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Influence of Nano Fluid and Receiver Tube Shape Modification on the Performance of Solar Parabolic Trough Collector with Closed System

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Abstract: ***Solar energy is one of the cleaner forms of renewable energy resources which achieve the need of people in the field of thermal energy. The parabolic trough solar collector is one of the most efficient and it has been studied widely. Direct absorption solar collector is a new technique used recently in harvesting solar energy. In this study, non-circulated Nano-Fluid (N-F) is used to absorb the solar radiation through a glass wall in parabolic solar collector closed system. In this study N-F is pure water with nano copper oxide. The nanoparticles used were 32 nm copper oxide particles with concentration of 0.05 %. The absorbed heat was directly transferred to circulated water flowing inside a copper tube submerged in the N-F. In addition to the absorption of solar radiation from the N-F, the heat transfer flowing through the walls was made into the water. There were two shapes for the copper tube of the receivers, the first was helical and the second was straight and they have the same surface area. A study of the effect of changing the volumetric flow rate and temperature of the inlet fluid on the efficiency of the new configuration was performed. The results show that Helical Tube (HT) has efficiency more than Straight Tube (ST) especially when using N-F. It is also found that N-F in direct absorption system with direct heat exchange improves the performance of solar collector. In addition, direct heat exchange within the solar receiver has reduced the overall thermal resistance of the solar collector system. The increase in the volumetric flow rate increased the Reynolds number.***

Keywords: Direct absorption solar collector, helical tube, nano-fluid

1. Introduction

Alternative and renewable energy sources are more and more sustainable solutions due to the vast consuming of oil products. Solar energy utilization is vital for our general public on account of its plenitude and its zero CO_2 impressions. Now a day, solar energy is covering variety of human needs of power since it is a cheapest power on earth. This type of power can provide the energy for water creation, house-warming, mechanical warmth request and power generation. One of concentrated collector system that can be used in applications with high temperature request; power generation and industrial processes is parabolic trough. Among all the concentrated solar power technology, parabolic trough concentrator is the most advanced technology for power generation. A parabolic trough concentrator is a line focusing solar collector that is straight in one dimension and curved as a parabolic shape in the other two dimensions. It is lined with mirror film of high reflectivity. Solar radiation, which enters Solar Parabolic Trough Collector (PTC) parallel to the plane of symmetry, is concentrated along the focal line, where a tube receiver is installed to receive the concentrated solar radiation. The receiver is the heart of concentrated solar power (CSP) system. And so, many researchers pay attention towards the design of a variety of solar receivers so that the thermal performance of CSP system can be improved. Nanotechnology was introduced in this field of solar harvesting via the new technique called direct absorption solar. This was recently used in the new generation of solar collectors instead of using the conventional method which absorbed solar radiation by the spectral selective coating of the metallic pipe. In the new technique, solar radiation is absorbed by the N-F. The nano-fluid is a compound produced by mixing nanoparticles with base fluid which flows through a glass tube and then passed into a heat exchanger to convey the absorbed heat into a cold fluid. The addition of nanoparticles to the fluid will improve the thermal properties of the fluid, which will increase the efficiency and performance of the solar collector. Direct Absorption Solar Collector (DASC) is a novel technique used recently for the new generation of solar collectors. Instead of using metallic tube painted with special spectral paint to absorb solar irradiation and transfer heat to a fluid inside the tube, flowing N-F in a glass tube absorbs solar irradiation directly and transport the absorbed energy as a heat exchanger for usage. Since, DASC's are frost developed, many researchers studied the performance of these collectors numerically and experimentally and compared it with the conventional solar collectors. Water was found to be the best absorber for solar radiation among four liquids, namely; water; ethylene glycol; propylene glycol and therminol VP-1, which has been tested by Otanicar et al. [1]). However, the above is still a weak absorber, only absorbing 13 % of the energy. The presence of nanoparticles promises superior capability for solar irradiation absorption since nanoparticles are generally opaque and may be black. Tyagi et al. [2]Observed that for the non-concentrating flat-plate collector the presence of nanoparticles increases the absorption of incident radiation by more than 9 times over that of pure water. The efficiency of Direct Absorption Collector by using N-F has been found to be up to 10 % higher than that of the flat-plate collector [2]. Nano-fluids, even of low-content, has good absorption in direct absorption collector (DAC) compared with the base

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fluid or compared with coating absorber as has been demonstrated by Luo et al. [3] and the model of Xu et al. [4]. The purpose of this research is to steady the performance analysis of the heat exchanger placed in the focal point of the parabola trough solar collector with using 0.05 % wtCuO/H_2O N-F, helical and straight receivers tube are used with different volumetric flow rate.

2. Material Method

2.1 Receiver (receiver tube)

The receiver of the conventional parabolic trough solar collector contains the receiver tube where the rays are focused, this tube usually is coated in black with a view to absorb more heat. In this study, the design of the receiver is changed, by replacing the spectral selective coating with a glass envelop filled with N-F. This was done by making the receiver consist of glass tube compound with a copper tube and filling N-F in gap between them (Figure 1). As the water is circulated in the copper tube, the N-F remains stationary inside the gap. The incident solar radiation passes through the glass wall, absorbed by nanoparticles, and converted into heat rapidly. The heat generated inside N-F will be transferred to the circulated water through the copper wall. In this study two types of tubes are used, the helical and straight. The specifications of each type are shown in Table 1.

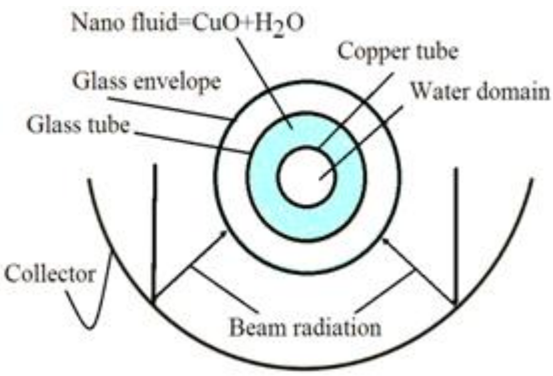

Figure1: Cross section of copper receiver tube

Table 1: Receiver and collector specifications

Receiver- glass tube			
Parameters	Symbol	Unit	Value
Inner diameter	D_{gi}	mm	46
Outer diameter	D_{go}	mm	48
Emissivity of glass	Ɛg	-	0.98
Transmittance of glass	τ_g	-	0.93
Material type	-	-	Pyrex glass
The first receiver straight copper tube model			
Inner diameter	D_{ci}	mm	20
Outer diameter	D_{co}	mm	23
Emissivity of copper	Ɛc	-	0
Material type	-	-	copper
The second receiver-helical copper tube model			
Inner diameter	dci	mm	5
Outer diameter	d_{co}	mm	6.35
Coil pitch diameter	P_{co}	mm	19
Roll diameter	d_{rol}	mm	38.6
Length of the coiled	L	m	6
Collector			
Width	w	m	1
Length	L	m	1.5
Rim angle	Ø	deg	90°
Optical efficiency	*f*	-	0.73
Focal length	F	m	0.25
Concentrating ratio	CR	-	6.31

2.1.1. Receiver with copper helical tube(HT)

A copper tube was procured from the market of outlet diameter 6.35mm and thickness 0.61mm for testing purpose. diameter roll of tube (d_o) is 6.35 mm and thickness of the tube is 0.61mm and the length of the coiled tubes is 6 m, the number of windings of the tube is 52 rolls and roll diameter is 38.6mm and the average distance between any roll and the other (coil pitch) is 19 mm. Two expanded copper pieces are used to expand the diameter at the ends of the tube, mounted by welding in order to link the tube with the tube which connected with a water tank. The HT is placed inside a glass tube opening from both sides. The size of the HT is designed on the basis of the diameter of the glass tube in which the HT is placed inside. There is no flexibility in choosing the glass tube because this tube with the current dimension is the available in the native markets. The helical pipe was manually wrapped according to the glass tube dimensions as shown in Figures 2 and 3.

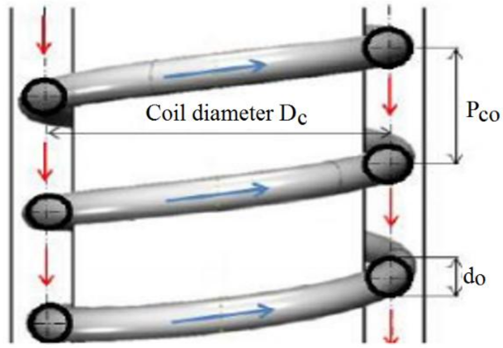

Figure 2: Helical coil design

The following equation has been used to design the HT receiver [5]

$$L_{coil} = N_{coil}\sqrt{(\pi d_o)^2 + p_{Pitch}^2} \qquad (1)$$

Where N_{coil} is the number of the coils in the HT, do is the coil outer diameter, and pitch is the average distance between each two neighboring turns in the HT.

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Figure 3: HT used in the study

2.1.2. Receiver with copper straight tube (ST)

The receiver tube is made with an outer glass tube and an inner copper tube sharing the same axis. The copper tube extends horizontally 1.5 meters and its diameter is 23 mm. The common axis spans the length of the focus of the mirror.

Figure 4: The second receiver- straight copper tube model

2.2. Nanoparticles

CuO nanoparticle was used in this study. Thermophysical properties of CuO nanoparticle are presented in Table 2.

Table 2: Thermophysical properties of nanoparticle

Nanoparticle name	ρ, kg.m^{-3}	Cp, J.(kg.K)-^{1}	k, W.(m.K)-^{1}	β, K^{-1}
CuO	6300	475	33	1.8x10^{-5}

2.3. Preparation of nano fluid

There are two methods for preparing the N-F: The first method is the one-step method and the second is the two-step method. The two-step method is used widely for preparing N-F. In this study, the two step method was used because it is economical.

In this study, the effective density of the N-F is calculated using Eq.2 [6].

$$\rho_{nf} = \rho_f (1 - \varphi) + \rho_p \varphi \qquad (2)$$

ρ_{nf} is the effective density of the N-F, is the density of the base fluid, ρ_p is the density of the nanoparticles, all quantities in kg/m^3.

Effective specific heat capacity (Cp_{nf}) has been estimated by supposing thermal equilibrium between the N-F and the copper particles. Eq.3 is used for the calculation of specific heat capacity.

$$Cp_{nf} = Cp_f (1 - \varphi) + Cp_p.\varphi \qquad (3)$$

Where Cp_{nf} is the effective specific heat of the N-F, $Cp_p$is the specific heat of the nanoparticle, Cp_f is the specific heat of the base fluid, all quantities in J(kgK) $^{-1}$.

Many models are used to calculate the dynamic viscosity of the N-Fs are found in the literature, but in this study, Einstein, [7] is used due to is validity for spherical particles with minimal concentration of 2 %. Also the model is the oldest used to determine the effective viscosity of N-Fs. The model for the effective viscosity of the N-F is represented in Eq.4.

$$\mu_{nf} = \mu_f (1 + 2.5\,\varphi) \qquad (4)$$

Where μ_{nf} is the effective dynamic viscosity of the N-F, μ_f is the dynamic viscosity of the base fluid in Pa.s, φ is the volume fraction on nanoparticles to base fluid. Maxwell [8] is selected as spherical particles of minimal 1 % concentration is used.

The model is as follows:

$$k_{nf} = k_f \frac{k_p + 2k_f + 2\varphi(k_p - k_f)}{k_p + 2k_f - \varphi(k_p - k_f)} \qquad (5)$$

Wherek_p is the thermal conductivity of nanoparticles, k_f is the thermal conductivity of the base fluid, k_{nf} is the effective thermal conductivity of N-F, all quantities in W(mK) $^{-1}$.

The thermal expansion characteristic is one such physical property, which plays an important role in many heat removal systems involving natural convection. The

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volumetric effective thermal expansion coefficient (β) of a N-F can be calculated by Eq.6 [9].

$$\beta_{nf} = \varphi\,(\beta)_p + (1-\varphi)\,(\beta)_f \qquad (6)$$

Where β_{nf} is the effective thermal expansion the N-F, βp is the thermal expansion the nanoparticles, βf is the thermal expansion the base fluid, all quantities in K^{-1}. One of the important parameters in preparing N-Fs is its volume fraction. It is the ratio of the total volume of the nanoparticles to the total volume of the nanoparticles and base fluid. The formula to calculate the volume fraction is given by Eq.7 [10].

$$\varphi = \left[\frac{\left(\frac{w_{CuO}}{\rho_{CuO}}\right)}{\left(\frac{w_{CuO}}{\rho_{CuO}} + \frac{w_{bf}}{\rho_{bf}}\right)}\right] \times 100 \qquad (7)$$

2.4. Optical absorption properties of nano fluid

Solar absorption is a key factor in the DASC. The addition of nanoparticles to water caused an increase in absorption of solar radiation 9 times compared to the pure water [2]. The nanoparticles used are 32 nm copper oxide particles with concentration 0.05%. The physical parameters using Eq.2 through 6 are computed as shown in Tables (3).

Table 3: Physical properties of N-F at concentrating 0.05% CuO/H_2O

Parameters	Unit	CuO nanoparticles	Pure water	0.055wt% CuO/ pure H_2O N-F
Cp	$J.(kg.K)^{-1}$	475	4181.8	4179.9466
ρ	$kg.m^{-3}$	6300	998.21	1002.65
k	$W.(m.K)^{-1}$	33	0.5984	0.599250883
μ	Pa.s	-	0.00089	0.000891113
β	K-1	0.000018	0.000207	0.000889564

2.5. Thermal efficiency

The thermal efficiency depends on the increase of the water temperature and the total solar irradiance collected by the mirror (G. Aa). The measurements were taken every 30 minutes and resulting in 9 readings per test. From these readings, the thermal efficiency was calculated as follows [4].

$$\eta_{th} = \frac{\dot{m}\, C_p (T_{wo} - T_{wi})}{G.A_a} \qquad (8)$$

Where T_{wo}, T_{wi} is outlet and inlet temperature of water respectively. In this study, the temperature of inlet and outlet in Equation (8) is measured by thermocouple of type T.

3. Results and Discussion

The experiments were carried out to investigate the influences of helical copper tube and a straight copper tube with the N-F and without the N-F for Konya climatic conditions from Turkey cities. In this study, a closed system was used and the volumetric flow rate was from 30 L/h to 90 L/h. Measurements were made from 9:30 am to 5 pm. Results of efficiency are presented below without N-F and with N-F for solar parabolic trough collector.

3.1. The effect of shape of the receivers' tube on the efficiency

Figures 5 through 6 show the effect of receiver shape on the efficiency of system at different conditions i.e. without using N-F, using CuO/H_2O N-F. All tests have been conducted at the same weather conditions. It can be seen that when using helical the efficiency increased by 26 % without using N-F, 40% when using CuO/H_2O nano at 13:00 compared to 20 % without using N-F, 30% when using CuO/H_2O N-F respectively at 12:30 when using straight.

It can be noted that maximum efficiency in the ST at 12:30 and for HT at 1:00. That means in the HT receiver the efficiency continues increasing with increase the solar intensity and inlet temperature due to secondary flows in the HT receiver. But after the time 1:00 Am the efficiency decreased due to decrease in solar intensity as shown in Figures 7 and 11. When the inner temperature increases throughout the day as shown in Figures 8 and 10, the expected thermal losses of the device will increase despite the decrease in the intensity of solar radiation after noon this also leads to decrease the thermal efficiency. For the ST it can be noted in Figures 5 and 6 that there is continuous increase in thermal efficiency with high intensity of solar radiation until 12:30 when reaches maximum value and then the thermal efficiency begins to decrease despite the increase in intensity of solar radiation as shown in Figures 7 and 11.This decrease in the thermal efficiency despite the increase in the intensity of solar radiation with the rise of the inlet temperature of the water induced as shown in Figures 8 and 10 due to poor performance of the straight copper tube at high inlet temperature of the water because the ST does not have secondary flows as in the HT and often the flow in the ST is laminar.

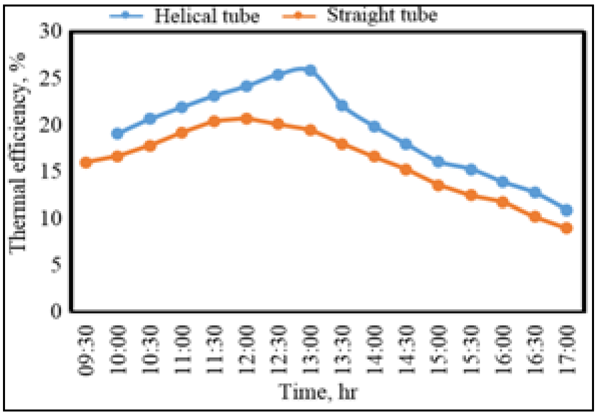

Figure 5: Comparison of the thermal efficiency between HT and ST without N-F for volumetric flow rate 90 L/h

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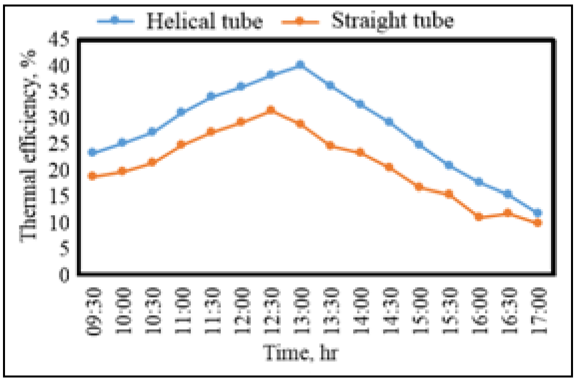

Figure 6: Comparison of the thermal efficiency between HT and ST with CuO/H_2O N-F at volumetric flow rate 90 L/h

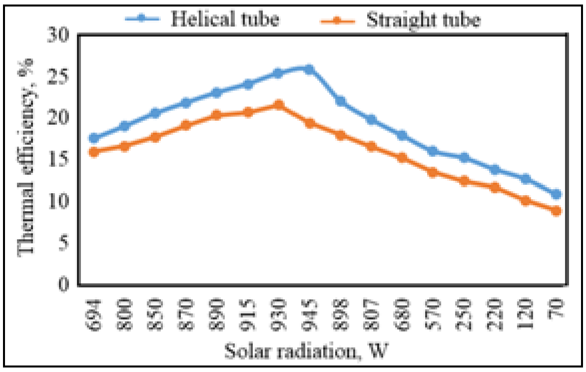

Figure 7: Comparison of the thermal efficiency with the variation in solar radiation at volumetric flow rate 90 L/h without using N-F for helical and ST

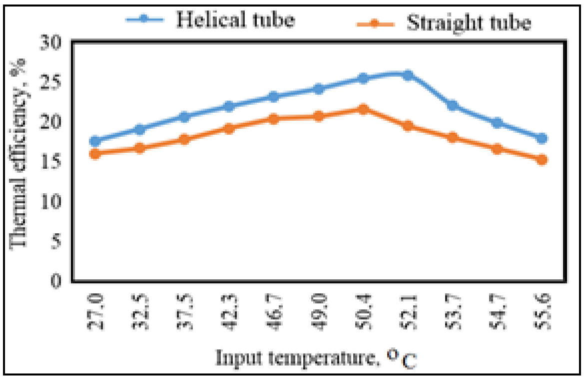

Figure 8: Comparison of the Thermal efficiency with the variation of input temperature at volumetric flow rate 90 L/h without using N-F for helical and ST

3.2The effect of using 0.05%wt CuO/H_2O nano fluid on the efficiency

The addition of nanoparticles to the fluid will improve the thermal properties of the fluid, and surface wettability, by varying particle concentrations to suit different applications which will increase the efficiency and performance of the solar collector. The nanoparticle in N-F caused high specific surface area and therefore more heat transfer surface between particles and fluids. The Brownian motion which is the random movement of particles is a key mechanism for the anomalous increase in the heat transport of N-Fs. Brownian motion tends to move the particles from higher concentration areas to the lower concentration areas [11]. Therefore, when using N-F at concentrating 0.05 % wtCuO/H_2O the efficiency of the solar collector increase to reach 40 % at 13:00 when using HTand 30 % at 12:30 when using STs as shown in Figures 6 and 9. The maximum useful heat 536 W to the HT and 420 W to the ST as shown in Figure 12. Similar readings were taken for the intensity of solar radiation and at the temperature of the water inlet at period from (9:30 to 2:00). Figures 9 have been drowning to compare the two models in similar conditions. It can be noted that maximum efficiency in the ST at 12:30 and for helical at 1:00. That means in the HT receiver the efficiency continues increasing with increase the solar intensity and inlet temperature due to secondary flows in the HT receiver.

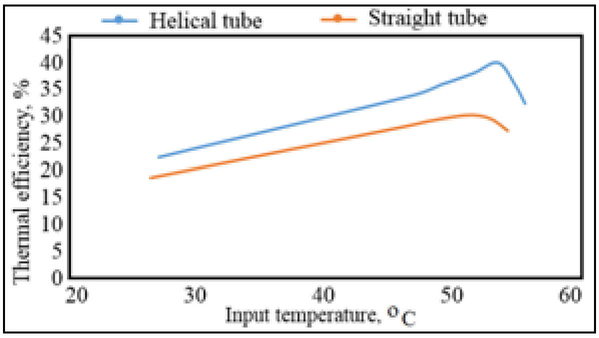

Figure 9: Comparison of the thermal efficiency between HT and ST with variation input temperature and volumetric flow rate 90 L/h with N-F0.055wt% CuO/H_2O

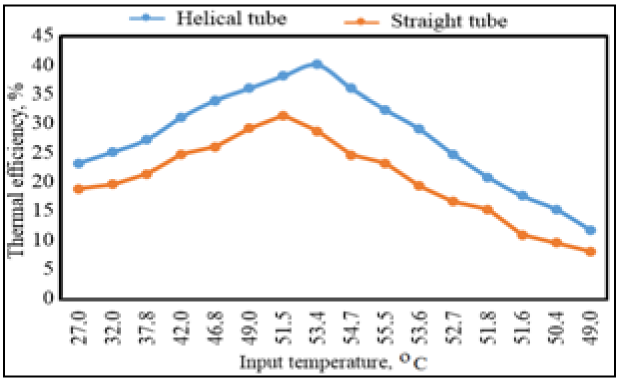

Figure 10: Comparison of the Thermal efficiency with the variation of input temperature at volumetric flow rate 90 L/h, N-F0.055wt% CuO/H_2O with the helical and ST

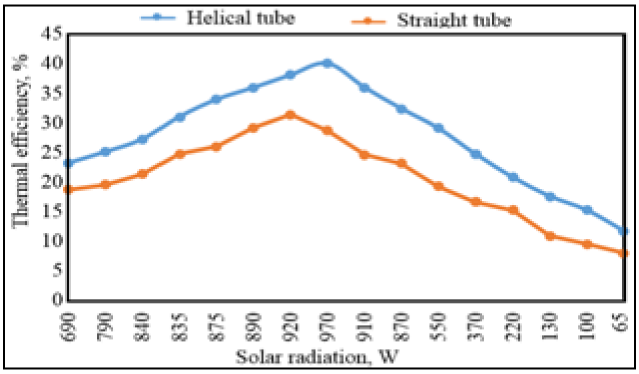

Figure 11: Comparison of the thermal efficiency with the variation solar radiation at volumetric flow rate 90 L/h, N-F0.055wt% CuO/H_2O with the helical and ST

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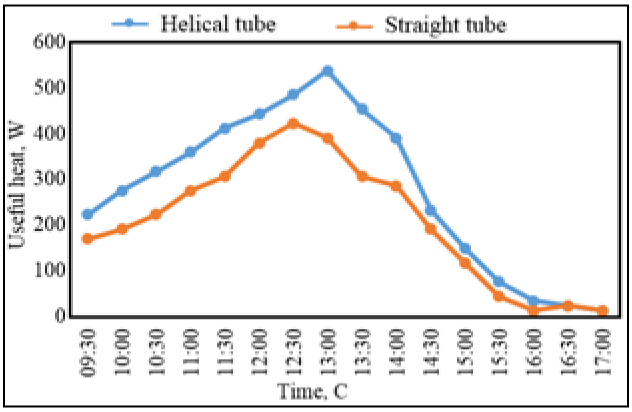

Figure 12: Comparison of the useful heat gain between HT and ST with N-F0.055wt% CuO/H_2O and volumetric flow rate 90 L/h

3.3The effect of the mass flow rate of the water on the efficiency

The effect of the volumetric flow rate on the thermal efficiency is investigated for both of helical and straight receiver tube using N-F at concentration 0.05 wt % CuO/H_2O. Both data sets show the same trend of increasing thermal efficiency with respect to increasing volumetric flow rate. The thermal efficiency is improved when the volumetric flow rate is increased (see Figure 13). The increase in the volumetric flow rate will increase Reynolds' number leading to increase in the heat exchange between N-F and the flowing water in the copper tube. The increase in efficiency is observed with increasing Reynolds.

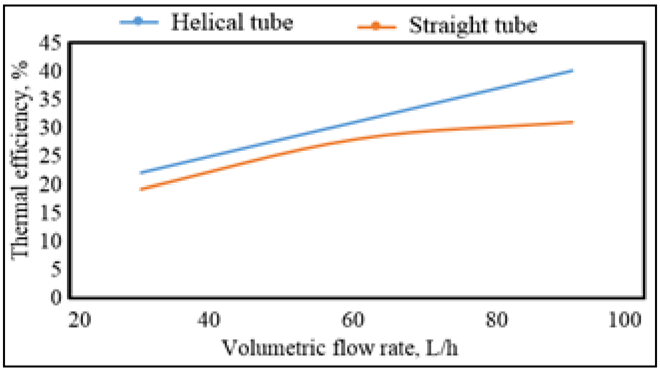

Figure 13: Percentage change of the thermal efficiency of PTC versus the volumetric flow rate for the HT and the ST with 0.05%CuO/H_2O N-F

4. Conclusions

The thermal performance of a parabolic trough solar concentrator is enhanced by using a HT receiver and directed with one axis solar tracking system. The system performance is analyses at different amount of water flow rates with N-F and without N-F. From experimentation and thermal performance evaluation, some conclusions could be find.

a) The efficiency of HT without N-F increased by 26 % at 13:00 compared to 20% at 12:300 when using straight at volumetric flow rate 90 L/h.The reason for this behavior is due to the low efficiency of the straight tube with high temperature of water entry while the HT maintains its performance due to secondary flows.
b) When using helical with (N-F 0.055wt % CuO/H_2O) the efficiency increased by 40 % at 13:00 compared to 30 % at 12:300 when using straight tube. The reason for this increase in the efficiency compared with HT without N-F was high thermal conductivity of the (N-F 0.055 wt % CuO/H_2O) compared with the thermal conductivity of the air.
c) The increase in the volumetric flow rate was increase Reynolds' number leading to increase in the heat exchange between N-F and the flowing water in the copper tube. The increase in efficiency was observed with increasing Reynolds.
d) Nano fluid in direct absorption system with direct heat exchange improves the performance of solar collector.
e) Direct heat exchange within the solar receiver was reduce the total thermal resistance of solar collector system.

References

[1] Otanicar, T. P., Phelan, P. E. ve Golden, J. S., 2009, Optical properties of liquids for direct absorption solar thermal energy systems, *Solar Energy*, 83 (7), 969-977.
[2] Tyagi, H., Phelan, P. ve Prasher, R., 2009, Predicted efficiency of a low-temperature nanofluid-based direct absorption solar collector, *Journal of solar energy engineering*, 131 (4), 041004.
[3] Luo, Z., Wang, C., Wei, W., Xiao, G. ve Ni, M., 2014, Performance improvement of a nanofluid solar collector based on direct absorption collection (DAC) concepts, *International Journal of Heat and Mass Transfer*, 75, 262-271.
[4] Xu, G., Chen, W., Deng, S., Zhang, X. ve Zhao, S., 2015, Performance evaluation of a nanofluid-based direct absorption solar collector with parabolic trough concentrator, *Nanomaterials*, 5 (4), 2131-2147.
[5] Ankanna, B. C. ve Reddy, B. S., 2014, Performance analysis of fabricated helical coil heat exchanger, *Int. J. Eng. Res*, 3, 33-39.
[6] Sokhansefat, T., Kasaeian, A. ve Kowsary, F., 2014, Heat transfer enhancement in parabolic trough collector tube using Al_2O_3/synthetic oil nanofluid, *Renewable and Sustainable Energy Reviews*, 33, 636-644.
[7] Einstein, A., 1906, Eine neue bestimmung der moleküldimensionen, *Annalen der Physik*, 324 (2), 289-306.
[8] Maxwell, J. C., 1881, A Treatise on Electricity and Magnetism: pt. III. Magnetism. pt. IV. Electromagnetism, Clarendon press.
[9] Tayebi, T., Chamkha, A. J., Djezzar, M. ve Bouzerzour, A., 2017, Natural convective nanofluid flow in an annular space between confocal elliptic cylinders, *Journal of Thermal Science and Engineering Applications*, 9 (1), 011010 (9 pages).
[10] Senthilraja, S., Vijayakumar, K. ve Gangadevi, R., 2015, A comparative study on thermal conductivity of

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Al_2O_3/water, CuO/water and Al_2O_3–CuO/water nanofluids, *Digest Journal of Nanomaterials and Biostructures*, 10 (4), 1449-1458.

[11] Singh, A., 2008, Thermal conductivity of nanofluids, *Defence Science Journal*, 58 (5), 600-607.

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