

# ***EXPERIMENTAL INVESTIGATION AND MATHEMATICAL STUDY OF PERFORMANCE CHARACTERISTICS OF SOLAR FLAT PLATE COLLECTOR USING $Al_2O_3$ / WATER NANO FLUID***

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*Abstract*— Effective utilization of solar energy is a major challenge faced by the society today. Solar energy is abundant source of renewable energy which is available without environmental impact. Due importance is being given by present researchers for efficient utilization of solar energy using nano fluids. Nano sized metal powders are mixed with base fluids since metals having higher thermal conductivity than fluids. In this research  $Al_2O_3$ /water nano fluid have been used as working fluid to measure the performance and efficiency of the solar flat-plate collector. Experimental investigation and mathematical study was made to compare the results. The volume fraction of the nanoparticle varies from 0.01% to 0.04% and mass flow rate varies from 0.025kg/sec to 0.034 kg/sec. It is observed that the maximum efficiency of the system was found as 78.5% for 0.04% particle concentration.

*Keywords*—Nano fluid, Solar flat plate collector, Collector efficiency, Thermal conductivity.

## **Introduction**

The transfer of heat from one medium to other or one place to other is an important requirement in many applications. Now a days it is

struggling to increasing the efficiency of the heat transfer medium due to poor thermal conductivity of base fluids such as water, glycol, oil etc. Now a days conventional fluids are replaced by nano fluids to improve thermal conductivity and enhance other heat transfer characteristics. Maxwell [1] observed that thermal conductivity of nano fluids increased by increasing the solid particle concentration in base fluids. But solid particle of millimeter and micrometer dimensions were used to enhance heat transfer characteristics. In later researches it is observed that using of micro sized particles increase the pressure loss in the pipe lines, clogging in flow path and sedimentation of solid particles. Due to the development of nano technology a new mixture was developed called nano fluid [2]. The developed nano fluid consists of nano sized solid particle uniformly mixed with base fluids to form colloidal mixture. Due to high thermal conductivity of solid particles mixed with base fluids the heat transfer

characteristics has been improved substantially. The study of performance characteristics of various nano fluids with different volume concentration was made by several authors and all finding shows improved thermal conductivity of nano fluid than base fluids. Masuda et al. [3] found that Al<sub>2</sub>O<sub>3</sub>/water nano fluid having 13nm sized Al<sub>2</sub>O<sub>3</sub> particles of 4.3% volume fraction increase the thermal conductivity by 30% when compared with water. Xuan et al. [4][5] have identified some of the concepts behind the enhancement of heat transfer by nano fluids: the increased thermal dispersion due to chaotic movement of nano particles which accelerates energy exchanges in the fluid thereby thermal conductivity of the nano fluid is increased. At the same time Keblinski et al. [6] explains the mechanism of heat transfer in nano fluids due to Brownian motion of the nano particles, nano particles clustering, ballistic heat transfer in the nano particles and layering of the liquid/particle interace at molecular level which tends to enhance the heat transfer characteristics.

Many researchers attempted to study the hydrodynamic and thermal behaviors of various nano fluids numerically and experimentally at different geometrical parameters and also at different flow conditions. B.C.Pak et al. [7] and Y.M.Xuan et al. [8] experimented convective heat transfer under laminar and turbulent flow when flow takes flow inside a tube. They developed empirical correlations for the Nusselt number using different nano fluids. M.Izadi et al [9] numerically studied laminar forced convection of Al<sub>2</sub>O<sub>3</sub>/water nano fluid. They investigated thermal and hydrodynamic behaviors of fluid flow throughout an annulus by solving two dimensional elliptical governing equations. They shown that the dimensionless axial velocity profile does not significantly change with nano particle concentration but the temperature profiles are affected by the nano particle concentration and also convective heat transfer coefficient increases with nano particle concentration. Ali Jabari Moghadam et al. [10] experimentally investigated the performance solar flat-plate collector using CuO-water nano fluid with 0.4% volume fraction and 40nm particle size. The experimental results proved

that collector efficiency improved by 21.8% at the mass flow rate of 1 kg/min when compared with water as fluid medium. Grimm [11] used aluminum nano particles of 1-80 nm size mixed with base fluid which gives 100% increase in the thermal conductivity of fluid for 0.5-10wt%. Yosefi et al. [12] tested the effect of MWCNT in solar flat-plate collector and shows 35% enhancement in collector efficiency for 0.4 wt%. BAA Yousef and NM Adam [13] made theoretical study to investigate the effect of mass flow rate, flow channel depth and collector length on the system performance and pressure drop with and without porous medium in solar flat-plate collector. The result shows 10-20% increase in thermal efficiency in double flow than single flow and 8% increase in thermal efficiency after using porous medium. Karim M.A and Hawlader M.N.A[14] reported that the V-corrugated is the most efficient collector than the flat plate and finned type collectors.

Pak and Cho [7] has calculated the properties of nano fluid as follows:

Thermal conductivity is calculated by,

$$\frac{k_{nf}}{k_w} = (0.9692\phi + 0.9508)$$

Density of the nano fluid,  $\rho_{nf} = \phi\rho_p + (1-\phi)\rho_w$

Dynamic viscosity,  $\mu_{nf} = (1 + 2.5\phi)\mu_w$

Specific heat of the nano fluid is given by,

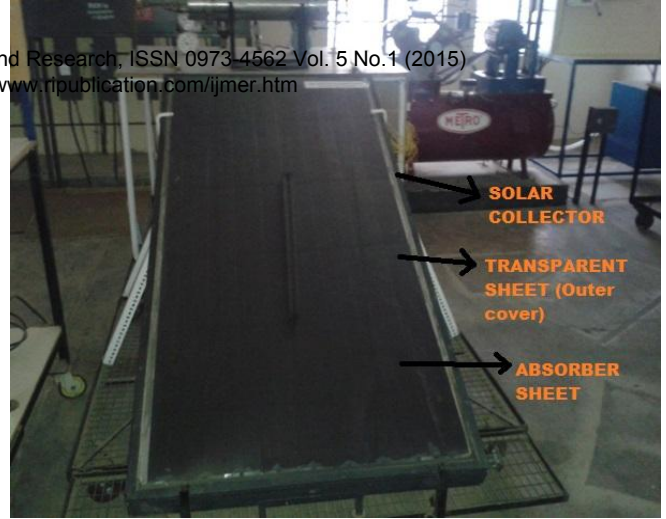
$$(\rho c_p)_{nf} = \phi(\rho c_p)_p + (1-\phi)(\rho c_p)_w$$

Where,

$\rho_{nf}$  is the density of the fluid,  $\rho_p$  is the density of the nanoparticles,  $\rho_w$  is the density of water,  $\mu$  represents viscosity,  $k$  stands for thermal conductivity,  $c_p$  represents specific heat and subscripts w and p are the properties of water and nanoparticles. Here  $\phi$  is the volume concentration of the nanofluid.

## EXPERIMENTAL SETUP

The schematic diagram of the test facility is a closed loop consisting of a flat plate collector, liquid pump, heat exchanger and storage tank is shown in figure 1. A Bypass valve is provided around the pump so that the mass flow rate can be adjusted to the prescribed value. The flow rate can be measured with the help of rotometer. The



combination of a heat exchanger and a storage tank enables to adjust the fluid inlet temperature. A set of k-type thermocouples with +/- 0.1% accuracy are attached at inlet and outlet of the collector. A pyrometer with a digital micro-voltmeter is used to determine the incident radiation on the flat plate collector.

**Specification**

- Occupied Area – 260 cm x 190 cm x 15 cm
- Absorber Area- 240 cm x 180 cm
- Header Pipe (Cu) - Φ2.54 cm
- Connector riser Pipe(Cu) - Φ1.25 cm
- Number of tubes - 9
- Absorber Sheet(Cu)

Figure 1 Solar flat-plate collector

The data is recorded under steady state condition for fixed values of mass flow rate and fluid inlet temperature. The collector is considered to be operating under steady state conditions.

**MATHEMATICAL FORMULATION**

The following polynomial equations have been framed from experimental data using mathematical modeling to predict the outlet temperature of the nano fluid.

**Water Stream**

$$T_o = (-101.6 + 0.288 S - 0.00016S^2) + (3.80 - 0.0076 S + 4.5 \times 10^{-6} S^2) t_i + (-0.022 + 5.85 \times 10^{-5} S - 3.46 \times 10^{-8} S^2) t_i^2$$

**Nanofluid 0.01% of Volume Concentration**

$$T_o = (8.4 + 0.043S - 1 \times 10^{-5} S^2) + (0.34 - 0.0033 S - 2 \times 10^{-6} S^2) t_i + (0.004 - 1 \times 10^{-5} S + 6 \times 10^{-9} S^2) t_i^2$$

**Nano fluid 0.03% of Volume Concentration**

$$T_o = (27.6 - 0.055S + 6 \times 10^{-5} S^2) + (1.19 + 0.057 S - 4 \times 10^{-6} S^2) t_i + (0.0072 - 2 \times 10^{-5} S + 1 \times 10^{-8} S^2) t_i^2$$

**Nano fluid 0.04% of Volume Concentration**

$$T_o = (37.2 - 0.062S + 5 \times 10^{-5} S^2) + (1.8 + 0.069 S - 4 \times 10^{-6} S^2) t_i + (0.0192 - 5 \times 10^{-5} S + 3 \times 10^{-8} S^2) t_i^2$$

Experiment was carried with water and nano fluid with 0.01%, 0.03 and 0.04% volume concentrations.

**RESULT AND DISCUSSION**

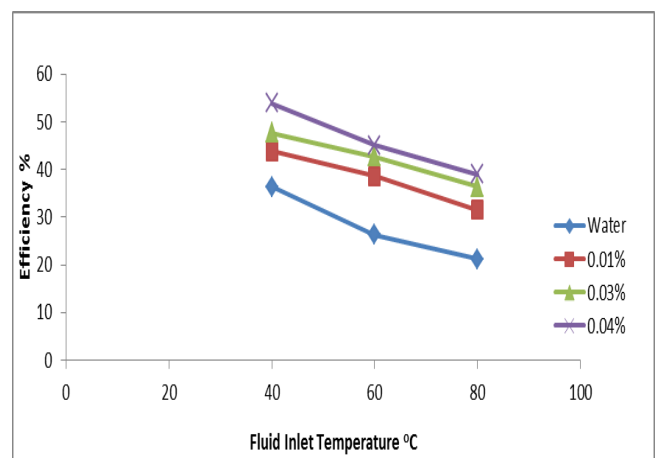


Figure 2 Variation of efficiency of a collector with fluid inlet temperature at mass flow rate 0.025 Kg /sec

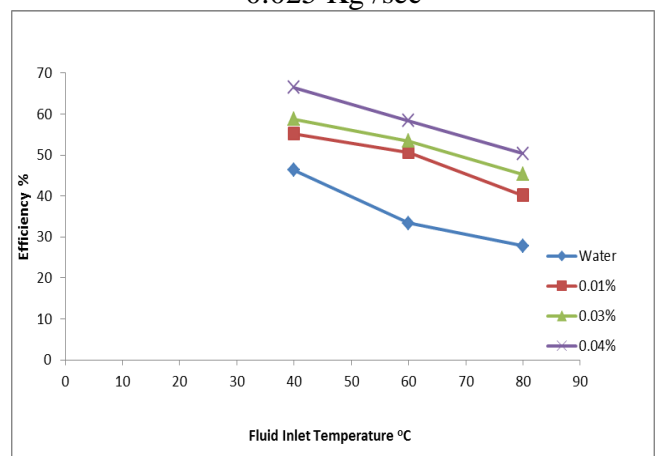


Figure 3 Variation of efficiency of a collector with fluid inlet temperature at mass flow rate 0.0306 Kg /sec

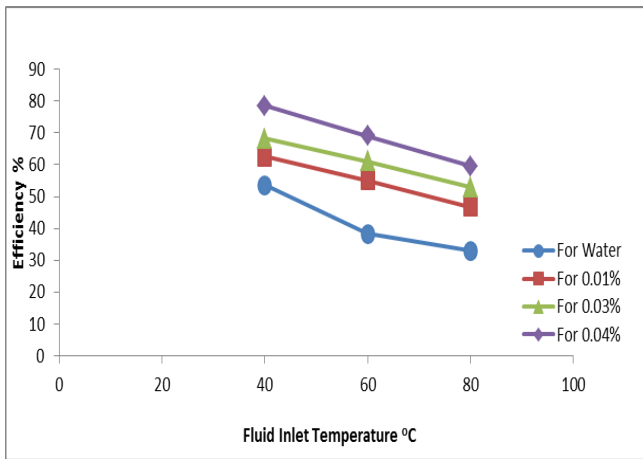


Figure 4 Variation of efficiency of a collector with fluid inlet temperature at mass flow rate 0.034 Kg /sec

The various mass flow rate such as 0.025 Kg /sec, 0.0306 Kg /sec and 0.034 Kg/sec has been maintained with each particle concentration to test the system performance characteristics.

The fluid inlet temperature is an operational parameter which strongly influences the performance of a flat plate collector. Results are obtained with fluid inlet temperature varying from 40°C to 80°C at mass flow rate of 0.025 Kg /sec, 0.0306 Kg /sec and 0.034 Kg/sec. Figure 2 shows the variation of efficiency of the collector with various fluid inlet temperature at 0.025 Kg /sec mass flow rate. The nano fluid with mass flow rate of 0.025 Kg/sec and at the inlet temperature of 40°C increases the collector efficiency by 45% when compared with water.

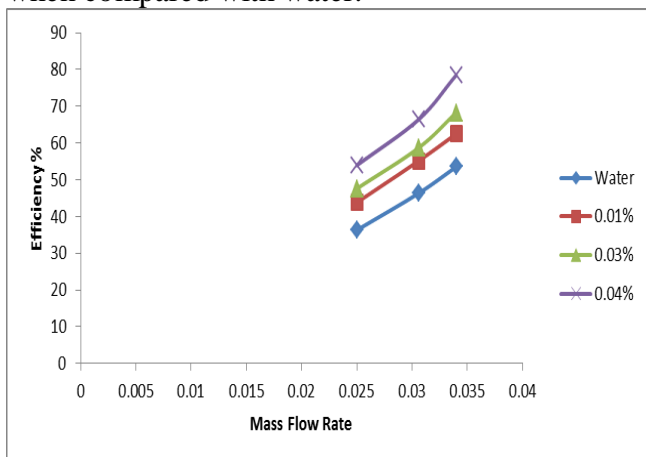


Figure 5 Effect of various fluid mass flow rate on the collector efficiency at inlet temperature of 40°C

Figure 3 the efficiency of the collector at the mass flow rate of 0.0306. The nano fluid with mass flow rate of 0.0306 Kg/sec and at the inlet temperature of 40°C increases the collector efficiency by 43.5% when compared with water. The efficiency of the collector decreases more or less linearly with increasing the value of  $T_{fi}$ .

Figure 4 shows the efficiency of the collector at the mass flow rate of 0.034. The efficiency value falling from 53.54% to 32.95% for water and from 78.5% to 67.5% as  $T_{fi}$  increases from 40°C to 80°C. The decrease in efficiency because of the higher temperature level at which the collector as a whole operates when the fluid inlet temperature increases. Because of this the top loss coefficient as well as temperature difference with the surroundings increases, the heat loss increases and the useful heat gain decreases.

The increase of collector efficiency at 40°C inlet temperature for various mass flow rate is shown in figure 5. This result can be ensured as  $Q_u = (m \cdot c_p \cdot (T_{fo} - T_{fi}))$  thus, the useful solar energy is directly proportional to the mass flow rate of the nano fluid. The efficiency increases by 8.96% at a nano particle concentration of 0.01% and by 24.96% at a nano particle concentration of 0.04% at mass flow rate of 0.034 Kg/sec.

## CONCLUSION

The performance characteristics of a solar flat plate collector operated with  $Al_2O_3$ / water nano fluid was experimentally investigated and the effect of the nano fluid on the efficiency of the collector is compared with that of water. The efficiency of the flat plate collector is found to increase with increasing the particle concentration and flow rate. The maximum efficiency of the system is found as 78.5% for 0.04% particle concentration. The primary reason for increased the efficiency is due to the enhanced thermal conductivity of the suspended particle. Also the outlet temperature of the nano fluid for different particle concentration have been obtained by using polynomial equation.

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