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Numerical Analysis of Heat Transfer Enhancement Using Water / FMWCNT Nanofluid Passed in a 2D Backward Facing Step Channel

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ABSTRACT

In recent years, the study of heat transfer of Nano fluids, rheological behavior, and significant developments in this field have led to the widespread use of industrial equipment among researchers. Current numerical analysis of three different ratios (0.0, 0.12, and 0.25 %) of a nanomaterial functional multi-walled carbon nanotube (FMWCNT) is used by mixing it with pure water to improve the thermophysical properties of water. The finite volume method (Ansys Fluent R23) was used for the Reynolds number range of (10000 -18000) with turbulent flow. The results of the numerical simulation were interpreted as the Nusselt number, the features of the distribution of fluid velocity, temperature, and pressure. The results of the current study indicate a decrease in surface temperature and an increase in the coefficient of heat transfer by forced convection as a result of enhancing the weight ratio of nanomaterial and the Reynolds number. The axial velocity of the flow increased by increasing the Reynolds number, resulting in enhanced momentum. The decrease in axial velocity and the increase in the probability of vortex generation at the beginning of the channel when the fluid momentum increases, especially near the lower wall.

1. Introduction

A helpful method for improving heat transfer is to incorporate solid particles into heat transfer fluid. utilizing suspended solids the size of a millimeter or micrometer causes some serious issues such clogging, excessive pressure drops, and corrosion, but utilizing large suspended solids shown the highest augmentation of heat transfer via liquids. To prevent the sedimentation properties of the fluid flow that may clog the channel, nanoparticles with very low concentrations and nanometre sizes are used. Based on these points, several researchers in their previous literature investigations have studied the enhancement of heat transfer and flow properties using nanomaterials. M. R. Sohel et al [1] presented an experimental study to enhance heat transfer using a nanofluid (Al_2O_3) instead of pure water with different fractional sizes (0.1 -0.25%) in a small heat sink for cooling electronics, also studied the effect of changing different flow rates (0.5 -1.25 L/min) on the overall thermal performance. The study successfully showed the number of Nusselt was increased by up to (18%). N. K. Chavda [2] conducted an experimental investigation to determine the effect of using different concentrations of nanoparticles (CuO) mixed with water to improve the thermal properties of a double tube in a parallel flow heat exchanger. The results showed that by increasing the concentration, the heat transfer rate increases and the thermal performance improves compared to using only water. A. M. Elfaghi and M. S. M. Hisyammudden [3] presented numerical model to investigate the

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characteristics of turbulent flow and forced heat transfer of a circular pipe subjected to a constant heat flux along the axis of fluid flow. The nanomaterial TiO_2 was used in combination with purified still water for improvement. Various turbulent models of the commercial code program (Ansys) have been used in the analysis of computational fluid dynamics (CFD). To increase efficiency for engineering and industrial applications, researchers paid attention to raising thermal characteristics. At the University of Edinburgh, researchers have presented a new approach using nanoparticles in a basic liquid to improve thermal conductivity and increase the rate of heat transfer [4] and [5]. The use of numerical simulations by computers to improve heat transfer in heat exchangers. To solve and evaluate problems of fluid flow based on mathematics, computational fluid dynamics (CFD) methods are used [6-8]. In the current study, a backward-facing step channel's heat transfer and nanofluid flow in water/functional multi-walled carbon nanotubes have been quantitatively examined. Various elements, including gravity, flow velocity, and constant heat flux, can affect the temperature changes of the cooling fluid throughout the channel. The impact of changes in heat flux and Reynolds number on surface temperature and heat transfer rate changes are investigated using the numerical solution.

2. Materials and Methodology

Recently, to predicting results in laboratory and industrial scales for engineering applications, Computational Fluid Dynamics and numerical simulation have become effective tools due to the high expenses of experimental platforms [9-17]. The finite volume method for solving the numerical computational domain has been used in current numerical analysis. The SIMPLEC algorithm and the second-order wind reversal estimation in the Ansys program were used. For all the governing equations, the maximum remaining limit of (10^{-8}) was chosen to minimize the calculation error as shown in Figure (1).

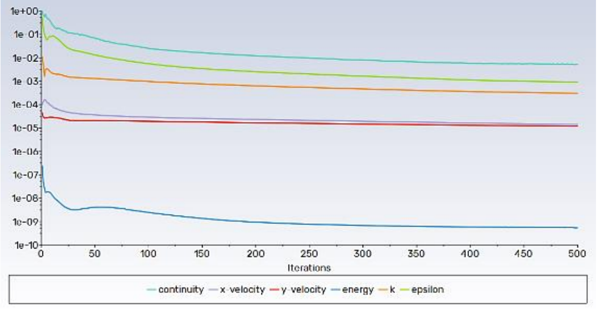

Figure 1. Iterations for the numerical domain

3. Description of Problem

In the current numerical investigation, a nanofluid with different weight ratios (0.0, 0.12, 0.25 %) was used for single-phase turbulent flow for the Reynolds number range (10000-18000). Numerical modelling was carried out by the Ansys Fluent R23 program using the limited channel finite volume method with a length of (L= 0.18 m) and a height of (H= 0.02 m). The schematic and various dimensions of the numerical problem are shown in Fig (2). The temperature of the working fluid entering the channel is (293K) and the heat flux applied to the upper wall of the channel is equal to ($40kW/m^2$). The inlet temperature, the velocity at the beginning of the channel. These boundary conditions of the numerical issue are the outlet pressure at the end and the continuous heat flow along the top wall's extension, while the lower wall is thermally insulated. The thermophysical characteristics of the working fluid with varying % weight are reviewed in Table (1) [18].

The fluid in a backward-facing step flow channel is Newtonian and stable. Furthermore, the single-phase, homogenous nanofluid characteristics are true across all weight percentages. The influence of water/FMWCNT nanofluid on a specific geometry, such as the Backward-Facing Channel, the investigation of flow parameters, including velocity, pressure drop, and pumping power, the investigation of heat transfer parameters, including temperature distribution and Nusselt number changes, and the use of the finite volume method and SIMPLEC algorithm with second-order discretization, have all contributed to the uniqueness and preference of this study over previous studies in the field.

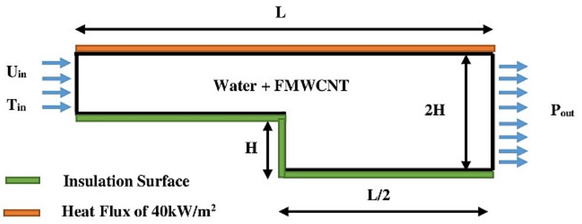

Figure 2. Schematic diagram of problem statement.

Table 1. Working fluid thermophysical properties [18].

wt (%) of Water / FMWCNT	Cp (J/kg.K)	μ (pa.s)	ρ (kg/m^3)	k (W/m.K)
0.0	4178	0.000765	995.8	0.62
0.12	4178	0.000780	1003	0.68
0.25	4178	0.000795	1008	0.75

4. Governing Equation of Present Work

The following equations for continuity, momentum, and energy are solved in the cartesian coordinate system for the turbulent flow of water/FMWCNT nanofluid passing in a two-dimensional backward-facing step channel [19–21]:

Equation of continuity:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \qquad (1)$$

Equations of momentum:

$$\frac{u\partial u}{\partial x}+\frac{v\partial u}{\partial y}=-\frac{\partial p}{\rho_{nf}\partial x}+\upsilon_{nf}\left(\frac{\partial}{\partial x}\left(\frac{\partial u}{\partial x}\right)+\frac{\partial}{\partial y}\left(\frac{\partial u}{\partial y}\right)\right) \qquad (2)$$

$$\frac{u\partial v}{\partial x}+\frac{v\partial v}{\partial y}=-\frac{\partial p}{\rho_{nf}\partial y}+\upsilon_{nf}\left(\frac{\partial}{\partial x}\left(\frac{\partial v}{\partial x}\right)+\frac{\partial}{\partial y}\left(\frac{\partial v}{\partial y}\right)\right) \qquad (3)$$

Equation of energy:

$$\frac{u\partial T}{\partial x}+\frac{v\partial T}{\partial y}=\frac{\left(\frac{\partial}{\partial x}\left(\frac{k_{nf}\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(\frac{k_{nf}\partial T}{\partial y}\right)\right)}{\rho_{nf}C_{pnf}} \qquad (4)$$

5. Test of Mesh Study

The outlet velocity of a computational domain has been examined at the channel's exit in a variety of mesh counts to guarantee that the outcomes of hydrodynamical parameters and heat transfer are independent of the grid test. The number of square meshes under study has fluctuated between (6332 to 240000). The outcomes attained and displayed in Figure (3).

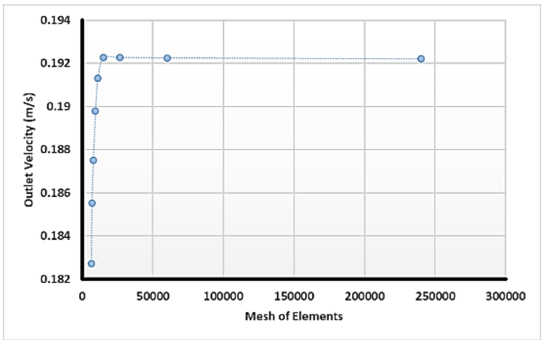

Figure 3. Grid independence of computational domain.

6. Results and Discussions

The axial velocity, temperature, and pressure distribution within the backward-facing step channel are depicted in Figures (4-6) at varying Reynolds numbers and weight percentages (0.25%). As the fluid velocity at the inlet increases, the effect of penetration of the non-viscous core near the expansion part gradually increases, moreover in this area and towards the lower wall the velocity contour becomes asymmetric. Due to the pressure drop around the expansion part this behavior occurs. In areas of low-pressure eddies accumulate with an increase in velocity at the inlet when the flow passes the channel expansion. This phenomenon is due to the decrease in pressure, and the separation of the flow occurs. By increasing the velocity of the fluid at the inlet the vortices are strengthened and move their position towards the channel at the outlet. At a heated wall, the temperature gradient decreases with increasing fluid velocity at the inlet. Since the strengthening of the coolant momentum around the expansion part temperature changes decrease. The amount of heat transfer is determined by the relationship between the velocity and temperature fields. Heat transfer increases by any factor that enhances the velocity of the fluid and eliminates the temperature gradients, on the other hand, the kinetic energy of the fluid and heat transfer coefficient decreases, and the temperature gradients inside the channel are strengthened. Figure (7) shows the change of Nusselt numbers against Reynolds numbers with different ranges and variable weight ratios. Heat transfer mechanisms such as forced convection heat transfer coefficient and Nusselt number are improved by optimizing the fluid velocity for all Nusselt numbers [22-25]. This behavior occurs as a result of high flow velocity, which leads to high heat transfer by forced convection. The ranges of the Reynolds number (10000-18000) are associated with the maximum and minimum values of the Nusselt number, respectively. The Nusselt number increases as the weight ratio of the nanoparticles increases because the heat transfer mechanism improves hence the thermal heat transfer coefficient of nano cooling. Also, the enhancement of the Nusselt number is achieved by adding a mass fraction of solid nanoparticles at higher velocities. High Reynolds number coolant is advised for systems utilizing nanofluids. The performance of the nanofluid's heat transfer is unaffected in any way by its employment in the creep flow system.

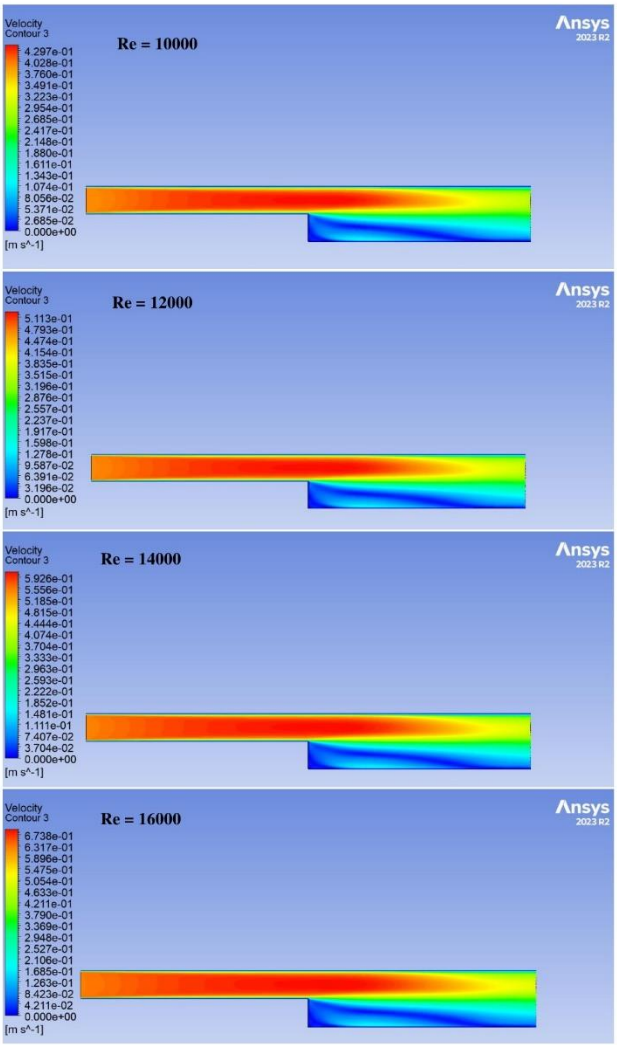

Figure 4. Contour of axial velocity along backward-facing channel.

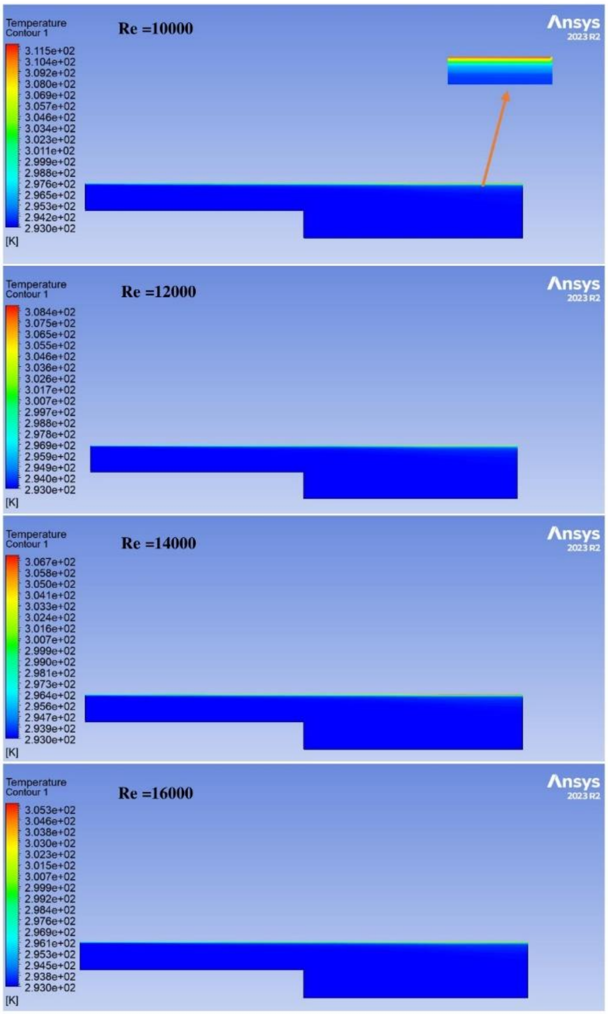

Figure 5. Contour of temperature along backward-facing channel.

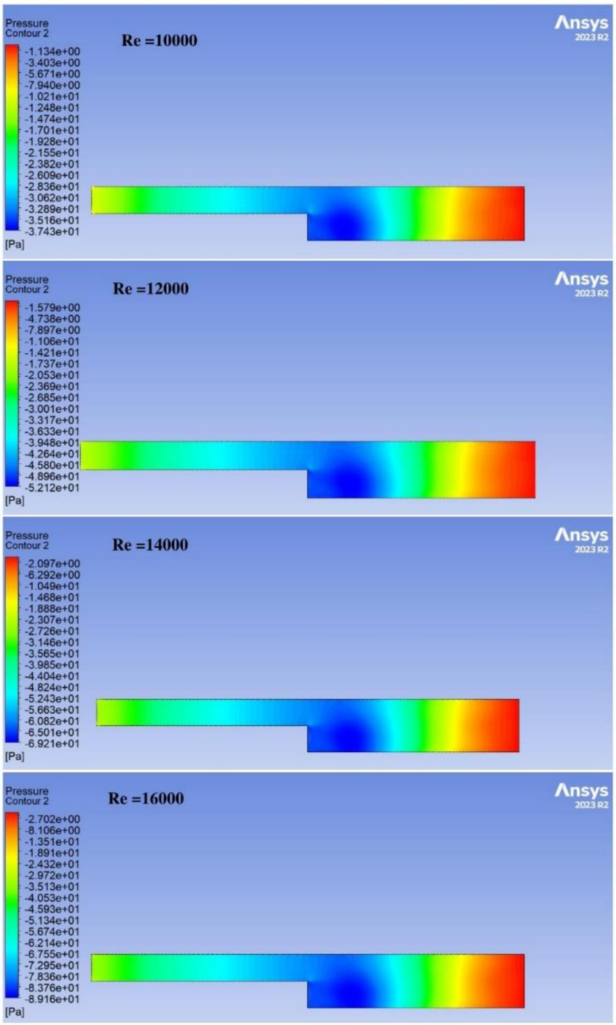

Figure 6. Contour of pressure along backward facing channel.

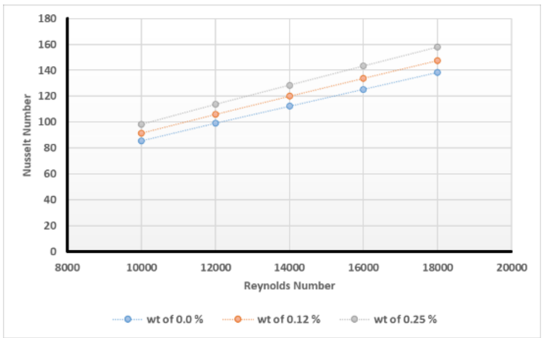

Figure 7. Variation of Nu against Re for different wight percentage.

7. Conclusions

This work presents a numerical analysis of the turbulent heat transfer induced convection and fluid flow of a water functional multi-walled carbon nanotube (FMWCNT) nanofluid in a two-dimensional backward-facing step channel. Consideration has been given to the channel walls being insulated from the bottom and applying a steady heat flux at the top. Research has been done on the impact of increasing weight percentages on fluid parameters. The results indicated a decrease in the friction factor, pressure, and heat transfer coefficient in different areas of the channel as a result of the decrease in fluid velocity. The addition of solid nanoparticles significantly affects the base fluid at high Reynolds numbers, in addition, it affects the friction factor, pressure drop, and heat transfer. Vortex generation and Reynolds number increase as a result of the separation of the nanofluid from the lower layer during the flow and the vortices are close to the channel outlet.

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