International Journal of Scientific Research & Engineering Trends
Volume 10, Issue 1, Jan-Feb-2024, ISSN (Online): 2395-566X

A Study on Effects of Different Nanofluids on Trapezoidal Corrugated Channel

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Abstract- Heating/cooling processes using different techniques are essential in many industrial applications such as production and electronics processes, and consequently, all machines require reducing or increasing heat transfer. Despite the high pressure drop caused by turbulent flow in complicated channels, the use of corrugation in heat exchangers has received a lot of attention during the last two decades. Therefore, corrugated surface technique is the promising method to intensify the thermal performance and compactness of heat transfer instruments in some cooling system applications, especially in compact plate heat exchangers. In this study a CFD analysis of trapezoidal corrugated channel was done by using different nano-fluids.

Index Terms- Nanofluids, trapezoidal corrugated channel, heat transfer

I. INTRODUCTION

The corrugated channel represents a prevalent configuration in heat exchangers, consisting of two corrugated walls positioned side by side, with the corrugations perpendicular to the flow direction. As the flow encounters and interacts with the corrugations, it undergoes deflection. This process interrupts the growth of the thermal boundary layer, leading to flow separation. At higher Reynolds numbers, streamwise (Goertler) vortices or spanwise vortices may also manifest. These phenomena exert a significant influence on the temperature field, resulting in substantial heat transfer enhancement when compared to a parallel-plate channel. It is crucial to note that while the gains in heat transfer are noteworthy, there is a concurrent increase in the losses of mechanical energy within the flow. The practical feasibility of employing this approach depends on various design constraints, particularly factors such as the pressure drop or pumping power required to sustain the flow. The consideration of these design constraints is essential in evaluating the overall efficiency and viability of utilizing corrugated channels for heat exchange applications.

Fig. 1: Corrugated channel

- Semicircle corrugated channel
- Trapezoidal corrugated channel
- Straight channel

To design more efficient energy systems poses a formidable challenge for researchers and engineers aiming to minimize energy consumption and enhance overall system efficiency. A key aspect of this challenge involves improving the heat transfer rate, particularly in the context of developing more compact heat exchangers. These heat exchangers play a critical role in various engineering applications such as space exploration, aeronautics, automotive industry, and ocean thermal energy conversion technology.

The utilization of corrugations in plate heat exchangers represents a strategy to augment the heat transfer rate and reinforce the structural integrity of the plates. The incorporation of complex corrugated channel geometries serves to enhance heat transfer efficiency, albeit with the trade-off of higher-pressure losses, especially in turbulent flow regimes.

Various flow control techniques have been developed to address the goal of improving heat transfer rates. These techniques fall into three main categories: active flow control, passive flow control, and compound flow control. Active flow control involves the use of external power input to enhance heat transfer, employing methods such as flow oscillation, flow vibration, surface vibration, magnetic fields, and similar approaches. While these techniques provide effective flow mixing and heat transfer enhancement, they require additional power input.

On the other hand, passive flow control techniques do not rely on external power input but may introduce further pressure drops due to geometric changes. Examples of passive flow control methods include the use of inserts, additives, rough surfaces, swirl flow devices, treated surfaces, extended surfaces, and coiled tubes. One notable observation is that reducing the hydraulic diameter of the flow passage tends to improve the heat transfer rate. Additionally, in some instances, this technique generates a secondary flow, enhancing heat transfer by mixing fluids between the core flow region and the region close to the wall surface.

The compound flow control technique involves combining two or more flow control methods to achieve enhanced heat transfer rates. An example of this approach could be a surface configuration with additives or flow vibration combined with additives. In the realm of industrial heat exchangers, corrugated channels are widely employed as a significant passive flow control technique to improve the heat transfer rate. This multifaceted approach to heat transfer enhancement underscores the complexity and diversity of strategies employed to optimize energy systems.

II. METHODOLOGY

1. Model Description

Figure 2 illustrates the two-dimensional geometry depicted in the schematic diagram of the trapezoidal corrugated channel, the geometric model under investigation in the physical problem. Typically, the corrugated channel features two walls – upper and lower – forming its geometry. The flow domain is divided into three segments: the test sections along the corrugations, heated from both upper and lower surfaces, with smooth and flat surfaces treated as adiabatic. The overall channel length measures 700 mm, with a corrugated section (L2) extending for 200 mm. To ensure fully developed flow in the test section, the upstream or inlet section spans 400 mm (L1). The remaining length accommodates the drift or outlet section, addressing the counter flow that might generate detrimental pressures potentially impacting calculation and simulation accuracy (Ajeel et al. 2018).

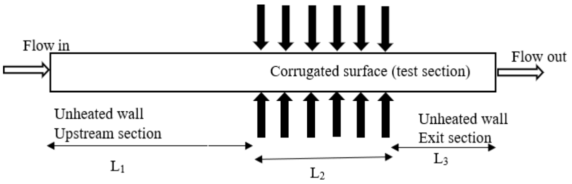

Fig. 2: Geometry of the corrugated channel

The configuration of the trapezoidal corrugated channel, created in ANSYS 16, is presented in Figure 3 This trapezoidal corrugated channel was selected based on the work of Ajeel et al. (2018), who explored four different geometries and identified this one as delivering optimal performance. The channel has a height (H) of 10 mm and a width that is 5 times the height. The wave pitch is set at (P = 1.5 H), while the wave width and height are (W = H / 2) and (H = H / 4), respectively. The channel's geometry is depicted in Figure 3.3, and the dimensions are detailed in Table 3.1. Heat is applied to the surfaces of the channel, with a constant heat input maintained at approximately 10 kW.

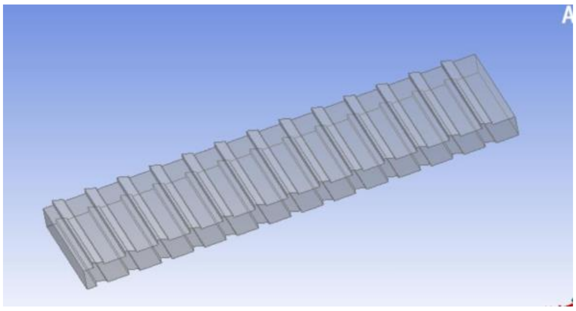

Fig. 3: Trapezoidal Corrugated Channel

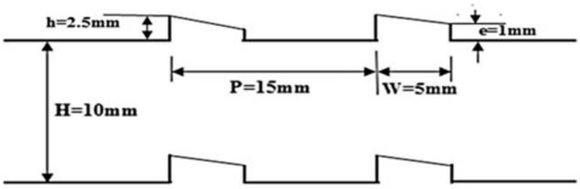

Fig. 4: Block diagram of trapezoidal channel

Table 1: Main geometry data for testing Trapezoidal Corrugated Channel

Channel height (H)	10 mm
Channel length (L2)	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

2. CFD Modelling

The governing equations are the standard continuity equation for conservation of mass, Navier– Stokes equation for conservation of momentum and energy equations for predicting the conjugate heat transfer. A turbulent flow forced convection in the corrugated and straight channels with a single-phase and three-dimensional (3D) model were executed.

The Reynolds Averaged Navier-Stokes (RANS) turbulence models mentioned above provide a cost-effective approach for computing complex turbulent industrial flows. Generally, the Navier-Stokes equations describe the motion of turbulent flow, but solving these equations for intricate flow problems is both expensive and time-consuming [26]. As an alternative, two methods have been proposed in the past: (i) Large Eddy Simulation (LES), where the large energy-containing eddies are simulated directly, and the small eddies are considered through averaging. The separation of large and small eddies necessitates careful tracking. (ii) Reynolds Averaging (RANS), where all eddies are considered, and Reynolds stresses are obtained by averaging the Navier-Stokes equations (time averaging for statistically steady flows, ensemble averaging for unsteady flows).

3. Boundary Conditions

In this study, numerical computations were conducted using the commercial CFD software FLUENT 16, which employs the finite volume method. The SIMPLE algorithm was utilized to obtain solutions for heat transfer, heat transfer coefficient and Nusselt number. The finite-element model was created and meshed using Ansys software.

The simulated flow is turbulent, and the relevant boundary conditions and interfaces are outlined in Table 4.1. The fluid considered in this numerical analysis is nanofluids, and its thermo physical properties were obtained at 300K with a volume fraction of 0.08, aligning with the conditions of the experimental investigations.

- The inlet fluid temperature is 300K
- A constant heat flux is assigned to the wall surfaces
- The inlet is velocity and is assumed uniform
- No slip boundary condition is assigned to all the surfaces
- Zero-gauge pressure is assigned at the outlet of the corrugated channel.

Table 2: Boundary conditions and interfaces conceived in the ANSYS-fluent 16 pre- processor

Sl.no	Fluid domain	Interface/boundary location	Interface/boundary type
1	nanofluid	Fluid_Inlet	Velocity Inlet
2	nanofluid	Fluid_outlet	Pressure Outlet (0 Gauge Pressure)
3		wall	Constant Heat Flux

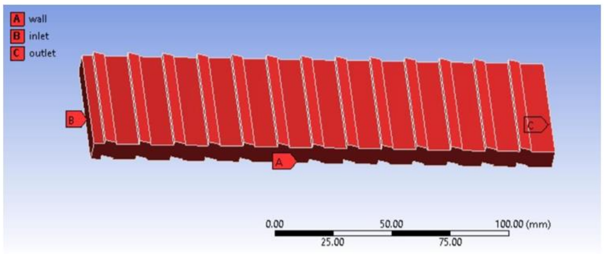

Fig. 5: Boundary condition in CFD

4. Meshing of Domain

Meshing is a crucial step in the engineering simulation process, involving the division of complex geometries into simpler elements that serve as discrete local approximations of the larger domain. The quality of the mesh significantly impacts the accuracy, convergence, and speed of the simulation. Through meshing, the domain is fragmented into pieces, with each piece representing an element. These elements are essential for applying the Finite Element method, as Finite Element relies on having a basis local to an element and combining multiple local solutions to construct the global one.

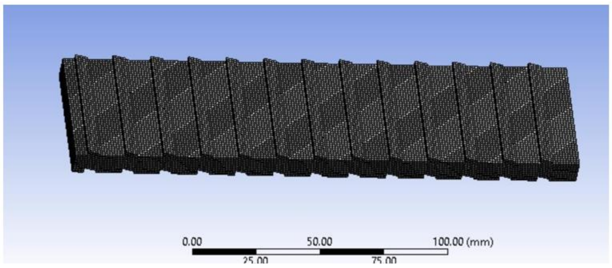

Fig. 6: Mesh model (no. of nodes=114087, no. of elements= 98700)

III. RESULTS AND DISCUSSION

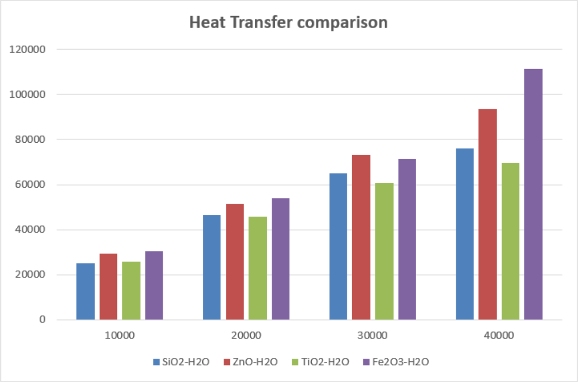

Fig. 7: Heat Transfer comparison

Max. heat transfer is achieved at higher Reynold number and it is maximum for Fe2O3-H2O.

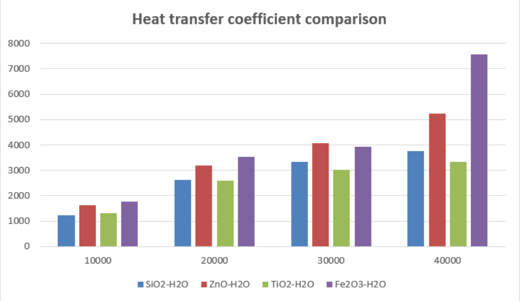

Fig. 8: Heat transfer coefficient comparison

Max. heat transfer coefficient is achieved at higher Reynold number and it is maximum for Fe2O3-H2O.

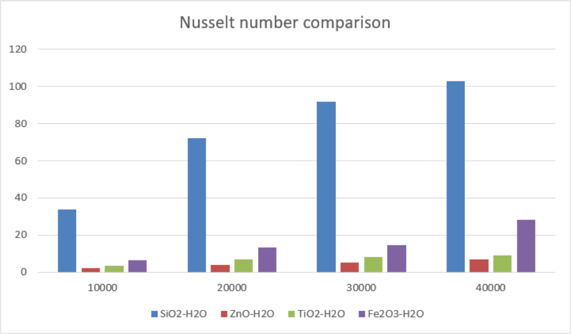

Fig. 9: Nusselt number comparison

Max. Nu number is achieved at higher Reynold number and it is maximum for Si2O3-H2O.

IV. CONCLUSION

In this investigation, the turbulent forced convective flow of four distinct nanofluids—ZnO (Ajeel et al., 2018), SiO2, TiO2, Fe2O3—was studied in trapezoidal corrugated channels at a Reynolds number (Re) of 10,000. The numerical solution involves solving the governing continuity, momentum, and energy equations using the finite volume approach in body-fitted coordinates. The channel was subjected to a constant heat flux of 10 kW, with a nanofluid volume fraction of 0.08. The findings of this numerical analysis are as follows:

1. In all cases, heat transfer increases with increase in Re.
2. In all cases, heat transfer coefficient increases with increase in Re.
3. In all cases, Nusselt number increases with increase in Re.
4. With regard to heat transfer, Fe2O3 shows max.values.
5. With regard to heat transfer coefficient, Fe2O3 shows max.values.
6. With regard to Nusselt number, SiO2 shows max.values.
7. The corrugation profile of the rectangular channel significantly influenced thermal performance compared to different nanofluids.
8. Generally, recirculation zones between corrugations had a noticeable impact on local thermal enhancement in all cases, and the distinct reverse flow patterns at different Reynolds numbers were evident.
9. With an increase in Reynolds number (Re), the recirculation zone before the corrugation decreased, while the recirculation zone after the corrugation expanded. This phenomenon is attributed to the effect of increasing velocity dependent on Reynolds number. Additionally, the largest recirculation zone was observed after the corrugation, corresponding to the region with the highest local Nusselt number.
10. It is crucial to consider particle surface properties and heat exchanger design for effective thermal performance.
11. In recent years, various industries have sought higher thermal performance to enhance efficiency, reduce costs and weight, and minimize heat exchanger size. The use of corrugated channels effectively reduces thermal resistance, leading to a decrease in the thermal boundary layer thickness.
12. Therefore, the corrugated surface geometry stands out as one of several suitable approaches to enhance heat transfer in these devices. This is due to the emergence of secondary flow regions in the corrugated channel trough, improving fluid blending and maximizing heat transfer efficiency.

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