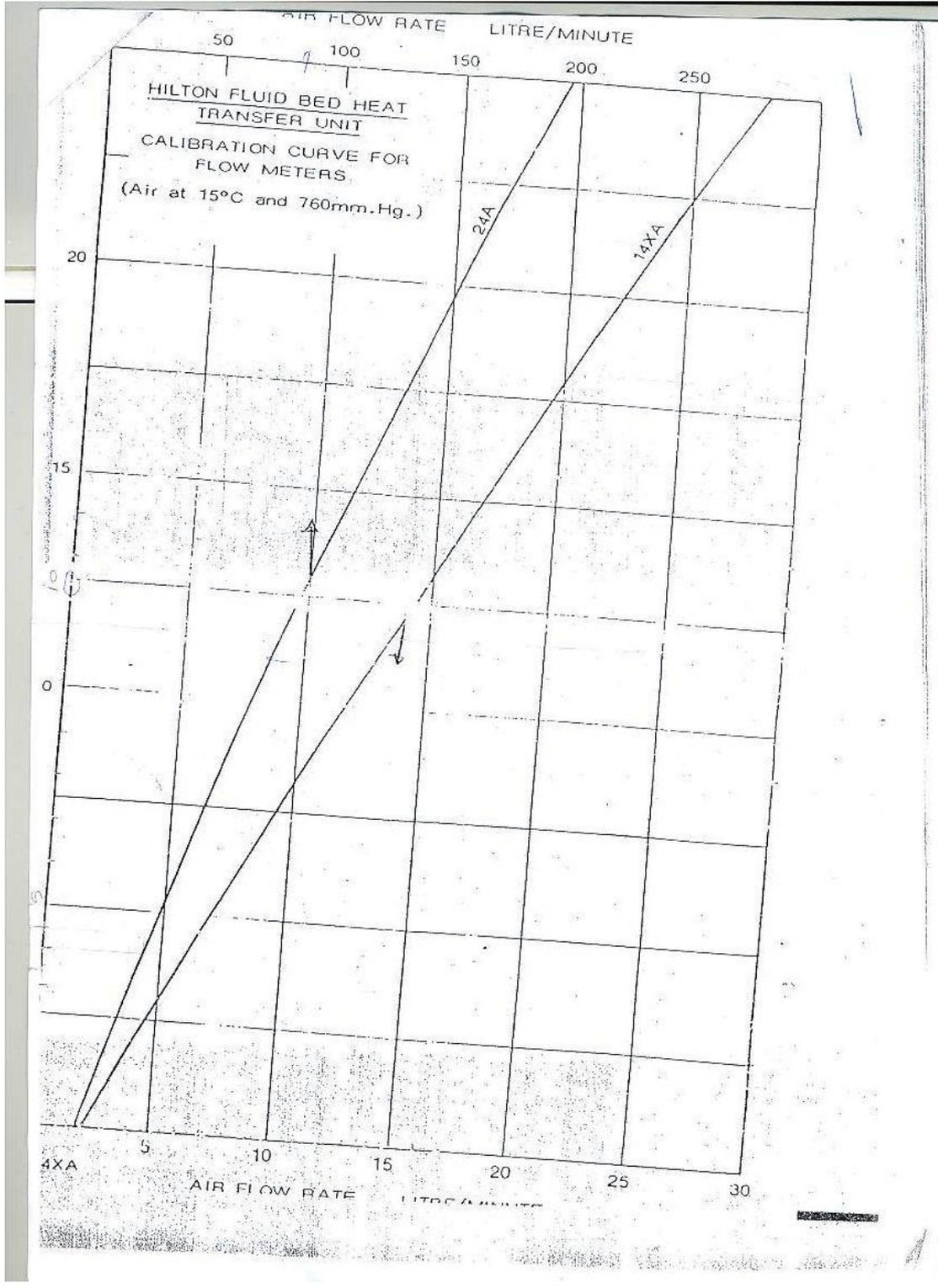


Figure (6): Calibration curve for flow meters for fluid bed heat transfer unit.

Experiment Number -7-

Jaw Crusher

Objective:

To study the comminution behavior of different materials, using a primary crusher (Jaw crusher), under various condition; taking in consideration power requirements.

Equipment:

The unit consists of a laboratory scale Jaw crusher of fixed speed. The gap between the two jaws can be altered using a hand wheel.

A sieve shaker is also available with a set of test sieves.

Theory:

A number of empirical laws have been put forward to estimate the energy required to effect a size reduction of a given material:

- a. Rittinger's law:

$$\frac{P}{m} = K_R \left(\frac{1}{L_2} - \frac{1}{L_1} \right) \dots \dots \dots (1)$$

- b. Kick's law:

$$\frac{P}{m} = K_c \cdot \ln \frac{L_1}{L_2} \dots \dots \dots (2)$$

- c. Bond's law:

$$\frac{P}{m} = 0.3162 \cdot W_i \cdot \left(\frac{1}{\sqrt{L_2}} - \frac{1}{\sqrt{L_1}} \right) \dots \dots \dots (3)$$

Where:

L_1, L_2 : Particles size of product and feed (mm).

P: Power required for crushing and grinding (Kw).

m: Feed rate (tons/hr).

W_i : Bond's work index (Kw.hr/ton).

K_R, K_c : Rittenger's constant and Kick's constant.

Procedure:

1. Prepare the material to be tested and sort according to the size.
2. Choose three samples of different sizes and weigh the required amount as instructed by supervisor of each sample.
3. Adjust the jaw gap setting as required, and tighten the hand wheel.
4. Switch on the jaw crusher.
5. Put the weighed sample into the crusher and immediately start the stop watch.
6. Once the crushing is complete, stop the stop watch and record the time.
7. Arrange the test sieves according to the size of the aperture, noting that the biggest aperture should be at top, and the smallest at the bottom and then the pan.
8. Put the crushed sample on the top sieve, and put the sieves on the sieve shaker.
9. Switch on the shaker and allow the screen process to proceed for about 15 minutes.
10. Weigh the collected solid on each sieve and record the weight.
11. Repeat using the other samples.
12. The process can be repeated using one of the following variable:
 - a. Initial material size.
 - b. Jaw gap setting.
 - c. Type of material

Calculation:

1. Draw graphs of accumulative weight percent of product passed against screen opening and find d_{80} .
2. Using Bond's law, find the power required for grinding.
3. Find a graphical relation between the power required and the variable selected.

References:

McCab, W.L., and Smith, J.C., Unit Operation of Chemical Engineering, McGraw-Hill, Inc, 3rd ed., (1976).

Experiment Number -8-

Gravity Sedimentation

Objective:

To demonstrate how the data obtained from batch settling tests can be used in design purposes (e.g. thickener design). This can be achieved through studying the settling behavior of different materials having different properties under various process conditions.

Equipment:

The main items of the apparatus are:

1. Five easily-removable glass tubes, mounted in support frame.
2. Back lighting to illuminate the sedimentation tubes and metric scales mounted alongside.

To help complete the experiments:

1. A stopwatch.
2. Containers to make up slurry solutions in water.
3. Specific gravity (density) bottle.

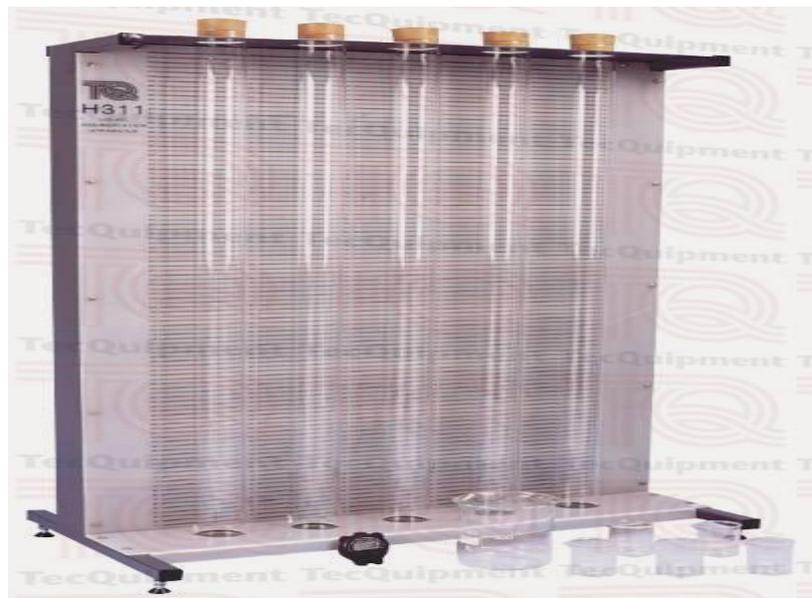


Figure (7): Schematic diagram for Sedimentation unit.

Theory:

The total weight of the solid in the slurry is $(C_0 \cdot Z_0 \cdot S)$, where (C_0) and (Z_0) represent the initial concentration and height of the suspended solid in a batch-settling test and (S) is the cross-sectional area of the cylinder in which the test is being performed. The quantity of solid passing through the limiting layer is $d.C_L \cdot S \cdot \theta_L(V_L + \bar{V}_L)$ where C_L is concentration of the limiting layer and θ_L is the time for this layer to reach the interface, V_L is the setting velocity and \bar{V}_L is the upward velocity of the capacity-limiting layer.

$$C_L \cdot S \cdot \theta_L(V_L + \bar{V}_L) = C_0 \cdot Z_0 \cdot S \dots \dots \dots (1)$$

If \bar{V}_L is assumed to be constant and Z_L is the height of the interface at O_L :

then

$$\bar{V}_L = \frac{Z_L}{O_L} \dots \dots \dots (2)$$

Substituting into equation (1) gives

$$C_L = \frac{C_0 \cdot Z_0}{Z_L + V_L \cdot \theta_L} \dots \dots \dots (3)$$

The value of V_L is the slope of the plot of height of interface versus time and is equal to:

$$V_L = \frac{Z_i - Z_L}{\theta_L} \dots \dots \dots (4)$$

$$Z_i = Z_L + V_L \cdot \theta_L \dots \dots \dots (5)$$

Combining equation (3) and (5) gives:

$$C_L \cdot Z_i = C_0 \cdot Z_0 \dots \dots \dots (6)$$

Procedure:

1. Fill one of the graduated cylinders with solution to a certain height.
2. Weigh the required amount of solid and add to the water in the cylinder.
3. Shake the cylinder to make the solution homogenous.
4. Record the height of the interface between the clear liquid and the settling slurry with time.
5. The experiment can be repeated at different :
 - a. Type of material.
 - b. Solid concentration.

- c. Particle size.
- d. Diameter of the cylinder.
- e. Initial height.

Calculation:

1. Plot the batch settling curves for each run.
2. Calculate the critical height, time, and concentration for each run.
3. Calculate the minimum height for each run.
4. Investigate the effect of the variable studied on the settling behaviour of solid.
5. Plot graphs of the variable studied versus critical height and concentration.
6. Calculate the minimum area of the thickener to handle 3.785×10^6 L/day with feed concentration of 200 g/liter solution and thickened sludge concentration of 700 g/ liter solution.

References:

1. Coulosn, J.M., and Richardson, J.F., "Chemical Engineering ", Vol. II, London.
2. Foust, A., et al., "Principle of Unit Operation", John Wiley, New York.
3. Svarovsky , L., ed. "Solid-Liquid Separation" , Butterworhts.

Experiment Number -9-

Filter Press

Objective:

To demonstrate the basics of filtration and to study the effect of certain variables such as solid concentration in slurry and size of solid particle on the resistance to filtration.

Equipment:

Batch filtration unit is a computer controlled unit consists of a plexiglass vessel with a heater and stirrer. Vertical plate filters, composed of sheets of nylon 5 microns in diameter. A variable speed centrifugal pump is connected to the plexiglass vessel.

A control unit is available with temperature sensors, pressure sensors, and flow rate sensors, also a computer is available with a data acquisitions card.

Theory:

The fluid velocity is constrained by the fact that it has to pass through an irregular medium, through some channels formed in the interstices of the cake and filter medium. Then we can apply the law of Hagen-Poiseuille:

$$\frac{dv}{A \cdot d\theta} = \frac{\Delta P}{\mu \cdot [\alpha \cdot (W/A) + r]} \dots \dots \dots (1)$$

Where:

V: filtrated volume.

θ : filtering time.

A: surface area of the filters.

P: total pressure fall.

μ : Filtrate viscosity.

r : filtering medium resistance.

W: cake weight.

α : Specific cake resistance.

If we consider the approximation that the cake is non-compressible and uniformly compacted, the mass of filter cake (W) is related to the volume of filtrate (V) using the following mass balance.

$$W = w \cdot V \dots \dots \dots (2)$$

- Constant pressure filtration testing:

It is clear that at a constant pressure the rate of filtration will decrease as the thickness of the cake increases and also its resistance to filtration. Therefore the Hagen-Poiseuille relation can be written as follows:

$$\frac{d\theta}{dV} = \frac{\mu \cdot \alpha \cdot w}{\Delta P \cdot A^2} \cdot V + \frac{\mu \cdot r}{\Delta P \cdot A} \dots \dots \dots (3)$$

Then the specific resistance of the cake (α) and filtering media resistance (r) can be calculated.

- Constant rate filtration testing:

In this case, the pressure will increase as the filtration process happens due to increasing the thickness of the cake and also the resistance to leakage.

For the study of filtration in these circumstances we can start from the Hagen-Poiseuille law as described above in equation (3).

Solving the expression to be:

$$\Delta P = \frac{\mu \cdot \alpha \cdot w}{A^2} \cdot \frac{dV}{d\theta} \cdot V + \frac{\mu \cdot r}{A} \cdot \frac{dV}{d\theta} \dots \dots \dots (4)$$

where

$$\frac{dV}{d\theta} = \text{speed}$$

Then the specific resistance of the cake (α) and filtering media resistance (r) can be calculated.

Procedure:

1. Fill the plexiglass feed tank to the level of 20cm.
2. Calculate the amount of solid needed to give the required in the feed tank.
3. Add this amount of solid into the feed tank.
4. Switch on the computer and follow the instructions given to you by the instructor.
5. Allow the stirrer to operate at a high speed for several minutes.
6. Make sure that all the valves lead to the membrane filter are open.
7. Operate the pump at the required pressure.
8. Record the level of filtrate in the discharge tank every 2cm at the beginning, then every 1cm with time.
9. After finishing the run wash out the filters and collect the outlet in a vessel
10. Use the slurry solution from the washing in the next run
11. Repeat at different pressures as instructed.

Calculation:

1. Assuming that $dt/dV = \Delta t / \Delta V$ and plot $\Delta t / \Delta V$ versus the average of V for each run.
2. From the slope and intercept of the plotted line, values of r and R should be found related to the variable being studied.
3. Calculate the resistance of filter medium to filtrate and the specific cake resistance at constant rate filtration.
4. Calculate the resistance of filter medium to filtrate and the specific cake resistance at constant pressure operation.

References:

1. Coulson, J.M., and Richardson, J.F., "Chemical Engineering", vol. II, 3rd edition.
2. Svarovsky, L., edn., "solid -Liquid separation" Butterworths (1981).

