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Experimental Investigation of SiO_2/Thermal Oil Nanofluid Application in a Cylindrical Cavity Receiver

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ABSTRACT In this study, a parabolic dish concentrator using a cylindrical cavity receiver was experimentally investigated. The effect of nanofluid application as the solar working fluid was studied in this research. The nanofluid of SiO2/thermal oil was examined in concentration of 0.8% Volume Fraction (VF) and volume flow rate of 10 ml/s. The designed experimental setup was included a parabolic dish concentrator, cavity receiver, and hydraulic circuit system. The main aim of this study was experimentally investigated the thermal performance of the cylindrical cavity receiver using silica/thermal oil nanofluid. The results indicated that the receiver heat gained and the thermal efficiency had a similar trend compare to the difference temperature. Finally, it was resulted that the application of the silica nanofluid didn't have an effective influence for improving the thermal performance of the investigated cylindrical cavity receiver compare to the pure thermal oil. Consequently, the application of the pure oil is recommended as the solar working fluid of the cylindrical cavity receiver instead of the silica/thermal oil nanofluid due to its less cost.

Keywords: Experimental study; silica/thermal oil nanofluid; cylindrical cavity receivers; thermal performance.

1. INTRODUCTION

The concentrator solar collector as an efficiently type of solar collector, can concentrate, absorb and convert the solar radiation to heat. In the recent years, the researchers have increased on the concentrated solar energy systems as a high-quality technology [2]. The most common type of high-temperature solar thermal system is the parabolic dish collector [3]. There are different types of the receiver for dish concentrator that includes the volumetric, particle, tubular cavity and spiral absorber receivers [4, 5]. The tubular cavity receivers because of especial structure have a higher efficiency compared to external receivers [6]. Some researches were experimentally and numerically studied thermal performance of the dish concentrator with cavity receivers [7-11]. Li et al. [7] Numerically and experimentally considered a linear Fresnel heliostat collector using a conical cavity receiver with the spiral tube. It can be observed from the literature review that there is no reported paper of experimental investigation of a cylindrical cavity receiver using nanofluid. Therefore, the novelty of the current study is the thermal performance investigation of the cylindrical cavity receiver using the silica/thermal oil nanofluid experimentally during the experimental tests. In this research, the thermal performance of the investigated solar system using the silica/thermal oil nanofluid in the concentration of 0.8% Volume Fraction (VF) and volume flow rate of 100 ml/s. The designed experimental setup was included a parabolic dish concentrator, cavity receiver, and hydraulic circuit system.

2. Experimental setup

The experiments were carried out in the Renewable Energy Research of the Tarbiat Modares University, Tehran, Iran (located at 35.68° N latitude and 51.42° longitude). The developed setup was included a parabolic dish concentrator, cylindrical cavity receiver, a heat exchanger system, and a hydraulic circuit (see Fig. 1). The characteristics of the parabolic dish concentrator are reported in Table 1 shows the investigated parabolic dish concentrator with the cavity receiver.

TABLE 1- PARAMETERS OF THE INVESTIGATED DISH CONCENTRATOR [20].

Parameters of the dish	Data
Aperture diameter	1.9 m
Focal length	0.693 m
Reflectivity	0.84
Tracking error	1°
Rim angle	45°
Concentration ratio	165

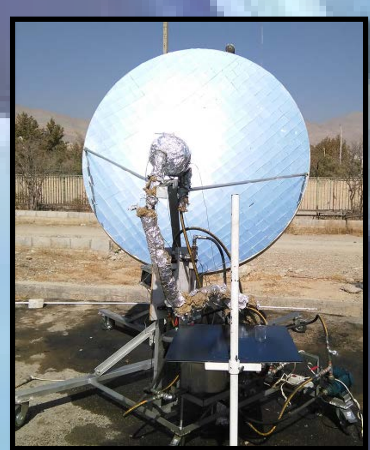

Fig. 1. The investigated parabolic dish concentrator with cavity receiver

Fig. 2. The coated cylindrical cavity receiver

- The cavity receivers were constructed in three stages. In the first stage, the cavity receiver were built using wounded copper tubes. In the second stage, the black chrome (Cr-Cr2O3) coating was used on the cavity's wounded copper tubes for the most absorption and lowest emissivity for the incoming solar radiation. Fig. 2 shows the coated cavity receiver by the Mina Company, Tehran, Iran. Finally, for decreasing the heat losses, the outer walls of the coated cavity receiver, except for the aperture, were insulated with mineral wool.
- Thermal oil was selected as the working fluid of the investigated solar system, because of its high heat transfer capacities and low viscosities. While it is recommended that the thermal oil is better in the higher temperature application in the solar collector systems such as dish concentrator [5]. The Behran thermal oil was selected as the solar working fluid in this study.

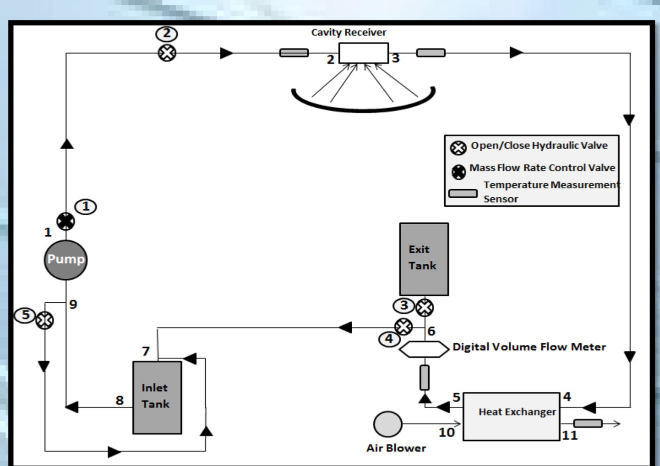

Fig. 3. Schematic of the hydraulic circuit

Instrumentation and measurement system

The thermal characteristics of the Behran thermal oil are obtained by Eqs. 1 to 4 as below [21]:

TABLE 2: ACCURACIES AND RANGES OF THE MEASURING INSTRUMENTS

Instrument	Accuracy	Range
K-type thermocouples	±0.55 °C	0-800 °C
Solar power meter	±0.1 W/m²	0-2000 W/m²
Anemometer	±0.2 m/s	0.9 to 35.0 m/s
Volume flow meter	±0.05 mA	0-20 mA

$$k_f = 0.1882 - 8.304 \times 10^{-5}(T_f) \quad (\frac{W}{mK}) \qquad (1)$$

$$c_{p,f} = 0.8132 + 3.706 \times 10^{-3}(T_f) \quad (\frac{kJ}{kgK}) \qquad (2)$$

$$\rho_f = 1071.76 - 0.72(T_f) \quad (\frac{kg}{m^3}) \qquad (3)$$

$$Pr = 6.73899 \times 10^{21}(T_f)^{-7.7127} \qquad (4)$$

During the experimental tests, different parameters were measured that includes: (1) fluid situations (flow rate, temperature), (2) solar irradiation, and (3) weather situations (ambient temperature, wind speed). Volume flow meter FLUIDWELL model: F016-P was used for measuring the volume flow rate of the solar working fluid (oil). While the working fluid temperatures (at inlet and outlet of the cavities) and surface temperature (top wall and the side wall of the cavities), were measured by using K-type thermocouples (Chromel-Alumel). The Omron data logger model: ZR-RX-45 was used to monitor and store the temperatures of the investigated setup at the different location. The radiation heat flux was measured by using Hukseflux Pyranometer, model SR12. The ambient temperature and wind speed were measured by a K-type thermocouple and anemometer CT model: AM-4220, respectively. Table 2 explained the accuracy and ranges of the measuring instruments.

3. ENERGY ANALYSIS

- An important parameter for thermal analysis is thermal efficiency. The thermal efficiency of the cavity receivers is defined as the receiver energy gained to the rate of the total incoming solar energy to the dish concentrator aperture and is expressed as:

TABLE 3: ACCURACIES AND RANGES OF THE MEASURING INSTRUMENTS

Property	SiO_2
Thermal conductivity (W/m K)	1.4
Heat capacity (J/kg K)	745
Density (kg/m3)	2220

$$\eta_{th} = {}_{net}/{}_{solar} \qquad (5)$$

$$Q_{net} = \dot{m} c_p (T_{out} - T_{in}) \qquad (6)$$

$$Q_{solar} = I_{sun} \pi D_{conc}^2 / 4 \qquad (7)$$

In these equations, η_{th} is the thermal efficiency, $Q_{net}(W)$ is the receiver energy gained, $Q_{solar}(W)$ is the total incoming solar energy, $\dot{m}\ (kg/s)$ is the mass flow rate of the solar working fluid, $c_p\ (\frac{J}{kg}.K)$ is the heat capacity of the solar working fluid, $T_{out}(K)$ and $T_{in}(K)$ are the outlet and inlet temperatures of the solar working fluid, respectively, $I_{sun}\ (W/m^2)$ is the solar irradiation, and $D_{conc}\ (m^2)$ is the aperture dish concentrator.

A) Nanofluid properties

- In this paper, the operation with nanofluids is investigated. The SiO2/thermal oil nanofluid is tested and its thermal properties are calculated according to the equations of this section. Table 3 includes the thermal properties of the examined nanoparticle. It is obvious, that the nanoparticle present high density, high thermal conductivity and low specific heat capacity.

Equations (8)-(11) present the thermal properties of the nanofluids. The base fluid is symbolized with (bf), the nanoparticle with (np) and the nanofluid with (nf). The thermal conductivity of the nanofluid is calculated according to the suggested equation by Yu and Choi [22]:

$$k_{nf} = k_{bf} \cdot \frac{k_{np} + 2 \cdot k_{bf} + 2 \cdot (k_{np} - k_{bf}) \cdot (1+\beta)^3 \cdot \varphi}{k_{np} + 2 \cdot k_{bf} - (k_{np} - k_{bf}) \cdot (1+\beta)^3 \cdot \varphi} \quad (8)$$

$$\rho_{nf} = \rho_{bf} \cdot (1-\phi) + \rho_{np} \cdot \phi$$

$$c_{p,nf} = \frac{\rho_{bf} \cdot (1-\phi)}{\rho_{nf}} \cdot c_{p,bf} + \frac{\rho_{np} \cdot \phi}{\rho_{nf}} \cdot c_{p,np}$$

RESULTS AND DISCUSSION

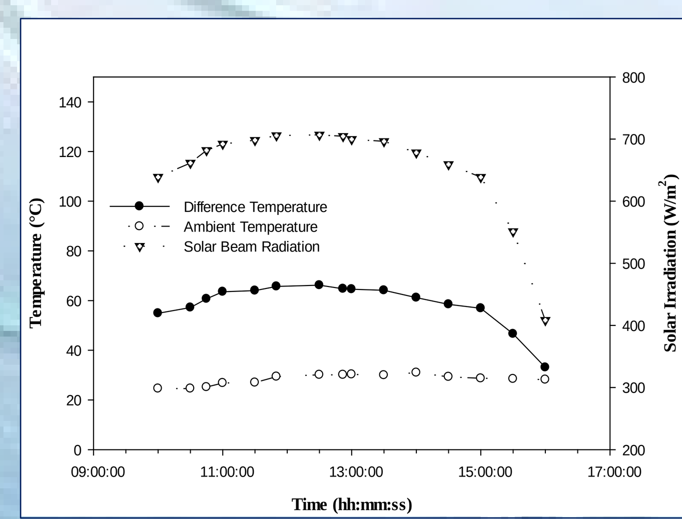

Fig.5. Variation of the solar irradiation, ambient temperature, and temperature difference between outlet and inlet of the cylindrical cavity receiver on 23th September 2016.

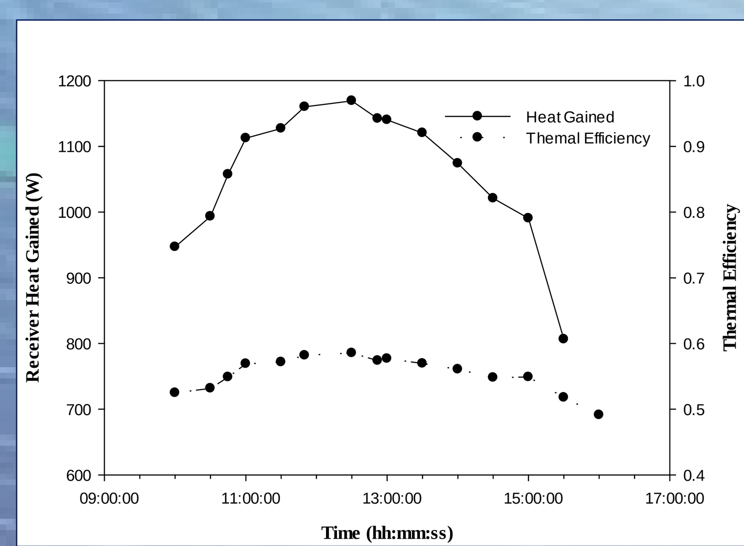

Fig.5. Variation of receiver heat gained ($\dot{Q}_{in}$), and thermal efficiency of the cylindrical cavity receiver on 26th September 2016.

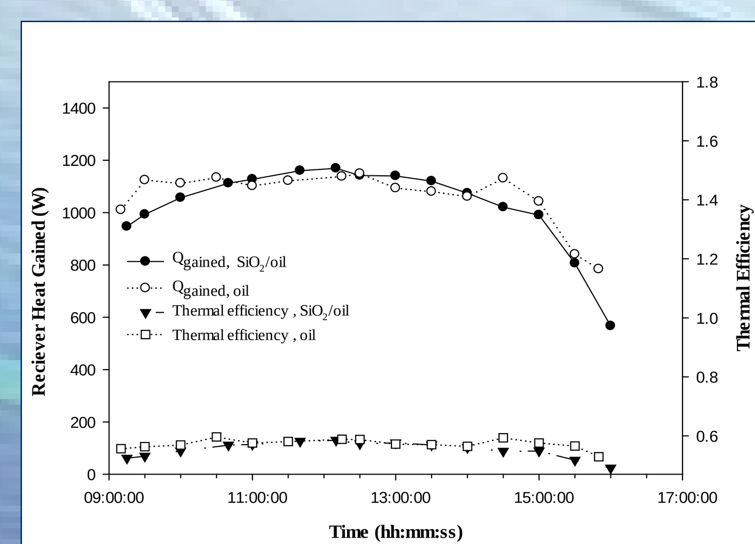

Fig.6 A thermal performance comparison between the silica/thermal oil nanofluid and pure thermal oil as the solar working fluid.

- Fig. 4 displays the variation of different parameters including the solar total radiation, ambient temperature, and the temperature difference between the inlet and outlet temperature of the working fluid on 23th September 2016 in Tehran, Iran. It shall be mentioned that the overall environmental and operational parameters for cylindrical cavity receiver were measured from 9:15 to 16:00 and the mass flow rate of the working fluid was 10 ml/s during the experimental tests. As shown, the temperature difference is ranged from 33.10°C at 16:00 to 66.18 °C at 12:10. And the solar total irradiance is varied in the range of 408.35 W/m2 at 16:00 to 706.65 W/m2 at 12:10.
- The receiver heat gained and thermal efficiency of the cylindrical cavity receiver are displayed in Fig. 5. It shows that the receiver heat gained is ranged from 566.71 W at 16:00 to 1169.2 W at 12:10. And the thermal efficiency is varied from 0.49 at 16:00 to 0.59 at 12:10. It can be concluded that the receiver heat gained and the thermal efficiency of cylindrical cavity receiver have a similar trend with the difference temperature.
- Finally, the investigated cylindrical cavity receiver was tested using the pure thermal oil as the based fluid of the silica/thermal oil nanofluid. Fig. 6 depicts a thermal performance comparison between the silica/thermal oil nanofluid and pure thermal oil as the solar working fluid for the investigated cylindrical cavity receiver. It can be seen from Fig. 6, the application of the silica nanofluid didn't have an effective influence for improving the thermal performance of the investigated cylindrical cavity receiver compare to the pure thermal oil. This issue is due to the thermal properties of the Silica nanoparticles. Consequently, the application of the pure oil is recommended as the solar working fluid of the cylindrical cavity receiver instead of the silica/thermal oil nanofluid due to its less cost.
- It can be concluded that the receiver heat gained and the thermal efficiency have a similar trend compare to the difference temperature. Consequently, the temperature difference is an effective parameter in the receiver heat gained and thermal efficiency of cylindrical cavity receiver.

4. CONCLUSIONS

In this study, a parabolic dish concentrator using a cylindrical cavity receiver was experimentally investigated. The effect of nanofluid application as the solar working fluid was studied in this research. The nanofluid of SiO2/thermal oil was examined in the nanofluid concentration of 0.8% Volume Fraction (VF) and volume flow rate of 10 ml/s. Comparison between the silica/thermal oil nanofluid and pure thermal oil as the solar working fluid for the investigated cylindrical cavity receiver was done. The results are extracted as followings:

- The temperature difference generally has a similar trend to the solar irradiation. Also, the ambient temperatures have generally higher amount in the afternoon compare to the morning.
- It can be concluded that the receiver heat gained and the thermal efficiency have a similar trend compare to the difference temperature. Consequently, the temperature difference is an effective parameter in the receiver heat gained and thermal efficiency of cylindrical cavity receiver.
- Finally, it could be resulted that the application of the silica nanofluid didn't have an effective influence for improving the thermal performance of the investigated cylindrical cavity receiver compare to the pure thermal oil. Consequently, the application of the pure oil is recommended as the solar working fluid of the cylindrical cavity receiver instead of the silica/thermal oil nanofluid due to its less cos

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