

Characterization and Performance Analysis of Non-Metallic Oxide Nano-Fluids in Compound Parabolic Trough Solar Collectors[†]

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Abstract: Solar energy is a viable source to fulfill the energy demands of a solar rich country such as Pakistan. Various types of solar thermal technologies are being used around the world, including flat plate, evacuated tube, and compound parabolic trough collectors. However, the performance of these collectors is strongly influenced by the nature of work fluid. Utilization of nanofluids with high thermal conductivity is a very attractive way to further enhance the performance of solar collectors. Therefore, this study deals with the characterization and thermal performance enhancement of compound parabolic collectors (CPC) by using non-metallic nanofluids such as water-based multi-wall carbon nano tubes (H₂O-MWCNT) with a thermal conductivity of 3000 W/m.K. In the current work, multiple tests are performed to analyze the thermal conductivity and stability of nanofluids through thermal analyzer and UV-Vis Spectroscopy, respectively. Test results show that the thermal conductivity of water-based MWCNT nanofluid is 37% higher than water at a concentration of 0.075%. Prepared nanofluids are then employed in CPC, and detailed experimentation is performed by varying the concentration of nanoparticles (0.025, 0.05, 0.075%) and their flow rate (0.015, 0.02 kg/s). Maximum temperature difference of 10.50°C with volumetric concentration of 0.075% is achieved in experimental analysis at flow rate 0.015 kg/s. Thermal efficiency enhancement of 19.37% with volumetric concentration 0.075% is recorded as compared to water at flow rate 0.015 kg/s.

Keywords: nanofluids; non-metallic oxides; CPC; characterization of nanofluid; MWCNT



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1. Introduction

In a research study, SWCNT/Water nanofluids were used in flat plate collector, and heat transfer enhancement of 95.12% and 26.25% was obtained for 0.3% and 0.1% volumetric concentration, respectively [1]. In another study, MWCNT/Water nanofluids were utilized and heat transfer enhancements of 16%, 21% and 34.13% were achieved for volumetric concentrations of 0.01%, 0.05% and 0.1% respectively [2]. Similarly, 0.05% wt% MWCNT/water nanofluids used in a heat-pipe-evacuated tube solar collector and maximum thermal efficiency of 55% were achieved [3]. In another study, distilled-water-based graphene nanofluids were used in flat-plate solar collector and heat transfer enhancement of 24.09% was recorded for 0.1 wt% at flow rate of 1.5 L/min [4]. In a similar study, SWCNT/water nanofluids were utilized in an evacuated tube solar collector and thermal efficiency of 93.43% for 0.2 vol.% at 0.025 kg/s flow rate was recorded [5]. In another study, various nanofluids such as MWCNT/water, graphene/water, copper oxide/water, aluminum oxide/water, titanium oxide/water, and silicon oxide/water nanofluids were

used in flat plate solar collector and 23.47%, 16.97%, 12.64%, 8.28%, 5.09%, and 4.08% thermal efficiencies of the collector were obtained, respectively [6]. In this study, effective thermal conductivity of water and Therminol-66-based MWCNT nanofluid was measured and thermal conductivity enhancement of 37% was found [7]. In another study, 44% enhancement in thermal efficiency was recorded by using Therminol[®]VP-1 based SWCNT nanofluids in parabolic trough solar collector [8]. Similarly, SWCNT/Water nanofluids are used in evacuated tube solar collector and 66% efficiency improvement with 0.2% volumetric concentration is recorded [9].

Unique work of this paper is the application of nonmetallic nanofluid in compound parabolic collector for real-time analysis of collector. In earlier studies, there is no application of nonmetallic nanofluids in compound parabolic solar collectors. In this study, the thermal conductivity of nonmetallic nanofluid is determined by using a TEMPOS thermal analyzer. The stability of these fluids is also analyzed with the help of UV-Vis spectrophotometer.

2. Materials and Methods

In this section, details about the selection of nanoparticles, preparation method, and experimental setup are presented.

2.1. Selection of Nanoparticles

The nanoparticles used in the experimental study were MWCNTs. The nanoparticles with 95% purity, 10–20 nm particle size, 30–100 μm length, 165 m^2/g specific surface area, 0.07 g/cm^3 bulk density and black color were purchased from NanoAmor (Nano structured and Amorphous Materials, Inc., Houston, TX, USA).

2.2. Preparation of Nanofluids

MWCNT/water nanofluids were prepared by two-step method with the help of magnetic stirrer, Ultra-Turrax T25 shear homogenizer and ultrasonic bath in several volumetric concentrations (0.025, 0.05 and 0.075%). First of all, weighted nanoparticles were introduced into the base fluids and hand-stirred using a glass rod, and then magnetic stirrer at 40 °C and up to 650 rpm was used to disperse particles into base fluids. In addition, the Ultra-Turrax T25 homogenizer was employed at 15,000 rpm to improve the homogenization of the mixture. Then, SDS was utilized in nanofluids as a surfactant to remove nanoparticle clusters and was placed in sonication bath for around 2 h at frequency of 40 KHz.

2.3. Experimental Setup and Measurement Procedure

The solar collector system performance relies on the area and the concentration ratio. The concentration ratio and collector area were 4.17 and 0.8 m^2 , respectively, for this collector. The length of the evacuated tube was 1.85 m, and area was 0.2 m^2 . The experimental setup was placed east–west direction. MWCNT/water nanofluids and conventional fluids such as water were experimented with in CPC in a closed loop. The cold fluid was entered by the pump into the absorber, and the heat was exchanged with the absorber tube. This hot fluid was then collected at hot fluid storage tank placed, at the outlet of the absorber tube and then delivered back to the absorber entrance side. Thermocouples of the K type were fitted for temperature monitoring at the inlet and outlet of the absorber. The flow meter was combined with Arduino to measure fluid flow. Using the pyranometer, hourly solar radiation was monitored, and radiations lay in the range of 625 W/m^2 to 1012 W/m^2 . The experimentation was held between 10:00 a.m. and 14:00 p.m., for 7 h.

3. Results and Discussion

In this section, the thermal conductivity and UV-Vis spectroscopy measurements of the non-metallic oxide nanofluids are presented. The performance study of nanofluids is provided in terms of obtained temperature difference, and thermal efficiency of the system, under a subtropical climate of Taxila Pakistan.

3.1. UV-Vis Spectroscopy

Spectral analysis through UV-Vis spectroscopy is a good technique to assess stability of nanofluids. UV-vis spectroscopy offers quantitative results consistent with the concentration of nanofluids. The UV and visible light are absorbed into the particulate fluid. The higher the absorption, the more the nanofluid is stable. Firstly, the gadget was calibrated with distilled water. Then, prepared nanofluid was inserted in the spectrophotometer in a small-band cell (3.5 mL) and examined for wavelengths of 300 nm to 700 nm. Figure 1a shows the UV-vis spectrograph of H₂O-MWCNT nanofluid at 30 °C. Several peak values are obtained at different wavelengths. Maximum peak values were obtained at 399 nm, 341 nm and 341 nm wavelengths with absorbance of 2.7, 2.1 and 1.4 at 0.075%, 0.05% and 0.025% volumetric concentrations, respectively.

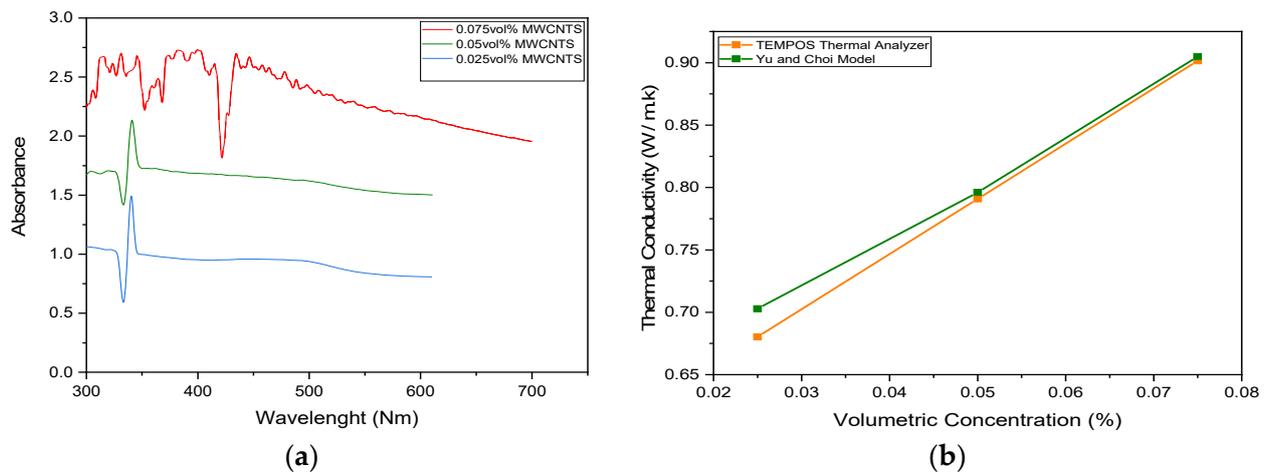


Figure 1. UV-vis spectroscopy (a) and thermal conductivity with different volumetric concentrations at 30 °C (b).

3.2. Thermal Conductivity Measurement (W/m·K)

TEMPOS Thermal Analyzer Instrument developed by Decagon Devices Inc. measures thermal conductivity of nanofluids at several volumetric levels (0.025, 0.05, 0.075%) at 30 °C. It operates on the basis of the transient hot wire method (after 1 min of fluid stability, the TEMPOS Thermal Analyzer measure). The precision of the device is $\pm 10\%$. The equipment is calibrated before the beginning of the experiment. For this experiment, the KS-3 sensor was employed. Nanofluid thermal conductivity directly related to nanoparticles concentration, i.e., the thermal conductivity, rises by the increase in the volume fraction of the base fluid nanoparticles. The dispersion stability of the nanofluid is important because if there is no dispersion or weak dispersion stability of the nanofluid, the thermal conductivity values might be disturbed because the nanoparticles might stick to the needle of the KS-3 sensor and the results will be different to what is expected. TEMPOS Thermal Analyzer comparison of experimental data with analytical model of thermal conductivity of MWCNT/H₂O nanofluid at various concentrations is presented in Figure 1b. The results demonstrate that the analytical model and experimental results have the same trend. At 0.075 vol% maximum thermal conductivity obtained from TEMPOS Thermal Analyzer and analytical model are 0.9015 W/m·K and 0.9282 W/m·K, respectively.

3.3. Variation in Temperature Difference and Thermal Efficiency

Figure 2a represents the change in temperature of MWCNT/Water nanofluid with multiple volumetric concentration and flow rate of 0.02 and 0.015 Kg/s, respectively. There is significant increase in the change in temperature with usage of nanofluid. Maximum value is obtained for the maximum volumetric concentration of the nanoparticles in base fluid. The higher temperature difference is achieved by utilizing MWCNT/water nanofluid. Temperature differences of 7.52 °C and 10.12 °C are achieved for 0.025% volumetric con-

centration at 0.02 and 0.015 kg/s, respectively, and temperature differences of 7.9 °C and 10.5 °C are achieved for 0.075% volumetric concentration at 0.02 and 0.015 kg/s, respectively. The maximum temperature differences such as 6.57 °C and 6.11 °C use water as a working fluid at flow rates of 0.015 kg/s and 0.02 kg/s, respectively. Because nanofluids are large in terms of surface, they absorb more heat from the sun compared to water since the radiation hits their particles. In addition, nanoparticle brownian movement also enhances the possibility of absorbing more warmth from the sun. Figure 2b represents the comparison of the thermal efficiencies of nanofluid obtained with mass flow rates of 0.02 kg/s and 0.015 kg/s, with water and MWCNT/water as conventional fluids.

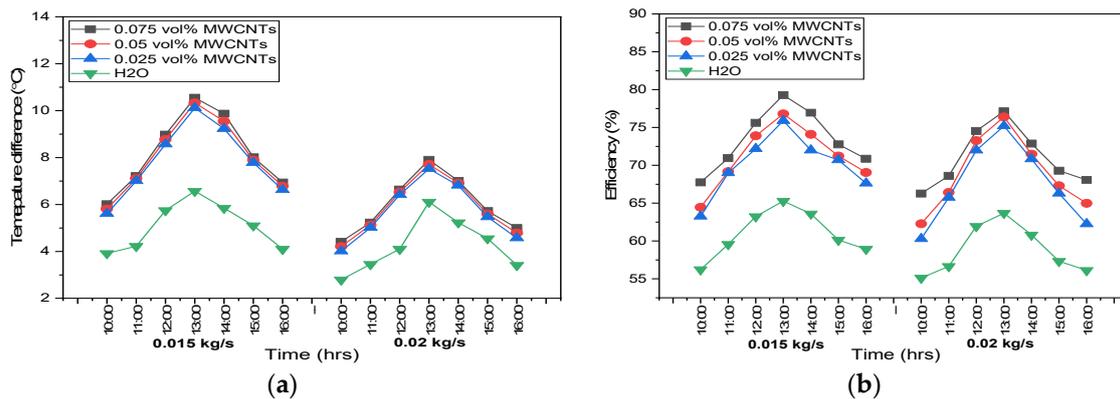


Figure 2. Variation in (a) temperature difference with flowrate and (b) efficiency with flowrate.

MWCNT/water exhibits higher thermal properties and better stability than other nanofluids, hence better thermal efficiency is obtained using it in CPC. Maximum thermal efficiency value is obtained at 13:00 p.m. Thermal efficiency of 75.1% and 75.8% is achieved for 0.025% volumetric concentration at 0.02 and 0.015 kg/s, respectively, and thermal efficiency of 77.1% and 79.2% are achieved for 0.075% volumetric concentration at 0.02 and 0.015 kg/s, respectively. Maximum thermal efficiency is 63.6% and 65.2% using water as a working fluid at flow rates of 0.015 kg/s and 0.02 kg/s, respectively.

4. Conclusions

In this study, the stability and performance analysis of a CPC with non-metallic oxide based nanofluid is performed under real conditions of sub-tropical climate of Taxila, Pakistan. Analysis has been done with three volumetric concentrations (0.025, 0.05 and 0.075%) and two mass flow rates (0.02 and 0.015 kg/s). Nanofluids are found to be stable during the duration of experimentation hours, i.e., 7 h daily. Maximum thermal conductivity enhancement of 37.2% is noted for MWCNT/water with 0.075% volumetric concentration. The maximum temperature difference of 10.55 °C is achieved by MWCNT/water nanofluid with 0.075% volumetric concentration at a lower flow rate of 0.015 kg/s. Enhancements of 19.37% and 16.23% in thermal efficiency are achieved by using non-metallic nanofluids at flow rates of 0.015 kg/s and 0.02 kg/s, respectively.

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