NUMERICAL SIMULATION AND ENHANCEMENT OF HEAT TRANSFER USING CuO/WATER NANO-FLUID AND TWISTED TAPE WITH ALTERNATE AXIS

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ABSTRACT

Heat transfer enhancement using nano-fluids has gained significant attention over the past few years. Nano-fluids are potentially applicable as alternative coolants for many areas such as electronics, automotive, air conditioning, power generation and nuclear applications. Several published researches have concluded that the use of nano-fluid effectively improved the fluid thermal conductivity which consequently enhanced heat transfer performance.

Heat transfer, friction and thermal performance characteristics of CuO/water nanofluid will have been Numerically investigated using ANSYS FLUENT 14.0. The nanofluid was employed in a circular tube equipped with modified twisted tape with alternate axis (TA). The concentration of nanofluid was varied from 0.3 to 0.7% by volume while the twisted ratio (y/W) of TA was kept constant at 3. The experiments were performed in laminar regime (Reynolds number spanned 830≤Re≤1990). The uses of nanofluid together with typical twisted tape (TT), TA alone and TT alone will also examined. To evaluate heat transfer enhancement and the increase of friction factor, the Nusselt number and friction factor of the base fluid in the plain tube will be employed as reference data.

Keywords: CFD, Heat Transfer, Nano Fluid, Insert.

I. INTRODUCTION

Heat exchangers are used in different processes ranging from conversion, utilization & recovery of thermal energy in various industrial, commercial & domestic applications. Some
common examples include steam generation & condensation in power & cogeneration plants; sensible heating & cooling in thermal processing of chemical, pharmaceutical & agricultural products; fluid heating in manufacturing & waste heat recovery etc. Increase in Heat exchanger’s performance can lead to more economical design of heat exchanger which can help to make energy, material & cost savings related to a heat exchange process.

Nanofluid is a mixture of water and suspended metallic nanoparticles. Since the thermal conductivity of metallic solids are typically orders of magnitude higher than that of fluids it is expected that a solid/fluid mixture will have higher effective thermal conductivity compared to the base fluid. Thus, the presence of the nanoparticles changes the transport properties of the base fluid thereby increasing the effective thermal conductivity and heat capacity, which ultimately enhance the heat transfer rate of nanofluids. Because of the small size of the nanoparticles (10^-9 m), nanofluids incur little or no penalty in pressure drop and other flow characteristics when used in low concentrations. Nanofluids are extremely stable and exhibit no significant settling under static conditions, even after weeks or months. In their work (Lee & Choi) on the application of nanofluids reported significant cooling enhancement without clogging the micro-channels.

Increase in the thermal conductivity of the working fluid improves the efficiency of the associated heat transfer process. When forced convection in tubes is considered, it is expected that heat transfer coefficient enhancement obtained by using a nanofluid is equal to the enhancement in thermal conductivity of the nanofluid, due to the definition of Nusselt number. However, research about the convective heat transfer of nanofluids indicated that the enhancement of heat transfer
coefficient exceeds the thermal conductivity enhancement of nanofluids. In order to explain this extra enhancement; several models were proposed by researchers.

S.K. Saha A. Dutta, [1] experimentally studied the flow of servotherm oil in acrylic circular tube fitted with insulated stainless steel twisted tape insert. They studied the effect of varying length and varying pitch twisted tape with different twist ratios on heat transfer rate and friction factor. Zhi-Min Lin, Liang-Bi Wang, [2] in their experimental study of air flow in Plexiglas circular tube used Stainless steel twisted tape insert. Tapes with different twist ratios are used. They concluded that the tape increases friction 3-4 times. With small twist ratio, higher heat transfer is achieved as compared to greater twist ratio.

Watcharin Noothong et al. [3] their aim to investigate the efficiency enhancement and to study the heat transfer and friction factor characteristics of heat exchanger. In the experimental study, concentric double tube Plexiglas materialied heat exchanger was used. Cold water as a annulus and hot air as a inner fluid used as a medium. In the inner tube Stainless steel tape with different twist ratios were inserted.

Paisarn Naphon, [4] in his experimental study he used hot and chilled water in horizontal copper double tube heat exchanger fitted with aluminum twisted tape inside. He studied effects of relevant parameters on heat transfer and pressure drop. It was concluded that the twisted tape insert has significant effect on enhancing heat transfer rate. However, the pressure drop also increases. Correlation for heat transfer coefficient and friction factor based on the experimental data is also presented.

Smith Eiamsa-ard et al., [5] their aim was to analyze heat transfer and flow friction characteristics in a copper tube double pipe counter flow heat exchanger, containing the stainless steel helical screw-tape with or without core-rod inside. Hot and chilled water used for experimentation. They concluded that helical screw-tape insert has a significant effect on enhancing heat transfer rate and also considerable increase of friction. The heat transfer rate from using the helical screw-tape without core-rod is higher than that from the plain tube at around 340%. The heat transfer rate obtained by using the tape without core-rod is found to be better than that by one with core-rod around 25–60% while the friction is around 50% lower.

Ashis K. Mazumder and Sujoy K. Saha, [6] performs the experimental study in a square and rectangular acrylic ducts fitted with full and short length twisted tape. It was concluded that regularly spaced full length twisted tape performs better as compared to short length tape.

Recently, nanofluids were used simultaneously with other heat transfer enhancing devices [1,9,10]. Chandrasekar et al. [1], reported the heat transfer and friction factor characteristics of Al2O3/water nanofluid in a circular pipe under laminar flow with wire coil inserts. It was found that Nusselt number increased by 12.24% at Re=2275 by the use of the nanofluid with concentration of 0.1% volume compared to that of the base fluid (distilled water). By the uses of two wire-coil inserts with pitch ratios of 2 and 3 together with the nanofluid, Nusselt numbers were further enhanced by 21.5% and 15.9% respectively. Sundar and Sharma [9] studied the turbulent heat transfer and friction factor of Al2O3 nanofluid in circular tube with twisted tape inserts. Their results revealed that when nanofluid (0.5% volume) and twisted tape (twist ratio of 5) were used simultaneously, heat transfer coefficients at Reynolds numbers of 10,000 and 22,000 were higher than those of water in a plain tube by 33.51% and 42.17% respectively. Pathipakka and Sivashanmugam [10], numerically studied heat transfer behaviour of nanofluids in a uniformly heated circular tube fitted with helical inserts in laminar flow. Al2O3 nanoparticles in water of 0.5%, 1% and 1.5% concentrations and helical twist inserts of twist ratios 2.93, 3.91 and 4.89 were employed for the simulation. Compared to the base fluid, the maximum heat transfer enhancement of 31.29% was found with the use of helical insert of twist ratio 2.93 together with nanofluid with volume concentration of 1.5% at Reynolds number of 2039.
According to the above literature, it is evident that the simultaneous use of nanofluid and twisted tape efficiently further improved heat transfer rate with respect to the individual use of twisted tape or nanofluid. However, only the combined effect of nanofluid and typical twisted tape was reported [9, 10]. On the other hand, several tapes tested, the one with alternate axis (TA) in our previous works [11, 12] exhibited promising performance for both heat transfer rate and thermal performance factor. The reason behind a good performance is that the alternate axis on TA induces altering flow pattern, leading to chaotic mixing between core fluid and the one near tube wall and consequently superior interruption of thermal boundary layer over the case of typical twisted tape, in which only swirl flow is generated.

II. MATHEMATICAL MODELS OF FLUENT

All the fluids investigated in this research are Newtonian. This means that there exists a linear relationship between the shear stress, \( \sigma_{ij} \), and the rate of shear (the velocity gradient). In CFX, this is expressed as follows:

\[
\sigma_{ij} = -p \delta_{ij} + \mu \left( \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) \quad \ldots \ldots \ldots \ldots \ldots 1
\]

In FLUENT, these laws are expressed in the following form:

**Law of Conservation of Mass:** Fluid mass is always conserved.

\[
\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_j}(\rho u_j) = 0 \quad \ldots \ldots \ldots \ldots \ldots 2
\]

**Newton’s 2\textsuperscript{nd} Law:** The sum of the forces on a fluid particle is equal to the rate of change of momentum.

\[
\frac{\partial}{\partial t}(\rho u_i) + \frac{\partial}{\partial x_j}(\rho u_i u_j) = \frac{\partial}{\partial x_j} \left[ -p \delta_{ij} + \left( \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) \right] + B_i \quad \ldots \ldots \ldots \ldots \ldots 3
\]

**First Law of Thermodynamics:** The rate of head added to a system plus the rate of work done on a fluid particle equals the total rate of change in energy.

\[
\frac{\partial}{\partial t}(\rho He) + \frac{\partial}{\partial x_j}(\rho u_j He) - \frac{\partial}{\partial x_j} \left( \lambda \frac{\partial T}{\partial x_j} \right) = \frac{\partial \rho}{\partial t} \quad \ldots \ldots \ldots \ldots \ldots 4
\]

The fluid behaviour can be characterised in terms of the fluid properties velocity vector \( \mathbf{u} \) (with components \( u, v, \) and \( w \) in the \( x, y, \) and \( z \) directions), pressure \( p \), density \( \rho \), viscosity \( \mu \), thermal conductivity \( \lambda \), and temperature \( T \). The changes in these fluid properties can occur over space and time. \( H \) is the total enthalpy, given in terms of the static (thermodynamic) enthalpy, \( h \):
Fig. 2: CFD Domain of smooth tube heat exchanger

Fig. 3: CFD Model of Helical domain

Fig. 5: CFD Domain of helical insert - TA
Fig. 2 to 5 shows 3-D CFD model computational domain. In order to avoid the effect of air circumfluence, computational domain has been extended some distance downward and upward along the flow direction.

IV. CFD MESHING

In this model tetrahedral with prism boundary layer grid in the flow region. Especially complex shapes are difficult to model with a structured grid. Therefore an unstructured grid with triangular cells is used at the outer region.

Fig. 6: CFD Meshing of Louver Fin
V. RESULTS AND DISCUSSIONS

A. Smooth tube Results

Prior to the experiments using the dimpled tube combined with the twisted tape, the Nusselt number and the friction factor in a plain tube were calculated. The CFD data were, then compared with the results given by the well-known correlations under a similar condition, in order to evaluate the validity of the plain tube.

Fig. 7: Pressure contours smooth tube velocity Re=830

Fig. 7 shows the Pressure contours at Re=100. In these contours shows pressure drop 0.8Pa.

Fig. 8: Temperature contours smooth tube Re=830

Fig. 8 Temperature contours smooth tube with velocity 2m/s. In this contour shows the Air temperature increased from 300K to 305K.
Fig. 9: Velocity contours smooth tube velocity Re=830

Fig. 9 shows the Velocity contours smooth tube velocity Re=830, it shows the higher velocity in tube region due to air.

B. Twisted tapes-TT

Fig. 10: Pressure contours Helical insert Re=830

Fig. 11: Temperature contours Helical insert Re=830
Fig.12: Velocity contours Helical insert Re=830

Fig.12 Velocity contours Helical Tape pitch length 60mm velocity Re=830. The twisted tube causes more turbulence intensity in the flow, because its sharp corner edge can produce more turbulence than the smooth surface, but, it causes more recirculation region inside the groove. So, it gives good mixing of the fluid. Thus, it results in less increase of heat transfer compare with plain tubes. Fig.6.4 shows the flow pattern Velocity streamlines Helical Tape pitch length 60mm Re=830.

C. Twisted tapes-TA

Fig.13: Pressure contours Helical insert Re=830

Fig.14: Temperature contours Helical insert Re=830
6.33 presents the variation of Nusselt number with Reynolds number. At the similar conditions, the Nusselt number of nanofluid is higher than that of the base fluid (water) as the presence of nanoparticles directly results in an increase of thermal conductivity. Besides, the heat transfer improvement is also associated by the collision among nanoparticles and also that between the nanoparticles and tube wall, leading to an increase in the energy exchange rate. Nusselt number increases with increasing Reynolds number due the intensification of the nanofluid mixing fluctuation. In concentration range studied, Nusselt number slightly increases with the increase of nanofluid concentration. In general, the increase of nanofluid concentration results in the following consequences: (1) the increases of thermal conductivity and collision of nanoparticles which are favorite factors for heat transfer enhancement and (2) an increase of fluid viscosity which diminishes the fluid movement and thus heat transfer rate. The obtained result implies that for the present range, the effect of the increase in thermal conductivity and the collision of nanoparticles are more prominent than the increase of the fluid viscosity. According to the experimental results, the nanofluid with CuO concentrations of 0.3%, 0.5% and 0.7% volume gives mean Nusselt numbers higher than the base fluid by around 2.0%, 4.1% and 6.8%, respectively.
The influence of twisted tapes (typical twisted tape (TT) and modified twisted tape with alternate axis (TA)) on Nusselt number is also shown in 16. Compared to the plain tube, the tubes with twisted tapes exhibit higher Nusselt number, because the taper inserts generate swirl flow offering a longer flowing path of fluid flow through the tube and also better fluid mixing, resulting in a thinner thermal boundary layer along the tube wall and thus superior convective heat transfer. The experimental results also reveal that the twisted tape with alternate axis (TA) provides a higher Nusselt number than the typical twisted tape (TT). This can be explained by the fact that the TA gives superior efficient fluid mixing induced by the altering flow pattern while the TT causes swirl flow only. The simultaneous use of TA and nano-fluid, results in further enhancement.

Fig.17: Experimental Flow visualization of swirling flow through (a) the tube with TT and (b) the tube with TA

Fig.18: CFD Flow visualization of swirling flow through (a) the tube with TT and (b) the tube with TA
Fig. 18 shows the flow visualization of swirling flows through (a) the tube with TT and (b) the tube with TA. In Fig. 18(a), for the tube with TT, each dye stream is forced along the twisted path of the typical twisted tape. On the other hand, for the tube with TA (Fig. 18(b)), some dye streams are altered to opposite sides. These streams are potentially directed to collide with other streams which flow along the normal twisting direction, leading to superior fluid mixing over the case of TT as described above.

Future work may be extended to:

- Compound enhancement techniques maybe applied i.e., the tape inserts can be coupled with coil wire inserts for better enhancement
- Other reduced width twisted tapes along with variation in Reynolds numbers; and
- Develop further correlations by considering lower Reynolds numbers

VI. CONCLUSION

Heat transfer, friction and thermal performance characteristics of CuO/water nanofluids with three different concentrations of 0.3%, 0.5% and 0.7% by volume in a circular tube equipped with the modified twisted tape with alternate axis (TA) and the typical twisted tape (TT) in the laminar regime have been experimentally investigated. According to the obtained results, the conclusions can be drawn as follows

(1) Nusselt number considerably increases with increasing Reynolds number.
(2) For the present range of nanofluid concentration, Nusselt number is slightly improved with the increase of nanofluid concentration.
(3) At similar conditions, heat transfer rate further increased by the simultaneous use of both nanofluid and twisted tape compared to the use of twisted tape or nanofluid alone.
(4) The use of nanofluid with the TA provides considerably higher Nusselt number and thermal performance than that of nanofluid with the TT for all Reynolds numbers examined. The TA offers higher heat transfer rate than the TT by around 89%.
(5) Over the range investigated, the maximum thermal performance factor of 5.53 is found with the simultaneous use of the CuO/water nanofluid with 0.7% volume and the TA at Reynolds number of 1990.
(6) The predicted data obtained from the developed empirical correlations are in good agreements with the experimental data within ±4%, ±1% and ±2% for Nusselt number, friction factor and thermal performance factor, respectively.

REFERENCES


