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Review on the Performance Evaluation of Thermal Exchangers using Different Baffle Designs

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Abstract: **The thermal performance of a heat exchanger depends upon various parameters like inlet temperature of hot fluid, type of hot fluid, type of cold fluid, the shape of baffles, the material of baffles, baffles angle, and property of ribs. Basically fluid flow and heat transfer characteristics largely depend upon the Reynolds number (Re). Reynolds number is basically the ratio of inertia force to viscous force. Re is only the factor by which we can decide whether the fluid is laminar or turbulent in shell and tube type of heat exchanger. The heat exchanger is an adiabatic device in which heat is transferred from one fluid to another fluid across a plate surface. In this paper, we have introduced some special types of triangular baffles with rectangular channels. The purpose of this apparatus is to enhance the performance of the heat exchanger. Heat exchangers, nowadays, are one of the most important heat & mass transfer apparatuses in industries like oil refining; heat treatment plants, electric power generation, etc. are long service life.**

Keywords: Heat Exchanger, Baffle, Heat Transfer, Reynolds number, CFD, Ribs, Baffle Angle, Helical Baffle, Triangular Baffles, Baffle Geometry.

I. INTRODUCTION

The devices that exchanges heat between two or more substances are referred as Heat Exchangers. In heat exchangers at various temperature, fluids, vapors, or gases are transferred. The process of exchanging heat can be gas to gas, liquid to gas, or liquid to liquid, and it can take effect throughout a divider which exists in solid state and restricts combining of liquids, either via straightforward contact with the liquid, this totally depends on the design of heat exchanger employed. Numerous different new designs, such as structural components, heat transfer techniques, and flow arrangements, also aid in classifying and categorizing the various types of heat exchangers [1].The use of baffled type channels is one of the commonly used passive heat transfer enhancement strategies in single-phase internal flow. This passive heat-transfer enhancement strategy has been used for various types of industrial applications such as heat exchanger, furnace design, nuclear reactor electronic cooling devices, thermal regenerators, internal cooling system of gas turbine blades and turbomachines.

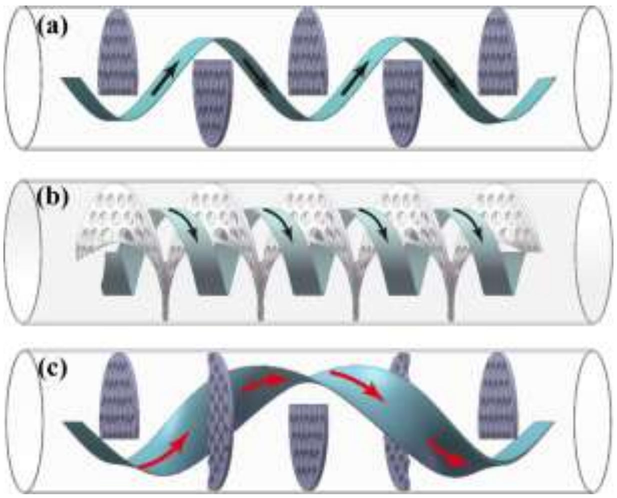

Fig. 1 Schematic diagrams of the main flow manner[9]

The diagram shown above are of (a) Shell and tube heat exchangers with segmented baffles (STHX-SG), (b) shell and tube heat exchangers with continuous helical baffles (STHX - CH) and (c) the shell and tube heat exchangers with staggered baffles (STHX-ST).The shell and tube heat exchanger (STHX) is one of the most widely used heat exchangers owing to its versatile usability, convenient maintenance, high-pressure resistance, and high-temperature resistance. The flow manner of the working fluid in the shell-side of the STHX can be divided into three types roughly: the cross flow, the longitudinal flow, and the helical flow. The conventional shell and tube heat exchanger with segmental baffles (STHX-SG), of which a cross flow is presented in the shell-side as illustrated in Fig. 1(a),is the most common STHX because of its simple installation, low cost, and high heat transfer performance.shell and tube heat exchanger with continuous helical baffles (STHX-CH), and the ideal helical flow was generated in the shell-side, as depicted in Fig. 1(b). However, the complexity of the fabrication about helical baffles wasunavoidable, which increased the manufacturing cost relative to the STHX-SG, obviously.shell and tube heat exchanger with staggered baffles (STHX-ST) in view of taking the advantage of both the simple fabrication of the STHX-SG and the helical flow of STHX-CH, as outlined in Fig. 1(c). In the STHX-ST, the baffles are arrayed according to a certain rule that the adjacent baffles are staggered by a constant clockwise or counterclockwise angle in sequence. The fabrication and installation for staggered baffles are quite simple compared with those for helical baffles.

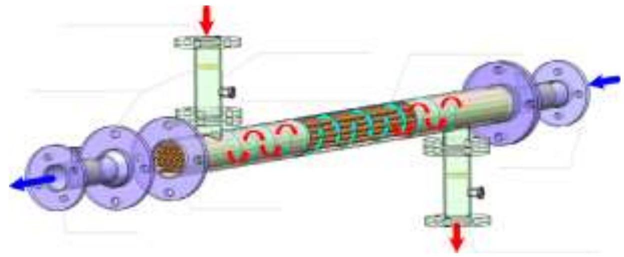

Fig. 2 Schematic diagram of the Shell and Tube Heat Exchangers with Segmented Baffles[7]

In the solar and nuclear plants, the molten salt shell-and-tube heat exchanger (STHE) is one of the critical units where the water medium could be heated sharply and then transferred into superheated steam with higher pressure and temperature. Thus, the thermal efficiency of plants is influenced significantly by the heat transfer performances (HTPs) of the molten salt STHE. Particularly, the molten salt STHE with segmental baffles (STHE-SBs) is one of the most common heat exchangers, which can improve the HTPs by enhancing the turbulence in the shell side of STHE-SBs. Fig. 2 depicts the diagram of shell and tube heat exchangers with segmented baffles.

Repeated ribs or turbulators have been used as the promoters of turbulence to enhance the heat transfer to the flow of coolants in a channel. These roughness elements break the laminar sub-layer of the flow. The heat transfer is enhanced as well as the pressure drop, an important parameter in the analysis of the overall performance of such flows. Investigations have been conducted to predict the effect of the number of ribbed walls on heat transfer and friction characteristics. Rib turbulators are widely used in gas turbine cooling. These turbulators are installed on the two opposite sides of the cooling channel. In some cases, rib turbulators are casted on one side or four sides of the cooling channel. In spite of turbine blade internal cooling has been widely considered in the past studies, there are other applications such as heat exchangers, electronic equipment and nuclear reactors and may use the results of enhanced internal cooling in channels with one, two or four rib-roughened walls.

Like jet impingement, ribs, and other heat transfer enhancement techniques, insertion of baffles in heat transfer devices is popular to promote better mixing of the coolant and increase cooling performance [2]. Applications of the inclined baffles may be in the large land based modern gas turbines, in which it has become a growing trend to increase the temperature of the combustion product to increase the specific thrust and to reduce the specific fuel consumption. Such a high temperature is far above the allowable temperature of super alloys and thermal barrier coatings (TBC) used in gas turbine blades. In gas turbine, usually air is used in the interior side of the blade to maintain the blade at the proper working temperature. Also in a number of other engineering and industrial applications such as, air-cooled solar collectors, laser curtain seals, labyrinth shaft seals, compact heat exchangers, and microelectronics, air is preferred as a coolant for its lightweight. However, due to the very low thermal conductivity internal cooling with gases is less effective than cooling with liquids. There are several techniques available to enhance the heat transfer coefficient of gases in internal cooling. The most commonly used technique for internal cooling enhancement is the placement of periodic ribs. Ribs are generally mounted on the heat transfer surface, which disturbs the boundary layer growth and enhances the heat transfer between the surface and the fluid. These ribs are small and do not disturb the core flow and therefore, the turbulence enhancement and boundary layer break down are mostly localized near the heat transfer surface.

Heat exchangers are the popular gadgets used in marketplace including both refrigerating and heating mechanisms. It works by exchanging temperatures in between at least 2 different mediums that operate at various temperature levels. Numerous types of heat exchangers (HEX), such as plate and shell, adiabatic wheel, pillow-plate, plate-fin, shell-tube, vibrant scraped surface, and others, have been recently developed to enhance the accuracy and capabilities of major industries. Shell and tube heat exchangers (STHX) have piqued the investigators' interest because they are used during 35–40% of chemical reaction industries throughout the world[3].

II. LITERATURE REVIEW

HouariAmeur et al. [4] Results on the flow fields and thermal distribution in a rectangular channel heat exchanger are provided in this paper. The baffling technique is used to enhance the performance of such systems. Effects of the inclination angle of baffles and the direction of inclination are investigated.

YounesMenni et al. [5] The turbulent convective thermal transfer in channel heat exchangers (CHEs) is studied numerically via the CFD (Computational Fluid Dynamics) method. Deflectors are inserted on the hot bottom walls of the heat channel to enhance the hydrothermal characteristics. Various shapes of in-line deflectors are considered, namely: rectangular (a/b = 0.00), cascaded rectangular-triangular (a/b = 0.25, 0.50, and 0.75), and triangular (a/b = 1.00) shapes. From the obtained results, the inclusion of in-line deflectors with a/b = 0.75 has given the most significant thermal enhancement factor, which was higher than that for a/b = 0.00, 0.25, 0.50, and 1.00 by about 5.36, 5.06, 67.27, and 3.88%, respectively.

HouariAmeur et al. [6] The present paper is a numerical investigation on the performance of perforated baffles in a plate-fin heat exchanger. Two types of perforations are studied, namely the circular and elliptical shapes. Values of heat transfer coefficient, pressure drop and thermal performance factor are determined for both cases and compared with those for a smooth channel. The obtained results showed a good enhancement in the thermal performance factor by the suggested design in baffles. In the case of low viscous fluids, the elliptical perforated baffle performs better (by about 63.4%) than the circular one for all values of Re. But for highly viscous fluids, the elliptical perforation shows higher thermal performance than the circular hole by about 25% for low Re and 27% for high Re. The overall thermal performance factors are about 1.55 and 1.74 for the circular and elliptical perforations, respectively.

Aadil Ahmad Rather et al. [7] This paper provides a brief research background on shell and tube heat exchangers. Shell and tube heat exchangers find a great use in industries for cooling and heating purposes. Many successful efforts have been made from years to increase the performance of STHXs. These efforts mainly include the variations in baffle types. Varying baffle types or baffle angles do provide a vast field to work on. There are many configurations given to baffles which provided better results at different stages of their usage. Many more alterations can still be done in STHXs to give better performance. These alterations can be done to different parts of STHX. This paper gives sum of such alterations which were successful and left enough traces for future to work on.

YounesMenni et al. [8] In this analysis, the baffling method is used to increase the efficiency of channel heat exchangers (CHEs). The present CFD (computational fluid dynamics)-based work aims to analyze the constant property, steady, turbulent, Newtonian, and incompressible fluid flow (air), in the presence of transverse-section, arc-shaped vortex generators (VGs) with two various geometrical models, i.e., arc towards the inlet section (called arc-upstream) and arc towards the outlet section (called arc-downstream), attached to the hot lower wall, in an in-line situation, through a horizontal duct. For the investigated range of Reynolds number (from 12,000 to 32,000), the order of the thermal exchange and pressure loss went from 1.599–3.309 to 3.667–21.103 times, respectively, over the values obtained with the unbaffled exchanger.

Mohamed Salmi et al. [9]The hydrothermal behavior of air inside a solar channel heat exchanger equipped with various shaped ribs is analyzed numerically. The bottom wall of the exchanger is kept adiabatic, while a constant value of the temperature is set at the upper wall. The duct is equipped with a flat rectangular fin on the upper wall and an upstream V-shaped baffle on the lower wall. The obtained results indicated that the triangular-shaped rib has the most significant hydrothermal behavior than the other cases. This indicates the necessity of roughness heat transfer surfaces for finned and baffled channels to improve significantly the performance of the air-heat exchangers they contain.

Ali J. Chamkha et al. [10] Numerical studies of the steady incompressible turbulent forced-convection flow around top and bottom surface-mounted staggered baffles as a function of the Reynolds number are considered in this recent contribution in order to examine two various geometries of solidtype baffles, a flat rectangular baffle (simple obstacle) and an arc-shaped baffle (new obstacle). Air is the heat transfer fluid with the Reynolds numbers ranging from 12 × 103 to 32 ×103. The dynamic thermo-energy model of air is governed by the Reynolds averaged Navier-Stokes equations with the Standard k-ε turbulence model and the energy equation.

Benyoucef B et al. [11] Characteristics of fluid flow and heat transfer are analyzed for a constant property fluid flowing turbulently through a two-dimensional horizontal rectangular cross section channel with staggered, transverse L-shaped baffles (STLBs) and a constant temperature along both walls. The Commercial CFD software FLUENT 6.3 is used to simulate the fluid flow and heat transfer fields. As a part of the same package, a preprocessor Gambit is used to generate the required mesh for the solver. The results reveal essentially, that the flow pattern of using STLBs is characterized by strong deformations and large recirculation regions. The highest values in the velocity and pressure fields are found near the top channel wall with an acceleration process that starts just after the second STLB.

Ahmed Azzi et al. [12] This is an original work as it uses a novel method for improving the heat transfer in a completely new flow geometry. The present research aims to conduct a computational fluid dynamical analysis on a turbulent-flow forced convection, in the presence of two transverse 450 V-upstream baffles, placed in an overlapping manner, inside a horizontal two-dimensional rectangular section channel. The channel width to height aspect ratio, channel length-to-aeraulic diameter, V-baffle spacing-to-channel height ratio, and V-baffle height to channel height blockage ratio are fixed at W/H = 1.321, L/Dh = 3.317, Pi/H = 0.972, and h/H = 0.547, respectively. The Reynolds number is varied from 12,000 to 32,000. The mathematical equations that describe the fluid flow and heat transfer in the computational domain, i.e., continuity, momentum, and energy, were solved using the finite volume method with the standard k- model to describe the turbulence.

W. Jian et al. [13] This paper proposes an enhanced structure in the arrangement of ladder-typed fold baffles to block triangular leakage regions. The shell-side flowing trends in STHXs-Helical Baffles were studied using a CFD simulation. The calculations showed that due to the obstruction of triangle-shaped leakage regions, the tangential and radial rate of change in the enhanced heat exchanger tends to increase noticeably, as well as a more uniform velocity allocation is attained.

Wang et al. [14] The heat exchange and flow resistance features of the Fin Baffle shell and tube heat exchangers (FB-STHX) and SB-STHX have already been evaluate with the help of experiments. There are certain performance comparisons in between FB-STHX and SB-STHX. Obtained from the experimental outcomes, the heat exchange and flow resistivity correlations for SB-STHX and FB-STHX were constructed. The exploratory findings confirmed that when the Re number on both the shell - and - tube sides would be the equal, the Nusselt number Nu for FB-STHX is about half that of SB-STHX, and the pressure loss of the aforementioned is about a third that of one or the other.

Xiao et al. [15] The heat exchange and fluid flowing performance of heat exchangers with various baffle tilt angles were investigated by employing the CFD technique inside this article. After discussing the impact of baffles and heat exchanger length on heat transfer features, a new viewpoint was offered, stating that comparing heat transfer performance between various thermal exchangers is better addressed under another necessary heat transfer capability. Various kinds of fluid flow then were used in the study to unveil the impact of Prandtl number on performance of heat transfer.

AbbasianArani et al. [16] In this study, the Computational fluid dynamic technique is used to identify the thermos-hydraulic actions of STHE in a three - dimensional geometry with novel baffles and ribbed tube. Because of the directional motion of the liquid all along axial direction of the pipes, the pressure loss reduces. In comparison to the familiar SB-STHE, the DiskBaffle–STHE (DB-STHX) and Combined segmental-disk baffle shell and tube heat exchanger (CSDB-STHE) dramatically eliminate the pressure loss on the sidewall of the shell, according to the finding of this research. Temperature distribution is also improved with novel pipes, thanks to the ribbed tube's boosting area for heat exchange.

El-Said &Abou Al-Sood et al. [17] An established the concept of heat, thermo-dynamic, and hydraulic assessments and performance evaluation of STHE with four distinct baffle architectures (CSSB, SSSB, FSB, and HSB) is presented in this work.

Wang et al. [18] The authors introduces a shell - and - tube exchanger connected to staggered baffles (STHXST). The STHX-ST attained the features of the STHX-simple SG's preparation and the STHX-helical CH's flow. Numerical assessments of effective thermal conductivity and pressure loss were performed for the three STHX. For the STHX-ST, the impact of various values, like the baffle cut and the staggered angle, were analysed and discussed. The STHX's multiple objective approach is carried by using a pairing of CFD, ANN, and GA.

Andrzejczyk et al. [19] To enhance the energy efficiency of the shell coil exchanger of heat, the paper presented a passive heat exchange enhancement technique in the form of truly innovative baffle configuration. Natural convection has an essential impact on the local Reynolds numbers as well as huge Richard's numerals owing to the existence of combined convection, as shown in this study. The effect of the provided heat flux valuation on the heat transfer rate is visible in all architectures.

E et al. [20] The flow ground and heat transport features of a baffle-cut heat exchanger of exhaust gas recirculation (EGR) in a diesel car are investigated using a 3-dimensional mathematical models at three distinct part loads in this study. To begin, an initial shell-and-tube exchanger with various EGR rates is designed to simulate to serve as a baseline for subsequent evaluations. However, some baffle-cut heat exchanger models are built, each with distinct neighboring baffle cuts but its the same overarching baffle cuts. Following that, all such new ones are designed to simulate under the same situations as the existing ones to make comparisons easier.

The above mentioned literature discusses about the work done by several researchers those who putted the efforts in their investigation including the parameters like different shapes of baffles, inclination angle and its direction, baffle cut, staggered angle, necessary heat transfer capability, perforated baffles and many more. Numerous researchers are working on boosting the effectiveness of thermal exchangers by modifying baffle topology. Shell and tube heat exchangers with segmental baffles are easier to design and less costly than most other baffles, but they are less comparable to another baffles in their classification. Recognizing how baffle geometries affects heat transfer and pressure drop can help inoptimize the heat exchanger for better efficiency and heat transfer at a lower price.

COMPUTATION FLUID DYNAMICS (CFD)

The evaluation of flowing fluid with the help of numerical methodologies is known as computational fluid dynamics (CFD). We can deploy CFD to solve complex situations encompassing liquid to liquid, liquid to solid, or liquid to gas interactions. Aerodynamics as well as hydrodynamics are two engineering sectors in which CFD analysis methods are more often used to achieve volumes including lift and drag, as well as ground characteristics like pressures and velocities. Physical laws applied in the dimension of partial differential equations are used in fluid mechanics.

CFD assessments have a great potentiality for time saving in the construction process, and are thus less expensive and quicker than traditional data procurement diagnostics. Moreover, in real-world tests, only a small number of volumes are evaluated at a period, whereas in a CFD simulation, all preferred quantities can be evaluated all at once, with high spatial resolution and also temporal resolution.

Various Types of Baffle Geometry

Huge number of baffle geometries has been proposed for the use in heat exchanger channel and more are still being developed Common Attributes of Baffles are

1) Shape: The majority of the baffles found in literature are square, rectangular, triangular, and helical or wedge shaped in the present work rectangular baffles have been studied.

2) Height: Small height baffles are chosen to minimize the pressure drop.

3) Spacing: It is the distance between two successive baffles.

4) Perforations: Perforations are the holes or slots in the baffles which causes less resistance against the stream and improve heat transfer and pressure drop over the channel.

5) Porosity: Porous medium can be defined as a material consisting of a solid matrix with an interconnected void. Due to its structural stiffness and light weight, thermal management can be used for in aerospace applications.

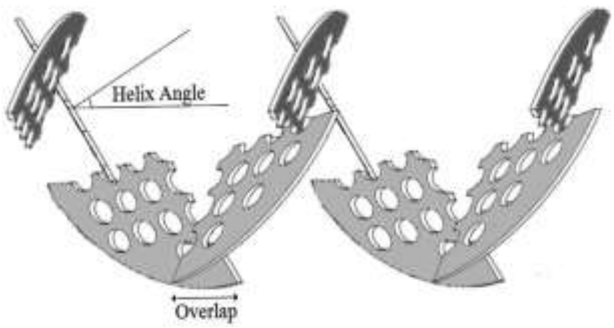

Fig.3 Schematic Diagram of Helical Baffle [22]

The authorexplains about the purpose of using helical shaped bafflesin shell and tube HEX as in fig. 3. The principal motivation for using helical baffles is to counteract the massive disadvantages of traditional segmental baffles, while also guaranteeing efficient combining in the fluid going to flow through the shell's sidewall [22].

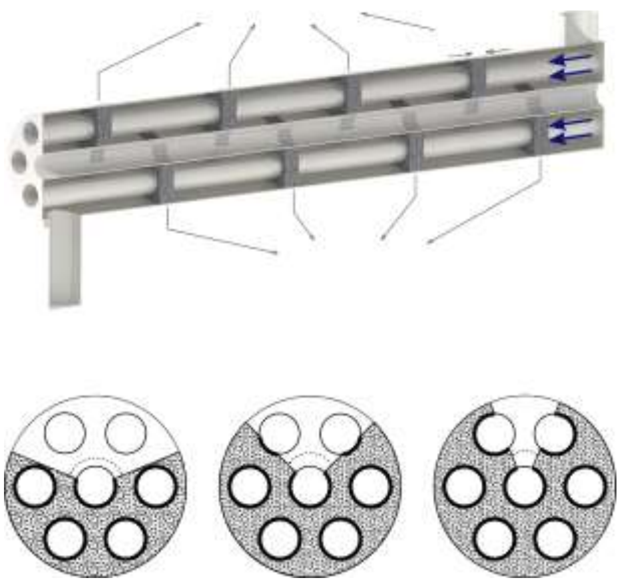

Fig. 4Schematic Diagram of porous baffles[23]

Increased thickness of porous baffle has benefits including both thermal and hydraulic performance of Shell and Tube HEX for small sized baffle angles, as it reduces pressure loss and improves thermal performance represented by fig. 4. The width of metal foams, on the other hand, seems to have no impact on pressure loss at greater baffle angles explained by the author [23].

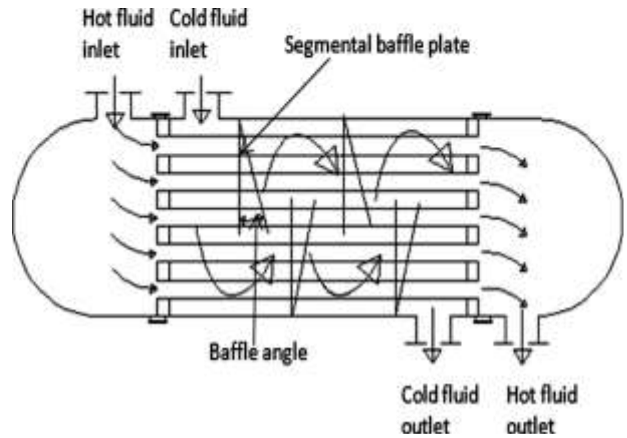

Fig.5Schematic Diagram of baffle angle in heat exchangers[21]

The above represented diagram in fig. 5 is given by the author which shows the shell and tube heat exchanger with baffle angle. With the help of this figure it can be seen that the baffle angle is also an important aspect to transfer the heat from one medium to another and also increase the efficiency and effectiveness of the thermal exchangers. The author explains that at baffle angle of 20 degrees, the entropy reduction rate for cylindrical shapes was reported to be greater than in any other shape and size [21].

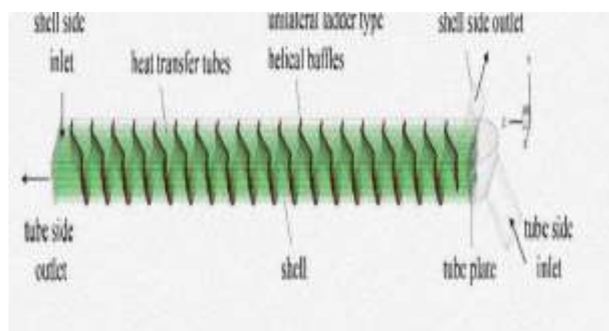

Fig. 6Schematic Diagram of Unilateral ladder type Helical Baffle (ULHB)[24]

Shell and Tube Heat Exchangers with Unilateral Ladder type Helical Baffle appears to have a lower pressure loss. STHX-ULHB shown in fig. 6 reduces pressure losses by 15.3–47.1 percent compared to segmental baffles, including an average value of 33.4 percent. The heat exchanger's total heat transfer heat transfer coefficient K as well as shell-side heat transfer coefficients are both greater than standard heat exchangers with segmental baffles.

Software which are used in the assessments of CFD Analysis are Artificial Neural Network (ANN) and Genetic Algorithm (GA) the author explains as per the orthogonal research experiment table [18], Simulated results are used to acquire data samples for the Artificial Neural Network. As the optimization techniques, ANN-trained networks for the Q and Dp are used. The GA is used by professional software MATLAB to perform multi-objective optimization.Numerous of researchers have used the techniques and numerous software to analyze the performance of CFD, neural networks, genetic algorithm, multi-objective optimization and many more are the techniques used for the assessment of CFD.

A. Types of Baffles Implementation of baffles are decided on the basis of cost, size, and their ability to lend support to the tube bundles and direct flow, often this is connected to available pressure drop and the size and number of passes within the exchanger. Special allowance changes are made for finned tubes.

The special types of baffles:

– Diamond Shaped baffles

– Z-Shaped baffles

– V-baffles

– 45° inclined baffles

– Porous baffles

These are the various components of the heat exchanger which effect the thermal performance of the apparatus

A. Ribs Placing ribs sporadically on the heat transfer surface increases the turbulence and since these ribs are small they do not disturb the core flow hence a high heat transfer performing surface could be achieved without incurring the penalties of frication and pressure drop.

B. Baffles Inserting baffles into the heat transfer devices promote mixing of coolants. These baffles can greatly disturb the bulk flow.

C. Extended Surfaces Use of heat sink such as fins increases the surface area in contact with the coolant. These extensive dissipation areas are widely recognized to improve the heat transfer. Variety of examples are louvered fin, plain fin, offset-strip fin, wavy fin, etc.

D. Twisted Tapes and Wire Coils Spiral tapes are metallic strips twisted in some ratio known as twist ratio, inserted in the flow. Wire coil inserts are made by tightly wrapping a coil of spring wire on a rod. When the coil helix is pulled up the wires forms a helical roughness. This section includes such surface which has fin scales or coating which may be continuous or discontinuous. It also includes rough surfaces which promotes turbulence in the flow field. It involves high velocity jet to cool directly the surface of inserts. It also includes the direction of heating or cooling fluid perpendicularly or obliquely to the heat transfer surface

E. Additives these include addition of gas bubbles, solid particles, liquid droplets, etc. which are introduced in single phase flow. Additive for gas is introduced as a dilute phase (gas solid suspension) or as dense phase (fluidized bed). Liquid additives usually depress the surface tension of liquids for boiling system.

CONCLUSION

It has been found through the review that some special types of baffles with channels can be used for enhancing the thermal performance of heat exchanger. Thus it is expected that by employing baffle in appropriate angle in the heat exchangers can achieve better performance. The literature survey mentioned above provide the different parameters on which researcher can work and can design heat exchanger. The overall effectiveness of a heat exchanger can be compared by considering various parameters as reviewed in this paper.

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