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Thermal Performance of Spiral Tube Heat Exchanger using Nano Fluid – Experimental Study

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ABSTRACT

Nano fluids are fluids containing suspended solid particles in a traditional heat transfer fluid. It is expected that the nano fluid will be in the next generation of heat transfer fluids due to their unique thermal properties. In this research, we have considered the heat transfer properties of nano fluids made up of Tio2 and sesame oil in the spiral heat exchanger, and it is compared to base fluid (sesame oil) properties. The Nusseltnumbers of nano fluids were obtained for different nano particle concentrations as well as various peclet number and Reynolds number. The experimental results emphasize the enhancement of heat transfer due to the nano particle's presence in the nano fluid heat transfer coefficient increases by increasing the concentration of nano particles in nano fluid. The increase in heat transfer co efficient due to presence of nano particles is much higher than the base fluid properties.

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INTRODUCTION

Now a day's energy consumption is tending to increase, however, the energy source is tending to decrease rapidly, So that many countries are trying to create energy policies to reduce energy consumption. Many countries intend to design and develop devices to reduce energy consumption in order to achieve the highest possible efficiency. In general the working fluids (for heat transfer) inside a heat exchanger may be water, ethylene glycol and mineral oils, which have been widely used for many decades in various sectors. These general heat transfer fluids, however, are often limited by their poor thermal properties in particular thermal conductivity. For the above reason development of high performance heat transfer fluids has been a subject of numerous investigations in the past few decades. As solid material in particular metals can have very high thermal conductivity, lots of studies have been carried out in the past on the thermal behavior of the suspension of particulate solid in liquids. These early studies however used the suspension of millimeter or micrometer sized particles, which, although showed some enhancement, experienced problems such as abrasion and channel clogging can be particularly serious for systems using mini and/or micro channels. A recent invention termed 'Nano fluid' has shown potential to resolve some disadvantages associated with suspense of large particles.

Nano fluid is liquid suspensions of nano sized metal or non metal particles like Cu,Al_2o_3,Sio_2,Cuo,Tio_2 and Fe_3o_4 were dispersed into a base fluid. This work is concerned about the heat transfer of the coil type heat exchanger using sesame oil suspension of Titanium dioxide (Tio_2) nano particles. The reason for choosing Tio_2 include (a) Tio_2 is generally regarded as a safe material for human being and animals (they are actually used in the cosmetic product and water treatment), (b) Tio_2nano particles are easily obtained (they are produced in very large industrial scales), (c) Tio_2nano fluids have an excellent stability even without using stabilizer and (d) Metal oxides such Tio_2nano particles are chemically more stable than their metallic counterparts.

In the present work we have experimentally investigated the heat transfer enhancement of a TiO_2 nano fluid cooling system, by replacing the base fluid, in occurrence sesame oil, by a nano fluid composed of sesame oil. Some most significant results and experimental data are presented and discussed.

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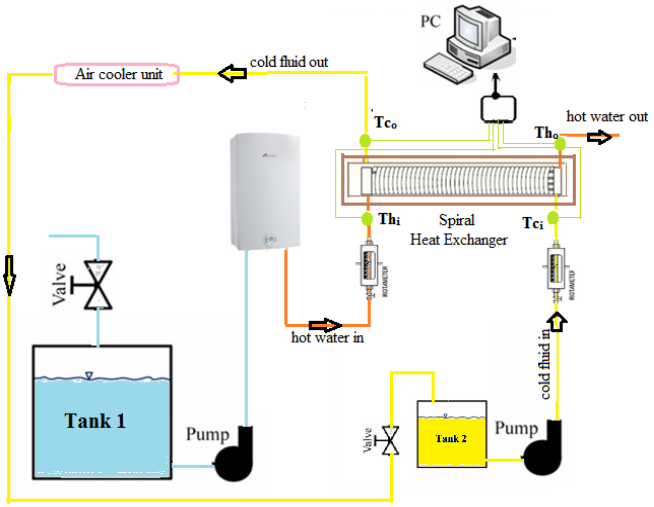

Fig. 1: Schematic illustration of the experimental setup arrangement.

Table I: Parameter dimension of experimental setup

PARAMETERS	DIMENSION
SHELL	
I.D.	101.6 mm
Length	300 mm
Material	Borosilicate glass
COIL	
I.D.	7.05 mm
O.D.	9.53 mm
Length	3 m
Material	copper
Exchange Area	0.15 m^2 (Approx)
SUMP TANKS	
Capacity	5 L & 50 L
Material	Stainless steel
Ports	Inlet/Outlet/Drain
FLOW METER	0-10 LPM
THERMOCOUPLE	K type

Experimental setup:

The experimental apparatus is relatively simple and consists of one open and one closed liquid circuit, Fig. 1 which is primarily composed of a 50 liter and 5 liter stainless tanks, 240 V AC/1-Phase/50 Hz pump, 3000 W Electric water heater, spiral heat exchanger, a mini air cooler, thermocouples and flow meter. The parameters of the experiment are shown in Table 1.

The experimental setup, after being carefully assembled, has been thoroughly checked with a particular emphasis on the detection of possible leaks from various connections in the piping system. It should be mentioned that TiO_2 - sesame oil Nano fluid, for which the particle mean diameter is approximately 40nm has purchased and ultrasonically mixed with sesame oil at particular concentration and nano fluids are prepared and filled in the 5 L tank , operate the experiment and take the readings. From the collected data of temperature and mass flow rates and the heat transfer properties are calculated from the equations.

Data Analysis:

The heat transfer performance of nano fluid through a spiral heat exchanger was defined in terms of convective heat transfer coefficient calculated as follows:

$$h_{exp} = \frac{c_{pnf} \cdot \rho_{nf} \cdot \hat{U} \cdot A(T_{b2} - T_{b1})}{\pi \cdot D \cdot L \, (T_w - T_b)_{LM}} \quad (1)$$

$$Nu_{exp} = \frac{h_{exp} \cdot D}{K_{nf}} \quad (2)$$

In which $(T_w - T_b)_{LM}$ is a logarithmic mean temperature difference.

The experimental results obtained from this investigation were compared with prediction of existing correlation for laminar flow of fluid inside the shell under the constant wall temperature boundary condition. In this equation the nano fluid convective heat transfer enhancement is due to thermal conductivity increase as follows:

$$Nu_{theo} = 0.027(Re_{nf})^{0.8} \cdot (Pr_{nf})^{\frac{1}{3}} \left(\frac{\mu_{nf}}{\mu_{wnf}}\right)^{0.14} \quad (3)$$

In Eqn. 3 Re_{nf} and Pr_{nf} are the nano fluid Reynolds and Prandtl number, respectively, which are defined as follows:

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$$Re_{nf} = \frac{\rho_{nf}\, U\, D}{\mu_{nf}} \quad (4)$$

$$Pr_{nf} = \frac{Cp_{nf}.\mu_{nf}}{K_{nf}} \quad (5)$$

The physical properties used for nanofluid were calculated from base fluid and nano particle properties at average bulk temperature using following correlations for density, viscosity, specific heat and thermal conductivity.

$$\rho_{nf} = v.\rho_s + (1-v).\rho_w \quad (6)$$

$$\mu_{nf} = \mu_w.(1+2.5v) \quad (7)$$

Eqn. (7) (Einstein equation) is applicable for spherical particle in volume fractions less than 5.0%.

Yu and Choi correlation (Yu and Choi, 2003; Trisaksri and Wongwises, 2005) was used for the determination of nano fluid effective thermal conductivity as follows:

$$k_{nf} = \left[\frac{k_s + 2k_w + 2(k_s - k_w)(1+\beta)^3.v}{k_s + 2k_w - 2(k_s - k_w)(1+\beta)^3.v} \right] k_w \quad (8)$$

In Eqn. (8) β Is the ratio of nano layer thickness of the original particle radius and β=0.1 were used to calculate the nano fluid effective thermal conductivity. The rheological and physical properties of the nano fluid were calculated at the mean temperature. Then the Nusselt number and convective heat transfer coefficient at different concentrations were calculated.

The uncertainty of the calculated heat transfer coefficient, pressure drop, peclet number, Nusselt number, and Reynolds number was calculated.

RESULT AND DISCUSSIONS

The heat transfer enhancement resulting from the use of nano fluids to be shown in the variation of the convective heat transfer co efficient h_w.

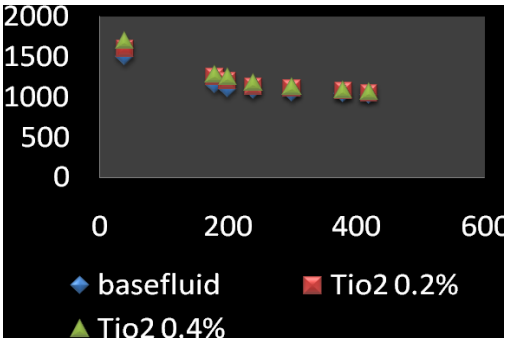

Fig. 2: sesame oil and Tio_2/sesame oil heat transfer coefficient versus X/D values.

Fig. 2 shows that axial profile of the heat transfer coefficient of nano fluids with different particle concentration in the laminar flow regime. In the figure Reynolds number is based on the viscosity of the base fluid. Hence the same Reynolds number is based on the viscosity of the base fluid, hence the same Reynolds number indicates approximately. The same fluid velocity indicates due to very low concentrations in the nano fluid. In figure clearly shows that the heat transfer coefficient increases with increasing particle volume concentration.

Fig. 3: Experimental values of heat transfer co efficient and calculated value for Tio_2/sesame oil nano fluid versus Peclet number at different volume concentration.

In Fig. 3 the heat transfers co efficient of nano fluid versus Peclet number at different concentration. The results are compared with theoretical values. Fig. 3 shows clearly the constant Peclet number heat transfer coefficient increases with nano particle concentration and the experimental values are higher than the theoretical values.

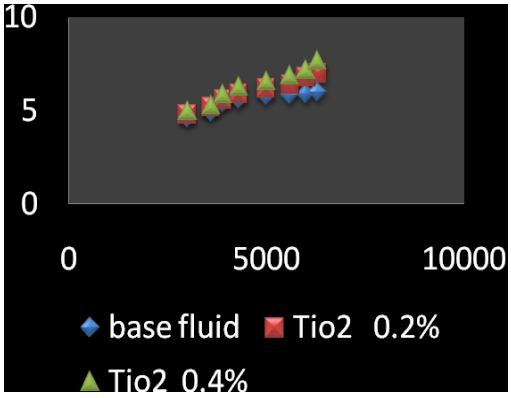

Fig. 4: Experimental Nusselt number for base fluid and Tio_2/sesame oil nano fluid versus Peclet number at different volume concentration

Fig. 4 represents Nusselt number variation versus Peclet number for different volume fraction of nano particles. Based on this figure the Nusselt number for nano fluid is greater than the Nusselt number of base fluid and heat transfer properties is higher for higher concentrations of particles.

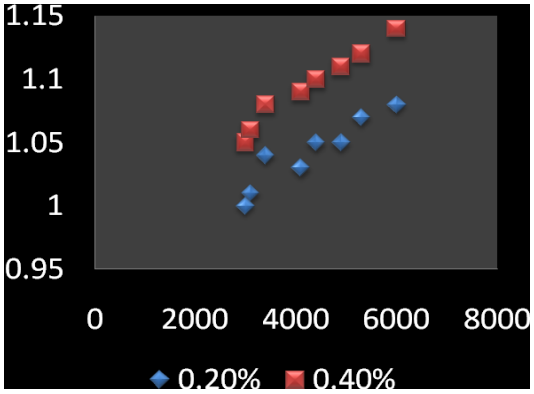

Fig. 5: Tio_2 / sesame oil nano fluid experimental heat transfer co efficient ratio to theoretical heat transfer coefficient ratio versus Peclet number at different volume concentration.

In the Fig. 5 shows that the ratio of the experimental value heat transfer coefficient to the theoretical value of heat transfer coefficient. The ratios increase with Peclet number as well as nano particle concentration. The above figure shows that 0.20% of Tio_2/sesame oil composition varies the Peclet number 3000 to 6200 varies the value of 1.0 to 1.08 and 0.40% composition varies the Peclet number from 3200 to 6400 varies the value of 1.05 to 1.14.

Conclusion:

Convective heat transfer of Tio_2/sesame oil nano fluid in turbulent flow through the spiral tube heat exchanger was investigated experimentally. The experimental results indicate that heat transfer coefficient of nano fluid increases with peclet number as well as nano particle concentration. The increase in heat transfer coefficient due to present of nano particle is much higher than the base fluid properties.

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