International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-9 Issue-2, December, 2019

Particle Optimization of Ceo2/Water Nanofluids in Flat Plate Solar Collector

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Abstract : ***The present research focuses on the role of CeO_2/water nanofluid for estimating the performance of flat plate solar collector in respect of energetic and exergetic performance. Based on our experimental findings on varying mass flow rate, the present analysis focuses on a wide range of concentrations to find optimum volume concentration for which thermal performance is maximum. CeO_2/water nanofluid exhibits high thermal conductivity improvement (~41.7%at 1.5% volume concentration) and comparatively lower dynamic viscosity. Performance evaluation of flat plate collector is based on first law analysis and qualitative nature of energy flow based on second law analysis. Experiments indicate that for~1.0% particle volume concentration at a mass flow rate of 0.03 kg/s, maximum collector efficiency is obtained up to 57.1% instead of water as the base fluid. Exergetic efficiency observed 84.6%at optimum concentration (~1.0% particle volume) of nanofluid at0.01 kg/s flow rate.***

Keywords: Flat plate collector, Nanofluid, Exergy Efficiency, Energy efficiency, Optimization.

I. INTRODUCTION

Solar collectors with flat plate are most primitive type of collectors but these collectors are suffered from relatively low efficiency with the use of conventional fluids. To overcome this critical problem, an innovative type of fluid was invented by Choi [1] (1995) which is called "Nanofluid". Nowadays, most of the scientists and engineers are focusing on new nanotechnology and most efficient devices to harness the solar energy.Nanoparticles are the innovative materials with base fluids to enhance the heat absorbing transporting ability. Verma *et al.*[2]did research on solar collector of flat plate type for finding energetic and exergetic performance by using different oxide of nanoparticles in DM water. He had evaluated six different varieties of nanofluids having graphene, MWCNTs, Al_2O_3, SiO_2, TiO_2 and CuO as nanoparticles with base fluid water. Pandey *et al.*[3] reviewed on different methods to improve collector efficiency. They studied the various different numerical models and he found feasibility about the graphene/water nanofluid because of very high thermal conductivity and stability of fluid. Yousefi*et al.* [4] had investigated the collector efficiency with or without the added surface active agent with Al_2O_3-water nanofluid experimentally and illustrated for 0.2wt% of the nanofluid, efficiency increased up to 28.3% with respect to conventional fluids like water, ethylene glycol etc. Muhammad *et al.*[5] have reviewed about the usage of nanofluids to improve the thermal performance of collectors. He had studied about the recent research work on FPC, ETC and DAC related to enhancement in performance of all three collectors and suggested about the hybrid type of nanofluids (two nanoparticles + base fluid) for heat transfer enhancement in FPSC.

Tiwari *et al.*[6] reviewed the usage of nanoparticles in collectors. He represents about the progressive evaluation on the analysis of applications of nanoparticles with base fluids for enhancing the instant collector efficiency and give more attention on thermal properties, optical properties, magnetic properties, electrical properties, convective heat transfer coefficient. Javadi*et al.*[7]did research on solar collectors for identifying the performance by using nanofluids. Study reveals that in direct absorption solar collector there is tremendous change in optical properties by using nanoparticles. Authors suggested future research workto minimize uncertainties in nanofluids by doing study in 2-phase manner.Sharafeldin*et al.*[8]did study on flat plate solar collector for finding the performance by using WO_3/Water nanofluid. Suman *et al.*[9]has reviewed comprehensively methodologies used to examined the collector performance. He reported that improvement in various solar collectors can be enhanced by applying collector coating, geometrical modifications and stability of nanoparticles in ethylene glycol.

Tiwari *et al.*[10]concentrated on the role of nanofluids in thermal properties (thermal conductivity, viscosity, density, specific heat, particle size) and for the most part on volume division dependent on exploratory observations. Authors suggest that more potential research is still awaited to get the long-term stability for incredible performance enhancement.Said *et al.*[11] has experimentally investigated the energy and exergy analysis by using Al_2O_3 nanofluid having different size of nanoparticles diameter, the two different sizes 13 nm and 20 nm of Al_2O_3 nanoparticles were used and found that thermal conductivity enhancement and efficiency was highest for 13 nm Al_2O_3 nanoparticle, compared to that of 20 nm Al_2O_3 nanoparticle. Shojaeizadeh*et al.*[12]did investigation on Al_2O_3/Water nanofluid for improving the performance of collector and solar radiation, result reveals 0.72% exergy efficiency. Sharafeldin*et al.*[13] had carried out the researchwith dispersing the cerium oxide nanoparticles in base fluid like water experimentally. Kasaeian*et al.*[14]study the solar energy system by using nanofluids.

Revised Manuscript Received on December 30, 2019.
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This research illustrated solar thermal electronics, photovoltaic and different variety of solar collectors. Verma *et al.*[15]did research on collector for finding the efficiency at different flow rates of nanofluids. Result shows 31.64% of collector efficiency was observed by using Al_2O_3/Water nanofluid with 1.5% volume concentration.Sarsam*et al.*[16] carried some reviews on FPSC at different oxides of nanoparticles.

Previous experimental and theoretical investigations are covered in this review paper and concluded that application of nanofluids effectively enhance the thermophysical properties and efficiency of flat plate collectors and authors also suggest that further research is needed with high thermal conductivity in some newly-developed nanoparticles.Nagarajan *et al.*[17] reviewed the nanofluids for solar collectors applications. A comprehensive study has been carried out on the application of solar collector with nanofluids and thermophysical properties of nanofluids have compiled. Zamzamian*et al.*[18]did research on synthesized Cu/EG nanofluid by using volume concentration (0.1%, 0.2%, and 0.3%) for finding thermal properties at varying temperatures. Dharmalingam*et al.*[19]studied an about the effect of various nanomaterials at different particle volume concentrations because of inherent thermal characteristics of nanofluids. This paper summarized about latest research work, development of enhancing heat transfer by using nanofluids, analyzing the challenges and their physical and chemical properties. Genc*et al.* [20]did experimental research on solar collector for finding thermal performance by using Al_2O_3/Water nanofluid, result found 74.39% of maximum collector efficiency with 3% volume concentration in the month of July. Jouybari*et al.*[21]study the effect of different types of nanoparticles and various porous channels in the field of FPSC. He reported that the thermal conductivity has a considerable improvement in thermal performance using SiO_2/deionized water nanofluids in FPSC as compare to other conventional nanofluids. Sharma*et al.*[22] reviewed about the rheological behavior in nanofluids and reported that the nanofluids which exhibit Newtonian behavior for spherical nanoparticles have a very low value of shear rate. Verma*et al.*[23-24]studied the hybrid nanofluid in collectors for finding thermal characteristics. They found that 71.54% and 70.55% of exergetic and energetic efficiency by using hybrid MgO nanofluid and 70.63% and 69.11% by using hybrid CuO nanofluid. They concluded that the MgO hybrid nano fluids were more efficient than CuO hybrid nanofluids and more closure to MWCNTs-water fluid. The review of literature shows there is a need for more comprehensive analysis of a wide range of nanofluids, their concentrations and particle sizes.

The present work is concerned with an impact analysis of a wide spectrum of CeO_2/water nanofluids on energetic and exergetic performance of flat plate solar collectors. Analysis of energetic performance has focused on qualitative behavior of solar collector in converting solar energy into other forms for performing useful functions. Exergy analysis has also provided useful statisticson optimum design of solar thermal systems and choice of nanofluids with optimum concentration. A wide range of concentrationsof CeO_2/water nanofluidhave been examined to find optimum vol. concentration for which thermal performance is maximum.

II. EXPERIMENTAL CONSIDERATION

A. Synthesis and measurement of thermophysical properties

In this present work, the synthesis of nanofluid which is used for experimentation and determination of thermophysical property is presented**.**Synthesis of CeO_2/water nanofluid is done by mixing of nanofluid in a beaker filled with double distilled water. Two step methods is most effective method for preparation of nanofluid and samples has been prepared for experimentation of flat plate collector and characterization of nanofluid.In this method, CeO_2-water nanoparticles with 30 nm particle size are dispersed into the base fluid in the form of powder. A mechanical mixer is used for proper mixing of nanoparticles into the base fluid for one hour and then this solution is dispersed into the De-mineralized water as base fluid using Homogenizer for about 4 to 5 hours. Ultra-Sonicator is used for mixed the nanofluid properly to avoid agglomeration and sedimentation in solution. The samples of required volume concentration are prepared in the following: 0.25%, 0.50%, 0.75%, 1.0%, 1.25% and 1.50% and homogeneoussolution are obtained continuously for 6-8 h using ultrasonic vibrator. To break down the agglomerated particles and dispersed the nanoparticles properly in solution, a magnetic stirrer is used. To get the long-term stability, a surfactant (Triton X-100) is added in a very small quantity by the supplier who manufactures the nanofluidwithout adversely affecting basic characteristics of nanoparticles.To attain proper stability of nanoparticles in base fluid, repetition of mechanical mixing and ultrasonic sonification is done at the time of performing test of each sample.

The measurement of nanofluid thermal conductivity was done by using transient hot-wire apparatus (KD-2 Thermal Properties Analyzer, Decagon Devices, Inc., USA). Similarly, viscosity measurement is done by using LVDV-II+ProBrookfieldviscometer (cone and plate, Spindle-CPE42).

B. Data Interpretation

The helpful heat energy rate can likewise be communicated in terms of the distinction between solar radiation energy absorbed by solar collector and the energy lost from the collector absorber plate as given by Eq. (1).

$$Q_u=A_cF_R[I_t(\tau_o\alpha_o)-U_L(T_i-T_a)] \qquad (1)$$

Where A_c is the collector gross area, F_R is the collector heat removal factor, I_t is the intensity of solar radiation normal to the collector, τ_o and α_o is transmittance and absorptance, T_a is the ambient temperature and U_L is the overall heat loss coefficient.

Now, heat removal factor, F_R can be calculated by the following expression used in Eq. (2).

$$F_R = \frac{\dot{m}C_p(T_o - T_i)}{A_c[I_t(\tau_o\alpha_o) - U_L(T_i - T_a)]} \qquad (2)$$

Another formula for heat extraction factor (F_R),

$$F_R = \frac{\dot{m}c_p}{A_c}\left[1 - \exp\left(-\frac{U_L F^{/} A_C}{\dot{m}c_p}\right)\right] \quad (3)$$

Here, F/ is the collector efficiency factor.

The thermal efficiency of flat plate solar collector is explained as ratio of the useful power extracted from the collector to the input energy coming from the solar radiations received by the absorber plate of the solar flat plate collector.

Collector efficiency can be calculated with the use of Eq. (4). In addition, experiments must be done under steady state conditions.

$$\eta_c = \frac{Q_u}{A_c I_t} (4)$$

Where η_i is the instantaneous efficiency of flat plate solar collector or simply says collector efficiency.

Further, the instantaneous efficiency can be described by Eq. (5) or (6) as follows:

$$\eta_c = \frac{\rho V C_p (T_o - T_i)}{A_c I_t} (5)$$

$$\eta_c = \frac{A_c F_R [I_t(\tau_o \alpha_o) - U_L(T_i - T_a)]}{A_c I_t} (6)$$

$$\eta_c = F_R(\tau_o \alpha_o) - F_R U_L \left(\frac{T_i - T_a}{I_t}\right) \quad (7)$$

First law of thermodynamics (energy analysis):

Thermal energy balance equation

$$m_p C_p \left(dT_{P,avg}/dt\right) + \dot{m}C_p \left(T_{out} - T_{in}\right) = \eta_o I A_c - U_C\left(T_{P,avg} - T_e\right)T_c \quad (8)$$

$$\dot{E}_{x,heat} - \dot{E}_{x,work} - \dot{E}_{x,mass,in} - \dot{E}_{x,mass,out} = \dot{E}_{x,dest} \quad (9)$$

Substituting terms into this equation yields:

$$\sum\left(1 - \frac{T_a}{T_{Sur}}\right)\dot{Q}_S - \dot{W} + \sum \dot{m}_{in}\psi_{in} - \sum \dot{m}_{out}\psi_{out} = \dot{E}_{x,dest} \quad (10)$$

$$\sum\left(1 - \frac{T_a}{T_{sur}}\right)\dot{Q}_S - \dot{m}\left(h_{out} - h_{in}\right) - T_a\left(s_{out} - s_{in}\right) = \dot{E}_{xdest} \quad (11)$$

Where $\dot{Q}_s$ is the total rate of exergy received from the solar radiation by the collector absorbed area.

$$\dot{Q}_S = I_t\left(\tau\alpha\right) = SA_c \quad (12)$$

The change in enthalpy and entropy of the nanofluid in the collector is:

$$\Delta h = h_{out} - h_{in} = c_{p,nf}\left(T_{f,out} - T_{f,in}\right) \quad (13)$$

$$\Delta S = s_{out} - s_{in} = C_{p,nf} \ln\frac{T_{f,out}}{T_{f,in}} - R\ln\frac{p_{out}}{p_{in}} \quad (14)$$

Where $\dot{E}_{xdest}$ is the exergy loss or irreversibility rate defined as:

$$\dot{E}_{xdest} = T_a \cdot S_{gen} \quad (14)$$

$$\eta_{ex} = 1 - \frac{T_a S_{gen}}{\left[1 - \frac{T_a}{T_s}\right]Q_s} \quad (15)$$

Pumping power and pressure drop:

$$\Delta p = f\frac{\rho V^2}{2}\frac{\Delta l}{d} + k\frac{\rho V^2}{2} \quad (16)$$

$$\Delta n_{ex} = \frac{\Delta \dot{I}}{\dot{E}_{x\,heat}} + \frac{\dot{I}\dot{E}_{x\,heat}}{\dot{E}_{x^2\,heat}} \quad (17)$$

$$\Delta \eta_{gen} = \frac{\Delta \dot{q}_a}{G_c} + \frac{\dot{q}_a \Delta G_c}{G_c^2} \quad (18)$$

Where each error component can be analyzed through the following relations:

$$\Delta E_{xheat} = \left(\frac{\Delta T}{T_s} + \frac{T_a \Delta T}{T_s^2}\right)A_c(\tau\alpha)G_c + \left(1 - \frac{T_a}{T_s}\right)A_c(\tau\alpha)\Delta G_c \quad (19)$$

$$\Delta \dot{I} = T_a \Delta \dot{s}_{gen} + \dot{s}_{gen}\Delta T \quad (20)$$

III. EXPERIMENTAL SETUP

The setup for experiment consists of a flat plate collector, which is capable for trapping the intensity of incident radiation in the form of heat by absorber plate mounted on the surface of the solar collector. Human interaction machine, achiller for heating and cooling nanofluid, rotameters regulate the mass flux rates about 5 l/min. Flow direction is adjusted with the use of athree-way solenoid valve, two pumps (500 W) are used for circulating the flow and pressure is measured by a pressure indicator for both DM water and nanofluid.Table 1 shows the technical specifications of FPSC. The photograph of the experimental setup is shown in Fig. 1.

IV. EXPERIMENTAL PROCEDURE

Apparatus consist of the solar module with 500 W capacity of 8 halogen lights having an adjustable inclination. The radiation intensity has been varied with increasing the power of halogen lights with a knob.The maximum intensity of this system is observed up to ~1300 W/m^2 (avg.). Before circulating the nanofluid and DM water as the base fluid in the circuit, set temperature of both DM water and nanofluid should be maintained properly by using chiller and heater devices. Circulation of both DM water and nanofluid should be one time. For storage of nanofluid and DM water, two insulated steel tanks are preferredwith the separate circuit having 10 L capacity. For circulation of nanofluid and DM water, two separate pumps of 500 W are required because of force mode of experimental setup. Pressure indicators are used to measure the loss of pressure in kP$_a$ between both inlet and outlet. Three-way by pass valves are used for testing of DM water and nanofluid. Rotameters are used tomeasure flow discharge with a range from 0 to 5 lpm and least count 0.1 lpm.

Solar irradiations are measured by a precise instrument i.e.Solarimeter (TENMARS-TM-207) which is capable to measure solar intensity from 0 to 2200 W/m^2. To measure the inlet or set temperature and outlet temperature (T-2 and T-1), K-type thermocouples are used as shown in the schematic. 6 K-type thermocouples are used to measure plate temperature and these thermocouples are attached with the surface of the absorber plate. Modeler is attached with the maximum capacity of 4 kW at a temperature of ~3000 K in the plate of a solar collector. The intensity of solar radiation is not steady in the whole universe, so modeler is required for steady state solar radiation where the thermal efficiency can be observed maximum compared to the actual source of solar energy. This is the complete working of the experimental setup.

Table- I:Technical specifications of flat plate collector

Specification	Dimension	Unit
Absorption area	0.375	m^2
Back insulation thickness	5	cm
Collector occupied area	75 × 50 × 6.3	cm
Collector riser tube outer dia (D_o)	1	cm
Collector riser tube inner dia (D_i)	0.8	cm
Center distance between tubes	3	cm
Conductivity of back insulation	0.04	W/m K
Edge area of collector	0.1572	m^2
Emissivity of absorbing	0.12	dimensionless
Effective absorptivity transmitivity product	0.816	dimensionless
Emissivity of glass cover	0.88	dimensionless
Glazing thickness	4	mm
Number of glazing plate	76 × 51 × 6.5	1
Thermal conductivity of absorbing plate	390	W/m K
Weight of collector	15	kg

Fig. 1. Photograph of the experimental setup

V. UNCERTAINTY ANALYSIS

At the time of performing experimental work in the laboratory, some uncertainties have arisen which are pointed out in Table 2. Uncertainty analysis is required to calibrate the equipments for accurate measurements in experimental work for determination of collector efficiency. Uncertainty depends on the specific heat, collector area, solar irradiation, mass flux rates and inlet and outlet temperature of working fluid.

Table- II: Uncertainties during measurement of experimental parameters

Variable	Uncertainty value (%)
Nanofluid inlet temperature	±0.15
Nanofluid outlet temperature	±0.15
Hot inlet temperature	±0.15
Hot outlet temperature	±0.15
Nanofluid side mass flux rate	±2.4
Hot side mass flux rate	±2.4
Nanofluid side differential pressure	±2.2
Hot side differential pressure	±2.2
Nanofluid thermal conductivity measurements	±4.5
Nanofluid viscosity measurements	±3.5
Nanofluid density measurements	±4.0
Nanofluid specific heat measurements	±4.5

VI. RESULTS AND DISCUSSIONS

Experimental results are indicated that the thermal conductivity increases linearly at different volume concentration and varying temperatures as shown in Fig. 2.Thermal conductivity mainly depends on the temperatures because of the energized nanoparticles with the molecules of the base fluid. It can be concluded that the nanofluids have lot of potential as compare to base fluids to enhance the heat transportability. Variation in performance parameters to enhance thermal conductivity is followed as: type of base fluid, particle volume fraction, pH value, temperature, the shape of a nanoparticle, type of material, surfactant and size of nanoparticles. From experimental data, thermal conductivity is observed for 55ºC are 0.634 for DM water and 0.781, 0.786, 0.798, 0.807, 0.815, 0.825 W/m K for volume concentration at 0.25%, 0.50%, 0.75%, 1.0%, 1.25% and 1.5%. Similarly for 60ºC, thermal conductivity for DM water is 0.638 and 0.799, 0.806, 0.815, 0.822, 0.831, 0.842 W/m K for same volume concentration and for 65ºC, thermal conductivity for DM water is 0.643 and 0.811, 0.821, 0.830, 0.839, 0.848, 0.861 W/m K for same volume concentration and for 70ºC, thermal conductivity for DM water is 0.648 and 0.834, 0.840, 0.848, 0.856, 0.865, 0.883 W/m K for same volume fraction and for 75ºC, thermal conductivity for DM water is 0.653 and 0.849, 0.861, 0.868, 0.878, 0.887, 0.909 W/m K for same volume concentration and for 80ºC, thermal conductivity for DM water is 0.659 and 0.865, 0.883, 0.892, 0.901, 0.910, 0.934 W/m K for same volume concentration respectively.

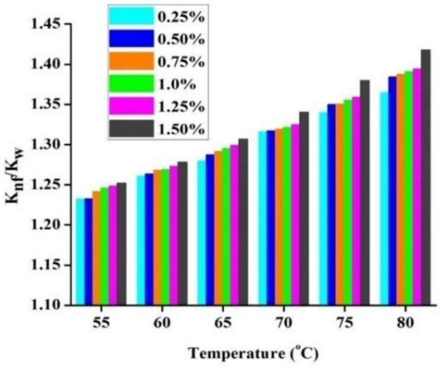

Fig. 2. Graph between K_{nf}/K_w and temperature

Viscosity is an inherent thermophysical property of fluids which arises due to frictional resistance between the adjacent layer of nanoparticles and fluids. It has the ability to transport heat of energy systems to improve the performance of the nanofluids. The viscosity of the used nanofluid is measured using the LVDV-II + Pro Brookfield Digital Viscometer Brookfield Engineering Laboratories, Inc.). The repeatability and accuracy are ± 1.0% and ± 0.2% respectively of the viscometer which is indicated by the manufacturer. The calibration of the viscometer is done with the DM water before the measurements and maximum uncertainty is computed lower than 0.2% in the measurement of viscosity. To set the temperatures of used nanofluid at different degrees, a computer controlled temperature bath is used for accurate measurement of viscosity. Pressure drop and fractional loss can be determined correctly due to variation in viscosity by experimental observation. Viscosity of the used nanofluid is measured at varying temperatures (55ºC, 60ºC, 65ºC, 70ºC, 75ºC and 80ºC) and volume concentration (0.25%, 0.50%, 0.75%, 1.0%, 1.25% and 1.50%) respectively.From the observation of experimental data, it is concluded that the viscosity increases linearly with particle volume fraction due to cohesive forces among like and unlike molecules increases at higher particle volume concentration as shown in Fig. 3 for CeO_2/water based nanofluid respectively. Further viscosity decreases with an increase in temperature because of fall in cohesive forces predominantly and across the adjacent layers, the viscosity increases marginally due to enhanced momentum transfer. Viscosity is more expressive in liquids due to cohesive forces than due to momentum transfer across the adjacent layers of the fluids.

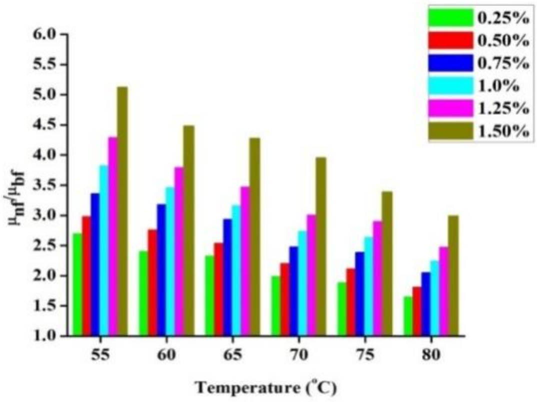

Fig. 3. Graph between ratio of viscosity versus temperature

Experimental observation of flat plate collector is administrated to find out variation in collector efficiency at varying mass flow rates (0.01 kg/s, 0.02 kg/s, 0.03 kg/s, 0.04 kg/s and 0.05 kg/s) and at different particle volume concentration (0.25%, 0.50%, 0.75%, 1.0%, 1.25%, 1.50% and 2.0%). Fig. 4 and 5 show the relation between collector efficiency and particle concentration at varying mass flow rates. In this graph, collector efficiency increases for each mass flow rate of nanofluid with volume concentration up to a certain point of volume concentration (1%) and decreases the collector efficiency with particle concentration after this valuable point of concentration. Experimental results exhibit that the maximum efficiency of flat plate collector is observed 57.1% at optimum particle concentration (vol 1%) with 0.03 kg/s mass flow raterespectively.

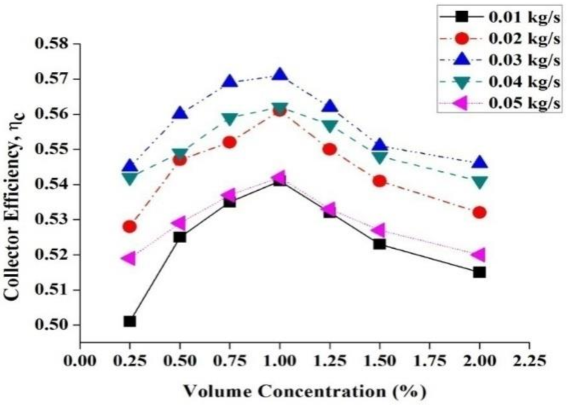

Fig. 4. Collector efficiency versus Volume fraction

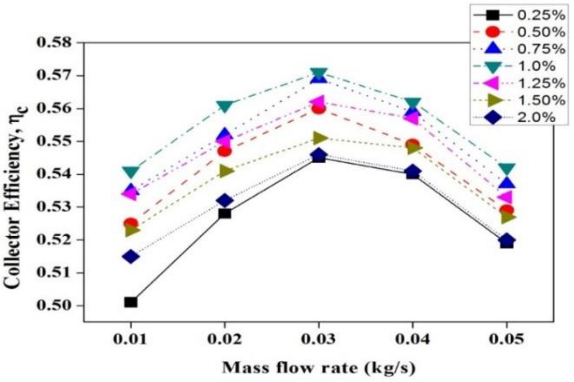

Fig. 5. Collector efficiency versus mass flow rate

Figure 6 illustrates the collector efficiency and reduced temperature difference parameter at the volume concentration of 0.25% to 2%. From the observed data, the efficiency of flat plate collector is inversely proportional to temperature reduced parameter at different particle concentrations. It means collector efficiency increases with decreasing the temperature reduced parameter. Experimental results shows that the maximum efficiency is observed 65.3% at optimum particle concentration (vol 1%) with temperature reduced parameter of 0.005 m^2 K/W and minimum collector efficiency is measured 54.6% at temperature reduced parameter of 0.02 m^2 K/W with particle volume fraction of 2% respectively. So, the temperature reduced parameter should be minimum for enhancement in efficiency of flat plate collector.

The intensity of radiation is the heart of any kind of collector because collector efficiency depends on solar intensity at varying particle concentrations from 0.25% to 2%. Results illustrate that the maximum collector efficiency is obtained 58.1% at an optimum particle concentration (vol 1%) with solar intensity of 700 W/m^2 and minimum collector efficiency is observed 43.1% at the intensity of 300 W/m^2 with concentration of 2% respectively. From experimental data, collector efficiency decreases beyond optimal values as shown in Figure 7.

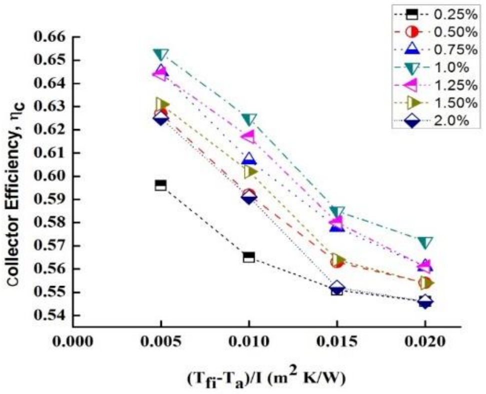

Fig. 6. Collector efficiency versus reduced temperature difference parameter

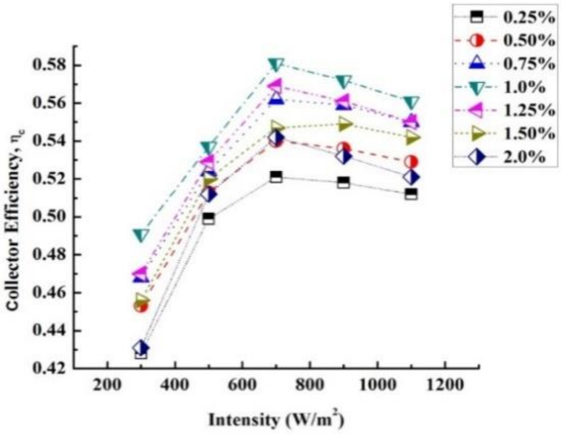

Fig. 7.Graph between collector efficiency and radiation intensity

Entropy generation is the drawback for enhancement in collector performance which encourage to move in the field of nanotechnology.Entropy generation is determined from experimental data and plotted the graph as shown in Fig. 8at varying the mass flow rates (0.01 kg/s, 0.02 kg/s, 0.03 kg/s, 0.04 kg/s and 0.05 kg/s) and at different particle volume concentration (0.25%, 0.50%, 0.75%, 1.0%, 1.25%, 1.50% and 2.0%). From the measured values, the entropy generation for DM water is found to be maximum 0.374 W/K at a mass flow rate of 0.05 kg/s. Entropy generation for all the particle volume concentration of CeO$_2$-water nanofluid is minimum in comparison with base fluid. Results shows that the minimum entropy generation is determined 0.03 W/K at optimum particle concentration (vol 1%) with mass flow rate of 0.01 kg/s.

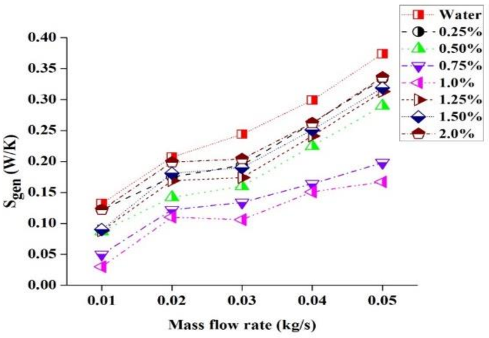

Fig. 8. Entropy generation versus mass flow rate

The graph between exergetic efficiency and mass flow rate is presented in Fig. 9 and illustrates that the exergetic efficiency increases with decreasing the mass flow rate of DM water and nanofluid at all volume concentrations. Exergetic efficiency is defined as whatever radiation incident on the flat plate solar collector that irradiations absorbed by the absorber plate and absorber plate converts these irradiations in the form of heat energy. This heat energy goes into the copper tubes which contains fluids in the form of liquids. There are several losses i.e. top losses, bottom losses, edge losses etc. occurred in the whole process. Apart from these losses, whatever energy is available that heat energy is useful energy and this useful energy is known as exergetic energy and this exergetic energy is required to determine true exergetic efficiency.

From the measurement of experimental data, it is observed that the maximum exergetic efficiency is obtained 84.6% at optimum particle concentration (vol 1.0%) with decreasing the rate of mass flow (0.01 kg/s) and minimum exergetic efficiency is calculated 24.2% at 0.05 kg/smass flow rate of base fluid. Results exhibits that the exergy efficiency increases with decreasing the mass flow rates of DM water and nanofluid but exergy efficiency is found higher for each particle volume concentration of CeO$_2$-water nanofluid in comparison with base fluid. From observing all the experimental results, it exhibits that the nanofluids have superior thermal properties to enhance the performance of the flat plate solar collector.

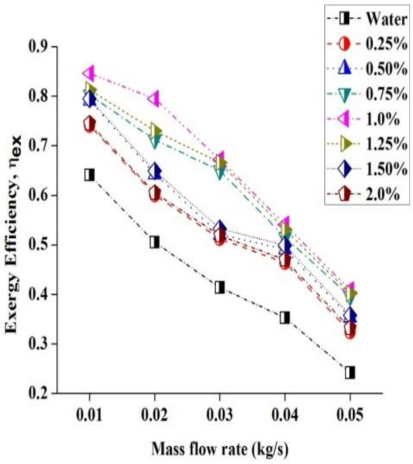

Fig. 9. Graph between exergetic efficiency and mass flow rate

VII. CONCLUSIONS

In present work, the impact of mass flow rate and particle volume fraction on the thermal performance of the flat plate collector is experimentally observed. The systematic measurement of all the related thermophysical properties (density, specific heat, viscosity and thermal conductivity) involved in heat exchanging processes are measured experimentally for CeO_2/water nanofluids at different particle volume concentration (0.25%~2.0%) and at different temperatures (55ºC~ 80ºC). On the basis of various experiment, it has been found that 1.0% volume concentration is optimum for different operating conditions. The finding reveals that a use of CeO_2/water at optimum particle volume concentration and 0.03 kg/s mass flow rate, maximum collector efficiency has been calculated 57.1%.At 0.005 m^2 K/W temperature reduced parameter and optimum volume fraction, efficiency is observed 65.3% and for 700 W/m^2 intensity of radiation, maximum instantaneous efficiency is found 58.1% at optimum concentration. Exergy efficiency is vital parameter to improve the thermal performance of flat plate collector. For 0.01 kg/s mass flow rate and optimum concentration (vol 1.0%), exergetic efficiency is obtained 84.6%.Highest entropy generation has observed 0.374 W/K at 0.05 kg/s mass flow rate with the use of base fluid which is the major drawback for improvement in performance of flat plate solar collector.

VIII. FUTURERECOMMENDATIONS

- Long-term stability of nanofluids suspension is still needed more attention.
- Hybrid nanofluids will be the new challenging area for researchers and scientists.
- Research should be carried out on the effect of particle shape on thermal performance of solar system.
- Practical applications of usage of nanofluid are still in critical phase due to the formation of sedimentation, agglomeration and clogging in a flow path.

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Retrieval Number: B3476129219/2019©BEIESP
DOI: 10.35940/ijeat.B3476.129219
Journal Website: www.ijeat.org

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