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To Investigate the Convective Heat Transfer Coefficient Using Nanofluid in a Right Angled, Triangular Shaped Corrugated Tube for Turbulent Flow

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Abstract

The fluid dynamics programme ANSYS Fluent, which is available commercially, is used to perform a numerical study of turbulence-forced convective flow through a right-angled, triangular-shaped corrugated tube. The impact of the Reynolds number on the convective transfer of energy and the loss of pressure was examined using numerical simulations for turbulent nanofluid flow within a tube with a constant flow of heat on the wall. In this research, a right-angled triangular-shaped corrugated tube is used to test the turbulent flow of many nanofluids, including Al2O3, TiO2, and CuO. (Reynolds numbers 5,000–25,000). To solve the equations that govern the system, a technique that makes use of finite volumes is employed. According to the findings, the coefficient of heat transfer improves as both the Reynolds number and the volume percent of the nanofluid increase. The nanofluid densities of TiO2-water are 27.35%, Al2O3-water is 44.66%, and CuO-water is 25.75% at a 5% volume fraction and a Reynolds number of 25000.

Keywords: *nano-fluids, Reynolds number, governing equations, CuO, Al2O3, and TiO2*

1. Introduction

The study of heat transmission is one of the most significant and widely used aspects of the engineering field. The requirement for energy savings and energy management has made the field even more important. On this path, it is important to find good ways to use less energy and make more. It is crucial to concentrate on both equipment miniaturisation and heat transmission per unit area in order to increase the energy effectiveness of heat transfer equipment. Nanofluids are created when nanoparticles of a size measured in nanometers are suspended in a base fluid. Making a nanofluid is primarily done to enhance the basic fluid's ability to transfer heat. However, the solid-particles, which can range in size from millimetres to micrometres, behave as a two-phase flow; this may have a negative impact on the flow properties of nanofluid. This results in a greater demand for the amount of power that is necessary to move the fluid, which may have an adverse impact on the flow characteristics of a nanofluid.

Nanofluids are fluids that contain nanoparticles and also contain a base fluid, such as ethylene glycol or water. The size of these nanopowders is less than 100 nanometers. Choi et al., who are regarded as the leading researchers in this field, used nanofluids for the first time at the Argon national laboratory. By incorporating nanofluids, base fluids' effectiveness in transferring heat is increased. When a small amount of solid nanoparticles having high thermal conductivity is introduced to the base fluid, the rate at which heat flows through the fluid increases. Heat conductivity rises as a consequence of this. Additionally, the base fluid's random movement and the nanoparticles may cause the thermal barrier layer to shrink, which would greatly aid heat transmission. When there is a higher concentration of nanofluid, there is a corresponding improved in the rate of heat transmission because the interaction and collision of nanoparticles become more intense? Furthermore, dispersal and the related mobility of the particles close to the wall contribute to the quick heat transfer from the wall to the nanofluid.

The following are some advantages of using nanofluids to enhance heat transfer:

- Reducing the heat transfer system's size
- Heat transfer Improving
- Thermal equipment cost and weight reduction
- Minimal clogging
- System miniaturisation and micro - channels cooling.

2. Literature Review

Mehmet Gürdal et al. (2021) investigated ferro-nanofluid flow through a pipe with dimples under the impact of an external magnetic field. The Nusselt numbers improved as the Reynolds number and pitches ratio decreased. P/d = 7.50 is the most effective dimple geometry. In the case of greatest magnetic field intensity = 2.5 vol% had the largest Nusselt number increment (72.48%) compared to distilled water, the smooth tube operating fluid. The highest PEC value was 1.126 for P/d = 7.5, = 2.5 vol%, and Ha = 75. Contour plots show how magnetic field intensity affects velocity and temperature distributions.

Wang, Wei, et al. (2021) examined the heat transmission and flow parameters of CuO-EGW and ethylene glycol/water nano-fluids in circular pipes containing or not containing trapezoidal ribs. With a constant heat flow and varying the bottom angle of the ribs, the friction factors and the Nusselt numbers in a tube with trapezoid ribs are examined. Under the context of this investigation, a nanofluid and a base fluid's convective The coefficients of heat transfer are examined and compared. The nanofluid has a concentration of 6% by volume of CuO–EGW. As the angle of slope got steeper, researchers found that In the CuO-EGW nanofluid as well as the basic fluid, the Nusselt number or friction factor increased. This occurred although the Reynolds number remained the same. When compared to the tube with a ribbed bottom angle of 75 degrees, the smooth tube has a Nusselt number for the CuO-

EGW nanofluid that is 135.8% higher on average, and the performance assessment threshold is 1.64.

Dadheech et al. (2020) examined the thermal behaviour of MoS2/C2H6O2 and SiO2-MoS2/C2H6O2 nanofluids while an angled magnetic field was present. Investigating the temperature and resolving the governing formulae and velocity profiles, they made use of appropriate similarity transformations using the Runge-Kutta method of the fourth order. They came to their conclusion that, for both nanofluids, increasing a convective parameter increases the velocity profile while lowering the temperature profile. They determined that increasing the volume fraction of either of the nanofluids resulted in improved temperature and velocity profiles for both nanofluids.

Faridi khouzestani et al. (2020) presented a numerical investigation on the transfer of heat and characteristics of flow of two pipes with two dimpled spiral center plates employing Tio2, CuO, and Al2O3, nanofluids as cooling fluids. In-line geometry trumps staggered geometry. Compared to a smooth spiral centre plate, in-line convection is 47.3% more effective with the basal flow. Nanofluids boosted the distribution of wall temperature, and thermal conductivity while simultaneously increasing dynamic viscosity. Nanofluids increased, which decreased Sa by 24.7%. Nanofluids reduce Tmax and increase. CuO–water nanofluid is also better in heat transfer and flow.

Ghafouri et al. (2017) conducted an investigation in which they wanted to determine how the nanoparticles size affected the heat transfer properties of a cooling chamber. For this, they employed a numerical simulation. When the diameter of nanoparticles is reduced, along with the volume percent, It seems that both the Nusselt number or the rate of heat transfer are rising. In a square enclosure, another research into coupled convection heat transfer utilizing an Al2O3-water nanofluid was conducted.

Ehsan, M., et al. (2016) investigated a wide range of the Reynolds numbers from 10000 to 30000, with various nano-particle volume fractions (1%–5%) and corresponding pipe wall roughness (0.001, 0.002, and 0.003). While doing a single-phase analysis, it is suggested that the governing equation (energy, momentum, mass) and through the SST k-turbulence models as well as the finite volume method, turbulence variables can be solved. When the Reynolds ratio or volume fraction go up, putting nanofluid into a rough tube instead of a smooth tube makes a big difference in how quickly heat moves. Ultimately, the optimal nanoparticle volume fraction is found, such that nanofluid requires less pumping energy than water. Also computed is the decrease in mass flow rate for nanofluids, which results in enhanced thermal performance.

Manca et al. (2012) investigated the range of 20,000 to 60,000 Reynolds numbers using an Al2O3 nanofluid and a ribbed tube. In terms of nanofluids, Single-phase experiments on nanoparticle volumetric from 0.0 to 0.04 with 38 nm particle sizes were carried out. Their observations revealed that as increased, heat transfer and p improved. When square forms are compared to rectangular shapes, rectangular shapes have a higher PEC.

3. Research Methodology

3.1 Governing Equations

Under circumstances of turbulent flow and steady state, the momentum, continuity, and energy equations for forced convection are:

Equation of Continuity

$$\frac{\partial}{\partial x_i}(pu_i)=0 \tag{1}$$

Equation of Momentum

$$\frac{\partial(pu_iu_j)}{\partial x_i}=-\frac{\partial p}{\partial x_i}+\frac{\partial}{\partial x_j}\left[u\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_i}{\partial x_i}\right)\right]+\frac{\partial}{\partial x_i}\left(-p\overline{u'_iu'_j}\right) \tag{2}$$

Equation of Energy

$$\frac{\partial}{\partial x_i}(-pu_iT)=\frac{\partial}{\partial x_i}\left((\Gamma+\Gamma_t)\frac{\partial T}{\partial x_j}\right) \tag{3}$$

Here Γ is the temperature-dependent diffusivity of molecules Γ_t is the thermal diffusivity in turbulent flows, and it has an expression:

$$\Gamma=\frac{\mu}{Pr'} \text{ and} \tag{4}$$

$$\Gamma_t=\frac{\mu_t}{Pr'_t} \tag{5}$$

- **Turbulent Kinetic Energy (KE)**

$$\frac{\partial(\rho k)}{\partial t}+\frac{\partial(\rho k u_j)}{\partial x_j}=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right]+G_k+G_b-\rho\varepsilon-Y_M+S_k \tag{6}$$

Turbulent dissipation rate:

$$\frac{\partial}{\partial y}(\rho\varepsilon)+\frac{\partial}{\partial x_j}(\rho\varepsilon u_j)=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial\varepsilon}{\partial x_j}\right]+\rho C_1S\varepsilon-\rho C_2\frac{\varepsilon^2}{k+\sqrt{v\varepsilon}}+C_{1\varepsilon}\frac{\varepsilon}{k}C_{3\varepsilon}G_b+S_\varepsilon \tag{7}$$

Where,

$$C_1=max\left[0.43,\ \frac{\eta}{\eta+5}\right],\eta=S\frac{k}{\varepsilon}\ and\ S=\sqrt{2S_{ij}S_{ij}} \quad (8)$$

"Here Gk represents the generation of turbulent kinetic energy due to the mean velocity gradients, Gb is the generation of turbulent kinetic energy due to buoyancy, YM represents the contribution of the fluctuating dilatation in compressible turbulence to the overall dissipation rate, and σk and σε are the turbulent Prandtl for k and ε respectively".

- The Reynolds number is expressed as:

$$Re=\frac{\rho_{nf}U_{av}D_h}{\mu_{nf}} \tag{9}$$

- Nusselt No is expressed as:

$$Nu=\frac{h_cD_h}{K_{nf}} \tag{10}$$

- Pressure drop is defined as:

$$\Delta P=\frac{fL\rho U_{av}^2}{2D_h} \tag{11}$$

3.2 Nanofluid thermophysical properties

In this research, it is assumed that water, as base fluid, is disseminated with CuO, TiO2, and Al2O3 nanoparticles of 50 nm size. Table 3.1 provides information on the base fluid and nanoparticle properties.

Using various empirical equations, the following list of practical thermophysical properties of various nanofluids has been established.

Table 3.1 Water and nanoparticle thermophysical properties

Chemical compound	**Density (kg m-3)**	**Specific heat (J kg-1 K -1)**	**Thermal conductivity (W m K-1)**	**Viscosity (N s m-2)**
Water	996.59	4179.2	0.6102	0.000892
Al_2O_3	3970	775	39	-
T_iO_2	4000	711	8.04	-
CuO	6500	525	17.65	-

4. Result & Discussions

4.1 Nusselt Number for Various Nanofluid Volume Fractions

Figures 4.1, 4.2, and 4.3, for TiO2-water, CuO-water, and Al2O3-water, show how the Nusselt numbers is impacted through both volume fraction and the Reynolds number. Figures clearly show how the Nusselt number for every nanofluid used in this study goes up as the Reynolds ratio and volume% of the nanofluids go up. This happened as a outcome of an increase in effective thermal conductivity, a rise in the energy exchange rate, and the erratic, chaotic motion of ultrafine particles in nanofluids brought on by both an increase in volume fraction and an increase in Reynolds number. In general, larger fluid velocity and temperature gradient are correlated with higher Reynolds numbers, which in turn leads to higher Nusselt numbers.

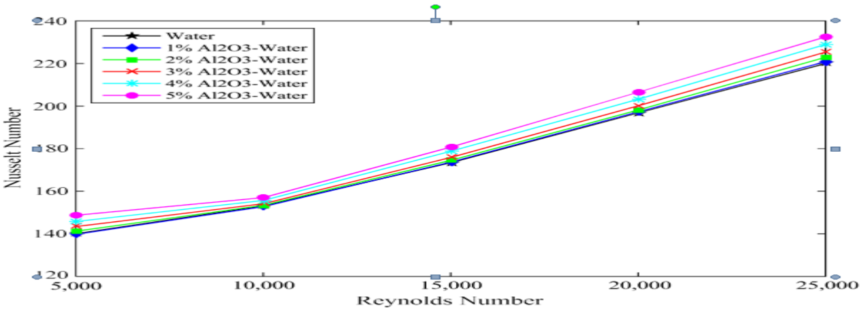

Fig 4.1: Nusselt Numbers comparison for the various volume fractions of Al2O3-Water nanofluid

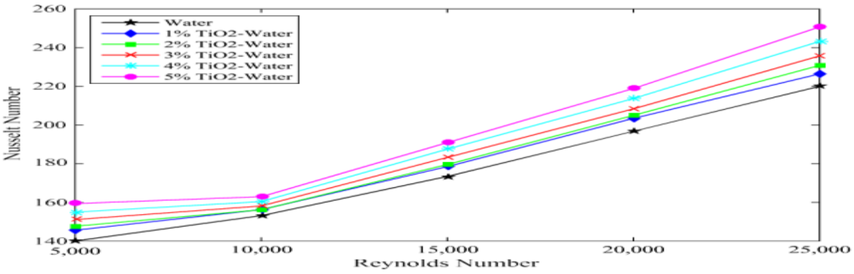

Fig 4.2: Nusselt Numbers comparison for the various volume fractions of TiO2-Water nanofluid

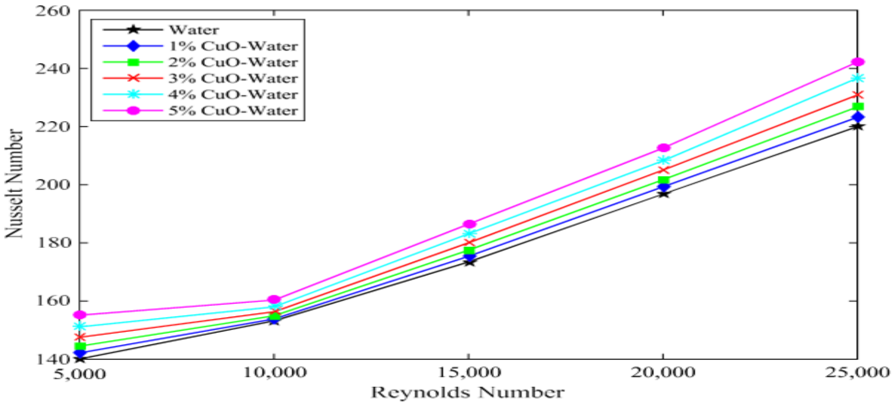

Fig 4.3: Nusselt Numbers comparison for the various volume fractions of CuO-Water nanofluid

Conclusion

ANSYS Fluent 12, a commercial CFD programme that is built on finite volumes, has been used to study three different nanofluids: Al2O3-water, CuO-water, and TiO2-water. This was done in order to evaluate the enhancements in heat transport as well as the benefits to pump power. For the heat transfer coefficient to go up in a noticeable way, both the volume% of all three nanofluids or the Reynolds number need to go up. Between 5000 and 10000 Reynolds numbers, the Nusselt number and the coefficient of heat movement both go up by a smaller amount. This is because the turbulent flow reaches its greatest development when the Reynolds number hits 10,000. The reason for this is the maximum development of the turbulent flow.

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