Effect of Twisted Tape Insert On Heat Transfer During Flow Through A Pipe Using CFD

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Abstract— *The effect of nanoparticles on the performance of nanofluids during flow through pipes with dual twisted tape inserts. A detailed literature survey on the use of twisted tape inserts and computation thermal properties of nanofluids is presented. Expressions for nanofluid thermal properties computation are discussed. Properties for Al_2O_3 and TiO_2 nanofluid with volume fraction of 0.1 are computed. CFD simulations to study the behaviour of fluid during heat transfer when flowing through pipes with dual twisted tape inserts. Results of these simulations are discussed in the paper.*

Keywords— ***nanofluid, CFD, Twisted Tape Inserts, Al_2O_3 nanofluid, TiO_2 nanofluid.***

I. INTRODUCTION

Augmenting heat transfer during flow through pipes has always been interest for various researchers. There are three ways of augmenting heat transfer in fluids [1]. They are:

i. Active (use of mechanical aids, magnetic fields etc)
ii. Passive (using swirl generators like twisted tape etc which do no use external energy)
iii. Compound

1.1 Passive Augmenting Techniques

A lot of investigation happened regarding the passive techniques i.e using swirl generators. A review of literature in this area has been presented in [2] & [3]. Sawarkar and Pramod [4] experimentally investigated into the effect of semi-circular cut twisted inserts into augmentation of heat transfer in horizontal pipes. Theoretical calculations that can be used for heat transfer coefficients are also detailed in their work. Tabatabaeikia, et al [5] investigated into the use of lovered tapes and modified twisted inserts for heat transfer augmentation during flow through pipes. Ebenezar Paul, et al [6] investigated to augmentation of heat transfer in Cu2O by the use of twisted tape inserts with alternate axis. These kinds of inserts are shown in Fig 2.3. Shrirao, et al [7], [8] performed experimental study on the mean Nusselt number, friction factor and thermal enhancement factor characteristics in a circular plain tube and internally threaded tube under uniform wall heat flux boundary conditions for pure water and Al2O3 nanofluid as working fluid. Shivaji Munde [9] performed experimental investigation of heat transfer of circular tube fitted with helical wire and twisted tape, have been studied under uniform heat flux conditions with Air as working fluid. Prakash and Karuppasamy [10] using experimental investigations showed that using twisted tapes with wires and rectangular cuts there is a 207% increase in heat transfer coefficient. As stated in [11], Nusselt number and friction factor obtained for louvered strip (with forward backward arrangement) > Nusselt number and friction factor for louvered strip (with semi-forward semi-backward arrangement)> Nusselt number and friction factor for louvered strip (with forward arrangement). A 3-D numerical model was developed to study the performance of (i) bare tube-in-tube heat exchanger, (ii) tube in tube with twisted tape insert and (iii) helical insert at annulus and twisted tape insert inside the inner tube of the heat exchanger in [12]. The use of vortex generator for heat transfer enhancement was discussed in [13]. Patil, et al [14] showed that the use of wire coil and screw tape insert enhances heat transfer coefficient by 150 times. Matini and Swapnil [15] experimentally investigated the influences of twisted tapes and wire coil on pressure drop, friction factor (f), heat transfer and thermal enhancement index (η). Johar & Hrshda [16] studied the effect of reduced twisted tape inserts with baffles and holes on heat transfer during flow through a pipe. Sarada, et al [17] investigated to the use of mesh for augmentation of heat transfer during flow through a pipe. Tamna, et al [18] investigated the use of dual twisted inserts in increasing the heat transfer during flow. Expressions given in this article are used to predict the Nusselt number and thus heat transfer coefficient in the current work.

1.2 Thermal Properties of Nano Fluids

Kumar & Chakrabarti [19] reviewed literature pertaining to numerical modelling and experimental results relating to heat transfer using nanofluid. Heat transfer enhancement characteristics and approaches by various investigators are summarized in the same article. Corcione [20] & Sivashanmugam [21] listed the empirical relations for predicting the thermal properties of nanofluid.

Mohan Kumar & Rajan [22] invested experimentally into the heat transfer characteristics of CuO nanofluid with three different concentrations and compared the results with available correlations. Iqbal and Rehman [23] summarized the work relating to heat transfer enhancement in nanofluids using twisted tapes. Bunker and Vishwakarma [24] investigated into enhancement of heat transfer for CuO nanofluid using swirl generator. Emprical relations pertaining to this process are also discussed. Kulakarni and Oak [25] investigated experimentally into heat transfer augmentation of CuO nanofluid using helical coil wire inserts. Empirical relations that can be used were summarized in this article. Robertis, et al [26] used Modulated Temperature Differential Scanning Calorimetry technique to measure the heat capacity of nanofluids prepared by one-step method, using sodium hypophosphite as reducing agent in ethylene glycol base fluid. Polyvinyl Pyrrolidone (PVP) was used as stabilizing agent for copper particles obtained from two different precursor salts, copper nitrate and copper sulphate.

ÖZERİNÇ [27] numerically, using CFD simulations, investigated into heat transfer characteristics of Al_2O_3-H_2O nanofluid using thermal dispersion model for hydrodynamically fully developed, thermally developing laminar flow. These results were then compared with experimental results presented in the literature surveyed by the same author. Aghaei, et al [28] numerically simulated the heat transfer through Al_2O_3-H_2O nanofluid for various volume fractions and with Reynold's numbers 10000, 20000 and 30000 and summarized that variations of the average Nusselt number relative to volume fractions are not uniform. Also for all of the considered volume fractions, by increasing the Reynolds number the skin friction factor decreases and with increasing volume fractions and Reynolds number the pressure drop increases. Sisodiya & Geete [29] investigated, using CFD techniques, into the use of Al_2O_3-Water nanofluid in helical coil heat exchangers. Various volume fractions are considered during the analysis.

Subramaniyan & Ilangovan [30] investigated into thermal conductivity of metallic and oxide nanofluids. Thermal conductivity of Cu_2O-TiO_2 nanocomposites with water as base fluid using Maxwell model for different volume fractions of nanophase is investigated. Highest thermal conductivity was observed for Cu2O-TiO2 (1:9) with water as base fluid. Bianco, et al [31] used two phase particle simulation model to numerically simulate and determine the thermal properties of nanofluid. These findings are validated using correlations available.

II. NANOFLUID CORRELATIONS

Use of nanofluids in heat exchangers is being widely investigated. When simulating the flow of nanofluids, due to limitations of CFD software and computational capability of the systems, equivalent properties of nanofluids are computed and are then used in simulation. The equations that are used for computing properties are as given in [29]. These equations are given below:

2.1 Nanofluid Density

$$\rho_{nf}=\varphi .\ \rho_s+(1+\varphi).\ \rho_f \tag{1}$$

Where ρ stands for density, subscript *nf* denotes nanofluid, *f* denotes base fluid, *s* denotes solid particle material, φ stands for volume fraction

2.2 Base fluid molecular diameter

$$d_f := 0.1 \cdot \left(\frac{6 \cdot M_f}{N_A \cdot \pi \cdot \rho_f} \right)^{\frac{1}{3}} \tag{2}$$

Where M_f is the molecular weight, N_A is Avogadro number.

2.3 Nanofluid Specific heat

$$C_{pnf} := \frac{1}{\rho_{nf}} \cdot \left(\varphi \cdot \rho_s \cdot C_{ps} + (1-\varphi) \cdot \rho_f \cdot C_{pf}\right) \tag{3}$$

Where C_p stands for specific heat of respective substance

2.4 Prandtl Number

$$Pr := \frac{C_{pf} \cdot \mu_f}{K_f} \tag{4}$$

Where K is the thermal conductivity and μ stands for dynamic viscosity

2.5 Nanofluid Thermal Conductivity

$$K_{nf} := \left(1 + 4.4\, Re^{0.4} \cdot Pr^{0.66} \cdot \left(\frac{T_c}{T_{ff}}\right)^{10} \cdot \left(\frac{K_p}{K_f}\right)^{0.03} \cdot \varphi^{0.66}\right) \cdot K_f \tag{5}$$

Nanofluid Dynamic Viscosity

$$\mu_{nf} := \frac{\mu_f}{1 - 34.87 \cdot \left(\frac{d_p}{d_f}\right)^{-0.3} \cdot \varphi^{1.03}} \tag{6}$$

In the current work, water is taken as the base fluid and nanoparticles are TiO_2 and Al_2O_3. Table 1 summarizes the properties of the components of nanofluid. Mathcad has been used to compute the material properties using the above expressions. Based on equation (5), it can be observed that the thermal conductivity is a function of Reynold's number. This variation for Al_2O_3-water, TiO_2-Water nanofluids is shown in Fig 1. The dynamic viscosity, based on equation (6) is dependent only on nanoparticle size. The dynamic viscosity is thus same for both the nanofluids as the particles is taken as 33nm and in this case the dynamic viscosity is calculated to be 0.0008313PaS. These computed values are then used in simulation.

TABLE 1
PROPERTIES OF COMPONENTS OF NANOFLUID

	Density (ρ) (kg/m^3)	k (W/mK)	cp (J/ kgK)	dp (nm)	Molicular Wt (gm/mole)
Water	997.1	0.613	4179	**	18.01528
Al_2O_3	3970	40	765	33	**
TiO_2	4000	11.7	697	33	**

(Data not required in the calculations are not listed in the table)

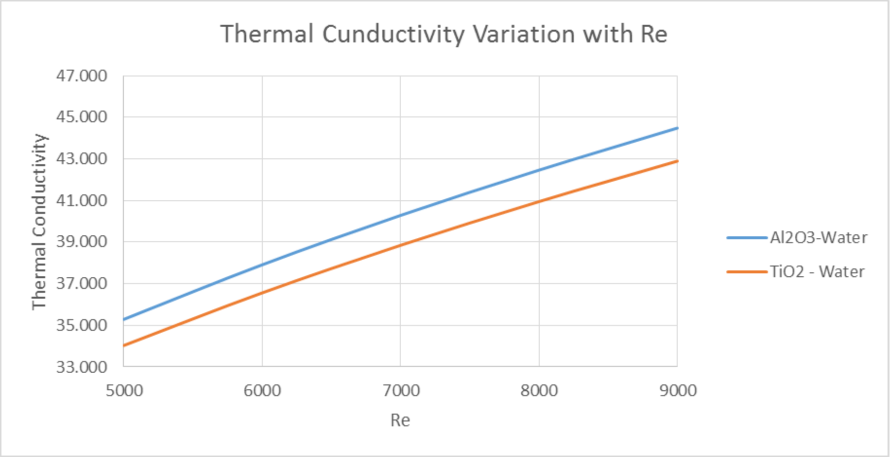

FIG 1: VARIATION OF THERMAL CONDUCTIVITY OF NANOFLUID WITH Re

III. CFD SIMULATION

Initially, CFD simulations are executed to study the effect of double twisted tapes. For this, the experimental conditions stated in [18] are simulated. The simulated model is shown in Figs 2 & 3. Flow through 3m length pipe is simulated. Fist 1m is considered as leading length and is taken so that flow completely stabilizes. For the next 1m length, a constant wall temperature of 150°C is simulated. This is the test section. Two swirl generators are simulated in this length. The next 1m is the trailing length. Average temperature at 11 points along the test section where taken as output. Average heat flux along the test section is also taken as output. Natural convection is simulated along the trailing end.

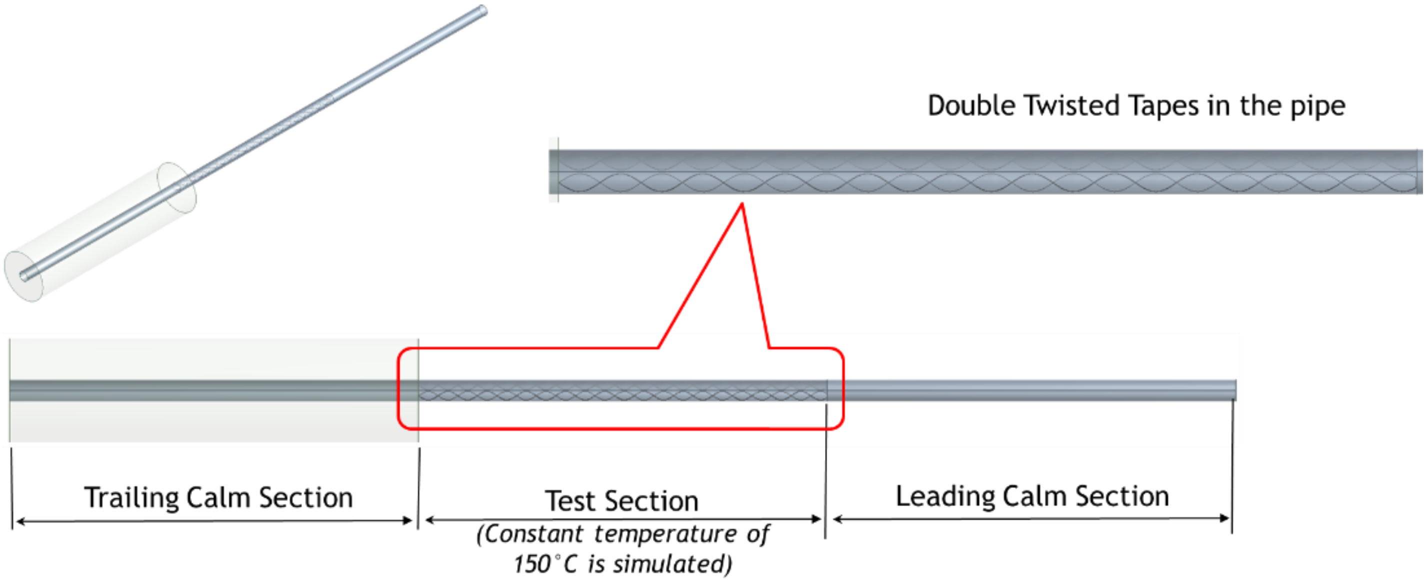

FIG 2: GEOMETRY DESCRIPTION USED FOR SIMULATING THE FLOW

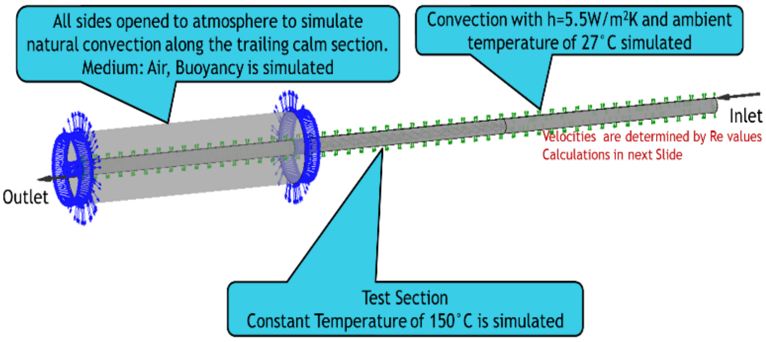

FIG 3: BOUNDARY CONDITIONS

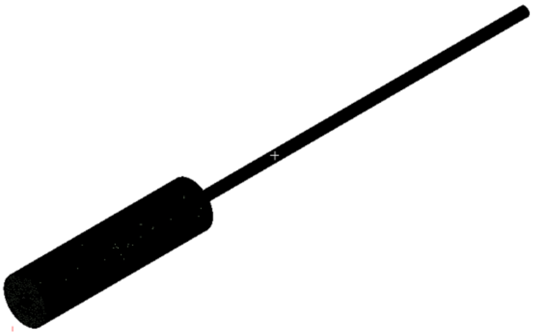

FIG 4: MESHED MODEL

IV. MESHING & GRID ANALYSIS

3 different cases (each with 5 different Re values) are studied during this project execution. The grid analysis was performed until the variation in target parameter (heat flux) is less than 1%. Grid with max element size of 1.5mm is chosen. The results of the simulations are presented in the next section. Fig 4 shows the grid generated.

V. CFD SIMULATION RESULT

Based on the thermal conductivities of the fluids, as shown in Fig 1, it can be observed that with low volume fractions like 0.01, there is little variation in thermal conductivity of the nanofluid and thus there is not much difference in thermal conductivities. Thus similar temperature rise is shown by both nanofluids simulated for a give Re. This variation for Re=5000 is shown in Fig 9. It can be observed that Nanofluids are receiving more heat than compared with that of plain water.

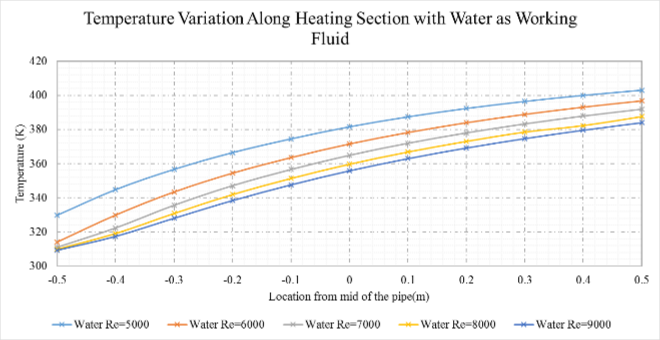

FIG 5: TEMPERATURE VARIATION WITH WATER AS WORKING FLUID

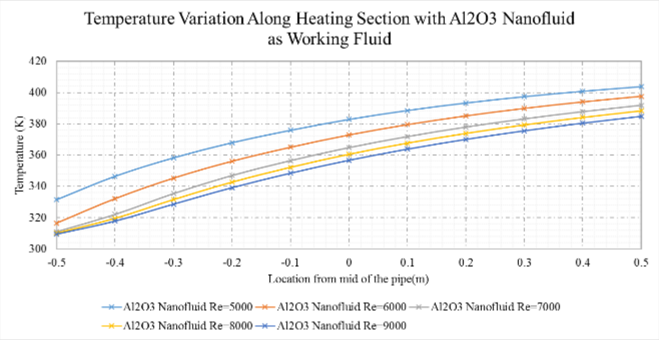

FIG 6: TEMPERATURE VARIATION WITH AL2O3 –WATER NANOFLUID AS WORKING FLUID

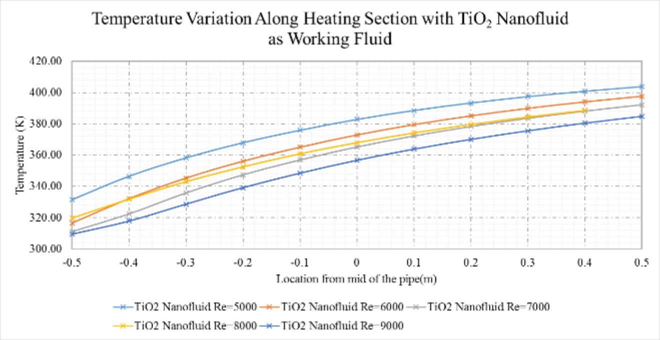

FIG 7: TEMPERATURE VARIATION WITH TIO2 –WATER NANOFLUID AS WORKING FLUID

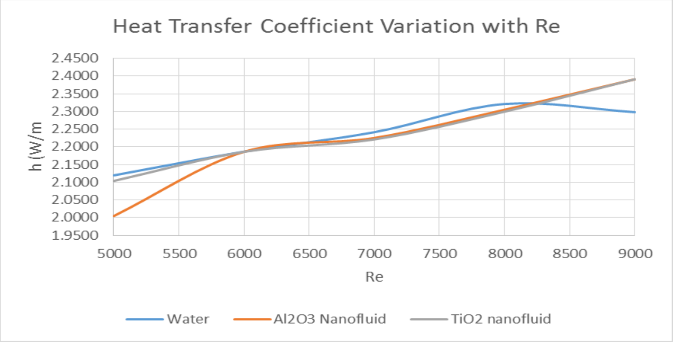

FIG 8: HEAT FLUX VARIATION

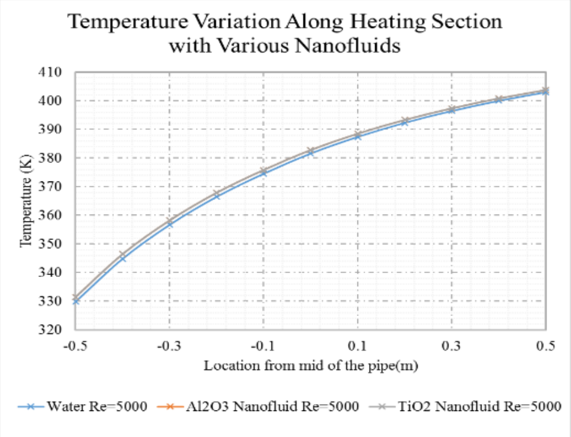

FIG 9: TEMPERATURE VARIATION DUE TO VARIOUS NANOFLUIDS

VI. CONCLUSION

Nanofluids are currently being used for better heat transfer. In the current work, the effectiveness of nanofluid during heat when flowing through a tube with dual twisted tape inserts was investigated. Literature survey pertaining to use of swirl generators and evaluating nanofluid thermal properties is presented. Numerical relations for calculating thermal properties are listed. CFD simulations are executed to compute the heat flux with various nanofluids is executed and the results were discussed. The results indicated that nanofluids show greater increase in temperature but low volume fractions, both Al_2O_3 and TiO_2 showed similar performance.

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