Effect of Using Nanofluids in Solar Collector: A Review

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Abstract: - The use of nanofluids for cooling is attracting considerable attention in various industrial applications. Compared with conventional fluids, nanofluids improve the heat transfer rate, as well as the optical properties, thermal properties, efficiency, and transmission and extinction coefficients of solar systems. The effects of different nanofluids on the cooling rate and hence the efficiency of solar systems can be experimentally investigated. Accordingly, this review paper presents the effects of nanofluids on the performance of solar collectors from the considerations of efficiency and environmental benefits. A review of literature shows that many studies have evaluated the potential of nanofluids for cooling different solar collectors. Also this paper presents an overview of studies about the performance of solar collector, such as flat-plate and direct solar-absorption collectors with the use of nanofluids as working fluid. The effect of surface-to-volume ratio on thermal conductivity is more than the effect of the surface size of nanoparticles.

Key-Words: - Solar collector, Nanofluids, Flat plate, Thermal Efficiency, Thermal conductivity.

1. Introduction

Solar Energy is the energy received from the sun that sustains life on earth. For many decades solar energy has been considered as huge source of energy and also an economical source of energy because it is freely available. However, it is only now after years of research that technology has made it possible to harness solar energy. In recent time due to the increasing energy demand in building sector a number of initiatives have been taken all over the world to promote R&D activities on new technologies for generating energy from renewable sources.

Nanotechnology allows the production of nano-scaled particles. The suspensions of these particles in conventional fluids have created a new type of heat-transfer fluid. Nanofluids are being given significant interest in thermal engineering. Nanofluids are a mixture of liquid (base fluid) and nanoparticles (nanometer sized material) [1]. This paper presents an overview of the recent developments in the study of heat transfer and solar collector with the use of nanofluids. Nanofluids containing small amounts of nanoparticles have substantially higher thermal conductivity than base fluids [2]. The thermal conductivity enhancement of nanofluids depends on the volume fraction, size, type of nanoparticles and base fluid. Suspended nanoparticles remarkably increased the forced convective heat transfer performance of base fluid. At the same Reynolds number, the heat transfer of the nanofluids increases with the increase the volume fraction of nanoparticles and decrease in nanoparticles size. Among these, one that has grown very vastly is the photovoltaic (PV) technology. The improvement of the energy performance of PV can be reached by combining PV system with solar thermal system, keeping the PV cells at lower temperatures and recovering thermal energy otherwise wasted.

This paper presents an overview of studies about the performance of solar collector, such as flat-plate and direct solar-absorption collectors with the use of nanofluids as working fluid. The effect of surface-to-volume ratio on thermal conductivity is more than the effect of the surface size of nanoparticles.

2. Performance of solar collector using nanofluids

The performance of a solar collector is described by an energy balance. Energy balance presents the distribution of incident solar radiation into useful energy gain, thermal losses, and optical losses. Thermal energy is lost from collector to the surroundings by conduction, convection, and radiation [3]. The performance of solar collector can be analyzed by following the procedure described by Hotteland Woertz [4] and extended by ASHRAE [5]. The basic equation is

$$Q_u = I_{t\theta}(\tau\alpha)_\theta - U_L(T_{p,m} - T_a) = \frac{\dot{m}\, C_p (T_{fe} - T_{fi})}{A_{ap}} \quad (1)$$

Eq. (1) may also be conformed for concentrating collectors [5]:

$$Q_u = I_{DN}(\tau\alpha)_\theta(\rho\Gamma) - U_L\left(\frac{A_{abs}}{A_{ap}}\right)(T_{abs} - T_a) \quad (2)$$

Different testing standards can be used to characterize the collector performance. Examples of such standards are ASHRAE-93; 2003, which is used in the USA, and EN-12975; 2006, which is used in European countries.

The steady-state thermal efficiency of a basic flat plate solar collector is calculated by Duffie and Beckman[3]:

$$\eta = \frac{\int Q_u d_\tau}{A_c \int G_T d_\tau} \quad (3)$$

The useful energy output of a collector is the difference between the absorbed solar radiation and the thermal loss:

$$Q_u = A_c[S - U_L(T_{p,m} - T_a)] \quad (4)$$

where S is the solar energy absorbed by a collector, G_T is the incident solar energy, U_L is the heat transfer coefficient, $T_{p,m}$ is the mean absorber plate temperature, Ta is the ambient temperature, and A_c is the collector area.

In recent years, the numbers of experimental, theoretical, and numerical works on the application of nanofluids in solar collector have increased. In this paper, we present the experimental, theoretical, and numerical works had conducted by different authors for different types of solar collector along with the types and results of nanofluids.

2.1. Flat plate solar collector

Yousefi et al. [6] investigated experimentally the effect of Al2O3–water nanofluid as working fluid on the efficiency of a flat-plate solar collector. The effects of mass flow rate, nanoparticle mass fraction, and surfactant on the efficiency of the collector were studied. Yousefi et al. [7] investigated experimentally the effect of MWCNT nanofluid as absorbing medium on the efficiency of a flat-plate solar collector. Yousefi et al. [8] investigated the effect of pH of MWCNT–H2O nanofluid on the efficiency of a flat-plate solar collector. The experiments were carried out using 0.2 wt.% MWCNT with various pH values (3.5, 6.5, and 9.5) and with Triton X-100 as additive.

2.2. Direct Absorption solar collector

Otanicar and Golden [9] determined the environmental and economic effects of using nanofluids to enhance solar collector efficiency as compared with conventional solar collectors for domestic hot water systems. Tyagi et al. [10] studied theoretically the capability of using a nonconcentrating direct absorption solar collector (DAC) and compared its performance with that of a conventional flat-plate collector. Otanicar et al. [11] investigated the use of nanofluid-based in direct absorption solar collectors. They found that mixing nanoparticles in a liquid (nanofluids) dramatically affects the liquid Thermophysical properties, such as thermal conductivity. Saidur et al. [12] analyzed the effect of using nanofluids as working fluid on direct solar collector. The extinction coefficient of water-based aluminum nanofluids was evaluated under different nanoparticle sizes and volume fractions.

2.3. Evacuated tube solar collector

Lu et al. [13] designed an especial open thermo-syphon device used in high-temperature evacuated tubular solar collectors. Liu et al. [14] designed a novel evacuated tubular solar air collector integrated with simplified compound parabolic concentrator (CPC) and special open thermo-syphon using water-based CuO nanofluid as working fluid to provide air with high and moderate temperatures.

2.4. Parabolic trough collector

Risi et al. [15] modeled and optimized transparent parabolic trough collector (TPTC) based on gas-phase nanofluids. Nasrin et al. [16] numerically investigated the influence of Prandtl number on free convection flow phenomena in a solar collector with glass cover plate and sinusoidal absorber. They used water–Al2O3 nanofluid as the working fluid.

2.5. Concentrated-Parabolic Solar Collectors

Lenert et al. [17] presented a combined modeling and experimental study to optimize the efficiency of liquid-based solar receivers seeded with carbon-coated absorbing nanoparticles. Khullar et al. [18] harvested solar radiant energy with the use of nanofluid-based concentrating parabolic solar collectors (NCPSC). The results of the model were compared with the experimental results of conventional concentrating parabolic solar collectors under similar conditions.

From the above-mentioned discussion, which is also summarized in Table 1, we find that the available experimental data from different research groups vary widely. Further investigations are necessary to clarify the current predicament. The performance of nanofluid solar collector is also summarized in Table 1.

Table 1. Summary of performance of solar collector using nanofluids.

Author	Type of collector	Type of nanofluids	Particle size, nm	Volume fraction, %	Results
Yousefi et al. [6]	Flat-plate	Al_2O_3 / water	15 nm	0.2, 0.4	- For 0.2 wt% the efficiency increases up to 28.3%. - The surfactant causes an enhancement in heat transfer efficiency is 15.63%
Yousefi et al. [7]	Flat-plate	MWCNT / water	10-30 nm	0.2, 0.4	- The 0.2 wt% MWCNT nanofluids without surfactant decrease the efficiency and to surfactant increase it. - Collector efficiency increases with increase the volume fraction compared with water.
Yousefi et al. [8]	Flat-plate	MWCNT / water	10-30 nm	0.2 wt. %	- The more differences between the pH of nanofluids and pH of isoelectric point cause the more enhancements in the efficiency of the collector.
Otanicar, Golden [9]	Direct Absorption	Graphite/ water, EG	-	0.1 wt. %	Using nanofluids solar collector leads to approximately 3% higher levels of pollution offsets than a conventional solar collector.
Tyagi et al. [10]	Direct Absorption	Al_2O_3 / water	Less than 20 nm	0.1-5 wt.%	The efficiency of a DAC using nanofluid is up to 10% higher than that of a flat-plate collector. Efficiency increases for nanofluids up to 2 wt. %.
Otanicar et al. [11]	Direct Absorption	CNT, graphite, and silver / water	D=6-20& L=1-5*10^3 nm, D=30, D=20-40nm	0-1 wt.%	For 30 nm graphite, a maximum improvement, over a conventional flat surface absorber, of 3%. With 20 nm silver an efficiency improvement of 5%. An enhancement in the efficiency compared with pure water until 0.5 with. %.
Saidur et al. [12]	Direct Absorption	Al_2O_3 / water	1, 5, 10, 20	2 wt.%	1.0% showing satisfactory improvement to solar absorption, aluminium nanofluids was a good solution for direct solar collector compared to others.
Lu et al. [13]	Evacuated Tubular	CuO / water	50 nm	0.8 - 1.5 wt.%	Enhance the thermal performance of the evaporator and evaporating HTC increase by about 30% compared with those of deionized water. The HTC in the evaporation section and the 1.2 wt.% corresponds to the optimal heat transfer enhancement.

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Liu et al. [14]	Evacuated Tubular	CuO / water	50 nm	1.2 wt. %	The solar collector integrated with open thermo-syphon has a much better collecting performance. Increase the collecting efficiency, max and mean value increase to 6.6% and 12.4%, respectively.
Risi et al. [15]	Transparent Parabolic Trough	(0.25% CuO, 0.05% Ni) / water	-	0.01-0.3	The optimization procedure find a maximum solar to thermal efficiency equal to 62.5%, for a nanofluids outlet temperature of 650 °C and a nanoparticles volume concentration of 0.3%.
Nasrin et al. [16]	Glass cover plate and sinusoidal absorber	Al_2O_3 / water	-	5 wt. %	The Al_2O_3 nanoparticles with the highest *Pr* were established to be most effective in enhancing performance of heat transfer rate than base fluid.
Lenert et al. [17]	Concentrated Parabolic	C-Co / VP-1	10-100 nm	-	Efficiency increases with increasing nanofluids height and solar flux. The optimum optical thickness foe a non-selective receiver is 1.7.
Khullar et al. [18]	Concentrated Parabolic	Al_2O_3 / VP-1	5 nm	-	The NCPSC has the potential to harness solar radiant energy and higher efficiency about 5-10% as compared to the conventional parabolic solar collector.
Chougule et al. [19]	Flat-plate	CNT / water	D=10-12. L=0.1-10μ	0.15 wt. %	- At 50° tilt angle both working fluids gave better performance as compared to the standard normal angle in both conditions. - Average collector efficiencies for water and nano working fluid are increased 12% and 11 % at 31.50° tilt angle, while 7% and 4% respectively at 50° tilt angle using the tracking system.
Tiwari et al. [20]	Flat-plate	Al_2O_3 / water	-	0.5-2wt. %	Using the 1.5% particle volume fraction of Al2O3 nanofluid increases the thermal efficiency as well as kgCO2/kWh saving in a hybrid mode of solar collector in comparison with water as the working fluid by 31.64%.
Taylor et al. [21]	Direct Absorption	Graphite, Al_2O_3,Cu /Therminol VP-1	20 nm	0.1 wt. %	Enhancement in efficiency of up to 10% as compared to surface-based collectors.

3. Conclusion

Nanotechnology allows the production of nano-scaled particles. The suspensions of these particles in conventional fluids have created a new type of heat-transfer fluid. Nanofluids are being given significant interest in thermal engineering. This paper presents an overview of the recent developments in the study of heat transfer and solar collector with the use of nanofluids. Nanofluids containing small amounts of nanoparticles have substantially higher thermal conductivity than base fluids. The thermal conductivity enhancement of nanofluids depends on the volume fraction, size, type of nanoparticles and base fluid. Suspended nanoparticles remarkably increased the forced convective heat transfer performance of base fluid.

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