ISSN (Online) 2456-1290
International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
Vol 2, Issue 5, May 2017

Analysis of various human synovial joint replacements: A review

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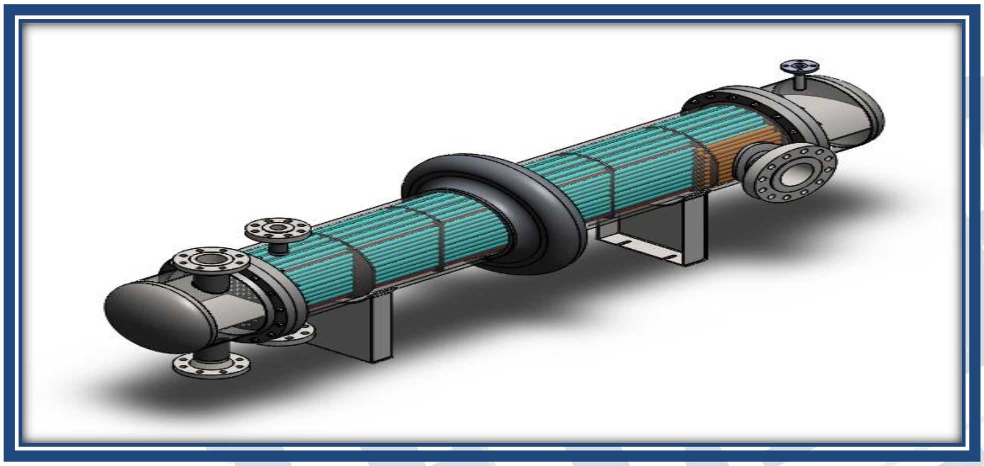

CHAPTER 1
INTRODUCTION

I. What is a heat exchanger?

Transfer of heat from one fluid to another is an important operation for most of the chemical industries. The most common application of heat transfer is in designing of heat transfer equipment for exchanging heat from one fluid to another fluid. Such devices for efficient transfer of heat are generally called Heat Exchanger.

A heat exchanger is a piece of equipment built for efficient heat transfer from one medium to another. The media may be separated by a solid wall to prevent mixing or they may be in direct contact.

Heat exchangers are widely used in space heating, refrigeration, air conditioning, power plants, chemical plants, petrochemical plants, petroleum refineries, natural gas processing, and sewage treatment.

The equipment goes under many names, such as boilers, pasteurizers, jacketed pans, freezers, air heaters, cookers, ovens and so on. The range is too great to list completely. The classic example of a heat exchanger is found in an internal combustion engine in which a circulating fluid known as engine coolant flows through radiator coils and air flows past the coils, which cools the coolant and heats the incoming air. Heat exchangers are found widely scattered throughout the food process industry.

Examples of Heat exchangers:

i. Intercoolers and preheaters
ii. Condensers and boilers in steam plant
iii. Regenerators
iv. Automobile radiators
v. Oil coolers of heat engine

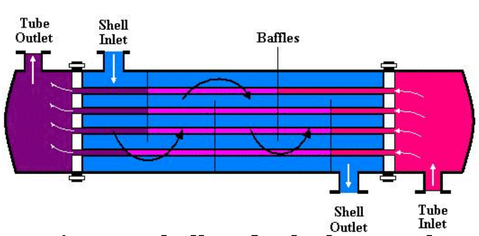

Fig 1.1: Shell and tube heat exchanger

- **NATURE OF HEAT EXCHANGE PROCESS**

ISSN (Online) 2456-1290
International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
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A. Direct contact heat exchangers

Direct contact heat exchangers involve heat transfer between hot and cold streams of two phases in the absence of a separating wall. Most direct contact heat exchangers fall under the Gas – Liquid category, where heat is transferred between a gas and liquid in the form of drops, films or sprays.

B. Indirect contact heat exchangers

Regenerators*:* A regenerative heat exchanger, or more commonly a regenerator, is a type of heat exchanger where heat from the hot fluid is intermittently stored in a thermal storage medium before it is transferred to the cold fluid. To accomplish this hot fluid is brought into contact with the heat storage medium, and then the fluid is displaced with the cold fluid, which absorbs the heat.

Recuperators*:* A recuperator is a special purpose counter-flow energy recovery heat exchanger positioned within the supply and exhaust air streams of an air handling system, or in the exhaust gases of an industrial process, in order to recover the waste heat.

I. DESIGN AND CONSTRUCTIONAL FEATURES

A. Shell and tube heat exchangers

Shell and tube heat exchangers consist of series of tubes. One set of these tubes contains the fluid that must be either heated or cooled. The second fluid runs over the tubes that are being heated or cooled so that it can either provide the heat or absorb the heat required. A set of tubes is called the tube bundle and can be made up of several types of tubes: plain, longitudinally finned, etc.

B. Concentric tube heat exchanger

Concentric Tube (or Pipe) Heat Exchangers are used in a variety of industries for purposes such as material processing, food preparation and air-conditioning. They create a temperature driving force by passing fluid streams of different temperatures parallel to each other, separated by a physical boundary in the form of a pipe. This induces forced convection, transferring heat to from the product.

II. PHYSICAL STATE OF FLUIDS

A. Condensers

A condenser is a device or unit used to condense a substance from its gaseous to its liquid state, typically by cooling it. In so doing, the latent heat is given up by the substance, and will transfer to the condenser coolant.

B. Evaporators

In evaporators the boiling fluid remains at constant temperature while the temperature of hot fluid gradually decreases from inlet to outlet.

III. TYPES OF FLOW

A. Parallel flow:

In parallel flow heat exchangers, the streams flow parallel to each other and in the same direction as shown in figure below, this is less efficient than countercurrent flow but does provide more uniform wall temperatures.

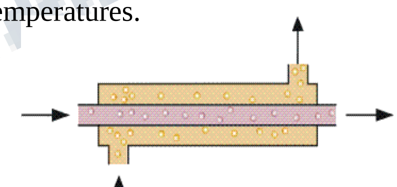

Fig.1.2: Parallel flow

B. Counter flow:

Figure below illustrates an idealized counter flow heat exchanger in which the two fluids flow parallel to each other but in opposite directions. This type of flow arrangement allows the largest change in temperature of both fluids and is therefore most efficient (where efficiency is the amount of actual heat transferred compared with the theoretical maximum amount of heat that can be transferred).

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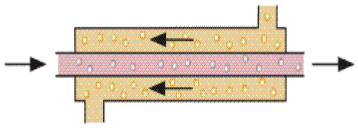

Fig.1.3: Counter flow

C. Cross flow:

Cross flow heat exchangers are intermediate in efficiency between countercurrent flow and parallel flow exchangers. In these units, the streams flow at right angles to each other as shown in Figure below

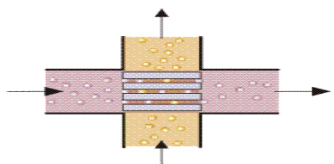

Fig.1.4: Cross flow

III. THERMAL DESIGN CONSIDERATIONS

The flow rates of both hot and cold streams, their terminal temperatures and fluid properties are the primary inputs of thermal design of heat exchangers. Thermal design of a shell and tube heat exchanger typically includes the determination of heat transfer area, number of tubes, tube length and diameter, tube layout, number of shell and tube passes, type of heat exchanger, tube pitch, number of baffles, its type and size, shell and tube side pressure drop etc.

1. Shell

Shell is the container for the shell fluid and the tube bundle is placed inside the shell. Shell diameter should be selected in such a way to give a close fit of the tube bundle. The clearance between the tube bundle and inner shell wall depends on the type of exchanger. Shells are usually fabricated from standard steel pipe with satisfactory corrosion allowance. The shell thickness of 3/8 inch for the shell ID of 12-24 inch can be satisfactorily used up to 300 psi of operating pressure.

2. Tube

The most efficient condition for heat transfer is to have the maximum number of tubes in the shell to increase turbulence. The tube thickness should be enough to withstand the internal pressure along with the adequate corrosion allowance. The tube length of 6, 8, 12, 16, 20 and 24 ft are preferably used. Longer tube reduces shell diameter at the expense of higher shell pressure drop. Finned tubes are also used when fluid with low heat transfer coefficient flows in the shell side. Stainless steel, admiralty brass, copper, bronze and alloys of copper-nickel are the commonly used tube materials:

3. Tube pitch, tube-layout and tube-count

Tube pitch is the shortest centre to centre distance between the adjacent tubes. The tubes are generally placed in square or triangular patterns as shown in the Figure 5. The widely used tube layouts are illustrated in Fig.5.The number of tubes that can be accommodated in a given shell ID is called tube count. The tube count depends on the factors like shell ID, OD of tube, tube pitch, tube layout, number of tube passes, and type of heat exchanger and design pressure.

Tube OD, in	Pitch type	Tube pitch, in
3/4	Square	1
1		1¼
3/4	Triangular	15/16
3/4		1

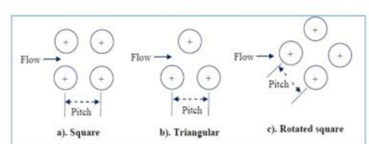

Fig. 1.5: Tube pitch and Tube Layout

4. Baffles

Baffles are used to increase the fluid velocity by diverting the flow across the tube bundle to obtain higher transfer co-efficient. The distance between adjacent baffles is called baffle-spacing. The baffle spacing of 0.2 to 1 times of the inside shell diameter is commonly used. Baffles are held in positioned by means of baffle spacers. Closer baffle spacing gives greater transfer co-efficient by inducing higher turbulence. The pressure drop is more with closer

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International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
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baffle spacing. The various types of baffles are shown in Fig. 6

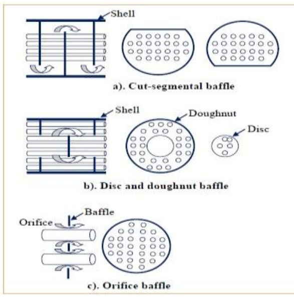

Fig. 1.6: Types of baffles

5. Fouling Considerations:

The most of the process fluids in the exchanger foul the heat transfer surface. The material deposited reduces the effective heat transfer rate due to relatively low thermal conductivity. Therefore, net heat transfer with clean surface should be higher to compensate the reduction in performance during operation. Fouling of exchanger increases the cost of

(i) Construction due to over sizing
(ii) Additional energy due to poor exchanger performance
(iii) Cleaning to remove deposited materials.

A spare exchanger may be considered in design for uninterrupted services to allow cleaning of exchanger. The effect of fouling is considered in heat exchanger design by including the tube side and shell side fouling resistances. Typical values for the fouling coefficients and resistances are summarized in Fig 7.

Fluid	Coefficient ($W.m^{-2}.^{\circ}C^{-1}$)	Resistance ($m^2.^{\circ}C.W^{-1}$)
River water	3000-12,000	0.0003-0.0001
Sea water	1000-3000	0.001-0.0003
Cooling water (towers)	3000-6000	0.0003-0.00017
Towns water (soft)	3000-5000	0.0003-0.0002
Towns water (hard)	1000-2000	0.001-0.0005
Steam condensate	1500-5000	0.00067-0.0002
Steam (oil free)	4000- 10,000	0.0025-0.0001
Steam (oil traces)	2000-5000	0.0005-0.0002
Refrigerated brine	3000-5000	0.0003-0.0002
Air and industrial gases	5000-10,000	0.0002-0.000-1
Flue gases	2000-5000	0.0005-0.0002
Organic vapors	5000	0.0002
Organic liquids	5000	0.0002
Light hydrocarbons	5000	0.0002
Heavy hydrocarbons	2000	0.0005
Boiling organics	2500	0.0004
Condensing organics	5000	0.0002
Heat transfer fluids	5000	0.0002
Aqueous salt solutions	3000-5000	0.0003-0.0002

Fig.1.7: Fouling coefficients and resistance for different fluids

6. Pressure drop and pumping power

An important consideration in heat exchanger design, besides the heat transfer requirements, is the pressure drop pumping cost. The heat exchanger size can be reduced by forcing the fluid it at higher velocities thereby increasing the overall heat transfer coefficient. But due to higher velocities there will be larger pressure drops resulting in larger pumping costs. The smaller diameter pipe for a given flow rate, may involve less initial capital cost but definitely higher pumping costs for the life of exchanger.

We know that,

$\Delta p \propto \dot{m}^2$

Where,

Δp = Pressure drop of an incompressible fluid flowing through the pipes

$\dot{m}$ = Mass flow rate

In order to pump fluids in steady state, the power requirement is given by,

$$Power = \int v.dp = \dot{m}/\rho.\ (\Delta p) \cong \dot{m}^3$$

This indicates that the power requirement is proportional to the cube of the mass flow rate of the fluid and it may be further increased by dividing it by the pump (fan or compressor) efficiency. Thus we find that the pumping cost increases greatly with higher velocities, hence, a compromise will have to be made between the larger overall heat transfer coefficient and corresponding velocities.

CHAPTER 2
OBJECTIVES

I. PROJECT OBJECTIVES

The objectives of this project are:

- To design a shell and tube heat exchanger.
- To increase heat transfer rate by making inner surface of tube rough and increasing outer surface area of tube by grooving.

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International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
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- To use inserts to increase turbulence inside the tubes.
- To conclude effect of roughness grooved surface and inserts on efficiency of heat exchanger.

II. PROJECT SCOPE

Since heat exchangers are widely used in every field it is necessary to find out different methods to improve their efficiency and that too in minimum cost. Efficiency of heat exchanger depends on various factors, heat transfer rate being one of them. This project is mainly concentrating on how to improve heat transfer rate of heat exchanger by using rough and grooved surfaces. Another factor for improving efficiency is turbulence of fluid experienced in tubes. Increasing turbulence to make heat transfer faster by convection is objective of this project. These simple techniques can improve efficiency of heat exchanger drastically with minimum cost.

CHAPTER 3
METHODOLOGY

In this project we are using three techniques to improve efficiency of shell and tube heat exchanger. Those techniques are as follows:

I. Using fins on outer surface of tubes:

Fins increases available surface area of tubes. Heat transfer is directly proportional to the surface area. Thus increasing surface area , we will increase heat transfer and which will finally lead to increase in efficiency.

II. Using inserts in the tubes:

Inserts are the additional materials which are used to create more turbulence in the tube. Inserts also push hot fluid towards the tube wall from core and hence hot fluid can transfer more heat to wall of the tubes

CHAPTER 4
LITERATURE REVIEW

Some of the papers published related to shell and tube heat exchanger and optimization done with using rough surfaces.

- R. Hosseini, A. Hosseini-Ghaffar, M. Soltani:

Experimentally obtained the heat transfer coefficient and pressure drop on the shell side of a shell-and-tube heat exchanger for three different types of copper tubes (smooth, corrugated and with micro-fins). Also, experimental data has been compared with theoretical data available. Experimental work shows higher Nusselt number and pressure drops with respect to theoretical correlation based on Bell's method. The optimum condition for flow rate (for the lowest increase of pressure drop) in replacing the existing smooth tube with similar micro-finned tube bundle was obtained for the oil cooler of the transformer under investigation.

- Andre L.H. Costa, Eduardo M. Queiroz:

Studied that techniques were employed according to distinct problem formulations in relation to: (i) heat transfer area or total annualized costs, (ii) constraints: heat transfer and fluid flow equations, pressure drop and velocity bound; and (iii) decision variable: selection of different surfaces and its characterization as integer or continuous. This paper approaches the optimization of the design of shell and tube heat exchangers. The formulation of the problem seeks the minimization of the thermal surfaces of the equipment, for certain minimum excess area and maximum pressure drops, considering discrete decision variables. Important additional constraints, usually ignored in previous optimization schemes, are included in order to approximate the solution to the design practice.

- Jiangfeng Guo et al.:

Took some surface parameters of the shell-and-tube heat exchanger as the design variables and the genetic algorithm is applied to solve the associated optimization problem. It is shown that for the case that the heat duty is given, not only can the optimization design increase the heat

ISSN (Online) 2456-1290
International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
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exchanger effectiveness significantly, but also decrease the pumping power dramatically.

- Sepehr Sanaye, Hassan Hajabdollahi:

Considered seven design parameters namely tube arrangement, tube diameter, tube pitch ratio, tube length, tube number, baffle spacing ratio as well as baffle cut ratio. Fast and elitist non-dominated sorting genetic algorithms with continuous and discrete variables were applied to obtain the maximum effectiveness (heat recovery) and the minimum total cost as two objective functions.

CHAPTER 5
DESIGN

- The heat exchanger used in this project is of shell and tube type. It consists of a shell which is made up of Polyvinylchloride (PVC). The internal diameter of PVC pipe is 110mm.
- The tubes are finned type and made up of copper. This Heat Exchanger consists of five copper tubes each having an internal diameter of 12.6mm. Copper is a very good conductor of heat and finned copper tubes means more dissipation of heat to the surrounding i.e. cold water in this case.
- The hot water is supposed to flow through the finned copper tubes and loose its heat to the cold water in the PVC shell as it progresses through the tube.
- A total of four holes are drilled on the PVC pipe, two for inlet and two for outlet of hot and cold water.
- The inlet and outlet of hot water are drilled at the opposite extreme ends of the PVC shell and are at an angle of 90 degrees with each other.
- The hot and cold water inlets and outlets are separated from each other with the help of two circular baffles, one in between the two inlets and one in between the two outlets.

I. DESIGNING OF HEAT EXCHANGER

We have selected counter flow shell and tube heat exchanger. Design specifications of same are as follows:

1. Shell

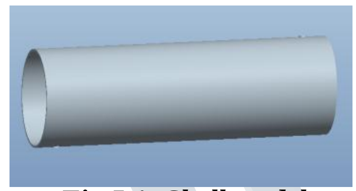

Fig 5.1: Shell model

Shell is the container for the shell fluid and the tube bundle is placed inside the shell.

A total of two holes are drilled on the PVC pipe, one for inlet and one for outlet of cold water.

Material used: Polyvinylchloride (PVC)
Outer diameter: 110 mm
Thickness: 2.4 mm
Length: 600 mm
Hole size on PVC for inlet and outlet of cold water: 13 mm on both sides 2 inch from ends 180◦ apart.

Fig 5.2: Actual Shell PVC pipe

2. Tube

The tubes used are finned type. Copper is a very good conductor of heat and finned tubes means more dissipation of heat to the surrounding

Material used: Copper (Cu)
Outer diameter: 15.8 mm
Inner diameter: 13.4 mm
Thickness: 1.2 mm
Length of tubes: 600 mm (2 feet)
Fins per tube: 240
Fin depth: 0.3 mm

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International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
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Fig5.3: Copper Tube (Actual)

3. **Tube pitch, Tube layout and tube count:**
   Tube pitch is the shortest centre to centre distance between the adjacent tubes.
   Tube Pitch: 30 mm
   Tube layout is rotated square with centre tube.
   Tube count is 5

4. Baffles:
Full Baffles: 2 (dia. 110 mm
Half baffles: 2
5 holes of 16 mm diameter

Fig 5.4: Actual Baffles

4. ***Endings:***
   Hard PVC ends are used to close two ends of heat exchanger.
   One hole is made on each part for inlet and outlet of hot water respectively.
   Internal Diameter: 110 mm
   Hole diameter: 13 mm

5. ***Pipes:***
   Rubber pipes are used for water inlet and outlet for hot and cold water.
   Pipe outer diameter: 13 mm
   Pipe thickness: 1 mm

II. ASSEMBLED MODEL OF SHELL AND TUBE HEAT EXCHANGER

➢ **Assembled view:**

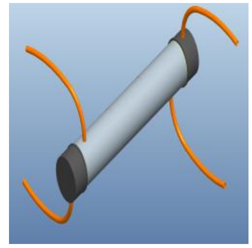

Fig 5.5: Assembled view of heat exchanger

➢ **Exploded view of heat exchanger:**

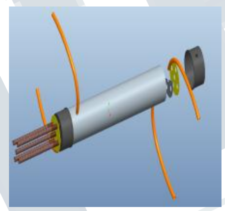

Fig 5.6: Exploded vie

CHAPTER 6
RESULT AND DISCUSSION
I. THEORETICAL CALCULATIONS
(By LMTD Approach)

I. Without fins:-

i. Mass flow rate for cold water = 293.04 kg/hr

$(\dot{m}_c)$ = 0.0814 kg/s

Mass flow rate for cold water = 195.36 kg/hr

$(\dot{m}_h)$ = 0.05426 kg/s

Inlet cold water temperature $(t_{ci}) = 20^0C$

Inlet hot water temperature $(t_{hi}) = 70^0C$

Outlet hot water temperature $(t_{ho}) = 40^0C$

ii. LMTD,

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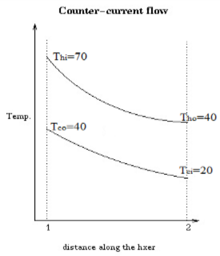

Fig 6.1: LMTD diagram

$$\theta_m = \frac{\theta_1 - \theta_2}{\ln(\theta_1/\theta_2)}$$

$$= \frac{30-20}{\ln(30/20)}$$

$= 24.66$

iii. Heat of water,

$Q_h = \dot{m}_h * c_{ph} * (t_{hi} - t_{ho})$
$= 0.05426*4200*(70-40)$
$= 6836.76$ W

Assuming complete heat transfer to cold water,

$Q_c = \dot{m}_c * c_{pc} * (t_{co} - t_{ci})$
6836.76 = 0.0814*4200*(t_{co}-20)............... [$\because Q_h = Q_C$]

$t_{co} = 40^0$C

iv. Number of tubes (n) = 5
v. Diameter of each copper tube (d) = 15.8×10^{-3} mm
Length of pipe = 0.6 m

$Q_1 = UA\theta m$
= 900× ($5\times0.6\times\pi\times15.8\times10^{-3}$)×6..............[where, A= $n\times\pi d^2\times L$]
Q_1= 3304.941 W..................... (I)

(II) With fins:-

With fins, area available for heat transfer increases

Fins per inch = 10
Fins on each tube = 240
Fins on 0.609 m =240
Fin depth = 0.3 mm
So,
Area increased due to fins = $2*(0.3*15.8)1*10^{-6}*\pi*240$
$=7.147\times10^{-3}$ m^2

Original area = $\pi\times15.8\times10^{-3}\times0.609$
= 0.030 m^2

Total area now = 0.0373 m^2 for each tube

So,
Increase in heat transfer for same flow is,
$Q_2 = UA\theta m$
= 900*0.0373*24.66*5
Q_2 = 4139.181 W..................... (II)

So,
Percentage heat transfer increased theoretically,
% increase in Q is

$$= \frac{Q_2 - Q_1}{Q_1}\times100$$

$$= \frac{4139.181 - 3304.941}{3304.941}\times100$$

% increase in Q = **20.15%**

CHAPTER 7
CONCLUSION

After all theoretical and practical calculations and testing prototype for different flows we can conclude following points:

- Copper already being good conductor of heat it accelerates heat transfer. Copper also has many qualities like rustproof, antifouling, corrosion free, cheap and easily available makes it very useful for heat exchanger
- Inserts are used in copper tubes. Inserts are twisted helically, such that water flowing through tubes moves in helically rotation and inserts push them towards the wall of copper

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ISSN (Online) 2456-1290

International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)

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tubes which helps in heat transfer. Also inserts increase turbulence of water inside the tubes.

- With external fins made on copper tubes, it increases contact surface (surface area) for convection heat transfer. Fins also make cold water turbulent while flowing from tubes surface. In result of this, we found 20.15% of increase in heat transfer theoretically.

APPENDIX A: DATA ANALYSIS

We will be using following basic formulae to calculation and design purpose:

1. Heat given up by the hot fluid,

$$\mathbf{Q = m_h C_{ph}\,(t_{h1} - t_{h2})}$$

2. Heat given up by the cold fluid,

$$\mathbf{Q = m_c C_{pc}\,(t_{c1} - t_{c2})}$$

Where,

Q = Heat in Watt

$m_h \& m_c$ = mass flow rate of hot and cold fluid respectively, kg/s

$C_{hc} \& C_{pc}$ = Specific heat of fluid at constant pressure, J/Kg°C

t = Temperature of fluid, °C

3. Total heat transfer rate in the heat exchanger,

$$\mathbf{Q = U.A.\theta_m}$$

Where,

Q = exchanged heat duty, watts

U = heat transfer coefficient, W/m^2°C

A = exchange area, m^2

θ_m= LMTD

4. Logarithmic mean temperature difference,

$$\theta_m = \frac{(\theta_1 - \theta_2)}{\ln\left(\frac{\theta_1}{\theta_2}\right)}$$

Where,

θ_1 = temperature difference between the two streams at end 1

θ_2 = temperature difference between the two streams at end 2

5. Arithmetic mean temperature difference (AMTD),

$$\mathbf{AMTD = \frac{\theta_1 + \theta_2}{2}}$$

6. Overall heat transfer coefficient (For Plane Wall),

$$\mathbf{U = \frac{1}{\frac{1}{h_i} + \frac{L}{k} + \frac{1}{h_o}}}$$

Where,

$h_i \& h_o$ = heat transfer coefficient of inner and outer surface, m^2°C$/W$

L = Length of wall, m k = heat conductivity, W/m°C

7. Overall heat transfer coefficient (For Tubewall),

Inner surface

$$\mathbf{U_i = \frac{1}{\frac{1}{h_i} + R_{fi} + \left(\frac{r_i}{k}\right)\ln\left(\frac{r_o}{r_i}\right) + \left(\frac{r_i}{r_o}\right)R_{fo} + \left(\frac{r_i}{r_o}\right)\frac{1}{h_o}}}$$

Outer surface

$$\mathbf{U_o = \frac{1}{\frac{1}{h_o} + R_{fo} + \left(\frac{r_o}{k}\right)\ln\left(\frac{r_o}{r_i}\right) + \left(\frac{r_o}{r_i}\right)R_{fi} + \left(\frac{r_o}{r_i}\right)\frac{1}{h_i}}}$$

Where,

$r_i \& r_o$= radii of inner and outer surface respectively, m

$R_{fi} \& R_{fo}$ = fouling factor for inner and outer surface respectively, m^2°C$/W$

8. Heat exchanger effectiveness,

$$\varepsilon = \frac{C_h(t_{h1} - t_{h2})}{C_{min}(t_{h1} - t_{c1})} = \frac{C_c(t_{c2} - t_{c1})}{C_{min}(t_{h1} - t_{c1})}$$

9. Heat transfer rate,

$$Q = \varepsilon\, C_{min}(t_{h1} - t_{c1})$$

10. Heat exchanger effectiveness in terms of NTU,

$$\varepsilon_{parallel} = \frac{1 - exp[-NTU(1 + R)]}{1 + R}$$

$$\varepsilon_{counter} = \frac{1 - exp[-NTU(1 - R)]}{1 - Rexp[-NTU(1 - R)]}$$

Where,
R = C_{min}/C_{max}
NTU = Number of transfer units

11. Power required to pump fluid in steady state,

$$Power = \int v\, dp = \frac{\dot{m}}{\rho}\Delta p = \dot{m}^3$$

12. Efficiency,

$$\varepsilon = \frac{Q_{Act}}{Q_{max}}$$

APPENDIX B:
GENERAL DATA

- Cp=4200 J/Kgk
- Fouling factor for clean water=0.0002 to 0.0006 m^2c/W
- U for water= 850 to 1170 W/m^2c
- hi & ho = 650 W/m^2c
- Nu = 0.023 $Re^{0.8}Pr^{0.4}$
- Density of water = 1000 kg/m^3
- K for copper = 355 W/$m.c$
- K for water = 0.615 W/$m.c$

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