

A REVIEW OF AVAILABLE HEAT TRANSFER TECHNIQUES

Santanu Kar[1], *Laxman Kumar Sahoo*[2]
[1, 2]*Gandhi Institute for Education & Technology, Bhubaneswar*

Abstract - ***Process equipment known as a heat exchanger is made to efficiently transfer heat from hot to cold fluids, either in the same phase or in a separate one. Either adding heat to a fluid or removing heat from one may be the goal. Heat exchangers find widespread usage in a variety of commercial and residential applications. There are two types of heat exchangers: regenerator or recuperator and direct contact type. The heat transfer occurs by convection in each fluid and by conduction through the walls in a regenerator or recuperator, as opposed to a direct contact type where the fluids are separated by a metal wall. The many types of heat exchangers currently in use in both industry and homes are presented in this review research Understanding the principles and applying them appropriately are essential in designing and assessing the effectiveness of a heat exchanger.***

Key Words: *Area density, LMTD, NTU, Overall heat transfer coefficient, Performance analysis, Tube spacing.*

1. INTRODUCTION

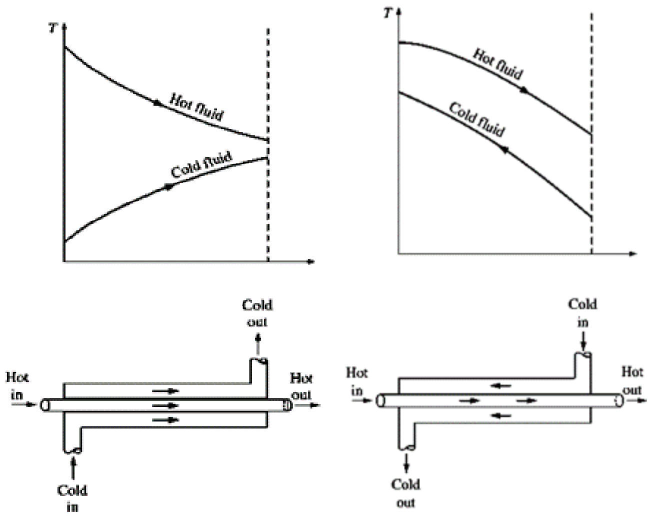
To reach a particular engineering objective, it is very important to apply certain principles so that the product development is done economically. This economy is important for the design and selection of heat transfer equipment. The heat exchangers are manufactured in different types, however the simplest form of the heat exchanger consist of two concentric pipes of different diameters known as double pipe heat exchanger. In this type of heat exchanger, one fluid flows through the small pipe and another fluid flows through the space between both the pipes. The flows of these two different fluids, one is at higher temperature called hot fluid and another is at lower temperature called cold fluid, can be in same or in opposite directions. If the fluid flows are in same direction then the heat exchanger is called as parallel flow heat exchanger and if the flows are in opposite direction then the heat exchanger is called as counter flow heat exchanger. In the cross flow arrangement, the two fluids are directed at right angles to each other. The cross flow type heat exchangers are commonly employed in air or gas heating and cooling applications.

Based on the nature of heat exchange process, the heat exchanger are classified in to direct contact type, regenerators and recuperators. In direct contact type the energy transfer between the hot and cold fluid is brought about by their complete physical mixing, there is simultaneous transfer of heat and mass. In a regenerator, the hot fluid is passed through certain medium called matrix. The heat is transferred to the solid matrix and accumulates there; the heat stored in matrix is subsequently transferred to the cold fluid by allowing it to pass over the heated matrix. In a recuperator, the fluids flow simultaneously on either side of a separating wall, the heat transfer occurs between the fluid streams without mixing or physical contact with each other. [4]

The further development is done in the heat exchangers to facilitate them in different applications as per necessity. These heat exchangers have large heat transfer surface area per unit volume and are known as compact heat exchangers.

If the area density β of a heat exchanger is greater than 700 known as compact heat exchanger.

$$area\ density = \beta = \frac{heat\ transfer\ surface\ area}{volume\ of the\ heat\ exchanger}$$



(a) Parallel flow (b) Counter flow

Fig -1: Double pipe heat exchangers with different flow and their respective temperature profile.

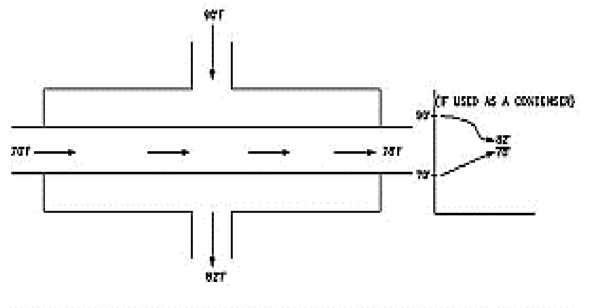


Fig -2: Cross flow type heat exchanger.

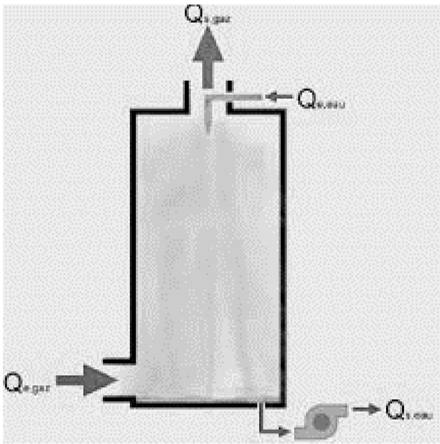


Fig -3: Direct contact type heat exchanger.

Fig -4: Regenerator heat exchanger.

2. DIFFERENT APPLICATIONS of HEAT EXCHANGER

1. Intercoolers and preheaters;
2. Economizers and super heaters;
3. Condensers and boilers in steam plant;
4. Condensers and evaporators in refrigeration units;
5. Regenerators;
6. Automobile radiators.
7. Cooling tower.
8. Heat pipes.

3. DIFFERENT TYPES OF HEAT EXCHANGERS

Following are the different types of heat exchangers used based on the applications:

3.1 Shell and tube heat exchanger

Shell and tube heat exchangers are generally used in the chemical and process industries. These devices are available in a broad range of configurations as defined by the Tubular Exchanger Manufacturers Association (TEMA). The applications of single-phase shell-and-tube heat exchangers are quite large because these are widely used in chemical, petroleum, power generation and process industries. In essence, a shell and tube exchanger is a pressure vessel with many tubes inside of it. One process fluids flow through the tubes of the exchange while the other flows outside of the pipes within the shell. The tube side and shell side fluids are separated by a tube sheet. In these heat exchangers, one fluid flows through tubes while the other fluid flows in the shell across the tube bundle.

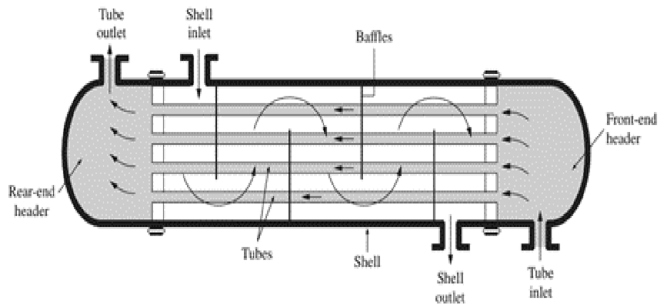


Fig -5: Shell and Tube type Heat Exchanger.

The baffles are primarily used in shell-and-tube heat exchangers for supporting the tubes and for inducing cross flow over the tubes, resulting in improved heat transfer performance. To induce turbulence outside the tubes it is customary to employ baffles that cause the liquid to flow through the shell at right angles to axes of the tubes. [9]

In these heat exchangers, the shell-side flow is complicated for two causes, the first is the approximately sinusoidal overall flow pattern as the fluid flows through the tube bundle, and the second is the influence of the various leakages through the clearances required for the construction of the exchangers. The various tube arrangements are as indicated in fig. 6 as shown. [8]

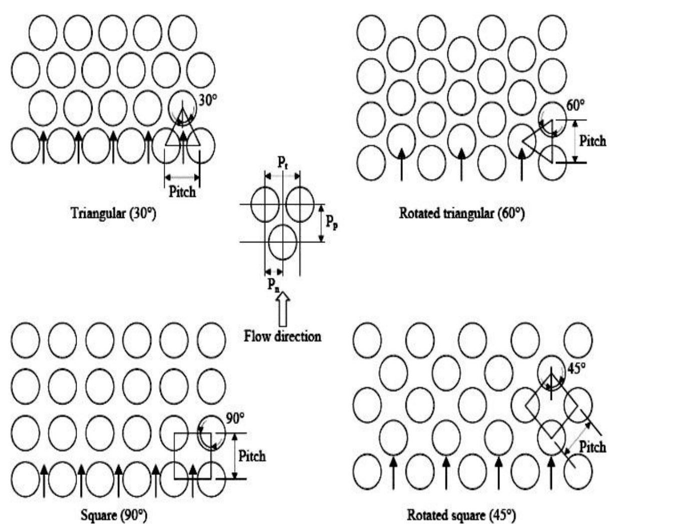
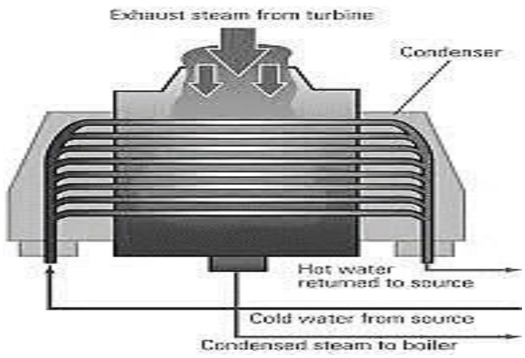


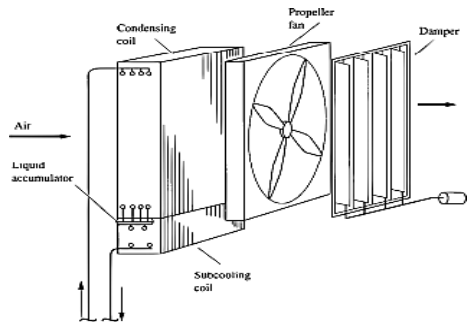
Fig -6: Various tubes arrangements in shell and tube type of heat exchanger.

3.2 Condenser

Condensers are the types of heat exchangers used to condense a substance from its gaseous to its liquefied state. In this process, the hot fluid (or gases) gives its latent heat to the cold fluid and comes to the liquid state. The condensers are used for industrial as well as domestic purpose. They are available for various ranges of size and shape. For example the condensers used in domestic refrigerator and air conditioners are quite small and the condensers used in power plants are of bigger sizes. Use of cooling water or surrounding air as the coolant is common in many condensers. The main use of a condenser is to receive exhausted steam from a steam engine or turbine and condense the steam. A steam condenser generally condenses the steam to a pressure significantly below atmospheric. This allows the turbine or engine to do more work. The condenser also converts the discharge steam back to feed water which is returned to the steam generator or boiler. In the condenser the latent heat of condensation is conducted to the cooling medium flowing through the cooling tubes. An Air cooled condenser, is simply a pressure vessel which cools a circulating fluid within finned tubes by forcing ambient air over the exterior of the tubes. Fig. 7 is showing water cooled condenser and air cooled condenser as well. [6]



(a) Water cooled condenser

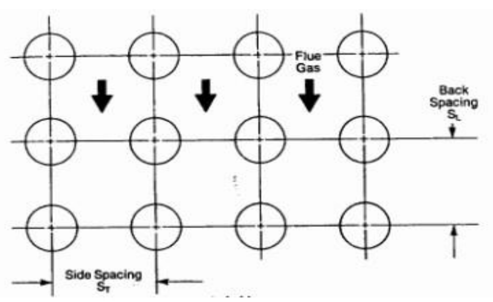


(b) Air cooled condenser

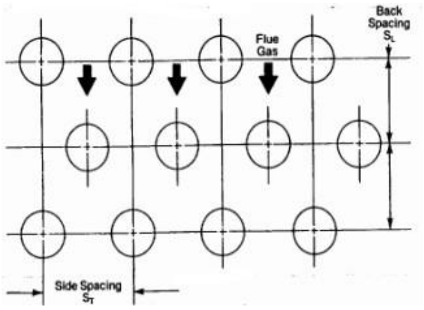
Fig -7: Condenser

3.3 Economizer and air-preheater

Economizer is a type of heat exchanger commonly used in a steam power plant particularly to heat the water entering the boiler so that the fuel consumption is reduced. The economizer not only pre-heats the feed water but also lowers the temperature of the flue gases flowing to the atmosphere. Economizers are basically tubular heat transfer surfaces used to preheat the boiler water before it enters the drum. The term economizer comes from early use of such heat exchangers to reduce operating cost or economize on fuel by recovering extra energy from flue gas. The different tubular arrangement of the economiser is as shown in Fig. 8. [1]



(a) In-line arrangement



(b) Staggered arrangement

Fig -8: Economizer and Air Pre-heater tube arrangement.

Air-preheater is the also a type of heat exchanger and used in the steam power plant just like the economizer. The difference between these two is that the air-preheater is used to preheat the air entering the furnace. The purpose is that the efficiency of the boiler and hence steam power plat increases as the fuel consumption decreases.

3.4 Radiator

Radiators are the types of heat exchangers used to transfer thermal energy from one medium to another for the purpose of cooling and heating. The major applications of radiators are in automobiles buildings and electronics. The radiators used in the cars and heavy vehicles are the compact heat exchangers. In compact heat exchangers, the two fluids usually move perpendicular to each other, and such flow configuration is called cross-flow. The cross- flow is said to be unmixed since the plate fins force the fluid to flow through a particular inter fin spacing and prevent it from moving in the transverse direction. Radiator is a heat exchanger that removes heat from engine coolant passing through it. Heat is transferred from hot coolant to outside air. Radiator assembly consists of three main parts core, inlet tank and outlet tank. Core has two sets of passage, a set of tubes and a set of fins. Coolant flows through tubes and air flows between fins. The hot coolant sends heat through tubes to fins. Outside air passing between fins pickups and carries away heat. [7]

Fig -9: Car radiator.

3.5 Cooling Tower

A cooling tower is a device in which recirculating condenser water from a condenser or cooling coils is evaporative cooled by contact with atmospheric air. It consists of a fan to extract intake air, a heat-transfer medium or fill, a water basin, a water distribution system, and an outer casing. According to the location of the fan corresponding to the fill and to the flow arrangements of air and water, cooling towers can be classified into the following categories: [10]

1. Counter flow induced draft
2. Cross-flow induced draft
3. Counter flow forced draft.

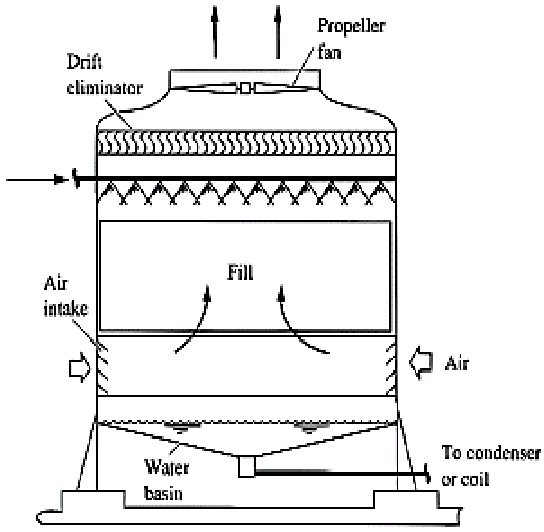


Fig -10: Counter flow induced draft.

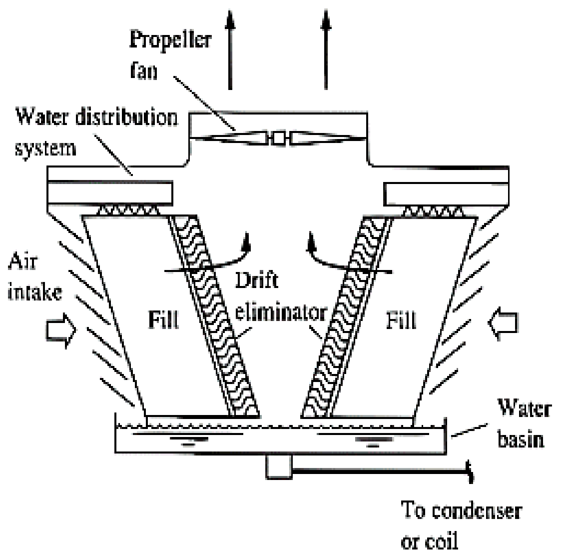


Fig-11: Cross-flow induced draft.

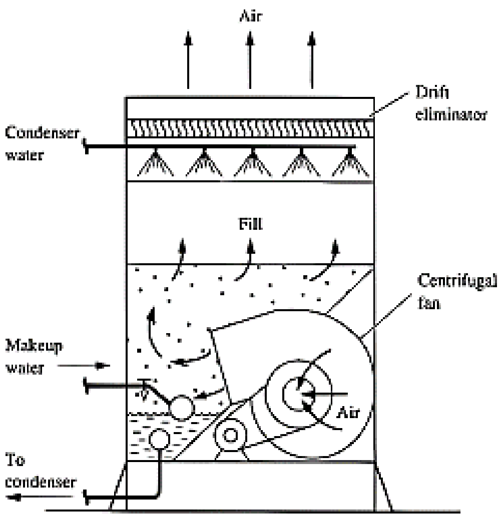


Fig-12: Counter flow forced draft.

3.6 Heat Pipe

The heat pipe is a highly effective passive device for transmitting heat at high rates over considerable distances with extremely small temperature drops, exceptional flexibility, simple construction, and easy control with no external pumping power. The operation of a heat pipe is easily understood by using a cylindrical geometry, as shown in Fig. 13. However, heat pipes can be of any size or shape. The components of a heat pipe are a sealed container (pipe wall and end caps), a wick structure, and a small amount of working fluid which is in equilibrium with its own vapor. Different types of working fluids such as water, acetone, methanol, ammonia or sodium can be used in heat pipes based on the required operating temperature. The length of a heat pipe is divided into three parts: the evaporator section, adiabatic (transport) section and condenser section. A heat pipe may have multiple heat sources or sinks with or without adiabatic sections depending on specific applications and design. Heat applied externally to the evaporator section is conducted through the pipe wall and wick structure, where it vaporizes the working fluid. The resulting vapor pressure drives the vapour through the adiabatic section to the condenser, where the vapour condenses, releasing its latent heat of vaporization to the provided heat sink. The capillary pressure created by the menisci in the wick pumps the condensed fluid back to the evaporator section. Therefore, the heat pipe can continuously transport the latent heat of vaporization from the evaporator to the condenser section. This process will continue as long as there is a sufficient capillary pressure to drive the condensate back to the evaporator. [2]

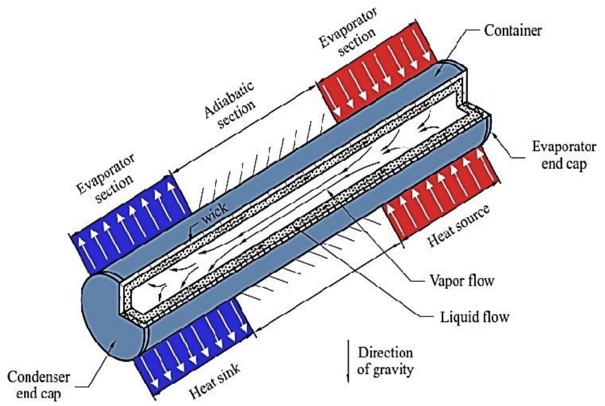


Fig-13: Schematic of a conventional heat pipe

The basic idea behind a heat pipe is the circular process shown in fig. 14. At the heat source the cold liquid is evaporated, the hot vapour flow is afterwards transported to the heat sink where the vapour condensates again and is transported back to the heat source. The problem of this process is the space consumption; hence it was necessary to develop a compacter way to transport the heat energy with the shown process. The idea of a heat pipe is now to include the complete convective transport in one pipe, where the vapour flow is in the center of the pipe and the liquid flow takes place on the outside of the cylinder.[5]

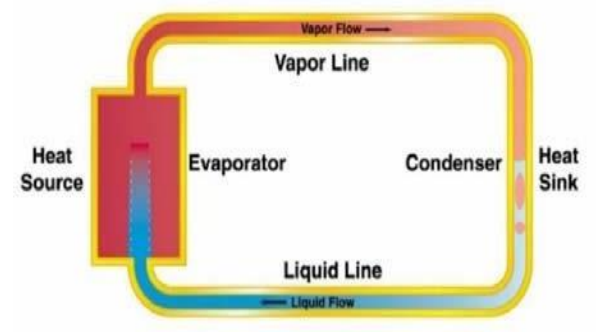


Fig-14: Circular process of heat pipe.

3.6.1 Types of Heat Pipes

1. Two-Phase Closed Thermo syphon
2. Capillary-Driven Heat Pipe
3. Vapour Chamber
4. Annular Heat Pipe
5. Rotating Heat Pipe
6. Loop Heat Pipe
7. Gas-Loaded Heat Pipe
8. Capillary Pumped Loop Heat Pipe
9. Pulsating Heat Pipe
10. Mono groove Heat Pipe
11. Micro and Miniature Heat Pipes
12. Inverted Meniscus Heat Pipe

4. PERFORMANCE ANALYSIS

Hot fluid give up the heat

$$Q_h = m_h c_h \, (t_{h1} - t_{h2})$$

The coolant picks up the heat

$$Q_c = m_c c_c \, (t_{c2} - t_{c1})$$

During the heat exchange between two fluids, the temperature of fluids change in the direction of flow and consequently there occurs a change in the thermal head causing the flow of heat. In parallel flow system, the thermal head is maximum at inlet and goes on diminishing along flow path and minimum at the outlet. In a counter flow system, both the fluids are in their coldest state at exit as shown in Fig, 1. The logarithmic mean temperature difference approach is used to estimate the heat transfers from hot to cold fluid. [3]

$$Q_{ex} = U\,A\,\theta_m$$

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

$$where, \theta_1 = (t_{h1} - t_{c2}), \theta_2 = (t_{h2} - t_{c1})$$

The LMTD is useful only when the inlet and outlet temperature of both fluids are known. Usually the inlet condition of fluids are known and outlet condition of fluid and the heat transfer is worked out by energy balance and resulting equations become unwieldy requiring a trial and error iteration approach. An analysis of the heat exchanger can be made more conveniently by the NTU approach which is based on the concept of capacity ratio, effectiveness and number of transfer units.

4.1 Capacity ratio

The product mass and specific heat of a fluid in a heat exchanger is termed as capacity rate. The ratio of minimum to maximum capacity rate is defined as capacity ratio. [4]

$$if\ m_h c_h > m_c c_c : C = \frac{m_c c_c}{m_h c_h}$$

$$if\ m_h c_h < m_c c_c : C = \frac{m_h c_h}{m_c c_c}$$

4.2 Heat exchanger effectiveness

$$\in = \frac{actual\ heat\ transfer}{maximum\ possible\ heat\ transfer}$$

Since either of the hot and cold fluid may have the minimum value of capacity heat rate, there are two possible values of effectiveness. [4]

$$\in = \frac{m_h c_h (t_{h1} - t_{h2})}{C_{min}(t_{h1} - t_{c1})}$$

$$\in = \frac{m_c c_c (t_{c2} - t_{c1})}{C_{min}(t_{h1} - t_{c1})}$$

4.3 Number of transfer units

NTU is the measure of the size of the size of the heat exchanger. [4]

$$NTU = \frac{UA}{(mc)_{min}}$$

Effectiveness for the parallel flow heat exchanger

$$\in = \frac{1 - \exp[-NTU(1+C)]}{(1+C)}$$

Effectiveness for the counter flow heat exchanger

$$\in = \frac{1 - \exp[-NTU(1-C)]}{1 - C\,exp[-NTU(1-C)]}$$

4.4 Overall heat transfer coefficient

The overall coefficient of heat transfer U is define in terms of the total thermal resistance. For a cylindrical separating wall, the cross-sectional area of the heat flow path is not constant but varies with radius, thus depending upon whether the inner or outer area is specified, two different values are defined for U. the surface deposits (fouling) increase thermal resistance with a corresponding drop in the performance of the heat exchanger. Since the thickness and thermal conductivity of the scale deposits is difficult to ascertain, the effect of scale on heat flow is considered by specifying an equivalent scale heat transfer coefficient (h_s). [4]

$$UA = \frac{1}{\left(\frac{1}{A_i h_i}\right) + \left(\frac{1}{A_i h_{si}}\right) + \left[\frac{1}{2\pi l k} \times \log_e\left(\frac{r_o}{r_i}\right)\right] + \left(\frac{1}{A_o h_{so}}\right) + \left(\frac{1}{A_o h_o}\right)}$$

For inner surface

$$U_i = \frac{1}{\left(\frac{1}{h_i}\right) + \left(\frac{1}{h_{si}}\right) + \left[\frac{r_i}{k} \times \log_e\left(\frac{r_o}{r_i}\right)\right] + \left(\frac{r_i}{r_o h_{so}}\right) + \left(\frac{r_i}{r_o h_o}\right)}$$

For outer surface

$$U_o = \frac{1}{\left(\frac{1}{h_o}\right) + \left(\frac{1}{h_{so}}\right) + \left[\frac{r_o}{k} \times \log_e\left(\frac{r_o}{r_i}\right)\right] + \left(\frac{r_o}{r_i h_{si}}\right) + \left(\frac{r_o}{r_i h_i}\right)}$$

The reciprocal of heat transfer coefficient is called fouling factor (R_f). It is determined experimently by testing the heat exchanger in both the clean and dry condition.

$$R_f = \frac{1}{U_{dirty}} - \frac{1}{U_{clean}}$$

5. CONCLUSIONS

This review indicates that Heat Exchangers are the heat transfer devices which are used in different applications. The heat exchangers can be used to recover the resources like water as it is converted into the steam which is condensed by using the condenser. Heat exchangers also useful for the economical running of industries and to control the pollution as in case of economizer and air pre-heater. The heat exchangers are also be used for cooling purpose as in case of radiators. So it is obvious that the heat exchangers are the useful tools in the industries.

The following points are worth bearing in mind;

a) The overall heat transfer coefficient depends upon the flow rate and properties of fluid, the material thickness and surface conditions of tubes and the geometrical configuration of the heat exchanger. It will decrease when the low thermal conductivity fluid flows on one side of the exchanger and it will increase when the high thermal conductivity fluid flows on one side of the exchanger.

b) For an efficient and effective design, there should be no high thermal resistance in the heat flow path.

c) The logarithmic mean temperature difference for a counter flow unit is greater than that of a parallel flow unit and accordingly the counter flow heat exchanger can transfer more heat than a similar parallel flow heat exchanger.

d) The NTU approach facilitates the comparison between the various types of heat exchanger which may be used for a particular application.

6. NOMENCLATURE

LMTD = logarithmic mean temperature difference across the heat exchanger structure.

NTU = number of transfer units.

c = specific heat (kj/kg-K)

h_{si} = heat transfer coefficient for scale formed on the inside surface. (W/ m^2 K)

h_{so} = heat transfer coefficient for scale formed on the outside surface. (W/ m^2 K)

m = mass flow rate (kg/s)

t = fluid temperature (^oC)

Δt = temperature drop or rise of a fluid across the heat exchanger. (^oC)

U = overall heat transfer coefficient between two fluids. (W/ m^2 K)

θ_m = logarithmic mean temperature difference across the heat exchanger structure. (^oC)

θ_1 = temperature difference across the inlet of heat exchanger. (^oC)

θ_2 = temperature difference across the outlet of heat exchanger. (^oC)

REFERENCES

[1] A. D. Patil, P. R.Baviskar, M. J.Sable, S. B.Barve, "*Optimization of Economiser Design for the Enhancement of Heat Transfer Coefficient",* International Journal of Applied Research in Mechanical Engineering, Volume-1, Issue-2, 2011.

[2] Amir Faghri, "*Heat Pipes: Review, Opportunities And Challenges*", Frontiers in Heat Pipes (FHP), 5, 1 (2014)

[3] B.Jayachandriah1, K. Rajasekhar, "*Thermal Analysis of Tubular Heat Exchangers Using ANSYS*", International Journal of Engineering Research, Volume No.3, Issue No: Special 1, pp: 21-25.

[4] Dr. D. S. Kumar, *"Heat and Mass Transfer*", SI Units, 6th Edition, S. K. Kataria and sons publication, CHAPTER 14, Heat exchangers.

[5] Fabian Korn, "*Heat pipes and its applications*", Project Report, 2008 MVK160 Heat and Mass Transport, Lund University, Lund, Sweden.

[6] Manish Baweja, Dr. D. N. Bartaria, "*A Review on Performance Analysis of Air-Cooled Condenser under Various Atmospheric Conditions*", International Journal of Modern Engineering Research, Volume-3, Issue-1, Jan-Feb 2013.

[7] P. S. Amrutkar, S. R. Patil, "*Automotive Radiator Performance-Review*", International Journal of Engineering and Advanced Technology, Volume-2, Issue-3, Feb-2013.

[8] Ray Sinnott and Gavin Towler, "*Chemical Engineering design,Fifth Edition*" (Coulson & Richardson's Chemical Engineering Series) CHAPTER 12. Heat-transfer Equipment.

[9] S. S. Shinde, P. V. Hadgekar, S. Pavithran, "*Comparative Thermal Analysis of Helixchanger with Segmental Heat Exchanger UsingBell delaware Method*", International Journal Of Advances In Engineering & Technology, May 2012. ISSN: 2231-1963.

[10] U. S. Deepartment of energy, "*Cooling Towers: Understanding Key Components of Cooling Towers and How to Improve Water Efficiency*", Federal Energy Management Program.