A Review of Heat Transfer Enhancement Techniques in Heat Exchangers

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I. Abstract

In recent days, the process industries have been trying a lot to reduce the loss caused due to dissipation of waste heat. The tremendous effort in finding solutions to use the thermal energy from waste heat and other sources had resulted in optimizing the heat exchangers. These heat exchangers may be optimized in the field of materials, flow configurations and design. This becomes a thrust area with huge potential as it is one of the ecodesign model. The concept of these heat exchangers could be extented to the fileds of the refrigeration and air conditioning system also. One of the problems faced in the process of these heat exchangers is the yielding of low heat transfer efficiency. 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 exhangers.

Keywords: *Heat Exchanger Configurations, Heat Transfer Enhancement, Compact Heat Exchangers, Nanofluids*

II. Introduction

The heat exchangers are listed to fnd its applications in a numerous way from domestic house-hold purposes to petroleum refineries and cryogenic processes. The heat exchangers had become one of the important requirements in process industries as they do not cause any harmful effects to the environments. The process involved in this energy transfer is also very cheap and simple. Industrialist and researchers had been attempting to enhance the heat transfer efficiency of heat exchangers by the optimization of heat transfer surfaces and usage of advanced materials favouring heat transfer enhancements. The industrial survey and research works had been carried out in a vast manner to improve the heat transfer enhancements and thus the enhancing their performances. In this paper, an effort has been taken to study and summarize the literatures related to heat exchangers under the following categories: general aspects of heat exchangers, effect of flow configurations of heat exchangers, the features related to compact heat exchangers and the applications of nanofluids in the heat transfer enhancement processes.

III. Literature

A. General Aspects of Heat Exchangers

Christopher Ian Wright (2014) performed the analytical process to study the effective management of heat transfer fluid flash point temperature using a Light End Removal Kit (LERK). In case of industrial process heat exchangers, the building-up of light ends is found to be a major problem in the processing fluids. These dangerous light-ends may result in fire hazards resulting in a huge damage. A kit called LERK has been used to control the formation of the light ends. The effectiveness of the LERK in restoring the mean closed flash point temperature to stable levels is observed. These mean values are found close to the values of virgin HTF.Installing the LERK not only increases the life of a heat transfer fluid, but also avoids the need for regular dilutions to raise the flash point temperature [1].

Weikla et al. (2013) had performed a comparative study of two types of heat exchangers namely Shell and Tube heat exchanger (STHE) and Coil wound heat exchanger (CWHE) for the special service conditions (molten salt service). Furthermore, the applications of these CWHE in the thermal energy storage plants are analyzed.The results obtained are that the CWHE have advantages over the STHE for the reasons like less heat transfer area, lower pressure drop, lower pumping cost and less number of shells and piping. These configurations have advantages like prevention against thermal shocks [2].

Tonio Sant et al. (2015) had done the discussion about the analysis of the wind powered system using the thermocline thermal energy of the sea water. The cold water (deep sea water) and the hotter are utilized in tapping the thermal energy with assistance of hydraulic turbine and heat exchanger. The water to be supplied for the purpose of cooling/ heating the buildings in townships is conditioned as per requirements using the heat exchangers [3].

Guo- yan Zhon et al. (2014) proposed a simple model to predict the temperature distribution in the shell and Tube heat exchanger by using the basis of differential theory. Based on the baffle arrangements and number of tube passes, the heat exchanger has been divided into number of small elements. The tube side current is considered series and shell side current is parallel. Two heat exchangers (AES and BEU) are considered for analysis by using the Cell model and Heat Transfer Research Incorporations (HTRI) method.From this paper, it is seen that the HTRI method used for predicting temperature of heat exchangers is more accurate. This model agrees for the heat exchangers with straight tubes or U-tubes while the Cell model is limited for the cases of straight tubes [4].

Saneipoor et al. (2014) had done an analysis of heat transfer with the Manroch heat engine using water/ glycol mixture as the working fluid. Four shell and tube exchangers are used in this experiment. The shell side fluid is the compressed air and the tube side fluid is water/ glycol (propylene glycol) mixture. The transient heat transfer analysis has been done as the hot fluid after passing through one set of heat exchangers become cold fluid and then sent through another set of heat exchangers. This procedure can be used for studying the heat exchangers working under transient conditions [5].

Neda Gilani et al. (2014) analyzed a direct evaporative cooler with various indoor and outdoor air conditions. Mathematical modeling has been carried out and the thermal comfort conditions have been achieved. By raising the relative humidity of air , a smaller heat exchanger can be utilized for the heat transfer purposes.It is found that the thermal comfort conditions achieved when the temperatures and relative humidity are in the prescribed ranges (27-47 ˚C and 10-60 %), restricts the physical characteristics and geometry of the evaporative cooler [6].

B. 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 1 and 2.

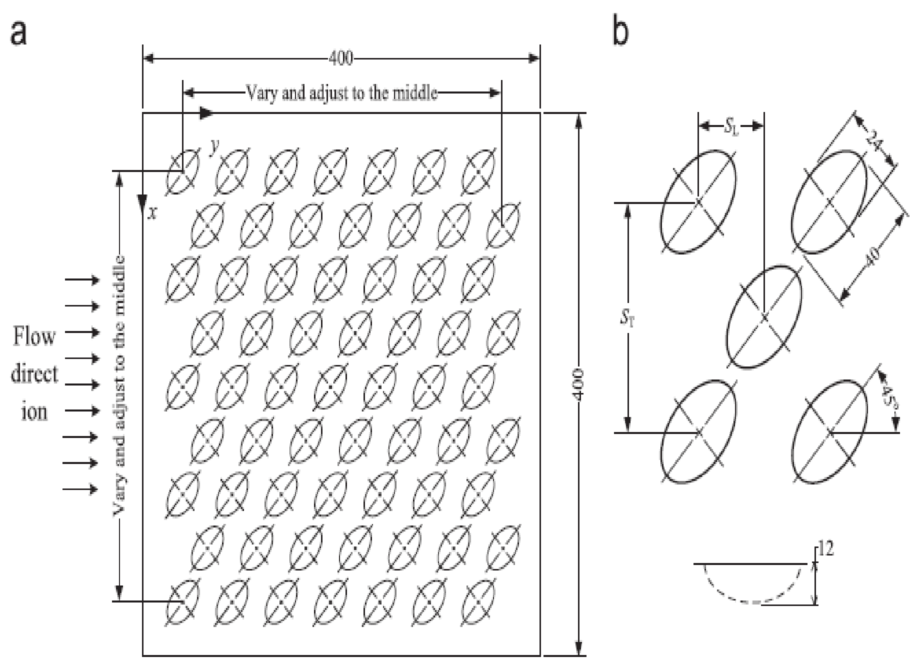


Figure 1: Dimples in Staggered arrangements

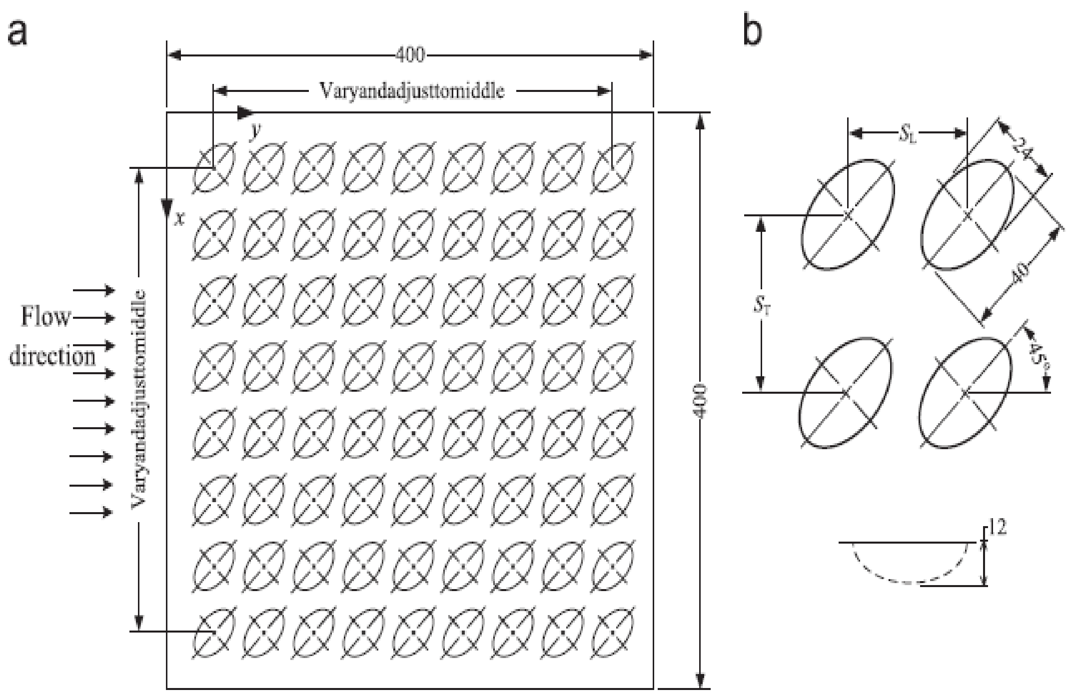


Figure 2: Dimples in Inline arrangement

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 – S_L/ D_{minor} = 1.875 and S_T/ D_{minor} = 1.875) had been found to provide optimal thermal resistance about 21.7% better than flat plate [7].

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 [8].

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 [9].

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 3.

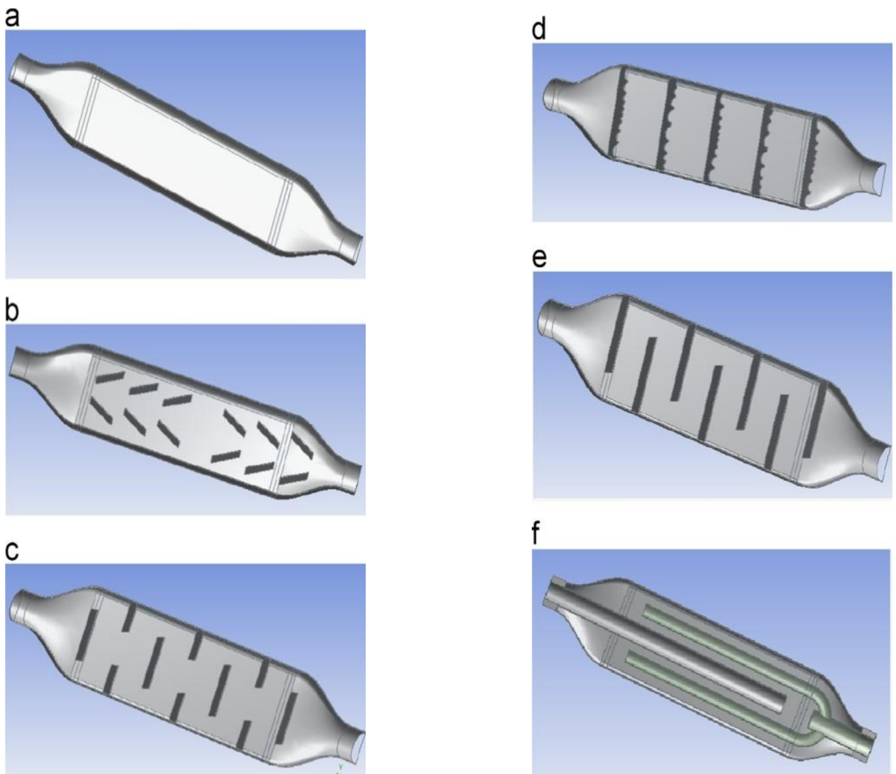


Figure 3: Various Configurations Exhaust Heat Exchangers

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 [10].

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 [11].

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 [12].

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- Improve- Control). 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 [13].

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 (L_y) range is from 2mm to 20mm. In-line arrangements in above exchangers is considered to be more effective regarding heat transfer enhancements [14].

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 [15].

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 + R-Trap G) provides the highest Nusselt number and best heat transfer rate [16].

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 [17].

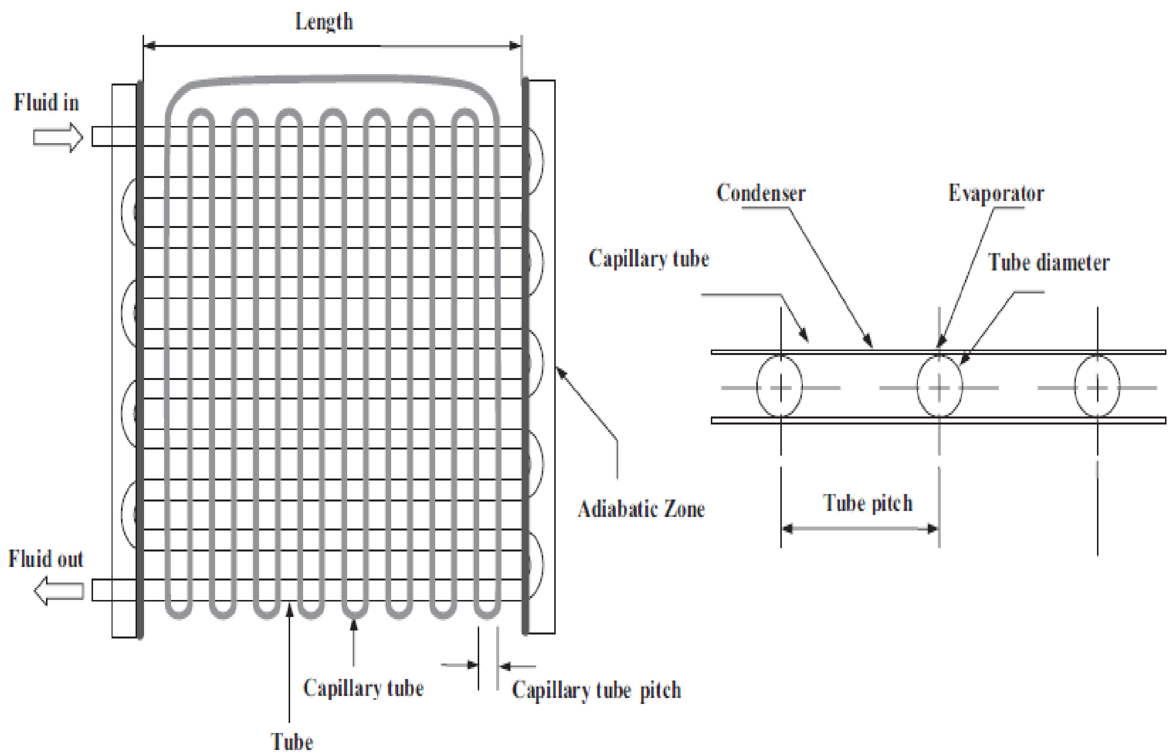
Dustin R. Ray et al. (2014) had done a comparative study regarding the heat transfer performance of three nanofluids. These nanofluids have the same base fluid (60:40 ethylene glycol and water by mass) with different nanoparticles like Al_2O_3, CuO and SiO_2. This similar condition has been found in 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% [18].

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. Features Related to Compact Heat Exchangers

Tawat Samana et al. (2013) studied the enhancement of the fin efficiency of a solid wire fin by oscillating heat pipe under forced convection by means of experiments. First they studied a wire – on – tube heat exchanger under forced convection for the enhancement of the fin efficiency of the solid wire fin. Then they replaced this wire fin with an oscillating heat pipe containing R123.



The testing setup was made with a wind tunnel which exchanges the heat between the hot water flowing inside the tube and air stream flowing across external surface. The oscillating heat pipe fin showed 5% fin efficiency more than the conventional fins. Further facts like the mass flow rate and the geometrical parameters of heat exchanger surface are considered. Furthermore, the air mass flow rate and the dimensions of the heat exchanger like the tube diameter; tube pitch, the wire diameter and wire pitch were found to be parameters affecting the performance of the air- side using the forced convection [19].

Due to its higher efficiency, micro channel heat exchangers (MCHX) have been utilized in the field of Heating, Ventilation, Air Conditioning & Refrigeration (HVAC & R). Yanhui Hana et al. (2011) had investigated about these exchangers. These heat exchangers have higher heat transfer rate, lower cost and compact size. This paper holds the discussion about the optimization of the MCHX and the analysis of their advantages and disadvantages. An attempt to reduce their weights is carried out. After the study of micro channel heat exchangers in depth, many problems related to industries can be resolved [20].

Mushtaq Ismael Hasan et al. (2012) had studied the axial heat conduction characteristics of a microchannel heat exchanger. The isosceles right triangular heat exchanger is considered for the study. Mathematical analysis of the heat conduction in separating wall for incompressible, 3D, laminar, steady state flow is performed. Using finite volume and hybrid differencing scheme, the various parameters which have effect on axial heat conduction were determined.

The increasing of the parameters like Reynolds number (Re), thickness of separating wall (t_s) and thermal conductivity ratio (K_r) shows increase in the axial heat conduction. Further, the increasing of parameters like channel volume and the hydraulic diameter (D_h) decreases the axial heat conduction [21].

Manglik et al. (2011) had done an investigation regarding the forced convection of air in the interfin paths of plate-fin heat exchangers. A dimensionless parameter (Ω), which is the ratio of the relative fluid-fin material conductance to the fin-size aspect ratio, has been considered. The fin conduction is also studied for the system. The plate-fins and partitions made of copper and stainless steel materials are used for analysis. This work provides a first kind of analysis and optimization about the fin effects in the heat transfer [22].

Valery Ponyavin et al. (2008) performed a study of the heat transfer and fluid flow distribution in a compact ceramic heat exchanger. It is found that the flow maldistribution due to design limitations may result in reverse flow of fluids. This may affect the performance of the heat exchangers.

Different types of improved designs are analyzed for the proper fluid flow in exchanger in considerations with a reduced pressure drop values [23].

The summary for the above review results revealed that the proper designs for the fluid flow in compact heat exchangers is essential. The axial heat conduction affecting parameters are Reynolds number (Re), thickness of separating wall (t_s) and thermal conductivity ratio (K_r).

IV. 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. A review on the compact heat exchangers had been also done to extract some useful facts regarding heat transfer. The conclusions drawn from literature review are listed below:

(i). The achievement of the thermal comfort conditions optimizes the size of the heat exchangers. CWHE could be preferred over STHE depending on the suitability.

(ii). 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.

(iii). 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.

(iv). The proper designs for the fluid flow in compact heat exchangers are essential. The axial heat conduction affecting parameters are Reynolds number (Re), thickness of separating wall (t_s) and thermal conductivity ratio (K_r).

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

- The analysis can be done with different fin profiles and different arrangements.
- The different types of dimple profiles can be analyzed.
- CWHE can be experimented for different types of applications and services.
- Metallurgical properties of the materials used for heat exchangers can be studied.
- Research on different types of nanofluid can be performed.

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