Experimental analysis of Thermal Performance of Solar Collector using CuO-H_2O Nanofluid

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Abstract: The peak performance of a solar collector with flat plate is increased by via Nano fluid which acts as a heat transfer layer. The thermal behaviour of solar collector while using nanofluids as heat transfer medium can be analysed using experimental or suitable numerical techniques. Experimental analysis is considered as prime important in the scientific society by providing opportunity to test theoretical hypothesis and physical statements of a problem. It gives average output values for the given input values of a system or process. In this work, experimental analysis of solar collector is performed using water and copper oxide-water (CuO-H2O) nanofluid as heat transfer medium with various concentrations of nanoparticle such as 0.1%, 0.2% and 0.3% mass fractions. Water and CuO nanofluid are circulated with 0.016kg/s and 0.033kg/s mass flow rate. The analysis done for this presentation claims the effectual property of CuO nanofluid containing various mass fractions of nanoparticle on collector outlet temperature, rate of heat transfer and efficiency is better than water. The pressure drop across the solar collector is more in CuO nanofluid due to its high density and viscosity.

Keywords: Solar flat plate collector, experimental analysis, CuO nanofluid, heat transfer, efficiency, pumping power.

I. INTRODUCTION

The sun is 1.39 x 10^9 metre diameter and 1.495 x 10^{11} metre away from the earth. Sun releases solar energy approximately in the range of 1350 W/m^2 to a perpendicular surface. Only 0.5% of energy emitted by sun is utilized for energy conversion out of 170 trillion KW [1]. Solar energy is converted into other forms such as heat energy or electrical energy using suitable devices. Heat energy is mostly used for drying food grains and fruits. Due to variation of energy potential, separate energy storage units are required to fulfil constant energy requirements [2]. Solar collector is a device used to convert the Sun's direct heat energy which is the solar energy into thermal force. Solar collector is an important component in solar-thermal power installations [3]. The appropriate performance level of solar collector is enhanced by implementing fluids having high thermal conductivity as heat transfer medium. Nanofluid consists of nano sized particles (1-100nm) mixed with water or some other fluids. Hence, it is called as new generation fluid. The properties of nanofluid depend on the characteristic features exhibited by each and every nano particle and its corresponding base fluid. The applications of nanofluids not only limited to thermal related applications. It also extended to chemistry, coating, tribology, environmental, surfactants and biomedical applications [4]. The nanofluid imparted solar collectors have been probed in the perspective of efficiency or environmental and economic considerations [5,6]. Tyagi et al.[7] explored the performance status and stages of solar collector (direct absorption) with the help aluminium-water based nanofluids by gradually varying the nanoparticle volume ratio from 0.1% to 0.5%. Based on the outcome under each ratio the collector efficiency is evaluated with Eqn. 1

$$\eta = \frac{Useful\ heat\ gain}{Available\ energy} = \frac{mC_p \Delta T}{AG_T} = \frac{mC_p (T_o - T_i)}{AG_T} \quad \textbf{(1)}$$

The experiment is carried out at constant solar flux of 1000W/m^2, nanofluid passing into the collector at a stable temperature of 35^{O}C, mass flow proportion of 1.2 kg/s. From the observation, the effectual efficiency of collector increases while using less nanoparticle concentration in terms of volume fraction. When nanoparticle volumetric fractional value is much higher than 2%, the effectual performance of the collector becomes constant and uneconomical. Also they stated that the efficiency slightly increases as nanoparticle size increases. Otanicar et al [8] analyzed the effectual status of carbon induced nanotubes silver and graphite on solar collector (direct absorption) experimentally and numerically. The efficiency also enhances up to 0.5% volume fraction. Beyond 0.5% volume fraction, the efficiency becomes constant and declines as the volume fraction of nanoparticle increases. The drop in efficiency is due to high absorption of fluid when nanoparticle concentration elevates. The effect of size of nanoparticle on efficiency is also investigated and shown in figure 1. A 6% increase of collector efficiency is obtained while decreasing nanoparticles size from 40nm to 20nm. Unlike stated by Tyagi et al, the efficiency increases as the nanoparticle size decreases.

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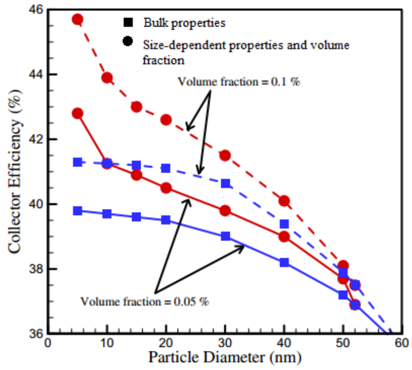

Figure 1 Effect of nanoparticle size on collector efficiency [8]

Yousefi et al. [9] observed the pH variation in water based multi walled carbon nanotubes nanofluid on solar collector efficiency. The p^H values such as 3.5, 6.5 and 9.5 is maintained with nanoparticle concentration as 0.2 wt%. Triton X-100 is the surfactant. They introduced pH of isoelectric point and stated that the dissimilarity between pH value and pH of isoelectric point increases the collector efficiency. Link et al [10] explained the optical properties of gold nanoparticles and analysed the effect of shape and size on radiative and photo thermal properties of gold nanoparticles. Khlebtsov et al [11] experimented the optical properties of the nanofluids due to size, structure and shape of silver and gold nanoparticles. The shape as well as size of the nanoparticle greatly influences the optical properties of nanofluids. In the current work, initially water is used as heat transfer medium to analyse the thermal performance of solar collector. Then CuO nanofluid is used as heat transfer medium with 0.1%, 0.2% and 0.3% mass fraction of nanoparticle. Both water and nanofluid is circulated with 0.016kg/s and 0.033kg/s mass flow rates.

II. EXPERIMENTAL SETUP

Figure 2 Experimental setup of solar collector

The experimental setuo of the solar collector is shown in figure 2. Solar collector is the rectangular box of 2m length, 1m width and 0.1m thickness. The solar collector consist of single toughened glass cover, corrugated copper plate brazed with riser tubes The sides and bottom of the collector is insulated using glass wool. The fluid is pumped using centrifugal pump from fluid tank to solar collector. The fluid enters the bottom of the collector through header pipe. The fluid rises from the bottom header pipe to the top header pipe through nine riser tubes of 12.5mm diameter. The hot fluid coming out from the collector is passed to the heat exchanger and again it is circulated to the collector through fluid tank. The hot fluid coming out from the solar collector is passed through the heat exchanger. The design of heat exchanger is made to reduce the temperature of fluid upto 25^{O}C. Furthermore, if the temperature is more than 25^{O}C, the fluid will be passed through ice sump to reduce excess heat thereby inlet fluid flow temperature to the solar collector is maintained as constant. The experimental setup is shown in figure 3.

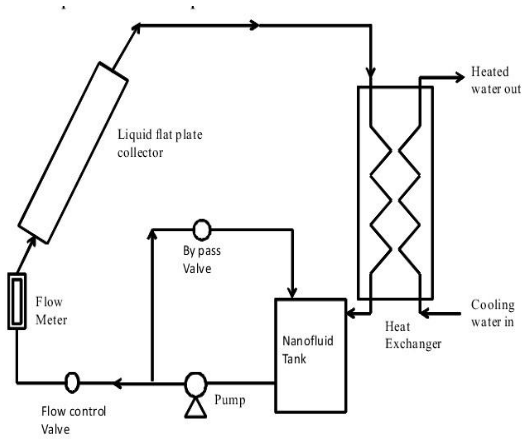

Figure 3 Flow diagram of the experimental setup

III. CHARACTERIZATION AND PREPARATION OF NANOFLUID

The CuO nanoparticles are produced by physical vapour synthesis method. The elemental analysis of CuO nanoparticle is measured by using Energy–Dispersive X–ray Spectroscopy (EDS). Each elements present in the nanoparticle have the capacity of emiting electromagnetic spectrum due to its unique atomic structure when exposed to X-ray radiation. Based on the electromagnetic emission spectrum, the chemical composition of the CuO sample is measured. The figure 4 shows the EDS analysis of CuO nanoparticle sample. The presence of gold in the CuO nanoparticle is not the part of CuO nanoparticle and it is due to coating of nanoparticles with gold for the feasibility of EDS analysis.

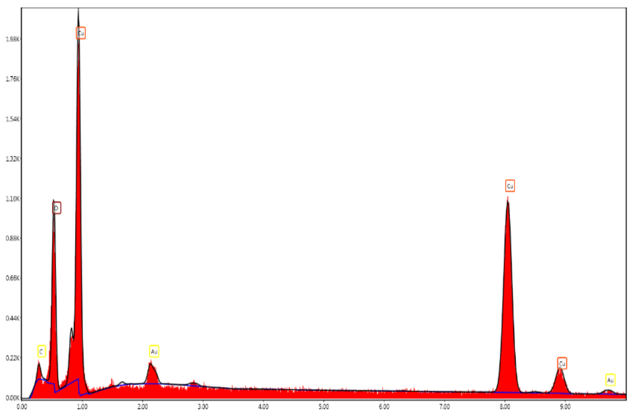

Figure 4 Energy–Dispersive X–ray Spectroscopy image of CuO nanoparticles

The nanoparticle sample is tested using Scanning Electron Microscope (SEM). The size of the nano particlulates can be measured using SEM analysis. In this analysis, the sample is placed underneath of the electron beam and scanned to create image of the particle. The electron beam interacts with nanoparticles and signals are produced. The obtained signals are processed to measure the size of the nanoparticle. The SEM analysis of CuO nanoparticle is shown in figure 5 and the nanoparticles are within the size range of 20 - 40 nanometer.

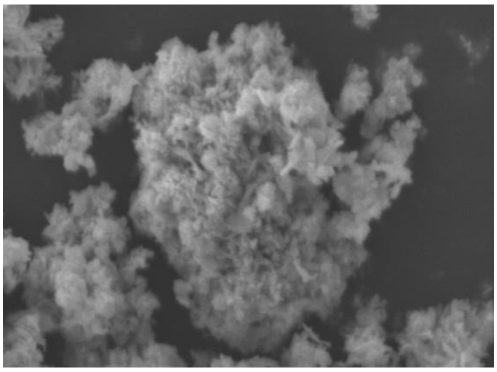

Figure 5 SEM image of CuO nanoparticles

S K Das and his co researchers [12] explained the preparation of nanofluid with proper suspension of nanoparticles in the base fluid as follows

$$\%\ \text{Mass fraction} = \frac{\text{Mass of the nanoparticle}}{\text{Mass of the basefluid}} \quad \textbf{(2)}$$

$$\%\ \text{Volume fraction} = \frac{\dfrac{\text{Weight of the nanoparticle}}{\text{Density of the nanoparticle}}}{\dfrac{\text{Weight of the nanoparticle}}{\text{Density of the nanoparticle}} + \dfrac{\text{Weight of the basefluid}}{\text{Density of the basefluid}}} \quad \textbf{(3)}$$

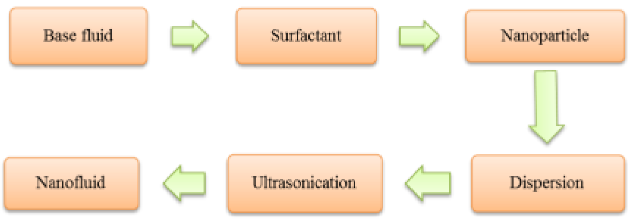

Figure 6 Preparation of nanofluid

Figure 6 shows the process steps of preparation of nanofluid. The surfactant is mixed with base fluid first and then nanoparticles are thoroughly mixed with existing mixture. Triton X-100 of 0.02wt% acts as a surfactant. Pure Distilled water is used as basal fluid and the surfactant and nanoparticle is mixed with base fluid to obtain complete dispersion. This dispersion is kept in ultrasonicator for 45 minutes to obtain the homogeneous suspension.

IV. DATA REDUCTION

The properties that influence the nature of nanofluids namely Viscosity, thermal conductivity, density and specific heat can be calculated as follows [14-18]:

$$\rho_{nf} = \rho_{np}(\varphi) + \rho_{bf}(1-\varphi) \quad \textbf{(4)}$$

$$\mu_{nf} = \frac{\mu_{bf}}{(1-\varphi)^{2.5}} \quad \textbf{(5)}$$

$$\frac{k_{nf}}{k_{bf}} = \frac{k_{np} + 2k_{bf} + 2(k_{np} - k_{bf})\varphi}{k_{np} + 2k_{bf} + (k_{np} - k_{bf})\varphi} \quad \textbf{(6)}$$

$$C_{p,nf} = C_{p,np}(\varphi) + C_{p,bf}(1-\varphi) \quad \textbf{(7)}$$

Where, ρ is the density, μ denotes viscosity, k denotes the constant of thermal conductivity, C denotes specific heat and subscripts bf, np and nf denotes type of the basal fluid, nanoparticles and nanofluids . Here φ is the volumetric concentration of the nanofluid. Table 1 lists the thermal and physical properties of basal fluid and nanoparticulates

Table 1 Properties of base fluid and nanoparticle

S.No	Properties	Thermal Conductivity (W/mk)	Density(kg/m^2)	Specific heat, J/kgK
1.	Water	0.613	997.13	4180
2.	Al_2O_3	39	3970	775
3.	CuO	18	6510	540
4.	Au	314	19320	129

The Reynolds number and velocity of the flow is calculated as follows.

$$\text{Reynolds number, } R_e = \frac{4m}{\pi D \mu} \quad \textbf{(8)}$$

$$R_e = \frac{\rho V D}{\mu} \quad \textbf{(9)}$$

Heat transfer rate and efficiency of the collector are calculated by

Heat transfer rate, $Q = mCp(T_o - T_i)$ (10)

Collector efficiency, $\eta = Q_u/(A_c G_T)$ (11)

The pumping power is calculated as [19],

$$\text{Pumping power} = \left(\frac{m}{\rho_{nf}}\right)\Delta p \quad (12)$$

Where, D is diameter , m is mass flow proportion, T_i and T_o is outlet and inlet temperature of nanofluid, C_p is a constant denoted as the specific heat capacity, G_T is assumed as the solar flux incident on the collector inclined exterior circumferential area and A_c being the area of collector.

V. EXPERIMENTAL ANALYSIS OF SOLAR FLAT PLATE COLLECTOR USING CUO NANOFLUID

The CuO-H_2O Nanofluid is prepared with the nanoparticle concentration of 0%, 0.1%, 0.2% and 0.3% mass fraction.

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The 0% nanoparticle concentration represents distilled water. The properties of CuO-H_2O nanofluid containing 0.1%, 0.2% and 0.3% mass fraction of nanoparticle is given in table 2. The water and nanofluid is circulated at 0.016kg/s and 0.033kg/s. The changes dealt in CuO-H_2O nanofluid on solar collector is studied experimentally. Initially, water is used as heat transfer medium and then CuO nanofluid containing 0.1%, 0.2% and 0.3% mass fraction of nanoparticle is tested using solar collector.

Table 2 Properties of CuO-H2O nanofluid against various mass fractions of nanoparticle

Nanoparticle concentration	Density	Viscosity	Thermal conductivity	Specific heat
	kg/m3	Ns/m2	W/mK	J/kgK
Water (0%)	997.13	0.00089	0.613	4180
CuO - 0.1%	1548.4	0.00111	0.795	3816
CuO - 0.2%	2099.7	0.00133	1.019	3452
CuO - 0.3%	2650.9	0.00156	1.297	3088

VI. RESULT AND DISCUSSION

The experimentally observed outlet temperature and pressure level status and calculated heat thermal rate, collector efficiency and pumping power is given in table 3. The impact of CuO nanofluid with 0%, 0.1%, 0.2%, and 0.3% mass fraction of nanoparticle on temperature measured at outlet of the solar collector in figure 7. As the mass fraction of nanoparticle increases the outlet temperature of the collector also increases. Because, addition of nanoparticle increases the nanofluid thermal conductivity. It helps to absorb more heat energy thereby the outlet temperature of the nanofluid increases. Lower mass flow rate fetches maximum temperature since the nanofluid has enough retention time within the collector. When the mass is increased the retention time decreases which reduces the heat energy absorption. The percentage of increase of outside temperature by 0.3% of proportion by volume for CuO nanofluid is 30.9% and 15.57% at 0.016kg/s and 0.033kg/s respectively when paralleled with water.

Table 3 Effect of CuO-H2O nanofluid on solar flat plate collector

Nanoparticle Concentration	Mass flow rate (kg/s)	Outlet Temperature (OC)	Heat transfer rate (W/m2)	Collector Efficiency (%)	Pressure Drop (pa)	Pumping Power (W)
0%	0.016	36.9	795.87	37.39	3328.10	0.053
0.1%		41.58	1012.31	47.56	5508.04	0.057
0.2%		45.8	1148.83	53.97	7368.30	0.056
0.3%		48.31	1151.70	54.11	9228.68	0.056
0%	0.033	32.1	979.37	46.01	3552.85	0.118
0.1%		34.2	1158.54	54.43	5741.03	0.122
0.2%		35.6	1207.51	56.73	7650.46	0.120
0.3%		37.1	1233.04	57.93	9620.81	0.120

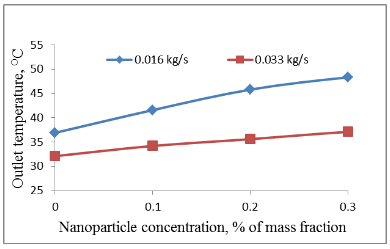

Figure 7 Effect of nanoparticle concentration on outlet temperature

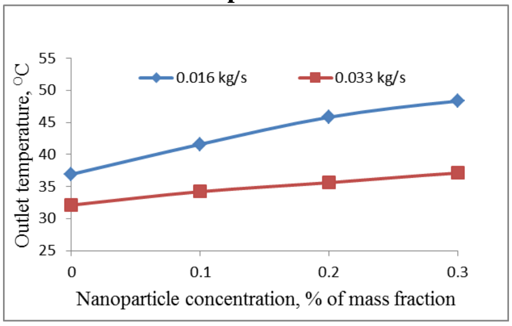

Figure 8 Effect of nanoparticle concentration on heat transfer rate

From the results of figure 8, the rate at which heat transfer occurs at an elevated rate as the nanoparticle concentration increases with elevation of nanoparticle composition increase beyond 0.2% mass fraction, the increase in percentage of heat transfer rate decreases. It is necessary to find out the optimum value of nanoparticle concentration to enhance the heat transfer rate.

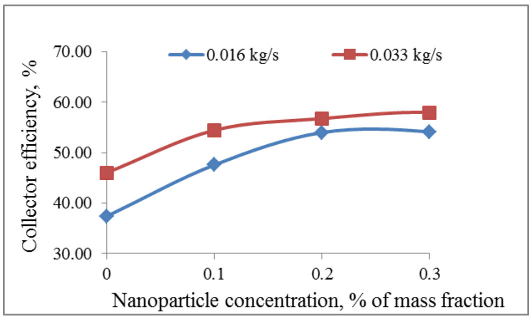

Figure 9 Effect of nanoparticle concentration on efficiency of the collector

The efficiency of the solar collector with respect to nanoparticle concentration is shown in figure 9. There is an increase in efficiency as the nanoparticle increases and for a proportional mass flow rate increase. The nanoparticle composition increases from 0.2% to 0.3%, while collector efficiency also upsurges as an outcome of decrease in elevated density and viscosity of nanofluid and due to high fluid absorption at higher concentration of nanoparticle.

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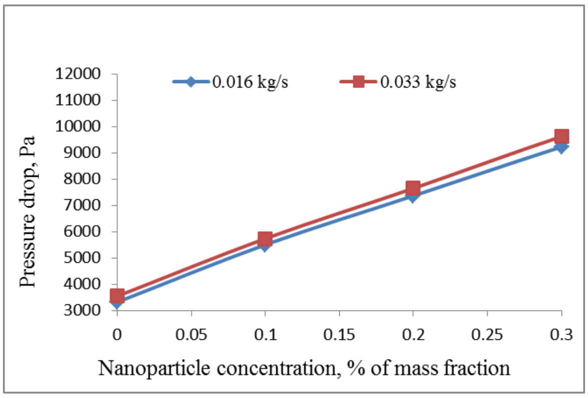

Figure 10 Effect of nanoparticle concentration on Pressure drop

The resistance offered to flow by the fluid within the flow path is prime importance to improve the heat transfer characteristics because the pumping cost should not pull down the benefit of enhanced heat transfer. The figure 10 shows the pressure drop variations. It is noted that the pressure drop upsurges as the nanoparticle concentration upsurges due to the higher concentration of nanoparticle. The pressure drop is mainly influenced by nanoparticle concentration and the impact of mass flow ratio on pressure declinination is less.

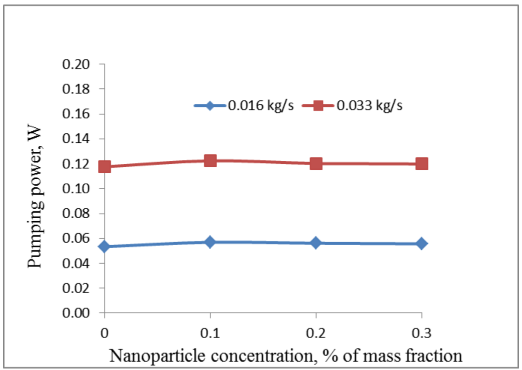

Figure 11 Effect of Nanoparticle Concentration on Pumping Power

In forced circulation, it is necessary to find the pumping power requirement to maintain required mass flow proportions. The figure 11 shows the pumping power of the collector. The pumping power is in direct proportion with pressure drop and indirect proportion with density. The density of the nanofluid increases as the nanoparticle concentration increases. Hence, pumping power is constant even the nanoparticle concentration increases. But the pumping power increases as the mass flow rate increases due to increasing of fluid load as mass flow rate (MFR) increases and in turn more power is required to drive the pump.

VII. CONCLUSION

The ultimate outcome of a solar collector with flat plate model using CuO-H_2O and water as nanofluid with 0.1%, 0.2% as well as 0.3% proportions of nanoparticle is tested experimentally. The heat transfer medium is distributed across through collector using forced circulation with the mass flow proportion of 0.016kg/s and 0.033kg/s. Maximum outlet temperature is obtained with 0.3% nanoparticle concentration at 0.016kg/s. The percentage of increase of outlet temperature with 0.3% volume fraction for CuO nanofluid is 30.9% and 15.57% against 0.016 and 0.033kg/s respectively when associated with water. The transfer rate of the energy in the form of heat increases when the nanoparticle increases in concentration. At the same time, increase in percentage of the above heat transfer rate diminutions as the nanoparticle mass fraction beyond 0.2%. But the heat transfer rate is indirectly proportionate to mass flow rate. The collector efficiency is directly proportional to mass fraction of nanoparticle and mass flow proportion rate. There is also a significant pressure drop across the collector which is mainly influenced by nanoparticle concentration and simultaneously the mass flow rate on pressure drop is less. The pumping power requirement is constant even the nanoparticle concentration increases. The effect of CuO nanofluid on the performance of the designed model collector is better than water. The experimental analysis can be conducted with higher mass fraction/volumetric fraction of the nano particulates to optimize the collector's ultimate efficiency, temperature, heat transfer rate, pressure drop and pumping power. Suitable numerical technique can also be developed to substatiate the heat transfer proportions and its characteristics of the collector using different nanofluids.

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