Thermal Performance on Parabolic Solar trough Collector by using Rgo/Water Nanofluid

Ananda Gowda, Shivappa Dassappa

Abstract*: The solar water heating systems are one of the popular devices to harness the sun radiation incident on the surface of earth at free of cost. The ASHARE standards 93-86 were followed to study the thermal performance of parabolic solar trough collector using rGO/water nanofluid with the mass fraction of 1% used as a working coolant. To enhance the efficiency regarding temperatures variations, flow rate, and incident solar radiations was examined. These results show that influencing of nanofluid on the collector had more efficient than with pure water owing to solar radiation and flow rate. The efficiency of solar parabolic trough collector has improved with an effect of nanofluid compared to pure water.

Keywords: Flow rate, mass fraction, parabolic trough collector, rGO/water nanofluid, solar radiation;

I. INTRODUCTION

Solar energy is radiant light and heat from the sun that has harnessed using a range of ever-evolving technologies such as heating, photovoltaic, thermal energy storage and artificial photo-synthesis [1, 2, 3]. These solar thermal systems can be used in hot water generation, desalination process and power plant applications. A common working fluid coolant as air heater or base fluid were used-to converts incoming incident solar radiation into heat in the form of industrial processing unit and domestic usage[4,5,6].For cloudy seasons, the existing flat-plate and evacuated tube type of solar collector are gradually reduced fluid outlet temperature with lower the thermal efficiency [7, 8]. For the improvement of existing flat plate and evacuated tube type via different mode of techniques were used. In the recent decades many researchers are studied on performing using nanofluid instead of base fluid [9,10]. They selected nano-particles size between 10-50nm and different concentration were tested to analyze the thermal performance on solar thermal systems. The working fluid coolant as nanofluid were used to establish the thermal properties and compared with base fluids [11,12]. The recent experimental investigation using nanofluid in solar thermal systems was tested with Al_2O_3 as fluid coolant on a flat plate and evacuated tube type of collectors [13]. From this study shows that nanofluid increases the efficiency and fluid outlet temperature of working coolant. The behavior of carbon nanotube (multi-walled) with base fluid and explained the optimal level of PH was inserted to increase the collector efficiency [14, 15,16]. The deionized water/CuO nanofluid was used in tubular type of solar collector to investigate thermal performance of nanofluid. They showed that increasing trend in heat transfer coefficient by 28% and enhanced the thermal properties of nanofluid [17, 18]. Many researchers had reported the study of various types of nanofluid with mini-channel based solar collectors was constructed such as Al_2O_3,SiO_2, and CuO as fluid coolants. The combinations of nanofluid have lowest entropy and gradually fluid outlet temperature decreased [19,20]. The numerical investigation of free convection on cylindrical type of solar collector with two different nano-fluids such as Cu/water and Ag/water are slightly increasing in thermal efficiency [21]. The optimization of solar efficiency was studied on flat plat type collectors using Al_2O_3/water and pure water. The low fluid outlet temperature exhibits on direct absorption type of solar collectors and investigated thermo-physical properties of nanofluid [22,23]. Through this literature finding, the aim of the present research was design and development of parabolic solar trough collector using rGO/water as nanofluid with pure water. The effect of reduced graphene oxide (rGO) as nanofluid on PSTC and varying mass fraction 1% were selected as coolant to study the thermal performance.

II. EXPERIMENTATION METHODOLOGY

A.The parabolic solar trough collector system

The design and showed a prototype of PSTC line flow diagram as shown in Fig.1.The working principle of PSTC mainly comprises a storage tank, temperature sensors, driving pump, receiver tube and parabolic reflector mirror. The PSTC was developed with help of designing parameters for small –scale domestic usage as illustrated in Table-I. To enhance the thermal performance of the collector with consideration of optimum tilting angle 48^0 were averagely selected on variation of incident solar radiation. The location of experimental testing has done at BTL Institute of Technology, Karnataka, India (latitude$12^0 18^1 15^{11}$N, longitude $72^0 50^1 5^{11}$W). The reflecting mirror has made up Al anode strips and tubular type of copper receiver tube was constructed (see Fig.2). The fluid inlet temperature flow inside the receiver tube and outer side nanofluid (rGO) was circulating as working coolant. For influencing of nanofluid on the outer side of tube section, the heat transfer capability was established and heated fluid outlet temperature is collected in the storage tank. The k-type of thermocouples was used to measure the inlet, ambient and fluid outlet temperature conditions with connected to a data-logger (ktt-31-kimo-datta logger). The solar meter (TES-132) were used for the measuring of incoming solar radiation incident on the collector. The maximum rate of fluid flow 2.2LPM is tested for different conditions with varying mass fraction 0.5-1% as working coolant depends on the sun radiation availability.

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Table- I Technical specifications of PSTC

Parameters	Specifications	Units
Latitude angle(ϕ)	$12^0 18^1 45^{11}$N	…..
Longitude(l)	72^0 $50^1 5^{11}$W	…..
Azimuth angle (γ)	256.35^0	…..
Solar irradiation(GNI)	1000	w /m^2
Width of the collector(W)	1.75	mts
Length of the collector(L)	1.75	mts
Aperture area(A_a)	3.01805	m^2
Rim angle(ψ)	90^0	…..
Focal length(f)	0.5345	mts
Height of parabola(h)	0.3543	mts
Concentration ratio(CR)	21.32	…..
Reflectivity(α)	0.96	…..
Absorptivity(ρ)	0.92	…..
Transmissivity(τ)	0.04	…..
Absorber thickness(t)	1.5	mm
Outside glass envelope diameter(d_{go})	110	mm
Inside glass envelope diameter(d_{gi})	70	mm
Outer receiver tube diameter(d_o)	25.4	mm
Density of graphene oxide(ρ_{rGO})	1910	kg/m^3

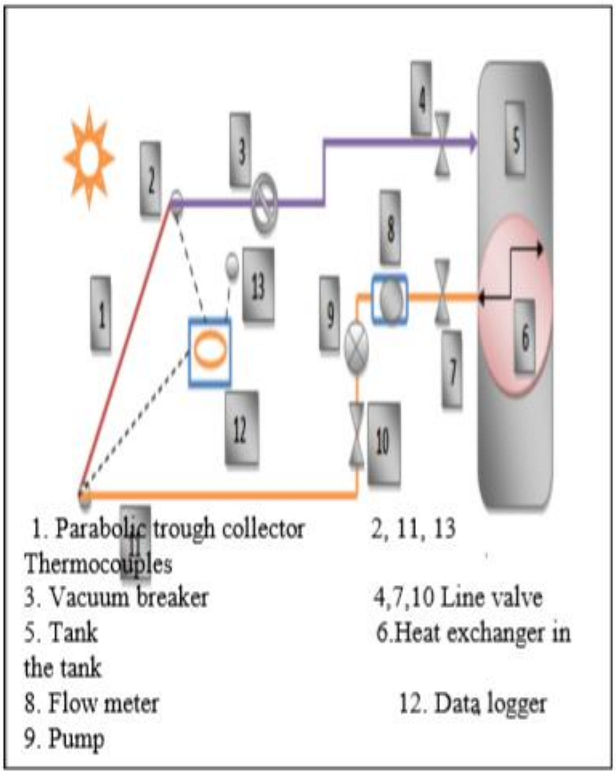

Fig.1 The flow diagram of PSTC

Fig.2 The working setup of PSTC

B. The preparation of nanofluid

For preparing reduced graphene oxide as nanofluid concentration sample solution by two-step techniques were used. The chemical composition of rGO nanofluid as shown in Table-II.

Table-II Chemical composition of rGO nanoparticles

Elements	Carbon	Oxygen	Hydrogen	Sulphur
Percentage (%)	90	8	<1	<1

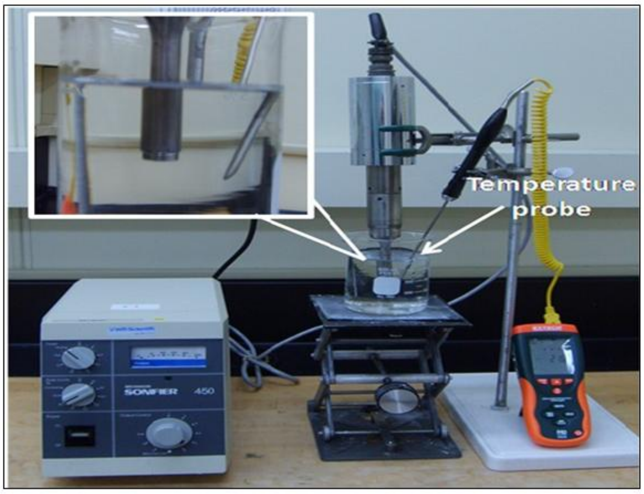

Fig 3.The nanofluid sample preparation of rGO/water

The thickness of nanoparticles were selected 10nm,the purity of rGO(99%),the lateral dimensions of particles 5-10µm,the average layers of particles 4-8 numbers, and surface area 210m^2/g. In a first step, the available rGO nanoparticle in the market as per required particle size (Platonic Nanotech Lab) was provided After this, the amount of nanoparticles were suspended in fresh water as per required sample solution on the vertical ultrasonic bath mixer (NCES-11) for crushing large agglomeration of nanoparticles in a beaker for a duration of 60min to make stable sample using a magnetic stirrer (see Fig.3).Later, the device produced a homogenous suspension of nanofluid in pure water without no surfactants. The behavior of dispersion of nanoparticles was showed in (TEM) Transmission Electronic Microscopy (see Fig.4).

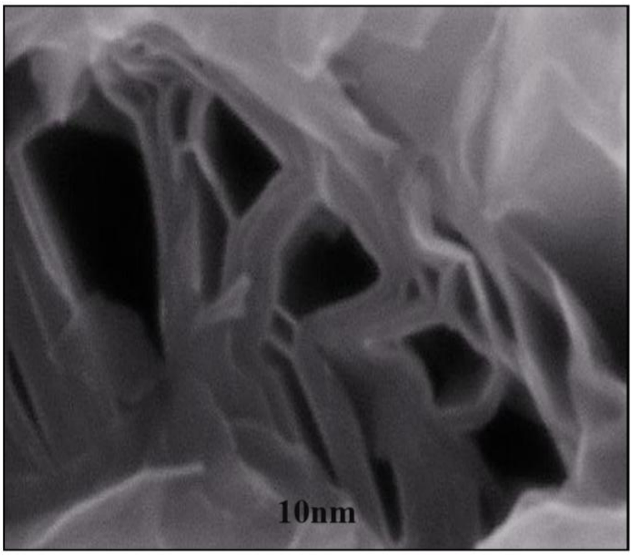

Fig 4.The images of TEM on rGO/water nanofluid

III. TESTING METHODOLOGY

The following factor influencing on thermal performance such as incident radiation, temperature variation, and flow rate. For the measurements of incoming radiation, rate of heat gain and fluid coolant passing on the collector consider as quasi-static condition.

A. The time constant

The heat capacity is mainly depending on duration of time intervals to establish time-reaction and also enabling time-dependent behavior of a transient condition. After fluctuation in the incident radiation on the reflecting mirror surfaces, the time constants of intervals is required to leaves out fluid coolant to achieve 65% under Quasi-static condition. The time constant can be calculated by the relation.

$$\frac{1}{e} = \frac{T_{0,\tau} - T_i}{T_{0,i} - T_i} \quad (1)$$

B. The time attempt

For the collection data period and specific time intervals prior to data recorded is collectively known as Pre-data period. We prepared the data period under steady-state conditions according to ASHARE standards 93-86[24]. For steady-state conditions, the fluid flow rate and irradiation must be falls within ±1.5%, ±55w/m^2 respectively. For the complete testing period, the fluid inlet temperature was minimized to ±0.1K and temperatures of surrounding condition not exceed to be ±1.5K.

C. The governing equations

The study the performance at various fluid inlet temperatures conditions. We followed the guidelines of ASHARE standards 93-86. Each tested data were arranged and taken into one-point analysis, other data neglected. In the next step, the fluid flow of nanofluid or water, fluid inlet and outlet temperatures established by measuring instruments. Thereafter, energy gained on the collector Eq. (2) and amount of energy lost from tube was expressed in connection of useful energy as shown in Eq. (3).

$$Q_u = mC_p\left(T_0 - T\right) \quad (2)$$

$$Q_u = A_c F_R G_T\left(\tau\alpha\right) - U_L\left(T_i - T_a\right) \quad (3)$$

Here,(kg/s) m be the fluid flow rate;(w) Q_u be the heat gain;(kJ/kg K) C_{pw} be the specific heat capacity of coolant;(m^2) A_c be the surface area of collector;(^{0}c) T_O,T_i be the fluid inlet and outlet temperatures; (τα) product of absorption-transmittance;(w/m^2-K) U_L be the collector loss coefficient;(w/m^2) G_I be the solar irradiation[25,26];

The specific heat capacity of nanofluid is calculated by Eq.(4).

$$C_{peff} = C_{p,nf}\left(\phi\right) + C_{p,bf}\left(1-\phi\right) \quad (4)$$

Here,(4.18kJ/kg-K) $C_{p,bf}$ be the specific heat of H_2O;(746J/kg-K) $C_{p,nf}$ be the specific heat of rGO as nanofluid; ϕ be the mass fraction of nanofluid[27];

The instantaneous efficiency can be estimated by the relation heat useful energy gained to incident radiation on the collector; Eq.(5) and Eq.(6).

$$\eta_i = \frac{Q_u}{A_c G_T} = mC_{peff}\left(T_o - T_i\right) \quad (5)$$

$$\eta_i = F_R\left(\tau\alpha\right) - F_R U_L\left(\frac{T_i - T_a}{G_T}\right) \quad (6)$$

The F_RU_L and F_R(τα) are constants for the range of temperatures incident on normal conditions. From the Eq.(6) got tested data taken against $\left(\frac{T_i - T_a}{G_T}\right)$ yield as a straight line versus efficiency data values are plotted with (τα)F_R vertical axis intersect to the line.

Table-III The uncertainty results for the experimental data

Parameters	Error percentage (%)
Global irradiance(GNI)	±1.45
Rate of fluid flow(LPM)	±5.54
DT(T_o-T_i)^{0}c	±1.35

To enhance maximum efficiency of collector, the fluid inlet temperature equal to surrounding temperature. Due to loss of energy, it shows the slope line F_RU_L with intersect of horizontal axis is known as a stagnation point [28, 29].

At this point the collector efficiency becomes zero (no fluid allows via collector).

D. The experimental error analysis

As per ASME guidelines, every tested measurement has error and there are no absolute temperatures. The following factors influencing such as unbalanced devices, error in data-recorded, and systems error. These errors affect the results in experimental data and deviated errors are shown in Table.3.For error uncertainties, it found that slightly experimental results varied from desired measurements [30, 31]. The error uncertainty of the collector efficiency is calculated using root-square method Eq.(7)

$$S_n^2 = \left[\left(\frac{\Delta m}{m}\right)^2 + \left(\frac{\Delta\left(T_o - T_i\right)}{\left(T_o - T_i\right)}\right)^2 + \left(\frac{\Delta G}{G}\right)^2\right] \quad (7)$$

Note: the maximum uncertainty was found 5.5% according to the several experimental data

IV. RESULTS AND DISCUSSION

The thermal performance of PSTC with influencing of rGO as nanofluid mainly depends on temperature variation and rate of fluid flow. Each experimental data values recorded under Quasi-static conditions, the average tilting angle fixed 48^0. The PSTC has exposed to solar radiation during the time intervals of 10.00AM to 17.00PM in the year of 2018 and recorded data logged every 10min. These results are presented in graphs with describing the parameters of temperature variations and solar efficiency.

A. The effect of solar radiation

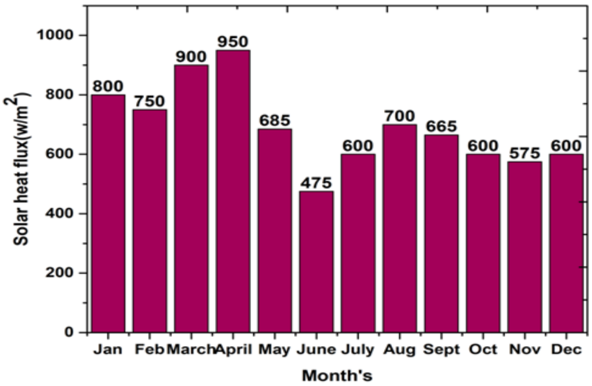

Fig.5 Distribution of solar radiation on collector throughout the year of 2018

The experimental data were performed for the year of 2018 and sky is visible with incident radiation on those testing days. The solar radiation incident on collector was suitable and normal during the tested days. These data chart is like to reported in previous studies (see Fig.5). The distribution of incoming solar radiations falls on collector via used water as fluid coolant. In other hand, the working fluid coolant replace to nanofluid with slightly increasing in incident radiation on collector (see Fig.6). For this effect, it's found that heat transfer ability was improved and receivable energy gain in nanofluid as increased [32, 33]. The principle of Brownian motion was used to study the properties of nanofluid (see Fig.7).

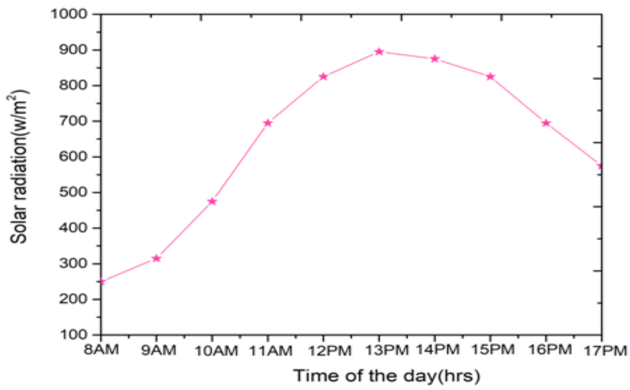

Fig .6 Distribution of solar incident radiation during testing days

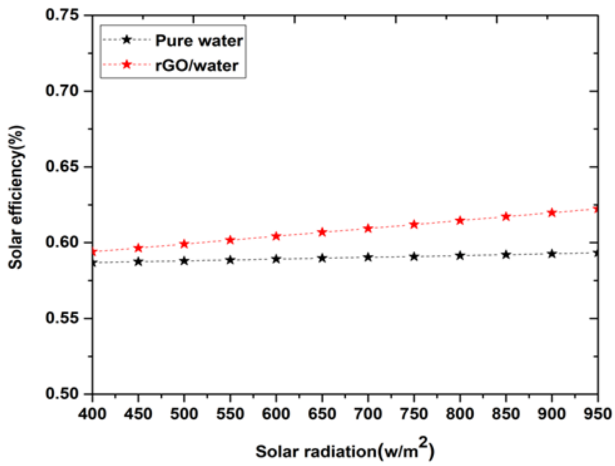

Fig .7 Distribution of solar incident radiation on efficiency with influencing rGO/water and base fluid as coolant

B. The effect of flow rate

To determine the efficiency of PSTC on influencing flow rate with consideration of varying fluid flow by controlling and a regulating valve were used.

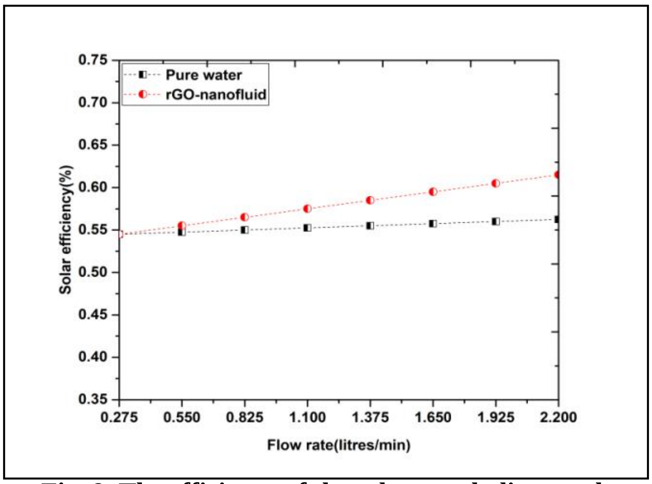

Fig. 8 The efficiency of the solar parabolic trough collector with rGO/water nanofluid and pure water for various flow rates

The suitable range of fluid flow 0.275-2.2LPM was selected and several tests were ministered. The mass fraction of 1% rGO/water as nanofluid and pure water versus collector efficiency was presented in results. For effect of nanofluid as a coolant, the efficiency was increased via increasing fluid flow (see Fig.8).. According to nature of curve shows that increasing the Reynolds number it leads to the heat transfer capability and these result are reasonably agreed with previous work of eristafari etal [34,35]. At meanwhile, an efficiency of the collector increases marginally to higher usage on nanofluid compared with pure water. After examined several experimental results, we come to understand that fluid motion, fluid flow, turbulence particles in nanofluid helps to increases the rate of heat transfer ability and subsequently increasing in efficiency[36,37].

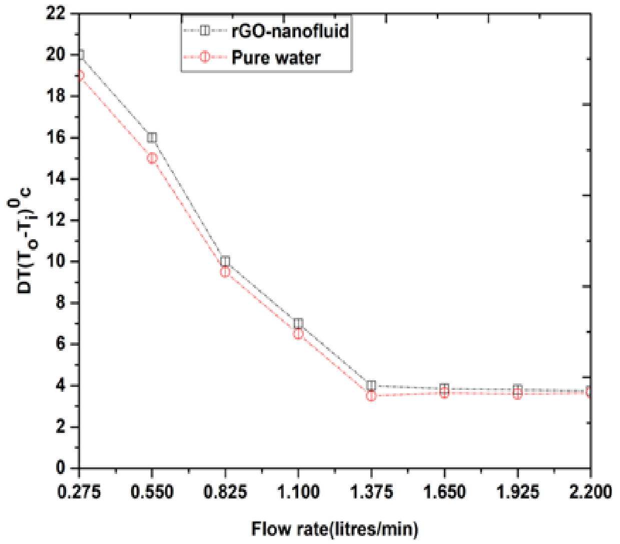

Fig. 9 The variation of fluid outlet and inlet temperatures on nanofluid versus fluid flow rate

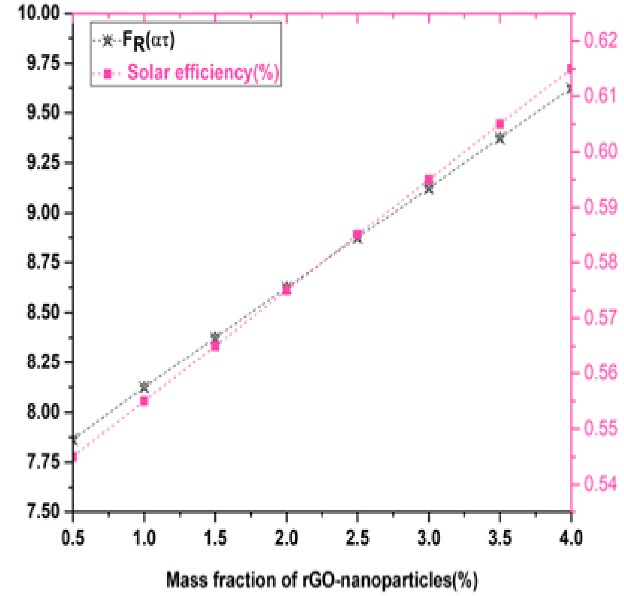

Fig. 10 The variation of mass fraction of rGO-nanofluid and thermal removal factor versus solar efficiency

A change in fluid temperature (ΔT) was decreased while increasing the fluid flow (see Fig.9). The heat removal factor plays a major role in PSTC for both fluid coolants with a product of (τα) absorption-transmittance (see Table 4). The effect of mass fraction rGO/water on solar efficiency with heat removal factor slope shows that increasing optical properties via solar radiation also increased compared to the pure water (see Fig.10).

C. The comparison study between nanofluid and water

The PSTC was tested with rGO/water nanofluid and pure water as fluid coolants. The effect of nanofluid is slightly higher than base fluid as illustrated (see Fig.11). The effect of mass fraction 0.5-1% as nanofluid is increased while fluid outlet temperature of the collector was improved compared to pure water. From this observation, it found that nanofluid have more efficient in heat transfer capability owing to pure water. For main reason is nanofluid conductivity not more significantly higher than base fluids.

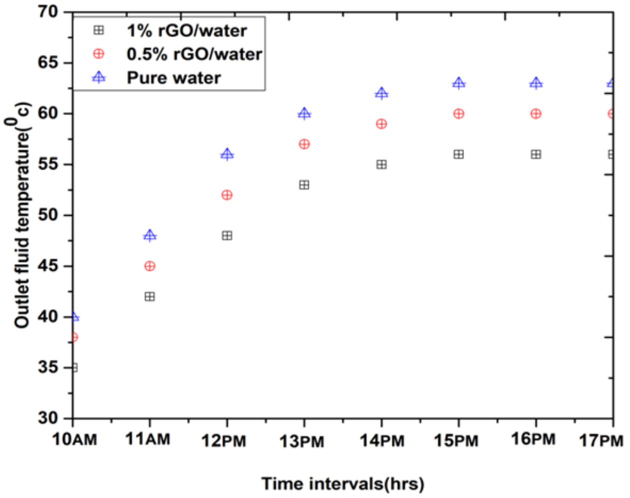

Fig .11 The comparison difference of outlet temperature on effect of mass fraction of nanofluid during testing days

V. CONCLUSION

According to ASHARE standards 93-86 was followed to enhance thermal behavior at different flow rate 0.275-2.2LPM. The present investigations on PSTC were using rGO/water nanofluid and pure water with consideration of mass fraction 0.5-1% as fluid coolant. The following points were summarized with reference of previous studies.

- The solar radiation incident on collector was increased in summer and decreased in winter season for both fluid coolants.
- The influencing of nanofluid on PSTC was increased the efficiency compared to pure water. However, it found that no apparent effect on the both working coolant owing with solar radiation.
- The solar efficiency of the PSTC is slightly increased by increasing fluid flow rate. At higher fluid flow rates, the heat transfer ability is more effective in influencing of nanofluid compare to pure water.
- The DT(T_o-T_i)of the nanofluid is decreased while increasing the fluid flow rate and this trend of slope shows that reasonable increased in efficiency of the collector.
- The outlet fluid temperature on collector was increased, when the mass fraction using 1% as fluid coolant. It's observed that thermal performances of the PSTC were improved compared to previous studies.

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