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An Experimental Appraisal on the Efficacy of MWCNT-H2O Nanofluid on the Performance of Solar Parabolic Trough Collector

Harwinder Singh* and Pushpendra Singh

Department of Mechanical, Production and Industrial Engineering, Delhi Technological University, India

Abstract

An application of MWCNT nanoparticles and distilled water was used to prepare the nanofluid and this type of MWCNT based absorbing medium was found to be highly efficient in investigation of the performance of solar parabolic trough collector due to better thermo physical properties (i.e. thermal conductivity) acquired by the MWCNT based nanofluid. In present research study author decided to take volume concentration 0.01% and 0.02% and high quality surfactant Triton X-100 was used to enhance the dispersion quality of nanoparticles in conventional fluid. The test were performed under different volume flow rate conditions of nanofluid i.e. 160 L/h and 100 L/h. Experimental results show that with an incremental change in volume concentration from 0.01% to 0.02%, there is a substantial increment in efficiency of parabolic collector but observed only at 160 L/h.

Keywords: Parabolic trough collector; MWCNT nanofluid; Triton X-100 surfactant; Collector performance testing

Abbreviations

Q_u: Useful heat gain (Watt); Q_u: Useful heat gain (Watt); $\dot{m}$: Mass flow rate (Kg/s); C_{nf}: Specific heat of MWCNT nanofluid $\left[\frac{J}{kg-k}\right]$; C: Specific heat of base fluid $\left[\frac{J}{kg-k}\right]$; *t*: Time interval (half an hour); D_i: Internal diameter (m); U_l: Overall heat loss coefficient; F: Collector efficiency factor; F_R: Collector heat removal factor; G_T: Total solar intensity (W/m^2) $\left(\frac{W}{m-k}\right)$; T_{max}: Maximum temperature (K); T_{mini}: Minimum temperature (K); Tout: Outlet temperature (k); Tin: Inlet temperature (k); W: Width of collector (m); L: Length of collector (m); T: Total experimental duration; D_o: Outer diameter (m); C: Concentration ratio; F_R: Collector heat removal factor; h_f: Convective heat loss coefficient; K_{nf}: Thermal conductivity $\left[\frac{W}{m-k}\right]$; S: Absorbed heat flux

Greek symbols

φ_p: Weight fraction of MWCNT nano particles in nano fluid; ρ_{nf}: Density of MWCNT nanofluid $\left[\frac{kg}{m^3}\right]$; ρ: Density of base fluid $\left[\frac{kg}{m^3}\right]$; ρ_{np}: Density of nano particles$\left[\frac{kg}{m^3}\right]$; μ_{nf}: Dynamic viscosity of MWCNT nanofluid $\left[\frac{Kg}{m-sec}\right]$; μ: Dynamic Viscosity of base fluid$\left[\frac{Kg}{m-sec}\right]$; ν_{nf}: Kinematic viscosity of MWCNT nanofluid $\left[\frac{m^2}{sec}\right]$; ν: Kinematic viscosity of base fluid$\left[\frac{m^2}{sec}\right]$; E_i: Instantaneous energy production; ηth: Thermal efficiency; η_{ot}: Overall thermal efficiency

Introduction

Parabolic trough collector is a prominent way to convert solar radiations into solar thermal energy and transfer this heat or thermal energy to working fluid for purpose of electric power generation. These days solar energy devices are in use widely and enhancement in performance of solar device are very necessary due to purpose of decrease down the effect of environmental pollutants released from conventional methods. From the last two decades scientists gave effort to improve the performance of solar parabolic trough collector and thermal storage systems for achievement of maximum power and there was a performance booster comes after the discovery of nanoparticles. Application of nanoparticles in conventional fluid also become a new approach to enhance the thermo physical properties of working fluid and among other nanoparticles, MWCNTs possess better thermal, mechanical and optical characteristics and MWCNTs based nanofluid as a working fluid has an capability to enhance the outcome of solar thermal devices. Suspension of metallic and non metallic particles in base fluid is simply known by nanofluid and this term is originated and investigated by Haddad and it has also been seen that nanofluid attain higher dispersion quality as comparison to microfluid [1]. Due to hydrophobic nature, MWCNT nanoparticles have poor dispersion quality in base fluid and stability of nanoparticles in base fluid can be increased with the help of surfactant, which has both hydrophobic and hydrophilic functional groups [2]. Davis et al. evaluate the shear thinning behavior in the viscosity of CNT nanofluid and they found that viscosity of CNTs based nanofluids is function of concentration of nanoparticles in base fluid, He also concluded that with increase in concentration of CNTs, interactions between nanotubes with each other increases and which results in movement between tubes will be stopped [3]. Ding et al. study about the heat transfer process with nano fluid containing CNTs and results concluded that carbon nano tubes enhance the heat convection coefficient as comparison to total enhancement in thermal conductivity. The reason behind more enhancements in heat convection coefficient is high aspect ratio of using CNTs [4]. Lotfi et al. studied experimentally that heat transfer can be enhanced due to presence of MWCNT nanoparticles in water as comparison to simple water and enhanced heat transfer due to MWCNT and water based nano fluids used in horizontal shell and heat exchanger applications [5]. Yousefi et al. evaluate the effect of MWCNT nanofluid on the efficiency of flat plate collector with different mass flow rate of nanofluid 0.0167 to 0.05 kg/s and also with decided weight fraction of CNTs was 0.2% and 0.4%, he concluded an substantial

***Corresponding author:** Harwinder Singh, Department of Mechanical, Production and Industrial Engineering, Delhi Technological University, Delhi College of Engineering, Shahbad Daulatpur, Main Bawana Road, Delhi 110042, India, Tel: +91-7503678148; E-mail: harrymehrok14@gmail.com

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increase in efficiency with surfactant at 0.2% MWCNT nanofluid, while an incremental change in efficiency was observed at 0.4% MWCNT nanofluid without surfactant [6]. Kasaeian et al. conducted an experimental study on solar trough collector with the application of MWCNTat decided volume concentration 0.2% to 0.3% in mineral oil and he concluded that 4-5% and 6-7% enhancement in efficiency with MWCNT and mineral oil based nanofluid as comparison to pure oil [7]. Yousefi et al. studied experimentally that effect of Al_2O_3 nanofluid on flat plate collector with different mass flow rates 1, 2 and 3Lit/min and he concluded that 28.3% enhancement in efficiency at 0.2% weight fraction of nanoparticles along with 15.63% efficiency enhancement with the application of surfactant Triton X-100 due to enhancement in heat transfer [8].

Experimentation & Data Findings

Nanomaterial

In this experimental study high class MWCNT nanoparticles (97% purity) with 20-40nm in diameter were obtained from Nano Green Technologies LLP (India). The Triton X-100 was used to achieve high quality dispersion of MWCNT in distilled water as base fluid for investigation and it is non-ionic natural surfactant (Table 1).

The SEM (Scanning Electron Microscopy) image of MWCNT nanoparticles produced by secondary electron at different resolution and magnification is shown in (Figures 1 and 2).

Preparation of nanofluid

MWCNT with 0.01% and 0.02% volume concentration used in distilled water and Triton X-100 surfactant was used in sufficient amount to avoid aggregation and instability between nanotubes, which results in better dispersion behavior. BRANSON 3510 Sonication device followed by magnetic stirrer was used for homogeneous mixing of MWCNT particles in distilled water. Sonication time also affect to dispersion behavior and corresponding thermal properties of carbon nanotubes and after going through several literature study in this field, the soniaction time was decided 45 minutes for mixture amount of 2 liters. Surfactant Triton X-100 due to its non ionic nature showed better dispersion quality for MWCNTs based suspension among other surfactants. Proper dispersion of carbon nanotubes in base fluid is not easy to maintain so that surfactant like Triton X-100 is necessary for better dispersion. It has been seen that Triton X-100 has acquired benzene ring in structure and absorb to graphitic surface in very strong manner due to π-π stacking type interactions [6]. In this experimental study Triton X-100 is used almost same in amount as calculated for MWCNT in base fluid after going through many research discussions. Surfactant is used to bring single phase in solution used as working fluid and fig showed MWCNT based nanofluid contain Triton X-100 with it for proper suspension of MWCNTs throughout experimental span (Figure 3).

Experimental methodology

Item Description (MWCNTs)	
Purity	> 97%
Length of Nanotubes	1-10 micrometer
No. of Walls	3-15
Density	0.15-0.35g/cm^3
Surface Area	350 m^2/g [9]
Specific Heat	630 J/Kg-k [9]
Thermal conductivity	1500 W/m-k [9]

Table 1: Properties of MWCNT nanoparticles.

The parabolic trough collector was experimentally tested at Thapar University (Punjab). The parabolic trough collector has a copper receiver tube in which working fluid is flowing and gets heated at outlet. Temperatures measure at inlet and outlet through thermocouples and flow in piping and receiver was forced convection due to electric pump with 18W capacity used at inlet side. Collector system also has a storage tank with certain 8L capacity and ball valve was used at inlet side after pump to control the volume flow rate of working nanofluid in solar concentrating collector system. Storage tank and piping system was fully insulated through glass wool and aluminium foil insulation to prevent heat loss from the solar system. Total solar heat flux throughout the day was measured by solar power meter (Tenmars TM-207) and also flowing wind speed was measured by CFM/CMM vane anemometer (PRECISE AM804). Temperatures at inlet and outlet was measured after half an hour as decided before initializing the experimental work and experimental readings were taken from forenoon 9:30 am to afternoon 3:00 pm according to Indian standard time (Table 2 and Figure 4).

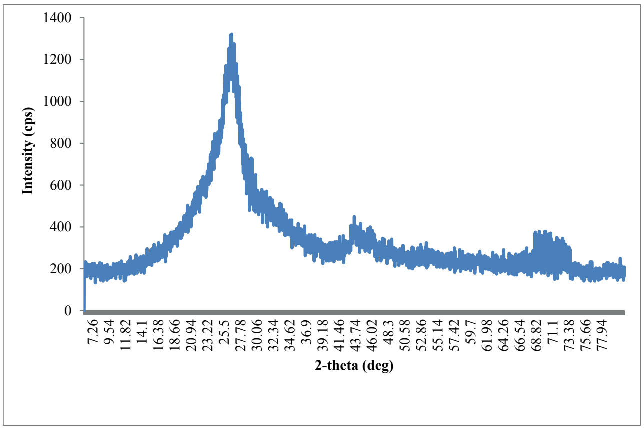

Figure 1: XRD image of MWCNT nanoparticles.

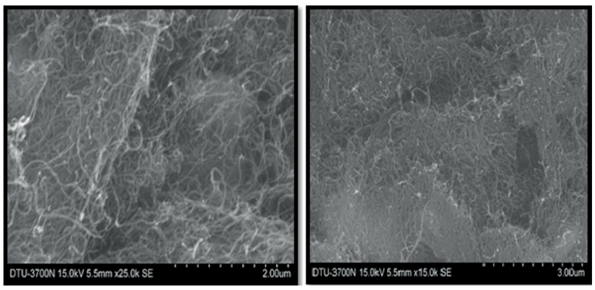

Figure 2: SEM image of MWCNT nanoparticles.

Figure 3: Sample of mixture (φ_v = 0.01%) and bucket of MWCNT nano fluids at 0.01% and 0.02% volume concentration.

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Length of collector	1.2 m
Breadth of collector	0.915 m
Aperture area	1.0188 m^2
Rim angle	90˚
Focal length	0.3 m
Inside diameter of receiver tube	0.027 m
Outside diameter of receiver tube	0.028 m
Inside diameter of glass cover	0.064 m
Outside diameter of glass cover	0.066 m
Concentration ratio	9.66

Table 2: The specification of parabolic trough collector [10-13].

Figure 4: Parabolic trough collector (location: Thapar university).

Performance Testing of Parabolic Solar Collector

Thermal steady state analysis was employed to evaluate the performance of solar parabolic collector and further assume piping and storage system was fully insulated. Various experiments were performed on solar collector through different volume flow rate and at certain weight fraction of nanoparticles in distilled water i.e. 6L. Data related to performance of solar parabolic collector was evaluated through efficiency and also useful heat gain as discussed below:

$$Q_u = mC_{nf}\left(T_{out} - T_{in}\right) \quad (1)$$

and

$$Q_u = F_R\left(W - D_O\right) L\left[S - \frac{U_l}{C}(T_{fi} - T_a)\right] \quad (2)$$

Here $\dot{m}$ is mass flow rate and C_{nf} is specific heat of nanofluid, which is calculated as follow:

$$c_{nf} = \frac{[(1-\varphi_p)\,\rho_f c_f + \varphi_p \rho_{np} c_{np}]}{\rho_{nf}} \quad (3)$$

Here 'c_f' & 'c_{np}' is specific heat of base fluid (water) and nanopartcles (MWCNT). Further 'φ_p' is volume concentration of nanoparticles. Density and viscosity of mixture can be calculated through given equations:

$$\rho_{nf} = \left(1 - \varphi_p\right)\rho_f + \varphi p \rho_{np} \quad (4)$$

$$\mu_{nf} \quad \mu_f / \;\; 1 - \varphi_p \;\; ^{2.5} \quad (5)$$

Here 'ρ_{nf}' & 'ρ_{np}' is the density of nanofluid and nanoparticles. Instantaneous energy production is directly proportional to useful heat gain and is described as below:

$$E_i = \frac{Q_u}{G_T R_b W\ L} \quad (6)$$

Here 'G_T' is total solar intensity W/m^2 and 'R_b' is bond resistance is taken as constant. Further thermal and overall thermal efficiency of solar parabolic trough collector is discussed in following equations:

$$\eta_{ot} = \frac{\mathrm{mCnf(Tmax - Tmini)}}{\mathrm{A}_{aper} G_{avg} T} \quad (7)$$

Here 'ηth' is thermal efficiency of parabolic collector and further G_T and t is total solar intensity (W/m^2) and time interval (half an hour).

$$\eta_{ot} = \frac{\mathrm{mCnf(Tmax - Tmini)}}{\mathrm{A}_{aper} G_{avg} T} \quad (8)$$

Here 'η_{ot}' is overall thermal efficiency of parabolic collector and further G_{avg} and 'T' is average solar intensity (W/m^2) and total test time period for experimental work.

Also collector efficiency factor (F) and heat removal factor (F_R) of collector system is discussed below:

$$F = \frac{D_i h_f}{D_i h_f + D_O U_l} \quad (9)$$

$$\mathrm{F_R} = \frac{\dot{m}\mathrm{C_P}}{\eth \mathrm{D_O L U_l}}(1 - exp\ (-\frac{F\pi D_O U_l L}{\dot{m}\mathrm{C_P}})) \quad (10)$$

This equation almost matches with Hottel-Whillier-Bliss equation of flat plate collector. Here 'h' is convective heat transfer coefficient $\left[h = N_U \times \frac{K}{D_i}\right]$ & 'F_R' is an important design parameter because it is measure of the thermal resistance comes in the path of absorbed solar radiation in reaching the collector fluid. In equation '$F_R U_l$' is a negative efficiency parameter and it has negative effect on useful heat gain further effect encountered on instantaneous efficiency of collector, which is defined by the ratio of useful heat gain to the incident radiation coming on the solar collector.

Thermophysical properties of MWCNT nanofluid and water

Thermal properties like thermal conductivity and viscosity of water was calculated through various experimental test runs on KD2 Pro conductivity meter and kinematic viscometer with different temperature. Experimentally measured density of water was found almost equivalent to standard density of water, therefore standard value of density was considered for research work. All experimental and standard results were used to calculate the thermophysical properties of MWCNT based nanofluid for both 0.01% and 0.02% weight fraction (Tables 3 and 4).

Results and Discussion

MWCNT based nanofluid used as working fluid

In this present study nanofluid was prepared at 0.01% and 0.02% of MWCNT in distilled water as base fluid with the application of Triton X-100 surfactant in appropriate amount. Prepared nanofluids

Thermal conductivity (K)	$1000\frac{kg}{m^3}$
Density (ρ)	$1000\frac{kg}{m^3}$
Dynamic viscosity (μ)	$0.854*10^{-3}\frac{Kg}{m-sec}$
Kinematic viscosity (v)	$0.854*10^{-6}\frac{m^2}{sec}$
Specific heat (C_p)	$4.187\frac{KJ}{kg-k}$

Table 3: Thermophysical properties of water.

Thermo physical Properties	Mixture I (φ_p= 0.01%) (MWCNT+ Distilled Water)	Mixture II (φ_p= 0.02%) (MWCNT + Distilled water)
Thermal Conductivity (K_{nf})	$0.617369817\frac{W}{m-k}$	$0.617369817\frac{W}{m-k}$
Dynamic viscosity (μ_{nf})	$0.000854213\frac{Kg}{m-sec}$	$0.000854427\frac{Kg}{m-sec}$
Kinematic viscosity (v_{nf})	$0.854*10^{-6}\frac{m^2}{sec}$	$0.854*10^{-6}\frac{m^2}{sec}$
Specific heat (C_{Pnf})	$4186.91\frac{J}{kg-k}$	$4186.82\frac{J}{kg-k}$
Density (ρ_{nf})	$999.925\frac{kg}{m^3}$	$999.85\frac{kg}{m^3}$

Table 4: Calculated thermo physical properties of MWCNT nanofluid.

as working fluid was flowing through collector receiver tube at different volume flow rates. It has been seen that overall thermal efficiency outcomes from 0.02% weight fraction MWCNT nanofluid at 160 L/h was 5.45% and higher than as comparison to results found at different fraction and with different flow rates. Figure showed that thermal efficiency of 0.02% weight fraction MWCNT nanofluid at 160 L/h was 12.63% measured, which is greater than other results of thermal efficiency from nanofluid at different weight fraction and volume flow rates. Further this experimental study also include heat losses in collector and it has been seen that F_RU_l has a negative effect on instantaneous efficiency and useful heat gain, further calculated values of F_RU_l in case of MWCNT nanofluid at various flow rates are shown in (Tables 5 and 6). Surfactant Triton X-100 is a non-ionic and high foaming surfactant, which reduces heat transfer b/w water and nanotubes. Surfactant mixed at higher amount with MWCNT nanofluid has also considerable negative effects on performance of solar collector [6]. Overall thermal efficiency of 0.02% MWCNT based nanofluid at 100 L/h showed poor results as comparison to other results outcomes from various experiments conducted

Different volume flow rate	F	F_R	F_RU_l
160 L/h	0.9754369	0.97186	12.9063
100 L/h	0.8586555	0.85422	11.3440

Table 5: F_RU_l for parabolic trough collector with 0.01% MWCNT nanofluid.

Different volume flow rate	F	F_R	F_RU_l
160 L/h	0.9754437	0.97178	12.9052
100 L/h	0.8586919	0.85426	11.3467

Table 6: F_RU_l for parabolic trough collector with 0.02% MWCNT nanofluid.

through MWCNT nanofluid and decrement in thermal efficiency can be due to higher viscosity of fluid and corresponding pressure drop at 100 L/h. It has also been seen that enhancement in thermal conductivity is dependent upon bulk temperature of nanofluid; Therefore Incremental change in mass flow rate has a considerable effect on bulk temperature and thermal conductivity of MWCNT nanofluid [6]. Further results of Thermal efficiency along with instantaneous energy production are shown graphically as below for different 0.01% & 0.02% volume concentration and at different decided flow rates 160 L/h and 100 L/h (Figures 5-8).

Water as working fluid

Water (base fluid) was used as working fluid in solar parabolic trough collector. Experimental study was done during 9: 00 am to 3: 00 pm and data related to inlet and outlet temperature, temperature difference, useful heat gain and efficiency of collector was measured at various flow rates. (Figures 9 and 10) showed graphical variations in thermal efficiency and instantaneous energy production of collector through water at 160 L/h and 100 L/h. Figure 10 showed maximum thermal efficiency was 7.28% measured during the time interval 11: 00-11: 30 am for water at 160 L/h and further maximum thermal efficiency at 100 L/h was 6.39% measured during the time interval 10: 30-11: 00 am. F_RU_l is a negative efficiency parameter, which account an effect on performance of solar collector as discussed before and (Table 7) showed F_RU_l for water used as working fluid in solar collector device.

Water showed higher value of 'F_R' at 160L/h as comparison to 'F_R' at 100 L/h. basically a heat removal factor is defined by the heat lost from the collector system and collector efficiency factor is completely opposite to heat removal factor, it means that how much heat absorbed by the collector system and denoted by 'F'. Thermal losses from the receiver tube can calculate through loss coefficient 'U_L' and it depends upon area of receiver tube. Collector efficiency factor and loss coefficient can be calculated from similar expression as described for flat plate collector case. Parabolic trough collector is a type of concentrating collector and used to produce high temperature, which means that thermal radiations are important for evaluation of thermal losses and are temperature dependent.

Effect of inlet temperature and mass flow rate

Inlet temperature of fluid has considerable effect on collector performance, when inlet temperature of fluid is increasing results in surface temperature of absorber tube and convective losses from absorber tube are also increases. These losses are increases continuously with change in day time and have a negative effect on collector performance or instantaneous efficiency as shown in graphical results of MWCNT nanofluid and water. Mass flow rate of fluid also showed great effect on system performance because of

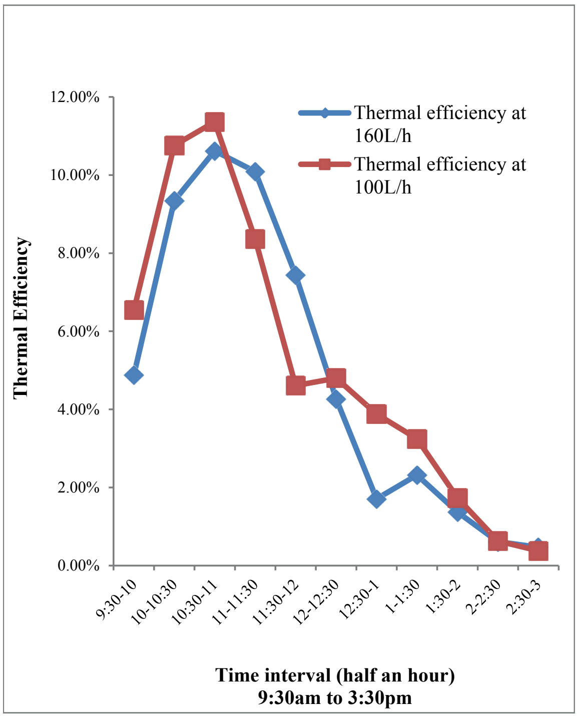

Figure 5: Thermal efficiency of MWCNT nanofluid at 160L/h & 100L/h with 0.01%.

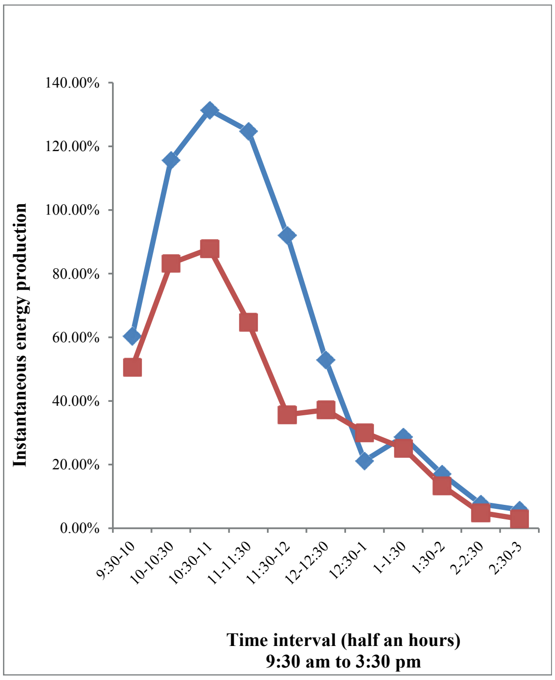

Figure 6: Instantaneous energy production of MWCNT nanofluid at 160L/h & 100L/h with 0.01%.

increasing coefficient of heat transfer increasing, which results in incremental change occur in collector efficiency factor and collector heat removal factor also increased as shown in Tables 5 and 6 for MWCNT nanofluid and also same behavior shown in Table 7 for water.

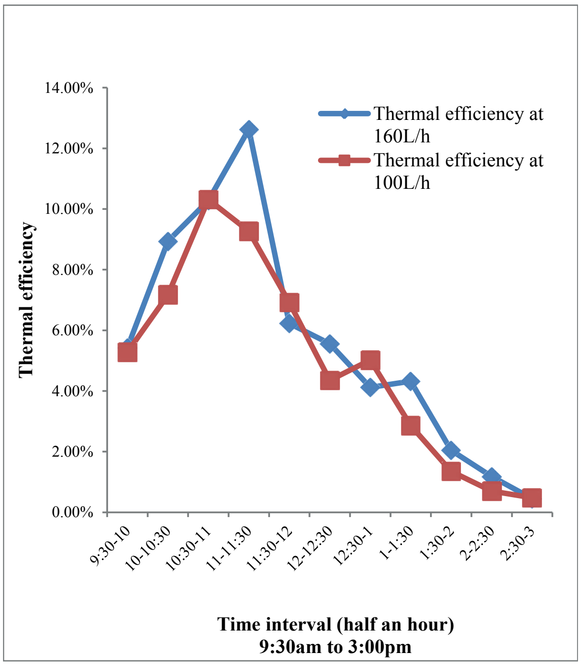

Figure 7: Thermal efficiency of MWCNT nanofluid at 160L/h & 100L/h with 0.02%.

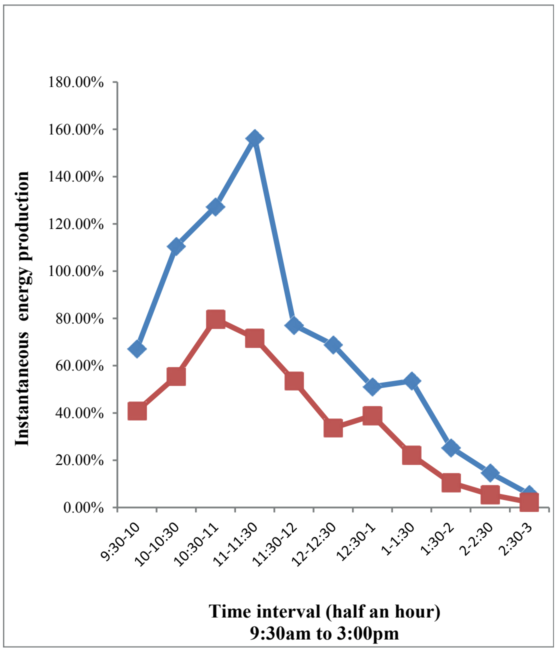

Figure 8: Instantaneous energy production of MWCNT nanofluid at 160L/h & 100L/h with 0.02%.

Conclusion

In this experimental study effect of MWCNT nanofluid on solar parabolic trough collector performance was investigated. The effect of mass flow rate of MWCNT nanofluid mixture containing Triton X-100 at different weight fraction 0.01% and 0.02% was studied. The results showed that 0.02% MWCNT nanofluid possess highest value

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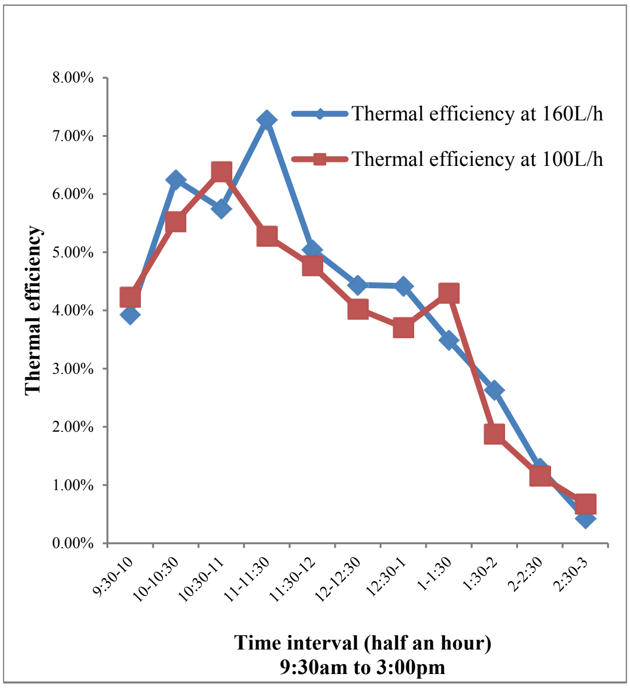

Figure 9: Thermal efficiency for water at 160L/h and 100L/h.

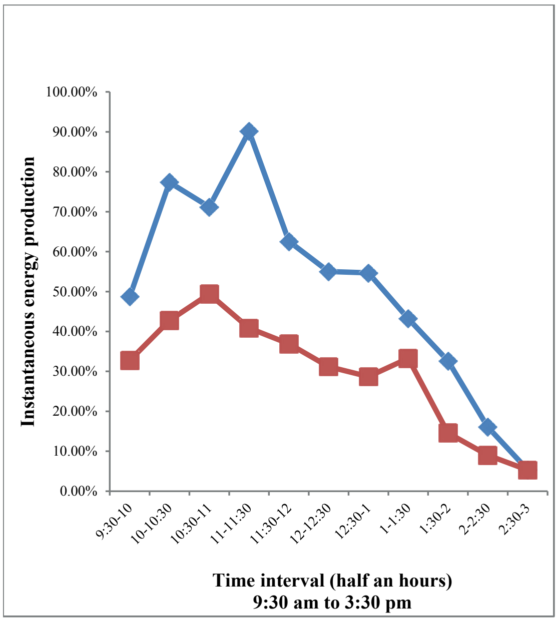

Figure 10: Instantaneous energy production for water at 160L/h and 100L/h.

of thermal, overall thermal and instantaneous energy production among other concentration of nanofluid and water and further also at different flow rates. 0.02% MWCNT nanofluid at 160 L/h showed lowest amount of F_RU_l and highest value for collector efficiency factor among other concentration of fluid. Temperature difference

Different volume flow rate	F	F_R	F_RU_l
160 L/h	0.975429002	0.97185	12.9061
100 L/h	0.858619195	0.85419	11.3436

Table 7: F_RU_l for parabolic trough collector with water as working fluid.

increased by increasing the mass flow rate of fluid was measured in this experimental study, which results in incremental change occur in efficiency.

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