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Augmentation of the Thermal Efficiency of PTC using CeO_2 Nanofluid

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Abstract:In the current scenario, experts largely focused on mi niaturizing devices and energy efficiency during the development of solar system.In the present study, nanofluid is used as a working fluid to see its effect on the thermal performance of PTC. The Thermal analysis of PTC heating water using CeO_2 nanofluids as a working fluid is presented. The experimentation were carried out using cerium oxide nanofluid, water and synthetic oilThe result shows hat CeO_2 nanofluid can be a good choice as a working fluid for smooth flow condition to use in PTC rather than water or any other synthetic oil. Experiment result shows, CeO_2 - water can increase thermal efficiency by 2.66 times w.r.t water and 1.7 times w.r.t. synthetic oil.

Keywords : PTC, Nanofluids, Thermal Efficiency, Voumteric concentration.

I. INTRODUCTION

Power has been a major need to survive on the planet Earth. Conventional resources also play a major role in meeting the demand for energy use in the manufacturing, agricultural and household sectors. Conventional resources have their own limits. These resources creates a lot of pollution as well as they are depleting the by the day by day use. Due to these problem researchers started to work on sources of energy which are pollution free and more amount of energy can be derived from them. Solar energy is one of the dominating source of energy that can fulfill the energy demand all alone[1]. The one of the simplest way to utilize the solar energy is its conversion to the thermal energy by the help of solar collectors. These solar collectors can be a part of solar water heater or solar air heater. The use of sloar collects is limited as it has low thermal efficiency. Heat transfer rate between the absorber plate and working fluid is too low. Water and synthetic oils are the conventional heat carrying fluid used in solar collectors but they have low heat carrying capacity and less capacity to absorb heat.

Choi [2] was the first to give the concept of using nanofluid to enhance the heat transfer rate. Bellos and Tzivanidis [3] studied the parametric investigation of nanofluid utilization in PTC. They found that the thermal performance of the collector is increased to 0.6% with nanofluid. Lu et. al. [4] investigated the effect of using copper oxide nano particle mixed with water on the heat transfer rate through CPC. They found that by using copper oxide with water, thermal efficiency augment to 30% with 1.2% copper oxide concentration in water. Later on Liu et. al. [5] investigated that the thermal augmentation by using copper oxide with water is 12.74%. Chaudhari et. al. [6] investigated the use of 0.1% of aluminum oxide with water to see the thermal performance of PTC. They found that the thermal efficiency was augmented by 7% and heat transfer coefficient was augmented by 30% by the use of aluminum oxide with water in PTC. Rios et. al. [7] studied the effect of using aluminum oxide with water in conventional PTC. They found that the thermal efficiency of conventional PTC was enhanced by 24%. Rehan et. al. [8] studied the effect of using aluminum oxide and ferrous oxide in water at different concentration on the thermal performance of PTC. They found that the thermal performance of PTC was increased by 17% for aluminum oxide and 13% by using ferrous oxide. Subramani et. al. [9] studied the consequence of using aluminum oxide - water at different concentration on the thermal performance of PTC. They found that the thermal performance of PTC was increased from 3.5% to 8.5%. The maximum value of thermal performance was found at concentration of less than 0.2%. Later Subramani et. al. [10] studied the effect of using titanium oxide with water at different concentration on the thermal performance of PTC. They found that the thermal performance of PTC was increased about 8.6%. The maximum value of thermal performance was found at concentration of less than 0.2%. Short summary of literature review is shown in Table I.

Table I. Literature studies over nanofluids used in PTC

Investigators	Nanofluids	Findings
Chaudhari et. al. [6]	Al_2O_3+Water	Thermal performance was augmented by 7% and heat transfer coefficient was augmented by 30%
Rios et. al. [7]	Al_2O_3+Water	Thermal performance was augmented by 24%

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Rehan et. al. [8]	Al_2O_3+Water Fe_2O_3+Water	Thermal performance was augmented by 13% by aluminum oxide and 11% by ferrous oxide
Subramani et. al. [9]	Al_2O_3+Water	Thermal performance was augmented by 8.5%
Subramani et. al. [10]	TiO_2+Water	Thermal performance was augmented by 8.6%

The previous studies show that by using the nano particle with base fluid in PTC, its thermal performance is enhanced by good percentage. In this study, authors use the cerium oxide with water to see the enhancement of thermal performance.

II. THEORETICAL ANALYSIS AND METHODOLOGY

A. Thermal Efficiency

This part of the paper deals with the methodology use to find out the thermal performance of PTC.

The useful energy that the working fluid carries away is given by the equation

$$Q_u = m \times c_p \times (T_{out} - T_{in}) \qquad (1)$$

The amount of the solar energy available on the collector is given by

$$Q_s = A_a \times I \qquad (2)$$

The thermal efficiency of the collector is given by the ratio of useful heat gain to the total heat available.

$$\eta_{th} = \frac{Q_u}{Q_s} \qquad (3)$$

B. Nanofluid preparation and properties

The very first step of experimentation is the preparation of nanofluids. Water is selected as base fluid and nano particles of cerium oxide For the preparation of nanofluid. Commercially available colloidal Tek[R] suspension containing CeO_2 Nano CE- 6042, 100 ml fluid in water, 20 nm in diameter; has obtained from Alfa Aesar[R]. Desired amount of nanofluid is prepared by mixing the nano particles in the base fluid i.e. water in different concentrations. The nanofluid is kept for half an hour on the ultrasonic sonicator to have uniform dispersion and stable suspension.

Properties of cerium oxide nanofluid are varied with its concentration in the base fluid. The properties are dependent upon the volume fraction of nanofluid. Usually the vol. fraction is taken from 1 to 4% depending upon the nano particles [11] and in this study vol. concentrations are taken as 1% and 2% respectively. The properties are determined by using equations given below:

Density of the nanofluid is given by

$$\rho_{nf} = \rho_{bf} \times (1-\varphi) + \rho_{np} \times \varphi \qquad (4)$$

The specific heat is given by

$$c_{pnf} = \frac{\rho_{bf} \times (1-\varphi)}{\rho_{nf}} c_{pbf} + \varphi c_{pnp} \qquad (5)$$

The thermal conductivity of nanofluid can be determined by using Maxwell's relation as given below [12]

$$k_{nf} = \frac{k_{np} + 2k_{bf} - 2\varphi(k_{bf} - k_{np})}{\frac{k_{np}}{k_{bf}} + 2 + \frac{k_{bf} - k_{np}}{k_{bf}}} \qquad (6)$$

The viscosity of the nanofluid can be determined by equation given below [13]

$$\mu_{nf} = \mu_{bf} \times (1 + 2.5\varphi + 6.5\varphi^2) \qquad (7)$$

C. Methodology

A parabolic trough type solar concentrator system consists of a set of parabolic shaped ribs which hold a sheet of acrylic glass as a reflective surface for concentrating the solar rays to a focal line, where the receiver tube is placed for absorbing the solar radiation. This concentration of solar energy heats the fluid in the receiver tube. The fluid is then moved to the heat exchanger where the heat exchanger transfers the thermal energy to another medium for industrial heating, power generation or domestic heating purpose. The PTC used for experimentation has the following specifications as given in Table II. Experimental set-up line diagram is shown in Fig.I.

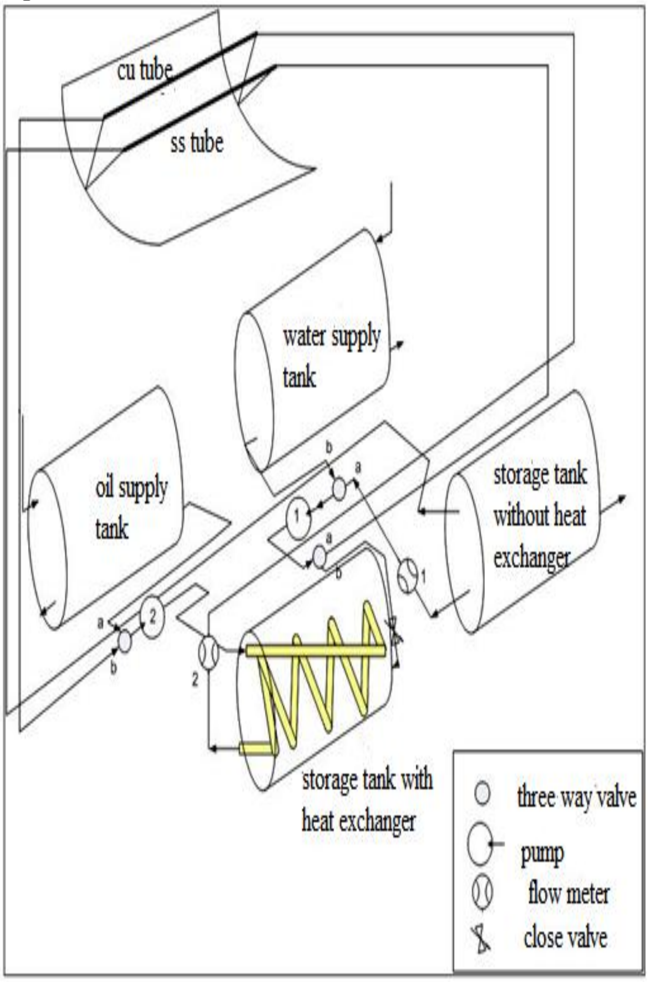

Fig.I. Line diagram of Experimental Set-up

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Table II. Physical parameters of PTC (Experimental set-up details)

S.No	Components	Specifications
1.	**Heat generating unit with tracking system**	
	Parabolic trough reflector • Length • Arc length • Depth • Focal length • Material	 4 ft 5.5 ft 0.68 ft 1.99 ft Acrylic glass
2.	**Absorber tube** • Length • Outer diameter • Absorber • Piping material	 4ft 1 inch Copper and SS GI
3.	**Piping material** • Inner diameter • Outer diameter	 15.75 mm 21.50 mm

III. RESULT AND DISCUSSION

In this part of the paper, the effect of temperature gradient rise on the thermal efficiency is shown for water, synthetic oil and cerium oxide nanofluid used as a working fluid in PTC.

Fig. II. Show the variation of efficiency with respect to temperature gradient rise through out a day by using water as a working fluid in PTC. From the graph it can be easily seen that the efficiency first increases and then it decreases. The efficiency lies within the range from 12% to 20% throughout a day. Maximum efficiency was found at noon time i.e. 20%.

Fig. III. Show the variation of efficiency with respect to temperature gradient rise through out a day by using synthetic oil as a working fluid in PTC. From the graph it can be easily seen that the efficiency first increases and then it decreases. The efficiency lies within the range from 18% to 30% throughout a day. Efficiency of PTC is increased by 1.5 times as compared to water.

Fig.IV. and Fig.V. shows the variation of efficiency with respect to temperature gradient rise through out a day by using cerium oxide nanofluid as a working fluid at different concentration in PTC. It can be easily seen from the graph that efficiency get increased by the use of nanofluid in PTC. The efficiency lies within the range from 32% to 38% throughout a day for 1% concentration of cerium oxide in water and 35% to 42% for 2% of volumetric concentration of cerium oxide in water. Efficiency of PTC is increased by 2.66 times as compared to water and 1.7 times as compared to synthetic oil. Variation in the efficiency throughout the day is due to interminent nature of solar radiations. Summary of results are shown in table III.

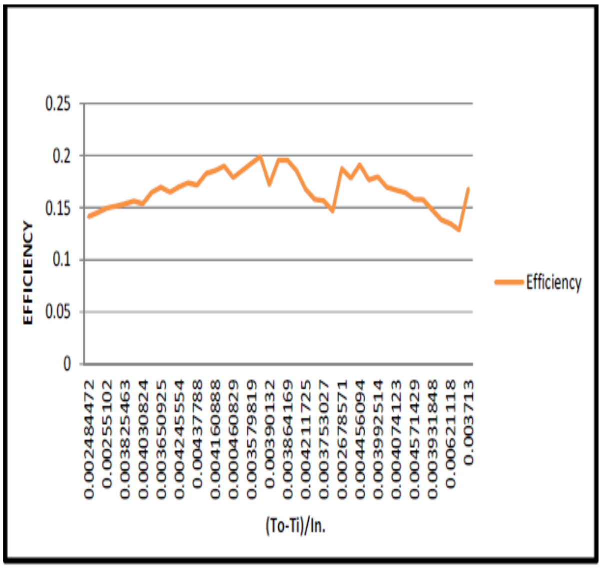

FIG. II. Variation of Efficiency w.r.t Temperature gradient rise for water used as a working fluid in PTC

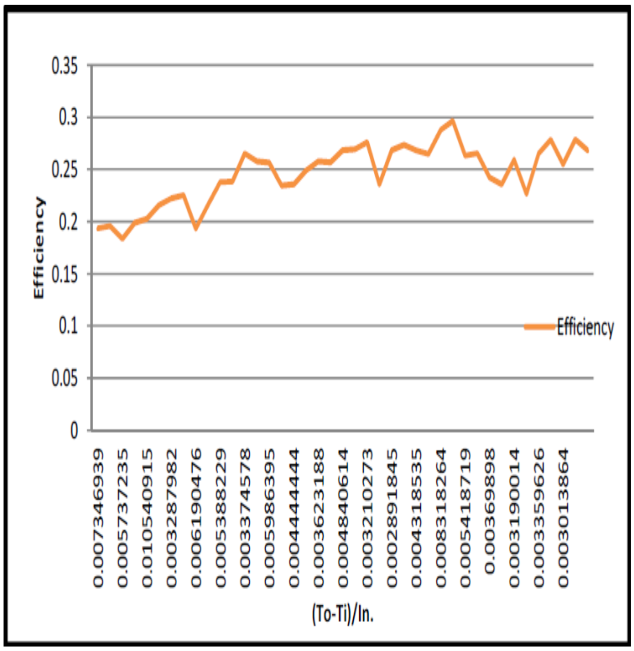

FIG. III.Variation of Efficiency w.r.t Temperature gradient rise for oil used as a working fluid in PTC

Fig.VI. shows the comparison of using water, oil and cerium oxide nanofluid with different concentration as working fluid in PTC respectively. Graph shows that the maximum efficiency of PTC can be achieved by using cerium oxide with 2% volumetric concentration nanofluid in PTC.

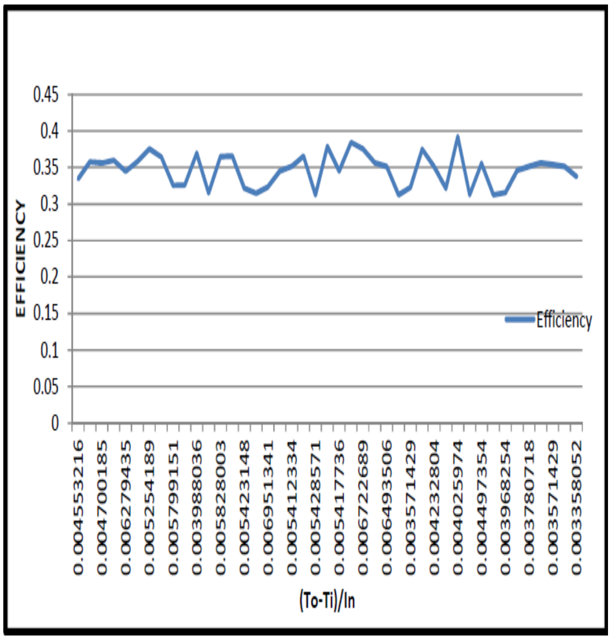

FIG. IV. Variation of Efficiency w.r.t Temperature gradient rise for 1% volumetric concentration of nanofluid used as a working fluid in PTC

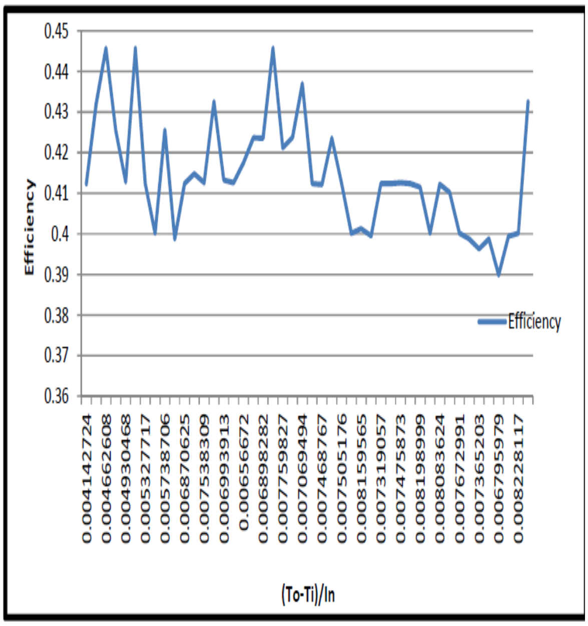

FIG. V. Variation of Efficiency w.r.t Temperature gradient rise for 2% volumetric concentration of nanofluid used as a working fluid in PTC

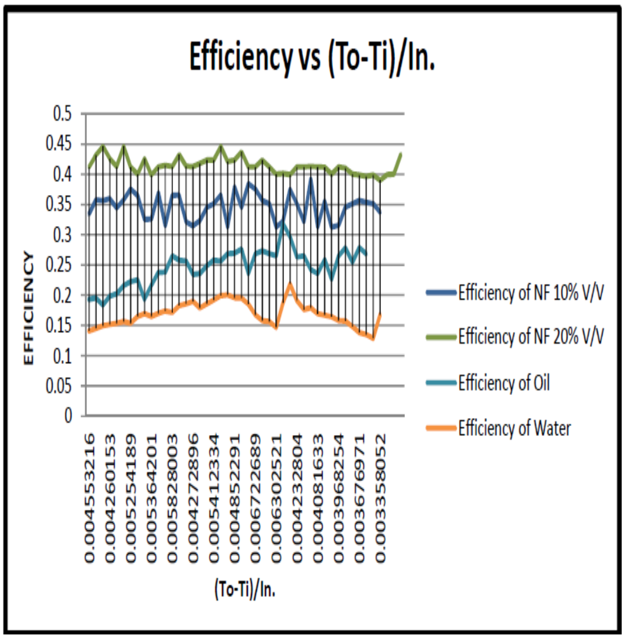

Fig.VI. Comparison of different working fluid used in PTC

Table III. Summary of Present study

S.no.	Working Fluid	Results
1.	Water	12 to 20% enhancement in thermal efficiency
2.	Synthetic oil	18 to 30% enhancement in thermal efficiency
3.	Cerium oxide nanofluid A) With 1% concentration B) With 2% concentration	32 to 38% enhancement in thermal efficiency. 35 to 42% enhancement in thermal efficiency.

IV. CONCLUSIONS

Present study shows that the use of nanofluid as working fluid in PTC enhances the thermal efficiency as compared to any other working fluid. Outcomes of this experimental work are as follows:

1. By using water as working fluid in PTC, thermal efficiency is increased to 12% to 18%.
2. By using synthetic oil as working fluid in PTC, thermal efficiency is increased to 18% to 30% and increment in efficiency is 1.5 times of water.
3. By using cerium oxide nanofluid, thermal efficiency get enhanced.
4. Maximum thermal efficiency is achieved at 2% volumetric concentration of cerium oxide nanfluid.
5. Thermal efficiency is increased to 2.66 times as that of water and 1.7 times as compared to synthetic oil by using nanofluid as working fluid in PTC.

A. Abbreviations and Acronyms

PTC : Parabolic trough collector
GI : Galvanized iron
SS : Stainless steel
CeO_2 : Cerium oxide
Al_2O_3 : Aluminum oxide
Fe_2O_3 : Ferrous oxide
TiO_2 : Titanium oxide
Q_u : Useful energy
T_i : Inlet temperature
T_o : Outlet temperature
C_p : Specific heat
m : mass flow rate
Q_s : Total energy
A_a : Absorber tube area
I : Solar intensity
C_{pnp} : Specific heat of nano particles
C_{pnf} : Specific heat of nanofluid
C_{pbf} : Specific heat of base fluid
k_{nf} : thermal conductivity of nanofluid
k_{bf} : thermal conductivity of base fluid
k_{np} : thermal conductivity of nano particles

Greek symbols

η_{th} : Thermal Efficiency
ρ_{nf} : density of nanofluid
ρ_{bf} : density of base fluid
ρ_{np} : density of nano particles
φ : Volumetric concentration
μ_{nf} : viscosity of nanofluid
μ_{bf} : viscosity of base fluid

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