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Performance augmentation in flat plate solar collector using MgO/water nanofluid

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ABSTRACT

In present work, testing of solar collector has been performed for MgO/water working fluid having particle size ~40 nm and particle volume concentration at 0.25, 0.5, 0.75, 1.0, 1.25 and 1.5% at 0.5, 1.0, 1.5, 2.0, 2.5 lpm respectively. Performance analysis of solar collector is based on first law of energy balance and qualitative nature of energy flow based on second law analysis. Parameters of performance analysis are chosen in order to examine both quantitative and qualitative characteristics of system performance. These parameters are thermal efficiency, energetic efficiency, pumping power, entropy generation; Bejan number and reduction in surface area. Experimental observation establishes thermal efficiency enhancement 9.34% for 0.75% particle volume concentration at flow rate 1.5 lpm. Exergetic efficiency enhancement observed 32.23% for same concentration and flow rate. Bejan number also reaches closer to unity (0.97) which throws light on systems qualitative response in terms of decline in entropy generation contribution due to internal irreversibilities and frictional heat loss. Entropy generation is 0.0611 W/K for 0.75% particle concentration compare to 0.1394 W/K for same flow rate and 0.071 W/K for 1.5% particle volume concentration. In this endeavor some penalty in form of rise in pumping power loss also incurred. 6.84% enhancement in pumping power loss observed for optimum flow rate and particle volume concentration which has not as much pronounced effect as enhancement in thermal efficiency and exergetic efficiency.

1. Introduction

Energy provides life sustaining and life propagating force to all living and non living beings. Whether industrial sector or domestic, energy is the fundamental necessity to perform various processes. Demand for energy consumption increasing every day in every nook and cranny. Conventional energy resources are limited and will fail to meet energy requirement of growing population and enhanced industrial activities for ever [2]. Hunt for new resources of energy always accompany with technological growth and its engineering applications. Development of energy efficient systems based on efficient materials has been major issue for scientists and engineers. Flat plate solar collectors are simplest in design, low cost and offer less maintenance among all types of collectors. Flat plate solar collectors basically used for heating of water by absorbing solar energy [3]. Conventional solar collectors, which uses water as heat absorbing and transporting medium, exhibits low thermal conversion efficiency. Thermal absorption efficiency and heat transportability capacity can be enhanced by employing new materials. Nanofluids, first introduced by Choi [4] have great potential to enhance heat absorption as well as transportation capacity. Since their inception, lot of research has been done with respect to application of nanofluid as heat absorbing and transport medium in heating and cooling systems. Experimental, computational and theoretical findings of researchers are highly promising. Tyagi et al. [5] observed 10% enhanced efficiency of DASC on absolute basis compare to flat plate solar collector using Al_2O_3/water nanofluid. Natrajan and Sathish [6] experimentally studied performance of CNT/water nanofluid with SDS as surfactant for solar water heating system and find that nanofluid based solar collector are more efficient compare to conventional one. Otanicar et al. [7] reported maximum enhancement in efficiency of DASC by 5% for Ag/water nanofluid (20–40 nm) at 0.5% volume fraction. Kameya and Hanamura [8] studied effect of Ni/water nanofluid as heat absorber. They found that absorption coefficient is much higher than that of base fluid in range of visible to near-infrared spectrum of solar radiation at 1.0 wt%, and ~4.9 nm particle size. Yousefi et al. [9] observed 28.3% enhancement in thermal efficiency of flat plate solar collector with Al_2O_3/water nanofluid at 0.25 wt%, size 15 nm for volume flow rate 2 l/min. Yosefi et al. [10,11] reported effect of pH variation on efficiency of solar collector when in their

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Nomenclature

SDS	sodium dodecyl sulphate
FPSC	flat plate solar collector
DASC	direct absorbing solar collector
LPM	litre per minute
CNT	carbon nano tube
MWCNT	multi walled carbon nanotubes
PEG	propylene ethylene glycol
TEM	transmission electron microscopy
XRD	X-ray diffraction
CP	centipoise
H.I.M.	human interaction machine
F_R	heat removal factor
U_L	overall heat transfer loss coefficient
DM	demineralized
PLC	programme logic controller

Symbols

φ	particle volume fraction (%)
τ	absorptance
α	transmittance

experimental analysis of MWCNTs/water as working fluid in FPSC, they observe that variation of pH value above or below the isoelectric point causes efficiency enhancement. Said et al. [12] in their theoretical analysis reported 15.33% enhancement in heat transfer coefficient and entropy generation reduction by 4.34% when SWCNTs based nanofluid was used compare to water for FPSC. Zamzamian et al. [13] performed experimental analysis on use of Cu/EG nanofluid having particle size 10 nm over efficiency enhancement of FPSC. Experimental findings reveal that 0.3 wt% and 1.5 l/min flow rate achieve optimum results. He et al. [14] reported that for Cu/water based nanofluid having 0.1 wt% and particle size 25 nm, optimum efficiency, which is 23.83% achieved for 140 l/h volume flow rate for FPSC. Efficiency decreases at higher concentration, 0.2 wt% for same flow rate. Vincely and Natrajan [15] on the basis of experimental findings reported that for graphene oxide nanofluid at 2 wt% concentration, and 0.01167 kg/s mass flow rate thermal efficiency of FPSC enhanced by 7.3%. Convective heat transfer coefficient enhanced by 8.03%, 10.93% and 11.5% for 0.5, 1 and 2% particle wt concentration respectively. Jeon et al. [16] used gold nanorods in three different aspect ratio and studied the effect of widening of broad band spectrum over visible and infrared region for absorption utilization, experimental findings indicates that high aspect ratio widens absorption spectrum thus can enhance thermal efficiency of solar collector. Shareef et al. [17] experimentally studied the effect of flow rate on temperature difference at outlet and inlet. Experimental findings reveals that at 0.5% particle volume fraction and 2 l/min flow rate, maximum temperature difference achieved was 23.5 °C, compare to 10.7 °C for pure water as heat transporting fluid in solar collector.

With use of surfactant Triton X100 efficiency enhancement was 15.63%. In another experiment using MWCNT/water nanofluid same authors [10] observed that positive impact of nanofluid in terms of efficiency of FPSC increases with increase or decrease of pH value of MWCNT with respect to its isoelectric value. Authors used 0.2 wt% with pH values 3.5, 6.5 and 9.5 and Triton X as surfactant. Taylor et al. [18] performed theoretical model study on applicability of nanofluids for high concentration solar dish. Authors observed 10% enhancement in thermal efficiency for graphite nanofluid at 0.001% concentration, suitable for power generation at rate of 10–100 MWe. Tiwari et al. [19] theoretically investigated effect of Al_2O_3/water nanofluid on efficiency of flat plate solar collector. Investigation observed 31.64% enhancement in thermal efficiency at 1.5% volume fraction. Saidur et al. [20] performed theoretical analysis on weight reduction, cost saving and environmental impact for different nanofluids. For 1000 units weight reduction estimated were 1229, 8625, 8857 and 8618 kg for CuO, SiO_2, TiO_2 and Al_2O_3 respectively. Alim et al. [21] theoretically investigated effect of various nanofluids on pressure drop and entropy generation. Authors selected Al_2O_3, CuO, SiO_2, TiO_2 nanoparticles dispersed in water ranging in 1–4 wt% and volume flow rate 1–4 l/min. Investigation conform that minimum entropy generation observed for CuO along with enhancement of heat transfer coefficient by 22.1%. There is small penalty of pressure drop which is 1.58% compare to conventional fluid water. Javadi et al. [22] presented comprehensive review on application of nanofluids in performance enhancement of solar collectors. Authors observed that nanofluids have great potential in harnessing of solar energy and convert it to useful thermal energy which can be used for water and air heating systems. Ladjevardi et al. [23] performed theoretical/computational analysis on applicability of graphite nanofluid in DASC and observed that up to 50% solar insolence can be absorbed by nanofluid of 0.000025 wt% compare to water which can absorb only 27% for relatively marginal 0.0045 $/l increase in cost. Thermophysical properties of nanofluids which are greatly responsible for thermal performances, are depends upon particle concentration, size of particle and type of nanofluid [24–26]. Rahman et al. [27] performed simulated model study on effect of solid volume fraction and tilt angle on quarter circular solar collector. Observations revealed that both solid volume fraction (0–0.12%) and tilt angle (0–60°) plays important role in enhancement of heat transfer parameters. Goudarzi et al. [28,29] carried on experimental investigation on effect of $CuO—H_2O$ nanofluid, pH variation and receiver helical pipe on thermal efficiency of solar collector. Results show an appreciable enhancement about 25.6% in thermal efficiency of solar collector and 24.2% enhancement with SDS. Parvin et al. [30,31] performed simulation study on Cu-water nanofluid. Result shows that both mean Nusselt number and entropy generation increases with increase in the volume fraction. Khullar et al. [32] performed novel experimental study which reveals that nanofluid volumetric absorption system can prove to be more efficient than conventional one, notwithstanding, higher stagnation temperature can also be achieved, thus suitable for power generation purpose. Mahian et al. [33], analytically investigated entropy generation and heat transfer flow rate for Al_2O_3/water nanofluid. Size of particle, 25, 50, 75 and 100 nm, mass flow rate maintained 0.1–0.8 kg/s, volume concentration maintained 0–4%. Findings establishes that there is critical mass flow rate for values higher than that, the effect of roughness on entropy generation become important and should be taken into account. Moghadam et al. [34] experimentally investigated effect of CuO/water nanofluid and find that efficiency of solar collector increases by 21.8% for mass flow rate 1 kg/min, volume fraction 0.4% and size of particles ~40 nm. Michael and Iniyan [35] reported 6.3% enhancement in thermal efficiency of flat plate solar collector when CuO/water nanofluid used as working fluid having volume fraction 0.05% and mass flow rate 0.1 kg/s in thermosyphon mode. Said et al. [36] experimentally investigated TiO_2 nanofluid with PEG dispersant as working fluid in FPSC and observed enhancement in energy efficiency, 76.6% for 0.1% volume fraction and 0.4 kg/min flow rate. Highest exergy efficiency achieved was 16.9% for 0.1% volume fraction and same flow rate. In general, established perception as depicted by various authors