PERFORMANCE ANALYSIS OF SOLAR COLLECTOR USING AL_2O_3 WATER BASED NANOFLUID WITH INCLINED PLATE

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Abstract

Nano fluids are developing fluids with improved thermal properties than the traditional fluids. The use of Nano fluids achieves the maximum possible thermal performance with the smallest possible concentration by uniform dispersion and constant suspension of nanoparticles in the base fluid such as water. This paper gives us the significant increase in heat transfer rate and thermal efficiency of inclined flat plate solar collector by using Al_2O_3 water based Nano fluid. Also, designing copper tube as a flow medium provides the significant increase in the result. This article presents the mathematical formulation for the design of component of inclined flat plate collector.

Keywords: Nano fluid, Thermal efficiency, Heat transfer

I.INDRODUCTION

In today's world demand of energy is increasing day by day. Also energy conversion systems are facing the problem of having low thermal performance. The fluids with Nano sized solid particles suspended in base fluid are called "Nano fluids." The suspended metallic or nonmetallic nanoparticles change the transport properties and heat transfer characteristics of the base fluid. Nano fluids are the new generation heat transfer fluids for various industrial and automotive applications because of their excellent thermal performance. Most solar water heating systems have two main parts: a solar collector and a storage tank. The most common collector is called a flat-plate collector but these suffer from relatively low efficiency. There are so many methods introduced to increase the efficiency of the solar water heater [1]. But the best approach is to introduce the Nano fluids in solar collector instead of conventional heat transfer fluids (like water). The addition of aluminum oxide particles were reported to enhance the resulting thermal conductivities of base fluids by up to 30% at particle volume fraction of Al_2O_3 of 5% , 4% or 3% [2]. Previous studies have discussed the thermal conductivities of Nano fluid [3]. Otanicar [4] has studied environmental and economic influence of using Nano fluids to enhance solar collector efficiency in compare with conventional solar collectors. Yousefi et al. [5] experimentally investigated the effect of Al_2O_3 Nano fluid in a flat-plate solar water heater and reported that using the surfactant the maximum enhanced efficiency is 15.63%. Not much information is available for flat-plate solar collectors using Nano fluids which motivated this study. The major goal of the present study is to theoretically investigate the performance of flat-plate solar collectors with Al_2O_3/water Nano fluid. The effect of using Al_2O_3 Nano fluid with different particle volume concentrations (0.5-2%) are investigated in this study.

Objective:

To increase the efficiency of flat plate conventional solar collector by increasing the thermal conductivity of the suspension that enhances the heat transfer characteristics. Due to this the problem of rapid settling of micro and milli meter sized particles reduces which will ultimately eliminate clogging and fouling. Also reduce the pumping power which is required more in conventional flat plate solar collector. Numerical and theoretical calculation for a solar collector will give the significant increase in the efficiency by the use of nanoparticles in the base fluid.

LITERATURE SURVEY

[1]. Nadeem Ahmad Sheikh, Farhad Ali, et al. They studied the performance of a solar collector using CeO_2 and Al_2O_3 water based Nano fluids with inclined plate. They observed that the use of Nano fluids achieves the maximum possible thermal performance with the smallest possible concentration by constant suspension of the nanoparticles in the base fluid. The purpose of their article is to provide the mathematical formulation for the Nano fluid and to simulate the use of nanoparticles to increase the heat transfer rate of solar equipment by obtaining the exact solutions for the problem.

[2]. Ahmed Kadhim Hussein, et al. They studied the applications of nanotechnology to improve the performance of solar collector. In this paper, he reviewed including theoretical, numerical and experimental up to date works related with the nanotechnology applications in the flat plate, direct absorption, parabolic trough, wavy heat pipe and another kind of solar collectors. It was found that the use of Nano fluid in the solar collector field can play a crucial role in increasing the efficiency of this devices. They concluded that the nanoparticles must be dispersed uniformly in the base fluid to enhance the solar weighted absorption and increase the efficiency of the solar collector.

[3]. Pankaj Raj, Sudhakar Subudhi, et al. They comprehensively analyzed the recent development in solar technology namely flat plate solar collector and direct absorption solar collector. The use of Nano fluids as an absorber fluid showed the promising increase in collector's efficiency. The major challenge still lie in cost reduction of the solar collector so that it can be used effectively for both domestic and industrial use. They concluded that the proper dispersion of nanoparticle and long term stability is necessary for proper absorption of sunlight and increase the efficiency of solar collector. Also, effective particle size, adding surfactant to the Nano fluid and a suitable selection of pH has a positive impact on increasing collector efficiency.

[4.] Hemant Kumar Gupta, Ghanshyam Das Aggarwal,et al. They performed an experimental investigation of a low temperature Al_2O_3-H_2O nanofluid based direct absorption solar collector. Thermal performance study of direct absorption solar collector using Nano fluid of four different concentrations 0.001%, 0.005%, 0.01% and 0.05% with 20 nm alumina nanoparticles in distilled water is carried out. The collector efficiency increase for all four concentrations of nanofluid than pure water. Collector efficiency enhancement of 39.6% and 22.1% is noticed for 0.005vol% and 0.001 vol% respectively. Enhancement in efficiency with nanoparticle concentration beyond 0.005 vol% is found to be lower as compared to other concentrations.

[5]. M. Ghanbarpour, E.Bitaraf Haghigi, R.Khodabandeh, et al. They says, various suspensions containing Al_2O_3 nanoparticles were tested in concentration ranging from 3% to 50% in mass and temperature ranging from 293 K to 323 K. The results reveal that both the thermal conductivity and viscosity of Nano fluids increase with temperature and particle concentration accordingly while the increase in viscosity is much higher than the increase in thermal conductivity. The thermal conductivity and viscosity enhancement are in the range of 1.1–87% and 18.1–300%, respectively.

WORKING METHODOLOGY

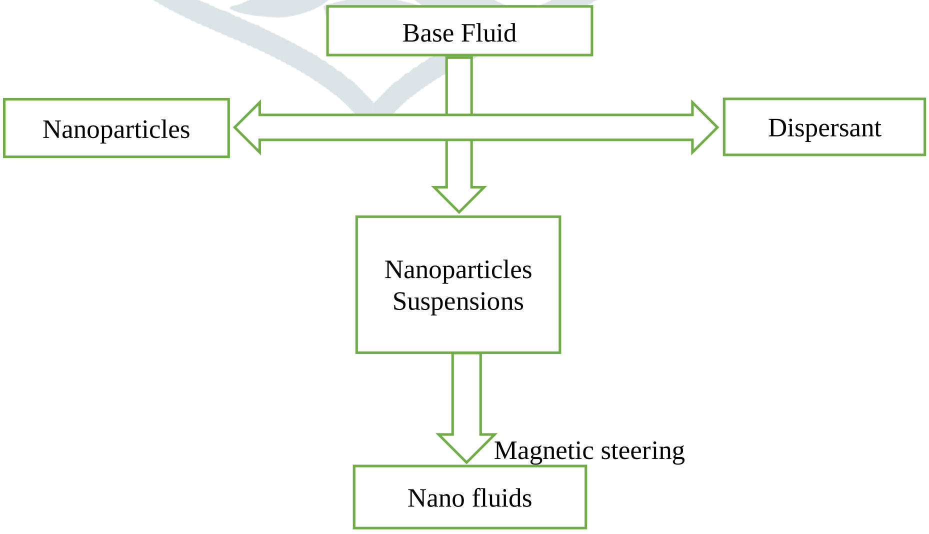
The working principle of this project is quite simple. All the dimensions taken as same as conventional solar collector as per ASHRAE standard.

Table 1 Flat-plate solar collector geometry

PROPERTY	VALUE
Width×Length	1×2 m
Glazing Transmittance	0.90
Absorber Absorptance	0.95
Absorber Thickness	0.25mm
Width of Absorber fin	115mm
Riser pipes diameter(outer/inner)	11/9 mm
Bond conductance	58w/mk
Heat transfer fluid	Al_2O_3/water Nano fluid
slope	80° with vertical(April)

Preparation of Nano fluid-

Two step method is used in preparation of Nano fluid. Volume fraction of 0.5%, 1.0%, 1.5% & 2% is taken in consideration which provides significant variation. Higher the concentration greater the efficiency [6]



Procedures to prepare Nano fluids using two step method

To avoid bubble formation, the stirring speed is kept at optimum level 800r/min. It was confirmed that this method is effective to reduce the formation of bubbles, and improve the quality of the obtained Nano fluids [2,8]

SI	ITEM	DESCRIPTION
1	Product Name	Aluminium oxide(Al_2O_3)
2	Particle Shape	Spherical
3	Average Particle	<50nm
4	Specific Surface	>10 m^2/g
5	Purity	>99.8%
6	Appearance (color)	White
7	Appearance (form)	Powder

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

$$Q_u = \dot{m}C_p(T_{fo} - T_{fi})$$

where, Qu is the rate of useful energy gained, $\dot{m}$ is the mass flow rate of fluid flow, Cp is the heat capacity of water or Nano fluid, Tfi and Tfo are the inlet and outlet fluid temperature of solar collector. The effective specific heat of the Nano fluid can be calculated from Xuan and Roetzel relation [7] as:

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

where, ρcp refers to the heat capacity, ρnf is the effective density of Nano fluid, the subscripts p, w and nf refer to the nanoparticle, base fluid and the Nano fluid, respectively and ϕ is the nanoparticle volume concentration. The Cp, np and Cp,f are 780 and 4182 respectively. The density of Nano fluid is calculated using the following equation:

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

where, ρnf is the effective density of Nano fluid. 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).

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

where FR is the 'collector heat removal factor' defined as the ratio of the actual heat transfer to the maximum possible rate, Ac 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 Ta is the ambient temperature. The relation between the collector efficiency factor F'and the heat removal factor F_R is given as:

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

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

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

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

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 that is η = FR (τα) . If the efficiency test is performed at near the normal incidence conditions so that F_R (τα) is constant and both FR 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 $\frac{Tfi-Ta}{I}$ according to Eq. (7). The intersection of the line with the vertical efficiency axis equals to F_R(τα).

The slope of the line is equal to F_RU_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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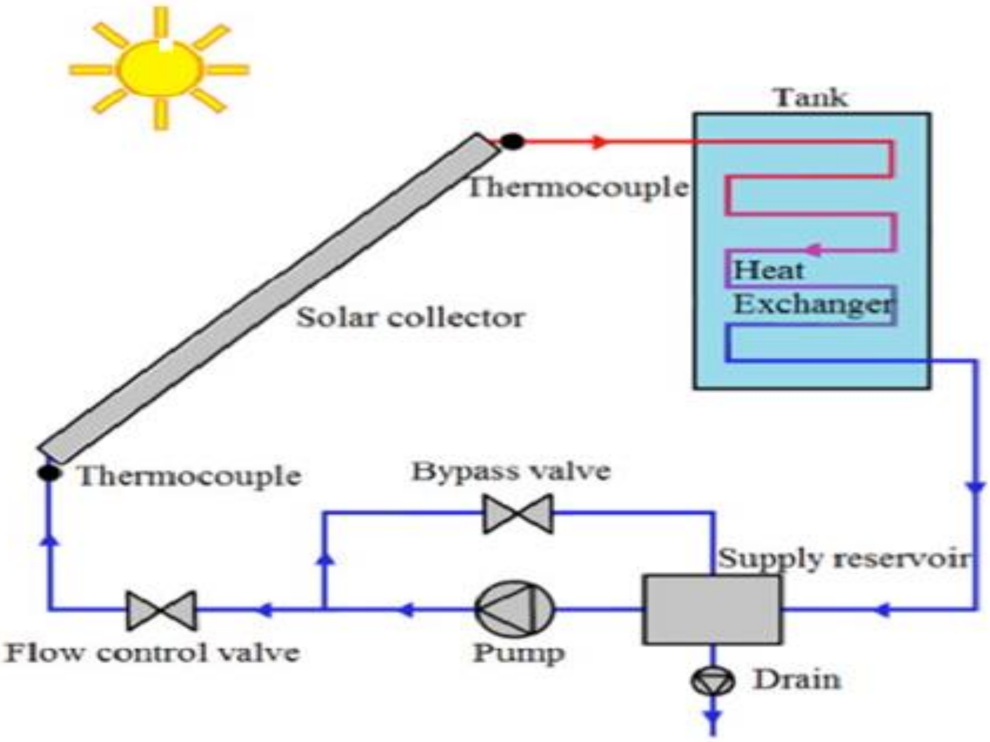
Experimental Setup-



Project Outcomes-

The solar collector is tested for various flow rates 0.5, 1.0, 1.5, 2.0 lit/min. The performance parameters are calculated for various input parameters. The results has been tested with the design example. Table 2 show that the ($\tau\alpha$), value of the collector for 2 Lit/min is highest, and the F_RU_L value in this mass flow rate is lowest. Therefore based on the Eq. (7) the efficiency of solar collector in this mass flow rate is highest. Solar collector efficiency decreases with decreasing the mass flow rate. The efficiency of flat-plate solar collector with Al_2O_3 Nano fluid is higher than the efficiency of flat-plate solar collector with water as working fluid. This can be deduced by comparing the value of ($\tau\alpha$) for Al_2O_3 Nano fluid and water, which shows that the removed energy parameter, F_RU_L, values for Al_2O_3 Nano fluid and water are close to each other. However, the absorbed energy parameter, ($\tau\alpha$), value for nanofluid is higher than that for water by 31.64%. This causes the efficiency of solar collector with 1.5% particle volume fraction of Al_2O_3 Nano fluid become greater than that with water by 31.64%.

Table2: Efficiency parameter of the Flat-plate solar collector for water at various flow rates.

Mass flow rates (lit/min)	F_RU_L	$F_R(\tau\alpha)$
0.5	48.6	0.482
1.0	44.68	0.493
1.5	39.52	0.516
2.0	35.96	0.524

Table3: Efficiency parameter of the Flat-plate solar collector for Al_2O_3 Nano fluid at various concentration

% concentration	F_RU_L	$F_R(\tau\alpha)$
0.5	49.23	0.549
1.0	45.19	0.649
1.5	42.36	0.726
2.0	36.29	0.639

By comparing the efficiencies of Nano fluid with different concentrations, it can be seen that the efficiency at 1.5% particle volume fraction of Al_2O_3 Nano fluid is higher than that the other three particle volume fraction concentration. 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 Nano fluid is greater than that for other three in lower temperature differences. In 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 Nano fluid were 0.5, 1, 1.5 and 2 Lit/min. $(\tau\alpha)$ and F_RU_L values of solar collector for each mass flow rate of Al_2O_3 Nano fluid are presented in Table 4. For the wide range of temperature differences, the efficiency of solar collector increase with increasing the mass flow rate.

Table4: Efficiency parameter of the Flat-plate solar collector for Al_2O_3 Nano fluid mass flow rates.

Mass flow rates (lit/min)	F_RU_L	$F_R(\tau\alpha)$
0.5	42.6	0.643
1.0	34.52	0.702
1.5	24.56	0.712
2.0	26.52	0.616

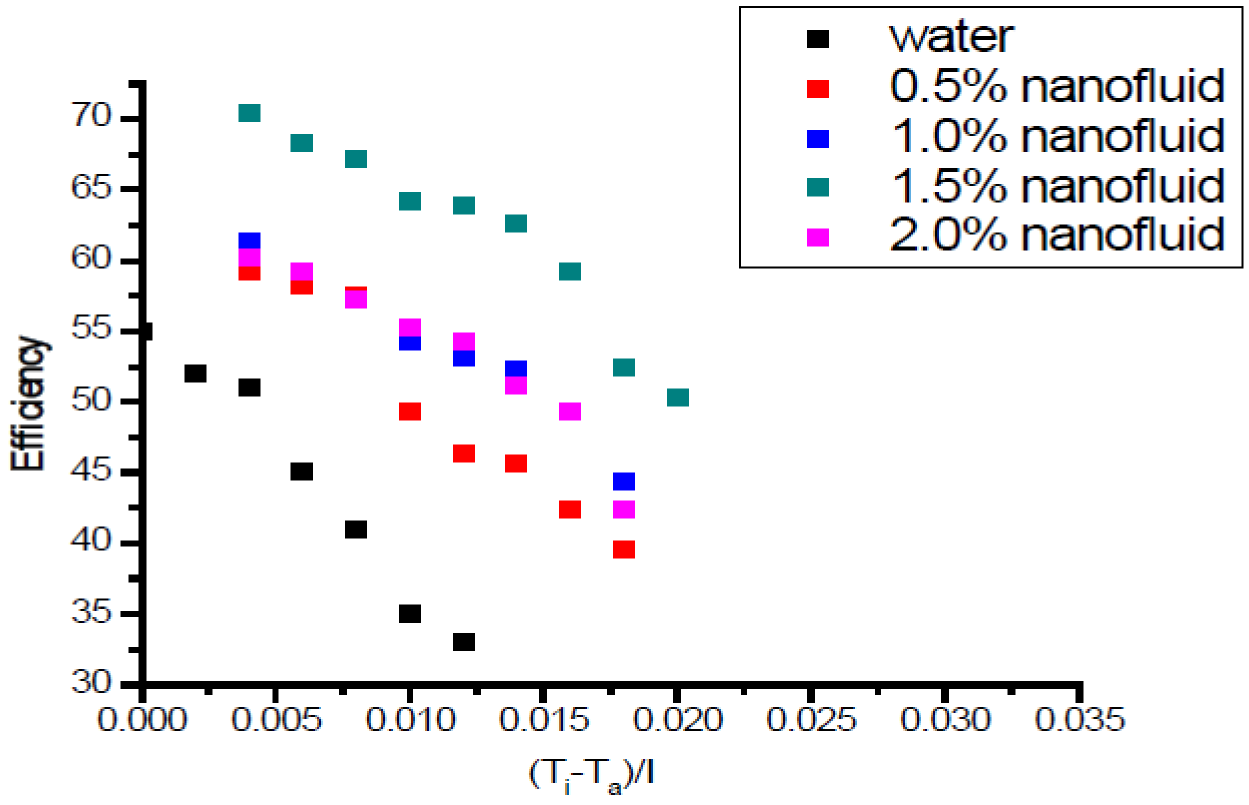


Fig. Efficiency of the flat plate solar collector for Al2O3 Nano fluid

REFERENCE

[1] Gupta, H. K., Agrawal, G. D., & Mathur, J. (2015). An experimental investigation of a low temperature Al_2O_3-H_2O nanofluid based direct absorption solar collector. Solar Energy, 118, 390–396.

[2] Hussein, A. M., Sharma, K. V., Bakar, R. A., & Kadirgama, K. (2013). The Effect of Nanofluid Volume Concentration on Heat Transfer and Friction Factor inside a Horizontal Tube. Journal of Nanomaterials, 2013, 1–12.

[3] Ahmadi, M. H., Alhuyi Nazari, M., Ghasempour, R., Madah, H., Shafii, M. B., & Ahmadi, M. A. (2018). Thermal conductivity ratio prediction of Al_2O_3 /water nanofluid by applying connectionist methods. Colloids and Surfaces A: Physicochemical and Engineering Aspects, 541, 154–164.

[4] Otanicar, T. P., & Golden, J. S. (2009). Comparative Environmental and Economic Analysis of Conventional and Nanofluid Solar Hot Water Technologies. Environmental Science & Technology, 43(15), 6082–6087.

[5] Ransmark, S.-E. (1980). FLAT-PLATE SOLAR COLLECTORS. Solar Energy International Progress, 187–214.

[6] Bait, O., & Si–Ameur, M. (2018). Enhanced heat and mass transfer in solar stills using nanofluids: A review. Solar Energy, 170, 694–722.

[7] Xuan, Y., & Roetzel, W. (2000). Conceptions for heat transfer correlation of nanofluids. International Journal of Heat and Mass Transfer, 43(19), 3701–3707.

[8] Gupta, H. K., Agrawal, G. D., & Mathur, J. (2015). An experimental investigation of a low temperature Al_2O_3-H_2O nanofluid based direct absorption solar collector. Solar Energy, 118, 390–396.

[9] Farajzadeh, E., Movahed, S., & Hosseini, R. (2018). Experimental and numerical investigations on the effect of Al_2O_3/TiO_2 H_2O nanofluids on thermal efficiency of the flat plate solar collector. Renewable Energy, 118, 122–130.

[10] Hussein, A. K., Li, D., Kolsi, L., Kata, S., & Sahoo, B. (2017). A Review of Nano Fluid Role to Improve the Performance of the Heat Pipe Solar Collectors. Energy Procedia, 109, 417–424.