Design Aspect of Shell and Tube Heat Exchanger Using Evacuated Tube Type Two Fluid Solar Water Heat Exchanger : A Review

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Abstract: *This paper deals with various methodologies adopted by present researcher for analysis of heat transfer by the help of shell and tube type heat exchanger using evacuated tube. This review will assist researchers working in the field of development of the exchanger design which analysis heat transfer area and pressure drops. The review includes key areas of researches as the development of various system components that includes the collector, heat transfer fluid and heat exchanger. This literature progressively discusses about the research methodology, experimental analysis done ,software's and the outcomes of the discussed researches and is intended to give the readers a brief variety of the researches carried out on the design the shell and tube heat exchanger using evacuated tube.*

Keyword: *Shell-and-Tube Heat Exchangers (STHE), Solar Water Heating System (SWHS), Finite Element Analysis (FEA), Evacuated Tube Solar Collector (ETSC), Heat Exchanger.*

I. INTRODUCTION

Solar water heating (SWH) systems have a widespread usage and applications in both domestic and industrial sector. Solar water heating is not only environmentally friendly but requires minimal maintenance and operation cost compared to other solar energy applications. SWH systems are cost effective with an attractive payback period, depending on the type and size of the system. Extensive research has been performed to further improve the thermal efficiency of solar water heating. SWH technology has matured and many different designs have attained commercialization yet there exists opportunities for further improvements in efficiency and reliability [1]. Most of these enhancements have focused on the problems associated with low ambient temperatures and the transitions in solar radiation ratios with respect to the season. From'80s to the current date, there has been an increasing interest to enhance thermal performance of SWH systems by means of improving the absorber plate characteristics, enhancing the thermal stratification of the storage tank, optimizing the design parameters and extending the heat-transfer area [16].

Fig-1:Shell and Tube Heat Exchanger of Type Water To Oil

II.   BRIEF INTRODUCTION

A solar water heater consists of a collector to collect solar energy and an insulated storage tank to store hot water. The solar energy incident on the absorber panel coated with selected coating transfers the hat to the riser pipes underneath the absorber panel. The water passing through the risers get heated up and are delivered the storage tank. The re-circulation of the same water through absorber panel in the collector raises the temperature to 80 C (Maximum) in a good sunny day. The total system with solar collector, storage tank and pipelines is called solar hot water system.

- *Direct* or *open loop* systems
- *Indirect* or *closed loop* systems

2.1 Introduction

A Solar Water Heating System (SWHS) is a device that makes available the thermal energy of the incident solar radiation for use in various applications by heating the water [25]. The SWHS consists of solar thermal collectors, water tanks, interconnecting pipelines, and the water, which gets circulated in the system. Solar radiation incident on the collector heats up the tubes, thereby transferring the heat energy to water flowing through it. The performance of the SWHS largely depends on the collector's efficiency at capturing the incident solar radiation and transferring it to the water. With today's SWHS, water can be heated up to temperatures of 60 °C to 80 °C. Heated water is collected in a tank insulated to prevent heat loss. Circulation of water from the tank through the collectors and back to the tank continues automatically due to the Thermosiphon principle [26].

2.2 Evacuated tubes

Evacuated tubes are the absorber of the solar water heater and they absorb solar energy converting it into heat for use in heating water. Evacuated tube consists of two glass tubes made from extremely strong borosilicate glass. The outer tube is transparent to allowing light rays to pass through with minimal reflection and the inner tube is coated with a special selective coating (Al-Nickel/Al) which features excellent solar radiation absorption and minimum reflective characteristics. The free ends of tubes are fused together with each other and the air contained in the space between the two layers of glass is pumped out to expose the tube to high temperatures. This vacuum plays an important role in the performance of the direct flow evacuated tubes

2.3 Evacuated tube solar collector (ETSC)

A variety of technologies exist to capture solar radiation, but of particular interest of authors is evacuated tube technology [27,28,29]. ETSCs have much greater efficiencies than the common FPC, especially at low temperature and isolation. The inner tube is coated with selective coating while the outer tube is transparent. Light rays pass through the transparent outer tube and are absorbed by the inner tube. Both the inner and outer tubes have minimal reflection properties. The solar collector of the domestic hot water system is an evacuated tube collector, which consists of a series of vacuum sealed glass tubes. all have an external glass envelope, an internal absorber plate, and a heat transfer pipe containing fluid [30] .The glass envelope is actually two glass tubes, one within the other, and joined at the exposed end to create a vacuum layer around the central absorber and heat pipe. The glass tubes are evacuated during manufacturing, which, at its end use, reduces the convective and conductive heat loss from the hot copper tubes to the cool ambient air. The sun's radiation penetrates the vacuum to the copper heat pipe and heats the internal fluid to a boil; which then causes it to rise to the bulb at the top of the tube. The manifold that spans the top of the collector contains and insulates the hot bulbs at the tops of each tube. Water from the solar loop enters the manifold and absorbs the heat from the bulbs in series, where it then exits the manifold as hot water. The inner tube gets heated while the sunlight passes through the outer tube and to keep the heat inside the inner tube, a vacuum is created which allows the solar radiation to go through but does not allow the heat to transfer. In order to create the vacuum, the two tubes are fused together on top and the existing air is pumped out. Thus the heat stays inside the inner pipes and collects solar radiation efficiently. Therefore, an ETSC is the most efficient solar thermal collector [29]. The performance of evacuated tube solar collectors is better when compared to flat plate collector in high temperature applications. So, the evacuated tube is considered to be an important component in thermal application, particularly in solar water heating systems [31]. Different parameters like optical design, optimum operating conditions, heat transfer in tubes and performance studies of solar collectors have been studied by several researchers [32-40]. Extracting heat from the evacuated tube is a major difficulty in evacuated tube solar collector applications [34]. Various designs of heat extraction manifold have been developed for single ended

evacuated tube. The fluid-in-glass and fluid-in-metal are the significant designs for better performance. Between the two, fluid-in-glass collector is widely used because of its low manufacturing cost and high thermal efficiency [31].

2.4 Heat Exchanger

A heat exchanger is a device that is used to transfer thermal energy (enthalpy) between two or more fluids, between a solid surface and a fluid, or between solid particulates and a fluid, at different temperatures and in thermal contact. In heat exchangers, there are usually no external heat and work interactions. Typical applications involve heating or cooling of a fluid stream of concern and evaporation or condensation of single or multi component fluid streams. In other applications, the objective may be to recover or reject heat, or sterilize, pasteurize, fractionate, distill, concentrate, crystallize, or control a process fluid. In a few heat exchangers, the fluids exchanging heat are in direct contact. In most heat exchangers, heat transfer between fluids takes place through a separating wall or into and out of a wall in a transient manner. In many heat exchangers, the fluids are separated by a heat transfer surface, and ideally they do not mix or leak. Such exchangers are referred to as direct transfer type, or simply recuperates. In contrast, exchangers in which there is intermittent heat exchange between the hot and cold fluids via thermal energy storage and release through the exchanger surface or matrix—are referred to as indirect transfer type, or simply regenerators. Such exchangers usually have fluid leakage from one fluid stream to the other, due to pressure differences and matrix rotation/valve switching. Common examples of heat exchangers are shell-and-tube exchangers, automobile radiators, condensers, evaporators, air pre-heater, and cooling towers. If no phase change occurs in any of the fluids in the exchanger, it is sometimes referred to as a sensible heat exchanger.
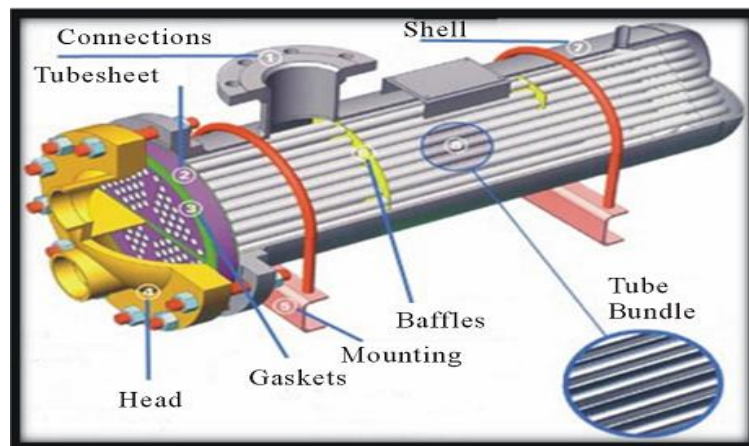

Fig 2: Major Components of a Typical STHE.

III. Previous Researchers

Shell-and-tube heat exchangers are the most common type of thermal equipment employed in chemical process industries. Shell and Tube heat exchangers are having special importance in boilers, oil coolers, condensers, pre-heaters . They are also widely used in process applications as well as the refrigeration and air conditioning industry. The robustness and medium weighted shape of Shell and Tube heat exchangers make them well suited for high pressure operations [14]. A vast amount of the material is published regarding STHE which depicts various factors affecting the thermal efficiency of the STHE. On the basis of that a brief summary is reviewed as follows:

An experimental and theoretical analysis done by **Gaddis and Gnielinski [1]** for evaluating the shell side pressure drop in shell-and-tube heat exchangers with segmental baffles. In this analysis, correlations for calculated the pressure drop in an ideal tube bank coupled with correction factors, which take into account the influence of leakage and bypass streams, and on equations for calculating the pressure drop in a window section from the Delaware method. The measured shell side pressure drop was compared with the shell side pressure drop, calculated by the help of computational procedure. The expected deviations between actual and calculated pressure drops will lie then most probably within + 35%. Comparison between experimental measurements and theoretical predictions for experimental points having geometrical and operational parameters within the ranges shown in fig
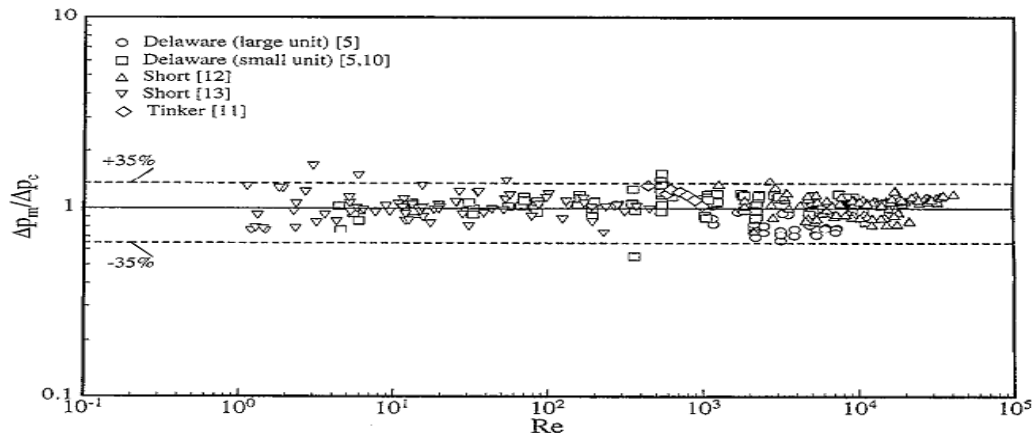
Fig.3: Comparison Between Experimental Measurements And Theoretical Predictions For Experimental Points Having Geometrical And Operational Parameters Within The Ranges

Thermal behavior of the shell-side flow of a shell-and-tube heat exchanger, was analyzed by **Baghban et al. [2]** using theoretical and experimental methods. The experimental method provided the effect of the major parameters of the shell-side flow on thermal energy exchange and in the numerical method, besides the effect of the major parameters, the effect of different geometric parameters and Reynolds no (Re) on thermal energy exchange in shell-side flow has been considered. Numerical analysis for six baffle spacing's namely 0.20, 0.25, 0.33, 0.50, 0.66, and 1.0 of inside diameter of the shell and five baffle cuts namely 16%, 20%, 25%, 34%, and 46% of baffle diameter, have been carried out.

A computer-based design model prepared by **YUSUF [3]** , for shell and tube heat exchangers with single phase fluid flow both on shell and tube side. The program was developed to determined the shell, the tube bundle, and optimum heat transfer surface area required to maintained the specified heat transfer duty by calculated minimum or allowable shell side pressure drop. The result carried out of the total number of 240 exchangers was restricted to single-segmental baffle having 25% baffle cut that is most frequently used, triangular-pitch layout that results in greatest tube density.

An Analytical expression presented by **Serna and Jimenez [4],** which relate the shell-side pressure drop with the exchanger area and the film coefficient based on the full Bell–Delaware method. In addition to the derivation of the shell side compact expression, they developed a compact pressure drop equation for the tube-side stream, which accounts for both straight pressure drops and return losses. For an efficient design algorithm, compact formulation is used and found a satisfactory performance of the proposed algorithms over the entire geometry range of single phase, shell and tube heat exchangers.

For calculating shell side heat transfer coefficient in a single segmental shell and tube heat exchanger, a chart method used by **Ayub [5]**. In this method of chart , product of actual data taken over a span of several years. The carried out results were compared with known methods and commercial/proprietary computer codes prevalent in the industry. The results from this method compared with HTRI computer program which was more reliable and comparable to the HTRI software.

A Genetic Algorithm (GA) applied by **Resat et al. [6]** for the optimal design of shell-and-tube heat exchanger by varying the design variables. The given design variables were outer tube diameter, tube layout, number of tube passes, outer shell diameter, baffle spacing and baffle cut. They concluded that the combinatorial algorithms such as GA provided significant improvement in the optimal designs compared to the traditional designs. GA application for determined the global minimum heat exchanger cost was significantly faster and had an advantage over other methods in obtaining multiple solutions of same quality.

Another researcher, **Hosseini et al. [7]** done a experimentally analysis on Heat transfer coefficient and pressure drop on the shell side of a shell-and-tube heat exchanger. Three different types of copper tubes (smooth, corrugated and with micro-fins) are analysis and compared theoretical data available. The result carried out from   Experimental analysis 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.

Later, **Babu and Munawarb [8]** studied first time DE, an improved version of genetic algorithms (GAs), has been successfully applied with different strategies for 1,61,280 design configurations using Bell's method to find the heat transfer area. In the application of DE, 9680 combinations of the key parameters are considered. For comparison, GAs are also applied for the same case study with 1080 combinations of its parameters. For this optimal design problem, it is found that DE, an exceptionally simple evolution strategy, is significantly faster compared to GA and yields the global optimum for a wide range of the key parameters.

Genetic Algorithm(G.A) was used to analysis by **Xie et al. [9]** of Compact Heat Exchanger (CHE). Genetic Algorithm (GA) used to search, combine and optimize structure sizes of the CHE. Genteic Algorithm flow chart is shown fig. The geometries of the fins were fixed while three shape parameters are varied for the optimization objectives with or without pressure drop constraints, respectively. Performance of the CHE was evaluated according to the conditions of the structure sizes that the GA generated, and the corresponding volume and cost are calculated. It is shown that with pressure drop constraints the optimized CHE provides about 30% lower volume or about 15% lower annual cost, while without pressure drop constraints the optimized CHE provides about 49% lower volume or about 16% lower annual cost .
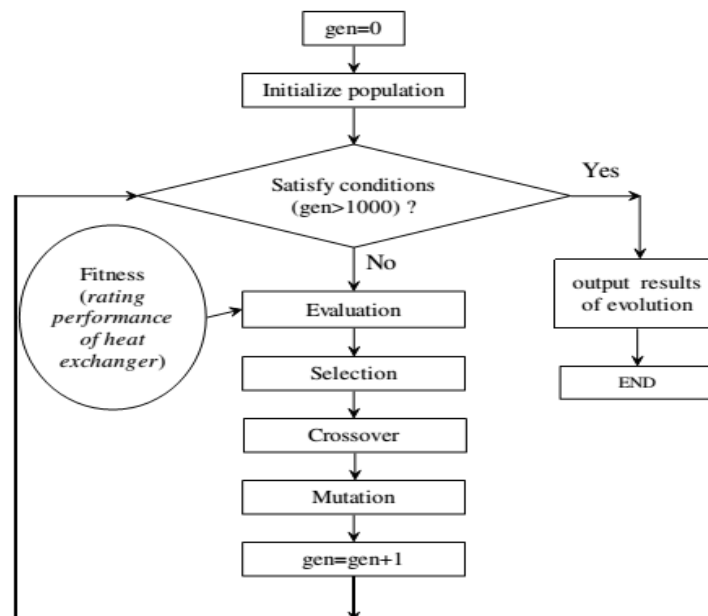

Fig.4: Flow chart of Genetic Algorithm (GA).

Later, **Costa [10]** studied the design optimization of shell-and-tube heat exchangers, consists of the minimization of the thermal surface area for a certain service, involving discrete decision variables. The heat exchanger rating code implemented for the solution of the examples employs the following thermo flui-dynamic equations:

- the Bell Delaware method is used for shell side film coefficient and pressure drop evaluation
- for tube side film coefficient calculations, the Gnielinski correlation is utilized in turbulent flow, the Sieder and Tate correlation is employed in developing laminar flow and Nusselt number equals to 3.66 is used in established laminar flow;
- for tube side pressure drop, the Darcy equation is used together with an expression for the pressure drop in the exchanger heads

The optimization algorithm is based on a search along the tube count table where the established constraints and the investigated design candidates are employed to eliminate non optimal alternatives, thus reducing the number of rating runs executed.

José M. Ponce-Ortega et al [11] presented an approach based on genetic algorithms for optimum design of shell and tube heat exchanger and for optimization major geometric parameters such as the number of tube-passes,

standard internal and external tube diameters, tube layout and pitch, type of head, fluids allocation, number of sealing strips, inlet and outlet baffle spacing, and shell side and tube-side pressure drops were selected. Genetic algorithms provide better expectations to detect global optimum solutions than gradient methods, in addition to being more robust for the solution of non-convex problems.

Later, **Fesanghary et al. [12]** explores the use of global sensitivity analysis (GSA) and harmony search algorithm (HSA) for design optimization of shell and tube heat exchangers (STHXs) from the economic viewpoint. Comparing the HSA results with those obtained using genetic algorithm (GA) reveals that the HSA can converge to optimum solution with higher accuracy.

JiangfengGuo et al. [13] studied geometrical 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 exchanger effectiveness significantly, but also decrease the pumping power dramatically.

GopiChand [14] studied of thermal analysis of shell-and-tubes heat exchangers of water and oil type. Thermal analysis by using theoretical formulae are done on shell and tubes heat exchanger. Geometric model of shell and tube heat exchanger is design using Pro-e and done the thermal analysis by using Floefd software. They compared obtain result from Floefd software and theoretical formulae. Theoretical calculations were done on Matlab code, which is useful for calculating the thermal analysis of a counter flow of water-oil type shell and tube heat exchanger. The result obtained an error of 0.023in effectiveness by using the thermal analysis.

Another researcher , **Patel and Rao [15]** studied optimization technique called particle swarm optimization (PSO), for design optimization of shell-and-tube heat exchangers from economic view point. Three design variables such as shell internal diameter, outer tube diameter and baffle spacing are considered for optimization. Two tube layouts viz. triangle and square are also considered for optimization. The results were compared with those obtained by the previous researchers. PSO converges to optimum value of the objective function within quite few generations and this feature signifies the importance of PSO for heat exchanger optimization.

Later, **Rathore and Bergaley [16]** studied on low-finned tube Heat Exchangers over Plain tube (Bare Tube) units. The result carried out of finned tube heat exchanger is more economical than Conventional Bare tube Exchanger. The tube side pressure drop and fluid velocity is higher than the conventional bare tube exchanger, which prevent fouling inside the tubes. The shell side pressure drop is some lesser but fluid velocity is higher than the conventional heat exchanger which saves the outer surface of tubes from fouling creation and fluid transfer time. The shell diameter of finned tube Exchanger is lesser than Conventional bare tube heat exchanger, which saves sheet material and reduces the size of the shell, which helps to easily installation in the plant.

Later, **Kotwal and Patel [17]** did Finite Element Analysis (FEA) on Computational Fluid Dynamics (CFD) analysis in the field of heat exchanger by using Different turbulence models available in CFD tools i.e. Standard k-ε model, k-ε RNG model, Realizable k-ε, k- ω and RSM model in conjunction with velocity pressure coupling scheme. They concluded the steady increase in computing power has enable model to react for multi- phase flows in realistic geometry with good resolution and the quality of the solution has proved that CFD is effective to predict the behavior and performance of heat exchanger.

Thermal analysis of shell and tube type heat exchangers of water and oil type studied by **HariHaran et al. [18].** The robustness and medium weighted shape of Shell and Tube heat exchangers make them well suited for high pressure operations. The thermal analysis by using theoretical formulae for counter flow shell and tube heat exchanger of water and oil type and designed a geometric model of shell and tube heat exchanger using ProE. Thermal analysis done by using ANSYS software and compared both result obtained from ANSYS software and theoretical formulae. For simplification of theoretical calculations ,C code was used calculating the thermal analysis of a counter flow of water-oil type shell and tube heat exchanger. The carried out result was getting an error of 0.0274 in effectiveness.

An experimental analysis was conducted by **Kirtan [19]** on shell and tube type heat exchanger .In this experiment analysis, parameter viz. design of shell and tube type heat exchanger baffle is changed. Performance in terms of effectiveness for normal flat baffle and for helical baffle ,cutting ratio was measured and compared them. The result

carried out that effectiveness of helical baffle is high compared to flat baffle for same inlet temperature of hot water and cold water.

Kirubadurai et al. [20] was designed the new shell and tube heat exchanger which analyzed of orifice baffle and convergent divergent tube in a shell and tube heat exchanger. The result from the experimental analysis obtained a maximum heat transfer coefficient and a lower pressure drop. From the numerical experimentation, the result shows that the performance of heat exchanger increases in modified baffle and tube than the segmental baffle and tube arrangement. The aspected result carried out by them are follow:-

- From the Numerical Experimentation Results it is confirmed that the Performance of a Tubular Heat Exchanger can be improved by modified heat exchanger instead of Segmental heat exchanger.
- Use of modified Baffles in Heat Exchanger Reduces Shell side Pressure drop, pumping cost, weight, fouling etc. as compare to Segmental Baffle for a new installation.
- The Ratio of Heat to increase cross flow area resulting in lesser mass flux throughout the shell Transfer Coefficient to Pressure Drop as higher than that of Segmental Baffle.
- The Pressure Drop in modified Baffle heat exchanger is appreciably lesser as Compared to Segmental Baffle heat exchanger
- Modified Baffle is the much higher than the Segmental baffle because of Reduced by Pass Effect &Reduced shell side Fouling. The modified heat exchanger is twice higher than the Segmental heat exchanger.

An experimental analysis done by **Surendran and Suresh [21],** on heat transfer enhancement techniques in double pipe heat exchange. The parameters analyzed in the experiment set up are the outlet and inlet temperatures of both inner and outer tube, the heat transfer coefficients and the heat exchanger effectiveness. They concluded that the trapezoidal cut twisted tape method provided the higher rate of the heat transfer than other methods.

Another researcher, **SrinivasaRao et al. [22]** studied inlet temperature of shell and with a given bundle arrangement of square pitch. The thermal analysis was done on the design of shell and tube exchanger using Kern method for water and steam combination is validated by well-known Dittus-Boelter equation of turbulent flow inside tube. The analysis was extended with different fluid combinations such as sulphur-dioxide on the tube side steam on shell side and carbon-dioxide side on tube side and steam on shell side. From analysis result concluded of shell and tube heat exchanger for three different fluid combinations (water-steam, CO2-steam and SO2-steam) using kern's method are follow

a. Parameters the values for Nusselt number, Reynolds number, heat transfer coefficient, and pressure drop and friction factor are determined.

b. Validation for Nusselt number on tube side for water using (petukhov equation) is compared with well known Dittus-Boelter equation with a deviation of 10 percent.

c. From the data arrived and drawn it is found that as Reynolds number increases Nusselt number increases and friction factor decreases both tube and shell side fluids.
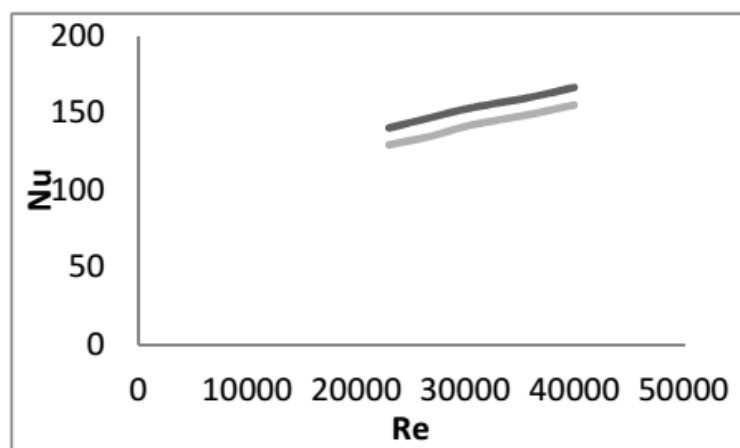

Fig.5: Variation of Nu vs. Re

Analysis on Tube Bundle Geometry in Shell and tube heat exchanger was done by **DurgeshRai [23]**, Orientation of tube layout had a significant influence on tube side pressure drop and heat transfer of the heat exchangers. The result carried out of the following were the noticeable results found:

1. Increase in Heat exchanged by 11.04%.
2. Decrease in pressure drop in tube side by 29.59%.
3. Decrease in heat transfer coefficient in tube side by 11.2%.
4. Increase in Uf and Uc by 1.97% & 0.5% respectively.

A FEA analysis done by **Kiran et al.[24]** on 125KVA diesel generator which loses the exhaust gases at a temperature of 350°C. waste heat was recovered by replacing the silencer of the power plant by a heat exchanger. Fluid flow in the Heat exchanger was considered as a fluid dynamic problem and was modeled using finite element method software CREO 2. The flow field in the tube due to the oscillation conditions of inlet flow is analyzed. Next the modeled Heat exchanger is to be Computational Fluid Dynamics (CFD) software ANSYS FLUENT. the result carried out about 72% of heat is recovered and 28% heat is lost to the atmospheres by the help of FEA analysis.
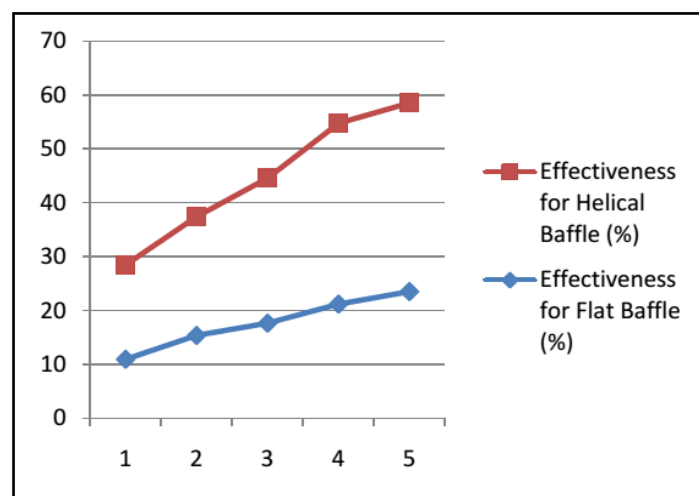

Fig : Diagram of Effectiveness

IV.   CONCLUSION

This work has provided a comprehensive literature review of existing research carried out in terms of design, and analysis of Shell and Tube Heat Exchanger Using Evacuated Tube Type Two Fluid Solar Water Heat Exchanger. An effort has been made to comprise all the important contributions to this area and highlighting the most pertinent literature available for investigating the hub and upright assembly. The concluding remarks and future work from the current literature survey are as follows:-

    i.   From the review of available literature on shell and tube heat exchanger using evacuated tube type two fluid solar water heat exchanger, it is apparent that nearly all the research conducted has been purely simulation based on finite element method.

    ii.   For calculating of shell and tube heat exchanger using evacuated tube type two fluid solar water heat exchanger different types of design are available.

    iii.   The FEA is a useful tool since they provide accurate results to access shell and tube heat exchanger using evacuated tube type two fluid solar water heat exchanger

    iv.   Most of the shell and tube heat exchanger using evacuated tube type two fluid solar water heat exchanger was done in various condition, simulating actual working conditions in software.

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