Experimental Study and Performance Enhancement of Designed DPHE by using HDPE

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Abstract - *In Chemical Industry, Heat exchanger equipment's are frequently used to either heat or cooled process fluid. There are different variety of heat transfer equipment are available depending upon application and requirement. Double pipe heat exchanger (DPHE) is a primary, common and simple type out of all present. That's why for the study of heat transfer related phenomenon; we focus on the DPHE and their designing. In our designed double pipe heat exchanger, inside pipe is made of copper and for outer shell we used high density poly ethylene (HDPE). Copper has high thermal conductivity but at the same time increases the weight of the equipment, so in order to avoid bulkiness of equipment we use outer shell as plastic (HDPE); instead of using Carbon steel. plastic have low thermal conductivity which also act as an insulation and decreases heat loss and saves insulation cost. Further heat loss is prevented by applying two layers of insulation viz i. Sunpro Polycoated paper ii. Heatlawn sheet. To increase the heat transfer area, we use Fins of copper material. Baffles is also Provided. These are some short description of our designed double pipe heat exchanger and it can be extended to industrial scale.*

Key Words: Process fluid, DPHE, Thermal conductivity, HDPE, Sunpro Polycoated paper, Heatlawn sheet, Fins, Baffles.

1. INTRODUCTION

In a chemical process industry, we come across situations where heat is either given out or absorbed, fluids are either heated or cooled and whenever it is necessary to prevent the loss of heat from a hot vessel or a stream pipe. Therefore, in evaporators, driers, distillation units, furnaces and reactors, one of the major problems is that of heat transfer at the desired rate. The controlled of heat flow in the desired manner forms one of the most important sectors of chemical engineering.[1]

Heat transfer deals with the study of such rate of exchange of heat between hot and cold bodies. The hot and cold bodied are called source and receiver respectively. In all such cases, the temperature difference between a source and receiver acts as a driving force for heat transfer.[2] Various types of heat exchangers equipment are used in the industries depending upon the applications involved (That means based on the service required- for heating, cooling, condensation and vaporization), but their common task is to transfer heat from a hot fluid to a cold fluid.[1]

The exchange equipment involves heat transfer either by conduction-convection or by radiation mode. The commonly used types of heat transfer equipment used in industries are:

1. Double pipe Heat exchanger
2. Shell and tube Heat exchanger
3. Plate type Heat exchanger
4. Scraped surface Heat exchanger
5. Spiral coiled Heat exchanger

among the all, the double pipe heat exchanger is one of the simplest types and it is also economical for small scale.[3] The heat exchanger can be operated in different way such as co-current or counter current flow. Counter current flow type is more efficient for double pipe heat exchanger and cross flow does not work.[1]

2. DESIGN PRINCIPAL

Any substance made up of atoms and molecules has ability to transfer heat. When this atom or molecules receive heat, they start vibrating and deliver or transfer heat to its adjacent molecule.[4] In this way heat energy gets transferred through any material medium. This forms the basic principle for heat transfer. It is not true that for the propagation of heat energy, material medium is necessary, it can travel through vacuum also. This happens when heat travel in the form of electromagnetic wave. This results in three different modes of heat energy transfer which are as follows- Conduction in Solids, Convection of Fluids (Liquid or Gas) and Radiation in free Space (Vacuum).

A) Conduction

B) Convection

C) Radiation [1]

A. Conduction

It is our general experience that when a hot body comes in contact with colder one, after some time cold body also gets heated. This is called as conduction.[2] Now the Question arises why and how's cold body gets heated? The answer to this question is that every substance is made up of atoms or molecules and this all have their own capability to hold the heat within it. If this atom receives heat beyond its capacity, it starts vibrating and deliver or transmit heat to its adjacent molecule or atom and this process continues till the object end is reached.[4][5]

B. Convection

In heat transfer, the exchange of heat from a wall to a fluid or from a fluid to a wall is very Important.[3] It is considered as necessary mode for transfer of heat in case of liquid and gases.[6][7] This mode is further distinguished depending upon whether any external sources like pump, blower or agitator used or not: -

i. Free or natural convection

To explain this phenomenon, let us consider a heated surface surrounding an air molecule. The molecules which is nearer to the heated surface will first receives heat and because of this its density decreases and moves away from heated surface and replaces colder molecules position. And this process continuous till the entire surrounding molecules gets heated. This type of convection does not require any internal sources like pump, blower or agitator i.e. It occurs naturally due to difference in density, so it is called natural or free convection.

ii. Forced convection

when a fluid is forced to flow over the surface by an internal source such as fans, blower and pumps, creating an artificially induced convection current.[1]

C. Radiation

It is a special mode of heat transfer which is quite different than conductive and convective mode. The specialty of this mode is that it does not require any material medium to pass through, so it can transfer energy through vacuum also.[3] For the propagation of heat energy, this mode uses electromagnetic waves (such as visible light, U.V. and I.R. radiation) which carry energy in the form of photons and travels at the speed of light through space. All the matter with the temperature above 0 ^{0}k can emit radiation but is of small magnitude.[4] Radiative heat transfer usually takes place simultaneously with conductive and convective heat transfer mode. But this mode becomes more dominant as the material body approaches higher temperature. This is all about the theoretical part now come to an example part. The most common and day to day life example is transfer of heat from sun to earth. We know that for the survival of life on earth it must warm. The warm-up of earth surface is done by the heat energy which is coming from the sun. If suppose a radiation mode is absent, then what happens that heat energy can't penetrate the earth atmosphere; because in between the earth atmosphere and sun, free space and vacuum is present, where conduction and convection mode doesn't work. So, without the radiative mode life won't be possible on the earth.

The governing law used in heat transfer are: -

1. Fourier's law of heat conduction (Conduction Law)
2. Newtons Law of Cooling (Convection Law)
3. Stefan-Boltzmann Law (Radiation Law)

1. Fourier's law of heat conduction

Fourier's law of heat conduction states that "The rate of heat flow by conduction is directly proportional to the area normal to the direction of heat flow, and to the temperature gradient in the direction of heat flow".

$$Q = \frac{[K.A.(T_{hot} - T_{cold})]}{d}$$

Where, Q - Transfer of heat per unit time,

K -Thermal conductivity of the body,

A - Area of heat transfer,

T_{hot} - Temperature of the hot region,

T_{cold} - Temperature of the cold region,

d - Thickness of the body.

2. Newton's law of cooling

Newton's law of cooling states that "Heat flux from the solid surface to the fluid is directly proportional to the temperature difference between the surface and the fluid".

$$Q = h_c \cdot A \cdot (T_s - T_f)$$

Where, Q - Heat transferred per unit time,

h_c - Coefficient of convective heat transfer,

A - Area of heat transfer,

T_s - Surface temperature,

T_f - Fluid temperature.

3. Stefan-Boltzmann Law

It states that "The total emissive power of a black body is directly proportional to the fourth power of its absolute temperature". This law is related to the total amount of radiation emitted by a body to its temperature.

$$E_b = \sigma T^4$$

Where, Eb – Emissivity of Black Body,

σ - Stefan Boltzmann constant

= 5.67 * 10-8 W/(m^{2}K^4),

T - Absolute Temperature

This is the Fundamental relation for all the radiant heat transfer calculations.[1]

3. SPECIFICATION OF FABRICATED HEAT EXCHANGER

The experimentation of Double pipe heat exchanger having following specifications are mention below:

Table -1

Material of Outer shell	H.D.P.E.
Material of Inner tube	Copper
Length of Shell	28.5 cm
Diameter of Shell	8 cm
Length of Copper Tube	18 cm
Diameter of Copper Tube	5 cm
Diameter of Fin	6 cm
Diameter of Baffle	6.2 cm

4. DESIGN DISCRIPTION

The design description of Double pipe heat exchanger is given below.

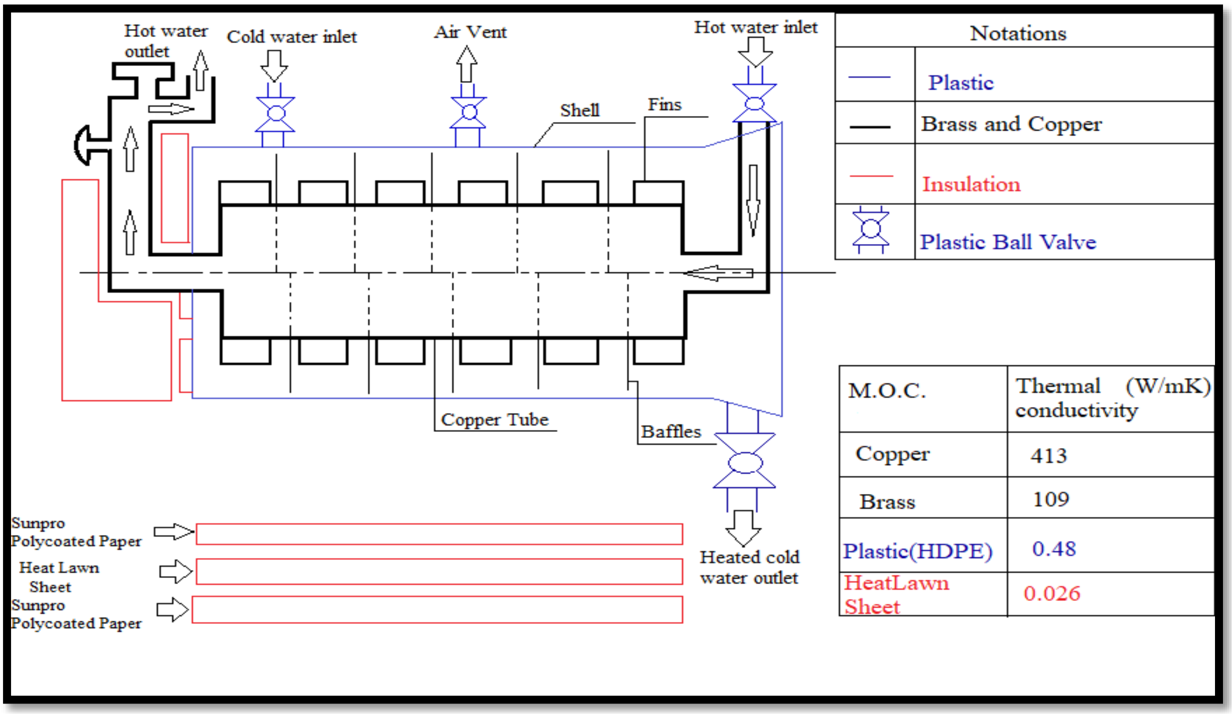


Fig. 1 Schematic representation of Double Pipe Heat Exchanger (Dimensions 28.5cm*8cm*20.6cm)

Components of fabricated heat exchanger -

A. Shell & Tube:

A double pipe heat exchanger refers to as pipe-in- pipe exchanger comprising an inner pipe and outer shell. One fluid flow through the inner pipe while the other flow through annuals region. The inner pipe is made up of copper having length 17cm and diameter 5cm. The MOC of outer shell is food graded plastic i.e. HDPE having the length of 28.5cm and diameter of about 8cm. The inlet of cold water is provided from top left of the shell and the outlet removed at bottom right of the shell. At top mid position of the shell we kept a vent valve.[2]

Fig. 2 Shell and Head

Fig. 3 Copper Tube

B. Insulation:

Insulation is nothing but barrier to heat flow.[1] In our model insulation comprises of two layers:

- In the first layer we use “Sun pro poly coated envelope paper”. The main function of this layer is to reflect and trapped heat inside the shell.
- In the second layer of insulation we used “Heat lawn sheet” having thermal conductivity of 0.026 W/m°k

Both the layers are economical and light in weight. The insulations are arranged according to the concept of critical radius of insulation i.e. in decreasing order of thermal conductivity.

Fig. 4 Sunpro polycoated paper

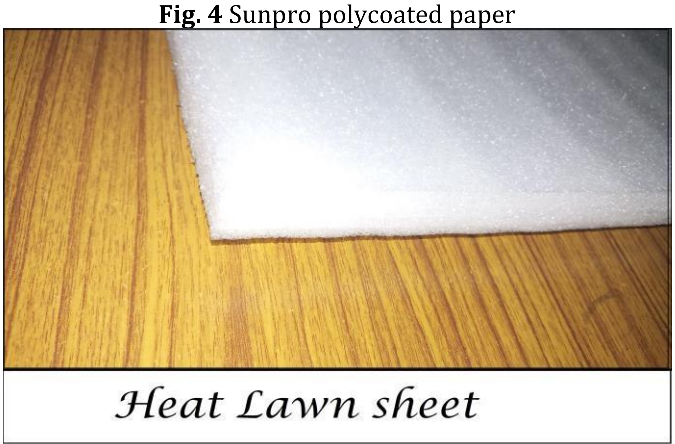


Fig. 5 Heat lawn sheet

C. Fins

The metal piece that are used to extend or to increase heat transfer are called as Fins. Fins are used to increase heat transfer surface area to enhance the heat transfer rate. They are also referred to as Extended surface.

Common types of fins are: -

i. Longitudinal fins
ii. Transverse fins
iii. Pin fin and Flat fin

Longitudinal fins are used when the direction of flow is parallel to the axis of the tube whereas transverse fins are used when the direction of flow is at right angle to the tube.

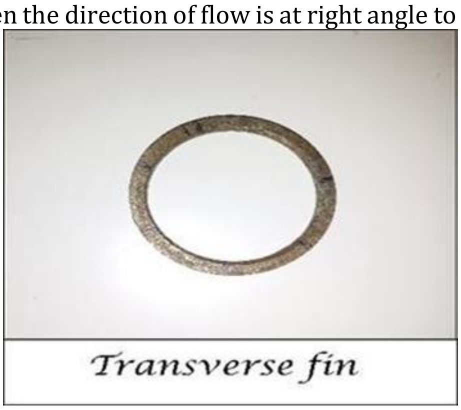


Fig. 6 Transverse Fins

D. Baffle

Baffle are used to support tube in proper position as vibration of tube caused by flow can disturb their position and second is to increase rate of heat transfer by increasing turbulence and residence time of shell side fluid. It avoids bypassing of shell side fluid.

Various transverse baffles are use:

i. Segmental Baffle
ii. Disc Baffle
iii. Orifice Baffle
iv. Ring Baffle

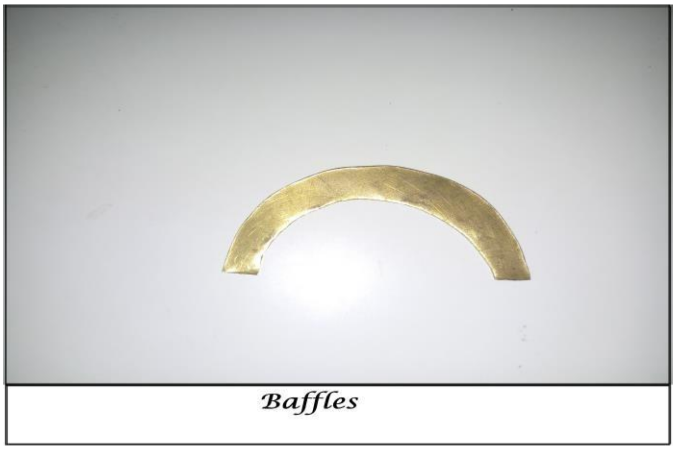


Fig. 7 Baffles

Diameter of baffle 6.2cm and thickness is 0.5cm. We had used Segmental baffle in our designed model for simplicity. This baffle causes the fluid to flow at right angle to the axis of the tube.[8]

E. Nozzle

Nozzle is a device used to control the flowrate of fluid. In a nozzle, the velocity of fluid increase at the expense of its pressure energy.

Two types of Nozzle we used:

i. Nozzle-T-valve
ii. Flush valve

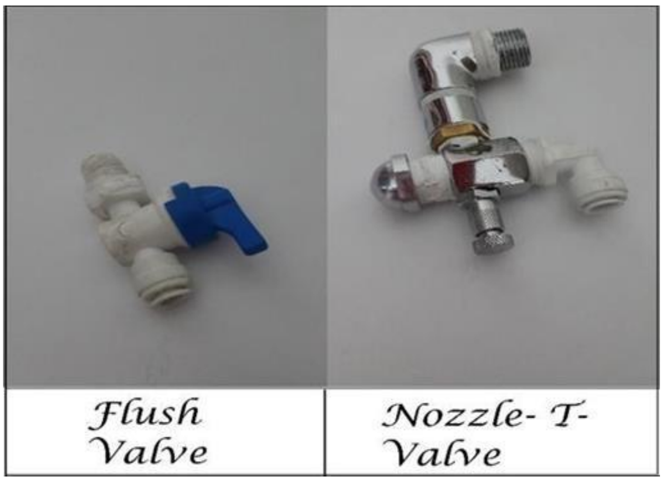


Fig. 8 Flush Valve and Nozzle-T-Valve

Nozzle-T-Valve: M.O.C. - Brass
It can withstand at high temperature and as it is an alloy it can't get corroded easily.
Flash Valve: M.O.C. - Plastic (HDPE)
With the help of flush valve, we can adjust the pressure drop for shell side fluid. It is also used in venting.

5. EXPERIMENTAL PROCEDURE

a. Semi-Batch Process:

1. Taking 300ml of hot water at 65⁰C in a standard 500ml beaker.
2. Fill the Tube side with Hot water and through shell side adjust the flow rate of cold water as 25ml/5sec.
3. Continued this process and note down both outlet stream temperature after 3 min interval.
4. Similarly, by varying the Hot water inlet temperature and flow rate. repeated the above procedure and note down the corresponding reading.

b. Batch Process:

1. Taking 300ml of hot water at 70⁰C in a standard 500ml beaker
2. As the process is batch both shell side fluid (cold water) and tube side fluid (Hot water) is stationary.
3. After every 2 min interval, sample of hot water outlet and cold water outlet was taken and this collection of data was continued for 10 min.
4. Similarly, repeat the above procedure for hot water temperature at 75⁰C and note down the corresponding reading.

6. OBSERVATION TABLE

Table-2

Semi-Batch Process

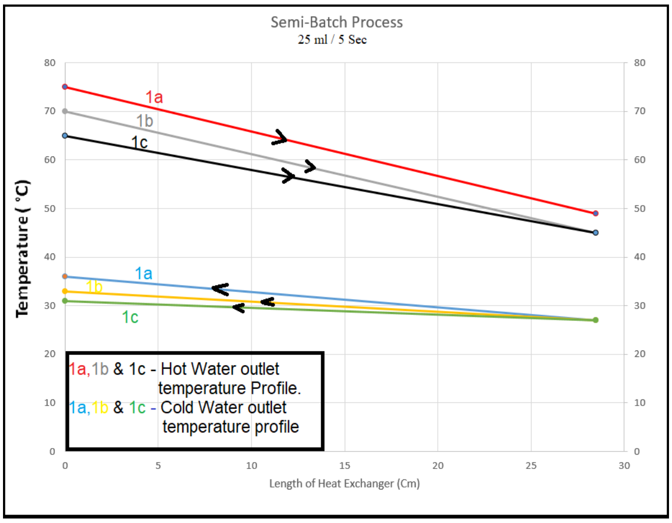
Parameter	Temperature(⁰C)					
Flow Rate	25ml/5Sec			25ml/10Sec		
Hot Water inlet Temperature (⁰C)	65	70	75	65	70	75
Hot water outlet Temperature (⁰C)	45	45	49	40	42	44
Cold water Inlet Temperature (⁰C)	27	27	27	27	27	27
Cold water outlet Temperature (⁰C)	31	33	36	33	34	35
LMTD	23.5	26.4	29.7	21.1	24.0	27.3
Q (W)	496	558	627	223	253	288
U (W/m² ⁰K)	451.0	451.6	451.1	225.8	225.2	225.4

Table-3

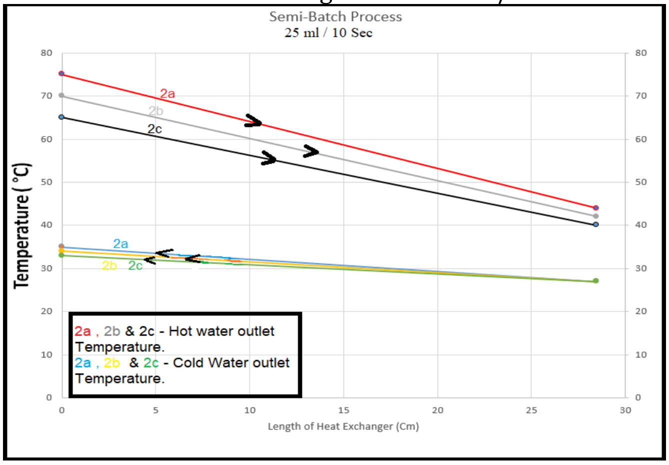
Batch Process

Parameter	Temperature (⁰C)									
Time Interval (Min)	2		4		6		8		10	
Hot Water inlet Temperature (⁰C)	70	75	70	75	70	75	70	75	70	75
Hot water outlet Temperature (⁰C)	36	39	35	39	34	38	35	39	36	39
Cold water Inlet Temperature (⁰C)	27	27	27	27	27	27	27	27	27	27
Cold water outlet Temperature (⁰C)	32	34	34	37	34	38	34	39	35	39
LMTD	20.1	23.6	20.2	22.6	17.7	21.5	18.6	21.9	19.1	22.2

7. Graph

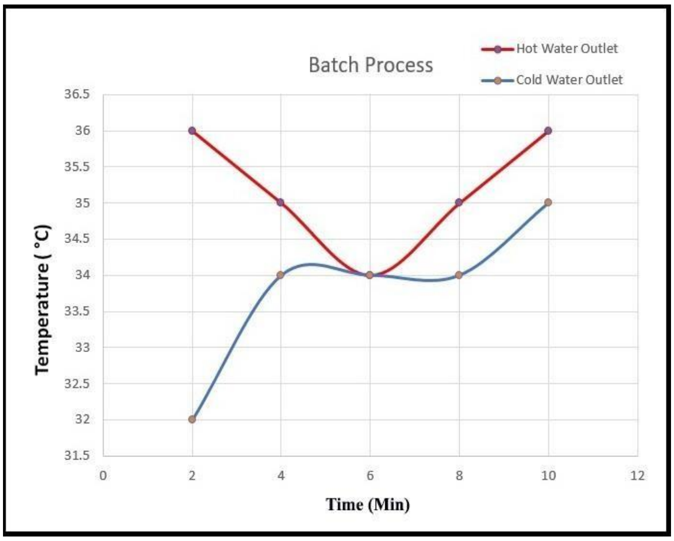


Graph no.1 Temperature-Length curve for counter current flow arrangement at 25ml/ 5sec

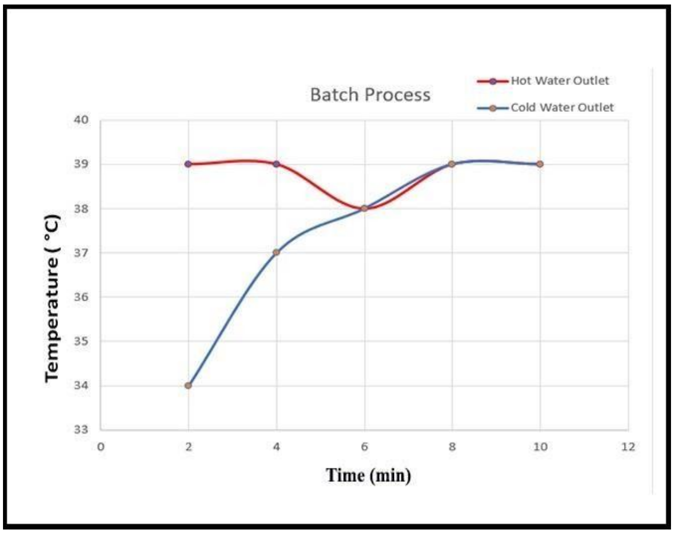


Graph no. 2 Temperature-Length curve for counter current flow arrangement at 25 ml / 10 Sec

- Graph no.1 and Graph no. 2, both are plotted for semi batch process, one at a flowrate of 25 ml/ 5sec while other at 25ml/10sec respectively.
    - Both Graphs are drawn for counter current flow, which shows that as we move from inlet to outlet point of hot water, the temperature difference (Driving force here) between hot water and cold-water side remains more or less nearly constant over the entire length of heat exchanger.
    - That means from graph no. 1 and graph no. 2, we see that in counter-current flow arrangement, the temperature difference will show less variation throughout the length of heat exchanger and also heat is transferred at almost constant rate irrespective of the length of heat exchanger, which is also a maximum value for a given surface area when compared with co-current flow.



Graph no. 3 Temperature-Time curve for Hot water inlet Temperature at 70^{0}C



Graph no. 4 Temperature-Time curve for Hot water inlet temperature at 75 ^{0}C

- Graph no. 3 and Graph no. 4 are drawn for batch operation, when we see variation of both outlet temperature of hot and cold water with respect to time (at the interval of 2min). This Batch operation curve shows that initially we have maximum temperature difference between hot and cold-water side and accordingly heat transfer rate is also maximum.
- Then as the time passes, both hot and cold-water temperature approaches to each other and a point comes where these two temperatures overlap and at that point, so we get zero heat transfer rate because driving force (temperature difference here) become zero.
- After this zero-heat transfer rate point, the temperature difference may again cause up to sometime interval or remains zero as seen in graph no. 3 and graph no. 4 respectively.

8. SAMPLE CALCULATION

Heat Transfer area

Total Heat transfer area = Surface area of Tube + Extended area of fins (Number of fins 6) + Extended area of Baffles (Number of Baffles 10)

Surface Area of Tube = $2 \pi R L$
$=2*3.142*0.026*0.18$
$=0.0294 \ m^2$

Extended area of fin = 6*2*[Area – Inner Area]
$=6*2* [\pi r_1^2 - \pi R^2]$
$= 12*[(3.142*0.03^2) - (3.142*0.026^2)]$
$= 0.00845 \ m^2$

Extended area of Baffles =5*2*[Area – Inner Area]
$= 5*2*[\pi r_2^2 - \pi R^2]$
$=5*2*[(3.142*0.031^2) - (3.142*0.026^2)$
$= 0.00895 \ m^2$

Total Heat transfer area (A) = 0.0294+0.00845+0.00895
$A = 0.0468 \ m^2$

A. Semi-batch process: - (flow rate: - 25ml/5sec.)

a. LMTD:

$$LMTD = \frac{\Delta T_2 - \Delta T_1}{Ln\,(\Delta T_2 / \Delta T_1)}$$

$\Delta T_1 = T_1 - t_2$

Where,
$\Delta T_1 = T_1 - t_2$
$\Delta T_2 = T_2 - t_1$
T_1 = Inlet of Hot Water
T_2 = Outlet of Hot Water
t_1 = Inlet of Cold Water
t_2 = Outlet of Cold Water

$\Delta T_1 = 65-31 = 34\,^0C$
$\Delta T_2 = 45-27 = 18\,^0C$
LMTD= 23.5

b. Mass flow rate:

Mass flow rate($\dot{m}$) = ρAV
Volumetric flow rate (υ) = AV
$\dot{m} = \rho\upsilon$

$$= \frac{1000 * 25 * 10^{-6}}{5} \qquad (1m^3 = 1000\,kg)$$

$\dot{m}$ = 0.005 kg/ Sec

c. Rate of heat transfer:

$Q = \dot{m}\, C_P\, \Delta T_{LMTD}$
$C_P = 4224\ J/Kg\,^0K$
$\Delta TLMTD = 23.5\,^0K$
$Q = 0.005*4224*23.5$
Q = 496

d. Overall heat transfer coefficient:

$Q = UA\Delta T_{LMTD}$

$$U = \frac{496}{0.0468 * 23.5}$$

$U = 451 W/m^2\,^0K$

Symbol

R= Outer radius of inner tube.
r_1= Outer radius of Fin
r_2= Outer radius of Baffle
Q= Heat flow rate
ṁ= Mass flow rate
U= Heat transfer coefficient
υ= Volumetric flow rate
C_P=Specific Heat Capacity of water

B. Batch process: -

$$LMTD = \frac{\Delta T_2 - \Delta T_1}{Ln\,(\Delta T_2 / \Delta T_1)}$$

$\Delta T_1 = 70 - 32 = 38\ ^0C$
$\Delta T_2 = 36-27 = 9\ ^0C$

LMTD = 20.1

9. ADVANTAGES

1. It is simple in construction, cheap and easy to clean.
2. It is used for High Viscous, pressure and temperature fluid.
3. It is better for sensible heating and cooling of fluids.
4. It can be used as several fouling conditions since it can be easily cleaned.
5. Other utilities can easily be added without disturbing original model.

10. DISADVANTAGE

1. Small heat transfer surface in a large floor space as compared to other types of heat exchanger.
2. Dismantling requires large time.
3. Maximum leakage points.

11. RESULT AND DISCUSSION

❖ In case of semi batch process,

- For flow rate of 25 ml/5sec; we get, average LMTD = 26.5, average rate of heat transfer Q = 560.3 W and average overall heat transfer coefficient
U = 451.2 W/$m^2\ ^0K$.
-For Flow rate of 25 ml/10sec; we get, average LMTD=24.1, average rate of heat transfer Q = 254.6 W, average overall heat transfer coefficient
U=225.7 W/$m^2\ ^0K$.

❖ In case of batch process,

- For inlet hot water temperature = 70 ^0C we got average LMTD = 19.14
- For inlet hot water temperature = 75 ^0C we got average LMTD = 22.4

12. CONCLUSIONS

1. The research indicates that heat exchanger are the heat transfer devices which are used in different applications.
2. Heat transfer related study is successfully done with the help of DPHE Such as heat transfer rate, Heat transfer coefficient and LMTD.
3. As the inlet temperature of hot water increases, LMTD value also increases and automatically heat transfer rate.
4. In case of semi batch Process by increase the flow rate, we get higher value of heat transfer coefficient.
5. For Batch process, the variation of LMTD with residence time is not linear.
6. For counter current flow, the temperature difference between hot and cold-water side does not show much variation, so thermal stresses will not vary, thus the life of heat exchanger will get increased while comparing with co-current flow arranged, temperature difference varies rapidly, so thermal stresses also increases, thus the life of heat exchanger will get decreased.
7. As the temperature difference between both the fluid increases the rate of heat transfer increases. Hence, from the above data we can also conclude that the rate of heat transfer is directly proportional to the temperature gradient.

12. APPLICATIONS

a. Pharmaceutical industry: -

In the pharmaceutical industry, thermal energy management is very important. The substances used to create cosmetic and pharmaceutical solutions often must be combined, mixed, and processed at specific temperatures, for a particular period. and for that Heat exchangers are used to manage thermal energy Because heat exchangers can provide reliable thermal management for longer and without failing, they are often ideal for helping companies improve production, as well as maintain a high level of quality for their products.

b. Slurry Reactor: -

The slurry reactor is a multistage flow type reactor it can be operated in either semi-batch or continuous type. The gas is bubbled inside the reactor from the bottom with the help of sparer inside the liquid having small size suspended solid catalyst pellets inside the reaction tank. The gas is absorbed inside the liquid from the surface of the bubble. The absorbed gas then diffuses through the liquid to the catalyst surface and the reaction between them takes place. When there is rection between gas, liquid, and catalyst, heat is generated inside the slurry reactor so to remove thermal energy from the slurry reactor, cooling coils or DPHE are used. This thermal energy is removed with the help of Heat exchanger which reduces the cost of heat production.

Using DPHE gives us two advantages: -

1. If we use any Heat Exchanger inside the slurry reactor a thin layer of wax is formed on the surface of the tube which can hinder the process of heat transfer between the coolant and the solution in the slurry reactor. So, to remove accumulated wax from the surface it is difficult in case of shell and tube heat exchanger because for maintenance of S & T it takes time than that of DPHE.

2. The use of DPHE is more effective than the other types of heat exchanger because there is no chocking problem and easy to assemble and maintain.

In upcoming days, this type of operation will be used widely in industry because it is beneficial for both aquatic and human life.

c. Air conditioner: -
With the use of R1234yf/GWP:4 (a low global warming potential (GWP) refrigerant) over R134a/GWP:1340 (a high GWP refrigerant) has been proved to have a reduced cooling capacity in air conditioning and refrigeration. One useful method to overcome this decrease in cooling capacity problem is to use a tube in tube heat exchanger (DPHE) where hot liquid high pressure refrigerant from the condenser flows through the inside tube and its surrounded by warm, low pressure refrigerant vapor (may contains tiny droplets of liquid) flowing through the evaporator through the outer shell in counter current manner and heat exchange between them takes place. After the heat transfer, the liquid leavening from the inside tube is subcooled which increases the evaporator performance while the shell side is completely vapor (dryness factor=1) which enhances the performance of compressor. Hence, the cooling capacity of air conditioning and refrigeration increases.

13. FUTURE SCOPE

a. The double pipe heat exchanger type has low heat transfer rate compared with other types of heat exchangers. Therefore, our aim is to enhance the heat transfer rate. This can be done by rotating inner pipe which induces turbulence and causes the more heat exchange between two fluids. The heat transfer rate and efficiency of equipment gets increased.
b. Efficiency can also be increased by sending some portion of outlet of cold fluid into inlet of cold fluid as a reflux like we do in distillation. This will increase overall efficiency of heat exchanger.
c. In industry, a carbon steel material shell is used to fabricate the Heat exchanger shell. But in our model we are using HDPE, it is used because it is economical and can be used on lab-scale for the experimental purpose to study various heat transfer phenomenon's on our model and it can withstand about 120 ^{0}C but above that temperature, if we want to use, then we have to put inner lining of Carbon steel which a very less thickness that not only reduces the MOC cost but also helps to improve tensile strength to Carbon steel. And also acts as a primary barrier for heat loss. If we use this concept then we can use High-temperature fluids for the heat transfer process. Similarly, if we use Teflon as an inner lining so we can use it up to the temperature of 200-300 ^{0}C

ACKNOWLEDGMENT

This research paper was supported by Datta meghe college of engineering, Airoli. We are thankful to our Head of Department Dr. (Mrs.) K. S. Deshmukh for provided expertise that greatly assisted the research. We express our appreciation to Mr. Tapre sir, Mrs. Dhokpande mam and Mrs. Raut mam for sharing pearls of wisdom with us during the course of this research.

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