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Soğutucu olarak MWCNT-Su ve GNP-Su nanoakışkanları kullanan güneş enerjili termoelektrik jeneratörlerin ısı transfer performansının deneysel olarak incelenmesi

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Experimental Study On Heat Transfer Performance Of Solar Thermoelectric Generators Using MWCNT-Distilled Water And GNP-Distilled Water Nanofluids As Coolants

Highlights

- *This paper focuses on performance enhancement of concentrator thermoelectric generator system*
- *An experimental investigation was performed to obtain accurate comparison between different types of nanofluids.*
- *Thermal, electrical, and overall maximum efficiency values are 20.22%, 4.12% and 24.35% for GNPs-distilled water, respectively.*
- *The temperature difference increasing of 3.36% for GNPs-distilled water provides a 20.12%, 36.35% and 38.12% increase in electrical, thermal and total efficiencies comparing to distilled water.*

Graphical Abstract

An experimental study of the effect of different types of nanofluids on the performance of a concentrator thermoelectric generator (CTEG) system.

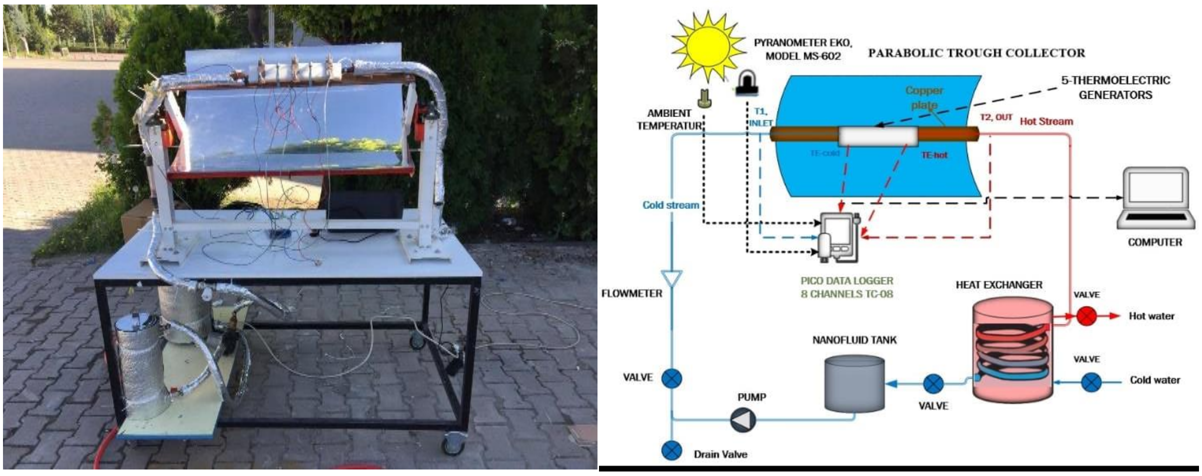

Figure. Schematic diagram of the experimental setup.

Aim

Enhancement the performance of CTEG systems by using the nanofluids as cooling fluids.

Design & Methodology

Nanofluids were used in the experimentally prepared CTEG system and experimental studies were carried out.

Originality

The comparison between different types of nanofluids as coolant which used in CTEG systems.

Findings

GNP-distilled water nanofluid showed the best performance compared to the others.

Conclusion

The maximum electrical energy production was observed for GNPs-distilled water nanofluid.

Declaration of Ethical Standards

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Experimental Study On Heat Transfer Performance Of Solar Thermoelectric Generators Using MWCNT-Distilled Water And GNP-Distilled Water Nanofluids As Coolants

Araştırma Makalesi/Research Article

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ABSTRACT

The solar thermoelectric generators (STEGs) have emerged during the past decade as a promising substitutional among other green power production systems. A solar thermoelectric generator (STEG) is a system that can generate electrical energy directly from solar energy without any intermediate energy forms such as work in the traditional power generation systems. Recent developments in solar thermoelectric generator have achieved several improvements as a result of its optimized systems such as concentrated systems and also the boosts from nanotechnology. In this study, a concentrator thermoelectric generator (CTEG) using Graphene Nanoplatelets (GNPs), and Multiwall Carbon Nanotubes (MWCNTs) dispersed in distilled water as base fluid was investigated experimentally. The CTEG system was designed, constructed in Karabük University Energy Systems labs, Turkey and have been commissioned outdoor by testing, balancing and adjusting. Experiments were performed for 0.25 wt.% nanoparticle mass concentration of MWCNTs-distilled water and GNPs-distilled water nanofluids with a constant volume rate of flow ($\dot{v}$=0.5 L/min). Experiments study aimed to study effect of nanoparticle types on thermal and electrical energetic efficiency. The obtained results showed that the CTEG is enable to generate (E_{max}=3.7 W) of electrical power output for an average temperature difference of 38°C. MWCNTs-distilled water nanofluid presented an enhancement in electrical performance more than GNPs-distilled water nanofluid and distilled water, while GNPs-distilled water nanofluid presented maximum thermal increment. The total efficiency for the day-long periods were 16.34%, 24.03% and 20.21% for distilled water, GNPs-distilled water, MWCNTs-distilled water respectively. The results of the study made a solid basics about the prospects of CTEG applications related with nanotechnology to be one of the potential choices for cooling technique by using different types of nanofluids as coolants.

Keywords: Solar Energy, Concentrator thermoelectric generator (CTEG), nanofluids, cooling technique.

Soğutucu Olarak MWCNT-Su ve GNP-Su Nanoakışkanları Kullanan Güneş Enerjili Termoelektrik Jeneratörlerin Isı Transfer Performansının Deneysel Olarak İncelenmesi

ÖZ

Son yıllarda, güneş enerjili termoelektrik jeneratörler diğer yeşil güç üretim sistemleri arasında umut verici bir konu olarak ortaya çıkmıştır. Geleneksel enerji üretim sistemlerindeki gibi bir ara enerji formu olmaksızın güneş enerjili termoelektrik jeneratör doğrudan güneş enerjisinden elektrik enerjisi üretebilen bir sistemdir. Güneş enerjili termoelektrik jeneratördeki son gelişmelerle, konsantre sistemler gibi optimize edilmiş sistemlerin ve ayrıca nanoteknolojinin sağladığı desteklerin bir sonucu olarak çeşitli iyileştirmeler sağlanmıştır. Bu çalışmada, baz akışkan olarak su içinde dağıtılan Grafen Nanoplateletler (GNP'ler) ve Çok Duvarlı Karbon Nanotüpler (MWCNT'ler) kullanan bir yoğunlaştırıcı termoelektrik jeneratör (CTEG) deneysel olarak incelenmiştir. Karabük Üniversitesi laboratuvarlarında yoğunlaştırıcı termoelektrik jeneratör sistemi (CTEG) tasarlanıp, imalatı gerçekleştirilmiş ve dış şartlarda deneyler yapılmıştır. Deneyler, MWCNTs-Su ve GNPs-Su nanoakışkanlarının ağırlıkça %0.25 nanoparçacık kütle konsantrasyonu için sabit debide ($\dot{v}$=0.5 L/dk) gerçekleştirilmiştir. Deneylerde termal ve elektriksel enerji verimliliği üzerindeki nanoparçacık tipinin etkisi amaçlanmıştır. Elde edilen sonuçlar, CTEG sisteminin 38°C'lik bir ortalama sıcaklık farkı için maksimum 3.7 W elektrik gücü çıkışı üretmeye olanak sağladığını göstermiştir. Elektrik performansı için MWCNTs-su nanoakışkanın artış oranı diğer akışkanlara göre daha büyükken GNP'ler-su nanoakışkanın termal performansı maksimum artışı göstermiştir. Günlük toplam verim değerleri saf su, GNPs-su, MWCNTs-su için sırasıyla %16.34, %24.03 ve %20.21 olarak hesaplanmıştır. Çalışmanın sonuçları, CTEG uygulamalarındaki soğutma tekniği için farklı türlerde nanoakışkanların kullanımının potansiyel seçeneklerden biri olma beklentileri hakkında sağlam bir temel oluşturmuştur.

Anahtar Kelimeler: Güneş enerjisi, yoğunlaştırıcı termoelektrik jeneratör (CTEG), nanoakışkanlar, soğutma tekniği.

1. INTRODUCTION

The current world is facing difficult issues, such as increasing environmental pollution, energy costs and climate change. These issues have received substantial attention in power generation applications. Green power production has been always one of the primary concerns of scientists so solar thermoelectric generators have been investigated over years. Solar energy of thermoelectric power generation applications got a lot of attention since

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the 1950s. Through the 1960s, a lot of research on thermoelectric power generation was strengthened and a lot of thermoelectric systems were designed successfully [1]. Thermoelectric generation operation is a solid-state processing of temperature gradient into electrical energy directly and vice versa. There are three important parameters to optimize TEG efficiency: heat source, cooling technique and thermoelectric element material [2]. In CTEG, the temperature difference is an essential parameter in which it has reverse effects on the power conversion efficiency of the CTEG. So, the excessive temperature of CTEG systems can be managed by several active cooling techniques which using heat transfer fluids like water or coolants. While different investigations were already implemented to optimize the cooling process by using water, the obtained results have been affected by a lower thermal conductivity of fluids that constrains CTEG efficiency improvement [3]. Nanoparticle based fluids, i.e., nanofluids, have obviously improved the heat transfer process, enabling higher efficiency in CTEG systems. In this regard, an interesting review article comes from Abdelkareem et. al [4] that present the outlooks of thermoelectric generators with nanofluids. The review discussed the specialized applications of TEG systems because of its major role in decreasing costs and relieving various environmental issues that come with consuming fossil fuels. Also, they demonstrated that TEG applications are a good prospect waste heat recovery (WHR) appliance that can be utilized for direct heat to power conversion especially if these systems were associated with heat transfer improvement technology such as nanotechnology. Numerous researcher's investigations have been made on different types of TEG systems based on Solar Heating TEG (E.Özbaş [5]), thermoelectric self-cooling system (M. Şener et al. [6]), solar parabolic dish collector (PDC) (S. Shanmugam et al. [7]), concentrator thermoelectric generator (CTEG) (Fan et al. [8]) and hybrid solar thermoelectric generator (HSTEG) system (P. Sundarraj et al. [9],). S. Shanmugam et al. [7] performed a theoretical and experimental investigation of connecting 4 TE modules in a set between the heat source/sink for a PDC. The outlet temperature was maintained at 35°C by adjusting the water flow of rate which changed between 0.6 and 0.9 kg/s. The cold surface temperature was changed between 32 and 34°C. The obtained results demonstrated that the system was capable to generate power output of 14.7 W and the accuracy between the theoretical analysis compared to experimental one was 10%. In contrast Fan et al. [8] established CTEG system in labs of university. The system had a reflector with diameter of 1.8 m which concentrate the lights onto a receiver of 260 mm diameter made by copper. Also, a 2D tracking device was applied to track the path of sun. Furthermore, the heat of system was removed by microtube heat sink. Under various heating ratios, the tests were performed on the modules individually then for the overall system. The study results showed that, the system was capable to produce electric power up to 5.9 W under the temperature variation of 35°C, conforming to electrical performance of 2.9%. In a similar way an experimental and theoretical study was performed by P. Sundarraj et al. [9] for hybrid solar TEG. The HSTEG forms from six thermoelectric generator modules, a stainless-steel cooling block and an electrical heater. The HSTEG powered by 382 W input power of the heater. Thus, the efficiencies result was 61% for thermal and 1.2% for electrical one with 92°C of average temperature with a capability to generate 4.7 W of electric. G. Muthu et al. [10] presented an experimental study and theoretical validation on the behavior of a designed parabolic collector for TEG system. A maximum power outputs of 15.35 W and 16.43 W were obtained from experimental results and theoretical analysis, respectively. The standard deviation and average error between experimental and theoretical investigations were 0.869 and 11.12%, respectively. The uncertainty electrical power was 2.07%. Recently, most of the researchers' experimental studies was performed in order to get a common base between different TEG systems and nanofluid technology. Ahammed et al. [11] was investigated the capability of using nanotechnology applications as cooling technique in electronic device of TEG. 0.1% and 0.2% of Al_2O_3 nanoparticles dispersed in water was used as base fluid through mini channel to eject the heat from hot part of TEG. The results observed an increase in temperature variation up to 9.15% using 0.2% Al_2O_3-water so the cooling capacity was enhanced. For the similar nanoparticle type, a theoretical analysis of heat exchanger with nanofluid cooling for STED system was presented by Nnanna et al. [12]. A comparison of nanofluid and distilled water showed that Al_2O_3/water enhanced the thermal contact conductance between TEG modules and heat source, which in turn improved the total efficiency. On the other hand, CuO nanoparticles was used in experimental tests of Chang et al. [13]. The TEG system surface was coated with thin film of CuO and consequently heat transfer improvement reached to 10% and the output of total power to 2.35%. Upon to experimental and theoretical investigations, the comparison between different types of nanoparticles on thermal and/or electrical efficiencies of CTEG systems was not explored clearly. Therefore, this study performs a detailed tests between two types of nanofluids (MWCNTs-distilled water / GNPs-distilled water) to examine their effects on CTEG performance. In labs of Karabuk University (Latitude: 41.21°N; Longitude: 32.65°E) the working setup was established, tested and analyzed perfectly. The tests were performed for 0.25 wt.% mass concentration of MWCNTs and GNPs in distilled water and in constant condition of flow rate (0.5 L/min). The research conclusions were illustrated in detail for thermal/electrical energetic performance depending on stable weather days.

2. MATERIAL AND METHODS

2.1. Experimental Procedures

The system setup was designed and fabricated in labs of Karabük University in Türkiye. Between the receiver plate and heat sink, the experimental setup consists of five thermoelectric modules (model No: TEG1-24111-6.0) attached in a set. Also, it has a trough collector adjusted manually to track the sun facing to the south direction continuously. The graphical illustration of experimental system was given in Figures.1-2.

Figure 1. Setup view with piping system and storage tanks

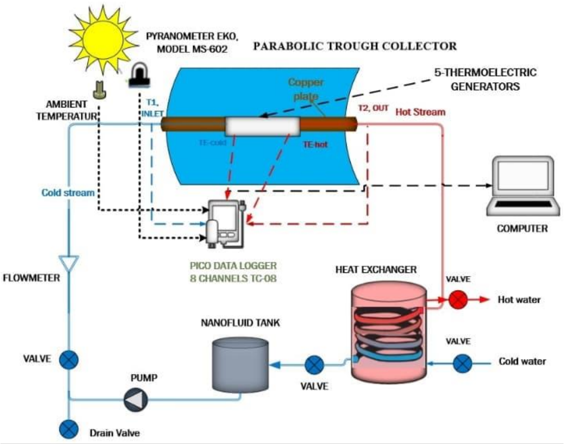

Figure 2. Graphical illustration of experimental system

To ensure a perfect connect a thermal conductive paste (k_{paste}=3 W/m°C) was spread between the back surface of the receiver plate and thermoelectric modules. As shown in the previous figures, the system contains a heat exchanger, nanofluid storage tank then a variable speed pump was used to circulate coolants throughout system ducts and also the nanofluid's volumetric rate measured flow meter was attached. For temperatures measurement, data logger connected by K type thermocouples with systems parts to measure inlet and outlet temperatures of fluid in cooling duct, surface temperatures of thermoelectric cells and ambient temperature. A Pyranometer device was used for overall solar radiation. Constant resistor loads were connected to thermoelectric generators (TEGs) to obtain the maximum electrical power and ensure a continuous production of electricity from thermoelectric generators. Constant resistor loads were connected to thermoelectric generators (TEGs) to obtain the maximum power of electricity and ensure a continual generation. Furthermore, all parameters were measured every 20 s and imported to laptop simultaneously. The specifications of TEG and trough collector are illustrated in Table 1.

Table 1. Experimental system specifications

CTEG Specifications	Measures
Collector length	0.9 m
Aperture width	0.6 m
Aperture area	0.54 m^2
Area of the receiver plate	0.054 m^2
Area of heat sink	0.0198 m^2
Hot Side Temperature (°C)	300
Cold Side Temperature (°C)	30
Tracking mechanism	Mechanical
Matched Load Resistance (ohms)	4.4
Open Circuit Voltage (V)	17.7
Matched load output current (A)	2
Matched load output voltage (V)	8.8
Matched load output power (W)	17.6
Number of thermocouples	127
Number of modules	5

The thermoelectric generators, receiver plate and cooling system image are shown in Figure 3.

Figure 3. Copper receiver plate, heat sink and thermoelectric module

2.2. Testing Procedure

Before experimental tests, to reach the best accuracy the period of the experimental setup has been determined in the preliminary experiments during August and September months in 2019. Thus, several experiments were performed in Energy Systems Department's yard in Karabuk University, Türkiye. The tests were performed from early morning (9:30 am) until evening (5:00 pm). The measurements of generated voltage and current, solar irradiance and different temperatures (inlet, outlet, ambient, surface) for stable condition's days was imported simultaneously and the average values were taken and applied in data analysis. In terms of nanoparticles, Multi-Walled Carbon Nanotube (MWCNTs) and Graphene Nanoplatelets (GNPs) were provided by NANOGRAFI Company. The images of MWCNTs and GNPs are shown in Fig. 4. During the experiments period no sedimentation was observed. The thermophysical properties of MWCNTs nanoparticles [14], graphene nanoplatelets (GNPs) [15] and distilled water [16] are presented in Table 2.

Table 2. Thermophysical properties of nanoparticles and distilled water [14-16]

Material	**ρ**	**Cp**	**k**
	(kg/m³)	**(kJ/kgK)**	**(W/mK)**
MWCNT	1600	0.796	3000
Graphene	2100	0.710	5000
Distilled water	997	4.180	0.607

2.3. Data Reduction

The thermophysical properties of distilled water, GNPs-distilled water and MWCNTs-distilled water has been calculated theoretically by using following equations. Density and heat capacity are defined by (Xuan and Roetzel model [17-18]) :

$$\rho_{nf} = \emptyset.\rho_{np} + (1-\emptyset).\rho_f \qquad (1)$$

$$\left(\rho_{nf}C_{p,nf}\right) = \emptyset\left(\rho_{np}C_{p,np}\right) + (1-\emptyset)\left(\rho_f C_{p,f}\right) \qquad (2)$$

Where: ρ refers to density (kg/m³) and C_p refers to specific heat (kJ/kgK). The thermal conductivity model of the nanofluid is described as (Maxwell-Garnet model [19]):

$$k_{nf} = k_f \frac{k_{np}+2k_f-2\emptyset\left(k_f-k_{np}\right)}{k_{np}+2k_f+\emptyset\left(k_f-k_{np}\right)} \qquad (3)$$

k, refers to thermal conductivity (W/mK), and ∅ refers to volume fraction of nanoparticles. The thermal energy of the system Q_u (W) of the system is given by:

$$Q_u = \dot{m}\times C_p(T_o - T_i) \qquad (4)$$

Where ṁ is the mass flow rate and C_p is the specific heat (J/kgK) and T_i, T_o refers to coolant inlet fluid temperature and outlet fluid temperature, respectively. Then the output electrical power P (W) can be calculated by:

$$P = I\times V \qquad (5)$$

Where generated current is I (Amper), and the generated voltage is V (Volt). The efficiency of CTEG is related to the amount of generated electrical/thermal energy that TEG produced from the sun radiation. The (η_{Th}) and (η_{ele}) efficiencies are expressed as:

$$\eta_{Th} = \frac{Q_u}{I_{sol}\times A_{th}} \qquad (6)$$

$$\eta_{ele} = \frac{P}{I_{sol}\times A_{TE}} \qquad (7)$$

Where, I_{sol} is the solar radiation falling on receiver and A_{TE} is the area of the receiver plate (m²). Lastly, the total efficiency of system can be expressed as:

$$\eta_{tot} = \eta_{th} + \eta_{ele} \qquad (8)$$

3. RESULTS AND DISCUSSION

The measurements were collected simultaneously and continuously in every 20 second for a time period between 9:30 am to 5:00 pm for all coolants during the selected days in August and September months. Because of the checking the accuracy of the experimental setup and measurements, first of all, experimental data were collected which back to steady weather condition of experiments days which are 10th of August for distilled water, 28th of August for MWCNTs-distilled water nanofluid and 18th of September for GNPs-distilled water nanofluid. Thermophysical properties of nanofluids are estimated by Equations. (1-4) and given in Table 3.

Table 3. Thermophysical properties of nanofluids

Nanofluids	**ρ**	**C_p**	**k**
	(kg/m³)	**(kJ/kgK)**	**(W/mK)**
0.25 wt.% MWCNTs-distilled water	1091	3.4063	0.943
0.25 wt.% GNPs-distilled-water	1128	3.4126	0.524

3.1. Surface Temperature Measurements

Since temperature values was one of the main factors affecting the efficiency of the system, it had the spot within the field of research and study. The inlet and outlet temperatures were taken to find the amount of heat that the fluid gained. The temperature of hot and cold sides were measured to determine the cooling performance of the fluid used. The measurement values was taken by two thermocouples attached to two places on the surface as shown in Fig. 1. through the day these values were averaged and plotted in Figs.5–7.

For the MWCNTs-distilled water case, the hourly average data according to 28th of August day. The weather was slightly windy and cloudy at afternoon period for a short time, which affected the hot side temperature, the current and the voltage of CTEG directly. Whereas, inlet and outlet temperatures of MWCNTs-distilled water nanofluid weren't affected because of lack of rapid response capability of the system to solar radiation sudden variations. At noon, the hot side of TH reached 68.27°C, while the cold side of TE was 33°C as well as solar radiation and ambient temperature measures was 956 W/m² and 34°C.

Regarding to GNPs-distilled water nanofluid case in Fig.6, the testing day was 18th of September and the weather was steady most of the day so the hot surface temperatures for the TE increased gradually from 38.7°C at 09:30 AM to 67.5°C at 14:45 PM, respectively, which progressively decreased until 17:00PM. At noon, the average values of hot side was 73.4°C and the radiation was measured as 958W/m^2 and the ambient value was 30°C.

In terms of distilled water in Fig.7, the testing day was 10th of August. At noon, the average measured hot side surface temperature was 68.2°C because of best conditions weather. At this period, the daylight time was longer than the nighttime, so the values of radiations and temperatures was almost the highest in tests. The radiation reached to 894 W/m^2 and the cold side and ambient values was 31.6°C and 37°C, respectively. Regarding to used coolants, the highest measured values of temperature between the hot and cold sides for distilled water, GNPs-distilled water and MWCNTs-distilled water were 35.7°C, 36.9°C and 37.7°C, respectively.

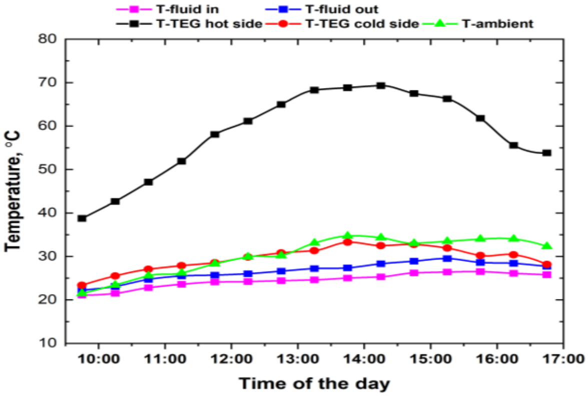

Figure 5. Temperature distribution of measured and calculated parameters for 0.25 wt.% MWCNTs-distilled water

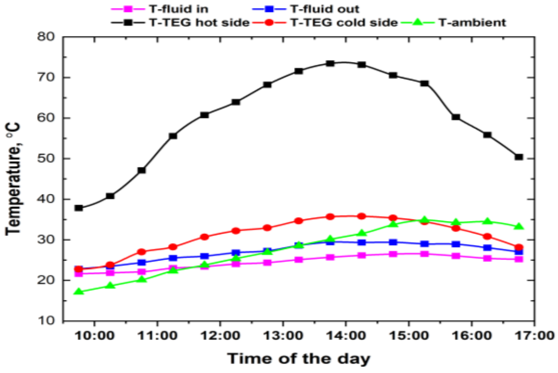

Figure 6. Temperature distributions of measured and calculated parameters for 0.25 wt.% GNPs-distilled water

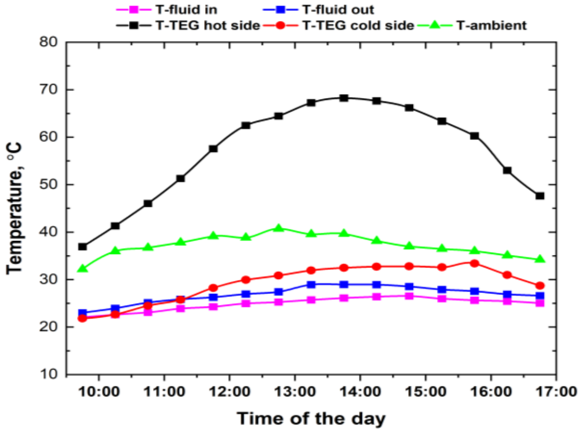

Figure 7. Temperature distribution of measured and calculated parameters for distilled water

3.2. Electrical Power and Efficiency

The output of electrical power which generated by CTEG system are given in Figs. 8–10. It seems that the variation of electrical power followed the same trend as the solar radiation along the time of the day. So at noon period, the production of electricity was the highest over the day. The maximum electric power for MWCNTs-distilled water nanofluid, GNPs-distilled water nanofluid and distilled water were 0.68(W), 0.74(W) and 0.65(W) for a single thermoelectric generator, respectively.

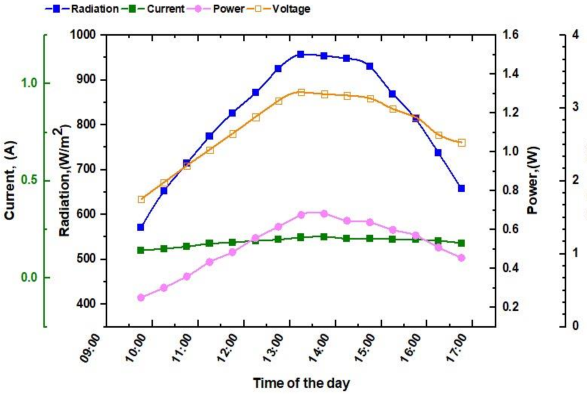

Figure 8. Hourly average variations of measured and calculated parameters for 0.25 wt.% MWCNTs-distilled water

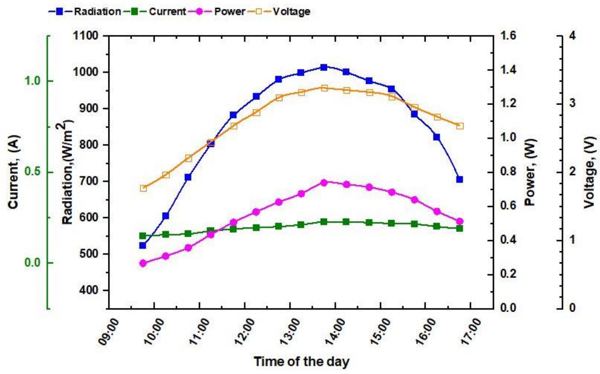

Figure 9. Hourly average variations of measured and calculated parameters for 0.25 wt.% GNPs- distilled water

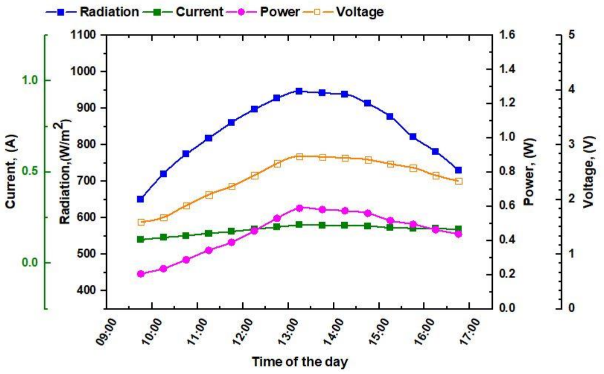

Figure 10. Hourly average variations of measured and calculated parameters for distilled water

With the aim of getting a clear comparison between different types of coolants, the measured values of weather conditions such as (ambient temperature, solar radiation), hot side temperature of thermoelectric and obtained efficiencies were averaged for test duration between 9:30 AM and 17:00 PM and for the period of radiation peak (11:15–15:45) and it have been summarized in Tables 4-5, respectively.

As demonstrated in Tables 4-5, Some points can be noted. Firstly, the obtained analysis concluded to good agreement with the study of Fan et. al [8] for average values of electrical efficiency. Secondly, nanofluids had a main role in increasing the heat transfer capacity, which in turn led to reducing the TEG modules temperature, which increased electrical performance. As a comparison, GNPs-distilled water nanofluid usually showed higher values in electrical efficiency than MWCNTs-distilled water nanofluid and distilled water. Similar results appeared in numerical study of Rejeb et. al [20] while 0.5% graphene-water nanofluid increased the total electrical power about 11.15% comparing to water while this values up to 20% in our study because of different conditions. This results as shown in Figure.11, MWCNTs-distilled water nanofluid is the most electrically efficient fluid coolant as compared to rest of the coolants.

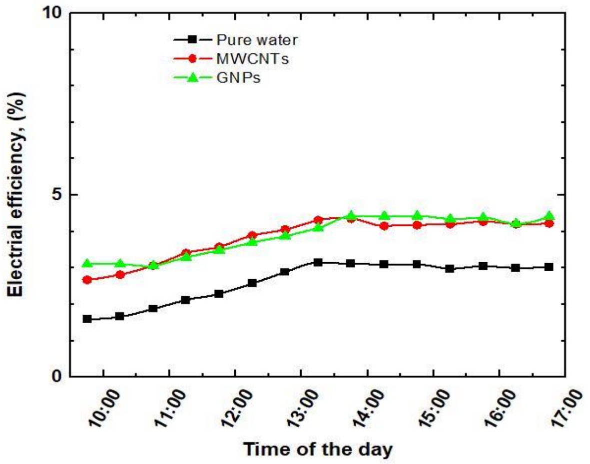

Figure 11. Electrical efficiency of the system for used coolants

3.3. Thermal and Overall Energetic Efficiencies

As we mentioned before, the overall efficiency was affected by both electrical and thermal efficiencies according to Eq.(8). During the test day, because of different weather conditions the values of thermal efficiency doesn't follow a specific trend. The changes in humidity, wind speed and ambient temperature caused a fluctuate in the results as shown in figures 12-13. Average values of thermal and total efficiencies was given in Table 6. The outputs showed that GNPs-distilled water nanofluid had higher thermal efficiency than MWCNTs-distilled water nanofluid and distilled water because of high heat capacitance so consequently the maximum total energetic performance was obtained for GNPs-distilled water nanofluid. As a result, the daily averages of total efficiency for the day-long periods were 16.34%, 24.03% and 20.21% for distilled water, GNPs-distilled water, MWCNTs-distilled water respectively. Whereas during the peak period, the daily averages of total efficiency were 17.63%, 20.40% and 24.35% for distilled water, GNPs-distilled water, MWCNTs-distilled water respectively.

Table 4. Average measured data of weather conditions, cells temperature, and electrical enhancement during the experiment period (9:30 - 17:00)

Coolants	I_{sol}(W/m^2)	T_{amb} (°C)	T_h (°C)	T_c (°C)	V (v)	P (W)	η_{ele}(%)
Distilled water	839	36.8	57	29.2	2.67	0.50	3.1
GNPs-distilled water	897	29.16	63.02	32.5	2.90	0.60	4
MWCNTs-distilled water	813	30.26	58.6	29.5	2.7	0.51	3.8

Table 5. Average measured data of weather conditions, cells temperature, and electrical enhancement during the experiment period (11:15 - 15:45)

Coolants	I_{sol}(W/m^2)	T_{amb}(°C)	T_h (°C)	T_c (°C)	V (v)	P (W)	η_{ele}(%)
Distilled water	894	37.8	62.86	31.06	2.25	0.56	3.43
GNPs-distilled water	958	29.89	67.8	33.8	3.06	0.65	4.12
MWCNTs-distilled water	887	31.7	64.12	30.9	2.96	0.59	4.04

Table 6. Average data of thermal and total efficiencies.

Fluids	Duration between 9:30-17:00		Duration between 11:15-15:45	
	Thermal Eff. (%)	Total Eff. (%)	Thermal Eff. (%)	Total Eff. (%)
Distilled Water	13.70	16.34	14.83	17.63
GNPs-distilled water	20.01	24.03	20.22	24.35
MWCNTs-distilled water	16.39	20.21	16.40	20.40

As compared before, Rejeb et. al [20] mentioned in their numerical study that thermal power increased about 6% for 0.5% graphene/ water nanofluid comparing to water but this ratio is up to 36% in our study.

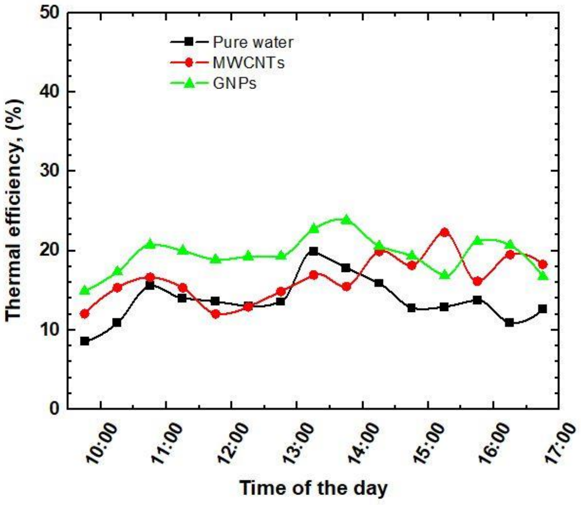

Figure 12. Thermal efficiency of the system for used coolants

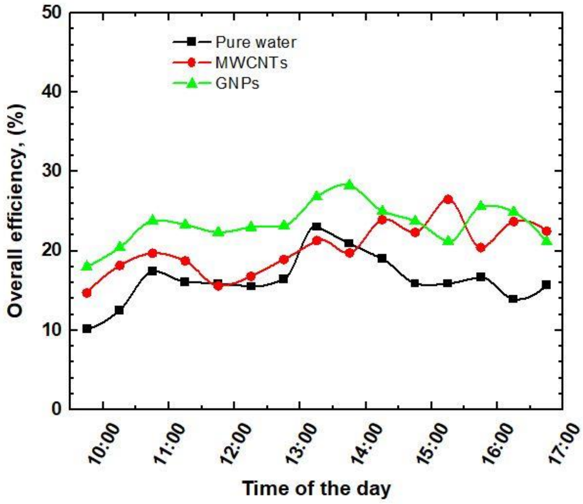

Figure 13. Overall efficiency of the system for used coolants

4. CONCLUSION

The performance evaluation of concentrator thermoelectric generator (CTEG) system using nanofluid cooling technique has been examined experimentally. Two types of nanoparticles of GNPs and MWCNTs with mass concentration of 0.25 wt.% in distilled water was used as coolant nanofluids with steady rate of flow (0.5 L/min). The effects of weather conditions, solar radiations, temperatures (sides, inlet, outlet, ambient) and efficiencies (thermal, electrical and total) of the system have been investigated in detail. Several key conclusions can be summarized as:

- GNPs-distilled water coolants showed higher stability more than MWCNTs-distilled water and distilled water regarding to electrical performance during the solar peak radiation while the modules temperatures reaches the highest values.
- The thermoelectric generator system could generate electricity about 3.7W with a temperature gradient of 38C° between hot and cold surfaces in case of GNPs-distilled water nanofluid. The power of each module was about 0.74 W at this temperature difference.
- In terms of thermal efficiency, GNPs-distilled water nanofluid showed higher value than MWCNTs-distilled water and distilled water.
- Because of the relatively high heat capacity of GNPs-distilled water nanofluid. Comparing to other coolants, the highest improvement for thermal performance was obtained from it and consequently in overall performance.
- GNPs-distilled water nanofluid preserved higher stability in electrical performance than other coolants. This stability predicated to high values of GNPs thermal conductivity, which give the capability to disperse heat quicker than the other coolants.
- The highest electrical energy generation level was observed when GNPs-distilled water nanofluid was used as a coolant.
- Nevertheless, this experimental tests didn't take many various parameters into account so other parameters still need to be investigated such as wind parameter, reflectivity, the flatness of the reflecting material as well as experimental errors. So these tests are subject to moreover both numerically and theoretically investigations in order to draw a solid conclusion for effects of nanofluids types on cooling technique for different thermal systems like CTEG.

NOMENCLATURE

A_{th}- Area of the receiver plate [m^2]
I_{sol}- total incident solar radiation [W/m^2]
m- Mass [kg]
P- Electric power [W]
V- Voltage [V]

Q_u- Useful thermal power [W]
K- Thermal conductivity [W/m^2.K]
C_p- Specific heat [kJ/kg.k]
T – Temperature [°C]
$\dot{m}$- Mass flow rate [kg/s]
I- Current [A]

SUBSCRIPTS

n- Nanoparticle
nf- nanofluid
c- Cold side
h- Hot side
o- Outlet
f- Base fluid
i- Inlet

GREEK SYMBOLS

η_{ele}- Electric efficiency [%]
η_{th}- Thermal efficiency [%]
$\emptyset$- Volumetric ratio of nanofluid [-]
ρ- density [kg/m^3]

DECLARATION OF ETHICAL STANDARDS

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

AUTHORS' CONTRIBUTIONS

Abdalhakim Faitori M. BEN SAOUD: Performed the experiments, analyse the results and prepare the draft.

Abdulla ALAKOUR: Wrote the manuscript.

Engin GEDİK: Analyse the results, wrote the manuscript.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

REFERENCES

[1] AFSHARİ, F., "Experimental study for comparing heating and cooling performance of thermoelectric Peltier." ***Politeknik Dergisi***, 23(3), pp.889-894 (2020).

[2] Ahiska, R., Savaş, Y. And Hakan, I.Ş.I.K., "Mikro denetleyicili smps ve kontrol sisteminin termoelektrik uygulamalari. " ***Politeknik dergisi***, 5(1):59-68 (2002).

[3] Fakoor, R., Ladhak, F., Nazi, A., Huber, M.,"Using deep learning to enhance cancer diagnosis and classification", ***Proceedings of the 30th International Conference on Machine Learning***, Atlanta, Georgia, (2013).

[4] Abdelkareem, Mohammad Ali, et al. "Prospects of Thermoelectric generators with nanofluid." ***Thermal Science and Engineering Progress*** (2022).

[5] ÖZBAŞ, E., "Experimental investigation of passive water cooling in solar heating thermoelectric generator." ***Politeknik Dergisi***, 23(4), pp.1231-1236 (2019).

[6] ŞENER, M., mertkan ARSLAN, F., GÜRSES, O. and GÜRLEK, G., "Experimental investigation of thermoelectric self-cooling system for the cooling of ultrasonic transducer drivers. " ***Politeknik Dergisi***, pp.1-1 (2021).

[7] Shanmugam, S., Eswaramoorthy, M., and Veerappan, A. R., "Modeling and analysis of a solar parabolic dish thermoelectric generator", ***Energy Sources, Part A: Recovery, Utilization, And Environmental Effects***, 36 (14): 1531–1539 (2014).

[8] Fan, H., Singh, R., and Akbarzadeh, A., "Electric power generation from thermoelectric cells using a solar dish concentrator", ***Journal Of Electronic Materials***, 40 (5): 1311–1320 (2011).

[9] Sundarraj, P., Taylor, R. A., Banerjee, D., Maity, D., and Roy, S. S., "Experimental and theoretical analysis of a hybrid solar thermoelectric generator with forced convection cooling", ***Journal Of Physics D: Applied Physics***, 50 (1): 15501 (2016).

[10] Muthu, G., Shanmugam, S., and Veerappan, A. R., "Theoretical and experimental study on a thermoelectric generator using concentrated solar thermal energy", ***Journal Of Electronic Materials***, 48 (5): 2876–2885 (2019).

[11] Ahammed, N., Asirvatham, L. G., and Wongwises, S., "Entropy generation analysis of graphene–alumina hybrid nanofluid in multiport minichannel heat exchanger coupled with thermoelectric cooler", ***International Journal Of Heat And Mass Transfer***, 103: 1084–1097 (2016).

[12] Nnanna, A. G. A., Rutherford, W., Elomar, W., and Sankowski, B., "Assessment of thermoelectric module with nanofluid heat exchanger", ***Applied Thermal Engineering***, 29 (2–3): 491–500 (2009).

[13] Chang, H., Kao, M.-J., Cho, K.-C., Chen, S.-L., Chu, K.-H., and Chen, C.-C., "Integration of CuO thin films and dye-sensitized solar cells for thermoelectric generators", ***Current Applied Physics***, 11 (4): S19–S22 (2011).

[14] Nasrin, R., Rahim, N. A., Fayaz, H., and Hasanuzzaman, M., "Water/MWCNT nanofluid based cooling system of PVT: Experimental and numerical research", ***Renewable Energy***, 121: 286–300 (2018).

[15] Contreras, E. M. C., Oliveira, G. A., and Bandarra Filho, E. P., "Experimental analysis of the thermohydraulic performance of graphene and silver nanofluids in automotive cooling systems", ***International Journal Of Heat And Mass Transfer***, 132: 375–387 (2019).

[16] Sengers, J. V and Watson, J. T. R., "Improved international formulations for the viscosity and thermal conductivity of water substance", ***Journal Of Physical And Chemical Reference Data***, 15 (4): 1291–1314 (1986).

[17] Pak, B. C. and Cho, Y. I., "Hydrodynamic and heat transfer study of dispersed fluids with submicron metallic oxide particles", ***Experimental Heat Transfer An International Journal***, 11 (2): 151–170 (1998).

[18] Xuan, Y. and Roetzel, W., "Conceptions for heat transfer correlation of nanofluids", ***International Journal Of Heat And Mass Transfer***, 43 (19): 3701–3707 (2000).

[19] MAXWELL-GARNETT, J. C., "Colours in metal glasses and in metallic films", ***Phil. Trans. R. Soc. Lond, A***, 203: 385–420 (1904).

[20] Rejeb, O., Shittu, S., Li, G., Ghenai, C., Zhao, X., Ménézo, C., Jemni, A., hedi Jomaa, M. and Bettayeb, M., "Comparative investigation of concentrated photovoltaic thermal-thermoelectric with nanofluid cooling." ***Energy Conversion and Management***, 235, p.113968,(2021)