Heat Exchanger: A Reliable and Booming Prospect for Modern Needs- An overview

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***Abstract*— A heat exchanger is a device which is basically used for the transfer of thermal energy (enthalpy) between two or more fluids, between a solid surface and a fluid, or between solid particles and a fluid, which are in thermal contact and at different temperatures. Heat exchangers play a vital role in all modern day applications. Heat exchangers are used in cars, refrigerators, drain back systems, antifreeze solar hot water systems. In fact many of the houses have two or more heat exchangers. Heat exchangers have contributed tremendously in industrial sector and have a lot of industrial importance. The main objective of this paper is to illustrate the applications of heat exchangers in various sectors. The paper also emphasizes the classification and types of heat exchangers. Furthermore, the paper provides framework for the selection and preferable choice of heat exchangers. Apart from this, the paper also brings out the importance and significance of heat exchangers.**

***Index Terms*— Heat exchanger, Industrial sector, Importance and significance of heat exchangers. Selection and preferable choice of heat exchanger, Thermal energy.**

I. INTRODUCTION

Heat transfer can be done using three modes namely conduction, convection and radiation. In a heat exchanger all the three modes are involved for the heat transfer. These three modes decide the heat exchange in any process or system: mechanical, chemical or nuclear. A heat exchanger is a device which transfers heat from one fluid to another fluid. A single or composite wall divides two fluids referred as a recuperative heat exchanger. On the other hand when there exists direct contact between two fluids it is referred as regenerative heat exchanger. The heat exchangers which are widely used in technology oriented domains particularly in Mechanical Engineering and Electrical Engineering.

Heat exchanger design follows the fundamentals of thermodynamics, which is essentially a science involving heat energy flow, temperature and the relationships to other forms of energy. Heat can be transferred in three modes namely conduction, convection and radiation. These modes help in understanding the heat exchanger thermodynamics. Nevertheless, in spite of the design and type of heat exchanger all types of heat exchangers function under the same fundamental principles namely zeroth law of thermodynamics, first law of thermodynamics and second law of thermodynamics. These laws illustrate and dictate the transference or exchange of heat from one fluid to another.

Heat exchanger thermal output is the amount of heat transferred between the fluids and the corresponding temperature change at the end of heat transfer process. The transference of heat within the heat exchanger results in a change of temperature in both the fluids which leads to lowering the temperature of one fluid as heat is removed and the temperature of other fluid is raised as heat is added. The optimal type and design of heat exchanger are determined by the desired thermal output and rate of heat transfer.

The rest of the paper is organized into sections as follows: Section II describes the heat exchanger fundamentals. Section III focuses on heat exchanger classification and types. Section IV includes applications of Heat exchanger. Efficiency improvement methods of heat exchanger are reported in section V. finally section VI summarizes the paper and presents the concluding remarks.

II. HEAT EXCHANGER FUNDAMENTALS

A. Design Optimization of Heat Exchanger

The design optimization of heat exchanger is a daunting task which requires skillful selection of the heat exchanger dimensions. In order to design the optimal heat exchanger for a particular application with given specifications and requirements involves finding the temperature change of fluids, the heat transfer coefficient and the heat transfer construction and relating them to the rate of heat transfer. The two major problems which evolve in fulfilling this objective are calculating the device's rating and size. The rating in this context refers to the thermal effectiveness calculation, that is efficiency of the heat exchanger of a given design and size which includes the rate of heat transfer the amount of heat transferred between fluids and their corresponding temperature change and the total pressure drop across the device. The sizing means to calculate the required total dimensions of the heat exchanger, which is the surface area available for use in the heat transfer process, which includes the length, width, height, thickness, number of components, component geometries and arrangements etc. for an application with given process specifications and requirements.

B. Performance of a Heat Exchanger

There are two approaches which are more commonly used to evaluate the performance of a heat exchanger namely log mean temperature difference (LMTD) and effectiveness (NTU).

1. Log mean temperature difference (LMTD)

Temperature difference between hot and cold fluids varies with the length of the heat exchanger. The integrated temperature difference over the entire length of heat exchanger is defined as the log mean temperature difference (LMTD).

$$\mathrm{LMTD} = \Delta\theta = \frac{\theta_2-\theta_1}{\ln\frac{\theta_2}{\theta_1}} = \frac{\Delta T_2-\Delta T_1}{\ln\frac{\Delta T_2}{\Delta T_1}} \quad (1)$$

Where $\theta_2 = \Delta_2 = T_{h2} - T_{c2}$

$\theta_1 = \Delta 1 = T_{h1} - T_{c1}$

T_h and T_c stand for hot and cold fluid temperatures and 1 and 2 stands for entry and exit of fluids as represented in figure 1 [1]. The following equation 2 gives the Heat transfer in a heat exchanger considering the overall heat transfer by conduction and convection.

$$Q = UA\,\Delta T_m \quad (2)$$

Where Q is the heat transfer rate in W, which is equal to the heat exchange in either hot side or cold side fluid.

$$Q = (m\,C_p\,\Delta T)_h = (m\,C_p\,\Delta T)_c \quad (3)$$

U is the overall heat transfer coefficient in $W/m^2 K$.

For a plain wall as shown in figure 1 the heat transfer through it is expressed by equation 4

$$Q = \frac{T_1-T_2}{\frac{1}{h_i A_i}+\frac{\Delta x}{kA}+\frac{1}{h_2 A}} = UA\Delta T_{overall} \quad (4)$$

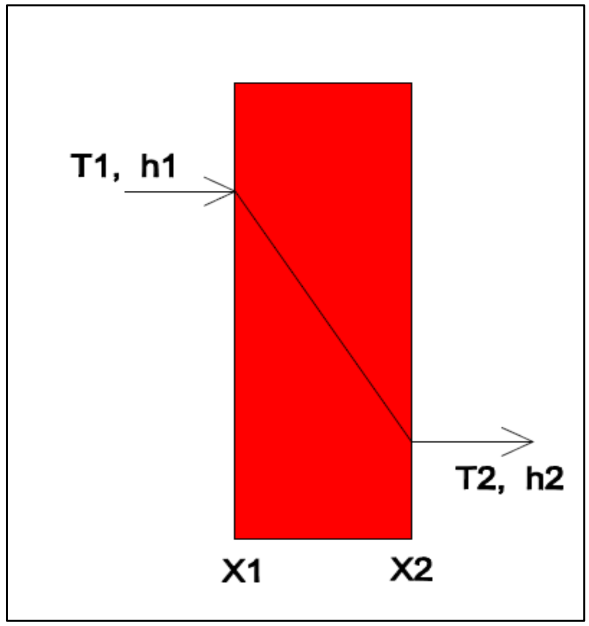

Fig.1 Heat transfer in case of plain wall

For a cylinder (tube) as shown in figure 2 the heat transfer through it is expressed by equation 5

$$Q = \frac{T_1-T_2}{\frac{1}{h_i A_i}+\frac{\Delta \ln\left({r_0}/{r_i}\right)}{2\pi kL}+\frac{1}{h_0 A_0}} = UA\Delta T_{overall} \quad (5)$$

In a heat exchanger the heat transfer process is affected by factors such as film or deposit of sediment, organic growth, scale etc. maximum number of other fluids have tendency of fouling with the exception of air and liquefied natural gas. Equation 6 is written taking fouling into account on both sides of the tube.

$$Q = \frac{T_1-T_2}{\frac{1}{h_i A_i}+\frac{R_{fi}}{A_i}+\frac{\Delta \ln\left({r_0}/{r_i}\right)}{2\pi kL}+\frac{R_0}{A_{io}}+\frac{1}{h_0 A_0}} \quad (6)$$

Therefore, taking into account fouling the overall heat transfer coefficient is defined as

$$U = \frac{1}{\frac{1}{h_i}+R_{fi}+\frac{A\Delta \ln\left({r_0}/{r_i}\right)}{2\pi kL}+R_{f0}+\frac{1}{h_0}} \quad (7)$$

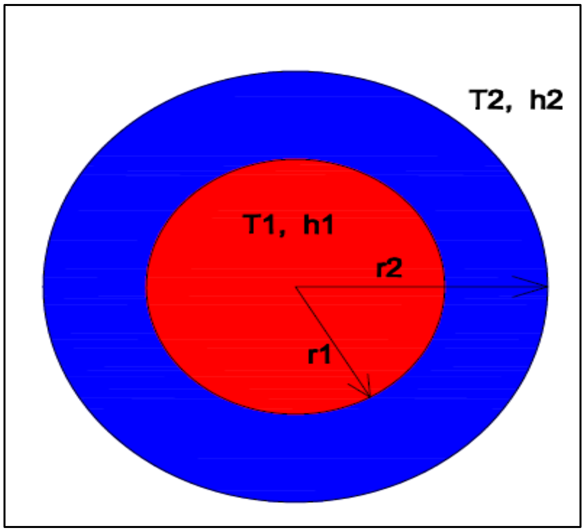

Fig.2 Heat transfer in case of cylinder (tube)

2. Effectiveness-NTU Method

Whenever the inlet fluid temperatures are known, as far as the new heat exchanger design and sizing are concerned, the effectiveness method is desirable. The effectiveness of a heat exchanger is defined as the ratio of actual heat transfer to maximum possible heat transfer [1], [2].

Effectiveness= ϵ = (Actual heat transfer / Maximum possible heat transfer)

Actual heat transfer is calculated by either energy lost by the hot fluid or energy gained by the cold fluid.

For parallel flow, counter flow and boiler/condenser exchangers the effectiveness is calculated using equations 8, 9 and 10.

$$\epsilon_{parallel} = \frac{1-\exp\left[\left(\frac{-UA}{C_{min}}\right)\left(1+\frac{C_{min}}{C_{max}}\right)\right]}{1+\frac{C_{min}}{C_{max}}} \quad (8)$$

$$\epsilon_{counter-flow} = \frac{1-\exp\left[\left(\frac{-UA}{C_{min}}\right)\left(1-\frac{C_{min}}{C_{max}}\right)\right]}{1-\left(\frac{C_{min}}{C_{max}}\right)\exp\left[\left(\frac{-UA}{C_{min}}\right)\left(1-\frac{C_{min}}{C_{max}}\right)\right]} \quad (9)$$

$$\epsilon_{boiler\ or\ condenser} = 1 - \exp\frac{-UA}{C_{min}} \quad (10)$$

Where U= overall heat transfer coefficient

A= area of heat exchanger

C= m C_p = mass flow rate x specific heat of fluid = capacity rate

C_{min} = capacity rate of fluid having minimum m C_p value

C_{max} = capacity rate of fluid having maximum m C_p value

UA/ C_{min} = number of transfer units

C. Choice of Heat Exchanger

The choice of a heat exchanger is a cumbersome task as numerous options are available in the market. Generally plate heat exchangers yield good results for liquid to liquid applications (excluding solid particles). The initial price of the plate type heat exchanger is low in comparison with a shell and tube heat exchanger but the prime drawback is that the high pressure cannot be withstand owing to the gasket material. Spiral plate heat exchanger is a good choice of preference in case of solid particles. In case of HVAC applications plate and frame as well as shell and tube units are more preferable. A back flushing heat exchanger is more suitable for frequent fouling conditions since it possesses a four way valve to periodically change the direction of flow and ultimately the fouling and sediments are cleaned. With respect to low temperature operations, ethylene and propylene glycols are added to fluids in order to decrease the freezing points of fluids.

Essentially the choice of heat exchanger depends on the following parameters

1. Application (to cool, to heat or to exchange heat)
2. Fluid handled (single phase or two phase)
3. Operating pressure and temperature
4. Fouling characteristics of fluid
5. Location and plan
6. Accessibility for cleaning and maintenance
7. Future expansion
8. The desired thermal outputs
9. Size limitations
10. Cost

D. Desired Heat Exchanger Specifications

The table I illustrates the heat exchanger specifications with desired or recommended nature.

TABLE IHEAT EXCHANGER SPECIFICATIONS

Sl. No	Specifications	Desired Value
1.	Heat transfer coefficient	High
2.	Size	compact
3.	Temperature distribution	uniform
4.	Fouling	Low
5.	High pressure Application	yes
6.	High temperature Application	Yes
7.	Maintenance cost	Low
8.	Fluid velocity	High
9.	Turbulence	High
10.	Surface area	High
11.	Temperature differential	Large
12.	Ideal material	Copper, Aluminum

III. HEAT EXCHANGER CLASSIFICATION AND TYPES

A detailed classification of Heat exchangers is based on various features listed as follows

1. Transfer process
2. Number of fluids
3. Construction features
4. Degree of surface compactness
5. Flow arrangements
6. Heat transfer mechanisms.
7. Physical state of fluids and process function

1) Classification according to the Transfer process

In this type of classification, the heat exchangers are divided into two main types namely

a. Indirect contact type
b. Direct contact type

Indirect contact type is divided into three types namely direct transfer type, storage type and fluidized bed type. Direct transfer type is further subdivided into single phase and multiphase. Direct contact type is also classified into three type's namely immiscible fluids, gas- liquid and liquid- vapor.

2) Classification based on the Number of fluids

In this type of classification, the heat exchangers are classified into three types namely

a. Two fluid
b. Three fluid
c. N fluid (N>3)

3) Classification according to the Construction

In this type of classification, the heat exchangers are divided into four main types namely

a. Tubular
b. Plate type
c. Extended surface
d. Regenerative

Tubular type is divided into four type's namely double pipe, shell and tube, spiral tube and pipe coils. In this classification shell and tube is further classified as cross flow to tubes and parallel flow to tubes. Plate type is classified into four types as PHE, spiral, plate coil and printed circuit. PHE is further classified into three types namely gasketed, welded and brazed. Extended surface is divided into two types namely plate fin and tube fin. Tube pin is further classified into two types as ordinary separating wall and heat pipe wall. Regenerative is classified into three types namely rotary, fixed matrix and rotating hoods.

4) Classification according to the Degree of surface compactness

In this type of classification, the heat exchangers are divided into two main types namely

a. Gas to fluid
b. Liquid to liquid and phase change

This gas to fluid and liquid to liquid and phase change are further classified as compact and non-compact where the β varies. In gas to fluid category $\beta>700$ $m2/m^3$ for compact and $\beta<700$ m^2/m^3 for non-compact, whereas in Liquid to liquid and phase change $\beta>400$ m^2/m^3 for compact and $\beta<400$ m^2/m^3 for non-compact.

5) Classification according to Flow arrangement

In this type of classification, the heat exchangers are divided into two main types namely

a. Single pass
b. Multi pass

Single pass is divided into five different categories namely counter flow, parallel flow, cross flow, split flow and divided flow. Multi pass is also divided into three type's namely extended surface, shell and tube, and plate type. Extended surface type is further subdivided into three types namely cross counter flow, cross parallel flow and compound flow. Shell and tube type is further subdivided into parallel counter flow (m- shell passes and n- tube passes), split flow and divided flow. Plate type is further subdivided into Fluid 1 m passes and fluid 2 n passes.

6) Classification according to Heat transfer mechanisms

In this type of classification, the heat exchangers are classified into four main types namely

a. Single phase convection on both sides
b. Single phase convection on one side and two phase convection on other side
c. Two phase convection on both sides
d. Combined convection and radiative heat transfer

7) Classification according to the Physical state of fluids and process function

In this classification, the heat exchangers are classified into six types namely

a. Condensers
b. Evaporators
c. Heaters
d. Coolers
e. Chillers

f. Liquid to vapor phase change heat exchangers [1], [2], [19]

The table II illustrates the main classification of heat exchangers

TABLE IIIHEAT EXCHANGER CLASSIFICATION

Sl No.	Classification Criteria	Heat Exchanger Falling Under Classification
1.	Transfer Process	a. Indirect contact type b. Direct contact type
2.	Number of fluids	a. Two fluid b. Three fluid c. N fluid (N>3)
3.	Design and constructional features	a. Tubular b. Plate type c. Extended surface d. Regenerative
4.	Surface compactness	a. Gas to fluid b. Liquid to liquid and phase change
5.	Flow arrangement	a. Single pass b. Multi pass
6.	Heat transfer Mechanisms	a. Single phase convection on both sides b. Single phase convection on one side and two phase convection on other side c. Two phase convection on both sides d. Combined convection and radiative heat transfer
7.	Physical state of fluids and process function	g. Condensers h. Evaporators i. Heaters j. Coolers k. Chillers l. Liquid to vapor phase change heat exchangers

The heat exchangers which are widely used in practice are shell and tube heat exchanger and plate heat exchanger [9]. Apart from this heat pipe heat exchanger is also used in many applications. The pictorial view of shell and tube heat exchangers, plate heat exchanger and heat pipe heat exchanger are depicted in figures 3, 4 and 5 respectively.

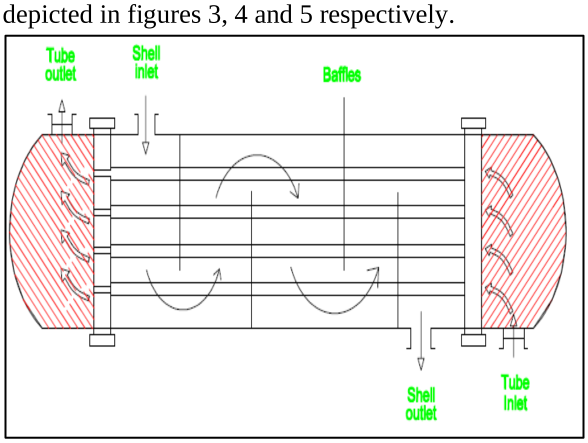

Fig.3 Shell and tube heat exchanger

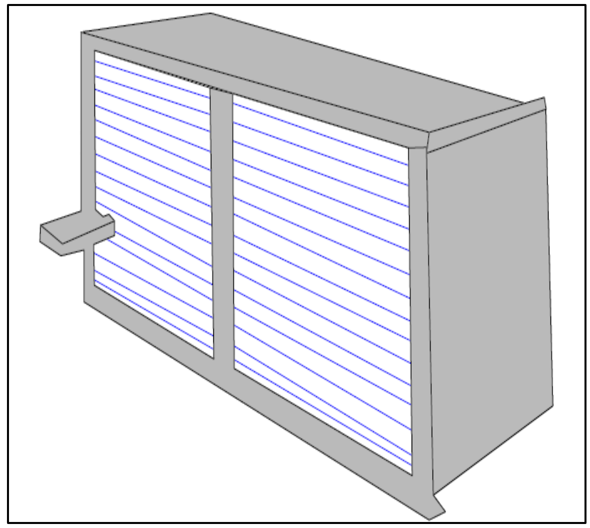

Fig.4 Plate heat exchanger

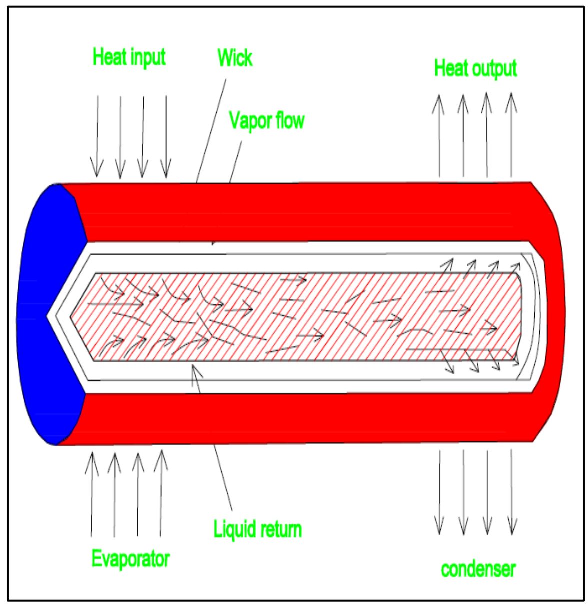

Fig.5 Heat pipe heat exchanger

IV. APPLICATIONS OF HEAT EXCHANGER

Heat exchangers are widely/extensively used in various applications in different fields such as chemical, mechanical, petrochemical, paper, jute and textile industries for the purpose of gaining or rejecting heat. When the heat exchangers are used in HVAC applications they are known as evaporator or condenser, when used in internal combustion engines it is known as radiator. When they are used in power plant domain they are known as superheater, air preheater, condenser, reheater or economizer. Furthermore heat exchangers are also used in a compressor where they are known as intercooler. Even though the name varies but the task remains the same, which is exchange of heat. Some of the applications of heat exchangers are as follows

1) Preheater: In a preheater input fluid is heated prior supply to the process. In many cases, preheating of fluid is carried out with waste heat. Hence, it saves energy as well as minimizes thermal shock stress. With respect to thermal power plants, live stream is trapped off and is used to preheat the condensate. In case of rotary or plate type heat exchanger, exhaust gas will be used to preheat the air. The figure 6 shows an air preheater.

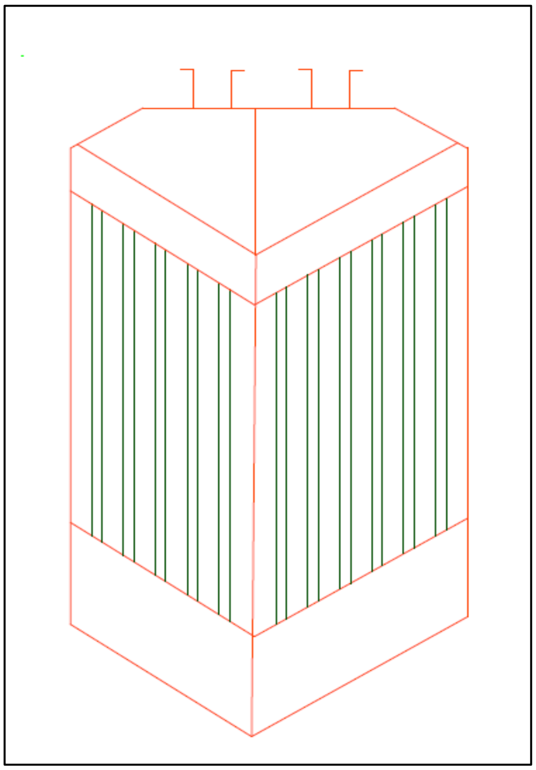

Fig. 6 Air Preheater

2) Evaporator and Condenser: In all vapor compression and vapor absorption cycle based HVAC systems, a minimum of two heat exchangers will be used. In an evaporator, the low temperature and low pressure refrigerant evaporates absorbing heat from the surrounding air or water. Whereas in a condenser, the high temperature and high pressure refrigerant condenses by rejecting heat to the surrounding air or water. figure 7 shows the pictorial view of an Evaporator

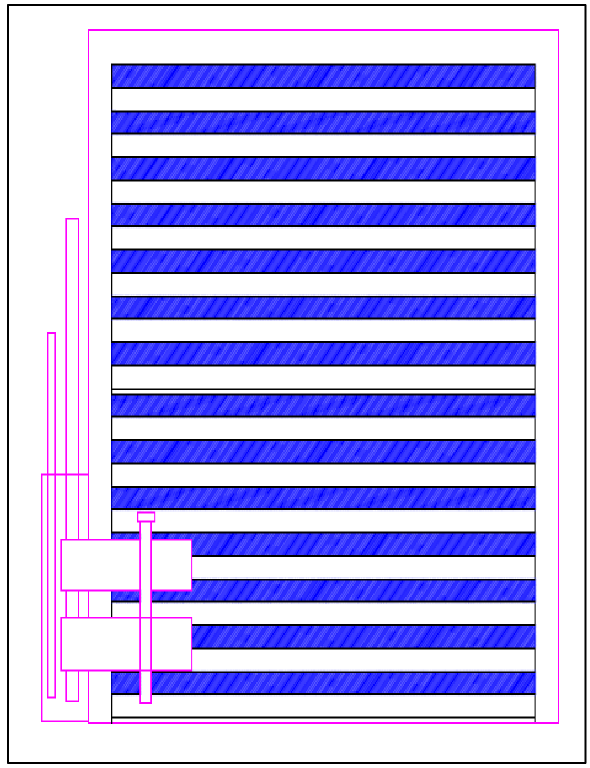

Fig.7 Evaporator

3) Radiator: In cars the most prevalent radiator is an air to liquid heat exchanger. Hot coolant is made to pass through the radiant tubes due to which it picks up heat from the engine and discharges it to the atmosphere. As air is a poor conductor it requires much larger surface area and therefore the radiator tubes are externally finned.

4) Steam condenser: It is a more widely used component in thermal power plants. In this heat exchanger, steam gives up its latent heat of condensation to the cooling water. After the steam condenses, the condensate temperature reduces and is sub cooled and collected in the bottom or condenser known as the hot well. Figure 8 depicts a steam condenser.

Apart from this, shell and tube heat exchangers find use in oil cooling and refining, preheating, steam generation, boiler blow down heat recovery and vapor recovery systems. The double heat exchangers are used in Industrial cooling processes and small heat transfer area requirements [22]. Plate heat exchangers finds application in cryogenic, food processing, chemical processing, furnaces as well as closed loop to open loop water cooling. Condensers and Evaporators are used in distillation and refinement processes, power plants, refrigeration and HVAC.

Compact heat exchangers are used in limited space requirements (example aircrafts), Automotive and electronics cooling.

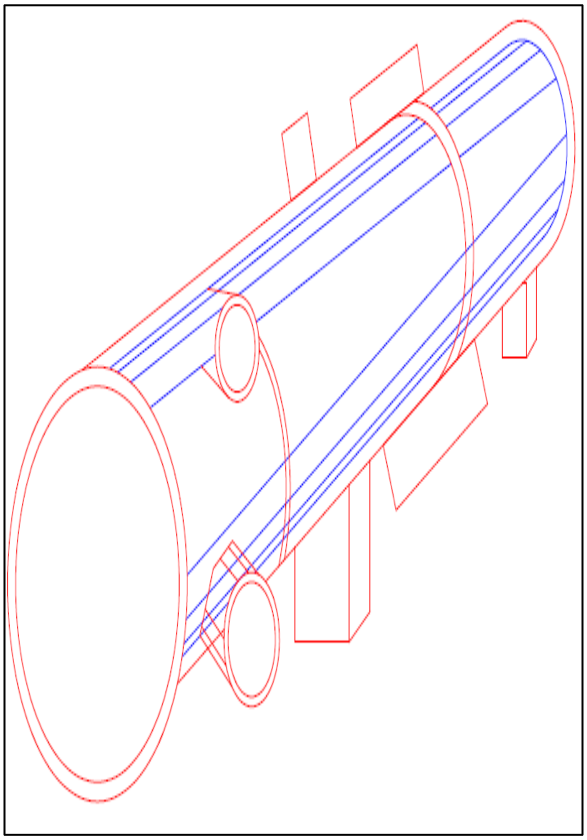

Fig.8 Stem condenser

In the R&D field heat exchangers are extensively used with Photovoltaic panel (PV) to absorb the excessive heat and thus the PV panel cools down significantly resulting in increase in efficiency of the PV panel. Various coolants are also used in conjunction with heat exchangers. This is the case where a PV system is allied to thermal (T) resulting in a PV/T hybrid system. The way how the heat exchanger is placed on the PV panel is a major task as various heat exchangers have different capacities of absorbing the heat. The types of heat exchangers employed in a PV/T system are plate heat exchanger, shell and tube heat exchanger, converging channel heat exchanger, plate fin heat exchanger, heat pipe heat exchanger etc. in this context if a heat exchanger is used with water as coolant then it is referred to as water heat exchanger and on the other hand if a heat exchanger is used along with air as coolant then it is referred to as air heat exchanger [3].

The figure. 9 depict the applications of heat exchanger in various domains.

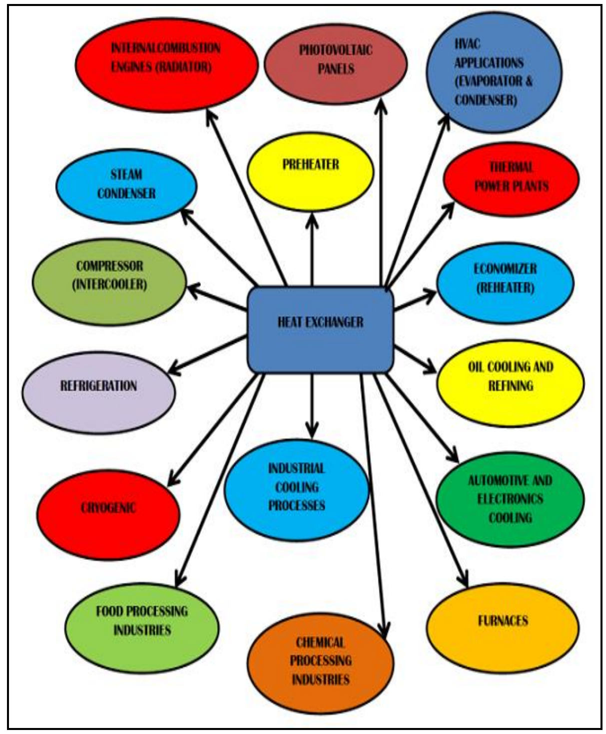

Fig.9 Heat Exchanger used in various sectors

V. EFFICIENCY IMPROVEMENT METHODS OF HEAT EXCHANGER

First and foremost thing in a system employing heat exchanger is to find out whether a heat exchanger is properly designed. If a heat exchanger is found oversized, required changes in flow, piping and construction may result in improved efficiency of the heat exchanger. Following are some of the methods to improve the efficiency of heat exchangers.

1) By using heat exchanger tube inserts

In this method heat exchanger tubes are inserted with spiral wires to increase heat transfer rate between hot and cold fluids. Tube inserts are most effective with high viscosity fluids in a laminar flow regime. Apart from enhanced heat transfer rate it also prevents formation of deposit and it breaks the boundary layer in tube side flow. Use of tube inserts are advisable for liquid type fluids having velocities in the range of 0.6 to 3 m/s and operating below 360°. In case of dirty hydrocarbon applications tube inserts are used to promote radial flow of fluid and this churning motion reduces the material deposits on the tube wall. Figure 10 depicts tube insert for heat exchanger.

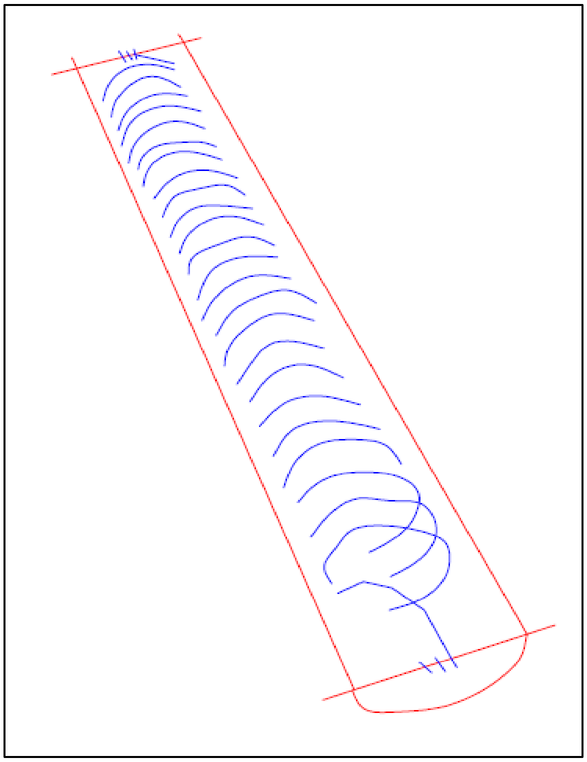

Fig.10 Tube insert for heat exchanger

2) By using Fins

Use of fins on a heat exchanger tube increases heat transfer rate. With the use of fins, the area of heat transfer and film Coefficient increase. Fins are usually attached on the low heat transfer coefficient side. The added performance results in higher pressure drop on the fin side fluid. Figure 11 shows the pictorial view of finned tubes.

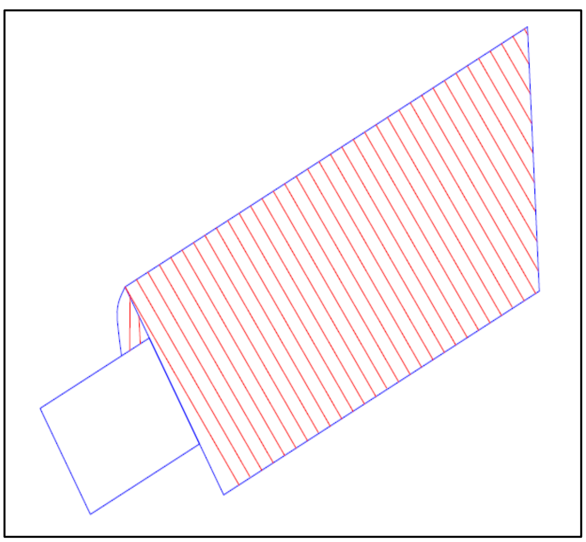

Fig.11 Finned tubes

3) By using Deformed tubes

Research shows that different deformations like corrugation, twist, or spirally fluted tubes increase heat transfer performance of a heat exchanger, of course at the cost of pressure drop. Deformed tubes increases turbulence and enhance boiling. Figure 12 shows the pictorial view of corrugated tube.

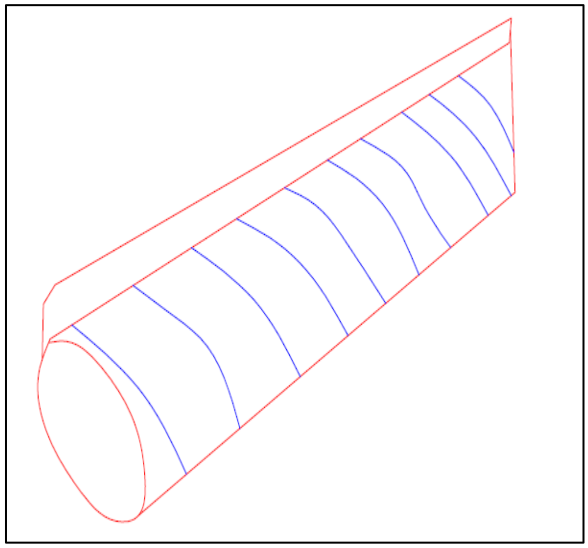

Fig.12 corrugated tube

4) By using Baffles

Baffles increase the flow passage of the shell side fluid and hence increase the efficiency of the heat exchanger. The basic type of baffle is a single segment baffle, which changes the direction of fluid and achieves cross flow arrangement. Baffles also leads to dead spots and vibration, which can overcome by proper baffle design. Use of helical baffles is more effective compared to conventional ones. Figure 13 shows spiral baffles used for a shell and tube heat exchanger.

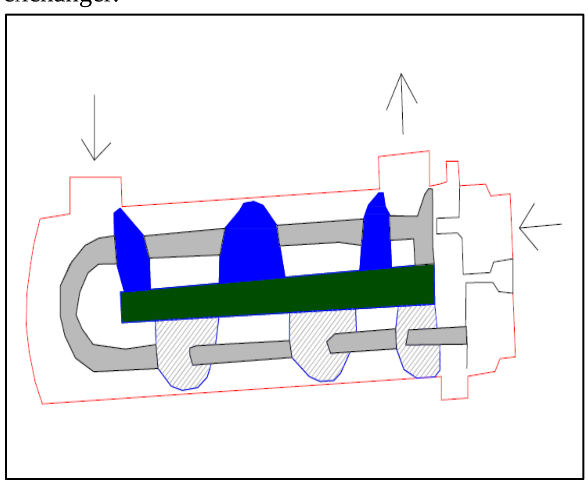

Fig.13 spiral baffles

VI. CONCLUSION

In this paper the importance of heat exchangers is emphasized in continued intensive research and development. The paper also brings out the working knowledge of heat exchanger fundamentals and provides a framework for producing material selection of heat exchangers. A variety of heat exchangers are available in the market. Shell and tube and plate type heat exchangers are commonly used heat exchangers. Economic and environmental factors are of utmost importance in selection of heat exchangers and improving the reliability of the same. A new thrust has been given to the use of heat exchangers employed in modern day applications. It is imperative to utilize the energy resources in the best possible way and the selection and use of suitable, economical and efficient heat exchangers is crucial in this endeavour.

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