Review On Heat Transfer Enhancement Techniques in Heat Exchanger

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Abstract— Heat exchangers are crucial components in various industrial processes and energy systems, facilitating the efficient exchange of thermal energy between fluids. To optimize their performance, researchers and engineers have developed and explored numerous heat transfer enhancement techniques. This abstract provides a concise overview of these techniques, which include passive and active methods. Passive techniques involve the use of enhanced surfaces, geometrical modifications, and advanced materials to augment heat transfer. Active techniques employ external mechanisms like mechanical agitation, pulsating flow, and fluid additives to enhance thermal performance. This abstract summarizes the key principles and benefits of these methods, highlighting their potential to improve heat exchanger efficiency, reduce energy consumption, and minimize environmental impact. Moreover, it underscores the importance of selecting the most suitable technique based on specific application requirements. A better understanding of these techniques will aid engineers and researchers in designing more efficient heat exchangers and addressing the ever-growing demand for enhanced heat transfer solutions in various industries. An effort has been made in this paper to review the literature related to the heat exchangers and heat transfer enhancement techniques to improve the efficiencies of heat exchangers.

Key words: Heat Transfer Enhancement Techniques

I. INTRODUCTION

Heat transfer enhancement techniques in heat exchangers can be categorized into active and passive methods. These methods are employed to improve the efficiency of heat transfer in various industrial and engineering applications

A. Active Heat Transfer Enhancement Methods:

1) Mechanical Agitation: This involves the use of mechanical devices like agitators or pumps to increase fluid movement within the heat exchanger, which enhances heat transfer.
2) Ultrasonication: Ultrasonic waves are used to create micro-turbulence in the fluid, breaking boundary layers and promoting heat transfer.
3) Electromagnetic Fields: The application of electromagnetic fields can induce motion in electrically conductive fluids, leading to improved heat transfer.
4) Jet Impingement: High-velocity jets of fluid are directed at the heat transfer surface to disrupt boundary layers and enhance heat transfer.
5) Microchannels: Utilizing micro-sized channels increases the surface area available for heat transfer and can lead to significant improvements in heat exchange efficiency.

B. Passive Heat Transfer Enhancement Methods:

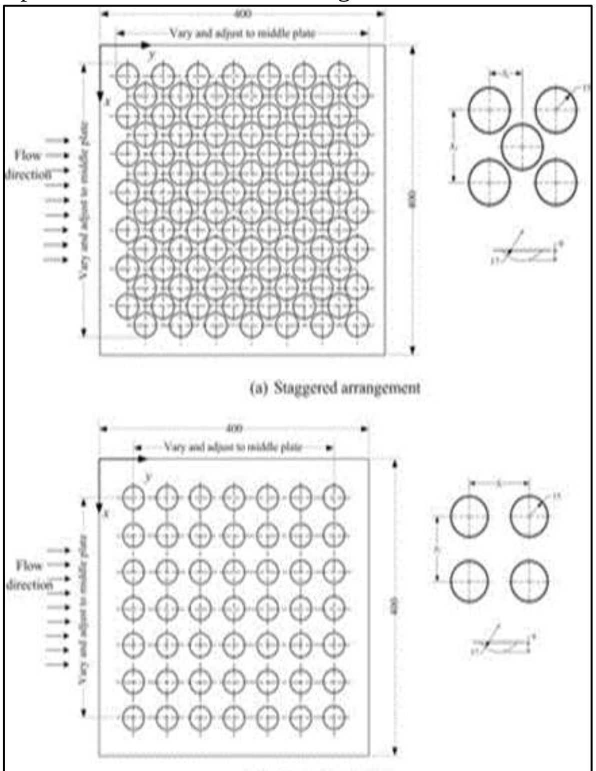
1) Ribs and Fins: Adding ribbed or finned surfaces to the heat exchanger increases the surface area for heat transfer and enhances convective heat transfer.
2) Vortex Generators: Small devices or structures can be incorporated into the heat exchanger to create vortices that enhance heat transfer by breaking boundary layers.
3) Swirl Flow: Introducing a swirl to the fluid flow promotes mixing and turbulence, which can improve heat transfer.
4) Structured Surfaces: Surface modifications like dimples or grooves create controlled turbulence and disrupt boundary layers.
5) Nanofluids: Adding nanoparticles to the heat transfer fluid can significantly increase its thermal conductivity and heat transfer capabilities.
6) Phase Change Materials (PCMs): The use of materials that undergo phase changes (e.g., solid-liquid) can store and release heat efficiently, enhancing heat transfer.

Both active and passive heat transfer enhancement techniques have their advantages and applications, and the choice of method depends on the specific requirements and constraints of a given heat exchanger system. These methods play a crucial role in improving energy efficiency and performance in various industries, such as HVAC, automotive, and industrial processes. In this paper, an effort has been taken to study and summarize the literatures related to heat exchangers under the following categories: effect of flow configurations of heat exchangers and the applications of nanofluids in the heat transfer enhancement processes.

II. LITERATURE

A. Heat Transfer Enhancement by Flow Configuration Modifications

Nopparat Katkhawa et al. (2013) studied the different types of dimple arrangements and dimple intervals. They studied the heat transfer characteristics in case of external flow conditions. The stream of air flows over the heated surface with dimples. The velocity of air stream varies from 1 to 5 m/s. The temperature of the air stream and dimpled surfaces were measured. The arrangements of dimples in different patterns has been shown in Figure A and B.



(a) Staggered arrangement

(b) Inline arrangement

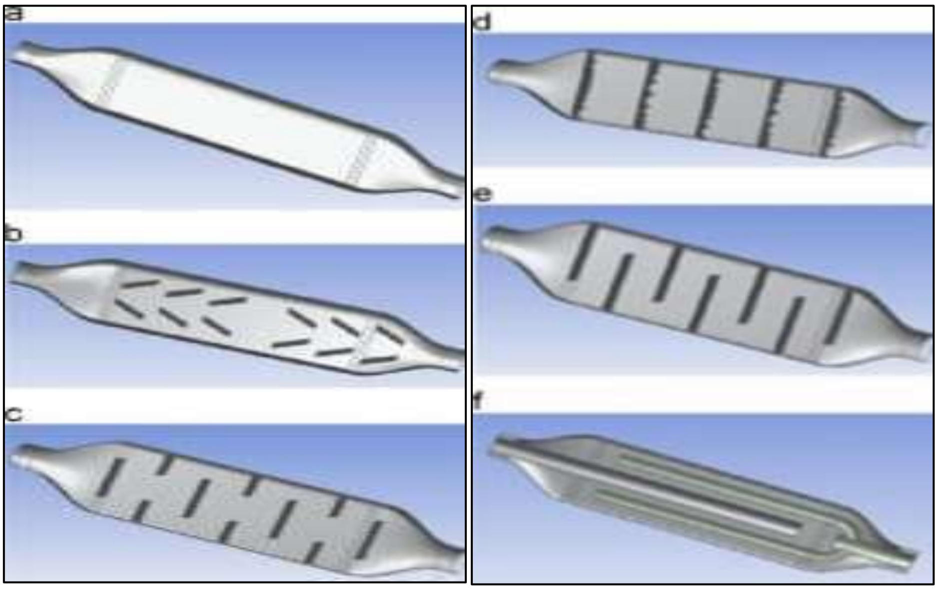
Since the usage of baffles, fins and turbulizers for the conventional enhanced heat transfer approaches results in a significant pressure drop of the stream, the dimples are preferred. In this paper, the dimple arrangements (staggered and inline) with various dimple pitches are compared and studied. The staggered dimple arrangement (Dimple pitches – SL/ Dminor = 1.875 and ST/ Dminor = 1.875) had been found to provide optimal thermal resistance about 21.7% better than flat plate [1].

Eiamsa-ard et al. (2014) assessed the thermal performance of a heat exchanger tube equipped with regularly- spaced twisted tapes as swirl generators. The factors like heat transfer, friction factors and thermal performance factors in a heat exchanger are reported in case of a heat exchanger provided with the regularly - spaced twisted tape (RS-TT) across fluid flow. This is studied in comparison with the effect of full length twisted tape. Further, the physical behavior of fluid flow, fluid temperature and Nusselt number are observed. The observations from this paper is that the full length twisted tapes showed higher heat transfer rate, thermal performance factors and friction factors [2].

Hitami et al. (2014) had done the numerical study of the finned type heat exchangers for IC Engines exhaust waste heat recovery. Two cases of heat exchangers are studied as follows: one type of heat exchanger is used in the spark ignition exhaust recovery system and another type of heat exchanger is used in the compression ignition exhaust recovery system. The compression engine heat recovery system has water as cold fluid while in case of the spark ignition system, a mixture of water (50%) and ethylene glycol (50%) has been used as cold fluid.

The conclusions are obtained in relations with viscous models (Shear-stress transport k-ω and Renormalization group k-ε models). The efficiency of the heat recovery system increases with the increase in the fin numbers and length of the recovery models [3].

Shengqiang Bai et al. (2014) analyzed the exhaust heat exchangers used in automobile thermo electric generators. The major disadvantages of the heat recovering exchangers are that pressure drop of the fluids. A comparative study has been made between six different models of heat exchangers as shown in Figure C.



B. Various Configurations Exhaust Heat Exchanger

The experiments have been conducted with 1.2L gasoline. From this study, it is concluded that the exchangers with 7 baffles provided maximum heat transfer with a considerable pressure drop of fluid [4].

Vahabzadeh et al. (2014) had done the analytical investigation of porous pin fins with variable sections in fully wet conditions. The paper holds the investigations for the temperature distribution, efficiency, heat transfer rate and optimization of the porous pin fins in fully wet conditions. The aluminium made fins are used and they are tip insulated. The temperature of fin determines the heat transfer coefficient. Using the energy balance, Darcy model and Least Square Method (LSM), the analytical solution for temperature distribution is obtained. The geometric and thermo graphical parameters (power index for geometry, porosity, Biot number and relative humidity) are analyzed.

The following conclusions are obtained. LSM can be conveniently used for engineering problems. Relative humidity is directly proportional to temperature distribution. The rectangular and concave parabolic profile fins are mostly approached fin profiles [5].

Sunil Chamoli (2015) had performed a Taguchi experimental design to optimize the design parameters for the rectangular channel with V down perforated baffle turbulators. The design parameters considered were open area ratio, Reynolds number, relative roughness height and relative roughness pitch along with Nusselt number and friction. The aim of this analysis is to maximize heat transfer and minimize pressure drop with this configuration. Experimental results are checked with optimal values. The Reynolds number and the relative roughness height for corresponding Nusselt number and friction are found to be the most affecting parameters [6].

Srinivasan et al. (2014) had investigated the ways to improve the effectiveness of the shell and tube heat exchangers by implementation of Six sigma DMAIC (Define- Measure- Analysis- ImproveControl). Define phase – the Critical to Quality (CTQ) parameters are identified. Measure Phase – the effectiveness of the exchanger has been measured as 0.61. Analysis Phase – the reasons for the effectiveness reductions are identified. Improve Phase – Existing design has been modified by brainstorming and the solutions are identified. Control Phase – Strategies are recommended for improving performance.

The effectiveness of the exchangers has been improved by recovering the heat energy of the exhaust (flue) gas by using the circular fins rolled over the tubes. The monetary profit achieved by following these strategies is about Rs. 0.34 million/ year [7].

Jiin-Yuh Jang et al. (2013) conducted an analysis regarding the span angle and location of the vortex generators provided in a plate – fin and tube heat exchanger with in-line and staggered arrangements. Block type vortex generators are mounted behind these tubes. Comparing the plain surface and surface with vortex generators, the area reduction ratio is better in surface with vortex generators. Span angle range considered for vortex generators is from 30° to 60°and transverse location (Ly) range is from 2mm to 20mm. In-line arrangements in above exchangers is considered to be more effective regarding heat transfer enhancements [8].

The literature review results revealed that the provision of baffles in the heat exchangers causes huge pressure drop of the heat transfer fluid. This limitations can be overcome by using dimples, fins, full length twisted tapes and vortex generators.

C. Applications of Nanofluids in the Heat Transfer Enhancement

Abed et al. (2014) studied numerically the enhancement of heat transfer in the channel V- shaped wavy lower plate using liquid nanofluids. The range of Reynolds number studied is about 8000 – 20000(Re). The effects of different types of nanoparticles (Al_2O_3, CuO, SiO_2 and ZnO) along with the study fluid are investigated. Furthermore, the effects of different volume fractions (range 0-4%) of these nanoparticles are studied.

It is found that the heat transfer was enhanced with the increase of the concentrations of the nanoparticles in the base fluids. The SiO_2- glycerin has the highest value of Nusselt number. The glycerin based nanofluids have greater heat transfer enhancements [9].

Ali Najah Al-Shamani et al. (2014) conducted an investigation regarding the heat transfer due to turbulent flow of nanofluids (base fluid with nanoparticles Al_2O_3, CuO, ZnO and SiO_2) through rib-groove channel. Under constant temperature range, the computations are performed for different types of nanoparticles with different volume fractions (range 1- 4%) using four different rib-groove shapes.

The conclusion obtained from the paper is that the trapezoidal with increasing height in the flow direction Rib-Isosceles Trapezoidal groove (Trap + RTrap G) provides the highest Nusselt number and best heat transfer rate [10].

Iniyan et al. (2014) used a condensing unit of the air conditioner to analyze the heat transfer enhancement performance of nanofluid (Al_2O_3/ water and CuO/ water). The condenser consists of a tube in tube setup configurations. The cooling medium used in the analysis is nanofluid flowing in the outer side of the tube of condenser.

The results from the study are summed up as that the CuO/ water nanofluid has more heat transfer rate than Al_2O_3/ water nanofluid. The Nusselt number of CuO/ water nanofluid had found to be 39.4% higher than the base fluid [11].

Dustin R. Ray et al. (2014) had done a comparative study regarding the heat transfer performance of three nanofluids. These nanofluids have the same base fluid (60:40 ethylene glycol and water by mass) with different nanoparticles like Al_2O_3, CuO and SiO_2. This similar condition has been found in the cases of automobile radiators. Some parameters like pumping power, heat transfer coefficients and surface area reductions are considered for the study.

Nanofluid exhibits better heat transfer enhancement at 1% volumetric concentration. Among all the three nanofluids, the Al_2O_3 nanofluid exhibited the optimal conditions like the reduction of surface area by 7.4% and pumping power by 35.3% [12].

The investigation results indicated that the increase in Nusselt number increases the heat transfer rate. The glycerin based nanofluid (SiO_2-nanoparticle) showed the better heat transfer characteristics. The water based nanofluid (CuO/ water) showed better heat transfer performances.

D. Heat Transfer Enhancement Using PCM

Phase change materials (PCMs) are widely used from a heat storage perspective because of high-energy storage density at a nearly constant temperature. The main disadvantage of phase change material is the low response to heat transfer rate because of low thermal conductivity.

Enhancing the heat transfer rate in PCM reduces the charging and discharging durations, which makes them more suitable for energy storage. Various conventional and newest methods are used to enhance the performance of phase change materials. Heat transfer enhancement has been investigated using different shapes and orientations of fins arrangement. The effect of modifying geometry on heat transfer rate has also been investigated. The effect of the arrangement of PCMs of various melting points on charging and discharging duration has been investigated. Others promising heat transfer enhancers based on carbon and metal material have been examined.

Thermal properties analysis of expanded graphite, carbon fiber, and carbon nanotubes in the category of carbon-based material and metal foam, nanoparticle, and metal oxide in the group of metal-based material has been extensively studied. The effect of various heat transfer enhancement technique on PCMs supercooling was also studied.

The literature review showed that the use of fins is the most common heat transfer enhancement media in concentric tube heat exchangers due to low cost and simplicity in usage and the use of various shapes and orientations gives a better thermal performance. The effect of geometry modification has been shown to have a promising effect in heat transfer enhancement because of more heat transfer area available to transfer heat without reduction in the mass of PCM. A cascaded system has been found to be effective in efficiently utilizing the energy of heat transfer fluid in the charging and discharging cycle. Metal foam material has been found to have a very high heat transfer rate in PCM but at the cost of a reduction in the storage capacity of PCM.

The effect of various weight per cent loading of carbon fiber, carbon nanotube, graphene, nanoparticle, and metal oxide was investigated. Graphene was found to be better heat transfer media due to having a high thermal conductivity value.

III. CONCLUSION AND FUTURE SCOPE

In this review paper, the discussion had been done about the various configurations for the heat transfer enhancement. Further, the usage of various nanoparticles in the base fluid for the heat transfer enhancement along with these configurations had been studied. The conclusions drawn from literature review are listed below:

1) The achievement of the thermal comfort conditions optimizes the size of the heat exchangers. CWHE could be preferred over STHE depending on the suitability.
2) The provision of baffles in the heat exchangers causes huge pressure drop of the heat transfer fluid. This limitations can be overcome by using dimples, fins, full length twisted tapes and vortex generators.
3) The increase in Nusselt number increases the heat transfer rate. The glycerin based nanofluid (SiO_2-nanoparticle) showed the better heat transfer characteristics. The water based nanofluid (CuO/ water) showed better heat transfer performances.

Based on the conclusions drawn from the above literature review, the following works related to the heat exchangers can be taken up in future.

1) The different types of dimple profiles can be analysed

2) Metallurgical properties of the materials used for heat exchangers can be studied.
3) Research on different types of nanofluid can be performed.

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