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Computational Analysis on the Effects of CuO-Water based Nanofluids on the Performance of Flat Plate Solar Collector

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Abstract

Objectives: In the present work, the effect of CuO-water based nanofluids on the performance of flat plate solar collector was studied using computational fluid dynamics. **Methods/Statistical Analysis:** The computational analysis was carried out for both water and nanofluids at varying mass flow rates of 0.00255 kg/sec, 0.0029 kg/sec and 0.00323 kg/sec. Comsol 5.2 software has been used for the simulating the performance of solar collector. The performance of flat plate solar collector is evaluated in terms of outlet fluid temperature by providing various inlet parameters such as inlet fluid temperature, ambient temperature, inlet pressure, solar irradiance, etc. **Findings**: The study was conducted for two volume fraction of CuO as 0.1% and 0.2% in base fluids. It has been found that the efficiency of solar collector increases with the use of nanofluids in comparison with water as nanofluids have better thermal properties. Also the efficiency of collector increases with the increase in mass flow rate for both water and nanofluids as working fluids. The efficiency is found to be slightly higher when the volumetric concentration of nano particles in a base fluid is higher. The temperature difference between inlet and outlet decreases as the inlet temperature increases. The maximum efficiency was found to be 55.3% using water whereas the maximum efficiency with CuO-water nanofluids was 73.4%. The maximum efficiency increase is found to be 25.9% with the use of nanofluids in comparison to water at a mass flow rate of 0.00255 kg/sec. **Application/Improvements:** Nan fluids are highly useful as heat transfer fluids due to enhanced thermal properties. The application areas of nanofluids are power generation, heating, cooling, air-conditioning, ventilation, etc.

Keywords: Diffuse Surface, Flat Plate Solar Collector, Nanofluids, Outlet Fluid Temperature, Performance, Solar Radiation

1. Introduction

With the increasing demand of energy day by day and depletion of fossil fuels, it focuses our attention towards unconventional energy resources. Solar energy can be converted into more useful form with the help of solar collectors. Nanofluids are widely used as heat transfer fluids as they have better thermo-physical properties and correspondingly improve the performance of heat exchangers. Many researchers have found out the use of nanofluids in solar collectors and concluded that there is an effective increase in the efficiency. In[1] experimentally investigates that the efficiency of a flat plate solar collector increases with the increase in weight fraction of nano particles in a base fluid. The efficiency at 0.4 wt% Multi-Wall Carbon Nano-Tube (MWCNT) nanofluid is higher as compared to 0.2 wt% MWCNT nanofluid. In[2] experimentally investigates that efficiency of a flat plate solar

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collector improves with the use of TiO_2-water nanofluid in comparison to the water. He found out that thermal conductivity is related with volume fraction of nano particles and rises up to 6% with 0.3% TiO_2. Also the energy efficiency increases by 76.6% for 0.1 volume% at 0.5 kg/min in comparison to water. In[3] compared the performance of solar collector using water and Al_2O_3-water based nanofluids. The increase in the collector temperature difference and absorption of solar radiation when using Al_2O_3-water nanofluids was observed. The maximum temperature difference observed for Al_2O_3-water nanofluids was 14.4 ˚C whereas for water the maximum temperature difference was 10.7 ˚C was observed. In[4] numerically investigates the performance of a solar collector using Cu based nanofluids. An effective improvement in the heat transfer rate for Cu based nanofluids was observed. The collector efficiency was found to be higher for higher values of solar irradiance and lower diameter. In[5] experimentally investigates the performance of a flat bed solar collector with or without porous medium. It was observed that as the mass flow rate increases, efficiency also increases. Also using the porous medium improves the performance of a flat plate solar collector. In[6] studied the applications of nanofluids in various fields. Nanofluids improve thermo physical properties and correspondingly thermal performance. Nanofluids have major applications in power generation, industrial and information technologies. B. In[7] theoretically investigates the effect of thermal and optical properties on the performance of a solar collector. It was found that by changing the absorbance from 0.95 to 0.97, the energy output increases of about 2.7% and by decreasing emittance of an absorber plate from 0.10 to 0.05 brings an increase of 3.8% at an operating temperature of 50 ˚C. In[8] studied the effect of changing of parameters on the performance of solar heaters. The optimized solar collector uses painted plastic sheets as an absorber and polyethylene sheet as a glazing instead of glass due to better absorbance-transmittance properties as that of glass. In[9] investigates the effect of various flow patterns on the performance of a flat plate solar collector. Double duct cross flow was found to be the best with maximum heat transfer area. The increase of about 8.3% in the performance of double duct cross flow was observed in comparison to single duct front pass.

2. Materials and Methodology

In this section, all the details related to computational analysis of a flat plate solar collector are described. Comsol 5.2 software has been used for the simulation purpose. The performance of a flat plate solar collector is evaluated using water and CuO-water based nanofluids by providing various inlet parameters.

2.1 Working Fluid

The analysis of a flat plate solar collector is carried out using two working fluids as given by,

- Water
- CuO-Water (nanofluid)

Table 1. Thermal properties of 0.1% CuO-Water nanofluids

Temperature	Density	Viscosity	Specific heat at constant pressure	Thermal conductivity
25	1003.78	0.826	4092	0.625
26	1002.59	0.802	4078	0.629
29	1001.63	0.771	4001	0.632
34	999.87	0.749	3989	0.638
38	998.45	0.701	3901	0.642

Table 2. Thermal properties of 0.2% CuO-Water nanofluids

Temperature	Density	Viscosity	Specific heat at constant pressure	Thermal conductivity
25	1004.56	0.834	4071	0.63
26	1003.65	0.811	4068	0.634
29	1002.67	0.796	3979	0.637
34	1000.25	0.766	3912	0.643
38	999.78	0.726	3878	0.65

2.1.1 Water

EThe simulation is done by flowing water in the collector at a given mass flow rate. The water used for the analysis is taken from the built-in library provided in the software.

2.1.2 CuO – Water (nanofluids)

Other than water, CuO-water based nanofluid is the other working fluid used in the computational analysis. Two concentrations of CuO in 100% of water are used for the simulation. The concentrations of copper oxide in water are 0.1% and 0.2% at different inlet parameters. The computational analysis is done for each of 0.1%CuO and 0.2% CuO in water at different mass flow rates. The varying concentration of CuO in water affects the thermo physical properties of nanofluids. The thermo physical properties of nanofluids also depend upon the temperature of the mixture. As the analysis is carried out at varying inlet parameters, properties of nanofluids also varies with the variation in temperature. The thermo physical properties of 0.1% CuO-water and 0.2% CuO-water based nanofluids at varying inlet temperature is given in Table 1-2.

2.2 Collector Specification

The specifications of flat plate collector used in the analysis are given in Table 3.

Table 3. The specifications of the flat-plate collector

Specification	Dimension	Unit
Collector dimension	915x810x95	mm
Collector area	0.74115	mm^2
Edges area	0.327	mm^2
Glazing (toughened glass)	t =3	mm
Absorber plate (copper)	t =0.12	mm
Header pipe	Ø = 25.4, t=0.71, l=882, n=2	mm
Riser pipe	Ø = 12.7, t=0.56, l=800, n=6	mm
Insulation (rock wool)	t(base)=50, t(sides)=25	mm

2.3 Computational Analysis

Comsol software has been used for the computational analysis. By providing various inlet conditions, temperature at the outlet is computed and subsequently efficiency at each inlet condition. The flat plate solar collector works on the principle of conduction, convection and radiation. Conduction occurs between absorber plate and tubes. The heat from the absorber plate conducts itself from copper plate to the copper tubes. Convection occurs between fluid and copper tubes, the fluid gets heated up due to the convection of heat from copper tubes to the working fluid flowing inside the tubes. Radiation is a process in which heat transfer takes place between two bodies placed at a distance due to the electromagnetic radiation. Radiation falls on to the glass cover from where it transmits the heat to the absorber plate due to the radiation phenomenon.

The flat plate solar collector is a multi physics problem. In order to simulate flat plate solar collector, different modules of the software are selected. The modules used for the computational analysis are given by,

Heat transfer with surface to surface radiation

- Heat transfer in fluids
- Laminar flow

Apart from the already built-in features in the module, more features can be added. Various modules in the software also have built-in equations in order to compute the necessary results. The equations are given by,

Heat transfer in solids is computed by:

$$\rho Cp\frac{\partial T\mathbf{2}}{\partial t} + \rho Cp.u.\nabla T2 + \nabla.q = Q + Q_{ted}$$

$$q = -K\,\nabla T$$

Heat transfer in fluids is computed by

$$\rho Cp\frac{\partial T\mathbf{2}}{\partial t} + \rho Cp.u.\nabla T2 + \nabla.q = Q + Q_{p} + Q_{vd}$$

$$q = -K\,\nabla T\mathbf{2}$$

Equation for thermal insulation

$-n.q = 0$

Heat transfer using surface to surface radiation

$$\rho Cp\frac{\partial T}{\partial t} + \rho Cp.u.\nabla T + \nabla.q = Q + Q_{ted}$$

$$q = -K\,\nabla T$$

2.3.1 Thermophysical Properties

Diffuse surfaces for absorber plate and glazing are also used with required absorptivity and emissivity.

Thermo physical properties of diffuse surfaces used for the computational analysis are given in Table 4.

Table 4. Thermophysical properties of diffuse surface

Glazing transmission	0.85
Glazing emissivity	0.88
Absorber emissivity	0.12
Absorption of absorber plate	0.96

External radiation source used with an intensity of 800W/m^2.

The computation is carried out by providing various inlet conditions.

Mesh size is also an important factor in order to find the best and optimized solution. Hence, simulation is carried out at different mesh sizes and grid dependency is checked.

The effect of mesh size on outlet temperature can be shown with the help of grid dependency check. Also the computation time depends upon the mesh size, the finer the mesh the more will be computation time.

Hence, simulation is carried out at different mesh size and grid dependency is checked. The effect of grid dependency on temperature is shown in Table 5.

Table 5, shows that outlet temperature depends upon the mesh size and no of elements. The finer the mesh size becomes the no of elements in the geometry increases.

Table 5. Grid dependency on temperature

Mesh size	No of elements	Temperature at outlet
Extremely coarse	73540	47.67
Extra coarse	105453	45.62
Coarse	243993	45.59

The grid dependency is checked as to obtain the suitable mesh size for which the outlet temperature does not depend upon the mesh size or is independent of the no of grids. The outlet temperature does not change significantly from extra coarse to coarse mesh size or we can say it is grid independent.

To simulate the performance of a flat plate solar collector, time-dependent study is carried out.

The simulation is carried out for 8 hours with a time interval, dt of 12 minutes.

2.4 Efficiency Calculation

The instantaneous collector efficiency can be calculated as follows

$$\eta = \frac{m\, C_{eff}\,(T_2 - T_1)}{G_T A_C}$$

$$m = \rho_{eff} x\ A\ x\ V$$

$$\rho_{eff} = (1 - \varphi_P)\,\rho_f + \varphi_p\ \rho$$

$$\varphi_P = \frac{V_P}{(V_P + V_f)}$$

$$C_{eff} = \frac{\{(1 - \varphi_P)\,\rho_f C_f + \varphi_P \rho_P C_P\}}{\rho_{eff}}$$

Where,

η = Instantaneous efficiency

m = Mass flow rate of fluid

C_{eff} = Effective specific heat

T_2 = Outlet fluid temperature

T_1 = Inlet fluid temperature

G_T = Global solar irradiation

A_C = Area of the collector

ρ_{eff} = Density of the nanofluids

φ_P = Volume fraction of nanoparticles

ρ_P = Density of nanoparticles

V_P = Volume of the nanoparticles

V_f = Volume of the base fluid

3. Results and Discussion

Computational analysis is done on the performance of a flat plate solar collector.

Figure 1, shows the temperature of fluid flowing inside the pipes at different points. Temperature differs at different points. Temperature is maximum in between the tubes as maximum solar radaition falls on it.

The maximum temperature on the flat plate collector system is 120 ˚C on the absorber plate. Figure 2 shows the temperature variation inside the flat plate solar collector.

The performance of solar collector depends upon different design and atmospheric parameters. The results are shown in the form of graphs.

First of all the graphs are plotted with water and then with CuO-water with different concentrations at different mass flow rates.

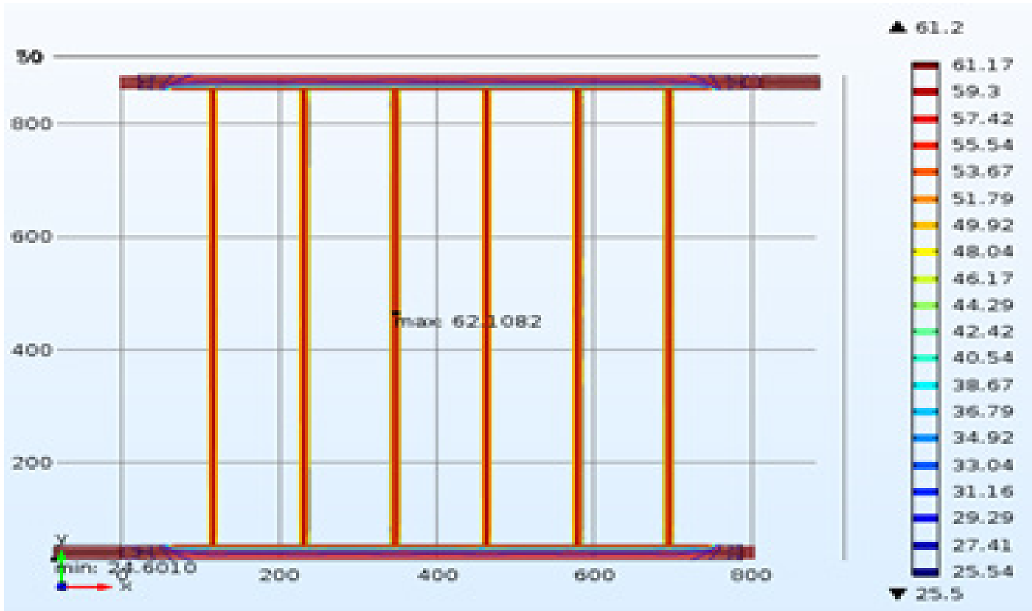

Figure 1. Temperature variation inside the pipes.

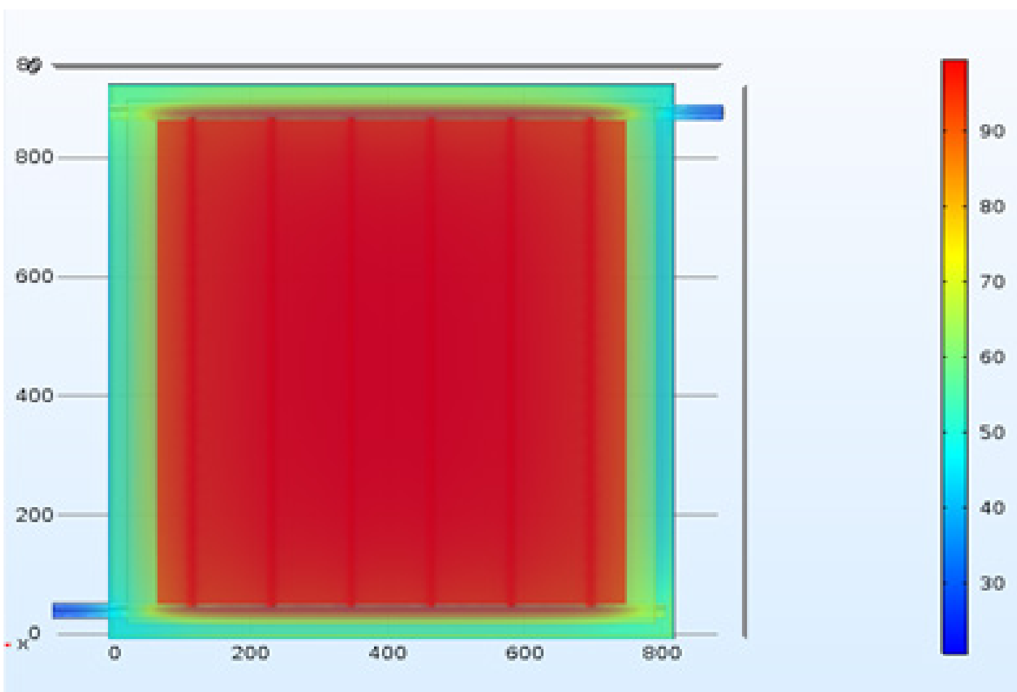

Figure 2. Temperature variation inside solar collector.

3.1 Water as Working Fluid

3.1.1 Effect of Change in Reduced Temperature with Efficiency for Water with Different Mass Flow Rates

Figure 3, shows the variation of efficiency with reduced temperature parameters $\frac{T_i - T_a}{G_T}$, for water as a working fluid with mass flow rates of 0.00255 kg/sec and 0.0029 kg/sec. The graph shows that the efficiency of flat plate solar collector increases with the increase in mass flow rate. Also efficiency decreases with the increase in reduced temperature at solar irradiation of 800 W/m^2.

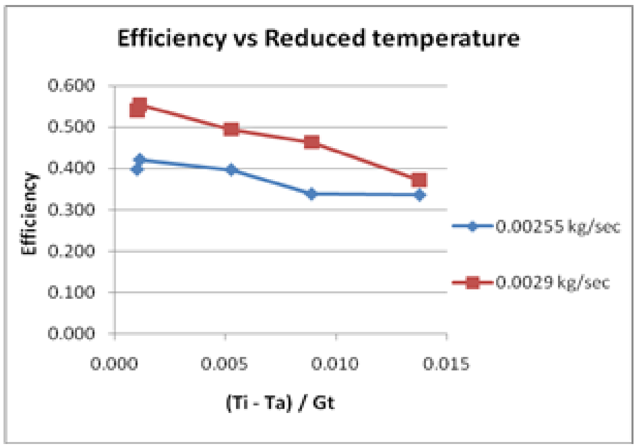

Figure 3. The efficiency of flat plate solar collector for water at different mass flow rates.

3.2 CuO-Water Nanofluid (0.1 vol% and 0.2 vol%) as Working Fluids

3.2.1 The Effect of Mass Flow Rate

Figure 4 and 5, shows the variation of efficiency with reduced temperature parameters $\frac{T_i - T_a}{G_T}$, for 0.1 vol% and 0.2 vol% CuO-water based nanofluids as working fluids with mass flow rates of 0.00255 kg/sec, 0.0029 kg/sec and 0.00323 kg/sec. The graph shows that the efficiency of flat plate solar collector increases with the increase in mass flow rate. Also efficiency decreases with the increase in reduced temperature at solar irradiation of 800 W/m^2.

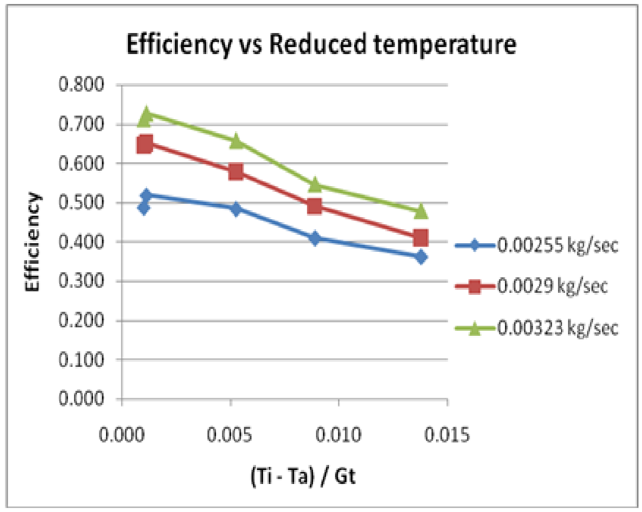

Figure 4. The efficiency of flat plate solar collector for 0.1 vol% CuO-water at different mass flow rates.

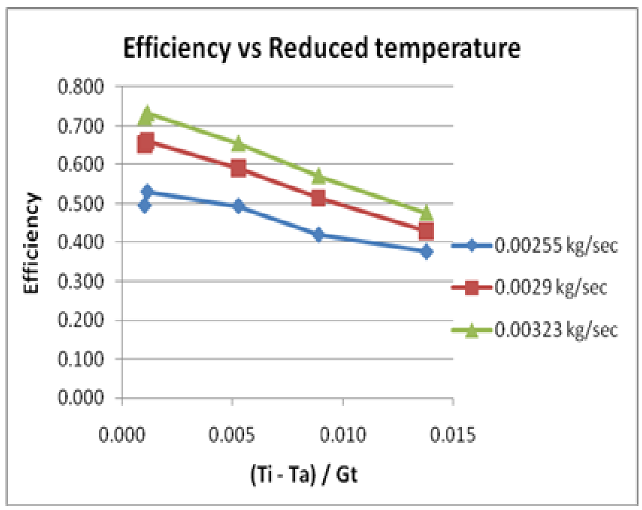

Figure 5. The efficiency of flat plate solar collector for 0.2 vol% CuO-water at different mass flow rates.

3.2.2 The Effect of Varying Nanofluids Concentration for Different Mass Flow Rates

Figure 6-8, shows the variation of efficiency with reduced temperature parameters $\frac{T_i - T_a}{G_T}$, for different concentrations of CuO-water based nanofluid with the mass flow

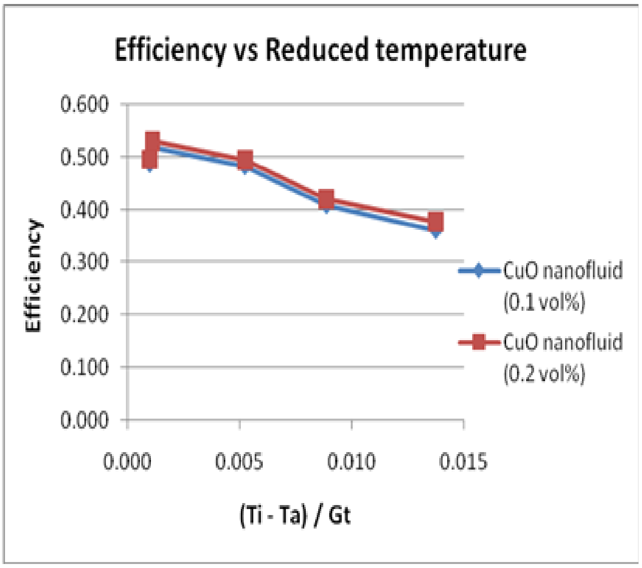

Figure 6. The efficiency of flat plate solar collector for CuO-water at 0.00255 kg/sec mass flow rate.

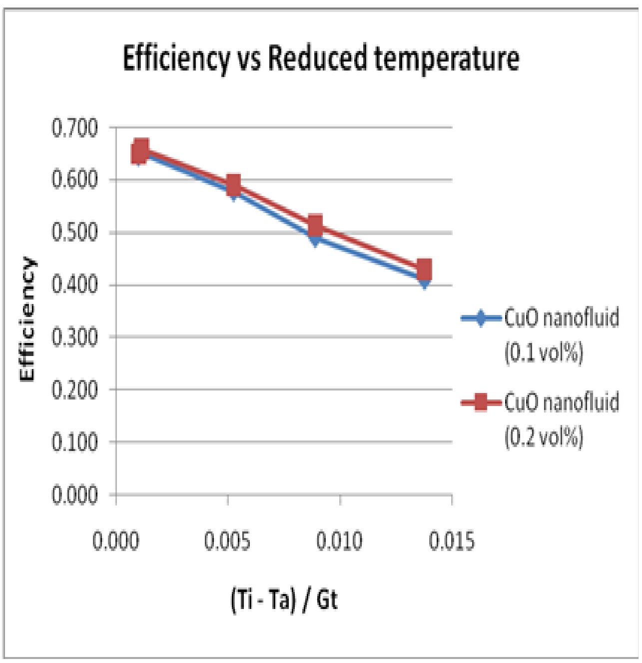

Figure 7. The efficiency of flat plate solar collector for CuO-water at 0.0029 kg/sec mass flow rate.

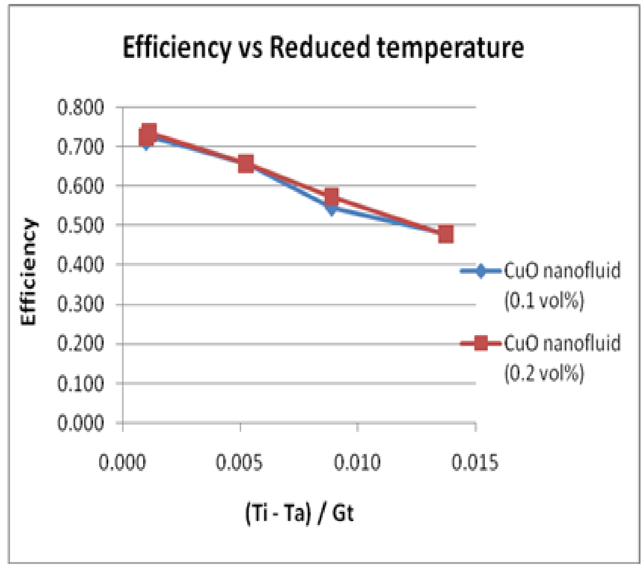

Figure 8. The efficiency of flat plate solar collector for CuO-water at 0.00323 kg/sec mass flow rate.

rates of 0.00255 kg/sec, 0.0029 kg/sec and 0.00323 kg/sec. The graph shows that the efficiency of flat plate solar collector increases with the increase in concentrations of CuO nanoparticles in the base fluid for higher values of reduced temperature. The efficiency for 0.2 vol% CuO in water is slightly more in comparison to 0.1 vol% CuO in water. Also the efficiency remains quite same for 0.1 vol% and 0.2 vol% concentrations of CuO nanofluids at lower values of reduced temperature.

3.3 Effect of Changing Working Fluids on the Performance of Solar Collector

3.3.1 Effect of Working Fluids for Different Mass Flow Rates

Figure 9 and 10, shows the variation of efficiency with reduced temperature parameters $\frac{T_i - T_a}{G_T}$, for different working fluids with the mass flow rate of 0.00255 kg/sec and 0.0029 kg/sec. The graph shows that the efficiency of flat plate solar collector is greater for CuO-water nanofluids in comparison with water as a fluid. Also the result

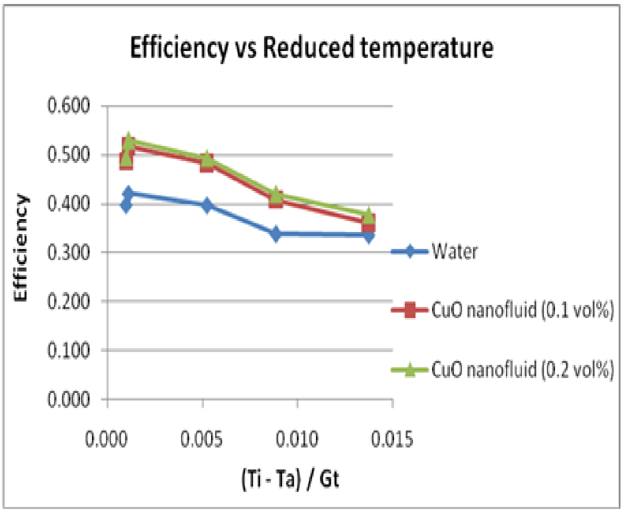

Figure 9. The efficiency of solar collector for CuO nanofluid and water at 0.00255 kg/sec mass flow rate.

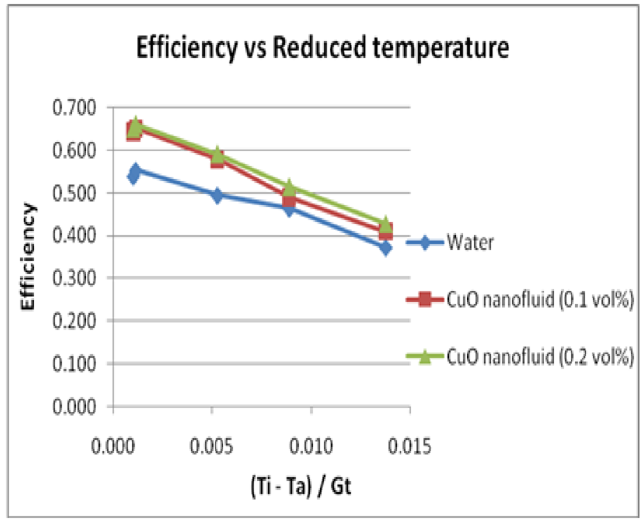

Figure 10. The efficiency of solar collector for CuO nanofluid and water at 0.0029 kg/sec mass flow rate.

shows that efficiency for 0.2 vol% CuO in water is slightly more in comparison to 0.1 vol% CuO in water at the same mass flow rate.

4. Conclusion

From the results obtained by carrying out computational analysis, following conclusions can be made:

1. The efficiency of solar collector increases with the use of nanofluids in comparison with water as nanofluids have better thermal properties.
2. The efficiency increases with the increase in mass flow rate for both water and nanofluids as working fluids.
3. The efficiency is found to be slightly higher when the volumetric concentration of nano particles in a base fluid is higher.
4. The maximum efficiency increase is found to be 25.9% with the use of nanofluids in comparison to water.
5. Also the temperature difference increases with the increase in mass flow rate.

5. Acknowledgement

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6. References

1. Yousefi T, Veisy F, Shojaeizadeh E, Zinadini S. An experimental investigation on the effect of MWCNT-H2O nanofluid on the efficiency of flat-plate solar collectors. Solar Energy. 2012 Feb, 86(2), pp. 771-779.
2. Said Z, Sabiha M A, Saidur R, Hepbasli A, Rahim N A, Mekhilef S, Ward T A. Performance enhancement of a Flat Plate Solar collector using Titanium dioxide nanofluid and Polyethylene Glycol dispersant. Journal of Cleaner Production. 2015 Jan, 92, pp. 343-353.
3. Shareef A S, Abbod M H, Kadhim S Q. Experimental investigation on a flat plate solar collector using Al2O3 Nanofluid as a heat transfer agent. International Journal of Energy and Environment. 2015, 6(4), pp.317-330.
4. Nasrin R, Alim M A. Thermal performance of nanofluid filled solar flat plate collector. International Journal of Heat and Technology. 2015, 33(2), pp.1-8.

5. Ranjithkumar K, Pradeep kumar S L, Jayaprakas L. Design and thermal analysis of solar plate collector with and without porous medium. International Journal of Innovative Research in Science, Engineering and Technology. 2015 Feb, 4(2), pp.1-11.
6. Kharad B N, Bhagat G P, Ghodke R M, Avhad A P. Heat Transfer Enhancement Using Nano Fluids – An Overview. International Journal of Innovative Research in Science, Engineering and Technology. 2014 Apr, 3(4), pp.629-641.
7 Hellstrom B, Adsten M, Nostell P, Karlsson B, Wackelgard E. The impact of optical and thermal properties on the performance of solar collectors. Renewable Energy. 2003 Mar, 28(3), pp.331–344.
8. Ion I V, Martins J G. Design, developing and testing of a solar air collector, The Annals of DUNAREA DE JOS. University of Galati FASCICLE IV Refrigerating Technique, Internal Combustion Engines, Boilers and Turbines. 2006, pp.1-4.
9. Ramadhani B, Minja R J A, Njau K N. Experimental analysis of air flow pattern in performance of flat plate solar collectors. African Journal of Agricultural Research. 2015 Feb, 10(6), pp. 524-533.