Journal of Solid and Fluid Mechanics (JSFM), 13(4): 1-3, 2023

Shahrood University of Technology

Journal of Solid and Fluid Mechanics (JSFM)

DOI: 10.22044/JSFM.2023.13065.3736

Manufacturing Engineering of Iran

# Comparative investigation of nanofluid heat transfer in a vertical annular channel with cosine heat flux by experimental and numerical methods

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Received: 05/02/2023 Revised: 07/10/2023 Accepted:09/19/2023

## Abstract

One method to improve heat convection is to increase the heat transfer coefficient of the working fluid. Adding metal or non-metal nanoparticles into the base fluid, known as nanofluid, is a technique to enhance the heat transfer coefficient. Research in the field of nanofluids has grown significantly in the last two decades. In this study, the effects of a homogenous combination of $Al_2O_3$ and $TiO_2$ nanoparticles with deionized water are investigated. The thermohydraulic performance of the nanofluid inside the vertical channel is analyzed by experimental and numerical methods for turbulent and laminar flow. The turbulence model utilized in computational fluid dynamics is the k-ε model in Fluent software. The heating rod in the test section produces cosine heat flux. The results show that increasing the concentration of nanoparticles significantly reduces the maximum temperature of the rod. The use of 1% homogeneous nanofluid reduces the maximum temperature by 20% at the Reynolds of 950 and 9.5% at the Reynolds of 4200 compared to pure water. Also, the heat transfer coefficient increases with the addition of nanoparticles. The results obtained by the k-ε turbulence model and the experimental method show a difference of 10% to 13%. This research shows that the combined nanofluid with suitable thermal performance can be one of the working fluids in future thermal cycles.

**Keywords:** Combined nanofluid, test loop, heat transfer, experimental method, numerical method.

## 1. Introduction

The concept of nanofluids was introduced around two decades ago to enhance the thermal conductivity of fluids. A nanofluid comprises a suspension of solid particles ranging in size from one to a hundred nanometers.

The pioneering work by Choi [1] introduced the concept of mixing nanoparticles into conventional coolants. Subsequently, numerous researchers delved into investigating the heat transfer of nanofluids. Wang et al. [2] examined the heat transfer coefficient of a nanofluid consisting of water and $AL_2O_3$ within a copper tube. This study was conducted under laminar flow conditions. In a similar study, He et al. [3] conducted experimental analyses on the heat transfer characteristics and pressure drop of a nanofluid composed of water and $TiO_2$. Their investigations were conducted in both laminar and turbulent flow regimes.

Duangthongsuk et al. [4] conducted an analysis of pressure drop and heat transfer for water and $TiO_2$ nanofluid, utilizing a heat exchanger with a configuration of two horizontally opposed tube flows. Their findings showed that the utilization of nanofluids at low concentrations had small pressure drop costs. Furthermore, Abbasi et al. [5] conducted empirical investigations into the heat transfer attributes of a $TiO_2$ nanofluid within a vertical channel, exploring a range of Reynolds numbers. Their results indicated a correlation between higher Reynolds numbers, increased nanoparticle volume fractions, and decreased surface temperatures of the rod.

Moraveji et al. [6] conducted a numerical simulation focusing on the heat transfer of an $Al_20_3$ nanofluid. Their study revealed a nearly 5% deviation between predicted numerical data and experimental data. The present study aims to investigate the effects of combined $TiO_2$ and $Al_2O_3$ nanoparticles within a test section with cosine heat flux. The experimental investigation employed the Isfahan pressure test loop, investigating diverse volume percentages of combined nanoparticles and Reynolds numbers. The obtained data provided valuable insights into heat transfer coefficients.

Furthermore, numerical simulations of the test section for both water and homogenous nanofluids were conducted using fluent software. The purpose of these simulations was to assess the performance of the k-ε method for simulating nanofluid heat transfer through a single-phase approach.

## 2. Experimental test

Isfahan test loop with a maximum pressure of 25 bar is designed and built to perform thermo hydraulic tests. Figure 1 shows a schematic picture of this test circuit.

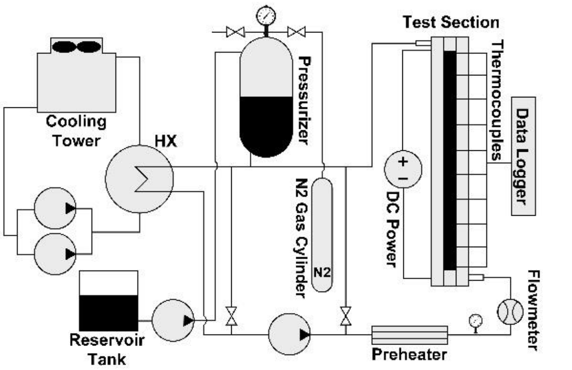


**Figure 1. Schematic picture of the test loop**

The preparation of nanofluids involves the mixing of nanoparticles into deionized water. Achieving a fully homogeneous mixture and preventing nanoparticle agglomeration necessitate the use of an ultrasonic stirrer. This procedure ensures the stability of the resulting nanofluid. In this study, $TiO_2$ nanoparticles and $Al_2O_3$ nanoparticles were combined with water in an ultrasonic device for 4 hours, resulting in a uniformly blended nanofluid with the desired concentration.

The nanofluid behaves as a Newtonian fluid at lower concentrations. The objective of the current experimental study was to clarify the relationship between the Reynolds number and the concentration of homogeneously dispersed nanofluids on the surface temperature of a rod. The experiments were conducted for 0.5%, 1%, and 1.5% volume concentrations nanofluids, at a constant fluid inlet temperature of 25 degrees Celsius.

## 3. Numerical simulation

To compare numerical methods with experimental data, the flow inside the test section was numerically simulated. This simulation helps to evaluate the performance of the k-ε turbulence model for single-phase nanofluids. The governing equations of fluid flows are the equations of conservation of mass, momentum, and energy.
Continuity equation:

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

Momentum equation:

$$\rho\left(\frac{\partial \bar{u}_i}{\partial t} + \bar{u}_j \frac{\partial \bar{u}_i}{\partial x_j}\right) = -\frac{\partial \overline{p^*}}{\partial x_i} + (\mu + \mu_t)\frac{\partial}{\partial x_j}\left(\frac{\partial \bar{u}_i}{\partial x_j}\right) \qquad (2)$$

Energy equation:

$$\rho\left(\frac{\partial \bar{T}}{\partial t} + \bar{u}_j \frac{\partial \bar{T}}{\partial x_j}\right) = \left(\frac{\mu}{Pr} + \frac{\mu_t}{Pr_t}\right)\frac{\partial}{\partial x_j}\left(\frac{\partial \bar{T}}{\partial x_j}\right) \qquad (3)$$

In the above equations, $\mu_t$ is the turbulent viscosity, and $Pr_t$ is the turbulent Prandtl. To check the independence of the mesh, three different meshes were designed. The considered limit for convergence in the simulation was $10^{-8}$.

## 4. Results

### 4.1. The results of the experiments

Experimental results for the surface temperature of the rod in different conditions were obtained by testing on the test loop. Then the heat transfer coefficient was obtained by performing mathematical operations on these results. Figure 2 shows the maximum temperature of the rod surface at various Reynolds numbers and concentrations.

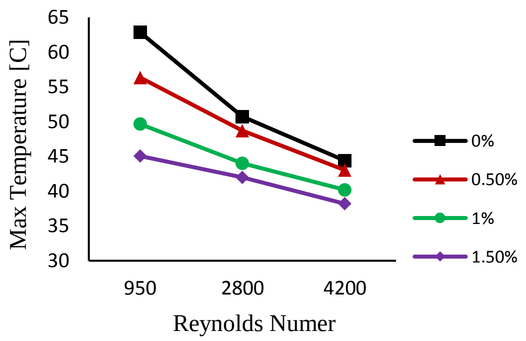


**Figure 2. The maximum temperature of the rod at various Reynolds numbers and concentrations**

The maximum temperature for 1% nanofluid decreases 20% at Reynolds of 950 and 9.5% at Reynolds of 4200. The thermal performance of nanofluid to lower the rod's temperature reduces as Reynolds increases. The heat transfer coefficient at a Reynolds number of 4200 is shown in Figure 3.

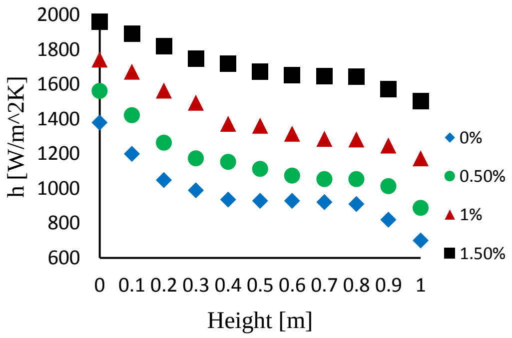


**Figure 3. Heat transfer coefficient for various concentrations at a Reynolds number of 4200**

### 4.2. Comparison of numerical and experimental results

The results obtained from the experimental test and the numerical simulation were compared with each other. Figure 4 shows the heat transfer coefficient diagram of 1% nanofluid at a Reynolds number of 4200.

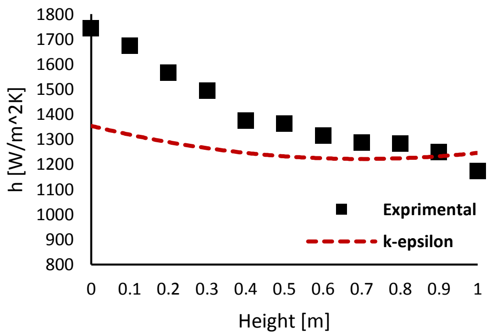


**Figure 4. Heat transfer coefficient of nanofluid 1% at a Reynolds number of 4200**

## 5. Conclusion

According to the results of the experimental tests on the test loop, it was found that the thermal effect of the combined nanofluid at low Reynolds is significant. Also, the obtained numerical results have acceptable validity, which shows that the k-ε turbulence model can be used in single-phase mode to simulate the performance of nanofluid. The results obtained from the experimental and numerical studies are written below.

- Nanofluid performance is better at low Reynolds.
- By increasing the concentration of nanoparticles, the wall temperature decreases and the heat transfer coefficient increases.
- As the Reynolds number increases, the surface temperature of the rod decreases.
- Numerical results show that the used k-ε turbulence model has a good performance in nanofluid simulation.

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