Effect of Volume Concentration on Various Thermo-Physical Properties of the CuO Nanofluid in Solar Flat Plate Collector

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Abstract – *Present study carries out a theoretical analysis for calculating various thermo-physical properties of nano fluids in flat plate collector. The water based Copper oxide (CuO) nanofluid is used as a working fluid. A mathematical model and a program, written in MATLAB code were used for calculating the thermo-physical properties of the fluid. The results showed that with the increase in the volume concentration of the nanoparticle, the density, viscosity and thermal conductivity increased whereas the specific heat decreased. The Nusselt number increased with the increase in volume concentration. However at the same volume concentration, Nusselt number increased with the diameter of nanoparticle in the base water.*

Key Words*: *Flat plate collector, Thermophysical properties, Mathematical Model, MATLAB, Nusselt number.

1. INTRODUCTION

The flat plate collector forms the heart of any solar energy collection system designed for operation in the low temperature range, from ambient to 60˚C, or the medium temperature range, from ambient to 100˚C.A solar collector is a special kind of heat exchanger that transfers the radiant energy of the incident sunlight to the sensible heat of a working fluid-liquid or air. The invention of the liquid heating flat plate solar water heater is credited to H.B Saussure, during the second half of the seventeenth century [4].Flat Plate collectors have the following advantages over other types of solar energy collectors:

(i) Absorb direct, diffuse and reflected components of solar radiation

(ii) Are fixed in tilt and orientation and, thus, there is no need of tracking the sun,

(iii) Are easy to make and are low in cost,

(iv) Have comparatively low maintenance cost and long life,

(v) Operate at comparatively high efficiency.

1.1 Objectives of the Study

The objectives of the current study are:

1. To develop a mathematical model and MATLAB Code for evaluating various parameters.
2. To study the effect of volume concentration of nanoparticles on various Thermo-physical properties of the nanofluid.

1.2 LITERATURE REVIEW

Morcos [1] developed a mathematical model for calculating the total solar radiation on a tilted surface. The model was then used to determine optimum tilt angles for a flat plate collector and the optimum tilt angle and surface azimuth angles for concentrating solar collectors on a daily basis, as well as for a specified period.

Saraf et al. [2] developed a mathematical model for calculating the useful energy gained by a flat plate collector under various operating conditions. The model was then used to determine the optimum tilt angles for a typical collector in Basrah on a daily basis, as well as on the basis of a specified period. The optimum tilt angle was found by searching its value for which the useful energy gained by the collector is a maximum for a particular day or a specified period. From the results, it was observed that changing the tilt angle eight times in a year determines the useful energy in Basrah near its value which is found by changing the tilt angle daily to its optimum value.

Choi and Eastman [3] studied low thermal conductivity is a primary limitation in the development of energy-efficient heat transfer fluids that are required in many industrial applications. They proposed that an innovative new class of heat transfer fluids can be engineered by suspending metallic nanoparticles in conventional heat transfer fluids. The thermal conductivity of metallic liquids is much greater than that of nonmetallic liquids. Therefore, the thermal conductivities of fluids that contain suspended solid metallic particles were enhanced when compared with conventional heat transfer fluids.

Yimin and Wilfried [4] described nanofluid as a solid-liquid mixture in which metallic or nonmetallic nanoparticles are suspended. The suspended ultrafine particles change transport properties and heat transfer performance of the nanofluid, which exhibits a great potential in enhancing heat transfer. The mechanism of heat transfer enhancement of the nanofluid was investigated. Based on the assumption that the nanofluid behaves more like a fluid rather than a conventional solid-fluid mixture, two different approaches for deriving heat transfer correlation of the nanofluid were developed.

International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 06 Issue: 06 | June 2019 www.irjet.net p-ISSN: 2395-0072

2. Methodology

2.1 Estimation of Heat transfer coefficient and Nusselt number

Li and Xuan [5] proposed the general form of Nusselt number relating to nanofluids for a laminar (Re < 2300) by

the following relations:

$$Nu_{nf} = 0.4328\,(1 + 11.285\O_p^{\,0.754} Pe_d^{\,0.218}) Re_{nf}^{\,0.333} Pr_{nf}^{\,0.4}$$

In the above equations, the dimensionless numbers are given by

Reynolds number:

$$Re = \frac{V \rho_{nf} D_i}{\mu_{nf}}$$

Peclet number

$$Pe_d = \frac{V d_p}{\alpha_{nf}}$$

Prandtl number

$$Pr = \frac{\mu_{nf} C_{pnf}}{k_{nf}}$$

Where V is the mean flow velocity, d_p is the diameter of nanoparticle, μ_{nf} and C_{pnf} are the dynamic viscosity and specific heat capacity of nanofluid respectively.

Thermal diffusivity and density of the nanofluid are given by [3] as

$$\alpha_{nf} = \frac{k_{nf}}{\rho_{nf} C_{pnf}}$$

$$\rho_{nf} = \O_p \rho_p + (1 - \O_p)\rho_{bf}$$

Where $\O_p$ is the volume concentration of nanoparticles, ρ_p is the density of nanoparticle, ρ_{bf} is the density of base fluid.

The dimensionless numbers defining Nusselt number are a function of thermo-physical properties of nanofluid (viscosityμ_{nf}, specific heat capacity, C_{pnf}, thermal conductivities , k_{nf},and density, ρ_{nf}). There are various correlations available for estimating the thermo-physical properties of nanofluids. Azmi et al. (2010) [28] developed the regression equations for estimation of nanofluids properties such as μ_{nf}, k_{nf} and C_{pnf} as a function of volume concentration, $\O_p$, particle size, d_p and temperature T_{nf}.

The regression equation for nanofluid viscosity, considering the particle size, concentration and temperature applicable for

$13 < d_p < 170\ nm, 0.03 < \O_p < 4\%, 15 < T_{nf} < 72°C$

is given by:

$$\mu_{nf} = \mu_w \left(0.9042 + 0.1245\O_p - 0.08445 \left[\frac{T_{nf}}{72}\right] + 0.6436 \left[\frac{d_p}{170}\right]\right)$$

The regression equation for nanofluid thermal conductivity, considering the particle size concentration and temperature applicable for

$13 < d_p < 150\ nm, 0 < \O_p < 20\%, 20 < T_{nf} < 70°C$ is given by:

$$k_{nf} = k_w \left(0.9808 + 0.0142\O_p + 0.2718 \left[\frac{T_{nf}}{70}\right] - 0.1020 \left[\frac{d_p}{150}\right]\right)$$

The regression equation for nanofluid specific heat, considering the particle volume concentration and temperature applicable for

$0 < \O_p < 6\%, 20 < T_{nf} < 70°C$ is given by:

$$C_{pnf} = C_w \left(1.036 - 0.0298\O_p - 0.07261 \left[\frac{T_{nf}}{70}\right]\right)$$

Where the subscript w and nf refer to water and nanofluid respectively. Using the above relations, the thermo-physical properties of nanofluid defining the dimensionless numbers (Re, Pe, Pr, and Nu) were calculated as a function of particle volume concentration for different nanoparticle sizes in a nanofluid. These dimensionless numbers are used to obtain the Nusselt number of nanofluid.

3. Results and discussion

3.1 Variation of Density of nanofluid

that with the increase in the volume concentration of the nanoparticle from 0.1 to 3.5% ,the nanofluid density increases from 983 kg/m³ to 1170 kg/m³ for different size of particles. It can also be seen from the figure that density of nanofluid is independent of the size of particle.

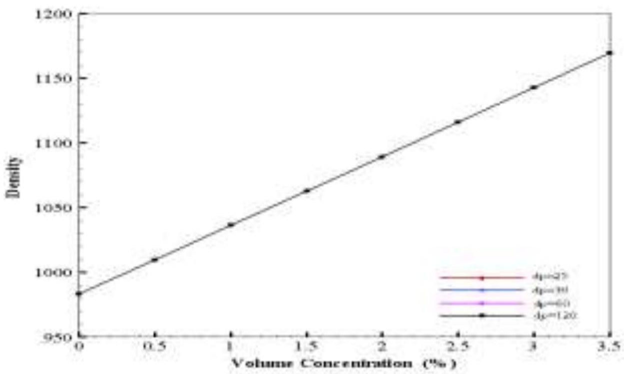

Fig -1: Variation of Density with volume concentration

3.2 Variation of Specific Heat of Nanofluid

Fig. 2 shows that with the increase in in the volume concentration of the nano particle from 0.1 to 3.5%, the nanofluid specific heat decreases from 4069 J/kgm³ to 3633 J/kgm³ for different size of particles. The figure also shows that the specific heat of nanofluid is independent of the size of particle.

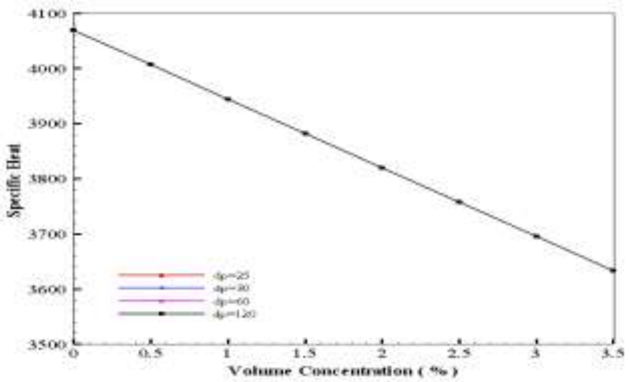

Fig -2: Variation of specific heat with volume concentration

3.3 Thermal conductivity of Nanofluid

Fig. 3 shows that the thermal conductivity of nanofluid increases as the particle volume concentration increases in the base water but decreases as the size of the particle increases. The maximum value of thermal conductivity occurs at 3.5% particle volume concentration with particle diameter of 25nm and the minimum value of thermal conductivity occurs at 0.1% particle volume concentration with particle diameter of 120 nm.

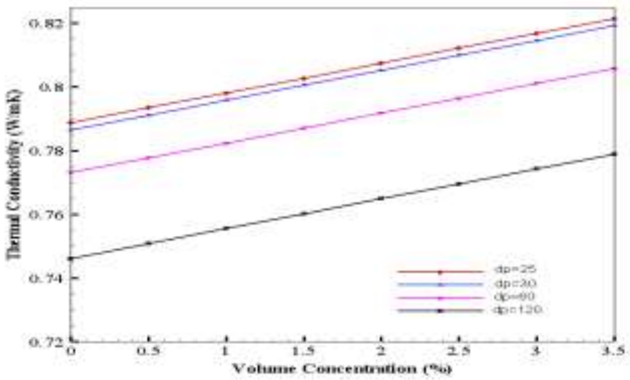

Fig -3: Variation of Thermal conductivity with volume concentration

3.4 Variation of viscosity of nano fluid

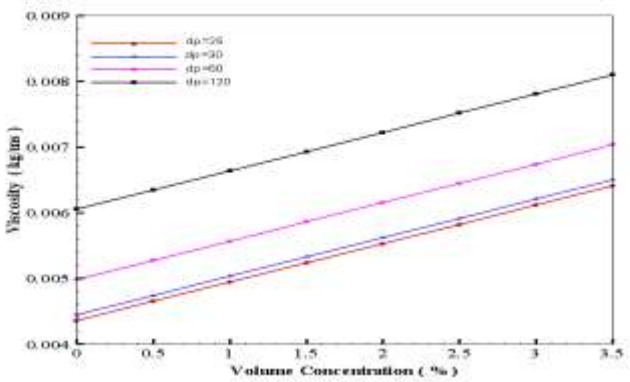

Fig -4: Variation of Viscosity with volume concentration

It can also be seen in figure 4 that as the particle size increases the viscosity of nanofluid also increases. The maximum value of viscosity for 3.5% CuO nanofluid with the particle diameter of 120 nm is 0.8099×10^{-9} kg/m^3.

3.4 Nusselt Number, Nu

The figure 5 depicts that as the volume concentration increases, the Nusselt number also increases. It also increases with respect to increasing diameter of nanoparticle in the base water.

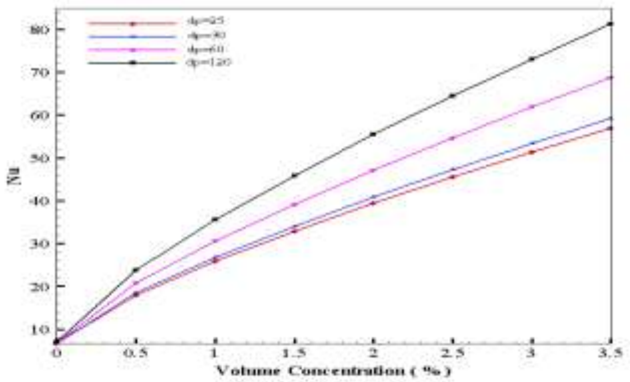

Fig -5: Variation of Nusselt number with volume concentration

4. Conclusions

The present study analyzed theoretically the efficiency of CuO-water nanofluid based flat plate solar collector for water heating applications using the MATLAB program. Following conclusions can be drawn from the current study:

1. With the increase in the volume concentration of the nanoparticle from 0.1 to 3.5%, the nanofluid density increases from 983 kg/m^3 to 1170 kg/m^3 for different size of particles. It can also be seen from the figure that density of nanofluid is independent of the size of particle.
2. With the increase in in the volume concentration of the nano particle from 0.1 to 3.5%, the nanofluid specific heat decreases from 4069 J/kgm^3 to 3633 J/kgm^3 for different size of particles. The figure also shows that the specific heat of nanofluid is independent of the size of particle.
3. The thermal conductivity of nanofluid increases as the particle volume concentration increases in the base water but decreases as the size of the particle increases. The maximum value of thermal conductivity occurs at 3.5% particle volume concentration with particle diameter of 25nm and the minimum value of thermal conductivity occurs at 0.1% particle volume concentration with particle diameter of 120 nm.
4. The viscosity of nanofluid increases as the volume concentration of particle in the base water increases. It can also be seen in figure that as the

particle size increases the viscosity of nanofluid also increases. The maximum value of viscosity for 3.5% CuO nanofluid with the particle diameter of 120 nm is 0.8099 10^{-9} kg/m^3.

5. As the volume concentration increases, the Nusselt number also increases. It also increases with respect to increasing diameter of nanoparticle in the base water.

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