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Performance of a FlatPlate Collectors Using Al2O3/Water Nanofluid

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Abstract:- **Theoretical analysis of flatplate collector using Al2O3/ water nanofluid has been carried out withvariable partial size(0.5% to 2.0%) and flow rates (0.5 to 2 litre/min). It has been observed thatefficiency increases with the use nanofluids in comparison with the use of water.It has been estimated that at1.5% particle volume fraction, the efficiency increases by 31.6% in comparison to that of water as working fluid.**

Keywords:-- **Flat Plate Collector, Heat transfer, Nanofluid, Performance**

I. INTRODUCTION

Currently, power generation from fossil fuels such as oil or coal is damaging our environment. Therefore, we need to shift from non-renewable energy sources to alternative renewable energy sources. One of the most promising renewable energies available is solar energy since it is freely available in abundant and ecofriendly. It is estimated that one hour of solar energy received by the earth is equal to the total amount of energy consumed by humans in one year [1]. Many research works have been reported in the literature on harvesting energy from solar. Generally, there are two ways of harvesting solar energy
(i)solar–electric conversion using photovoltaic solar cell
(ii) solar–thermal conversion

Solar–thermal systems has attracted many investigators, however major shortcoming of the solar collectors is their low thermal efficiency. Solar energy is widely used in applications such as electricity generation, chemical processing, and thermal heating due to its renewable and nonpolluting nature. Most solar water heating systems have two main parts: a solar collector and a storage tank. The most common collector is called a flatplate collector but these suffer from relatively low efficiency. Traditional working fluids (water- or oil-based fluids) have low heat absorption and heat transfer capacity. Heat transfer enhancement in solar devices is one of the key issues of energy saving and compact designs. There are so many methods introduced to increase the efficiency of the solar water heater [2-5]. Cheng et al. [6] discussed the need to improve the thermophysical properties of working fluids used in solar energy and high temperatures. Nanofluid, an advanced kind of fluid containing small quantity of nanoparticles (usually less than 100 nm), was introduced by Choi [7] and it has been proven to provide efficient heat transfer compared to conventional fluids. The dispersion of a small amount of solid nanoparticles in conventional fluids such as water or ethylene glycol changes their thermal conductivity remarkably.

During the past decades, the technology to make particles in nanometer dimensions has been improved and a new kind of solid–liquid mixture, which is called a nanofluid, has appeared. Nanofluids are an advanced kind of fluid containing a small quantity of nanoparticles (usually less than 100 nm) that are uniformly and stably suspended in the liquid. Lee et al. [8] reported increase in thermal conductivity by 1.44% with the use of Al_2O_3 /Water nanofluid (0.01–03% volume frictional).One of the key features for heat transfer enhancement is the thermal conductivity; the majority of the studies [9-15] have discussed the thermal conductivity of nanofluids.

Recently some studies were reported about using the nanofluids in solar collectors. Natarajan[16] has investigated the thermal conductivity enhancement of base fluids using carbon nanotubes and observed in increases the efficiency of the conventional solar water heater.Tyagi et al. [17]has studied theoretically the capability of using a non concentrating direct absorption solar collector and compared its performance with that of a conventional flatplate collector.Otanicar [18] has reported environmental and economic influence of using nanofluids to enhance solar collector efficiency. Otanicar [19] has reported the effect of different nanofluids on the efficiency of the micro-solar-thermal-collector. He reported an efficiency improvement up to 5% in solar thermal collectors by utilizing the nanofluids as the absorption medium. Yousefi et al. [20]experimentally investigated the effect of Al_2O_3 nanofluid in a FPC water heater and reported that using the

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surfactant the maximum enhanced efficiency is 15.63%.The aim of the present study is to theoretically investigate the performance of FPC with Al_2O_3/water nanofluid. The effect of using Al_2O_3 nanofluid with different particle volume concentrations (0.5-2%) has been investigated.

II. THERMAL ANALYSIS

The Al_2O_3 nanofluid based FPCconsidered in present study. The physical dimensions and configuration of the FPCconsidered are given in Table 1.

Table1: Flatplate collector geometry

Property	Value
Width x length	1x2 (m)
Glazing transmittance	0.90
Absorber absorptance	0.95
Absorber thickness	0.25(mm)
Width of absorber fin	115(mm)

ASHRAE Standard suggests performing the tests in various inlet temperatures. The useful energy can be calculated using Eq. (1).

$$Q\_u = \; m\,C\_p\,(T\_fo - T\_fi\,) \qquad (1)$$

where, Q_u is the rate of useful energy gained, $\dot{m}$ is the mass flow rate of fluid flow, C_p is the heat capacity of water or nanofluid, T_{fi} and T_{fo} are the inlet and outlet fluid temperature of solar collector.

The effective specific heat of the nanofluid can be calculated from Xuan and Roetzel relation [21] as:

$$(\rho c_p)_{nf} = (1-\phi)(\rho c_p)_w + \phi(\rho c_p)_p \qquad (2)$$

where, ρc_p refers to the heat capacity,the subscripts *p*,*w* and *nf* refer to the nanoparticle, base fluid and the nanofluid, respectively andϕ is the nanoparticle volume concentration. The value of $C_{p,np}$ and $C_{p,nf}$ are 780 and 4182 respectively. The density of nanofluid is calculated from Pak and Cho [22] using the following equation:

$$\rho_{nf} = \phi\rho_p + (1-\phi)\rho_w \,(3)$$

where, ρ_{nf} is the effective density of nanofluid.

The useful energy can also be expressed in terms of the energy absorbed by the absorber and the energy lost from the absorber as given by Eq. (4).

$$Q_u = A_c F_R\left[I(\tau\alpha) - U_L\left(T_{fi} - T_a\right)\right] \qquad (4)$$

where F_R is the collector heat removal, A_c is the surface area of solar collector, I is the global solar radiation, τα is the absorptance–transmittance product, U_L is the overall loss coefficient of solar collector, and T_a is the ambient temperature. The relation between the collector efficiency factor $F'$and the heat removal factor F_R is given as:

$$F_R = \frac{\dot{m}C_p}{A_c U_L}\left[1 - Exp\left(-A_c U_L F'/\dot{m}C_p\right)\right] \qquad (5)$$

The instantaneous collector efficiency relates the useful energy to the total radiation incident on the collector surface by Eq. (6) or (7).

$$\eta = \frac{Q_u}{A_c I} = \frac{A_c F_R\left[I(\tau\alpha) - U_L\left(T_{fi} - T_a\right)\right]}{A_c I} \qquad (6)$$

$$\eta = F_R(\tau\alpha) - \frac{F_R U_L\left(T_{fi} - T_a\right)}{I} \qquad (7)$$

In a particular case of a solar collector where the temperature of the fluid entering the collector equals the ambient temperature i.e.$(T_{fi} = T_a)$, results collector efficiency is at its maximum.If the efficiency test is performed at near the normal incidence conditions so that $F_R(\tau\alpha)$is constant and both F_R and U_L are constant within the range of tested temperatures, a straight line will result when the efficiencies are obtained from averaged data is plotted against $\frac{(T_{fi} - T_a)}{I}$ according to Eq. (7). The intersection of the line with the vertical efficiency axis equals to $F_R(\tau\alpha)$. The slope of the line is equal to $F_R U_L$.At the intersection of the line with the horizontal axis collector efficiency is zero usually occurs when no fluid flows in the collector.

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III. RESULTS AND DISCUSSIONS

The solar collector is tested for various mass flow rates of 0.5, 1, 1.5 and 2 Lit/min. The performance parameters are calculated for various input parameters. Due to lack of available experimental data on solar collector using nanofluid, the results has been tested with the experimental data reported and found to be reasonable range within 5% of variation. Table 2 show that the $F_R(\tau\alpha)$, and found to be highest at mass flow rate of 2liter/min, and the F_RU_L value is lowest. Therefore based on the Eq. (7) the efficiency of solar collector at this mass flow rate is highest. Solar collector efficiency decreases with decreasing the mass flow rate.This is due to less contact period between fluid ant absorber. The efficiency of flatplate collector with Al_2O_3 nanofluid is higher than that with the use of water as working fluid. This can be deduced by comparing the value of $F_R(\tau\alpha)$ for Al_2O_3 nanofluid and water, which shows that the removed energy parameter, F_RU_L, values for Al_2O_3 nanofluid and water are close to each other. However, the absorbed energy parameter, $F_R(\tau\alpha)$, value for nanofluid is higher than that for water by 31.6% which lead to increase in efficiency about 31.6%.

Table2. Efficiency parameter of the FPC for waterat various flow rates.

Mass flow rates (Lit/min)	F_RU_L	$F_R(\tau\alpha)$
0.5	48.62	0.480
1.0	44.65	0.489
1.5	39.49	0.513
2.0	35.94	0.521

Table3.Efficiency parameter of the FPCfor Al_2O_3 nanofluid at various concentration

% Concentration	F_RU_L	$F_R(\tau\alpha)$
0.5	49.25	0.551
1.0	45.15	0.652
1.5	42.30	0.722
2.0	36.21	0.631

By comparing the efficiencies of nanofluid with different concentrations, it can be seen that the efficiency at 1.5% particle volume fraction of Al_2O_3 nanofluid is higher than that the other cases. Based on the Eq. (7),the $F_R(\tau\alpha)$ is dominant parameter in small temperature differences, and F_RU_L is dominant parameter in higher temperature differences. The value of $F_R(\tau\alpha)$ for 1.5% particle volume fraction nanofluid is greater than that for other three cases in lower temperature differences. At higher temperature differences, the value of F_RU_L for 1.5% particle volume fraction is larger than that for other concentration. So, the efficiency in this range is greater than the others.The mass flow rates of nanofluid were 0.5, 1.0, 1.5 and 2.0 Liter/min. The values $F_R(\tau\alpha)$ and F_RU_L of solar collector for each mass flow rate of Al_2O_3 nanofluid are presented in Table 4. It has been observed that for wide range of temperature differences, the efficiency of solar collector increase with increasing the mass flow rate. The variation of efficiency with the use various concentration of Al_2O_3 with the Parameter $(T_i\text{-}T_a)/I$ is shown in Fig.1 and highest for 1.5 % of concentration

Table4: Efficiency parameter of the FPC for Al_2O_3 nanofluid mass flow rates.

Mass flow rates (Lit/min)	F_RU_L	$F_R(\tau\alpha)$
0.5	42.61	0.642
1.0	34.50	0.700
1.5	24.57	0.713
2.0	26.55	0.615

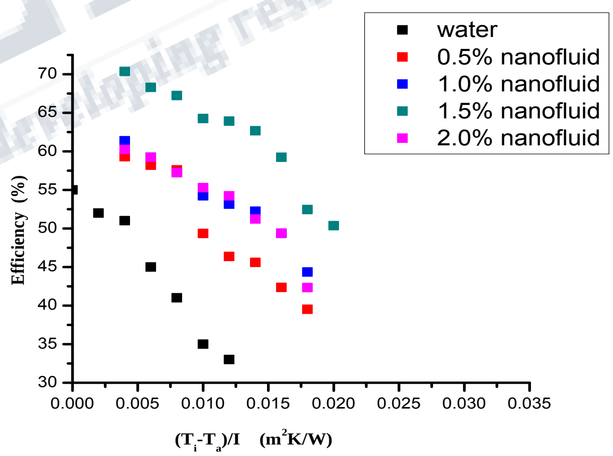

Fig.1.The Efficiency of the FPC for Al_2O_3 nanofluid

IV. CONCLUSIONS

The effect of using the Al_2O_3 nanofluid as absorbing medium in a flat plate solar collector is investigated. The effect of mass flow rate and particle volume fraction on the efficiency of the collector is investigatedshow that using the 1.5% particle volume fraction of Al_2O_3 nanofluid increases the efficiency of solar collector in comparison with water as working fluid by 31.6%.

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