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A Review of Heat Transfer Enhancement Methods

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ABSTRACT

Heat transfer is a particularly intriguing area for efficient, beneficial, and environmentally good reasons. Economic and environmental concerns demand that we achieve the highest potential efficiency from thermal power plants, which can only be accomplished by developing more efficient heat exchangers. Increasing the efficacy of new and existing heat exchangers is a common requirement for engineers working in heat exchanger design. Improving process plant efficiency and discovering innovative ways to minimise energy consumption is always a top design objective.As a result, heat transfer enhancement plays a significant role in enhancing energy efficiency and developing high-performance thermal systems.There are two types of heat transfer augmentation methods: passive and active. Active methods require external power to enter the process; passive approaches, on the other hand, do not require any more energy to increase the system's thermohydraulic performance. When examining heat transfer enhancement and friction losses to save energy and costs, passive approaches are frequently employed in both experimental and numerical applications.The current study provides an in-depth examination of experimental and numerical investigations on passive compound heat transfer enhancement strategies.

Keywords:Heat Exchangers, Heat transfer enhancement, Passive Techniques, Thermohydraulic performance, Dimples and ribs.

I. INTRODUCTION

Energy is essential for living a fulfilling life. Today's human life is dependent on an abundant and constant supply of power for both living and working. With the use of energy, all of humanity's accomplishments became possible. It is the most important component in all aspects of today's economic climates. Energy provides us with both heat and power. It powers our economy, transportation, and way of life. Every day, the need for energy grows rapidly. Because energy is being depleted at an alarming rate, it has become imperative to use heat more efficiently, implying that we must preserve [1]. Solar-thermal energy is a non-traditional form of energy that is growing increasingly popular.

Heat exchangers have different types with various applications. One of the applicable kinds of them is water to air heat exchanger which can be used for air conditioning and residential heating. There are few publications about water to air heat exchanger due to its expensive equipment studied the turbulent hydrothermal treatment in an air to water double pipe heat exchanger. Experimental investigation has been applied by to find the effect of circular ring on heat and fluid flow in an air to water heat exchanger. They found that opening area ratio has the maximum sensitivity on thermal performance. Due to significance of thermal performance, various methods for improving this parameter have been presented. Utilizing them cause heat transfer rate to augment while at the cost of augment in pressure loss. One of the most popular ways due to its low cost is swirl flow device.

Heat transfer enhancement is a process of increasing the heat transfer rate and thermohydraulic performance of a system using various methods. The methods of heat transfer enhancement are employed for developing the heat transfer without affecting the overall realization of the systems significantly, and it covers a wide range of areas where heat exchangers are used for such functions as air-conditioning, refrigeration, central heating systems, cooling automotive components, and many uses in the chemical industry.

In the passive techniques, any external power is not required; rather, geometry or surface of the flow channel is modified to increase the thermohydraulic performance of the systems. The inserts, ribs, and rough surfaces are utilized to promote fluid mixing and the turbulence in the flow, which results in an increment of the overall heat transfer rate. Passive techniques have also some advantages in relation to the other heat transfer enhancement techniques such as low cost, easy production, and installation.
Examples of passive enhancing methods are: (a) treated surfaces, (b) rough surfaces, (c) extended surfaces, (d) displaced enhancement devices, (e) swirl flow devices, (f) coiled tubes, (g) surface tension devices, (h) additives for fluids, and many others.

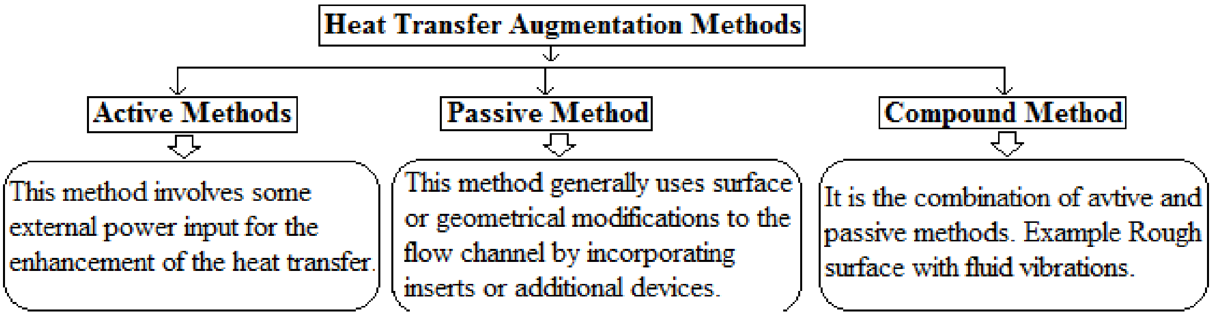

Figure 1 Augmentation methods

II. LITERATURE REVIEW

Pin fins, louvred fins, offset strip fins, slit fins, ribs, protrusions, and dimples are just a few of the heat transfer enhancers that have been researched to improve heat exchanger thermal efficiency. Dimples, on the other hand, have received a great deal of attention in recent years for their ability to improve heat transmission in interior cooling passages. This is due to past studies demonstrating that dimples may boost heat transmission in narrow channels while producing less pressure loss than other types of augmented heat transfer devices.

When compared to other heat transfer augmentation options, Ligrani et al. discovered that dimpled surfaces had a high heat transfer capacity and a low pressure loss penalty. According to Ligrani et al., the central and edge vortex pairs that are periodically shed from each dimple (along with the resulting shear layer reattachments, boundary layer re-initializations, and induced local unsteadiness) are critical components in augmenting local and spatially-averaged turbulence transport levels and surface heat transfer rates.

When compared to protruding turbulators, heat transmission on dimpled surfaces is better because vortex features induce mixing, drawing "cool" fluid from outside the thermal boundary layer into contact with the wall, improving convective heat transfer. As a result, extensive research has been conducted to determine the pressure loss and heat-transfer properties generated by the dimpled surface. Single-phase heat transfer fluids have a low heat transfer efficiency due to their low conductivity levels. Increasing heat transport is critical for achieving great energy efficiency and low operating costs. As a result, one technique is to achieve high thermal conductivity in fluids. Solid solids conduct heat more effectively than single-phase fluids, while single-phase fluid dispersion of nanometer-sized particles has a larger specific surface area than conventional fluids. Several research have been published on the synthesis of nanofluids utilising various types of nanoparticles, as well as their ability to conduct convective heat transfer.

Several studies have found that when dimple surfaces are mixed with nanofluids, heat transmission increases; nonetheless, the key concern is an increase in the system's friction factor, which is kept below acceptable limits. The study on dimpled surfaces, nanofluids, and dimple surfaces mixed with nanofluids is summarised here.

2.1. Previous Work

Several studies have reported on the formulation of nanofluids using various types of nanoparticles, as well as their capacity to conduct convective heat transfer.

Maxwell (1873) was the first to report the thermal conductivity enrichment of ordinary fluids in the presence of the problems of sedimentation, plugging, and erosion in flow tracks [1]. **Masuda et al. (1993)** then investigated the augmentation of thermal conductivity with the inclusion of micro-sized solid particles into the base fluid (single phase), but they met the same difficulties of sedimentation, increased pumping power, erosion, and clogging [2]. **Hamilton-Crosses (1962)** also made a contribution by expanding on Maxwell's work and developing a more precise model to predict the thermophysical characteristics of particles floating in fluids [3].

Choi's work transformed the world of heat transporting fluids in 1995 when he created nanofluids with superior thermal transport capabilities and higher stability than fluids containing milli and micro sized solid particles [4].With this invention, researchers started to investigate the nanofluids with great interest.

Pak and Cho (1998) conducted heat transfer and friction factor experiments for Al_2O_3/water and TiO_2/water nanofluids in the Reynolds number range from 104 to 105 and the particle concentration ranging from 0% to 3% and observed heat transfer enhancement compared to the base fluid (water); they also propose newly-developed Nusselt number correlation [5].

Later on, **Xuan and Li (2001)** used Cu/water and Cu/transformer oil nanofluids and observed heat transfer enhancements as compared to the base fluids. In another study, **Xuan and Li(2002)** observed heat transfer enhancement of 60% for 2.0% volume concentration of Cu/water nanofluid flowing in a tube at a Reynolds number of 25000 and they report separated Nusselt number correlations for laminar and turbulent flow, respectively [6,7].

Wen and Din (2004) conducted heat transfer experiments for Al_2O_3/water nanofluid in a tube under laminar flow and they observed heat transfer enhancement of 47% at 1.6% volume fraction as compared to the base fluid (water) [8].

Heris et al. (2007) also used Al_2O_3/water nanofluids in a tube under laminar flow and observed heat transfer enhancement using constant wall temperature boundary conditions [9].

Williams et al. (2008) reported convective heat transfer enhancement with alumina/water and zirconia/water nanofluids flow in a horizontal tube under turbulent flow [10].

Duangthongsuk and Wongwises (2010) found heat transfer enhancement of 20% and 32% for 1.0% vol of TiO_2/water nanofluid flowing in a tube at Reynolds numbers of 3000-18000, respectively [11].

Moraveji et al. (2011) simulated water-Al_2O_3 nanofluid through a tube under a constant heat flux. They found that the heat transfer coefficient rises by increasing the nanoparticle concentration and Reynolds number. Furthermore, the heat transfer coefficient increases by particle diameter reduction [12].

Ghozatloo et al. (2014) obtained heat transfer enhancement of 35.6% at a temperature of 38 °C for 0.1 wt% of graphene/water nanofluids flow in a tube under laminar flow [13].

Sundar et al. (2012) found heat transfer enhancement of 30.96% with a pumping penalty of 10.01% for 0.6% vol of Fe_3O_4/water nanofluid flow in a tube at a Reynolds number of 22000 [14].

Sundar et al. (2014) observed heat transfer enhancement of 39.18% with a pumping penalty of 19.12% for 0.6% vol of Ni/water nanofluid flow in a tube at a Reynolds number of 22000 [15].

Delavari et al. (2014) numerically simulated the heat transfer in a flat tube of a car radiator at laminar and turbulent regimes. They showed the ability of CFD to simulate the flow field and temperature distribution profile well and reported an increment of Nusselt number with increasing the nanoparticle concentration [16].

Chandrasekhar et al. (2017) experimentally investigated and theoretically validated the behavior of Al_2O_3/water nanofluid that was prepared by chemical precipitation method. For their investigation, Al_2O_3/water at different volume concentrations was studied. They concluded that the increase in viscosity of the nanofluid is higher than that of the effective thermal conductivity. Although both viscosity and thermal conductivity increases as the volume concentration is increased, increase in viscosity predominate the increase in thermal conductivity. Also various other theoretical models were also proposed in their paper [17].

Hady et al. (2017) experimentally investigated the performance on the effect of alumina water (Al_2O_3/H_2O) nanofluid in a chilled water air conditioning unit. They made use of various concentrations ranging from 0.1-1 wt % and the nanofluid was supplied at different flow rates. Their results showed that less time was required to achieve desired chilled fluid temperature as compared to pure water. Also reported was a lesser consumption of power which showed an increase in the cooling capacity of the unit. Moreover the COP of the unit was enhanced by 5 % at a volume concentration of 0.1 %, and an increase of 17 % at a volume concentration of 1 % respectively [18].

Rohit S. Khedkar et al. (2017) experimental study on concentric tube heat exchanger for water to nanofluids heat transfer with various concentrations of nanoparticles in to base fluids and application of nanofluids as working fluid. Overall heat transfer coefficient was experimentally determined for a fixed heat transfer surface area with different volume fraction of Al_2O_3 nanoparticles in to base fluids and results were compared with pure water. It observed that, 3 % nanofluids shown optimum performance with overall heat transfer coefficient 16% higher than water [19].

Han et al. (2017) in double tube heat exchanger flow turbulent and counter examine the enhancement of heat transfer by using nanoparticles aluminum oxide in water. They examine the rate of heat transfer with 0.25% and 0.5% by volume concentration at various inlet temperatures. In pipe flow the Reynold's number should be greater than 4000 for turbulent flow, as we know with higher turbulence the rate of heat transfer is high so with the various concentration and inlet temperature they also examine the rate of heat transfer at various Reynold's number i.e., 20000, 30000, 40000, 50000, and 60000. After the experiment they analyze that by using different concentration of Al_2O_3 that include 0.25% and 0.5% by volume concentration with Reynold's number varies from 20000 to 60000 maximum increase in heat transfer coefficient is about 9.7% and 19.6% respectively at 40^0C, and with same volumetric concentration and also Reynold's number varies from 20000 to 60000 the maximum increase in heat transfer coefficient is about 15% and 29% for volume concentration 0.25% and 0.5% respectively at 50^0C. Comparing the result at 40^0C and 50^0 with the volume concentration of 0.25% and 0.50%, the increase in heat transfer coefficient is about 5.3% and 9.4% respectively. The main conclusion is that at same nanoparticles concentration we can increase the rate of heat transfer with the increase in inlet temperature of nanofluid, which shows that nanofluid dependency on temperature. Nusselt number is also deal with heat transfer, by using nanofluid the Nusselt number also increases about 8.5% and 17% at the volumetric concentration of 0.25% and 0.50% respectively [20].

Akyürek et al. (2018) experimentally investigated the effects of Al_2O_3/Water nanofluids at various concentrations in a concentric tube heat exchanger having a turbulator inside the inner tube. Comparisons were done with and without nanofluid in the system as well as with and without turbulators in the system. Results were drawn and a number of heat transfer parameters were calculated on the basis of observed results. Various heat characteristics such as change in Nusselt number and viscosity with respect to Reynolds number, behaviours of nanofluid at various volume concentrations, changes in heat transfer coefficient, effect of the difference of pitch of turbulators on the heat transfer of nanofluid etc. were studied. They concluded that there exists a relationship between the varying pitches and the turbulence in the flow caused i.e. when the pitch is less there is more turbulence and vice versa [21].

Dimpled surfaces are recommended as a typical heat transfer enhancement passive approach because to their light weight, low pressure drops values, simplicity of production, and cheap maintenance costs. The potential of dimple surface approach in diverse thermal systems has been investigated via several experiments and computer analyses.

Kanokjaruvijit et al. (2005) increased heat transmission in cooling tubes with dimpled (concavity imprinted) surface area can be achieved in comparison to sticking out ribs. Heat exchangers and other hot-area elements might benefit from it (nozzle, blade, combustor lining, etc.). The friction factor and heat transfer coefficients were established experimentally in concavities (dimples) on one wall of rectangle-shaped channels surface. The thermal efficiency of dimple surfaces was higher than that of flat surfaces. The kind with continuous ribs, demonstrating that improved heat transmission can be achieved. Concavities were used to do this while keeping a low pressure drop [22].

Moon et al. (2012) A transient big band liquid crystal approach was utilised to investigate an 8 X 8 jet array impingement on a staggered dimples array at Reynolds number 11,500. The distance between the perforated plate and the target plate was estimated for jet diameters of 2, 4, and 8. When hemispherical and cusped elliptical dimple geometries were examined, it was revealed that the outcomes of hemispherical and cusped elliptical dimples behaved similarly. However, in terms of cost, manufacture, and pressure loss, the hemispheric form seemed preferred [23].

Griffith et al. (2015) The rate of heat transfer in rotating rectangular cooling channels was explored, and it was observed that channel orientation had a different impact, with the trailing-edge channel growing in Nusselt at the same rate as the orthogonal channel. Furthermore, the dimpled channel performs similarly to a 45-degree angled rib channel in terms of spanwise heat transmission, but with less variation [24].

Lauffer et al. (2017) Heat transfer studies were carried out utilising heater foils and a steady-state apparatus with liquid crystals on a rectangular dimpled channel with a 6-aspect ratio. Localized rib designs were revealed to boost heat transmission in these important locations while decreasing strain dramatically [25].

Chang et al. (2019) For four sets of dimple fin channels with rectangular cross sections, a channel aspect ratio (AR) of 6, and three varied fin length (L) to channel hyd, heat transmission and friction factor were evaluated. Using Reynolds numbers ranging from 1500 to 11,000 and Re on heat transfer upon channel with dimpled fins, Da (d), ratios (L=d) 8.9, 6.2, and 3.5, respectively. For both Re and L=d, the convex–convex dimpled fin channel showed the maximum Heat Transfer Enhancement [26].

Suresh et al. (2011) The heat transfer enhancement using the combination of helically dimpled tube and CuO-water nanofluid was investigated, and it was discovered that there was no increase in friction factor, and the thermohydraulic efficiency was 10% greater than plain tube utilizing the combination [27].

Rajabi et al. (2019) has used the nanofluids to run numerical simulations on heated walls of microchannel with spherical dimples and found that at a certain dimple depth, every 2% increase in volume fraction improves heat transmission by 2% [28].

Li et al. (2014) has analyzed that heat transfer rises with rise in concentration in microchannel with dimple + protrusion using Al_2O_3-water nanofluid [29].

Firoozi et al. (2019) explored the effect of Al_2O_3-water nanofluid on variety of dimple configuration, In the case of water flowing through the tubes, the improved tubes provide better average output as pitch is decreased, tube height is increased, and the filling angle is increased [30].

Josephine et al. (2019) the experimental analysis of the influence of dimpled layouts on flow and heat transfer properties is presented in this paper. Three plate surfaces (smooth, equally distributed spherical dimples, and irregularly distributed spherical dimples) were created and put in a channel one after the other. The average Nusselt number increases with the Reynolds number as a result of heat interaction with the airflow. Over the smooth channel, the equally and unevenly dimpled plate channels experienced a 75.7 percent and 91.8 percent increase in Nusselt number, respectively. The flow friction coefficients of the uniformly and unevenly dimpled plate channels were only 0.59 percent and 0.67 percent higher than those of the smooth plate channel, respectively [31].

III. CONCLUSIONS

Heat transfer augmentation in thermal systems is accomplished through the use of Active, Passive, and Hybrid techniques. Passive techniques are frequently employed since they do not require any external source of energy and instead use system energy to increase the rate of heat transfer. By obstructing the path of the fluid flow**.**Passive heat transfer enhancement techniques have various benefits over other heat transfer enhancement techniques, including low cost, ease of fabrication, and installation.Rib turbulators can enhance heat transmission significantly, but they generally come at a considerable cost in terms of pressure loss. Dimple techniques have lately gained popularity because to their ability to promote heat transmission while imposing a minor pressure penalty. When dimple surfaces are mixed with nanofluids, some studies have seen increased heat transmission, but the key concern is an increase in the system's friction factor, which is also regulated within acceptable ranges.

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