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Effect of Different Nanofluids on Thermal Performance in Trapezoidal Corrugated Channel

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ABSTRACT

Using corrugated channels is one of the passive heat transfer enhancement techniques in fabrication of heat exchange devices. 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 the present research, an experimental study of forced convective flows of different nanofluids through a trapezoidal corrugated channel at a constant wall temperature condition was performed. A numerical simulation of a corrugated channel was applied by using the nanofluid to probe the characteristics of the flow and thermal fields. For the purpose of solving the governing equations with corresponding boundary conditions, the finite volume method is employed by implementing the CFD commercial software ANSYS-FLUENT-V16. The channel was tested under constant heat flux of 10 KW and the volume fraction of nanofluid is taken as 0.08. it was found that the pressure drop is found highest in the nanofluid tio2-water and is decreasing in the sequence is TiO_2> SiO_2>Fe_2O_3> Al_2O_3> ZnO> CuO.

Keywords: *Corrugated channels, Nanofluids, Thermal fields, Forced convective flows*

1. INTRODUCTION

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.

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.

2. LITERATURE REVIEW

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.

Ajeel et al. (2019) presented heat transfer and flow characteristics of the symmetry semicircle-corrugated channel with (SiO_2) - 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 SiO_2 volume fractions of 0–8.0% was carried out by employing the finite volume method for discretization of the governing equations.

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 nanofluid under constant heat flux.

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.

Ajeel et al. (2019) presented heat transfer and flow characteristics of the symmetry trapezoidal-corrugated channel with silicon dioxide (SiO_2) - 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.

Ajeel et al. (2019) presented the forced convective turbulent flow of SiO_2-water nanofluid through different corrugated channels studied numerically and experimentally. All studies are performed for the straight channel (SC) and different two corrugated channels, namely semicircle corrugated channel (SCC) and trapezoidal corrugated channel (TCC) over Reynolds number ranges of 10000–30000.

Ajeel et al. (2019) presented the employment of alumina oxide (Al_2O_3) in water nanofluid for heat transfer enhancement with corrugation is performed numerically and experimentally over Reynolds number ranges of 10,000–30,000. Three corrugated channels, semicircle (SCC), trapezoidal (TCC), and straight (SC) are fabricated and tested with nanofluid Al_2O_3 volume fractions of 0%, 1%, and 2%.

Tokgöz et al. (2018) presented Heat transfer enhancement in channel flow is investigated by using corrugated duct in lieu of smooth duct. In this regard, periodic different cavities are applied on the duct walls using the same aspect ratios. The values of the Reynolds numbers are in the range of $10,000 \leq Re \leq 20,000$.

Ajeel et al. (2018) presented the effects of four different types of nanofluids which are Al2O3, CuO, SiO2 and ZnO–water under constant heat flux condition (10kw/m2). The governing equations of continuity, momentum and energy are solved using finite volume method (FVM). The study was carried out at 8% volume fraction of nanoparticles with 20nm particle diameters.

Ajeel et al. (2018) presented The performance of a trapezoidal-corrugated channel with four different kinds of nanofluids (ZnO, Al2O3, CuO, and SiO2), with four various nanoparticle volume fractions of 2%, 4%, 6% and 8% using water as base fluid.

Hosseinnezhad et al. (2018) presented the turbulent flow of water/Al2O3 nanofluid in a tubular heat exchanger with two twisted-tape numerically investigated in the three-dimensional coordinate. This numerical simulation has been done by using FVM, and all of the equations have been discretized by second-order upwind method.

Ajeel et al. (2018) presented numerical investigation of Thermal and hydraulic characteristics of turbulent nanofluid flow in a semicircle zigzag corrugated channel by implementing the finite volume method (FVM) to describe the governing equations.

Ma et al. (2018) presented numerical investigation of the laminar forced convection heat transfer of nanofluid through a bent channel. The lattice Boltzmann method was used for solving the governing equations in the domain. The effect of different parameters such as Reynolds number ($50 \leq Re \leq 150$), vertical passage ratio ($2.0 \leq M \leq 4.0$), and nanoparticle solid volume fractions (Φ = 0, 0.01, 0.03, 0.05) are analyzed in terms of streamlines, isotherms, and local Nusselt numbers

3. RESEARCH METHODOLOGY

The test sections along the corridors that are heated from the upper and lower surfaces, the bottom and the top, with smooth and flat surfaces, are considered as adiabatic surfaces. The total length of the channel was 700 mm while the corrugated section (L2) was 200 mm. To ensure a full-blown flow in the test part, the upstream or inlet section was 400 mm (L1). The remaining length was for the drift or outlet section to deal with the opposite flow which could create damaging pressures that could affect the accuracy of the calculation and simulation. (Ajeel et al. 2018). The main objective of the current study is to study the effect of different nanofluids flowing inside trapezoidal corrugated channel on the heat transfer characteristics. A numerical simulation of a corrugated channel was applied by using the nanofluid to probe the characteristics of the flow and thermal fields. For the purpose of solving the governing equations with corresponding boundary conditions, the finite volume method is employed by implementing the CFD commercial software ANSYS-FLUENT-V16.1. The SIMPLE algorithm is employed to joint of the pressure-velocity fields and a 2nd order upwind scheme was utilized for the convective terms.

Table 1: Main geometry data for testing Trapezoidal Corrugated Channel

Channel height (H)	10 mm
Channel length (L_2)	200 mm
Micro channel width (Ww)	50 mm
Pitch of corrugation (p)	15 mm
Corrugation width(w)	5 mm
Corrugation height (h)	2.5 mm

4. RESULTS AND DISCUSSION

The main objective of the current study is to study the effect of different nanofluids flowing inside trapezoidal corrugated channel on the heat transfer characteristics. The local *Nu* and pressure drop for water flow at the lower corrugated wall of the trapezoidal corrugated channel are computed at $Re = 10000$

Table 2: Thermophysical properties of nanoparticle-water at volume fraction of 0.08

nanofluid	ZnO-water	SiO_2-water	TiO_2-water	Fe_2O_3-water	Al_2O_3-water	CuO-water
density fluid	448.92	176.92	340.92	416.92	312.12	520.92
cp	4157825	3969985	4072985	4118465	4113601	4120545
k	18.30118	1.600835	6.245559	4.460214	21.90338	46.80931
viscocity	0.002371	0.002371	0.002371	0.002371	0.002371	0.002371

Heat Transfer

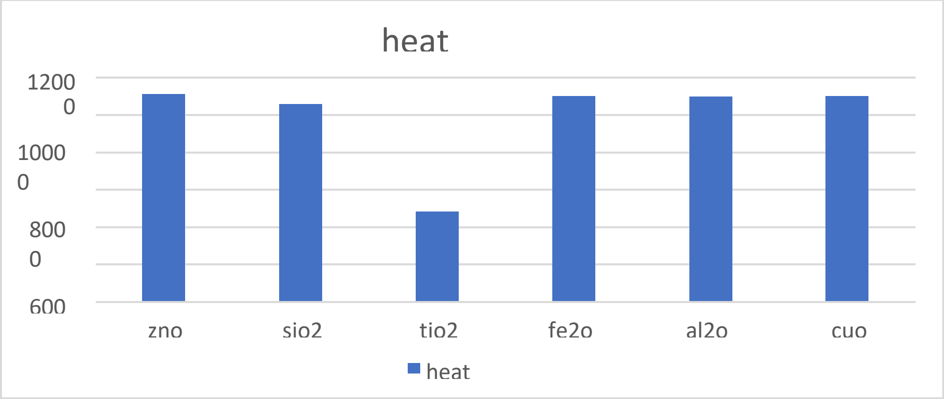

Fig. 1: Heat Transfer for Different Nanofluids

From the above graph it is observed that ZnO- water has highest heat transfer per unit area.

Heat Transfer Coefficient

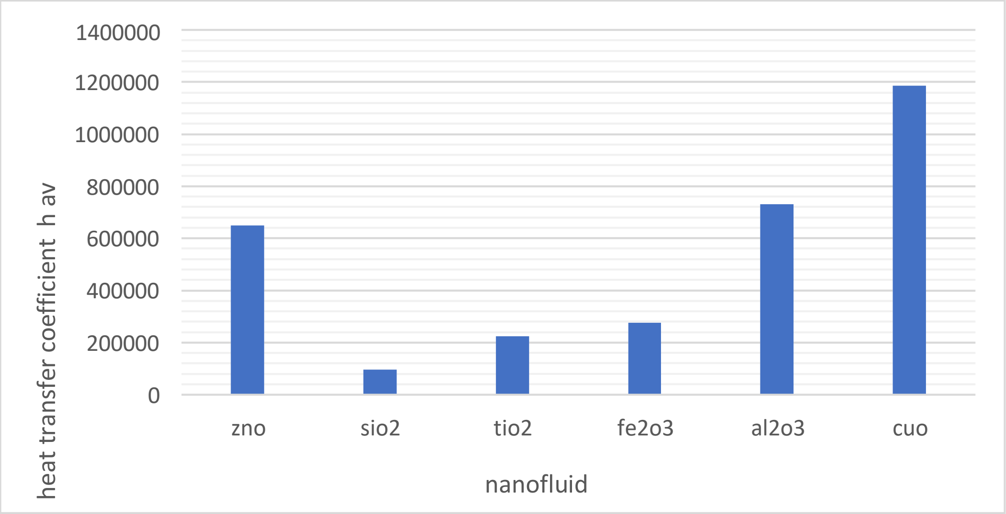

Fig. 2: Heat Transfer coefficient for Different Nanofluids

From the above graph it is observed that CuO- water has highest heat transfer coefficient.

Nusselt Number

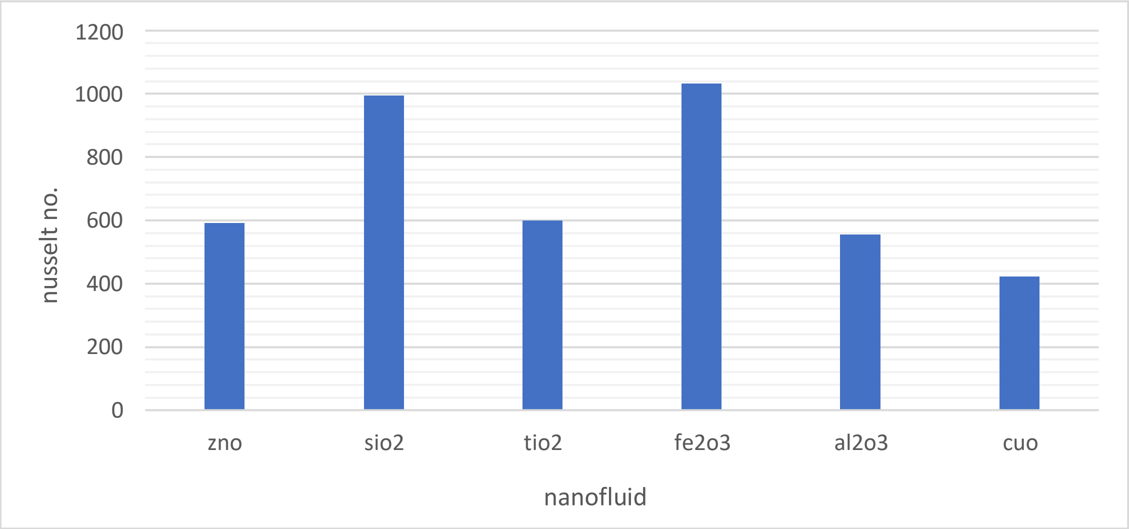

Fig. 3: Nusselt Number for Different Nanofluids

Of all corrugated channels, the Fe_2O_3- water was the best at processing Nusselt numbers, followed by the SiO2-water and TiO2- water; the CuO finished with the lowest results.

Pressure Drop

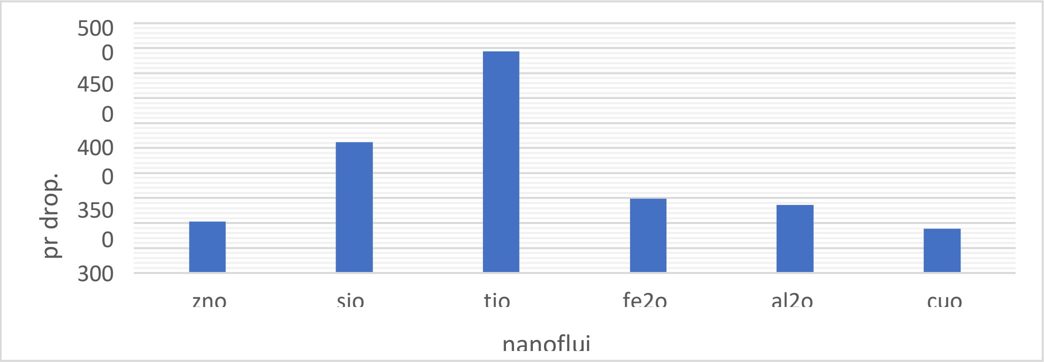

Fig. 4: Pressure Drop for Different Nanofluids

From the above graph it is observed that nanofluid TiO_2- water has highest Pressure drop.

Comparison from Ajeel et a

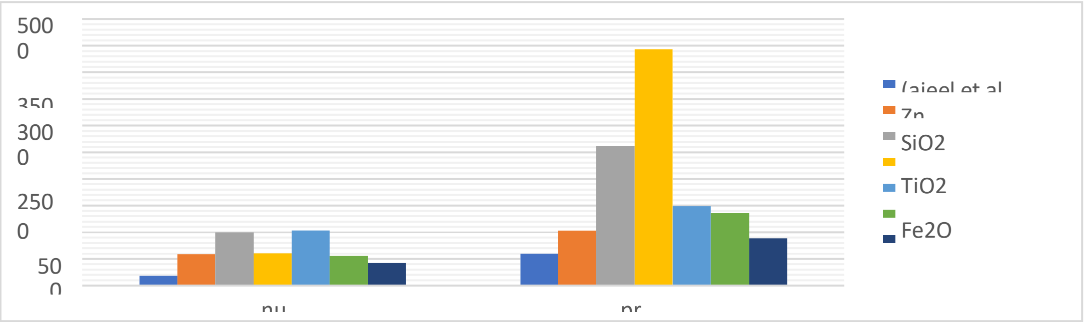

Fig. 5: Comparison from Ajeel et al. 2018

Of all corrugated channels, the Fe_2O_3- water was the best at processing Nusselt numbers, followed by the SiO2-water and TiO2- water; the CuO finished with the lowest results. While for the pressure drop, it is found highest in the nanofluid tio2 - water and is decreasing in the sequence is tio_2> sio_2>fe_2o_3> al_2o_3> zno> cuo.

Contours

The pressure, velocity, and temperature contour of sio_2 are shown below.

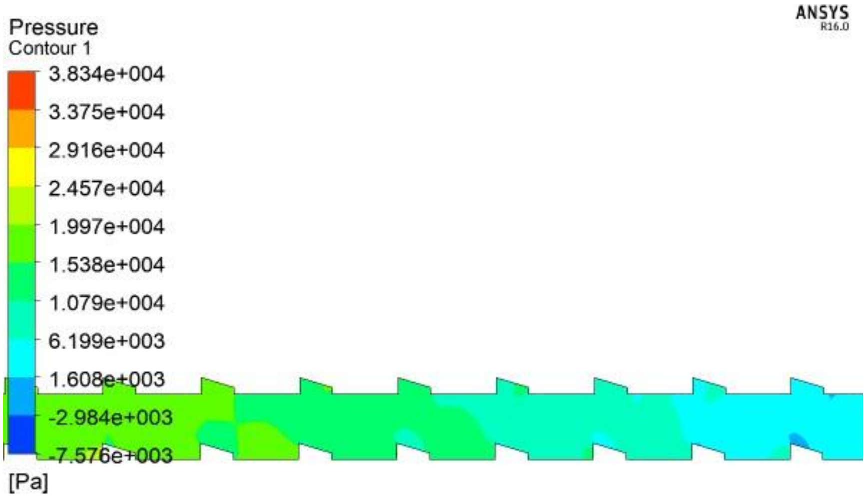

Fig. 6: Pressure contour

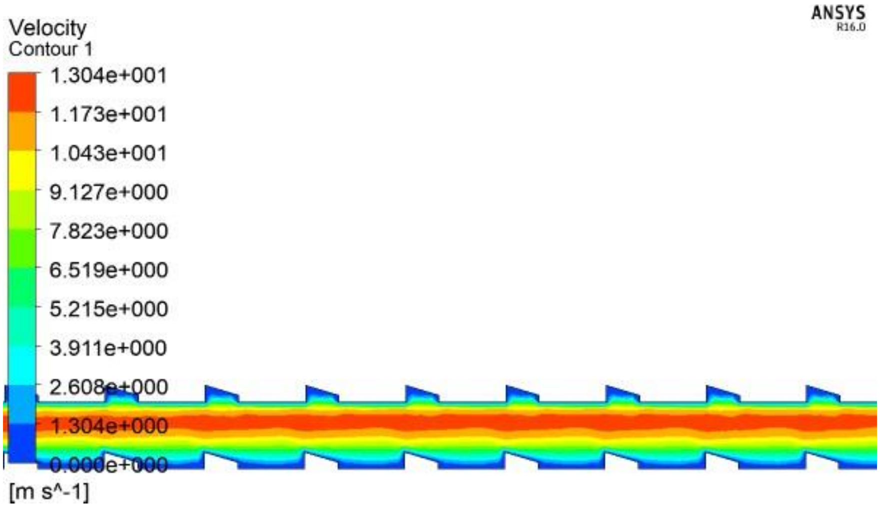

Fig. 7: velocity contour

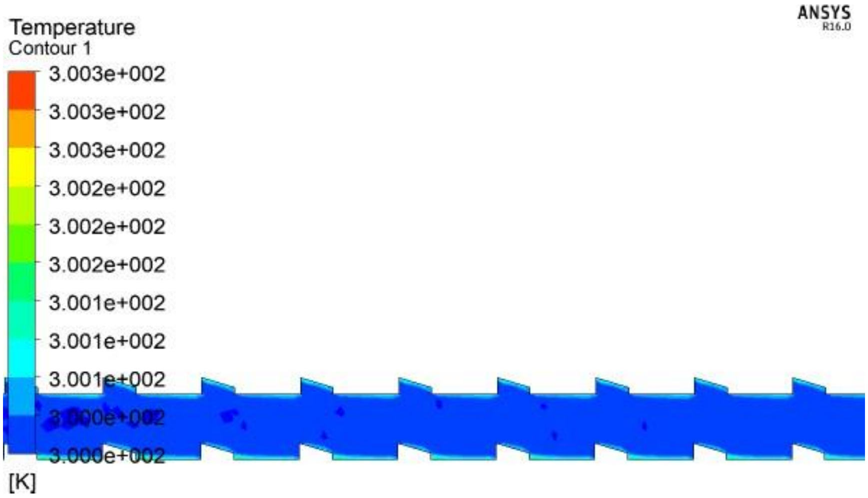

Fig. 8: temperature contour

The geometry of the corrugated channels is symmetrical because the top and bottom walls of the channel are asymmetrical and this makes the velocity and temperature contours symmetrical around the centerline of the channel. According to the velocity contours, the recirculation zones appear in the trough (wrinkle) of the corrugated walls. Therefore, the adverse flow occurred in the wrinkle nearby the corrugated walls where the flow ran in the direction opposite to the major flow.

5. CONCLUSIONS

In this paper, the 3-D turbulent forced convective flow of six different nanofluids ZnO (ajeel et al. 2018), SiO_2, TiO_2, Fe_2O_3, Al_2O_3, and CuO with base fluid as water for trapezoidal corrugated channels for *Re* 10,000 was investigated. The channel was tested under constant heat flux of 10 KW and the volume fraction of nanofluid is taken as 0.08. The conclusions of this numerical study are:

- The heat transfer is found highest in the nanofluid ZnO-water and is decreasing in the sequence is ZnO > CuO >Fe_2O_3> Al_2O_3 > SiO_2 > TiO_2
- The heat transfer coefficient is found highest in the nanofluid CuO-water and is decreasing in the sequence is CuO > Al_2O_3 > ZnO > Fe_2O_3> TiO_2 > SiO_2
- The pressure drop is found highest in the nanofluid tio2-water and is decreasing in the sequence is TiO_2> SiO_2>Fe_2O_3> Al_2O_3> ZnO> CuO.
- The Nusselt no is found highest in the nanofluid fe2o3-water and is decreasing in the sequence is Fe_2O_3 > SiO_2 > TiO_2 > ZnO > Al_2O_3 > CuO.

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