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Comparative study of parabolic trough collector through MWCNT/H_2o nanofluid and water

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Abstract

In this present work MWCNT nanofluid and water were used as working fluid to compare the thermal performance of solar parabolic trough collector. Both the fluids were flowing through receiver at different volume flow rates 160L/h and 100L/h. Experimental tests was performed only during sunny weather and temperature at outlet of receiver was measured through thermometer after every half an hour of total testing time period. MWCNT nanofluid with weight fraction 0.01% and 0.02% and water were used to find efficiency of system and it has been seen that MWCNT nanofluid 0.02wt% with 160L/h showed better results for overall thermal efficiency among other and also an application of surfactant Triton X-100 with in MWCNT nanofluid was used to enhance the quantity of heat absorption capability of base fluid.

Keywords: MWCNTs, Solar Parabolic Trough Collector, Surfactant Triton X-100, Thermal performance, overall thermal efficiency

1. Introduction

Solar parabolic trough collector is a prominent way to generate the electric power for both commercial and industrial purpose among other concentrating solar power technologies. Conventional fluids are having a limited capacity to extract and carrying heat in the receiver of parabolic trough collector, therefore concept of using nano fluids instead of conventional fluids become more popular in solar thermal collector. In this present study MWCNT nanofluid at different concentration and water as conventional fluid were used to examine and compare the performance of solar parabolic trough collector. Tooraj Yousefi et al [1] was conducted an experimental study through MWCNT nanofluid with 0.2wt% and 0.4wt % at different mass flow rates 0.0167kg/sec to 0.05kg/sec and also studied the effect of surfactant Triton X-100 on the stability of nanofluid. Xiang-Qi Wang et al [2] studied the heat transfer and fluid flow characteristics of nano fluids in forced and free convection. He also studied that nano fluids has a capability to enhance the heat transfer characteristics and concluded that nano fluids are superior to conventional fluids in term of thermal physical properties. It has been seen from review study that suspended carbon nanotubes possess higher thermal conductivity and aspect ratio as compare to other existing nano particles. Nor Azwadi Che Sidik [3] et al concentrated his review study upon synthesis process for nano fluids. Both metallic and nonmetallic particles can be used to prepare nano fluids, Apart from this it has been noticed in this review work that metallic particles acquire higher thermal conductivity value as comparison to nano fluids containing oxide particles and nano fluids possess also less specific heat and higher viscosity as compare to conventional fluids. John Philip et al [4] studied in his review work that enhancement in thermal conductivity with incremental change in particle volume fraction and effect of temperature on thermal conductivity of nanofluid. Tooraj yousefi et al [5] conducted an experimental study with the use of Al_2O_3-H_2O nanofluid as working fluid in flat plate collector. Volume concentration of nano particles were taken as 0.2% and 0.4% with the application of surfactant Triton X-100 and nanofluid was flowing through collector tubes with different mass flow rates i.e. 1, 2 and 3Lit/min and it was concluded in this experimental work that 28.3% enhancement in efficiency of collector along with 15.63% efficiency enhancement with the

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application of surfactant, which is due to enhancement in heat transfer. Zhongyang Luo et al [6] was proposed a simulation model of nano fluid solar collector based upon direct absorption solar collection process by solving the radiative heat transfer for particulate media along with conductive and convective heat transfer in collector for evaluation of efficiency and to achieve the purpose of improvement in efficiency various nanoparticles like TiO_2, Al_2O_3, Ag, Cu, SiO_2, graphite nanoparticles, and carbon nanotubes were used in process of manufacturing nano fluid. Further this study concludes that thermal conductivity decrease with increase in temperature and improvement in outlet temperature around 30k-100k along with enhancement in efficiency 2-25% through nanofluid than base oil. Omid Mahian [7] et al conducted a theoretical to evaluate the performance of mini channel-based flat plate collector by using four different types of nanoparticles like Cu, Al_2O_3, TiO_2 and SiO_2 in water as base fluid. Mass flow rate in this work was assumed 0.1% and 0.5kg/s along with 4% volume fraction of nanoparticles. This study was concluded that heat transfer coefficient generally higher in all types of Nano fluids except SiO_2-H_2O nanofluid and higher efficiency with maximum entropy generation was measured through SiO_2-water based nanofluid, while lower efficiency and lowest entropy generation was measured through Cu/water based nanofluid. Ali Ijam [8] et al examine the stability of nanofluid with the help of thermal conductivity and UV-measurement technique and further thermos physical properties and electrical conductivity of graphite oxide nano sheets-deionized water and ethylene glycol were investigated at different temperatures and it was concluded in this research study that enhancement in thermal conductivity in a linear way with increasing concentrations and temperature and maximum enhancement in thermal conductivity was measured from 6.67% to 10.47% with volume fraction 0.10% and range of temperature varies between 25 to 45^0C. Further an enhancement in electrical conductivity was noticed linearly with increasing the temperature of nanofluid and nonlinear enhancement in electrical conductivity was measured with increasing the concentration of graphite oxide nano sheets. Tooraj Yousefi et al [9] also conducted an experimental study related to the investigation of pH value MWCNT-H_2O nanofluid on the performance of the flat plate collector and results outcomes from the experimentation concluded that enhancement in efficiency of the collector due to high difference between *pH* of nanofluid and pH of isoelectric point.

2. Experimental Procedure

2.1 Working fluids

MWCNT nanofluid and water were used as working fluid in solar parabolic trough collector. MWCNTs with 97% purity mixed with base fluid (Distilled water) used to manufacture nanofluid. After reviewing all past research work and going through lot of test run, sonication time was decided up to 45 minutes with proper stirring for certain 8-10 minutes. Application of Triton X-100 was used for the proper dispersion of nanoparticles in base fluid during experimental work. Water as working conventional fluid was also used for evaluation and compares the performance of collector.

(a)

(b)

Figure 1(a) & (b) showed sonicated MWCNT nanofluid at different 0.01wt% and 0.02wt%

2.2 Mathematical equations

Important mathematical equations were used to evaluate the performance and properties of nano fluids are discussed as under:

Specific heat or heat capacity of nanofluid

$$c_{nf} = \{(1 - \varphi_p)\, \rho_f\, c_f + \varphi_p\, \rho_{np}\, c_{np}\} \,/\, \rho_{nf} \qquad (1)$$

Density of nanofluid

$$\rho_{nf} = (1 - \varphi_p)\,\rho_f + \varphi_p\,\rho_{np} \quad (2)$$

Instantaneous efficiency

$$\eta_i = Q_u / (G_T\, R_b\, W\, L) \quad (3)$$

Thermal efficiency

$$\eta_{th} = \frac{mCnf(Tout - Tin)}{A_{aper} G_T t} \quad (4)$$

Overall thermal efficiency

$$\eta_{ot} = \frac{mCnf(Tmax - Tmini)}{A_{aper} G_{avg} T} \quad (5)$$

2.3 Experimental set up

Parabolic trough collector has a receiver tube at focal point, which was covered by glass tube to maintain vacuum around absorber tube and it was coated black to absorb the maximum amount of solar radiations. Mirror strips were provided on parabolic shape of collector to reflect and concentrate the sun light on absorber tube. Inlet and outlet temperature measured through thermometer and storage tank of certain capacity around 10 Liters was also provided to store working fluid. Further proper aluminium foil and glass wool insulation was used to cover piping system and storage tank to reduce the heat losses. Pump was used for continuous forced flow of liquid through the receiver tube. Experiment was performed during the day time 9:30am to 3:00pm according to Indian standard time and during the conditions of continuous solar flux. Global solar flux and wind speed throughout the day measured with solar power meter and anemometer. Figure 2 showed experimental set up of solar parabolic collector, which is situated in Thapar University (Patiala).

Figure: 2: Experimental set up of parabolic through collector at Thapar University, Patiala

Table 1: Specification of parabolic trough collector (Thapar University)

Length of collector	1.2m
Breadth of collector	0.915m
Aperture area	1.0188m^2
Rim angle	90°
Focal Length	0.30m
Receiver internal diameter	0.027m
Receiver outer diameter	0.028m
Glass cover internal diameter	0.064m
Glass cover outer diameter	0.066m

2.4 Experimental findings

This section contains inlet and outlet temperatures along with total solar intensity data related to performance of solar parabolic collector. Transient analysis was done on solar collector and it was assumed that piping and storage tank are fully insulated; it means that heat losses from these system components are negligible.

Table 2: MWCNT nanofluid with 0.01wt% at 160L/h on (24/3/2015)

Time Interval	T_{in} (°C)	T_{out} (°C)	Solar Intensity (W/m^2)	Wind Speed (m/s)
9:30-10	24.9	27.9	941.454	0.9
10-10:30	27.9	33.1	1008.504	1
10:30-11	33.1	39.5	1123.949	0.2
11-11:30	39.5	45.5	1085.224	0.9
11:30-12	45.5	50.8	974.809	1
12-12:30	50.8	54.8	960.654	0.95
12:30-1	54.8	58	956.929	0.8
1-1:30	58	59.6	942.029	0.9
1:30-2	59.6	60.5	893.604	1.2
2-2:30	60.5	60.9	887.644	2.2
2:30-3	60.9	61.2	874.239	2.3

Table 3: MWCNT nanofluid with 0.01wt% at 100L/h (25/3/2015)

Time interval	T_{in} (^{0}C)	T_{out} (^{0}C)	Solar Intensity (W/m^2)	Wind Speed (m/s)
9:30-10	26.6	29.9	690.964	0.4
10-10:30	29.9	35.6	725.234	0.6
10:30-11	35.6	41.9	759.504	0.8
11-11:30	41.9	47	834.749	0.7
11:30-12	47	49.9	860.079	0.55
12-12:30	49.9	52.9	854.864	0.7
12:30-1	52.9	55.4	881.684	1
1-1:30	55.4	57.5	883.919	1.15
1:30-2	57.5	58.6	868.274	1.45
2-2:30	58.6	59	865.294	3.55
2:30-3	59	59.2	712.569	1.3

Table 4: MWCNT nanofluid with 0.02wt% at 160L/h (27/3/2015)

Time interval	T_{in} (℃)	T_{out} (℃)	Solar Intensity (W/m^2)	Wind Speed (m/s)
9:30-10	26.2	29.2	755.779	0.2
10-10:30	29.2	33.3	881.109	0.8
10:30-11	33.3	38.7	971.884	0.8
11-11:30	38.7	44.9	1089.134	1.1
11:30-12	44.9	50.5	990.309	0.6
12-12:30	50.5	55.7	976.739	0.75
12:30-1	55.7	59.5	980.619	0.8
1-1:30	59.5	62.6	950.769	0.85
1:30-2	62.6	64	936.814	2.5
2-2:30	64	64.8	922.659	2.1
2:30-3	64.8	65.1	901.799	1.4

Table 5: MWCNT nanofluid with 0.02wt% at 100L/h (28/3/2015)

Time interval	T_{in} (℃)	T_{out} (℃)	Solar Intensity (W/m^2)	Wind Speed (m/s)
9:30-10	26.4	29.4	777.384	0.95
10-10:30	29.4	33.9	859.334	2.05
10:30-11	33.9	40.9	929.364	2.35
11-11:30	40.9	47.4	959.909	3.2
11:30-12	47.4	52.3	969.594	3.65
12-12:30	52.3	55.4	974.809	0.3
12:30-1	55.4	58.9	953.204	3.25
1-1:30	58.9	61	1003.119	2.1
1:30-2	61	62	1013.549	1.7
2-2:30	62	62.5	975.554	2
2:30-3	62.5	62.7	958.419	2.65

Table 6: Water at 160L/h (12/3/2015)

Time interval	T_{in} (℃)	T_{out} (℃)	Solar Intensity (W/m^2)	Wind Speed (m/s)
9:30-10	17.6	19.8	765.464	0.5
10-10:30	19.8	23.4	788.559	0.25
10:30-11	23.4	26.9	833.259	1.15
11-11:30	26.9	31.5	864.549	0.5
11:30-12	31.5	34.8	893.604	0.65
12-12:30	34.8	37.8	924.149	1.1
12:30-1	37.8	40.9	960.654	0.4
1-1:30	40.9	43.3	940.539	0.65
1:30-2	43.3	45.1	934.579	1.1
2-2:30	45.1	46	948.734	0.7
2:30-3	46	46.3	946.499	1.9

Table 7: Water at 100L/h (13/3/2015)

Time interval	T_{in} (℃)	T_{out} (℃)	Solar Intensity (W/m^2)	Wind Speed (m/s)
9:30-10	15.3	18	873.489	1.65
10-10:30	18	21.6	891.369	0.8
10:30-11	21.6	25.8	900.309	0.7
11-11:30	25.8	29.3	907.759	1.45
11:30-12	29.3	32.6	946.499	1.55
12-12:30	32.6	35.4	950.969	2.5
12:30-1	35.4	38	959.164	1.4
1-1:30	38	40.9	922.659	0.55
1:30-2	40.9	42.2	944.264	2.65
2-2:30	42.2	43	940.539	1.05
2:30-3	43	43.5	999.394	1.4

3. Results and Discussions

This section includes the comparative study between the results achieved from MWCNT nanofluid (0.01wt% & 0.02wt %) and water at dissimilar volume flow rate 160L/h and 100L/h and results of comparative study are discussed and shown graphically in this area.

(a) It has been noticed during experimental work that maximum instantaneous efficiency through MWCNT nano fluid at 0.01% with 160L/h comes out 96.49% in the time interval 10:30-11:00am and also maximum instantaneous efficiency through water 90.17% was measured at 160L/h during the time interval 11:00-11:30am shown graphically in figure 3. After that value of instantaneous efficiency starts to decrease continuously and it can be due to increasing instability and agglomeration of MWCNTs in base fluid and also can be due to decreasing solar intensity after around 12:00am and increasing wind speed. Thermophysical properties of nanofluid and water also affect the performance characteristics like thermal conductivity of MWCNT nanofluid is higher as comparison to water, while other properties for MWCNT nanofluid like specific heat and density posses' lower value than water.

(b) Figure 4 showed graphical comparison between instantaneous efficiency from MWCNT nanofluid (0.01wt %) at 100L/h and water. Maximum instantaneous efficiency comes out 87.85% through MWCNT nanofluid during the time interval 10:30-11:00am and for water maximum instantaneous efficiency was 49.40% was measured in same time interval. Suspension of nano particles in to base fluid is the better solution to increase the heat transfer properties or to improve the thermos physical properties of the base fluid.

(c) Increasing concentration of nano tubes in base fluid has an ability to increase the thermos physical properties of nano fluids, which is further very helpful to enhance the performance of system. In figure 5 the maximum instantaneous efficiency 96.46% was measured by MWCNT nano fluid (0.02%) at 160L/h showed in the time interval 11:00-11:30am and water showed 90.17% in the same time interval, which is less in amount as comparison to nano fluid. It was also seen that increasing concentration of carbon nanotubes also increases the viscosity of nanofluid. Increasing viscosity of nanofluid also has an ability to increase pressure loss in the system, which directly affects to the efficiency of the collector system. Graphical figure 6 showed Maximum instantaneous efficiency from solar parabolic trough collector was 79.77% measured during the time interval 10:30-11:00am through MWCNT. Nano fluid (0.02%) at 100L/h and also water showed maximum instantaneous efficiency was 49.40% measured at same volume flow rate and also in same time interval.

(d) Maximum thermal efficiency through MWCNT nano fluid (0.01wt %) at 160L/h was 7.79% during the time interval 10:30-11:00am, which is larger than maximum thermal efficiency was achieved from water i.e. 7.28% in the time interval 11:00-11:30am as shown figure 7. Further Maximum thermal efficiency possessed by nano fluid (0.01wt %) at 100L/h was 11.36% during the time interval 10:30-11:00am, which is greater than maximum thermal efficiency of water 6.39% was measured at 100L/h in the same time interval is shown graphically in figure 8.

(e) MWCNT (0.02%) nanofluid at 160L/h possess maximum value of thermal efficiency was 7.79% during the time interval 11:00-11:30am as comparison to maximum thermal efficiency achieved from water i.e. 7.28% was measured in the same time interval as shown in figure 9 graphically, while MWCNT nano fluid (0.02%) at 100L/h showed Maximum thermal efficiency was 10.31% at 100L/h during time interval 10:30-11:00am and water showed maximum thermal efficiency 6.39% was measured in the same time interval as shown in graphical figure 10.

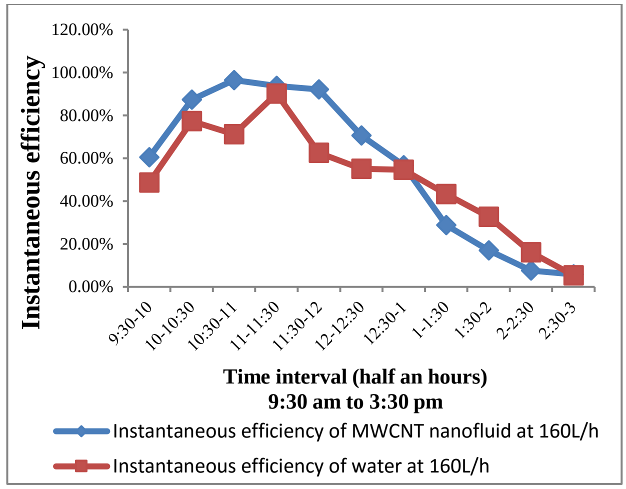

Figure. 3 variations in instantaneous efficiency with respect to time

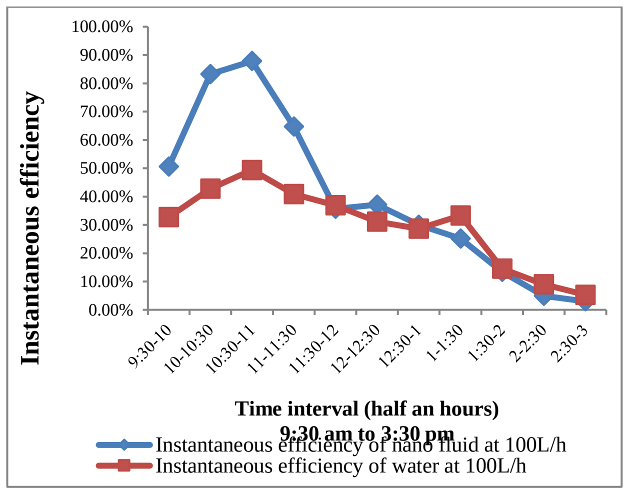

Figure. 4 variations in instantaneous efficiency with respect to time

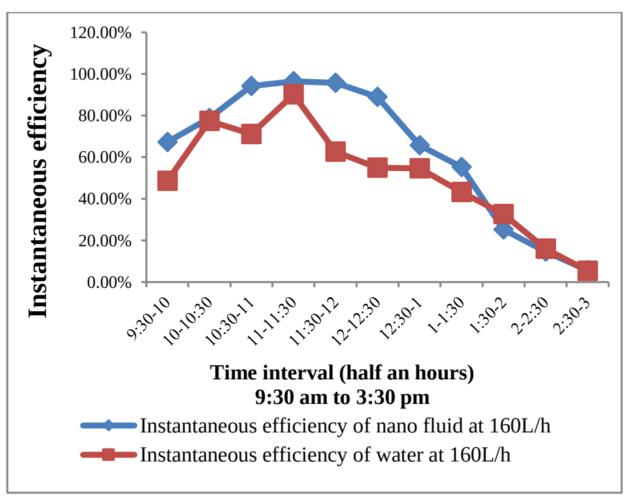

Figure: 5 variations in instantaneous efficiency with respect to time

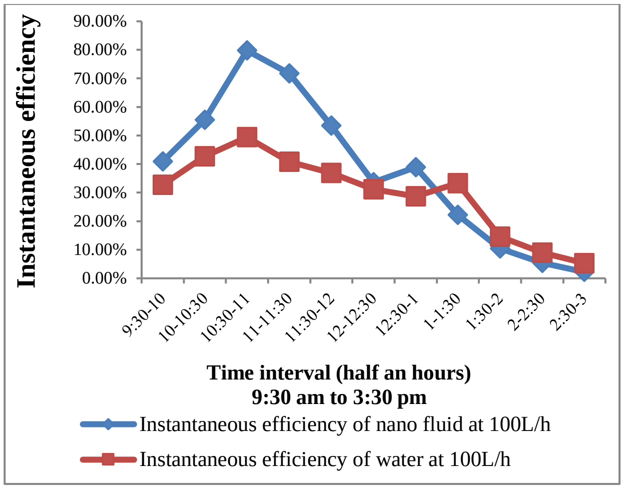

Figure: 6 variations in instantaneous efficiency with respect to time

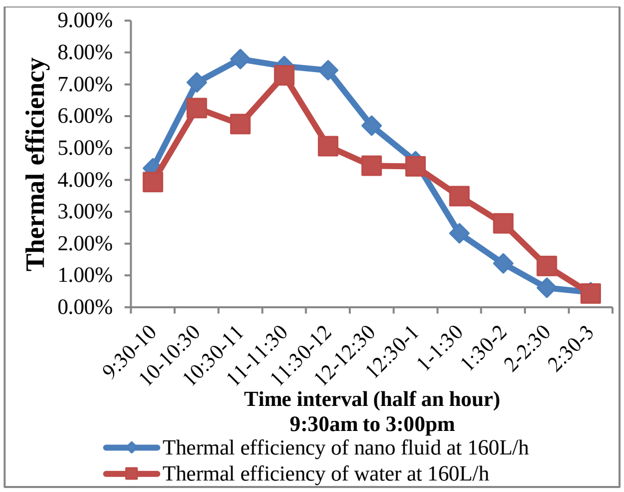

Figure. 7 variations in thermal efficiency with respect to time

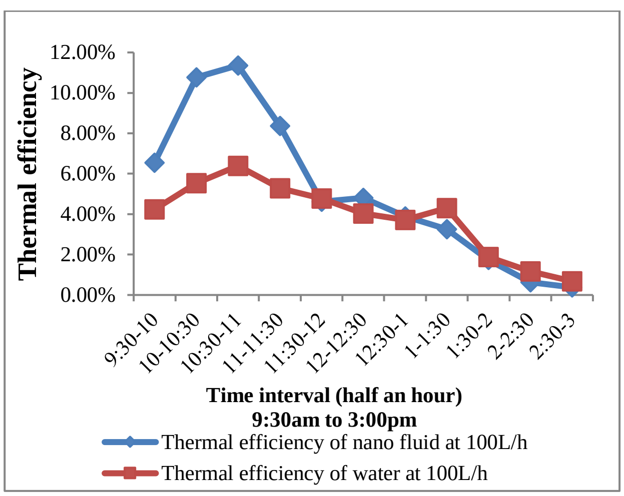

Figure. 8 variations in thermal efficiency with respect to time

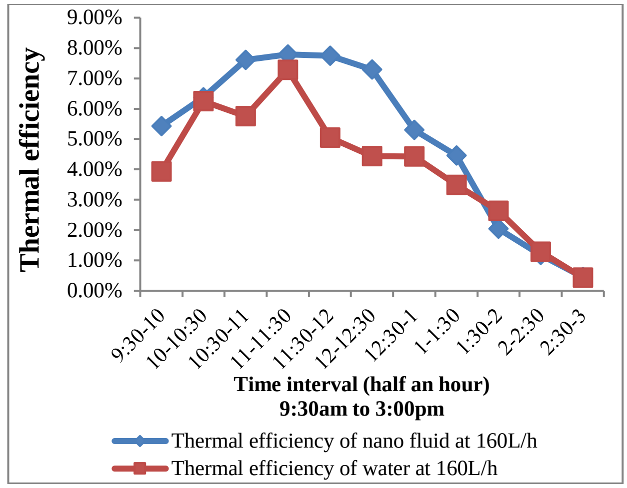

Figure. 9 variations in thermal efficiency with respect to time

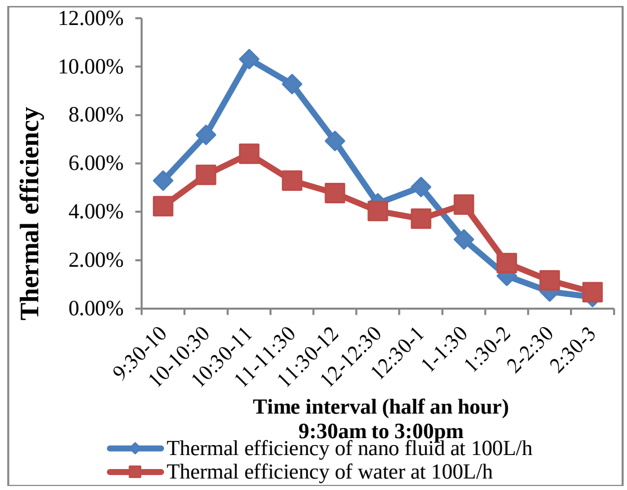

Figure. 10 variations in thermal efficiency with respect to time

4. Conclusion

In this research work comparative study has done between performance of solar collector due to MWCNT- Distilled H_2O nano fluid and simple water. Total amount of fluid was taken 6 litres and MWCNTs was used in 0.01wt% and 0.02wt% with water as reference fluid. Instantaneous efficiency and thermal efficiency showed better results than water up to certain time limit. Thermal conductivity is the only thermo physical property of nano fluid, which is responsible to enhance the efficiency of solar collector. MWCNT nano fluid 0.02wt% at 160L/h volume flow rate showed highest overall thermal efficiency, which can be due to higher heat transfer rate in nano fluid at high concentration of nanoparticles and high mass flow rate.

Nomenclature

$\dot{m}$ = mass flow rate (Kg/s)
C = Specific heat of water $\left[\frac{\mathrm{J}}{\mathrm{kg-k}}\right]$
C_{nf} = Specific heat of MWCNT nano fluid $\left[\frac{\mathrm{J}}{\mathrm{kg-k}}\right]$
G_T = Total solar intensity (W/m^2)
t =Time period (half an hour)
T_{out}= Outlet temperature (^{0}C)
T_{in}= Inlet temperature (k)
W = Width of collector (m)
ρ = Density of water $\left[\frac{kg}{m^3}\right]$
η_i = Instantaneous efficiency
η_{th} = Thermal efficiency
η_{ovt} = Overall thermal efficiency
T = Total experimental time period
Tmax= Maximum temperature (K)
Tmini = Minimum temperature (K)

Greek symbols

φ_p = Weight fraction of MWCNTs
ρ_{nf} = Density of nanofluid $\left[\frac{kg}{m^3}\right]$
ρ_{np} = Density of MWCNTs $\left[\frac{kg}{m^3}\right]$

Subscript

th = Thermal
ovt = Overall thermal
np = Nano particles
in = Inlet

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