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Applications of Nanofluids in Solar Energy- A Review

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ABSTRACT

As ever increasing need of energy for satisfying human activities, cannot be met by the conventional fossil fuels, there is a need for finding greener and economical fuels. Solar energy systems are considered as one of the most important alternatives to conventional fossil fuels, due to its ability to convert solar energy directly into heat and electricity without any negative environmental impact such as greenhouse gas emissions. However, the low thermal conductivity values of heat transfer fluids and poor optical properties of many absorbers and their coating reduces the efficiency of solar energy conversion. Hence, there is an imperative need to improve both thermal and optical properties of current solar conversion systems. Direct solar thermal absorption collectors incorporating a nanofluid offer the opportunity to achieve significant improvements in both optical and thermal performance. Utilizing nanofluid as a potential heat transfer fluid with superior thermo-physical properties is an effective method to enhance the thermal performance of solar energy systems. The purpose of this review paper is the investigation of the recent advances in the nanofluids' applications in solar energy systems, i.e., solar collectors (SCs), photovoltaic/thermal (PV/T) systems, solar thermoelectric devices, solar water heaters, solar-geothermal combined cooling heating and power system (CCHP), evaporative cooling for greenhouses, and water desalination.

Keywords: Nano Fluids, Solar Energy, Solar Collector, Photovoltaic Cell, Solar Water Heater etc.

1. INTRODUCTION

Common heat transfer fluids such as water, ethylene glycol, and heat transfer oil play an important role in many industrial processes such as power generation, heating or cooling processes, chemical processes, and microelectronics. As these fluids have relatively low thermal conductivity and thus cannot reach high heat exchange rates in thermal engineering devices. A way to overcome this barrier is to impregnate nano particles in such heat transfer fluids to improve their thermal conductivity. The suspension of nano-sized particles in a conventional heat transfer fluid which is known as base fluid is called as a nanofluid. Choi first used the term "nanofluid" in 1995. Nanofluids, compared to suspensions with particles of millimeter-or-micrometer size, show better stability, rheological properties, and considerably higher thermal conductivities.

In recent years, the use of solar energy has had a remarkable edge. The perceived shortage of fossil fuels as well as environmental considerations will constrain the use of fossil fuels in the future. Therefore, researchers are motivated to find alternative sources of energy. This has become even more popular as the price of fossil fuels continues to rise. The earth receives in just about 1 h more energy from the sun than that consumed by the entire world for 1 year. Most solar energy applications are financially viable while small systems for individual use require just a few kilowatts of power It is important to apply solar energy to a wide range of applications and provide solutions through the modification of the energy proportion, improving energy stability, increasing energy sustainability, and enhancing system efficiency . This paper presents a review of former studies on the application of nanofluids in solar thermal engineering systems. The former works on applications of nanofluids in solar energy are mainly related to their applications in collectors. Therefore, this review mainly investigates the effects of nanofluids on the efficiency improvement of solar collectors as well as on economic and environmental considerations regarding the usage of these systems. Other applications of nanofluids in thermal energy storage, solar cells, and solar stills are also reviewed. Some suggestions also are made for future works in this field. In addition, the existing challenges of using nanofluids in solar energy applications are discussed. Finally, the authors wish to mention that in contrast with the comprehensive references on nanofluids mentioned above much less is known about the application of nanofluids in solar energy applications. It should be reiterated here that, as this is the first systematic review paper on this subject, it is desirable to provide as complete details as possible. However, in an attempt to reduce the overall length of the paper, without compromising the technical quality, only some very important questions for problems of practical applications have been briefly described.

2. LITERATURE REVIEW

Tyagi et al. theoretically investigated the performance of a direct absorption solar collector (DAC) exploiting aluminium-water nanofluid as the absorbing medium. They showed that as the volume fraction of alumina in nanofluid increases augmentation of collector efficiency. This is due to the enhanced attenuation of sunlight as it passes through the collector. Since the attenuation varies exponentially with volume fraction, the efficiency initially increases rapidly at low concentrations and then reaches an asymptotic value in higher concentrations more than 1%. The result revealed that, under similar operating conditions, the efficiency for nanofluid-based direct absorption solar collectors is 10% higher.[1]

Otanicar et al. examined the effect of nanofluids based on carbon nanotubes, graphite and silver on the performance of a direct absorption collector experimentally and compared the results with numerical models. The efficiency in solar collector increased upto 5% by utilizing nanofluids as the absorption mechanism. The experimental and numerical results demonstrate an initial rapid increase in efficiency with volume fraction, followed by a levelling off in efficiency as volume fraction continues to increase exhibits the efficiency of the model and experiment for 30 nm graphite spheres with a 5% discrepancy in comparison. They reported that the enhanced efficiency may be due to modification of the optical properties of the fluid, heat loss reduction as the peak temperature places away from surface, and thermal conductivity enhancement.[2]

Tiwari et al. studied Al2O3/ water nanofluid to investigate the thermal performance of flat-plate collector. The results show that, in comparison with base liquid the nanofluids as working fluid increase the efficiency and for 1.5% particle volume fraction the efficiency increased to 31.64%. [3] Taylor et al.[4] investigated utilizing nanofluid receiver in power tower solar collectors theoretically, they also applied nanofluid in a laboratory-scale dish receiver; in both cases the enhancement of efficiency was observed comparing to base fluid. Sani et al.[5] and Mercatelli et al. investigated the potentiality of utilizing singlewall carbon nanohorns (SWCNHs) in ethylene glycol suspension and nominated that as a good choice for exploiting in solar collectors. Khullar et al.[6] investigated the enhancement of solar irradiance absorption capacity for nanofluid-based concentrating parabolic solar collectors (NCPSC) theoretically and compared the results with experimental data of conventional concentrating parabolic solar collectors which demonstrated 5–10% higher efficiency as compared to the conventional models. Kasaeian et al.[7] have studied the heat transfer modeling for different nanofluids, they also investigated the heat transfer enhancement for Al2O3/synthetic oil nanofluid in a parabolic trough collector tube numerically . Solar energy conversion to heat or electricity mainly utilizes surface absorbers. Temperature difference between absorber and heat transfer fluid is a common imperfection in these systems which happen due to thermal resistance at interfaces. One of the solutions to reduce heat loss is volumetric absorption. In volumetric absorption, solar radiation is absorbed by a volume of heat transfer fluid directly. Some researchers declared utilizing the concept of volumetric absorption in solar power collectors Veeraragavan et al [8] made an analytical model for volumetric solar flow receivers, which employed nanoparticles suspended in the base fluid and displayed an improvement in solar conversion efficiency by decreasing the temperature differences between the absorber and fluid. Lenert and Wang [9] studied the influence of different variations in nanofluid volumetric receivers theoretically and experimentally. In their theoretical part, a one dimensional transient heat transfer model was proposed and the enhancement of receiver efficiency with augmentation of nanofluid height and incident solar flux was proved. In the experimental part, carbon coated cobalt nanoparticles were added to Therminols VP-1in a liquid-based volumetric receiver. For the temperatures below 700 K, enhancement of nanofluid height lowered the receiver's efficiency. For the temperatures between 800 and 1200 K, the efficiency enhanced while no effect was observed for the temperatures above 1300 K.

3. APPLICATIONS OF NANOFLUIDS IN SOLAR ENERGY

3.1 Solar collectors

A solar collector absorbs sunlight by using working fluids which convert it into heat energy. Sunlight is absorbed by a working fluid which passes through the solar collector pipes .solar collectors with water as working fluid are widely used. However, they suffer from low efficiency. One of the most effective modifications to enhance SCs efficiency is using nanofluids as working fluids instead of water. Hordy et al. [10] used multi-walled carbon nanotubes and denatured alcohol as a nanofluid in a d, which showed excellent stability upon multiple cycles of boiling and condensation. That is due to the ability of this nanofluid to absorb approximately 100% of the incident solar irradiation over a very small fluid volume.

3.2 Evacuated solar collectors

Evacuated Tube Solar Collectors (ETSCs) have many advantages over the conventional solar collectors. The ETSCs have considerably lower cost, low heat losses and higher efficiencies compared to the conventional flat plate collectors .They are chosen for applications like building heating, air conditioning, desalination of seawater, and industrial heating which require higher temperature. The main part in the ETSC is the parallel evacuated glass tube which consists of an outer transparent tube and an inner tube coated with absorptive coating to maximize absorption of the incoming solar radiation. A vacuum is employed between the concentric inner and outer tubes to only allow solar radiation to transfer but not the heat. A heat pipe with high thermal conductivity material, is welded to the absorber plate and then placed inside the inner tube. Tong et al. [11] used multi-walled carbon nanotube/water nanofluid was used as a working fluid in an enclosed-type evacuated U-tube SC to assess its performance. The obtained results showed an increase by about 4% in the collector efficiency when the nanofluid was used instead of water. Sabiha et al. [12] performed an experimental study using single walled carbon nanotubes suspended in water as nanofluid to assess the thermal performance of an ETSC and found that the collector efficiency was increased as volume fractions of nanoparticles as well as flow rate was increased. The energy efficiency of the ETSC changed from 48.57% at 0.05 vol% of nanofluid and 0.008 kg/s mass flow rate to 93.43% at

0.2 vol% of nanofluid and 0.025 kg/s mass flow rate. Liu et al. [13] reported that using CuO/water nanofluid as working fluid in a ETSC integrated with a compound parabolic concentrator (CPC) enhances the mean collector efficiency by 12.4% .Moreover, the concentration of CuO nanoparticles has a significant influence on the thermal performance and the optimal heat transfer enhancement achieved using a mass concentration of 1.2%.

3.3 Photovoltaic thermal systems

Hybrid Photovoltaic thermal devices (PV/T) are devices which convert sunlight into electrical and thermal energies. This is done by combining a solar cell, which converts sunlight directly into electricity using semiconductors, with a solar thermal collector, which absorbs the energy remaining from solar cells. Consequently the effective costs for PV/T systems are lower than conventional photovoltaic cells as PV/T systems have higher efficiency. The main drawback of photovoltaic cells is its inability to absorb the incident sunlight from the complete solar spectrum. Therefore, integrating SCs with solar cells makes use of the most incident solar energy, and thus increases the overall .electrical and thermal efficiencies.

Optimizing optical properties of the working fluid in PV/T systems can improve the efficiency, it means that the more transmission of the visible light and the more absorption of the solar infrared radiation, improve the performance of PV/T systems. Moradgholi et al [14] studied the way in which the overall performance of the system was affected when Al_2O_3 as a working fluid in the PV/T system.. With different filling ratios, they found that the optimum values were 50% (filling ratio) and 1.5 wt% nanoparticle concentration. They found that thermal and electrical efficiencies with the optimum values mention above increased by 27.3% and 1.1%, respectively, compared with the conventional PV/T systems. Gangadevi et al [15] studied the influence of using Al2O3 nanofluid on the performance of PV/T with different optimum conditions (mass flow rate of 40 L/H) and 1.2 wt% nanoparticle concentration. The findings revealed that with 2 wt% nanoparticle concentration, the overall, thermal and electrical efficiencies improved by 58%, 45% and 13%, respectively, compared with the PV/T system that used water as a working fluid. Similarly, sardarabadi et al [16] found that PV/T performance with ZnO nanofluids improved and the thermal and electrical outputs increased by 5% and 13%, respectively, compared with the performance of water-based PV/T.

3.4 Thermal energy storage

Energy storage is a key issue in renewable energies field. Unlike fossil energies, solar thermal energy storage is very difficult as it needs facilities like materials and mediums with high availability storage especially for high-temperature thermal storage. Since nanotechnology can improve some thermo-physical properties of materials, hence using nanomaterials can play an important role in solar thermal energy storage Obtaining electricity from solar energy is applicable by using photovoltaic or solar-thermal energy conversion systems which is more reliable and cost effective in large scales comparing to photovoltaic systems. A storage medium plays the key role in solar-thermal power plants which should take advantage of high thermal conductivity, also capable of operating at high temperatures. Some of materials used as heat transfer fluid in high thermal-energy storage are Na-K eutectics and alkali metal salts eutectics. Usually these materials have poor thermo-physical characteristics. Increasing the thermal conductivity, the specific heat capacity of the storage medium also the operating temperature of these materials will improve the thermodynamic efficiency of system. Importing gaseous working fluid of small absorbing particles for solar-thermal electric generation was firstly mentioned by Hunt in 1978. Nanofluid has been introduced as the viable solution to improve heat transfer properties also enhancing the specific heat capacity (SHC) in some research. In Long Jianyou's research adding 9 wt% aluminium nanoparticles to paraffin and 0.5 wt% SDBS as dispersant, improved the heat transfer properties of paraffin for thermal energy storage applications.

Zhu [17] investigated the heat transfer enhancement in a two-dimensional enclosure containing nanofluids and simulated phase change behaviour of SiC-H_2O nanofluids for different volume fractions. The results showed that the freezing rate of nanofluids is enhanced due to the addition of nanoparticles. Adding 5% SiC nanoparticles into water, the total freezing time can be saved by 17.4%. Thus adding nanoparticles is an efficient way to enhance the heat transfer in a latent heat thermal energy storage system.

A anomalous enhancement of specific heat capacity of high-temperature nanofluids was reported by shin et al[18]. When Alkali metal chloride salt eutectics were doped with silica nanoparticles at 1% mass concentration, the specific heat capacity of the nanofluid was enhanced by 14.5%.

3.5 Solar thermoelectric devices

In thermoelectric devices, heat is converted into electricity directly or indirectly which happens through the Seebeck, Petlier and Thomson associated effects. Thermoelectric devices have many applications in solar energy conversion, electronic cooling, vehicle air conditioners and refrigerators. Thermoelectric power harvesting via solar energy is one of the alternatives in renewable energy resources. Chang et al fabricated CuO thin films via electrophoresis deposition process with CuO nanoparticles suspension and isopropanol as the dielectric. This CuO film was adhered between a thermoelectric generator and dye-sensitized solar cells which elevated conversion efficiency of solar energy.

3.6 Solar water heaters

Solar heaters for heating water for domestic purposes is a simple and cost effective technique to utilize the solar radiation. Its initial cost is very high, but there is no additional operating cost. It is simply converting the incident solar radiation into heat, and then transmitted to water as a transfer medium. Many researchers have investigated the thermal performance of solar water heaters under different operating conditions and using various solar collectors .The thermal performance of solar water heaters can be enhanced by nanofluids as working fluid in solar collectors. Kabeel et al. [19] investigated the thermal performance of a solar water heater. It consists of a helical coil heat exchanger integrated with a flat-plate solar collector and Al2O3/water nanofluid as a working fluid They found that solar collector efficiency was increased by 11% using nanoparticles with 3% volume fraction. Ebrahimnia-Bajestan [20] studied the convective heat transfer of TiO2/ water nanofluid flowing through a uniformly heated and results revealed that the use of TiO2/water nanofluid enhanced the average HTC by 21%. Natarajan and Sathish [21] analyzed and compared the effects of using nanofluids using carbon nanotubes and conventional fluids on the thermal performance of solar water heater. The results revealed that the use of nanofluids results in a significant increase in the conventional solar water heater efficiency.

3.7 Solar thermoelectric cells

In recent years, interest in the development of solar thermoelectric systems has been considerably increased. The thermoelectric cells can be used to convert the solar energy to electricity due to the temperature difference between two hot and cold surfaces. A greater temperature difference between the hot and cold surfaces of the thermoelectric cell leads to a bigger electricity production. Fan et al in their work shown a dish concentrates the solar radiation on the thermoelectric cells installed on the focal point of the dish. In this way the effects of different nanofluids with various mass flow rates on the efficiency of the solar thermoelectric cell can be studied.

4. CHALLENGES

The possible challenges for the application of nanofluids in solar thermal devices are mentioned briefly in the following sections.

High cost

The first possible challenge in the use of nanofluids in solar thermal devices is the high cost of nanofluids because of difficulties in production. The high cost of nanofluids to use in thermal engineering systems such as heat exchangers is emphasized as a disadvantage in some works

Instability and agglomerating

Instability and agglomerating of the nanoparticles is another problem. Therefore, using nanofluids in solar systems with natural circulation where there is no pump to circulate the fluid, is not reasonable. It should be also noted that for high temperature gradients the agglomeration of nanoparticles seems to be more serious. Therefore, exact investigations are needed for an appropriate selection of a nanofluid for applications in high temperatures.

Pumping power and pressure drop

Using a nanofluid with higher viscosity compared to the base fluid leads to the increase of pressure drop and consequently the increases in the required power for pumping. For example, Duangthongsuk and Wongwises found during their experiments that the pressure drop under a turbulent regime increases with an increase in volume fraction of TiO_2/water nanofluid. In another experimental research, Razi et al. also concluded that using CuO/oil nanofluid increases the pressure drop under a laminar regime.

Erosion and corrosion of components

Existing of nanoparticles in nanofluid may lead to corrosion and erosion of thermal devices in a long time. Celata et al investigated the effects of nanofluid flow effects on erosion and corrosion of metal surfaces. They conducted their experiments for TiO_2, Al_2O_3, SiC, ZrO_2 nanoparticles with water as the base fluid where the nanofluids flow in pipes with three different materials, i.e., aluminium, copper and stainless. They concluded that the nanofluids have no effect on the erosion of the stainless pipe, while the aluminium pipe has highest erosion. They also found that ZrO_2 and TiO_2 nanoparticles lead to highest erosion while SiC nanoparticles results in lowest erosion.

5. CONCLUSION

Nanofluids are advanced fluids containing nano-sized particles that have emerged during the last two decades. Nanofluids are used to improve system performance in many thermal engineering systems. This paper presented a review of the applications of nanofluids in solar thermal engineering. The experimental and numerical studies for solar collectors showed that in some cases, the efficiency could increase remarkably by using nanofluids. Of course, it is found that using a nanofluid with higher volume fraction always is not the best option. Therefore, it is suggested that the nanofluids in different volume fractions should be tested to find the optimum volume fraction. It is also seen that the available theoretical works give different results on the effects of particle size on the efficiency of the collectors. It is worth to carry out an experimental work on the effect of particle size on the collector efficiency. It is also concluded that some factors such as adding surfactant to nanofluid and a suitable selection of the pH of nanofluid are effective in the collector efficiency. From the economic and environmental point of view, the previous studies showed that using nanofluids in collectors leads to a reduction in CO_2 emissions and annual electricity and fuel savings. It is also stressed that for the numerical study of solar systems, it is better to use the new thermo-physical models and two phase mixture models for the nanofluid to have a more exact prediction of the system performance. This review reveals that the application of nanofluids in solar energy is yet in its infancy. Finally, the most important challenges on the use of nanofluids in solar systems including high costs of production, instability and agglomeration problems, increased pumping power and erosion are mentioned. These challenges may be reduced with the development of nanotechnology in the future.

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