given temperature will emit radiation of a whole range of wavelength and not a single wavelength. The total quantity of radiant energy of all wavelengths emitted by a body per unit area and time is the total emissive power.

When radiant energy falls upon a body, it may be all or partially absorbed, reflected or transmitted. The fraction of radiant energy absorbed is called absorptivity (α), fraction reflected is called reflectivity (ρ) and the fraction transmitted is called transmissivity (τ)

$$\alpha + \rho + \tau = 1$$

The substances having nearly complete or unit absorptivities are called black body. A black body absorbs all radiation falling on it.

The ratio of the total emissive power (E) of a body to that of a black body (E_b) at the same temperature is known as emissivity (e) of that body.

$$e = E/E_b$$

Emissivity depends on the temperature of the body only. The emissivity of a body is the measure of how it emits radiant energy in comparison with a black body at the same temperature.

As per Kirchhoff's law, when any body is in thermal equilibrium with its surroundings, its emissivity and absorptivities are equal.

Fig 1 Emissivity apparatus

VIII. Experimental set up:

Figure 2

IX. Resources required

Sr. No.	Name of Resource	Suggested Broad Specification	Quantity
1	Emissivity measurement apparatus		1
2	Black plate	Diameter = 0.15 m	1
3	Test plate	Diameter = 0.15 m	1
4	Thermocouples		4

X. Precautions to be followed

1. Keep the dimmer stat at zero position before switching on and switching off the heaters.
2. Keep the assembly undisturbed while testing.
3. Do not disturb the thermocouple setting.
4. Do not touch your finger to or scratch on the plate and test plate.

XI. Procedure

1. Check that the dimmer stats are at zero position and the duct is closed.
2. Switch on the main switch and give some power to both the plates by adjusting the dimmer stat. The power supplied to black plate heater should be equal to that of test plate heater.
3. Go on checking the temperatures of each of the plate surface. These temperatures are required to be equal. To get them equal, test and adjust the dimmer stat so as to get uniform temperature. Take an individual test for each plate, but the parameters of temperatures should be equal.
4. After getting equal temperatures on both the surfaces, individually note temperatures of each plate as well as duct temperatures.

XII. Resources used

SI No.	Name of Resource	Suggested Broad Specification		Quantity	Remarks (If any)
		Make	Details		
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XIII. Actual procedure followed

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XIV. Precautions followed

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XV. Observations and Calculations:

Plate	Input		Surface temperature
	V	**I**	
Test plate			
Black plate			

1. Diameter of the plate D =

2. Effective area of the plate A= -------------------m^2

Sample calculation for set no.

1. Enclosure temperature $T_E = T_3 =$ $^0C =$ K

2. Plate surface temperature (Ts) = $T_1 = T_2 =$ $^0C =$ K

3. Heat input to black plate Wb = V*I = W

4. Heat input to test plate W_T = V*I = W

5. Surface area of test plate (A) =

6. $Wb - W_T = \sigma.A[Ts^4 - T_E^4] (1 - \varepsilon)$

   σ = Stefan Boltzman constant = $5.67*10^{-8}$

   or ε =

XVI. Results

Emissivity of the material ε = ……………..

XVII. Interpretation of results

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XVIII. Conclusions

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XIX. Practical related Questions

Note: Below given are few sample questions for reference. Teachers must design more such questions so as to ensure the achievement of identified CO.

a. Define radiation.
b. Write any two examples for radiation.
c. Define the terms absorptivity, reflectivity and transmissivity.
d. Define emissivity and emissive power.

[Space for Answers]

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XX. References / Suggestions for further Reading

- https://vlab.amrita.edu/?sub=1&brch=194&sim=802&cnt=1
- https://nptel.ac.in/courses/112106139/pdf/4_2.pdf
- https://nptel.ac.in/courses/103103032/module7/lec30/1.html

XXI. Assessment Scheme

Performance Indicators		Weightage
Process related (15 Marks)		**60%**
1	Preparation of the experimental set up	20%
2	Setting and operation	20%
3	Safety measures, observation and recording	20%
Product related (10 Marks)		**40%**
4	Calculation and Interpretation of result	20%
5	Practical related question and submission of report	20%
Total (25 marks)		**100 %**

Names of Student Team Members

1…………………………

2…………………………

3…………………………

4…………………………

Marks Obtained			**Dated signature of Teacher**
Process Related(15)	**Product Related(10)**	**Total (25)**	

Practical No. 8: Determine Stefan Boltzman constant

I. Practical Significance

By knowing the value of Stefan Boltzman constant, we can calculate the total emissive power of surface. Stefan Boltzman law states that total emissive power of a surface is proportional to fourth power of absolute surface temperature.

II. Relevant Program Outcomes (POs)

PO 1. Basic knowledge: Apply knowledge of basic mathematics, sciences and basic engineering to solve the Chemical engineering problems

PO 2. Discipline knowledge: Apply Chemical engineering knowledge to solve industry based Chemical Engineering problems.

PO 3. Experiments and practice: Plan to perform experiments and practices to use the results to solve technical problems related to Chemical engineering.

PSO 2. **Material management and quality control:** Manage chemicals and equipment to produce quality chemical products.

III. Competency and Practical Skills

'Use heat transfer principles to increase efficiency and to save energy in chemical process plants.'

1. Use orifice meter for accurate measurement of flow rate.
2. Measure the differential pressure using manometer.

IV. Relevant Course Outcomes

1. Calculate amount of heat transfer by radiation.

V. Practical Outcome

Using Stefan Boltzman law apparatus determine Stefan Boltzman constant.

VI. Relevant Affective domain related Outcome(s)

1. Follow safe practices
2. Maintain tools and equipment.
3. Practice good housekeeping.
4. Follow ethical practices.

VII. Minimum Theoretical Background

All substances emit thermal radiation. When heat radiation is incident over a body, part of radiation is absorbed, transmitted through and reflected by the body. A surface which absorbs all thermal radiation incidents over it is called black surface (body). For black surface, transmissivity and reflectivity are zero and absorptivity is unity. Stefan Boltzman law states that total radiation from a perfect black body is proportional to the fourth power of the absolute temperature of the body.

$$W_b \propto T^4$$

$$W_b = \sigma T^4$$

For non black body $W/W_b = \varepsilon$

Therefore $W = \varepsilon\ \sigma\ T^4$

Where σ is Stefan Boltzman constant = $5.67*10^{-8}$ W/ m^2 K^4

ε is emissivity of the surface

T is absolute temperature

Fig 1 Stefan Boltzman apparatus

VIII. Experimental set up:

Figure 2

IX. Resources Required

Sr. No.	Name of Resource	Suggested Broad Specification	Quantity
1	Stefan Boltzman apparatus		1

X. Precautions

1. Never put ON the heater before putting water in the tank.
2. Put off the heater before draining the water from heater tank.
3. Drain the water after completion of experiment.
4. Operate all the switches and controls gently.

XI. Procedure

1. See that water inlet cock of water jacket is closed and fill up sufficient water in the heater tank.
2. Put ON the heater.
3. Blacken the test disc with the help of lamp black and let it cool.
4. Put the thermometer and check water temperature.
5. Boil the water and switch off the heater.

6. See that drain cock of water jacket is closed and open water inlet cock.
7. See that there is sufficient water above the top of hemisphere(a piezometer tube is fitted to indicate water level).
8. Note down the hemisphere temperature (up to channel 1 to 4).
9. Note down the disc temperature (i.e. channel 5).
10. Start the timer, buzzer will start ringing. At the start of timer cycle, insert test disc into the hole at the bottom of hemisphere.
11. Note down the temperatures of disc, every five times of the buzzer rings.
12. Take at least 8-10 readings

XII. Resources used

Sr No.	Name of Resource	Suggested Broad Specification		Quantity	Remarks (If any)
		Make	Details		
1					
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XIII. Actual procedure followed

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XIV. Precautions followed

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XV. Observations and Calculations:

Sr. No	Hemisphere temperature ^oC
1	T_1 =
2	T_2 =
3	T_3 =
4	T_4 =

Sr. No	Time interval	Test disc temperature ^oC
1	0	
2	25	
3	50	
4	75	
5	100	
6	125	
7	150	
8	175	
9	200	
10	225	

Sample calculation for set no.

1. Area of test disc $A = \pi d^2 /4$ =

2. Mass of test disc m = ………………kg

3. Plot a graph of temperature rise of test disc with time as base and find out its slope (dT/ dt)

4. Hemisphere temperature $T_H = (T_1 + T_2 + T_3 + T_4)/4$ =…………..^0C

   = …………..K

5. Initial test disc temperature $T_D = T_5 + 273$

6. $\sigma = m.Cp.(dT/dt) / A.(T_H^4 - T_D^4)$

   = …………………

XVI. Results

Stefan Boltzman constant σ = ……………………W / m^2 K

XVII. Interpretation of results

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XVIII. Conclusions

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XIX Practical related Questions

Note: Below given are few sample questions for reference. Teachers must design more such questions so as to ensure the achievement of identified CO.

a. Name laws of black body radiation
b. Explain Stefan Boltzman law with mathematical expression.
c. Explain Plank's law

[Space for Answers]

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XX References / Suggestions for further Reading

- https://www.youtube.com/watch?v=onGuJZS8-Sc
- http://vlab.amrita.edu/index.php?brch=194&cnt=1&sim=548&sub=1
- http://elartu.tntu.edu.ua/bitstream/123456789/1793/1/lab_O3.pdf

XXI. Assessment Scheme

Performance Indicators		Weightage
Process related (15 Marks)		**60%**
1	Preparation of the experimental set up	20%
2	Setting and operation	20%
3	Safety measures, observation and recording	20%
Product related (10 Marks)		**40%**
4	Calculation and Interpretation of result	20%
5	Practical related question and submission of report	20%
Total (25 Marks)		**100 %**

Names of Student Team Members

1. …………………………

2.…………………………

3.…………………………

4.…………………………

Marks Obtained			**Dated signature of Teacher**
Process Related(15)	**Product Related(10)**	**Total (25)**	

Practical No: 9: Compare the outside temperatures of black body and test plate.

I. Practical Significance:

Radiation is regarded as a phenomenon to hot and luminous bodies. The substances having nearly complete or unit absorptivities are called black body. A black body absorbs all radiation falling on it. Lampblack, platinum black and bismuth black are examples of black body.

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II. Relevant Program Outcomes (POs)

PO1. Basic knowledge: Apply knowledge of basic mathematics, sciences and basic engineering to solve the Chemical Engineering problems

PO2. Discipline knowledge: Apply Chemical Engineering knowledge to solve industry based Chemical Engineering problems.

PO3. Experiments and practice: Plan to perform experiments and practices to use the results to solve technical problems related to Chemical Engineering.

PO 8. Individual and team work: Function effectively as a leader and team member in diverse/ multidisciplinary teams.

PO 9. Communication: Communicate effectively in oral and written form.

PSO 2. Material management and quality control: Manage chemicals and equipment to produce quality chemical products.

III. Competency and Practical Skills

'Use heat transfer principles to increase efficiency and to save energy in chemical process plants.'

1. Use thermocouple to measure temperature.

IV. Relevant Course Outcomes

1. Calculate amount of heat transfer by radiation.

V. Practical Outcome–

Using emissivity measurement apparatus compare the outside surface temperatures of black body and test plate.

VI. Relevant Affective domain related Outcome(s)

1. Follow safe practices
2. Maintain tools and equipment.
3. Follow ethical practices.
4. Demonstrate working as a leader/a team member

VII. Minimum Theoretical Background

Radiation refers to the transport of energy through space by electromagnetic waves. It depends upon the electromagnetic waves as a means for transfer of energy from a source to a receiver. Heat transfer by radiation is of much more importance at higher temperature levels as compared to conduction and convection. Radiant energy is believed to originate within the molecules of the radiating body, the atoms of such molecules vibrating in a simple harmonic motion as linear oscillators. A body at a given temperature will emit radiation of a whole range of wavelength s and not a single wavelength. The total quantity of radiant energy of all wavelengths emitted by a body per unit area and time is the total emissive power.

When radiant energy falls upon a body, it may be all or partially absorbed, reflected or transmitted. The fraction of radiant energy absorbed is called absorptivity (α), fraction reflected is called reflectivity (ρ) and the fraction transmitted is called transmissivity (τ)

$$\alpha + \rho + \tau = 1$$

The substances having nearly complete or unit absorptivities are called black body. A black body absorbs all radiation falling on it.

The ratio of the total emissive power (E) of a body to that of a black body (E_b) at the same temperature is known as emissivity (e) of that body.

$$e = E/E_b$$

Emissivity depends on the temperature of the body only. The emissivity of a body is the measure of how it emits radiant energy in comparison with a black body at the same temperature.

As per Kirchhoff’s law, when any body is in thermal equilibrium with its surroundings, its emissivity and absorptivities are equal.

Fig 1 Emissivity apparatus

VIII. Experimental set up :

Figure 2

IX. Resources required

Sr. No.	Name of Resource	Suggested Broad Specification	Quantity
1	Emissivity measurement apparatus		1
2	Black plate	Diameter = 0.15 m	1
3	Test plate	Diameter = 0.15 m	1
4	Thermocouples		4

X. Precaution

1. Keep the dimmer stat at zero position before switching on and switching off the heaters.
2. Keep the assembly undisturbed while testing.
3. Do not disturb the thermocouple setting.
4. Do not touch your finger to or scratch on the plate and test plate.

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XI. Procedure

1. Check that the dimmer stats are at zero position and the duct is closed.
2. Switch on the main switch and give some power to both the plates by adjusting the dimmer stat. The power supplied to black plate heater should be equal to that of test plate heater.
3. Note down the temperatures of each of the plate surface.
4. Note down the temperatures of outside the test plate and black plate.
5. Repeat the procedure for different values of power input.

XII. Resources used (with major specifications)

Sr. No.	Name of Resource	Suggested Broad Specification		Quantity	Remarks (If any)
		Make	Details		
1					
2					
3					
4					

XIII. Actual procedure followed

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XIV. Precautions followed

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XV. Observations and Calculations:

Sr. No	Test plate				Black plate			
	V	I	Surface temperature	Outside temperature	V	I	Surface temperature	Outside temperature
1								
2								
3								
4								
5								

Sample calculation for set no.

1. Power input to test plate W_T=V*I =
2. Power input to black plate W_b =V*I =
3. Surface temperature of test plate =
4. Outside temperature of test plate =
5. Surface temperature of black plate =
6. Outside temperature of black plate =

XVI. Results

When the power input is …………..W,

Outside temperature of black plate = ………….

Outside temperature of test plate = …………

XVII. Interpretation of results

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XVIII. Conclusions

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XIX. Practical related Questions

Note: Below given are few sample questions for reference. Teachers must design more such questions so as to ensure the achievement of identified CO.

1. Define black body
2. Define gray body
3. Define monochromatic emissivity
4. Explain Kirchhoff's law of radiation

XX. References / Suggestions for further Reading

- http://www.svcetedu.org/cms/images/mech/uploads/htlab.pdf
- https://www.youtube.com/watch?v=pbCf4507QvM
- https://www.youtube.com/watch?v=YQTB50AaKsc
- https://www.youtube.com/watch?v=H3TcLoapJBo

XXI Assessment Scheme

Performance Indicators		Weightage
Process related (15 Marks)		**60%**
1	Preparation of experimental set up	20%
2	Setting and operation	20%
3	Safety measures, observation and recording	20%
Product related (10 Marks)		**40%**
4	Calculation and Interpretation of result	20%
5	Practical related question and submission of report	20%
Total (25 Marks)		**100 %**

Names of Student Team Members

1. …………………………
2. …………………………
3. …………………………
4. …………………………

Marks Obtained			Dated signature of Teacher
Process Related(15)	Product Related(10)	Total (25)	

Practical No: 10. Operate double pipe heat exchanger and calculate overall heat transfer coefficient for co current flow

I. Practical Significance:

The heat transfer coefficient is an important parameter during thermal application in Chemical Process industry. Double pipe heat exchangers are used in industries for heating or cooling of process fluids. Flow pattern affects the overall heat transfer coefficient.

II. Relevant Program Outcomes (POs)

PO1. Basic knowledge: Apply knowledge of basic mathematics, sciences and basic engineering to solve the Chemical **Engineering** problems

PO2. Discipline knowledge: Apply **Chemical Engineering** knowledge to solve industry based Chemical Engineering problems.

PO3. Experiments and practice: Plan to perform experiments and practices to use the results to solve technical problems related to Chemical **Engineering**.

PO 9. Communication: Communicate effectively in oral and written form.

PSO 2.Material management and quality control: Manage chemicals and equipment to produce quality chemical products.

III. Competency and Practical Skills

'Use heat transfer principles to increase efficiency and to save energy in chemical process plants.'

1. Use thermocouple to measure temperature.
2. Use rotameter to measure volumetric flow rate.

IV. Relevant Course Outcomes

1. Apply the concept of convection to operate heat exchanger.
2. Choose proper heat transfer equipment for given application.

V. Practical Outcome

Using double pipe heat exchanger calculate overall heat transfer coefficient for co current flow.

VI. Relevant Affective domain related Outcome(s)

1. Follow safe practices
2. Maintain tools and equipment.

VII. Minimum Theoretical Background

In its simplest form, the double pipe heat exchanger, (also known as a concentric pipe, hairpin, jacked pipe and jacketed U-tube heat exchangers), consists of a single tube mounted inside another. One fluid flows in the inner pipe, while a second fluid flows annular space created between two concentric pipes. The Overall heat transfer coefficient takes in to account the individual heat transfer coefficient of each stream and resistance of the pipe material. The heat transfer coefficient is the heat transferred per unit area per kelvin. When both fluids (hot and cold) flow in the same direction from one end of heat exchanger to the other end of heat exchanger then the flow is called co-current flow or parallel flow.

Double pipe heat exchangers are used when the heat transfer area required is relatively small.

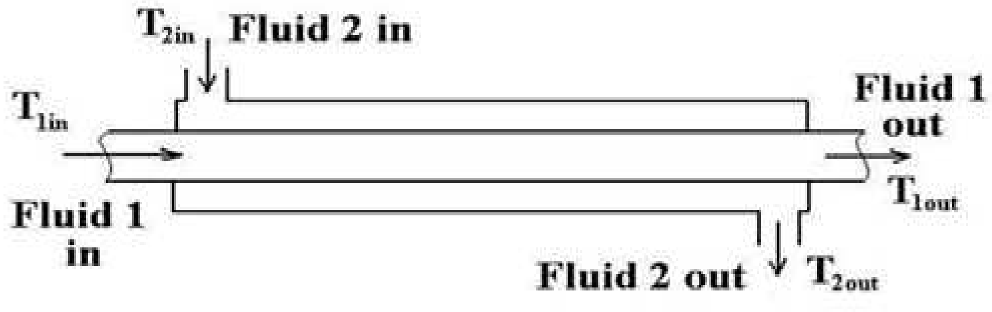

Fig. 1 Double pipe heat exchanger for co current flow

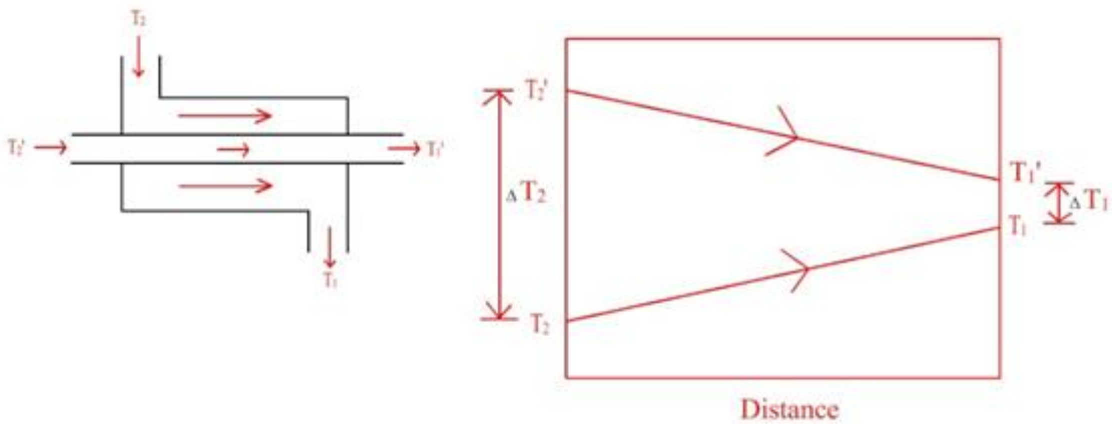

Fig. 2 Temperature profile for co current flow

VIII. Experimental set up:

Figure 3

IX. Resources required

SI No.	Name of Resource	Suggested Broad Specification	Quantity
1	Inner pipe	ID = 26mm OD= 43 mm length = 1.2 m	1
2	Outer pipe	ID = 68mm OD= 76 mm	1
3	Rotameter	1-10 LPM	2

X. Precautions

1. Adjust flow rate properly and, consider the reading corresponding to reading edge of the float.
2. Wait for the float to be stable before taking the reading.
3. Wait for steady state condition to reach before taking inlet and outlet temperatures of hot and cold fluid.

XI. Procedure

1. Make the hot and cold water to flow through double pipe heat exchanger by opening the valves.
2. Adjust the flow rates of both fluids by adjusting the valves.
3. Switch ON the heater and wait for steady state condition to be attained.
4. Measure the flow rate of hot and cold water with the help of rotameter.
5. Note down the readings of inlet and outlet temperatures of hot and cold water.
6. Repeat the procedure for different flow rates of cold water.

XII. Resources used (with major specifications)

Sr No.	Name of Resource	Suggested Broad Specification		Quantity	Remarks (If any)
		Make	Details		
1					
2					
3					

XIII. Actual procedure followed

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XIV. Precautions followed

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XV. Observations and Calculations:

1. Inner Diameter of inner pipe (di) =
2. Outer Diameter of inner pipe (do) =
3. Length of pipe (L) =

Sr. No.	Cold Water			Hot Water		
	Flow Rate (lit/Sec)	T_{ci} (K)	T_{co} (K)	Flow Rate (lit/Sec)	T_{hi} (K)	T_{ho} (K)
1						
2						
3						
4						

Sample calculation for set no

Properties of water at mean temperature

Cp_h = ……………. KJ/kgK

Cp_c = …………….. KJ/kgK

ρ_h = ………… kg/m^3

ρ_c = ……….. kg/m^3

Q = rate of heat transfer

1. $Q_h = m_h \times Cp_h \times (T_{hi} - T_{ho})$

   = ……………………..

   = …………….W.

Where

T_{hi} = Inlet temperature of Hot fluid in K

T_{ho} = Outlet temperature of Hot fluid in K

m_h = Mass flow rate of hot water in kg/sec

Cp_h = Specific heat capacity of hot water in KJ/kg.K

2. $Qc = m_c \times Cp_c \times (T_{co} - T_{ci})$

   = ……………………..

   = …………….W.

Where

T_{ci} = Inlet temperature of cold fluid in K

T_{co} = Outlet temperature of cold fluid in K

m_c = Mass flow rate of cold water in kg/sec

Cp_c = Specific heat capacity of cold water in KJ/kg.K

3. Q = (Qh+Qc)/2

   Q = ……………….

4. Overall Heat Transfer coefficient

   $Q = U \times A \times \Delta T_{lm}$

   Where $\Delta T_{lm} = \Delta T_2 - \Delta T_1 / \ln(\Delta T_2/\Delta T_1)$

   $\Delta T_1 = (\Delta T_{hi} - \Delta T_{ci})$ = ……….. ………………… =……….. K

   $\Delta T_2 = (\Delta T_{ho} - \Delta T_{co})$ = ……….. ……………….. =………. .K

ΔT_{lm} = ………………………………………… . = ……….K

Inside heat transfer area (A_i) = π x D_i x L

= ……………………………………

= ………………m^2

Outside heat transfer area (A_o) = π x Do x L

= ……………………………………

= ………………m^2

Overall heat transfer based on outside area (U_o)

5. Q = U_o x A_o x ΔT_{lm}

U_o = Q/(A_o x ΔT_{lm})

= …………………………………………….

= …………….W/m^2K

6. Overall heat transfer based on inside area (U_i)

Q = Ui x A_i x ΔT_{lm}

U_i = Q/(A_i x ΔT_{lm})

= …………………………………………….

= …………….W/m^2K

Sr. No.	Qh	Qc	Q	ΔT_{lm}	U_o	U_i
1						
2						
3						
4						

XVI. Results

1. Overall heat transfer based on inside area (U_i) =

2. Overall heat transfer based on outside area (U_o)

XVII. Interpretation of results

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XVIII. Conclusions

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XIX. Practical related Questions

Note: Below given are few sample questions for reference. Teachers must design more such questions so as to ensure the achievement of identified CO.

a. Give the range of rotameter used to find flow rates of hot and cold water.
b. Draw the temperature length curve for co current flow in double pipe heat exchanger.
c. Give any two advantages of double pipe heat exchanger.
d. Give any two disadvantages of double pipe heat exchanger.
e. Give any industrial application of co current flow double pipe heat exchanger.

[Space for Answers]

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XX. References / Suggestions for further Reading

- http://vlabs.iitb.ac.in/vlab/chemical/exp8/index.html
- https://www.che.utah.edu/site-specific-resources/chemical- https://nptel.ac.in /courses/103103032/11

XXI. Assessment Scheme

Performance Indicators		Weightage
Process related (15 Marks)		**60%**
1	Preparation of experimental set up	20%
2	Setting and operation	20%
3	Safety measures, observation and recording	20%
Product related (10 Marks)		**40%**
4	Calculation and Interpretation of result	20%
5	Practical related question and submission of report	20%
Total (25 Marks)		**100 %**

Names of Student Team Members

1. …………………………
2.…………………………
3.…………………………
4.…………………………

Marks Obtained			**Dated signature of Teacher**
Process Related(15)	**Product Related(10)**	**Total (25)**	

Practical No. 11: Operate double pipe heat exchanger and calculate overall heat transfer coefficient for counter current flow

1. Practical Significance

The heat transfer coefficient is a very important parameter during thermal application in Chemical Process industry. Double pipe heat exchangers are used in industries for heating or cooling of process fluids. Flow pattern affects the overall heat transfer coefficient. Heat transfer rate is more in counter current flow.

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II. Relevant Program Outcomes (POs)

PO1. Basic knowledge: Apply knowledge of basic mathematics, sciences and basic engineering to solve the Chemical Engineering problems

PO2. Discipline knowledge: Apply Chemical Engineering knowledge to solve industry based Chemical Engineering problems.

PO3. Experiments and practice: Plan to perform experiments and practices to use the results to solve technical problems related to Chemical Engineering.

PO6. Environment and sustainability: Apply Chemical engineering solutions also for sustainable development practices in societal and environmental contexts.

PO 8. Individual and team work: Function effectively as a leader and team member in diverse/ multidisciplinary teams.

III. Competency and Practical Skills

'Use heat transfer principles to increase efficiency and to save energy in chemical process plants.'

1. Use thermocouple to measure temperature.
2. Use rotameter to measure volumetric flow rate

IV. Relevant Course Outcomes

1. Apply the concept of convection to operate heat exchanger.
2. Choose proper heat transfer equipment for given application

V. Practical Outcome

Using double pipe heat exchanger calculate overall heat transfer coefficient for counter current flow

VI. Relevant Affective domain related Outcome(s)

1. Follow safe practices
2. Maintain tools and equipment.
3. Practice energy conservation.

VII. Minimum Theoretical Background

In its simplest form, the double pipe heat exchanger, (also known as a concentric pipe, hairpin, jacked pipe and jacketed U-tube heat exchangers), consists of a single tube mounted inside another. One fluid flows in the inner pipe, while a second fluid flows in the outer pipe annuals. The Overall heat transfer coefficient takes in to account the individual heat transfer coefficient of each stream and resistance of the pipe material.

The heat transfer coefficient is the heat transferred per unit area per kelvin. When both fluids (hot and cold) flow in the opposite direction from one end of heat exchanger to the other end of heat exchanger then the flow is called co-current flow or parallel flow.

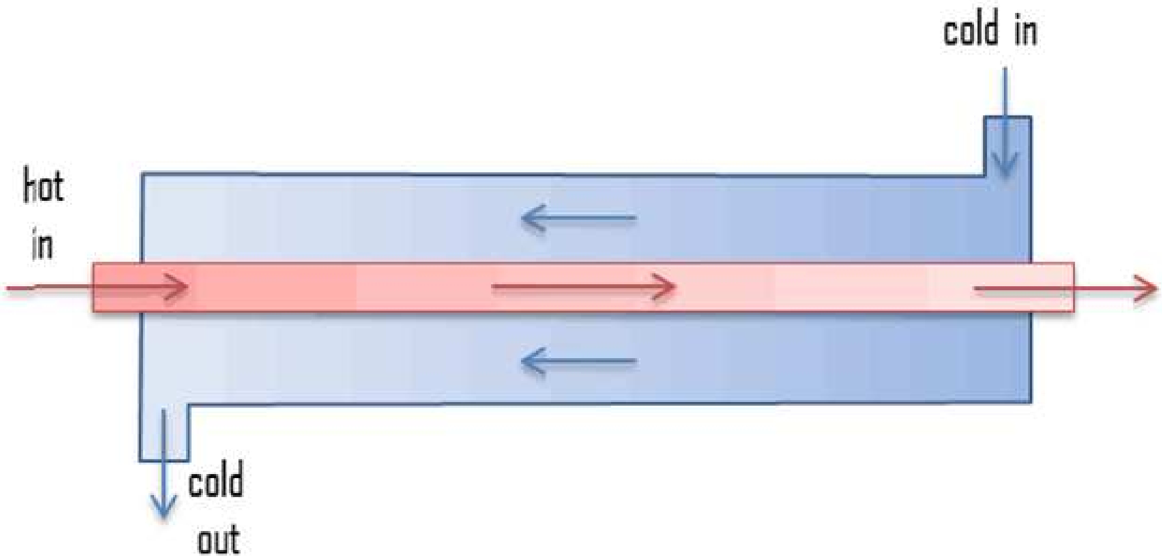

Fig 1 Double pipe heat exchanger-Counter current flow

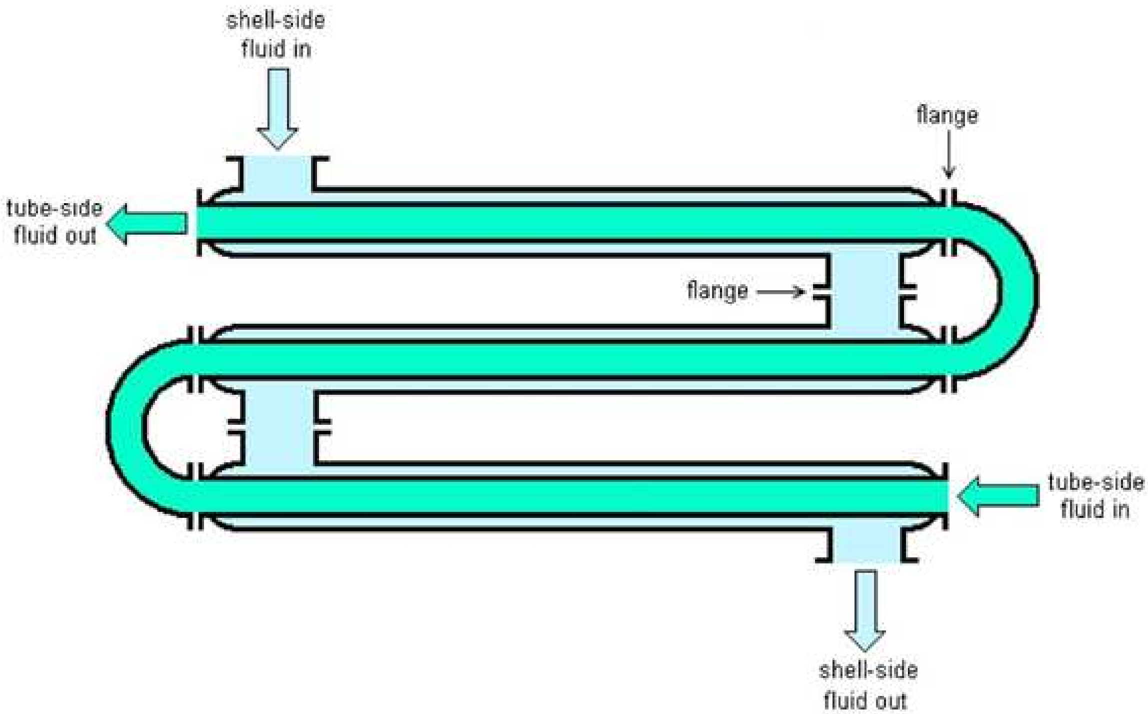

Fig 2 double pipe heat exchanger

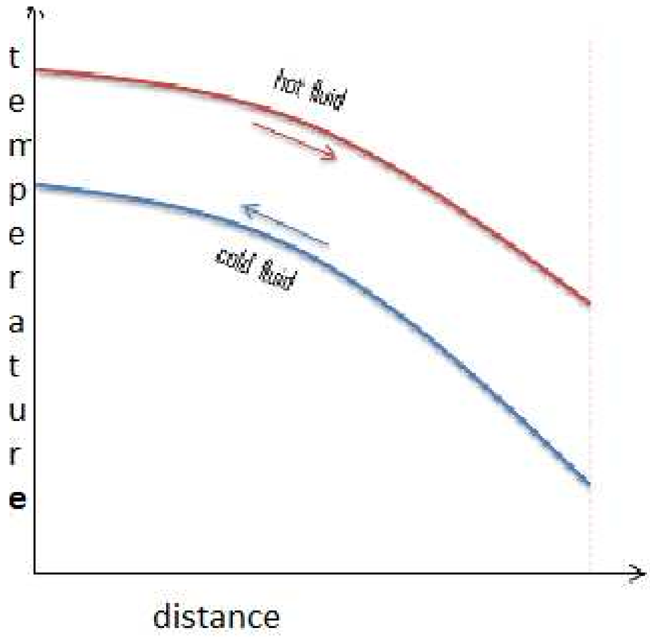

Fig 3 temperature profile for counter current flow

VIII. Experimental set up:

Fig4

IX. Resources required

SI No.	Name of Resource	Suggested Broad Specification	Quantity
1	Inner pipe	ID = 26mm OD= 43 mm, length = 1.2 m	1
2	Inner pipe	ID = 68mm OD= 76 mm	1
3	Rotameter	1-10 LPM	2

X. Precautions to be followed

1. Adjust flow rate properly and, consider the reading corresponding to reading edge of the float.
2. Wait for the float to be stable before taking the reading.
3. Wait for steady state condition to reach before taking inlet and outlet temperatures of hot and cold fluid.

XI. Procedure

1. Make the hot and cold water to flow through double pipe heat exchanger by opening the valves.
2. Adjust the flow rates of both fluids by adjusting the valves.
3. Switch ON the heater and wait for steady state condition to be attained.
4. Measure the flow rate of hot and cold water with the help of rotameter.
5. Note down the readings of inlet and outlet temperatures of hot and cold water.
6. Repeat the procedure for different flow rates of cold water.

XII. Resources used

Sr. No.	Name of Resource	Suggested Broad Specification		Quantity	Remarks (If any)
		Make	Details		
1					
2					
3					

XIII. Actual procedure followed

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XIV. Precautions followed

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XV. Observations and Calculations:

1. Inner Diameter of inner pipe (di) =
2. Outer Diameter of inner pipe (do) =
3. Length of pipe (L) =

Sr. No.	**Cold Water**			**Hot Water**		
	Flow Rate (lit/Sec)	T_{ci} (K)	T_{co} (K)	Flow Rate (lit/Sec)	T_{hi} (K)	T_{ho} (K)
1						
2						
3						
4						

Calculations:

Sample calculation for set no:

1. Properties of water at mean temperature

Cp_h = _...................... KJ/kgK

Cp_c = …………….. KJ/kgK

ρ_h = ………… kg/m^3

ρ_c = ……….. kg/m^3

2. $Q_h = m_h \times Cp_h \times (T_{hi} - T_{ho})$

= ……………………..

= …………….W.

Where

T_{hi} = Inlet temperature of Hot fluid in K

T_{ho} = Outlet temperature of Hot fluid in K

m_h = Mass flow rate of hot water in kg/sec

Cp_h = Specific heat capacity of hot water in KJ/kg.K

3. $Q_c = m_c \times Cp_c \times (T_{co} - T_{ci})$

= ……………………..

= …………….W.

Where

T_{ci} = Inlet temperature of cold fluid in K

T_{co} = Outlet temperature of cold fluid in K

m_c = Mass flow rate of cold water in kg/sec

Cp_c = Specific heat capacity of cold water in KJ/kg.K

4. $Q = (Q_h + Q_c)/2$

   Q = ……………….

5. Overall Heat Transfer coefficient

   $Q = U \times A \times \Delta T_{lm}$

Where $\Delta T_{lm} = \Delta T_2 - \Delta T_1 / \ln(\Delta T_2/\Delta T_1)$

$\Delta T_1 = (T_{hi} - T_{co})$ = ……….. ……………… =……….. K

$\Delta T_2 = (T_{ho} - T_{ci})$ = ……….. ……………….. =………. .K

ΔT_{lm} = …………………………………… = ……….K

6. Inside heat transfer area $(A_i) = \pi \times D_i \times L$

   = ……………………………………

   = ………………m^2

7. Outside heat transfer area $(A_o) = \pi \times Do \times L$

   = ……………………………………

   = ………………m^2

8. Overall heat transfer based on outside area (U_o)

$Q = U_o \times A_o \times \Delta T_{lm}$

$U_o = Q/(A_o \times \Delta T_{lm})$

= …………………………………………….

= …………….W/m^2K

9. Overall heat transfer based on inside area (U_i)

$Q = Ui \times A_i \times \Delta T_{lm}$

$U_i = Q/(A_i \times \Delta T_{lm})$
= …………………………………………….

= ……………W/m^{2}K

Sr. No.	Qh	Qc	Q	ΔT_{lm}	U_o	U_i
1						
2						
3						
4						

XVI. Results

The Overall heat transfer coefficient for counter current double pipe heat exchanger is found to be

U_o = ……………W/m^{2}K

U_i = ……………W/m^{2}K

XVII. Interpretation of results

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XVIII. Conclusions

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XIX. Practical related Questions

Note: Below given are few sample questions for reference. Teachers must design more such questions so as to ensure the achievement of identified CO.

a. Give the range of rotameter used to find flow rates of hot and cold water.
b. Draw the temperature length curve for Counter current flow in double pipe heat exchanger.
c. Give any two advantages of double pipe heat exchanger.
d. Give any two disadvantages of double pipe heat exchanger.
e. Give any industrial application of Counter current flow double pipe heat exchanger

[Space for Answers]

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XX. References / Suggestions for further Reading

- https://nptel.ac.in/courses/112105248/12
- https://www.youtube.com/watch?v=Z8yHW0KIhYA
- https://www.youtube.com/watch?v=ICwBmCbV2pI

XXI. Assessment Scheme

Performance Indicator		Weightage
Process related (15 Marks)		**60%**
1	Preparation of experimental set up	20%
2	Setting and operation	20%
3	Safety measures, observation and recording	20%
Product related (10 Marks)		**40%**
4	Calculation and Interpretation of result	20%
5	Practical related question and submission of report	20%
Total (25 Marks)		**100 %**

Names of Student Team Members

1. …………………………
2. …………………………
3. …………………………
4. …………………………

Marks Obtained			**Dated signature of Teacher**
Process Related(15)	**Product Related(10)**	**Total (25)**	

Practical No. 12: Operate shell and tube heat exchanger and calculate overall heat transfer coefficient

I. Practical Significance

The heat transfer coefficient is a very important parameter during thermal application in Chemical Process industry. Shell and tube heat exchangers comprise of a shell which allows one fluid to make its way through the tubes while another fluid flows through the shell in order to transfer the heat between the two different fluids. These heat exchangers are used in industries for heating or cooling of process fluids.

II. Relevant Program Outcomes (POs)

PO1. Basic knowledge: Apply knowledge of basic mathematics, sciences and basic engineering to solve the Chemical Engineering problems

PO2. Discipline knowledge: Apply Chemical Engineering knowledge to solve industry based Chemical Engineering problems.

PO3. Experiments and practice: Plan to perform experiments and practices to use the results to solve technical problems related to Chemical Engineering.

PO4 Engineering tools: Apply relevant technologies and Chemical engineering tools with an understanding of the limitations

PO 8. Individual and team work: Function effectively as a leader and team member in diverse/ multidisciplinary teams.

III. Competency and Practical Skills

'Use heat transfer principles to increase efficiency and to save energy in chemical process plants.'

1. Use thermocouple to measure temperature.
2. Use rotameter to measure volumetric flow rate.

IV. Relevant Course Outcomes

1 Apply the concept of convection to operate heat exchanger.

2 Choose proper heat transfer equipment for given application.

V Practical Outcome

Using shell and tube heat exchanger calculate overall heat transfer coefficient.

VI Relevant Affective domain related Outcome(s)

1. Follow safe practices
2. Maintain tools and equipment.
3. Practice energy conservation
4. Demonstrate working as a leader/ a team member.

VII Minimum Theoretical Background

A shell and tube heat exchanger is a class of heat exchanger designs. It is the most common type of heat exchanger in oil refineries and other large chemical processes, and is suited for higher-pressure applications. As its name implies, this type of heat exchanger consists of a shell (a large pressure vessel) with a bundle of tubes inside it. One fluid runs through the tubes, and another fluid flows over the tubes (through the shell) to transfer heat between the two fluids. The set of tubes is called a tube bundle, and may be composed of several types of tubes: plain, longitudinally finned, etc. Two fluids, of different starting temperatures, flow through the heat exchanger. One flows through the tubes (the tube side) and the other flows outside the tubes but inside the shell (the shell side). Heat is transferred from one fluid to the other through the tube walls, either from tube side to shell side or vice versa. Heat exchangers with only one phase (liquid or gas) on each side can be called one-phase or single-phase heat exchangers. Two-phase heat exchangers can be used to heat a liquid to boil it into a gas (vapor), sometimes called boilers, or cool a vapor to condense it into a liquid (called condensers), with the phase change usually occurring on the shell side. Counter current heat exchangers are most efficient because they allow the highest log mean temperature difference between the hot and cold streams.

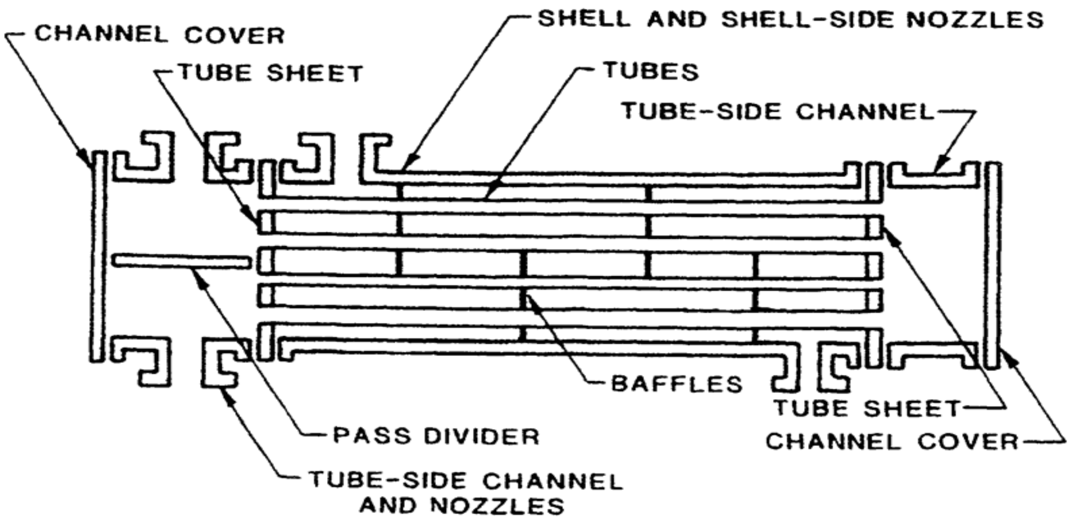

Fig 1 shell and tube heat exchanger

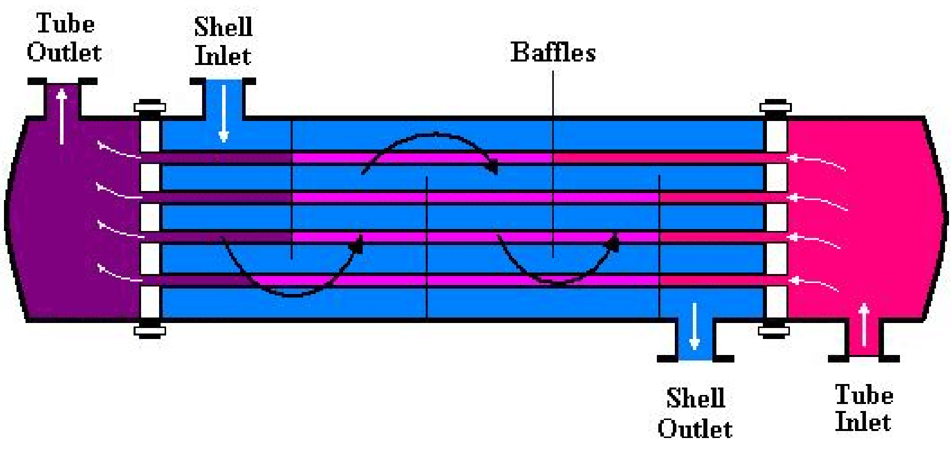

Fig 2 shell and tube heat exchanger

VIII. Experimental set up:

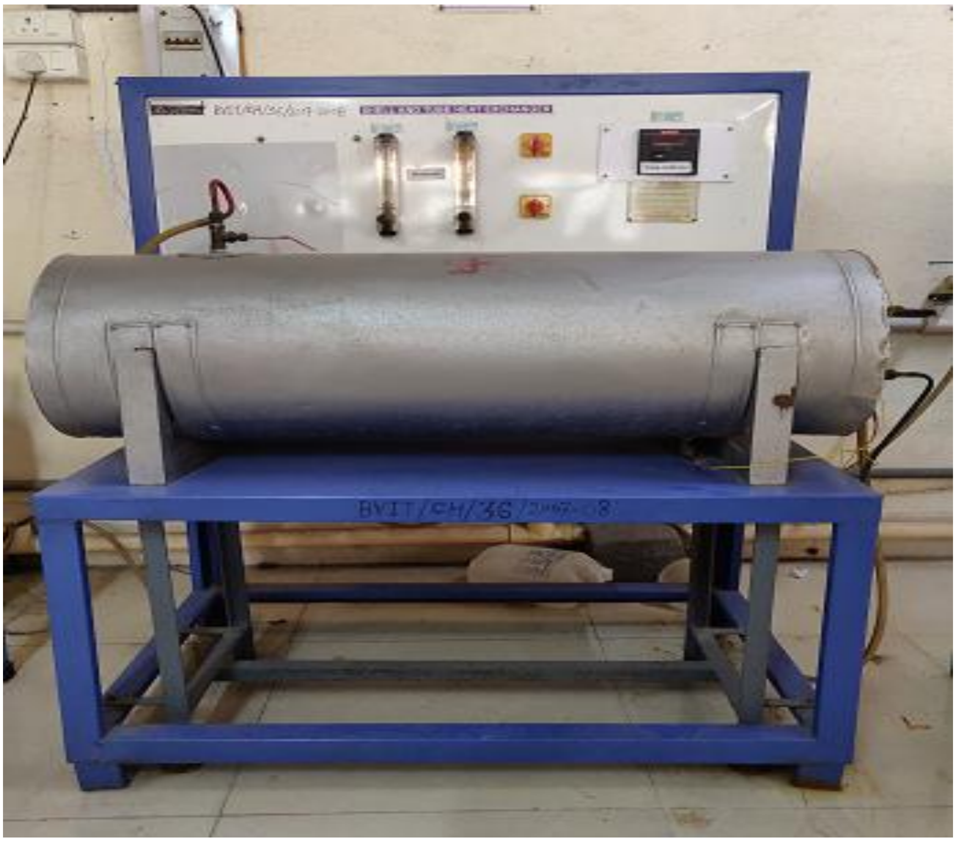

Fig 3

IX. Resources required

SI No.	Name of Resource	Suggested Broad Specification	Quantity
1	Tube	ID = 26mm OD= 32mm Length = 800 mm	14
2	Shell	ID = 250 mm length= 800 mm	1
3	Baffles		2
4	Rotameter	1-11 LPM	1

X. Precautions

1. Adjust flow rate properly and, consider the reading corresponding to reading edge of the float.
2. Wait for the float to be stable before taking the reading.
3. Wait for steady state condition to reach before taking inlet and outlet temperatures of hot and cold fluid.

XI. Procedure

1. Make the cold water to flow through shell side first and then allow hot water to flow through tube side of the shell and tube heat exchanger by opening the valves.
2. Adjust the flow rates of both fluids by adjusting the valves.
3. Switch ON the heater and wait for steady state condition to be attained.
4. Measure the flow rate of hot and cold water with the help of rotameter.
5. Note down the readings of inlet and outlet temperatures of hot and cold water.
6. Repeat the procedure for different flow rates of cold water.

XII. Resources used

Sl No.	Name of Resource	Suggested Broad Specification		Quantity	Remarks (If any)
		Make	Details		
1					
2					
3					
4					

XIII. Actual procedure followed

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XIV. Precautions followed

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XV Observations and Calculations:

1. Inner Diameter of inner pipe (di) = ……………..mm
2. Outer Diameter of inner pipe (do) = ……………..mm
3. Length of pipe (L) = ……………..mm
4. Number of Tubes (n) = ……………..mm

Sr. No.	Cold Water			Hot Water		
	Flow Rate (lit/Sec)	T_{ci} (K)	T_{co} (K)	Flow Rate (lit/Sec)	T_{hi} (K)	T_{ho} (K)
1						
2						
3						
4						

Sample calculation for set no

1.Properties of water at mean temperature

Cp_h = ……………. KJ/kgK

Cp_c = …………….. KJ/kgK

ρ_h = ………… kg/m^3

ρ_c = ……….. kg/m^3

2. $Q_h = m_h \times Cp_h \times (T_{hi} - T_{ho})$

= ……………………..

= …………….W.

Where

T_{hi} = Inlet temperature of Hot fluid in K

T_{ho} = Outlet temperature of Hot fluid in K

m_h = Mass flow rate of hot water in kg/sec

Cp_h = Specific heat capacity of hot water in KJ/kg.K

3. $Q_c = m_c \times Cp_c \times (T_{co} - T_{ci})$

= ……………………..

= …………….W.

Where

T_{ci} = Inlet temperature of cold fluid in K

T_{co} = Outlet temperature of cold fluid in K

m_c = Mass flow rate of cold water in kg/sec

Cp_c = Specific heat capacity of cold water in KJ/kg.K

4. $Q = (Q_h+Q_c)/2$

Q = ……………….

5. Overall Heat Transfer coefficient
   $Q = U \times A \times \Delta T_{lm}$

   Where $\Delta T_{lm} = \Delta T_2 - \Delta T_1 / \ln(\Delta T_2/\Delta T_1)$

   $\Delta T_1 = (T_{hi} - T_{co})$ = ……….. ………………… =……….. K

   $\Delta T_2 = (T_{ho} - T_{ci})$ = ……….. ……………….. =………. .K

   ΔT_{lm} = …………………………………… = ……….K

6. Inside heat transfer area $(A_i) = \pi \times D_i \times L \times n$
   = ………………………

   = ………………m^2

7. Outside heat transfer area $(A_o) = \pi \times Do \times L \times n$
   = …………………………

   = ………………m^2

8. Overall heat transfer based on outside area (U_o)

   $Q = U_o \times A_o \times \Delta T_{lm}$

   $U_o = Q/(A_o \times \Delta T_{lm})$

   = …………………………………………….

   = …………….W/m^2K

9. Overall heat transfer based on inside area (U_i)

   $Q = Ui \times A_i \times \Delta T_{lm}$

   $U_i = Q/(A_i \times \Delta T_{lm})$
   = …………………………………………….

   = …………….W/m^2K

Sr. No	Q_h (W)	Q_c (W)	$Q=(Q_h+Q_c)/2$	U_i ($W/m^2.K$)	U_o ($W/m^2.K$)

XVI Results

The Overall heat transfer coefficient for 1, 2 counter current Shell and Tube heat exchanger is found to be

U_o = ……………W/m^{2}K

U_i = ……………W/m^{2}K

XVII. Interpretation of results

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XVIII. Conclusions

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XIX. Practical related Questions

Note: Below given are few sample questions for reference. Teachers must design more such questions so as to ensure the achievement of identified CO.

a. Give advantages of shell and tube heat exchangers.
b. Define tube pitch and baffle pitch
c. Through which side of shell and tube heat exchangers the following liquids are directed? Give reasons also.
    1. Corrosive liquid
    2. Viscous liquid
    3. High pressure liquid
d. Give the uses of baffles in shell and tube heat exchangers

[Space for Answers]

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XX. References / Suggestions for further Reading

- http://textofvideo.nptel.ac.in/103101137/lec59.pdf
- https://www.youtube.com/watch?v=jc_hL_tSFzo
- https://www.youtube.com/watch?v=mw7J8zyLsvg
- https://www.youtube.com/watch?v=zUjTa5BajxQ

XXI. Assessment Scheme

Performance Indicators		Weightage
Process related (15 Marks)		**60%**
1	Preparation of experimental set up	20%
2	Setting and operation	20%
3	Safety measures, observation and recording	20%
Product related (10 Marks)		**40%**
4	Calculation and Interpretation of result	20%
5	Practical related question and submission of report	20%
Total (25 Marks)		**100 %**

Names of Student Team Members

1. …………………………

2.…………………………

3.…………………………

4.…………………………

Marks Obtained			**Dated signature of Teacher**
Process Related(15)	**Product Related(10)**	**Total (25)**	

Practical No. 13: Operate finned tube heat exchanger and calculate overall heat transfer coefficient

I. Practical Significance

The heat transfer coefficient is a very important parameter during thermal application in Chemical Process industry. Finned tube heat exchangers are specifically used when one or both of the fluids exchanging heat have low values of individual heat transfer coefficient. By attaching fins or metal pieces to heat transfer surface the area of heat transfer is increased which increases heat transfer rate and heat transfer coefficient.

II. Relevant Program Outcomes (POs)

PO1. Basic knowledge: Apply knowledge of basic mathematics, sciences and basic engineering to solve the Chemical Engineering problems.

PO2. Discipline knowledge: Apply Chemical Engineering knowledge to solve industry based Chemical Engineering problems.

PO3. Experiments and practice: Plan to perform experiments and practices to use the results to solve technical problems related to Chemical Engineering.

PO4.Engineering tools: Apply relevant technologies and Chemical engineering tools with an understanding of the limitations.

PO 8.Individual and team work: Function effectively as a leader and team member in diverse/ multidisciplinary teams.

PO 9.Communication: Communicate effectively in oral and written form.

PSO 2.Material management and quality control: Manage chemicals and equipment to produce quality chemical products.

III. Competency and Practical Skills

'Use heat transfer principles to increase efficiency and to save energy in chemical process plants.'

1 Use thermocouple to measure temperature.
2 Use rotameter to measure volumetric flow rate.

IV. Relevant Course Outcomes

1 Apply the concept of convection to operate heat exchanger.
2 Choose proper heat transfer equipment for given application.

V. Practical Outcome

Using finned tube heat exchanger calculate overall heat transfer coefficient.

VI. Relevant Affective domain unrelated Outcome(s)

1. Follow safe practices
2. Maintain tools and equipment.
3. Practice energy conservation.

VII. Minimum Theoretical Background

A heat exchanger is a device used to transfer heat between two or more fluids. It is used in both heating and cooling of process fluids. The fluids may be separated by solid wall to prevent mixing of fluids. They are widely used in space heating, refrigeration, air conditioning, power stations etc. The classic example of finned tube heat exchanger found in an internal combustion engine in which a circulating fluid known as coolant flows through radiator coils and air flows past the coils, which cools the coolant and heats the incoming air. Finned tube heat exchangers have tubes with extended outer surface area or fins to enhance the heat transfer rate from the additional area of fins. Finned tubes or tubes with extended outer surface area enhance the heat transfer rate by increasing the effective heat transfer area between the tubes and surrounding fluid. The fluid surrounding finned tubes maybe process fluid or air.

Types of Finned Tubes

Longitudinal Fins

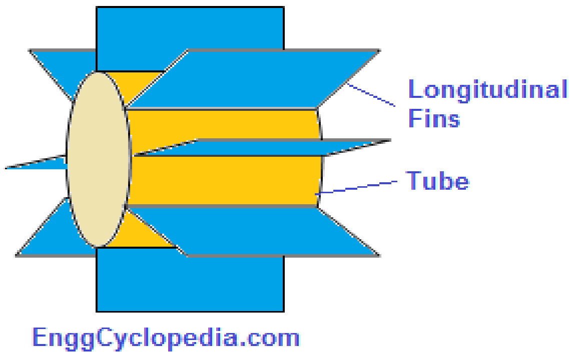

Fig.1 - Longitudinally finned tube in heat exchanger

Longitudinal fins on a tube are best suited for applications where the flow outside the tubes is expected to be streamlined along the tube length, for example double pipe heat exchangers with highly viscous fluid outside the finned tube. Longitudinal fins on a tube run along the length of tubes. The cross sectional shapes of this fin can be either flat or tapered. For different cross sectional geometries, various correlations are available in the literature to evaluate the heat transfer coefficients on outer side of the tubes.

Transverse Fins

Transverse fins are normally used for gas flows or turbulent flows and for cross flow type exchangers or shell and tube heat exchangers. For air coolers, tubes with transverse fins are best suited.

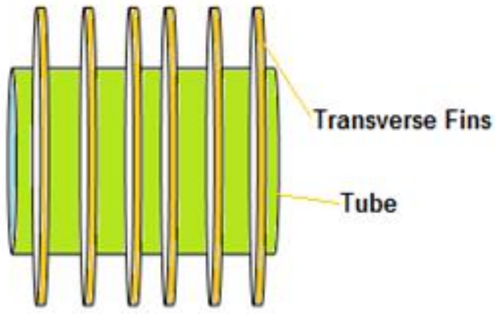

Fig.2 Transverse fins

VIII. Experimental set up:

Fig3

IX. Resources required

Sr. No.	Name of Resource	Suggested Broad Specification	Quantity
1	Finned tube heat exchanger set up	Length = 1m	1
2	Outer tube	OD =75 mm, ID = 70 mm	1
3	Inner tube	OD = 22.5 mm ID = 20.5 mm	1

Sr. No.	Name of Resource	Suggested Broad Specification	Quantity
4	Fins	Length = 1m, height = 12mm, thickness= 1mm	6
5	Orificemeter	Diameter = 30mm	1
6	Rotameter	2.5 – 25 LPM	1

X. Precautions

1. Adjust flow rate properly and, consider the reading corresponding to reading edge of the float.
2. Wait for the float to be stable before taking the reading.
3. Wait for steady U tube manometer fluid before taking the readings.
4. Wait for steady state condition to reach before taking inlet and outlet temperatures of hot and cold fluid.

XI. Procedure

1. Start the blower and adjust the required air flow rate with help of control valve and U tube manometer.
2. Start water flow on tube side and adjust the water flow rate with control valve and rotameter.
3. Switch ON the heater and keep constant flow rates of both fluids.
4. Wait for steady state condition by maintaining constant temperatures of both fluid inlet and outlet.
5. When steady state reaches, enter the observations in observation table.
6. Note down the readings of inlet and outlet temperatures of hot and cold water.
7. Repeat the procedure for different flow rates of hot water.

XII. Resources used

Sr No.	Name of Resource	Suggested Broad Specification		Quantity	Remarks(If any)
		Make	Details		
1					
2					
3					
4					
5					
6					

XIII. Actual procedure followed

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XIV. Precautions followed

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XV. Observations and Calculations:

1. Outer Diameter of tube (do) =
2. Length of tube (l) =
3. Length of fin (L) =
4. Height of fin (H) =
5. Thickness of fin (b) =
6. Area of fin (A) = L (2H+b) mm^2 =
7. Number of Fin (N) =
8. Fin area available for heat transfer (A_f) = A x N =
9. Tube area available for heat transfer (A_b) = (π x do x L – N x b) =
10. Total area of finned tube heat exchanger (At) = $A_f + A_b$ =
11. Outside diameter of pipe (Do) =
12. C/S Area of pipe (A_o) =
13. C/S Area of Orifice (A_2) =

Sr. No.	Air			Water		
	Manometer difference (Δh)	T_{ci} (K)	T_{co} (K)	Flow Rate (lit/Sec)	T_{hi} (K)	T_{ho} (K)
1						
2						
3						
4						

Sample calculation for set no

1. Air flow rate (Q)

$$Q = \frac{S_B * C_o}{\sqrt{1-\beta^4}} \frac{\sqrt{2\Delta P}}{\sqrt{\rho_a}} =$$

Q = -------------------------------

Where,

$S_B = \pi/4 * D_o{}^2$ = ----------------------------------m^2

Do = diameter of Orifice = ---------------m

β = do/dp = ------------------------.

Dp = diameter of pipe = ------------------m

$\Delta P = \Delta h\ (\rho_b - \rho_a) * g$ = ------------------

ρ_b = density of manometric fluid = -------------kg/m^3

ρ_a = density of air = ………… kg/m^3

Δh = Manometric difference =------------------m

2. Mass flow rate of air (m)
   $m = Q * \rho_a =$ =---------------- kg/m^3

3. Heat gained by air (Q_a) air

   $Qa = m * Cpa * (T_{co} - T_{ci})$
   =……………W

   m = mass flow rate of air (kg/s)

   Cpa = Sp. heat of air at mean bulk temperature (J/kg.K)

   T_{ci} (inlet air temperature) = ---------K

   T_{co} (outlet air temperature) = ----------K

4. Heat transfer from hot water (Q_h)

   $Qh = m_h * Cph * (T_{ho} - T_{hi})$ =------------------

=……………W

m_h = mass flow rate of hot water (kg/s)

Cph= Sp. Heat of hot water (J/kg.K)

T_{hi} (inlet water temperature) = ---------K

T_{ho} (outlet water temperature) = ----------K

5. $Q = (Q_a + Q_h) / 2$

= ------------------W

6. Overall heat transfer coefficient

$Q = U_i * A_i * \Delta T_{lm}$

=

$U_i = Q / A_i * \Delta T_{lm}$ = ------------------- W/m^2K

= ------------------- W/m^2K

Where,

A_i = inside heat transfer area of pipe = π * di * L

= ____________m^2

$$\Delta T_{lm} = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1/\Delta T_2)} = \text{------------------}$$

ΔT_1 =

ΔT_2 =

Sr. No	Q_h (W)	Q_a (W)	Q (W)	ΔT_{lm}	U_i ($W/m^2.K$)

XVI. Results

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XVII. Interpretation of results

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XVIII. Conclusions & Recommendation

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XIX. Practical related Questions

Note: Below given are few sample questions for reference. Teachers must design more such questions so as to ensure the achievement of identified CO.

a. Give the range of rotameter used to find flow rates of air and hot water.
b. Draw neat sketches of transverse fins and horizontal fins.
c. Give any two advantages of finned tube heat exchanger.
d. Give any two industrial applications of finned tube heat exchanger.
e. state the reasons why you would prefer finned heat exchanger for certain heat transfer process.

[Space for Answers]

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XX. References / Suggestions for further Reading

- http://volfram.in/finned-tube-type-heat-exchanger.html
- https://nptel.ac.in/courses/112105248/22
- https://nptel.ac.in/courses/103103027/pdf/mod1.pdf
- https://www.youtube.com/watch?v=_orVHvX0syw

XXI. Assessment Scheme

Performance Indicators		Weightage
Process related (15 Marks)		**60%**
1	Preparation of experimental set up	20%
2	Setting and operation	20%
3	Safety measures, observation and recording	20%
Product related (10 Marks)		**40%**
4	Calculation and Interpretation of result	20%
5	Practical related question and submission of report	20%
Total (25 Marks)		**100 %**

Names of Student Team Members

1. …………………………

2…………………………

3…………………………

4…………………………

Marks Obtained			**Dated signature of Teacher**
Process Related(15)	**Product Related(10)**	**Total (25)**	

Practical No. 14: Operate a heat exchanger for co current and counter current flows

I. Practical Significance

A heat exchanger is a device used to effect the process of heat exchange between two fluids that are at different temperatures. The three basic flow arrangements in a heat exchanger are co current or parallel, counter current and cross flow. The rate of heat transfer in counter current flow heat exchangers is more than that in co current flow exchangers. The parallel flow arrangement is used whenever it is necessary to limit the maximum temperature of the cooler fluid.

II. Relevant Program Outcomes (POs)

PO1. Basic knowledge: Apply knowledge of basic mathematics, sciences and basic engineering to solve the Chemical Engineering problems

PO2. Discipline knowledge: Apply Chemical Engineering knowledge to solve industry based Chemical Engineering problems.

PO3. Experiments and practice: Plan to perform experiments and practices to use the results to solve technical problems related to Chemical Engineering.

PO4.Engineering tools: Apply relevant technologies and Chemical engineering tools with an understanding of the limitations

PO6. Environment and sustainability: Apply Chemical engineering solutions also for sustainable development practices in societal and environmental contexts.

PSO 2.Material management and quality control: Manage chemicals and equipment to produce quality chemical products

III Competency and Practical Skills

'Use heat transfer principles to increase efficiency and to save energy in chemical process plants.'

1. Use thermocouple to measure temperature.
2. Use rotameter to measure volumetric flow rate.

IV. Relevant Course Outcomes

1. Apply the concept of convection to operate heat exchanger.
2. Choose proper heat transfer equipment for given application.

V. Practical Outcome

Compare the values of overall heat transfer coefficients for co current and counter current in any heat exchanger

VI. Relevant Affective domain unrelated Outcome(s)

1. Follow safe practices
2. Maintain tools and equipment.

VII. Minimum Theoretical Background

Heat exchangers according to the flow arrangement are parallel or co current flow heat exchanger, counter current flow heat exchanger and cross flow heat exchanger. Parallel flow heat exchanger is the one in which two fluid streams enter at one end, flow through it in the same direction and leaves at the other end. Double pipe heat exchangers and shell and tube heat exchangers can be operated in parallel flow fashion. Counter current flow heat exchanger is the one in which two fluid streams flow in opposite direction. Double pipe heat exchangers and shell and tube heat exchangers can be operated this way. Cross flow heat exchanger is the one in which one fluid moves through the exchanger at right angles to the flow path of the other fluid. Plate type heat exchangers employ cross flow.

The temperature gradient in case of parallel flow is maximum at the entrance and continuously decreases towards the exit, whereas the temperature gradient is fairly constant over the length of heat exchanger in case of counter current flow. Hence, with a counter current flow arrangement, the heating surface has nearly constant capacity through the exchanger and with parallel flow arrangement, the capacity at exit is much less as compared to that at the entrance. In parallel flow arrangement, it is not possible to bring the hot fluid temperature below the outlet temperature of the cold fluid and thus has a considerable effect on the ability of heat exchanger to recover heat. The parallel flow arrangement is used whenever it is necessary to limit the maximum temperature of the cooler fluid.

In counter current flow, it is possible for the cooling liquid to leave at a higher temperature than the heating fluid, and one of the greatest advantages of counter current flow is that it is possible to extract a higher proportion of the heat content of the heating fluid. The rate of heat transfer in counter current flow is more than that in co current.

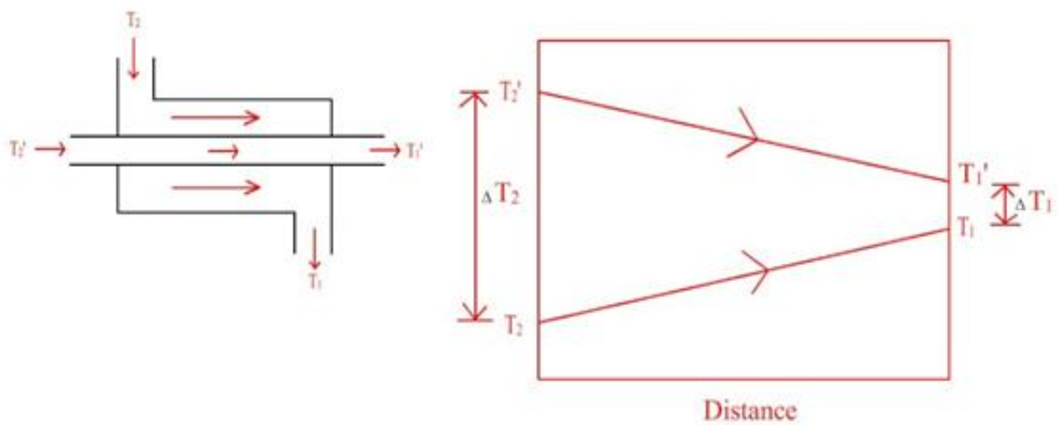

Fig.1 parallel flow heat exchanger with temperature profile

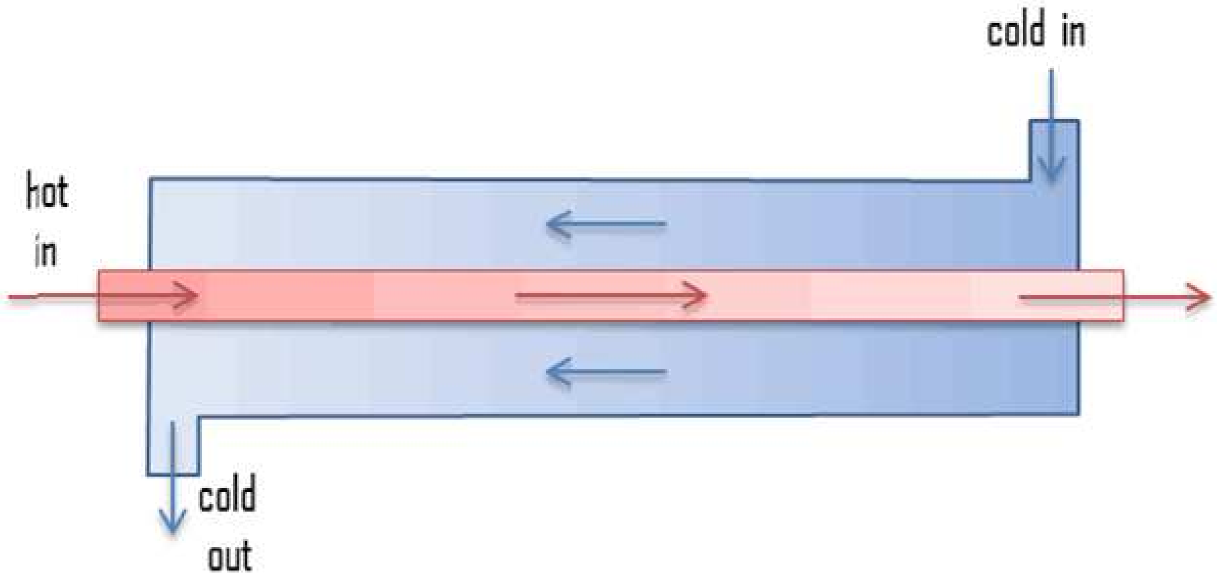

Figure 2 counter current flow heat exchanger

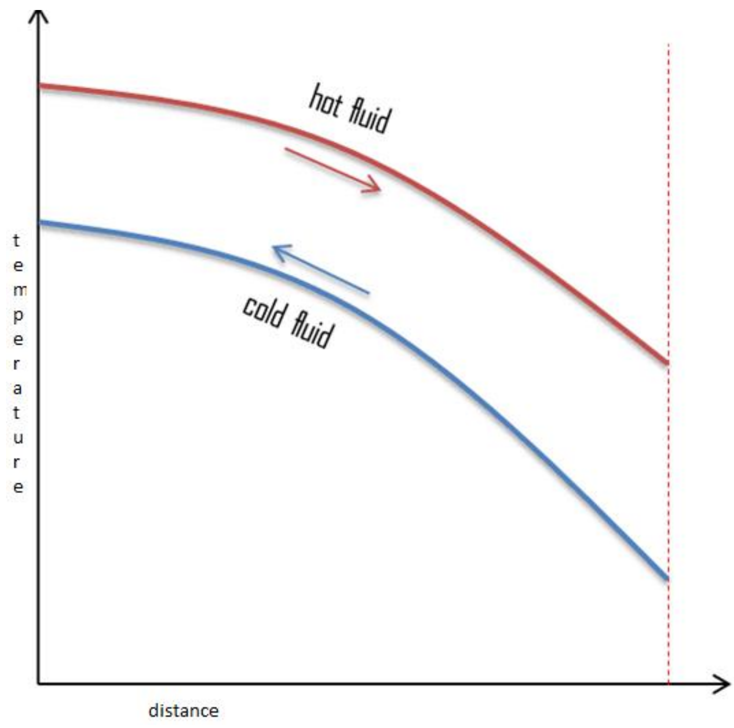

Fig.3 temperature profile in counter current flow

VIII. Experimental set up :

Fig 4

IX. Resources required

SI No.	Name of Resource	Suggested Broad Specification	Quantity
1	Inner pipe	ID = 26mm OD= 43 mm, length = 1.2 m	1
2	Inner pipe	ID = 68mm OD= 76 mm	1
3	Rotameter	1-10 LPM	2

X. Precautions

1. Adjust flow rate properly and, consider the reading corresponding to reading edge of the float.

2. Wait for the float to be stable before taking the reading.

3. Wait for steady state condition to reach before taking inlet and outlet temperatures hot and cold fluid.

XI. Procedure

a. Co current flow

1. Adjust the valves for co current flow.
2. Make the hot and cold water to flow through double pipe heat exchanger by opening the valves.
3. Adjust the flow rates of both fluids by adjusting the valves.
4. Switch ON the heater and wait for steady state condition to be attained.
5. Measure the flow rate of hot and cold water with the help of rotameter.
6. Note down the readings of inlet and outlet temperatures of hot and cold water after steady state is attained.
7. Repeat the procedure for a different flow rate of cold water.

b. Counter current flow

8. Adjust the valves for counter current flow.
9. Make the hot and cold water to flow through double pipe heat exchanger by opening the valves.
10. Adjust the flow rates of both fluids for values done for co current flow by adjusting the valves.
11. Switch ON the heater and wait for steady state condition to be attained.
12. Measure the flow rate of hot and cold water with the help of rotameter.
13. Note down the readings of inlet and outlet temperatures of hot and cold water after steady state is attained.
14. Repeat the procedure for a different flow rate of cold water.

XII. Resources used

SI No.	Name of Resource	Suggested Broad Specification		Quantity	Remarks (If any)
		Make	Details		
1					
2					
3					

XIII Actual procedure followed

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XIV. Precautions followed

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XV. Observations and Calculations:

a. Co current flow

Sr. No.	Cold Water			Hot Water		
	Flow Rate (lit/Sec)	T_{ci} (K)	T_{co} (K)	Flow Rate (lit/Sec)	T_{hi} (K)	T_{ho} (K)
1						
2						

b. Counter current flow

Sr. No.	Cold Water			Hot Water		
	Flow Rate (lit/Sec)	T_{ci} (K)	T_{co} (K)	Flow Rate (lit/Sec)	T_{hi} (K)	T_{ho} (K)
1						
2						

Calculations

a. co current : Sample calculation for set no:

1. Properties of water at mean temperature

Cp_h = ... KJ/kgK

Cp_c = ... KJ/kgK

ρ_h = ………… kg/m^3

ρ_c = ……….. kg/m^3

2. $Q_h = m_h$ x Cp_h x $(T_{hi} - T_{ho})$

= ……………………..

= …………….W.

3. Qc = mc x Cp_c x $(T_{co} – T_{ci})$

= ……………………..

= …………….W.

4. Q = (Qh+Qc)/2

Q = ……………….

Overall Heat Transfer coefficient

5. Q = U x A x ΔT_{lm}

Where $\Delta T_{lm} = \Delta T_2 - \Delta T_1 / \ln(\Delta T_2/\Delta T_1)$

$\Delta T_1 = (\Delta T_{hi} - \Delta T_{ci})$ = ……….. ………………… =……….... K

$\Delta T_2 = (\Delta T_{ho} - \Delta T_{co})$ = ……….. ……………….. =………. .K

ΔT_{lm} = ………………………………………… . = ……….K

6. Inside heat transfer area $(A_i) = \pi$ x D_i x L

= ……………………………………

= ……………..m^2

7. Overall heat transfer coefficient based on inside area (U_i)

Q = Ui x A_i x ΔT_{lm}

$U_i = Q/(A_i \times \Delta T_{lm})$

= …………………………………………….

= …………….W/m^2K

b. Counter current : Sample calculation for set no:

1. Properties of water at mean temperature

Cp_h = ……………. KJ/kgK

Cp_c = …………….. KJ/kgK

ρ_h = ………… kg/m^3

ρ_c = ……….. kg/m^3

2. Q = rate of heat transfer
   $Q_h = m_h \times Cp_h \times (T_{hi} - T_{ho})$

   = ……………………..

   = …………….W.

3. $Qc = mc \times Cp_c \times (T_{co} - T_{ci})$

   = ……………………..

   = …………….W.

4. Q = (Qh+Qc)/2
   Q = ……………….

   Overall Heat Transfer coefficient

5. $Q = U \times A \times \Delta T_{lm}$

   Where $\Delta T_{lm} = (\Delta T_2 - \Delta T_1) / \ln(\Delta T_2/\Delta T_1)$

   $\Delta T_1 = (T_{hi} - T_{co})$ = ……….. ………………… =……….. K

   $\Delta T_2 = (T_{ho} - T_{ci})$ = ……….. ……………….. =………. .K

   ΔT_{lm} = ……………………………………… . = ……….K

6. Inside heat transfer area $(A_i) = \pi \times D_i \times L$
   = ……………………………………

   = ……………… m^2

7. Overall heat transfer coefficient based on inside area (U_i)

   $Q = U_i \times A_i \times \Delta T_{lm}$

   $U_i = Q/(A_i \times \Delta T_{lm})$

= ……………………………………………….

= ……………W/m^2K

Sr. No.	Co current flow			Counter current flow		
	Q	ΔT_{lm}	**Ui**	**Q**	ΔT_{lm}	**Ui**
1						
2						

XVI. Results

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XVII. Interpretation of results

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XVIII. Conclusions

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XIX. Practical related Questions

Note: Below given are few sample questions for reference. Teachers must design more such questions so as to ensure the achievement of identified CO.

a. Differentiate between co current and counter current flow heat exchangers on the basis of rate of heat transfer and area required.
b. Give the expression to calculate LMTD for co current flow.
c. Give the expression to calculate LMTD for counter current flow.
d. Which type of flow will give higher value of heat transfer coefficient?

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XX. References / Suggestions for further Reading

- https://nptel.ac.in/courses/112105248/12
- https://www.youtube.com/watch?v=Z8yHW0KIhYA
- https://www.youtube.com/watch?v=ICwBmCbV2pI

XXI. Assessment Scheme

Performance Indicators		Weightage
Process related (15 Marks)		**60%**
1	Preparation of experimental set up	20%
2	Setting and operation	20%
3	Safety measures, observation and recording	20%
Product related (10 Marks)		**40%**
4	Calculation and Interpretation of result	20%
5	Practical related question and submission of report	20%
Total (25 Marks)		**100 %**

Names of Student Team Members

1. …………………………
2. …………………………
3. …………………………
4. …………………………

Marks Obtained			**Dated signature of Teacher**
Process Related(15)	**Product Related(10)**	**Total (25)**	

Practical No. 15: Determine capacity of an open pan evaporator.

I. Practical Significance

In chemical industry, the manufacture of heavy chemicals such as caustic soda, table salt and sugar starts with dilute aqueous solutions from which large quantities of water must be removed before crystallization can take place in suitable equipment. The purpose of the majority of power plant evaporators is the separation of pure water from raw or treated water. The impurities are continuously withdrawn from the system as blow down. In the power plant evaporator the unevaporated portion of the feed is the residue, whereas in the chemical evaporator it is the product.

II. Relevant Program Outcomes (POs)

PO1. Basic knowledge: Apply knowledge of basic mathematics, sciences and basic engineering to solve the Chemical Engineering problems

PO2. Discipline knowledge: Apply Chemical Engineering knowledge to solve industry based Chemical Engineering problems.

PO3. Experiments and practice: Plan to perform experiments and practices to use the results to solve technical problems related to Chemical Engineering.

PO 8.Individual and team work: Function effectively as a leader and team member in diverse/ multidisciplinary teams.

PO 9.Communication: Communicate effectively in oral and written form.

III. Competency and Practical Skills

'Use heat transfer principles to increase efficiency and to save energy in chemical process plants.'

Operate open pan evaporator.

IV. Relevant Course Outcomes

Calculate the energy associated with an evaporator

V. Practical Outcome

Using an open pan evaporator determine capacity of evaporator

VI. Relevant Affective domain related Outcome(s)

1. Follow safe practices
2. Maintain tools and equipment.
3. Demonstrate working as a leader / a team member.

VII. Minimum Theoretical Background

In an evaporation operation, the concentration of a solute in a solution is increased by boiling off the solvent. This operation is generally performed prior to crystallization. The heat required for evaporation is generally provided by the condensation of steam. The steam is on one side of a metal surface and the evaporating solution on the other side of the metal surface. In an evaporation operation, heat is utilized to 1) increase the temperature of the solution to its boiling point (sensible heat) and 2) supply the latent heat of vaporization of the solvent.

Performance of a steam heated tubular evaporator is evaluated in terms of capacity and economy. Capacity of an evaporator is defined as the number of kilograms of water vaporized/ evaporated per hour. If the feed solution is at the boiling temperature corresponding to the pressure in the vapour space of an evaporator, then all the heat that is transferred through the heating surface is available for evaporation and the capacity is proportional to the heat transfer rate. If cold feed solution is fed the evaporator, heat is required to increase its temperature to the boiling point and thus the capacity for a given rate of heat transfer will be reduced accordingly as heat used to increase the temperature to the boiling point is not available for evaporation. When the feed solution to the evaporator is at a temperature higher than the boiling point corresponding to the pressure in the vapour space, a portion of the feed evaporates adiabatically and the capacity is greater than that corresponding to the heat transfer rate.

Economy of an evaporator is defined as the number of kilograms of water evaporated per kilogram of steam fed to the evaporator.

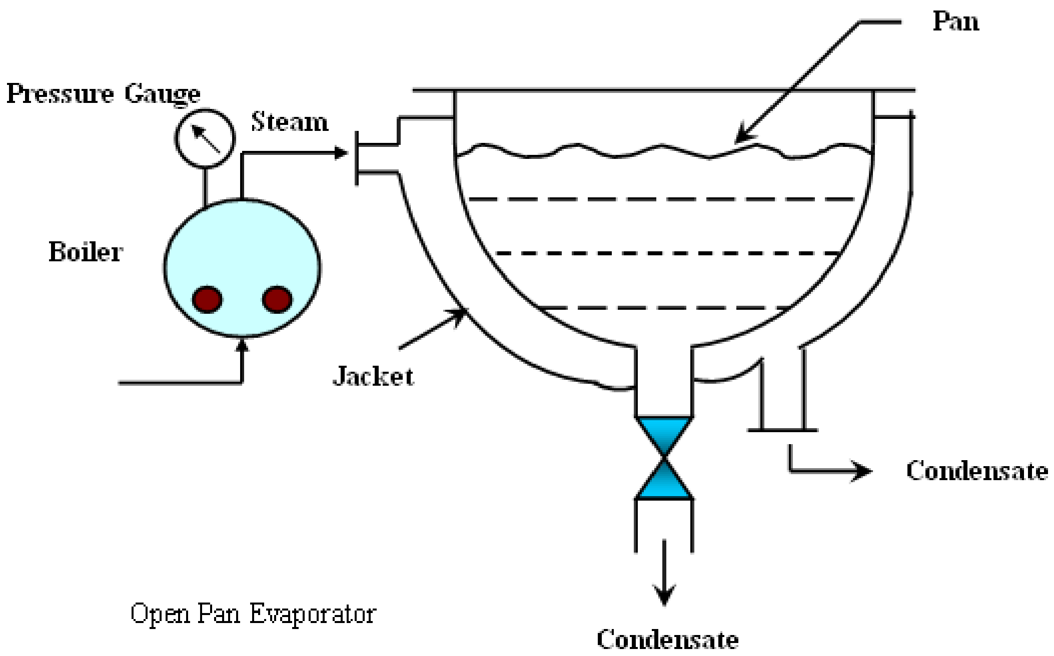

Fig 1 open pan evaporator

VIII. Experimental set up : -

Figure 2

IX. Resources required

SI No.	Name of Resource	Suggested Broad Specification	Quantity
1	Open pan	Diameter = 30 cm Height = 10 cm	1
2	Weighing machine	5 kg	1

X. Precautions

1. Pan should be cleaned before use.
2. Accurate weight should be taken.

XI. Procedure

1. Clean the pan and find its weight W_1 gm.
2. Prepare a 10-20 % NaCl solution.
3. Transfer the solution to the pan.
4. Take the weight of solution with pan W_2 gm.
5. Heat the solution using electric heater or flame for one hour.

6. Switch off the heater.
7. Allow the solution to cool.
8. Note down the weight of solution W_3.

XII. Resources used

Sr. No.	Name of Resource	Suggested Broad Specification		Quantity	Remarks (If any)
		Make	Details		
1					
2					

XIII. Actual procedure followed

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XIV. Precautions followed

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XV. Observations and Calculations:

1. Initial weight of pan W_1 = …………kg
2. Weight of pan and dilute solution W_2 = …………kg
3. Weight of pan and concentrated solution W_3 = ………kg
4. Weight of water evaporated = W_2-W_3 = …………kg
5. Capacity of evaporator =………………kg/h

XVI. Results

Capacity of evaporator =

XVII. Interpretation of results

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XVIII. Conclusions

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XIX. Practical related Questions

Note: Below given are few sample questions for reference. Teachers must design more such questions so as to ensure the achievement of identified CO.

a. Define evaporation
b. List the properties of solution which affect evaporation operation.
c. Define capacity and economy of evaporator.
d. How evaporation is different from drying?

[Space for Answers]

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XX References / Suggestions for further Reading

- https://www.youtube.com/watch?v=6FSdoqbk6QA
- https://www.youtube.com/watch?v=v3iBHPAPA4M
- https://www.youtube.com/watch?v=ZbeRFEC6DHc

XXI. Assessment Scheme

Performance Indicators		Weightage
Process related (15 Marks)		**60%**
1	Preparation of experimental set up	20%
2	Setting and operation	20%
3	Safety measures, observation and recording	20%
Product related (10 Marks)		**40%**
4	Calculation and Interpretation of result	20%
5	Practical related question and submission of report	20%
Total (25 Marks)		**100 %**

Names of Student Team Members

1…………………………

2…………………………

3…………………………

4…………………………

Marks Obtained			**Dated signature of Teacher**
Process Related(15)	**Product Related(10)**	**Total (25)**	

Practical No. 16: Calculate overall heat transfer coefficient for an evaporator.

I. Practical Significance

In chemical industry, the manufacture of heavy chemicals such as caustic soda, table salt and sugar starts with dilute aqueous solutions from which large quantities of water must be removed before crystallization can take place in suitable equipment. The purpose of the majority of power plant evaporators is the separation of pure water from raw or treated water. The impurities are continuously withdrawn from the system as blow down. In the power plant evaporator the unevaporated portion of the feed is the residue, whereas in the chemical evaporator it is the product.

II. Relevant Program Outcomes (POs)

PO1. Basic knowledge: Apply knowledge of basic mathematics, sciences and basic engineering to solve the Chemical Engineering problems

PO2. Discipline knowledge: Apply Chemical Engineering knowledge to solve industry based Chemical Engineering problems.

PO3. Experiments and practice: Plan to perform experiments and practices to use the results to solve technical problems related to Chemical Engineering.

PO4.Engineering tools: Apply relevant technologies and Chemical engineering tools with an understanding of the limitations

PO8. Individual and team work: Function effectively as a leader and team member in diverse/ multidisciplinary teams.

PO9. Communication: Communicate effectively in oral and written form.

III. Competency and Practical Skills

'Use heat transfer principles to increase efficiency and to save energy in chemical process plants.'

Operate an evaporator.
Use weighing balance for accurate weighing.

IV. Relevant Course Outcomes

Calculate energy associated with an evaporator.

V. Practical Outcome

Using an evaporator calculate overall heat transfer coefficient

VI. Relevant Affective domain related Outcome(s)-

1. Follow safe practices
2. Maintain tools and equipment.
3. Practice energy conservation

VII. Minimum Theoretical Background

In an evaporation operation, the concentration of a solute in a solution is increased by boiling off the solvent. This operation is generally performed prior to crystallization. The heat required for evaporation is generally provided by the condensation of steam. The steam is on one side of a metal surface and the evaporating solution on the other side of the metal surface. In an evaporation operation, heat is utilized to 1) increase the temperature of the solution to its boiling point (sensible heat) and 2) supply the latent heat of vaporization of the solvent.

Performance of a steam heated tubular evaporator is evaluated in terms of capacity and economy. Capacity of an evaporator is defined as the number of kilograms of water vaporized/ evaporated per hour. If the feed solution is at the boiling temperature corresponding to the pressure in the vapour space of an evaporator, then all the heat that is transferred through the heating surface is available for evaporation and the capacity is proportional to the heat transfer rate. If cold feed solution is fed the evaporator, heat is required to increase its temperature to the boiling point and thus the capacity for a given rate of heat transfer will be reduced accordingly as heat used to increase the temperature to the boiling point is not available for evaporation. When the feed solution to the evaporator is at a temperature higher than the boiling point corresponding to the pressure in the vapour space, a portion of the feed evaporates adiabatically and the capacity is greater than that corresponding to the heat transfer rate.

Economy of an evaporator is defined as the number of kilograms of water evaporated per kilogram of steam fed to the evaporator. In a single effect evaporator the amount of water evaporated per kg steam fed is always less than one and hence economy is less than one. The economy of an evaporator can be increased by 1. Use of multiple effect evaporation system and 2. vapour recompression.

VIII. Experimental set up :

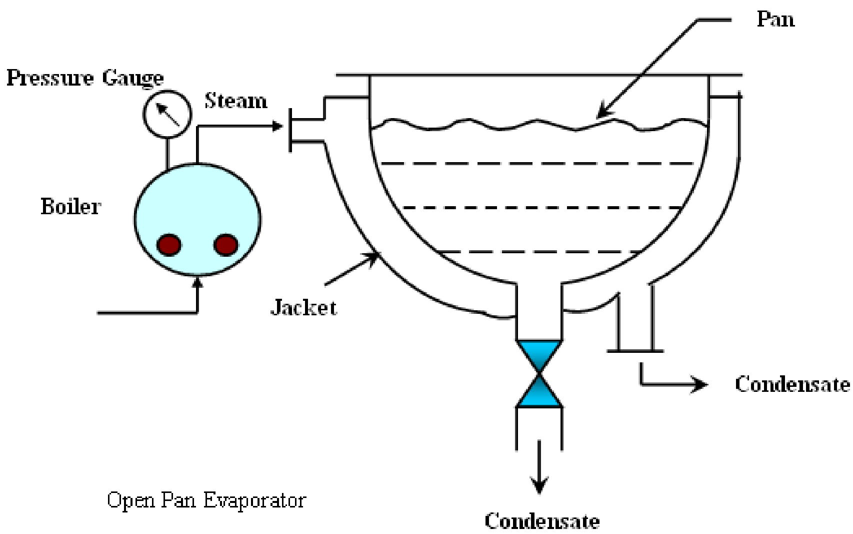

Fig. 1

IX. Resources required

SI No.	Name of Resource	Suggested Broad Specification	Quantity
1	Steam source	boiler	1
2	Open pan evaporator	2 lit Capacity	1
3	Temperature indicators	0-100^{0}C	2

X. Precautions

Steam pressure should not exceed the permissible limit.

XI. Procedure

1. The diameter of the vessel is measured.
2. The steam boiler is started and pressure is developed.
3. 0.5 liters of milk (or any other aqueous solution) is measured and poured into the pan.
4. Steam is allowed by opening the valve and steam pressure is adjusted to 0.5 to 1 kg/cm^2 and stop clock is started.
5. The evaporation is continued until 80% of the liquid is evaporated and milk/ solution gets concentrated.
6. The boiling temperature of milk/ solution is noted down.
7. Steam supply is stopped and the boiler is switched off.
8. The concentrated milk/ solution is collected and weighed.

XII. Resources used

SI No.	Name of Resource	Suggested Broad Specification		Quantity	Remarks (If any)
		Make	Details		
1					
2					
3					

XIII. Actual procedure followed

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XIV. Precautions followed

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XV. Observations and Calculations:

1 Diameter of pan = ………… cm

2. Height from center =…………..cm

3. Initial weight of milk/water (W_1) =…………Kg

4. Final weight of milk/water (W_2) =…………..Kg

5. Pressure gauge reading = …………..Kg/cm^2

6. Surface temperature (T_S) =……..……. ^0C

7. Initial temperature of milk (Tm_1) = ………….. ^0C

8. Final temperature of milk (Tm_2) =…………... ^0C

9. Time of evaporation (t) =…………... min

Sample calculation

1. Amount of water evaporated $V = W_1 - W_2$

2. Rate of evaporation $V_1 = V/t$ Kg/min

3. The rate of heat transfer = $V_1 * l$ J/min, where l = Latent heat of vaporization at atm pressure

4. Diameter of pan = d = cm

5. Heat transfer area =

6. Average milk boiling temperature = $(Tm_1+Tm_2)/2 = Tm$

7. $Q = UA\Delta T$

8. $U = Q/(A* Ts-Tm)$ $W/m^2\ ^oC$

XVI. Results

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XVII. Interpretation of results

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XVIII. Conclusions & Recommendation

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XIX. Practical related Questions

Note: Below given are few sample questions for reference. Teachers must design more such questions so as to ensure the achievement of identified CO.

a. Economy of a single pan evaporator is less than one. Give reason.

b. Explain the methods to increase economy of evaporator.

c. Give the different feeding arrangements for multiple effect evaporator.

[Space for Answers]

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XX. References / Suggestions for further Reading

- https://www.swep.net/refrigerant-handbook/6.-evaporators/asas1/
- https://nptel.ac.in/courses/103103032/39
- https://nptel.ac.in/courses/112105129/pdf/R&AC%20Lecture%2023.pdf

XXI. Assessment Scheme

Performance Indicators		Weightage
Process related (15 Marks)		**60%**
1	Preparation of experimental set up	20%
2	Setting and operation	20%
3	Safety measures, observation and recording	20%
Product related (10 Marks)		**40%**
4	Calculation and Interpretation of result	20%
5	Practical related question and submission of report	20%
Total (25 Marks)		**100 %**

Names of Student Team Members

1…………………………

2…………………………

3…………………………

4…………………………

Marks Obtained			**Dated signature of Teacher**
Process Related(15)	**Product Related(10)**	**Total (25)**	