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A Review on Nano Fluid Particles through a Rectangular Corrugated Channel

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Abstract- This review examines the thermal and hydraulic performance of nanofluids flowing through rectangular corrugated channels, focusing on their potential for enhancing heat transfer efficiency. Various nanofluids, including ZnO, CuO, Fe_2O_3, Al_2O_3, SiO_2, and TiO_2, are evaluated based on parameters such as heat transfer coefficient, pressure drop, and Nusselt number. The unique properties of nanofluids, coupled with the enhanced turbulence induced by corrugated geometries, result in significant improvements in thermal performance compared to conventional fluids. However, factors like pressure drop and flow resistance also vary widely depending on the type of nanoparticles used. This review highlights the critical role of nanoparticle selection and channel design in optimizing heat transfer while minimizing pressure losses, providing valuable insights for advanced thermal management systems.

Index Terms- Nanofluids, corrugated channel, heat transfer, Nusselt number, heat transfer coefficient

I. INTRODUCTION

Heat exchangers are a device that exchange the heat between two fluids of different temperatures that are separated by a solid wall. The temperature gradient, or the differences in temperature facilitate this transfer of heat. Transfer of heat happens by three principle means: radiation, conduction and convection. In the use of heat exchangers radiation does take place. However, in comparison to conduction and convection, radiation does not play a major role. Conduction occurs as the heat from the higher temperature fluid passes through the solid wall.

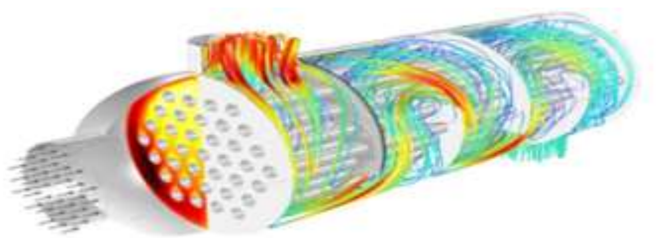

Fig. 1: Heat exchanger

The heat exchanger is a device used to transfer the heat from the hot fluid to cold fluid with maximum rate and minimum investment. The heat exchanger is an important device in various thermal systems for e.g. condenser and evaporator in refrigeration systems, boiler & condenser in steam power plants etc. The heat exchanger has wide variety of industrial applications such as process industries, chemical industries, food industries etc. Now there is need of the compact heat exchangers to give required heat transfer rate with minimum space requirement.

A large number of industries use processes in which heat is transferred between different fluids (or gases). The basic principle of heat transfer is extremely simple: two fluids at different temperatures are placed in contact with a conductive barrier (the tube wall) and heat is transferred from the hotter fluid to the colder fluid until they reach the same temperature. In industrial processes this is carried out in heat exchangers of various types and styles usually purpose built for the process and site conditions of the application.

The driving force for heat transfer is the difference in temperature between the hot and cold fluids. The greater the difference, the higher the rate at which the heat will flow between them. With complex processing sequences, the designer must optimise the temperature levels at each stage to maximise the total rate of heat flow.

A second factor controlling the transfer of heat is the area of the conductive barrier provided for heat flow. The greater the area then the greater amount of heat which can flow in a given time for a given temperature difference within the heat exchanger. The designer has to minimise this area to provide cost effective solutions to his client. With skill the amount of area can be minimised and configured to reduce the containment volume and overall cost.

The third and perhaps the most important factor controlling the transfer of heat is the rate at which the heat flows into or out from each of the fluids. A high resistance to heat flow in either fluid will produce a slow overall rate of heat transfer. The level of resistance to heat flow results from many different factors including the inherent thermal characteristics of the fluids but can be influenced by the designer in a very positive way by the generation of turbulence within the fluids to prevent the creation of a thermally resistant static "boundary layer" of fluid in contact with the heat transfer surface.

The fourth factor, also under the control of the designer, is the flow of heat through the conductive barrier between the fluids. The material chosen has to be compatible with the fluids of the process, it must not corrode or contaminate a food product, it must have an appropriate level of mechanical strength to withstand working temperatures and pressures, and it must have a low resistance to heat flow so that it does not become the overriding factor in the heat transfer process.

II. CORRUGATED CHANNEL

The corrugated channel is a common heat exchanger configuration. Such a channel is formed by two corrugated walls placed side by side, the corrugations being perpendicular to the flow direction. The flow impinges on, and is deflected by, the corrugations, thermal boundary-layer growth is interrupted by flow separation, and at sufficiently high Reynolds numbers, streamwise (Goertler) vortices or spanwise vortices may occur. These phenomena influence the temperature field significantly, resulting in sizable heat transfer enhancement in comparison to a parallel-plate channel. However, since the gains in heat transfer are accompanied by increased losses of mechanical energy in the flow, the practical utility of this approach would depend on design constraints such as the pressure drop or pumping power required to sustain the flow.

Fig. 2: Corrugated Fins

Designing more effective energy systems is a challenge for researchers and engineers to minimize the consumption of energy in order to improve energy system efficiency. In this respect, improving the heat transfer rate and hence producing more compact heat exchangers which are essential components for many engineering applications such as space, aeronautics, automotive industry, ocean thermal energy conversion technology is a major concern. Corrugations are used in plate heat exchangers to enhance the heat transfer rate and to improve the strength of plates. Complex corrugated channel geometry improves the heat transfer efficiency resulting in higher-pressure losses, especially in turbulent flow regime.

Flow control techniques consist of three main techniques: active flow control technique, passive flow control technique, and compound flow control technique for improving the heat transfer rate. The active flow control technique requires external power input in order to provide heat transfer enhancement. Some examples of active flow techniques include flow oscillation, flow vibration, surface vibration, magnetic field and other similar methods. This example provides better flow mixing and heat transfers enhancement. The passive flow control technique does not need any external power input to improve the heat transfer, but, causes a further pressure drop because of the geometrical changes. Some examples of the passive flow control methods are the use of inserts, additives, rough surface, swirl flow devices, treated surface, extended surfaces and coiled tubes. As seen from examples, reducing the hydraulic diameter of the flow passage improves the rate of heat transfer. Also, in some cases by applying this technique, a secondary flow can be obtained which upgrades the rate heat transfer by mixing fluids between the core flow region with the flow region close to the wall surface. The compound flow control technique involves combinations of the two or more flow control methods for enhancing the heat transfer rate. A surface configuration with additives or flow vibration with additives can be an example of the compound flow control technique. In industrial heat exchangers, corrugated channels are used significantly as one of the passive flow control techniques for improving the heat transfer rate.

III. NANOFLUID

A nanofluid is a fluid containing nanometer-sized particles, called nanoparticles. These fluids are engineered colloidal suspensions of nanoparticles in a base fluid. The nanoparticles used in nanofluids are typically made of metals, oxides, carbides, or carbon nanotubes. Common base fluids include water, ethylene glycol and oil.

Nanofluids have novel properties that make them potentially useful in many applications in heat transfer, including microelectronics, fuel cells, pharmaceutical processes, and hybrid- powered engines, engine cooling/vehicle thermal management, domestic refrigerator, chiller, heat exchanger, in grinding, machining and in boiler flue gas temperature reduction. They exhibit enhanced thermal conductivity, and the convective heat transfer coefficient compared to the base fluid.[6] Knowledge of the rheological behaviour of nanofluids is found to be critical in deciding their suitability for convective heat transfer applications. Nanofluids also have special acoustical properties and in ultrasonic fields display additional shear-wave reconversion of an incident compressional wave; the effect becomes more pronounced as concentration increases.

In analysis such as computational fluid dynamics (CFD), nanofluids can be assumed to be single phase fluids; however, almost all new academic papers use a two-phase assumption. Classical theory of single-phase fluids can be applied, where physical properties of nanofluid is taken as a function of properties of both constituents and their concentrations. An alternative approach simulates nanofluids using a two-component model.

Nanofluids can be considered as the future of heat transfer fluids in various heat transfer applications. They are expected to give better thermal performance than conventional fluids due to the presence of suspended nanoparticles which have high thermal conductivity. Today more than ever, cooling is one of the most pressing needs of many industrial technologies because of their ever-increasing heat generation rates at both micro-level (such as computer chips) and macro-level (such as car engines). However, conventional heat transfer fluids such as air, water, ethylene glycol, and oil show very low thermal conductivity compared to solids.

The major problem with the use of microparticles is that they settle very rapidly in liquids. They also cause abrasion, clogging, and additional pressure drops. Furthermore, high particle concentrations are required to obtain appreciable improvements in the thermal conductivities of these suspensions.

These problems severely limit the use of conventional solid-liquid suspensions as practical heat transfer fluids. Despite tremendous efforts, the technical barriers mentioned above still remain after more than 100 years. Modern nanotechnology has enabled the production of nanoparticles with average particle sizes below 100 nm. Nanoparticles generally have superior mechanical, optical, electrical, magnetic, and thermal properties.

Nanofluids are a new class of nanotechnology-based heat transfer fluids, obtained by dispersing and stably suspending nanoparticles with typical dimensions on the order of 10 nm.
The goal of nanofluids is to achieve the highest possible thermal properties at the smallest possible concentrations (preferably<1% by volume) by uniform dispersion and stable suspension of nanoparticles (preferably<10 nm) in host fluids. To achieve this goal it is vital to understand how nanoparticles enhance energy transport in liquids.
Combinations of nanoparticles and base fluids can produce many heterogeneous nanofluids. Nanoparticle materials may include:

- Oxide ceramic – Al_2O_3, CuO
- Metal carbides – SiC
- Nitrides – AlN, SiN
- Metals – Al, Cu
- Non-metals – Graphite, carbon nanotubes
- Layered – Al + Al_2O_3, Cu + C
- PCM – S/S

Functionalized nanoparticles whereas base fluids may include:

- Water
- Ethylene- or tri-ethylene-glycols and other coolants
- Oil and other lubricants
- Bio-fluids
- Polymer solutions
- Other common fluids

Applications of Nanofluid

- Nano fluids are primarily used for their enhanced thermal properties as coolants in heat transfer equipment such as heat exchangers, electronic cooling system (such as flat plate) and radiators. Heat transfer over flat plate has been analysed by many researchers.
- They are also useful for their controlled optical properties. Graphene based nanofluid has been found to enhance Polymerase chain reaction efficiency.
- Nano fluids in solar collectors is another application where nanofluids are employed for their properties.

The spreading of a nanofluid droplet is enhanced by the solid-like ordering structure of nanoparticles assembled near the contact line by diffusion, which gives rise to a structural disjoining pressure in the vicinity of the contact line. However, such enhancement is not observed for small droplets with diameter of nanometre scale, because the wetting time scale is much smaller than the diffusion time scale. Today more than ever, cooling is one of the most pressing needs of many industrial technologies because of their ever-increasing heat generation rates at both micro-level (such as computer chips) and macro-level (such as car engines). However, conventional heat transfer fluids such as air, water, ethylene glycol, and oil show very low thermal conductivity compared to solids.

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IV. PAST STUDIES

Ajeel et al. (2019) presented a numerical simulation performed on thermal performance comparison of a corrugated channel with three corrugation profiles. Semicircle, trapezoidal, and house shapes are considered as corrugation profiles for corrugated walls of channel using nanoparticles volume fractions of ZnO and Reynolds number ranging from 0 to 0.08 and 10,000–30,000, respectively. The influences of these profiles on heat transfer, pressure drop, streamwise velocity contours, temperature contours, and thermal performance of a corrugated channel are discussed in detail. Moreover, the results of corrugated channel are compared with straight one. Governing equations are discretized by using a finite volume method (FVM) and SIMPLE algorithm. The Nusselt number and pressure drop are about 1–4 times higher for the corrugated channels than for the flat channel, indicating the great effect of the corrugation profile. There are 7.4%, 8.7%, and 4.86% decrements in thermal performance for house shaped, trapezoidal, and semicircle, respectively, at Reynolds number between 10,000 and 30,000. Finally, it was found that among corrugated channels, the trapezoidal channel provides the highest thermal performance followed by the semicircle and house shaped channels.

Ajeel et al. (2019) presented heat transfer and flow characteristics of the symmetry semicircle- corrugated channel with (SiO2) - water nanofluid numerically over Reynolds number ranges of 10,000–30,000. The influence of geometrical parameters including height-to-width ratio (h/W) and pitch-to-length ratio (p/L) on the thermal and hydraulic characteristics are evaluated. A numerical simulation covering nanofluid with SiO2 volume fractions of 0–8.0% was carried out by employing the finite volume method for discretization of the governing equations. The outcomes revealed that the height-to-width ratio has greater influence on the promotion of heat transfer compared to the pitch-to-length ratio. At Reynolds number 30,000, there is 13.59% increment in Nuav due to a decrease of the pitch-to-length ratio from 0.175 to 0.075, with an increment of about 78.84% due to an increase of the height-to-width ratio from 0.0 to 0.05. The results indicate that the height-to-width ratio of 0.05 with a pitch-to-length ratio of 0.075 are the optimum parameters and have shown significant improvement in thermal performance factor. Furthermore, new correlations for Nusselt number and friction factor are developed and reported.

Ajeel et al. (2019) presented a numerical comparison of the thermal performance of different shapes of corrugated channels as well as straight channels in a turbulent flow of ZnO–water nano fluid under constant heat flux. The finite volume method with the SIMPLE technique was employed to solve the governing equations. Different forms of corrugated channels, including trapezoidal, house-shaped, and semicircle channels, were tested using nanoparticles volume fractions and Reynolds number ranging from 0 to 0.08 and 10,000 to 30,000, respectively. Heat transfer, pressure drop, streamwise velocity contours, temperature contours, and thermal performance were found and analysed. The simulation outcomes indicated that the performance of the corrugated channels was extremely affected by corrugation shape. For the channel shapes under consideration, the heat transfer and pressure drop increased when the nanoparticles volume fraction and Reynolds number increased. The trapezoidal channel has the best thermal performance followed by the semicircle and house-shaped channels.

Shirzad et al. (2019) presented the effect of using different nanofluid as a coolant fluid on the thermal performance of Pillow plate heat exchanger (PPHE). The objective of present study is using a new heat transfer enhancement method in PPHE by utilizing nanofluid instead of pure fluid as a heat transfer medium. Accordingly, heat transfer and pressure drop of three water- based nanofluids including Al2O3, CuO and TiO2 are studied by performing three-dimensional numerical simulations by the commercial CFD software. The fluid flow is turbulence, and the analysis is done at different Reynolds number (1000–8000). The results indicate that by increasing the nanoparticle volume concentration in the range of 2–5%, the heat transfer coefficient is improved significantly at low Reynolds number. In order to investigate the heat transfer and pressure drop of the proposed system simultaneously, the performance coefficient parameter is defined. Results showed that the heat exchanger performance is developed significantly at low Re number. On the other hand, the performance of different nanofluids is compared at two volume concentration. The Al2O3-water with ϕ=2% at all Reynolds numbers and the TiO2-water with ϕ=5% at higher Reynolds numbers have better performance among other nanofluids.

Ajeel et al. (2019) presented heat transfer and flow characteristics of the symmetry trapezoidal- corrugated channel with silicon dioxide (SiO2) - water as nanofluid performed numerically over Reynolds number ranges of 10,000–30,000. The influence of geometrical parameters including height-to-width ratio (h/W) and pitch-to-length ratio (p/L) on the thermal and hydraulic characteristics are evaluated. A numerical simulation covers nanofluid with SiO2 volume fractions 8% and carried out by employing the finite volume method (FVM) and SIMPLE algorithm for discretization of the governing equations and coupling of the pressure-velocity system while the k−ε turbulence model was employed to compute the turbulent flow. The outcomes revealed that the (h/W) ratio has a more influence on the promotion of heat transfer compared with the (p/L) ratio. At Reynolds number 30000, there is 16.63% increment in Nuav due to a decrease of the (p/L) ratio from 0.175 to 0.075, while the increment about 99.45% due to an increase of the (h/W) ratio from 0.0 to 0.05. The numerical results indicate that the h/W of 0.05 with a p/L of 0.075 are the optimum parameters and have shown significant improvement in thermal performance factor. Furthermore, new correlations for Nusselt number and friction factor are developed and reported.

V. CONCLUSION

Currently, the need to improve thermal performance and promote heat transfer in most engineering applications has pushed designers to look for new procedures and mechanisms in heat exchangers. While it is true that there are many techniques for both passive and active methods, corrugated surfaces are widely utilized to enhance heat transfer characteristics in a manner that conserves energy. Many techniques suffer in terms of heat transfer performance when they use traditional cool- ants such as water, oil, and FC-77. Traditional fluids have poor thermal properties, especially thermal conductivity, which is a major obstacle to achieving high thermal performance. To overcome these limitations, nanoparticles can be introduced into conventional liquids to improve the thermal properties of these liquids. In this regard, the studies have shown that the resulting mixture, called nanofluid, promotes heat transfer. many researchers have investigated various aspects of corrugated channel geometry to enhance heat transfer. However, the heat transfer performances of many other corrugated shapes have not yet been reported. In addition, very little studies have been done to investigate the impact of nanofluids on thermohydraulic properties through the corrugated channels. Thus, the current study attempts to full fill the existing gap by studying the influence of nanofluids on heat transfer rate and pressure drop as well as thermal performance factor in trapezoidal corrugated channel.

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