EXPERIMENTAL ANALYSIS OF HEAT TRANSFER CHARACTERISTICS OF SOLAR FLAT PLATE COLLECTOR USING H_2O AND AL_2O_3-H_2O NANOFLUID

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Abstract

In this work, performance analysis of Solar flat plate collector is carried out using H_2O and Al_2O_3-H_2O nanofluid as heat transfer medium. The concentration of Al_2O_3 nanoparticles various as 0wt%, 0.05wt%, 0.15wt% and 0.25wt% mixed with water. The mass flow rate of the working fluids is taken as 1kg/m, 2kg/m and 3kg/m for each concentration. The 0wt% represents pure distilled water(H_2O). From the experimental result, it is observed that the outlet temperature of the nanofluid decreases as the mass flow rate increases. The heat transfer rate and efficiency of the collector increase as the mass flow rate increases upto 2kg/m and then decreases. The maximum heat transfer rate is obtained at 2kg/m and fluid containing 0.25wt% of nanoparticles. The pressure drop across the collector increases as the nanoparticle concentration and mass flow rate increases. The requirement of pumping power to circulate the fluid increases as the mass flow rate increases. When compared with water, Al_2O_3-H_2O nanofluid gives better collector efficiency due to high thermal conductivity of Al_2O_3 nanoparticle. The maximum efficiency of the collector is obtained as 69.2% at 2kg/m and 0.25wt% of Al_2O_3 nanoparticle.

Keywords: Al_2O_3-H_2O Nanofluid, Heat transfer rate, Pressure drop, Efficiency, Mass flow rate, nanoparticle concentration.

1. Introduction

Nanotechnology is one of the important driving forces for the researchers in the area of energy conservation applications. Nanotechnology helps to rearrange the structure at the molecular level. Hence, the development of nanotechnology explore novel ideas in biomedical, food preservation and transportation, electronic chip cooling, manufacturing industries, environmental safety, etc.

The development of nanotechnology allows using nanoparticles in conventional heat transfer applications[1-3]. Due to the poor performance of low thermal conductivity fluids induce the researchers towards the development of high thermal conductivity fluid called nanofluid. It consists of mixing of nanosized particles(1-100nm) with suitable base fluid like water, oil, ethylene glycol, etc. The presence of suspended nanoparticles in base fluid increase the effective thermal conductivity and also, in turn, heat transfer characteristics. Not as like solid-liquid mixtures and micro-fluids, nanofluid exhibits appreciable suspension capacity with the help of suitable surfactant. Nanofluids are used in various engineering applications such as radiators, heat exchangers, lubricants etc. Therefore many research works have been carried out on testing various nanofluids such as SWCNT, MWCNT, Al_2O_3, CuO, Ag etc. Nanofluid is also used as heat exchanging medium in solar flat plate collector. T.P.Otanical et al[4] proposed a direct absorption solar collector operated with graphite, carbon nanotube and silver nanofluids as absorbing medium. It shows the collector efficiency improved upto 5% by using nanofluid as working medium when compared with water. Hemant Kumar Gupta et al[5] investigated Al_2O_3-H_2O nanofluid with 0.005% volume fraction of Al_2O_3 nanoparticles in direct absorption solar collector and suggested mass flow rate of 2lpm and 2.5lpm towards maximum collector efficiency for water and nanofluid. Al_2O_3-H_2O based nanofluid provides enhanced heat transfer characteristics[6] at higher Reynolds number as 1200. Siddharth Roy et al[7] showed an increase in the performance of solar flat plate collector while using Ag/H_2O nanofluid when compared with water as working medium. It was observed that the maximum percentage of efficiency increased as 18.4% for 0.04% volume concentration of nanoparticles at Reynolds number 25000. Z.Said et al[8] experimented ethylene glycol/water mixture (60:40 by mass) and water based alumina nanofluids of 0.05–0.1%v/v concentrations for analyzing the variation of pumping power of the flat plate collector due to the effect of density and viscosity. They suggested Al_2O_3-H_2O based nanofluid is good enough against aggregation and sedimentation than Al_2O_3-ethylene glycol/water mixture based nanofluids. They also reported that linearity is obtained between thermal conductivity and various concentrations of nanoparticles for both the nanofluids and at the same time the viscosity of Al_2O_3-H_2O based nanofluid decreases exponentially with increasing temperature. But Al_2O_3–EG/water mixture nanofluid shows Newtonian behavior. Yousefi et al[10] performed a test on multi-walled carbon nanotube nanofluid as fluid medium in solar flat plate collector. They analyzed the effect of variation of pH values (3.5, 6.5, and 9.5) of MWCNT nanofluid with 0.2wt% MWCNT on the efficiency of the collector. They proved that effective thermal conductivity increases due to the large difference between isoelectric point pH value and pH values of the nanofluid instead of pH value alone. Yousefi et al[11] investigated the effect of surfactant(Triton X-100) on the efficiency of the collector. They explained that due to the addition of surfactant the heat transfer is reduced[17]. This is because the addition of Triton X-100 leads to the formation of foam between water and riser tube which acts like insulator, therefore, the heat transfer rate is decreased. Sunil.K.Amrutkar et al[12] evaluated the performance of flat plate collector with modified geometry of absorber plate to improve the efficiency and reduce the cost of the collector. K.Vajravelu et al[13] studied the effect of Ag/H2O and Cu/H2O nanofluids under the influence of thermal buoyancy and reported that while increasing the nanoparticle volume fraction the velocity boundary layer thickness decreases.

From the literature survey, it is identified that Al_2O_3 nanoparticle possesses good thermal conductivity and lesser cost when compared with other high thermal conductivity metal oxide nanoparticles. At the same time, Triton X-100 is used as surfactant to avoid sedimentation and better suspension of nanoparticle.

An attempt has been made in this study to evaluate the heat transfer characteristics of solar flat plate collector using Al_2O_3-H_2O nanofluid in solar flat plate collector with three different mass flow rates such as 1kg/m, 2kg/m and 3kg/m. The concentration of Al_2O_3 nanoparticle in Al_2O_3-H_2O nanofluid is taken as 0.05wt%, 0.15wt% and 0.25wt% and each concentration of nanofluid is tested with abovementioned mass flow rates.

2. Characterization of Al_2O_3 nanoparticle

Nanoparticles have purchased from Sigma-Aldrich Corporation-An American Company. Nanoparticles are mixed with base fluid as per weight fraction i.e, 1% of weight fraction represents 1gram of Al_2O_3 nanoparticles mixed with 100ml of water.

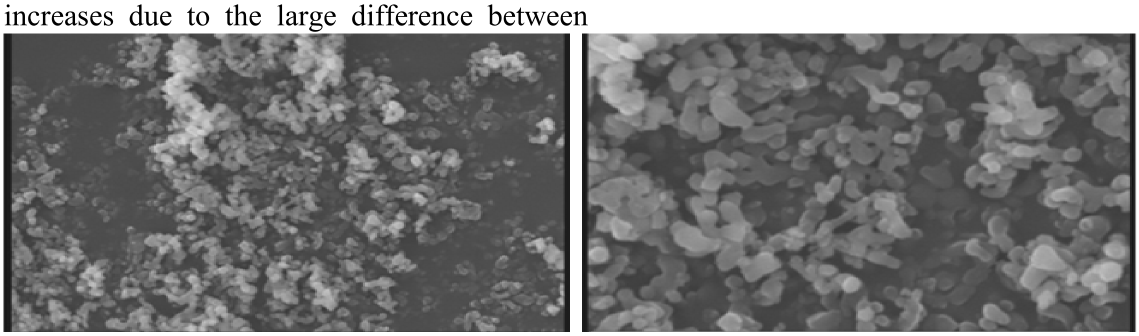

Figure 1 SEM image of Al_2O_3 nanoparticles

The SEM image of Al_2O_3 nanoparticles shown in figure 1, the size of Al_2O_3 nanoparticles is in the range of 20nm and its shape is not fully spherical and is mixed of spherical and cylindrical. From the SEM analysis, it is confirmed that Al_2O_3 nanoparticles are within the manufacturer's specification. Energy – Dispersive X–ray Spectroscopy (EDS) analysis is carried out for elemental analysis or chemical characterization of the sample. It measures the major elements present in the sample based on the electromagnetic emission spectrum of each element. Figure 2 confirms the purity of Al_2O_3 nanoparticle. The peak lines represent the nanoparticle containing aluminium and oxide molecules and other peaks represent impurities.

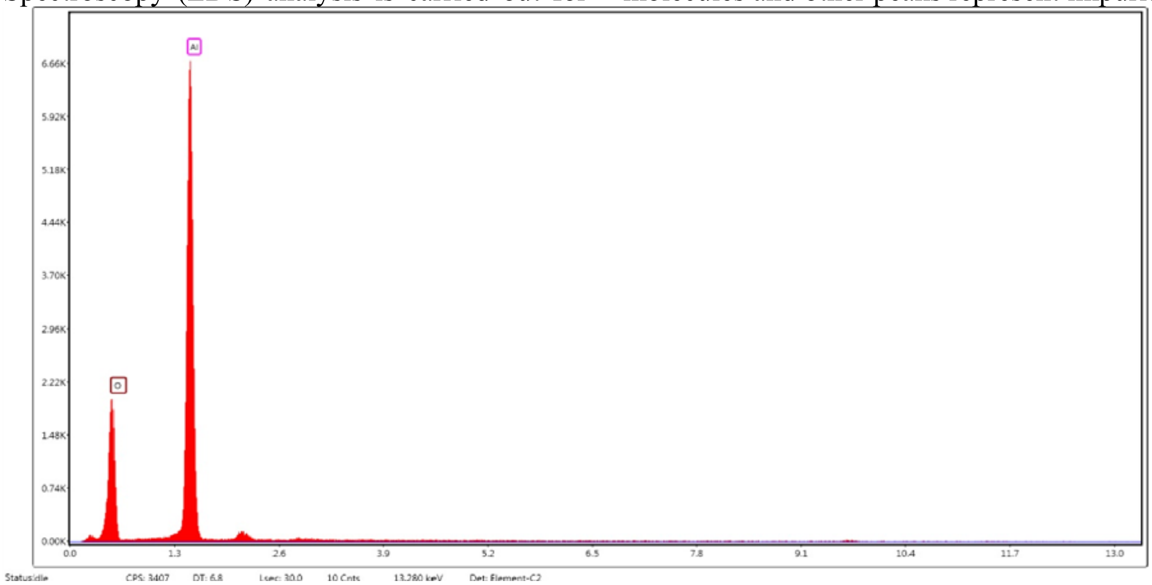

Figure 2 Energy – Dispersive X-ray Spectroscopy image of Al_2O_3 nanoparticles

3. Preparation of nanofluid

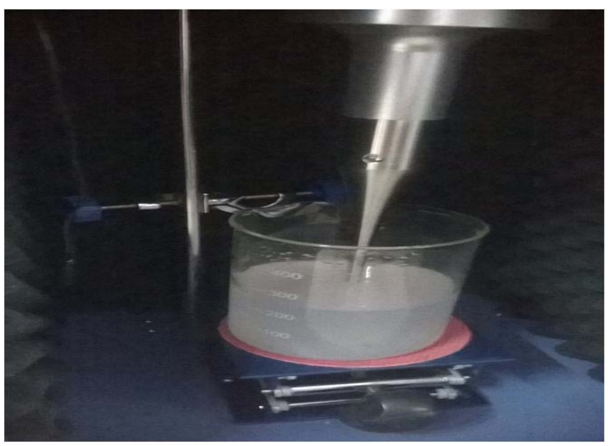

Figure 3 Ultrasonication of Al_2O_3 nanofluid

Nanoparticles are mixed with distilled water to prepare nanofluids. Addition of surfactant affects the heat transfer rate of the nanofluid but it is unavoidable to enhance the dispersion of nanoparticles in base fluid and reduce the sedimentation. Triton X-100 of 0.02wt% is used as surfactant. The nanofluid preparation is carried out by two-step process. The nanoparticle is mixed with distilled water to prepare the dispersion. Triton X-100 is added and dispersion is kept in ultrasonicator for nearly 45 minutes to obtain homogeneous suspension of nanoparticles. Figure 3 shows the setup of ultrasonic vibration and figure 4 shows the steps involved in nanofluid preparation.

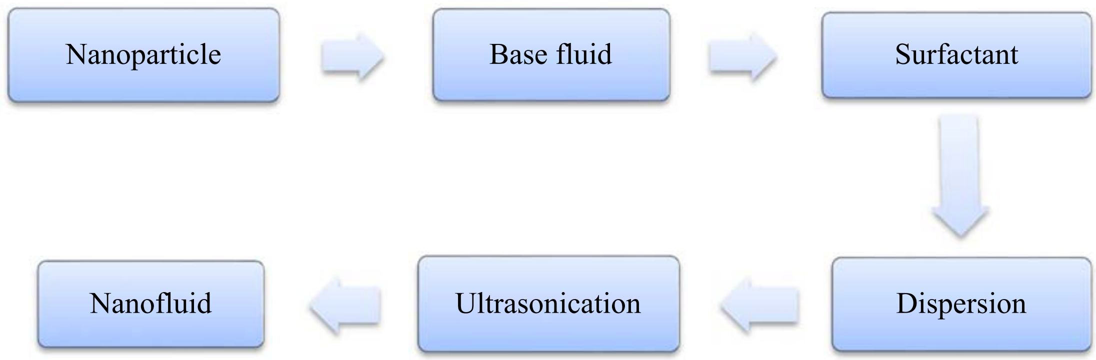

Figure 4 Steps towards preparation of nanofluid

4. Experimental setup and testing procedure

An experimental setup has been developed at SNS College of Technology, Coimbatore (Latitude 11^{O}0'N and Longitude 76^{O}9'E). The schematic diagram of the experimental setup is shown in figure 5.

The test facility is consisting of a solar flat plate collector, variable speed pump having stainless steel impeller to avoid erosion and corrosion, heat exchanger, ice sump, heater and storage tank. The size of solar flat plate collector is 2000mmx1000mmx100mm. The top side of the collector is covered with toughened glass of 4mm thickness. The absorber plate is made of copper sheet of 0.2mm thickness is placed below the glass cover and the space between the glass cover and absorber plate is maintained as 25mm. The area of the collector is 1.905m^2. There are two horizontal header pipes of diameter 25mm which are connected by 9 riser tubes of diameter 12.5mm. The header and riser pipes are made of copper and are firmly brazed with bottom side of the absorber plate. The bottom insulation has 50mm thickness whereas side insulation has 25mm thickness. Glass wool is used for both the bottom and side insulation. The whole setup is covered with aluminium sheet except the top. The inlet and outlet pipes are made of copper of 12.5mm diameter. A separate bypass valve is provided at the inlet to return the excess fluid thereby required mass flow rate of the fluid is maintained. The heat contained in the working fluid which is coming out from the collector is absorbed by the heat exchanger. An ice sump set up is used if required to reduce the excess heat. The heater enables to maintain the inlet temperature of working medium as 25^{o}C. A set of K type thermocouples of 13 numbers with ±0.1% accuracy are attached at different places such as inlet and outlet, glass cover, absorber plate and riser tubes to measure the temperature at an instant with the help of data logger.

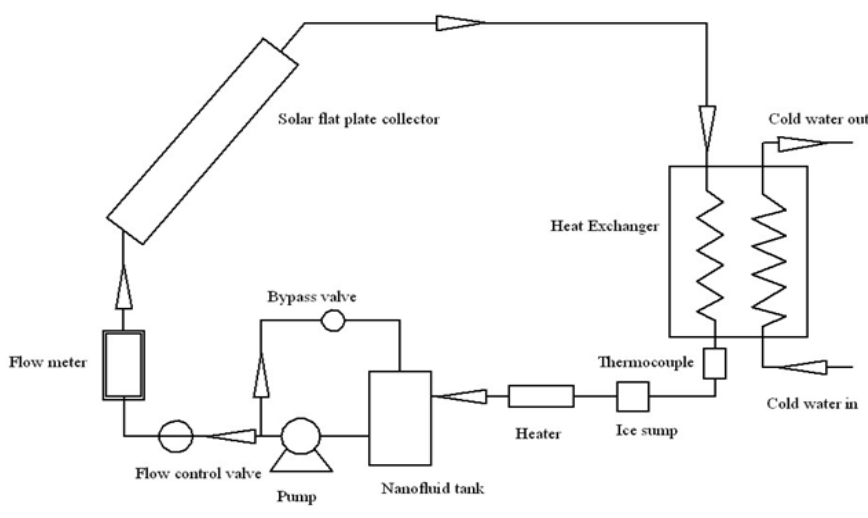

Figure 5 Schematic diagram of experimental setup

Two pressure sensors of ±0.1% accuracy is fixed at the inlet and outlet to measure the pressure variations. The solar flux incident is measured by pyranometer and the wind velocity is measured by using anemometer.

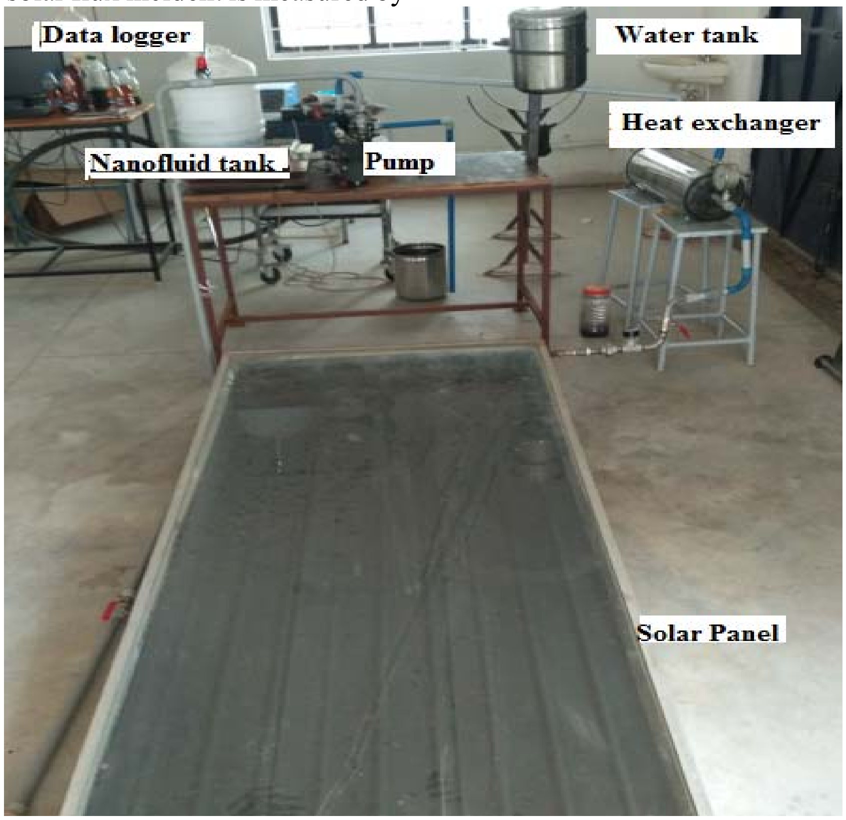

Figure 6 Photographic image of the collector

The photographic view of the experimental setup is shown in figure 6. The experimental tests are conducted with constant inlet temperature of $25^{O}C$. It is ensured that the variation of solar flux radiation is minimum i.e. $\pm 50 W/m^2$. Initially, the test is conducted with distilled water as fluid medium. The mass flow rate of water is set as 1kg/min in test 1. The preset time was given to establish the complete working condition. The outlet temperature of the collector is measured using data logger. The inlet and outlet pressure of the collector is measured using pressure gauges.

Table 1 Properties of water and Al_2O_3 nanoparticle

Description	Density(kg/m^3)	Viscosity(Ns/m^2)	Specific heat(J/kgK)	Thermal conductivity(W/mK)
Water	997.13	0.000893	4180	0.613
Al_2O_3 Nanoparticle	3970	-	775	36

The experiments are repeated with the mass flow rates of 2kg/m and 3kg/m for water and readings were noted. The same experimental procedure is carried out for Al_2O_3-H_2O nanofluid for three different proportions of Al_2O_3 nanoparticles such as 0.05wt%, 0.15wt% and 0.25wt% with the abovementioned mass flow rates. The outlet temperature and pressure drop have been measured for each concentration and mass flow rate combinations. The heat transfer rate, pumping power and efficiency have been calculated using suitable relations.

5. Data reduction

Table 1 shows the properties of water and Al_2O_3 nanoparticle. The density[14], viscosity by Einstein's equation[15] and specific heat[16] of nanofluid is calculated as

$$\rho_{nf} = \varphi\rho_{np} + (1-\varphi)\,\rho_w \tag{1}$$

$\mu_{nf} = (1+2.5\varphi)\mu_w$ (2)

$C_{p,nf} = \varphi C_{p,np} + (1-\varphi) C_{p,w}$ (3)

The thermal conductivity of nanofluid can be calculated as follows

$k_{nf} = k_w[\frac{kp+2kbf-2\varphi(kbf-kp)}{kp+2kbf+\varphi(kbf-kp}]$ (4)

The heat transfer rate, $Q=mC_p\Delta T$, (5)

Efficiency, $\eta = Q/(A_C I_T)$ (6)

Pumping power = $\Delta p * (\dot{m}/\rho)$ (7)

where, ρ – Density, μ - viscosity, C_p – specific heat, k – thermal conductivity, Q = Heat transfer rate, $\dot{m}$ = mass flow rate, C_p = specific heat, ΔT = temperature difference between fluid outlet and inlet, A_C = area of the collector, I_T = incident radiation and Δp = pressure drop. The suffix nf represents nanofluid, bf represents base fluid and p represents nanoparticle.

6. Result and Discussion

The temperature of the nanofluid coming out from the collector against nanoparticle concentration is shown in figure 7. From the observed values, it is noted that the outlet temperature decreases as the mass flow rate increases. This is because, at lower mass flow rate, the fluid has enough time within the collector to absorb heat by convection and the losses are reduced. At the same time the outlet temperature of the nanofluid increases as the concentration of nanoparticle increases.

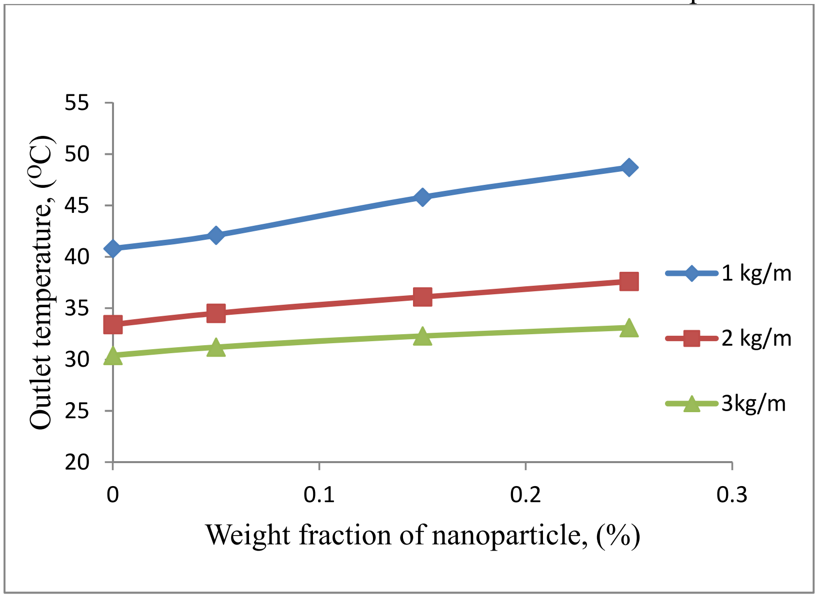

Figure 7 Outlet temperature vs nanoparticle concentration

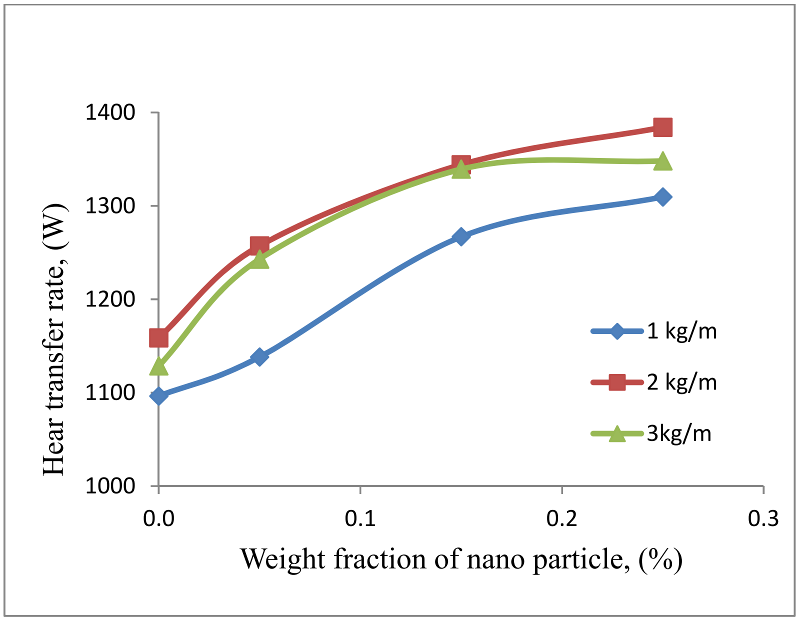

Figure 8 Heat transfer rate vs nanoparticle concentration

Figure 8 represents the heat transfer rate against nanoparticle concentration of Al_2O_3-H_2O nanofluid. It shows that the rate of heat transfer increases as the % of weight fraction of nanofluid increases. Also the heat transfer rate increases as the mass flow rate increases upto 2kg/m and then decrease. At higher mass flow rates, the temperature difference between the inlet and outlet of the collector decreases due to less retention time within the collector which reduces the heat transfer rate.

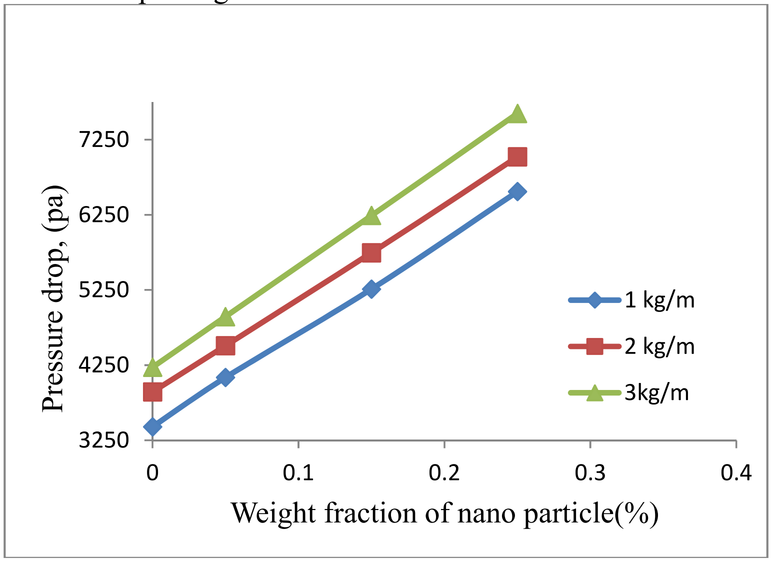

Figure 9 Pressure drop vs nanoparticle concentration

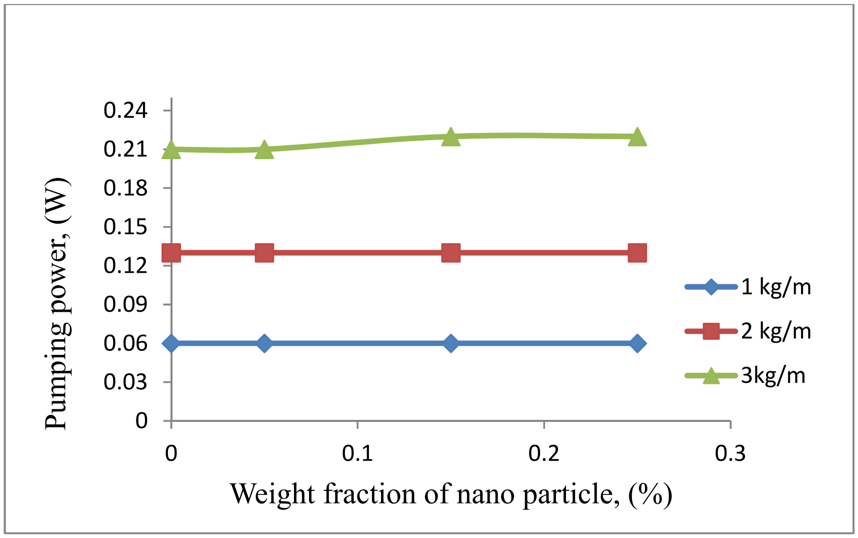

Figure 10 Pumping power vs nanoparticle concentration

Figure 9 shows the pressure drop of Al_2O_3 nanofluid. The pressure drop of the nanofluid increases as the mass flow rate increases. The pressure drop is directly proportional to the velocity of the fluid. The velocity of the nanofluid increases as the mass flow rate increases. At the same time, the addition of nanoparticle increases the density of the nanofluid which directly affects the pressure drop across the collector. The pumping power required to drive the nanofluid within the collector is shown in figure 10. The pumping power of the Al_2O_3 nanofluid increases as mass flow rate increases due to load of the fluid increases within the collector and pumping power is directly proportional to mass flow rate. But the effect of nanoparticle concentration on pumping power is less due to the variation of density. It is clearly understood that the density of the nanofluid depends on nanoparticle concentration and pumping power is inversely proportional to the density of the nanofluid

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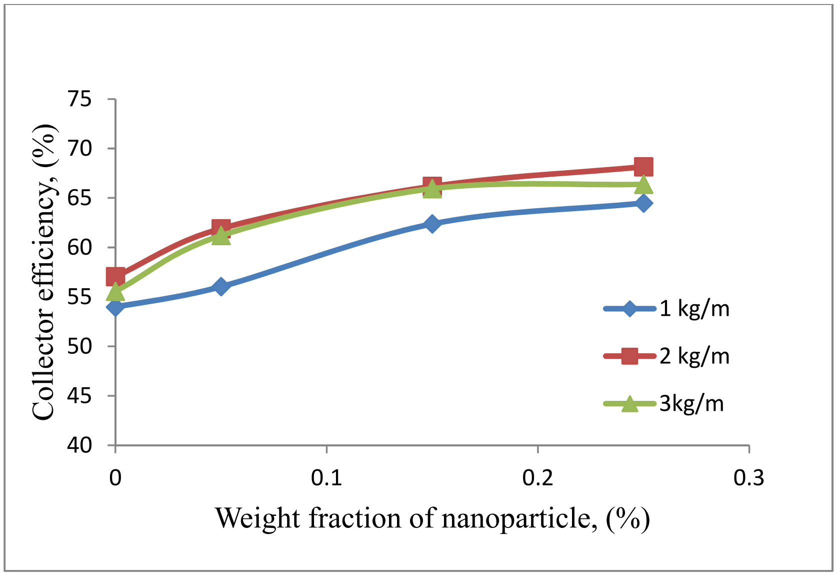

Figure 11 Collector efficiency vs nanoparticle concentration

The effect of nanoparticle concentration on collector efficiency is shown in figure 11. From the calculated values it is clear that the collector efficiency increases as the %weight fraction of nanoparticle increases. But this is true only upto certain mass flow rate i.e. 2kg/m. When the mass flow rate increases further, the collector efficiency decreases irrespective of weight fraction of nanoparticle. It is concluded that 2kg/m mass flow rate is the optimum value for the collector working with Al_2O_3 nanofluid having 0%, 0.05%, 0.15% and 0.25% weight fraction of the nanoparticle. The increase of collector efficiency is 19.4% at 0.25wt% for 3kg/m when compared with water. But the increase of efficiency of the collector is only 2.9% at 3kg/m mass flow rate when compared with 1kg/m.

7. Conclusion

In the present work, the effect of Al_2O_3 particle concentration contained in Al_2O_3-H_2O nanofluid and mass flow rates have been tested using solar flat plate collector. The outlet temperature and pressure drop are measured using thermocouple and pressure gauge respectively. The rate of heat transfer, pumping power and efficiency of the collector is calculated from the observed values. From the result, it is concluded that

1. The outlet temperature of the collector increases as the nanoparticle concentration increases and mass flow rate. The highest temperature enhancement is obtained at 1kg//m mass flow rate with 0.25wt% of nanoparticle concentration.
2. The maximum heat transfer rate is attained at 2kg/m due to heat transfer coefficient enhancement which will be effective to a certain limit only. The maximum heat transfer rate is obtained at 0.25wt% for 2kg/m mass flow rate. After 2kg/m the heat transfer rate of the collector starts decreasing.
3. The pressure drop of the nanofluid increases as the mass flow rate increases. Nanoparticle concentration also affects the pressure drop i.e. pressure drop increases when nanoparticle concentration increases.
4. The pumping power increases when the mass flow rate increases. But the nanoparticle concentration does not have much influence on pumping power upto 2kg/m. But the combined effect of higher mass flow rate and nanoparticle concentration adversely increases the requirement of pumping power and it is observed at 3kg/m mass flow rate.
5. The efficiency of the collector increases as the mass flow rate increases upto 2kg/m. When mass flow rate increases from 2kg/m to 3kg/m the efficiency decreases. The appreciable amount of reduction in the efficiency of the collector is observed only at 0.25% nanoparticle concentration at the mass flow rate of 3kg/m.

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