Performance Analysis and Characterization of Non-Metallic Oxide Nano-fluid in Compound Parabolic Trough Solar Collector

Muhammad Kaleem*[1], Muzaffar Ali[2], Javed Akhtar[3], Hamza Riaz [1]

1. Energy Engineering Department University of Engineering and Technology Taxila, Pakistan
2. Mechanical Engineering Department University of Engineering and Technology Taxila, Pakistan
3. Mechanical Engineering Department University of Chakwal, Pakistan

*Corresponding Author: Muzaffar.ali@uettaxila.edu.pk

ABSTRACT

Solar energy is sufficient source of energy for a solar-rich country like Pakistan to meet its energy needs. The Solar thermal technologies such like evacuated tube, flat plate, and compound parabolic trough collectors is being used all around the world. However, the type of the working fluid have a significant mpact on the performance of these collectors. The use of high thermal conductivity nanofluids to increase the performance of solar collectors is very smart technology. The purpose of this research is to improves the thermal performance analysis and characterization of non-metallic nanofluids such as water-based multi-wall carbon nanotubes (Water/MWCNT) with 3000W/mK thermal conductivity are employed in compound parabolic solar collectors (CPC). In this present work several test are perform to determine stability and thermal conductivity of the nanofluid using a thermal analyzer and UV-Vis spectroscopy, respectively. Water/MWCNT nanofluid have thermal conductivity is 37.2% better than water at 0.075% volumetric concentration according to test results. The prepared nanofluids are then used in CPC for extensive investigation, with nanoparticle concentrations (0.025, 0.05, 0.075%) at (0.02, 0.015 kg/s) flow rates. In the experimental investigation, a maximum temperature difference of 10.52°C was achieved with a 0.075% volumetric concentration at 0.015 kg/s flow rate. 19.36% thermal efficiency enhancement with volumetric concentration of 0.075% is record as compare to water at 0.015 kg/s flow rate.

Keywords: Non-metallic oxides, Nanofluids, MWCNT, CPC Characterization.

INTRODUCTION

Compound parabolic collector is solar thermal collector that is used to generate intermediate temperature by making use of solar radiations. Temperature range of this collector is required mostly in domestic sector for space heating or in industry for space or process heating. Performance of this collector is greatly affected by the concentration ratio of collector and the working fluid being used as heat absorbing fluid. Concentration ratio defines the opening of collector which leads to the number of rays coming into the aperture of collector. this type of collector with low concentration ratio does not need sun tracking for ray capturing compared to other solar thermal collectors e.g., parabolic trough collector or flat plate collector. Working fluid greatly affects performance of collector. In this research, nanofluid is integrated with the CPC to enhance its thermal performance. Nanofluids have high thermal conductivity compared to water and can absorb more heat than water which makes them as ideal fluid to be used in solar thermal collectors and increase their efficiency.

In a study, Water/SWCNT nanofluids was use in the flat plate collector and achieved 26.25% and 95.12% heat transfer enhancements at 0. 1%and 0.3% volumetric concentration respectively(Said et al., 2015). In a Similar study, prepared Water/MWCNT nanofluids was utilized and achieved 16%, 21% and 34.13% heat transfer enhancement for volumetric concentration of 0.01%,0.05% and 0.1% respectively (Eltaweel & Abdel-Rehim, 2019). In another study, in a evacuated tube solar collector, 0.05% Water/ MWCNT nanofluids were utilized and a maximum thermal efficiency of 55% was achieved. (Eltaweel et al., 2020). Similarly, in a flat-plate solar collector 0.1 wt% distilled water based Graphene nanofluid were utilize the heat transfer improvement of 24.09% is record at flow rate of 1.5 L/min (Kumar et al., 2021). In another study, 93.43% thermal efficiency for 0.2 vol % at 0.025 kg/s flow rate are observed by using Water/ SWCNT nanofluids in evacuated tube solar collector (Sabiha et al., 2015).In a research study, Water/grapheme, Water/ MWCNT, Water/ Copper oxide, Water/ Titanium oxide, Water/Silicon oxide and Water/ Aluminum oxide nanofluids are use in flat plate solar collectors, with thermal efficiencies of 16.97%, 23.47%, 12.64%, 4.08%, 5.09% and 8.28% respectively(Verma et al., 2017). In another study, Therminol66 based MWCNT nanofluid thermal conductivity and water was investigate 37% (Singh et al., 2020). In a study parabolic trough solar collector are investigate Therminol-®VP-1 base SWCNT nanofluids and 44% enhancement in thermal efficiency was recorded (Mwesigye et al., 2018). In a Similar study, 66% efficiency enhancement with 0.2% volumetric concentration are record by using Water/SWCNT nanofluids in evacuated tube solar collector (Mahbubul et al., 2018). In this research study Water/ SWCNT nanofluids use in evacuated tube solar collector with volumetric concentrations 0.05, 0.1, and 0.2% at a flow rate of 0.008, 0.017, and 0.025 kg/s. The maximum efficiency of 93.43% was achieved for 0.2 vol% of Water/SWCNT nanofluid at a mass flow rate of 0.025 kg/s (Sabiha et al., 2015).In another study the Al2O3, SiO2, Graphene, and graphene Nanoplatelets nanofluids with distilled water used in flat-plate solar collector with 0.25, 0.5, 0.75 and 1vol% at 0.0085, 0.017, and 0.0255 kg/s flow rates and 67.03%, 4.45%, 72.45%, and 76.56% thermal efficiencies of collector are obtained respectively (Liu et al., 2020).Similarly examined Cu-TiO_2 hybrid nanofluids and obtained heat transfer enhancement of 52% for 2.0% volumetric concentration of nanoparticles. In another study(Kumaresan & Velraj, 2012).In another study prepared MWCNT-Fe_3O_4 hybridnanofluids and found heat transfer enhancement of 31.10% for 0.3% volumetric concentration(Sundar et al., 2014). In a research study obtained 26% improvement in thermal efficiency using Al_2O_3-TiO_2/H_2O hybrid nanofluid in Evacuated Tube Collector(Farajzadeh et al., 2018) used hybrid nanofluid Al_2O_3-CuO/H_2O in direct absorption solar parabolic trough collector and 48% efficiency enhancement is obtained(Menbari et al., 2017).

It can be observed from the relevant literature studythat the performance of Compound Parabolic Collector has not been tested by using nonmetallic nanofluids as working fluid for real time investigation of collector. In previous studies, the nonmetallic nanofluids are not investigated in compound parabolic solar collector. TEMPOS thermal analyzer is measured thermal conductivity of a nonmetallic nanofluid in this work. UV- Vis spectrophotometer is also used to assess the stability of these fluids.

Materials and Methods

This section contains key parameters used in the study, selection of nanoparticles and nanofluid preparation method with experimental setup is given.

Selection of nanoparticles

Efficiency of compound parabolic collector is low if fluid used for heat transfer is ordinary water. But if modifications are made in fluid and nanofluid with multiple nanoparticles and multiple base fluid is used then the increase in efficiency of the system is possible because of the enhancement in the thermal conductivity of the fluid. Non-metallic nanoparticles carry higher thermal conductivity as compared to metallic nanoparticles so, CPC will give high efficiency when non-metallic nanoparticles are inserted in the collector system. MWCNTs nanoparticles were used in the experiment. Table 1 shows the properties of nanoparticles. The nanoparticles with > 95% purity were purchase from NanoAmor (Nano structured and Amorphous Materials, Inc. Houston USA)

Table 1: Properties of the Nanoparticles

Parameter	MWCNTs
Particle size	10-20 nm
Length	30-100 um
Purity	> 95%
Specific Surface area	> 165 m^2/g
Bulk density	0.07 g/cm^2
Morphology	Aligned shape
Colour	Black

Preparation of Nanofluids

MWCNT/Water nanofluids are prepared in multiple volumetric concentrations(0.025, 0.05, and 0.075%). By using a magnetic stirrer, homogenizer Ultra-turreax-t25, and sonication bath in two step method .First, weighted nanoparticles are added to base fluids and manually-stirred with glass rod, particles are dispersed into the base fluids using a magnetic stirrering at 45°C and up to 730 rpm. Furthermore, the homogenizer Ultra-Turrax T25 at 16000 rpm is used to raise the homogenization of the nanofluid. Step by Step Preparation of nanofluids is shown in Figure 1(a, b, c). SDS is presently employed in the nanofluids as a surfactant to eliminate nanoparticles cluster and is Ultrasonication for around 3 hours at a frequency of 45 KHz.

Figure 1:Step by step nanofluids preparation (a) Magnetic Stirring (b) Ultra-Turrax T25 Homogenization (c) Ultrasonication (d) TEMPOS Thermal Analyzer

Measurement Procedure and Experimental Setup

Performance analysis of solar collector is determined by concentration ratio and the collector area. This collector's collector area and concentration ratio are 0.8 and 4.17m^2, respectively. The area of the evacuated tube is o.2m^2 and length is 1.85m^2. Due to more hours of sunshine, compared to north-south, the compound parabolic collector is oriented east-west for the experimentation throughout the entire direction. To effectively collect the incident radiation from the receiver, seasonal tilt is necessary. Experimental setup is shown in Figure 2.

Water base MWCNT nanofluids and water use as conventional fluids are tested in a closed loop in CPC. The pump introduces cold fluid in absorber, and exchange heat with absorber tube. These hot fluids are collected and returned to the absorber entry side through the hot fluid tank. Thermocouples of the K type are installed at the absorber inlet and outlet for temperature monitoring. To measure fluid flow, the flow meter is connected to an Arduino. Hourly solar radiations are monitored using the Pyranometer. To measure the ambient temperature, the k type thermocouple is utilized. The experimentation is performed between 10:00 to 16:00 for 6 hours.

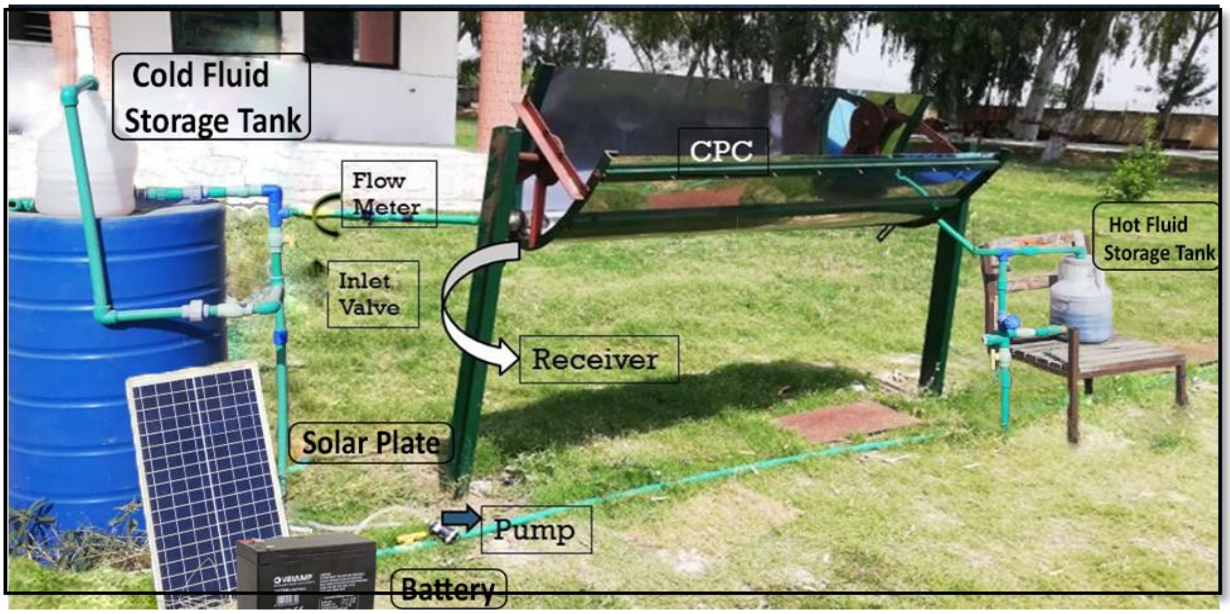


Figure 2: Experimental setup

Key Parameters

The thermal efficiency of the system is used to determine the working of the system how much heat is turned into power.

thermal efficiency of CPC is determined by (Bellos et al., 2016)

$$\eta = \frac{Q_u}{Q_s} \qquad \textbf{(1)}$$

Where, η = efficiency, Q_u= useful solar heat gain, Q_s= total energy

By the following equation, useful solar thermal collector gain is calculated.

$$Q_u = \dot{m} * C_p * (To - Ti) \quad \textbf{(2)}$$

Where,$\dot{m}$= mass flow rate, To= outlet temperature, Ti= inlet temperature

The solar energy entering into collector is given by:

$$Q_s = A_a * G_e \quad \textbf{(3)}$$

Where, A_a= Aperture area, G_e= Solar radiation

Specific heat capacity of the nanofluids can be found by the equation:

$$Cp_{nf} = (1 - \varphi)Cp_{bf} + \varphi Cp_{np} \quad \textbf{(4)}$$

Where, Cp_{nf} =Specific heat of fluid, Cp_{bf}= specific heat of base fluid, Cp_{np}= specific heat ofnanoparticles, φ= Volume fraction.

Equation 5 represents Yu and Choi Model for the thermal conductivity calculation of nanofluids (Yu & Choi, 2004).

$$\frac{k_{eff}}{k_f} = \frac{k_p+2k_f+2(k_p-k_f)(1+\beta)^3\phi}{k_p+2k_f-2(k_p-k_f)(1+\beta)^3\phi} \quad \textbf{(5)}$$

Where,k_{eff}= Thermal conductivity of nanofluid, k_f= thermal conductivity of base fluid, k_p= thermal conductivity of nanoparticles, β= nanofluid thickness.

Results and Discussion

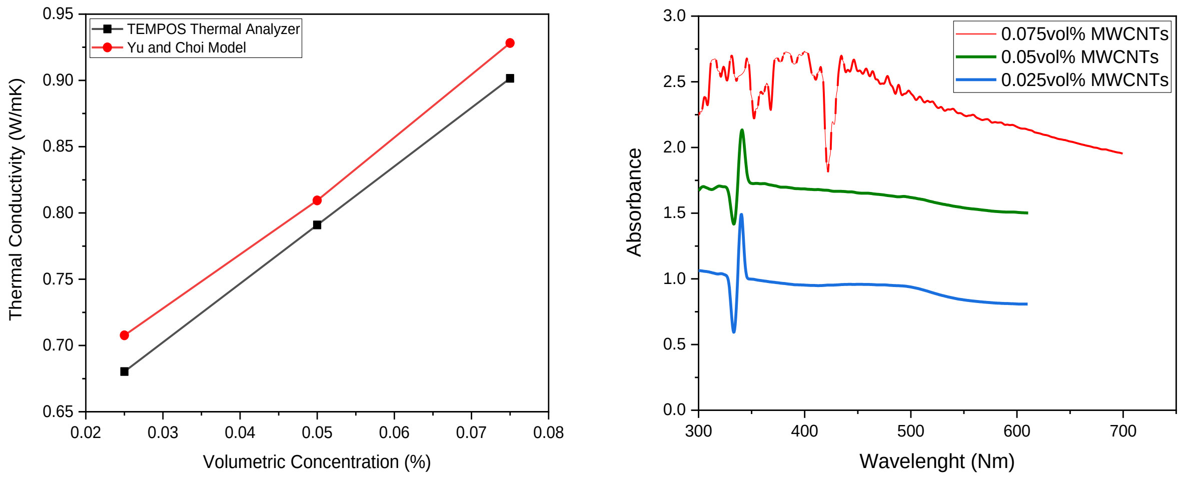
This section describes the UV-Vis spectroscopy and thermal conductivity studies of Water/MWCNT nanofluids. Under subtropical environment of Taxila, Pakistan, The performance of Water/MWCNT nanofluids, is assessed in terms of temperature different, heat gain and system thermal efficiency

UV-Vis Spectroscopy

The use of a UV-vis spectrophotometer to perform spectral analysis on nanofluids is a useful way to evaluate their stability. Advantages of UV-vis spectroscopy has the providing quantitative results that correspond to nanofluid concentration. The UV-vis spectrophotometer is a suitable approach to determine its stability by doing spectral analysis of nanofluids. UV-vi spectroscopy yields quantitative data that are compatible with nanofluid concentration. Particle fluid absorbs UV and visible light. Higher the absorption, and more the stability. First, the device was calibrated using the base fluid. Alone, i.e. (water). Water/MWCNT nanofluid are insert in Spectrophotometer small-band cell (3.5ml), it was examine in wavelengths at 300 nm- 700 nm. Figure 3(b) show the Water/MWCNT nanofluid UV-Vis spectroscopy graph at 30^{o}C. Several peak values at different wavelengths are obtained. Highest Peak value was obtained at 399nm, 341nm and 34 1nm and 2.7, 2.1and 1.4 for 0.075%, 0.05% and 0.025% volumetric concentration.

Thermal Conductivity Measurement

Decagon Devices Inc.'s TEMPOS Thermal Analyzer Instrument tests nanofluid thermal conductivity at multiple (0.025, 0.05.075%) volumetric concentrations at 30oC. It work on the principle of transient hot wire method; TEMPOS Thermal Analyzer measures behind 1 minute of fluid stability. TEMPOS Thermal Analyzer show in Figure 3(b). The precision of the device is ± 10%. For each sample, experiments have been performed three times and the average value is presented. To regulate the temperature, a hot water bath was employed. Before the experiment begins, the equipment is calibrated. The KS-3 sensor was used in this experiment.The concentration of nanoparticles has a direct relationship with nanofluid thermal conductivity, i.e. The thermal conductivity increase with increasing base fluid nanoparticles volume fraction. The nanofluids dispersion stability is crucial because, without the dispersion stability, As the nanoparticles are connected to the KS-3 sensor needle, the thermal conductivity values may fluctuate, and the results are not predicted. Thermal conductivity of nanofluid has direct relationship with volumetric concentration of nanoparticles i.e. The nanofluid thermal conductivity rise with volume fraction of base fluid nanoparticles increases.Comparison of the analytical model of thermal conductivity with an experimental data of Water/MWCNT nanofluid at different concentrations using the TEMPOS Thermal Analyzer is shown in Figure 3(a). Results indicate that the experimental data and the analytical model follow the similar pattern. Highest thermal conductivity values obtain from the analytical model and TEMPOS Thermal Analyzer and at 0.075vol% are (0.9282, 0.9015W/m.K) respectively. Equation 5 represent Yu and Choi Model of conductivity. The Thermal conductivity values obtained lie between data from analytical model. As a reference, 0.6194W/m.K is the thermal conductivity value of distilled water.



(a) (b)

Figure 3: thermal conductivity and UV-Vis spectroscopy with various volumetric concentration at 30ºC

Climatic Conditions

Climate variation was measured with the use of K-type thermometer and Pyranometer in terms of ambient temperature and solar radiation respectively. In addition, in the current study, the analysis is provided in the form of a percentage per volume fraction based on different quantities of nanoparticles. The collector's average outlet temperature is 40°C to 55°C. The environmental conditions of Taxila, Pakistan are shown in Figure 4. The total effect of ambient temperature is between 32.5°C and 35°C.

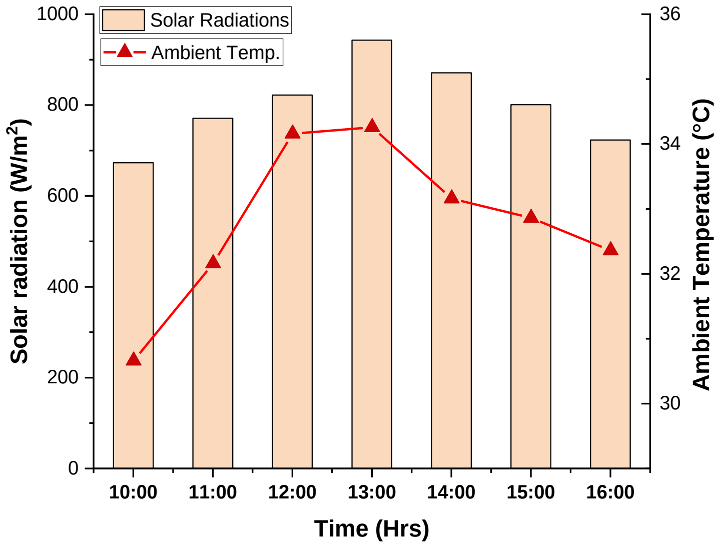
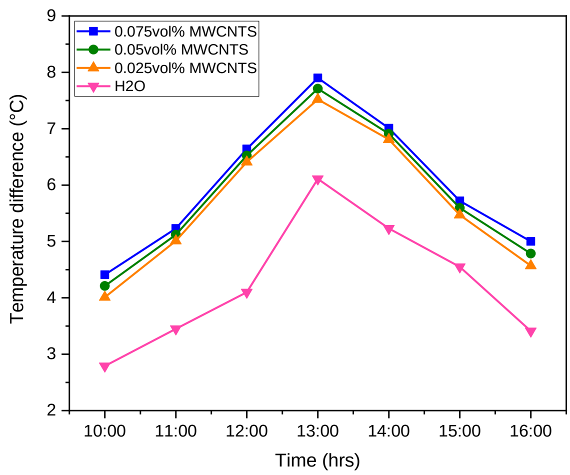
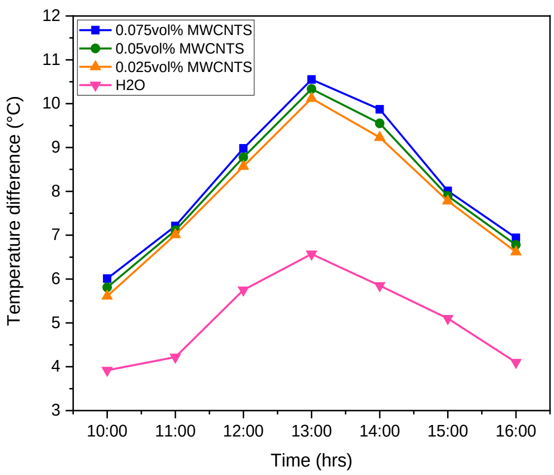


Figure 4: Average Climate Conditions of Taxila

Variation in Temperature difference

Figure 5(a, b) show that the temperature change of a Water/MWCNT nanofluids with various volumetric concentrations at 0.02 and 0.015 kg/s flow rates . The usage of nanofluid leads in a considerable rise in temperature change. The largest volumetric concentration of nanoparticles used in the base fluid obtain the highest value.. Water/MWCNT nanofluid is used to achieve a greater temperature difference. Temperature difference of 7.51°C & 10.11°C is achieve for volumetric concentration of 0.025% at (0.02, 0.015 kg/s)flow rates . The temperature difference 7.8 & 10.54°C is achieve for 0.075% volumetric concentration at (0.02, 0.015 kg/s)flow rates respectively. Highest temperature difference by using a working fluid as a water such as 6.56°C & 6.10°C at (0.015, 0.02 kg/s) flow rates respectively.





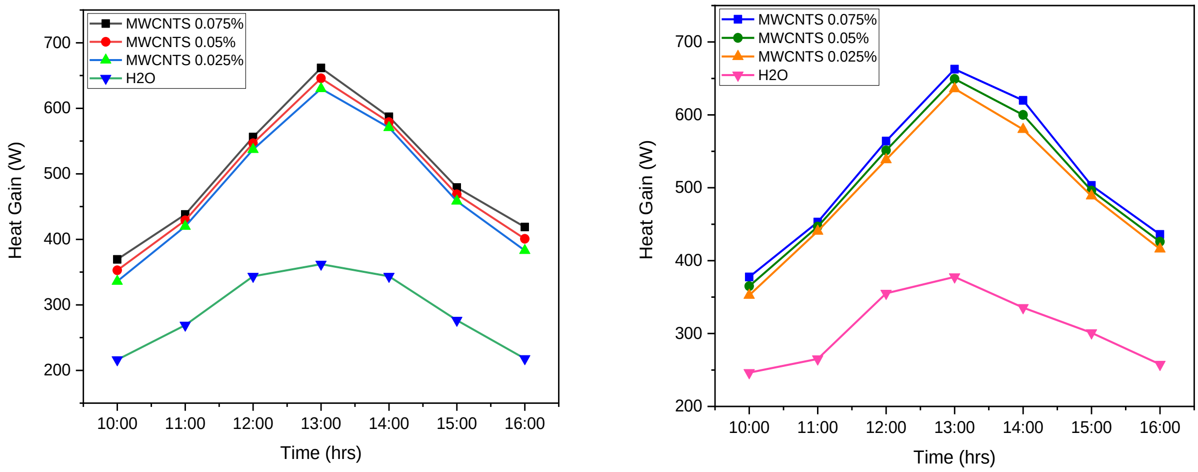
(a) (b)

Figure 5: Variation in temperature difference with flow rate (a) 0.02 kg/s (b) 0.015 kg/s

Nanofluids have a larger surface area than water; they absorbed more heat from the sun as the radiation strikes their particles. The mobility of nanoparticles also increased the chance of absorbing more heat from the sun.

Variation in Heat Gain

Comparison of the heat gain of nanofluids with lowest volumetric concentration of 0.025% at 0.02, 0.015 kg/s is shown here Figure 6(a, b).Temperature difference and specific heat capacity of nanofluids play important role to determine heat gain of the system. The higher heat gain is obtained by utilizing Water/MWCNT nanofluid. Heat gain of 630.01W and 635.91W is recorded for volumetric concentration of 0.025% at a (0.02, 0.015 kg/s) flow rate respectively and heat gain of 661.61W and 662.66W is achieve for volumetric concentration of 0.075% at 0.02, 0.015 kg/s flow rate respectively. Minimum heat gain is obtained by utilizing water as a working fluid. Heat gain of 377.72W and 362.01W is recorded at a (0.015, 0.02 kg/s) respectively.



(a) (b)

Figure 6: Variation in heat gain with flow rate (a) 0.02 kg/s (b) 0.015 kg/s

Variation in Thermal efficiency

Nanofluid thermal efficiencies are determined with the mass flow rates 0.02 kg/s, and 0.015 kg/s are shown in Figure 7(a, b).with Water/MWCNT and Water as working fluids. Water/MWCNT has stronger thermal property and more stable than other nanofluids, resulting in increased thermal efficiency when used in CPC. At 13:00, the maximum thermal efficiency value is attained. For 0.025% volumetric concentration at 0.02, 0.015 kg/s flow rate, thermal efficiency are 75.2% and 75.7%, respectively, while volumetric concentration of 0.075% at (0.02, 0.015 kg/s), flow rate thermal efficiency are 77.1% and 79.3% respectively. By water as conventional fluid, the highest thermal efficiency are 63.7% and 65.3%, respectively, at (0.02, 0.015 kg/s) flow rates.

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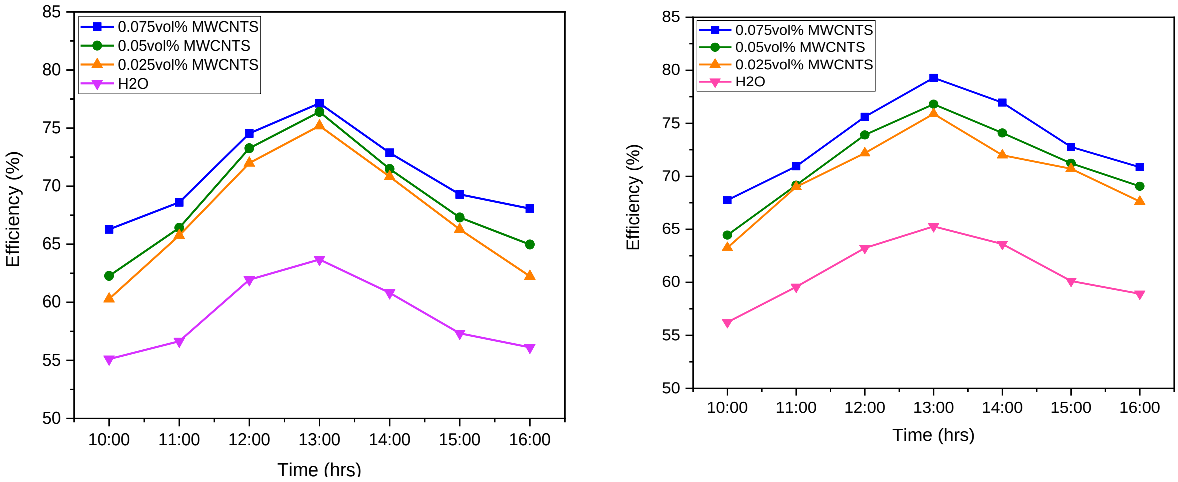

(a) (b)

Figure 7: Variation in Thermal efficiency with flow rate (a) 0.02 kg/s (b) 0.015 kg/s

Conclusion

In this research the performance analysis, stability of compound parabolic collector with Water/MWCNT nanofluid are examined in under sub-tropical environment of Taxila, Pakistan. The study employed with these (0.025, 0.05, and 0.075%) volumetric concentrations at (0.015, 0.02 kg/s) mass flow rates. Nanofluids are stable throughout the testing hours, i.e., 6 hours every days. The Water/MWCNT nanofluid with 0.075% volumetric concentration exhibited the maximum thermal conductivity of 37.2%. At a minimum flow rate of 0.015kg/s a Water/MWCNT nanofluid with a volumetric concentration of 0.075% obtain a maximum temperature difference of 10.52°C. By investigate the Water/MWCNT nanofluids at (0.015, a0.02 kg/s) flow rates, respectively, increases thermal efficiency by 19.36% and 16.22%.

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