Applications of Nanofluid in Solar Energy – A Review

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***Abstract* - From last two decades, the use of nanofluids is increasing as an advance kind of liquid mixture. It is a small concentration of nano size solid particle suspended in fluid. The aim of this review paper is exploration of nanofluids application in solar thermal engineering system. The lack of conventional fuels and environmental hazardous motivated to use alternative energy sources such as solar energy. So, it is necessary to improve the effectiveness and performance of the solar thermal systems. In this review paper we are going to study effect of nanofluids, on various parameters s.a. efficiency, cost, on the performance of solar collector and solar water heaters. Apart from also reviewed application of nanofluid in thermal energy storage (TES), solar stills and solar cells.**

Keywords—nonofluid,nanoparticle,effectiveness, isoelectric, solar thermal energy.

I. INTRODUCTION

In many industrial processes like refrigeration and air conditioning, power generation, textile, chemical processes and electronic the conventional fluids s.a. water, heat transfer oil and ethylene glycol plays an important role. But, the thermal conductivity of these fluids is relatively low and thus unable to reach high heat transfer rate. Heat transfer rate can be increase by increases the surface contact area and this concept can use to overcome our problem. The use of very fine solid particles suspended in conventional fluids results to enhance their thermal conductivity. Nanofluid is the suspension of nano-sized particles in conventional base fluid. Fluid is the suspension of nano-sized particles in conventional base fluid. In 1995, Choi is the first person who use the term 'Nanofluid' [1].

From last some years, many researchers are interested for investigation of nanofluid on the improvement of heat transfer in thermal engineering devices by theoretically and practically. They use different types of preparation methods, properties and different mathematical model for the calculation of thermo physical properties of nanofluids [2-4]. Some researchers also reviewed the effect on nanofluid on flow and heat transfer in natural and forced convection [5-7].

This paper reviewed of previous studies on the application of nanofluids in solar thermal engineering systems. The previous works on applications of nanofluids in solar energy are mostly related to their applications in collectors. For that reason, this review mostly examines the effect of nanofluids on the efficiency enhancement of solar collectors with on economic and environmental considerations concerning the usage of these systems. Additional applications of nanofluids in solar cells, thermal energy storage, and solar stills are also reviewed.

II. Applications of nanofluids in solar energy

First up all, the application of nanofluids in collectors and water heaters are investigated from the efficiency, economic, and environmental consideration. Some reviews are also on optical properties and thermal conductivity of nanofluids, because these parameters can decide the ability of nanofluids to augment the performance of solar systems.

A. Collectors and solar water heaters

Solar collectors are also one kind of heat exchangers which convert solar radiation energy into heat energy of the conveying medium. Solar collectors absorb the incident solar radiation and convert it into heat. This heat transfers to a fluid like water, air, oil etc. which flows through the collector. The energy collected is carried from the working fluids can be use for different purposes like heating water, textile, and space conditioning equipment and to a thermal energy storage tank [8]. Solar water heaters are the mainly popular devices in solar energy field. As discuss in introduction, nanofluid based solar collectors are studied in two phases. One is from effectiveness viewpoint and other is from cost.

Tyagi et al. [9] theoretically studied the effects of various parameters on the efficiency of a low temperature nanofluid based direct absorption solar collector. They use mixture of water and aluminum nanoparticles as a working fluid. A diagram of the direct absorption collector is shown in Fig. 1. For adiabatic condition, the top surface of this collector is covered by a glass and the bottom side is well insulated. The efficiency of the collector is calculated by the following equation:

$$\eta = \frac{useful\ gain}{available\ energy} = \frac{mcp(Tout - Tin)}{AGT}$$

Where m is the mass flow rate of the fluid flowing through the collector;

Cp is the specific heat

Tin and Tout are the mean fluid inlet and outlet temperatures resp.

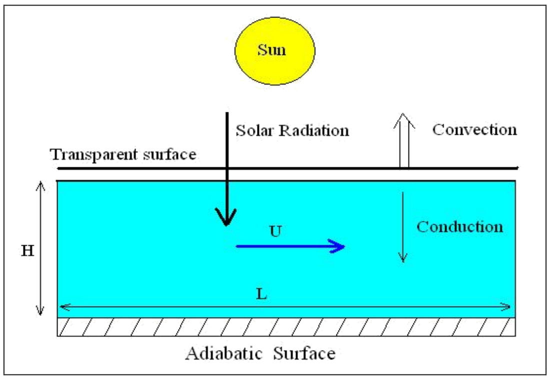
A is the cover area of the collector

G_T is the solar flux incident on the solar collector.

In this analysis, they assumed that the values of Tin, G_T, and m are 35^0C, 1000 W/m^2 and 1.2kg/s, respectively.

Tyagi et al. [9] plotted (Fig. 2) Effect of particle volume fraction on collector efficiency, where the volume fraction varies from 0.1% to 5%. Their results explained that the efficiency increases remarkably by increasing volume fraction of nanoparticles to the working fluid. They

Fig. 1. Schematic of the nanofluid-based direct absorption solarcollector



attributed the increase of collector efficiency to the increase in attenuation of sunlight passing through the collector due to the nanoparticles addition that leads to the increase of collector efficiency. As the efficiency remains nearly constant for a volume fraction higher than 2%, so increasing the volume fraction nanoparticles is not favorable. In this paper they also studied the effects of nanoparticles size on the collector efficiency with the volume fraction is equal to 0.8%. The results discovered that the efficiency increases to some extent with an increase in the size of nanoparticles (Fig. 3). Khullar et al. [10] compares theoretical outcome of nanofluids based concentrating parabolic solar collector with the experimental outcome of concentrating parabolic solar collectors under parallel circumstances. They used Aluminum nanoparticles with 0.05 volumetric fraction suspended in base fluid Therminol VP-1 for the investigation.

Khullar and Tyagi [14] examined the latent of the nanofluid based concentrating solar water heating system as an alternative for fossil fuels. Nanofluid based solar water system helps to save electricity nearly 1716kWh/household/year. It also saves LPG gas up to 206kg/household/year. This helps to save money. They also conclude that, due to conventional fuel, annual CO2 emission of one house is 2.2 to 103 kg/year. This can be reduced by using nanofluid based concentrating solar water heating system. It helps to solve environment problem.

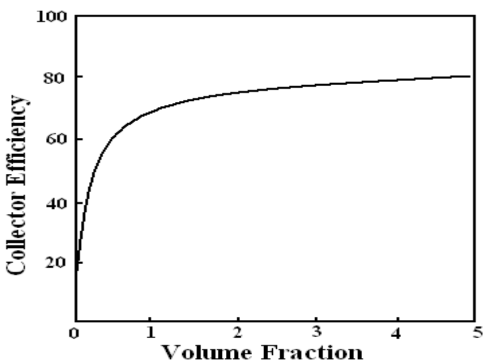


Fig 2 Collector efficiency as a function of the particle volume fraction[9]

Yousefi et al. [11] experimentally studied the effects of Al_2O_3+water nanofluid on the efficiency of a flat-plate solar collector. They examine the effects of two different weight fractions of the nanofluid, with 0.2% and 0.4% and the diameter of particles was 15 nm.

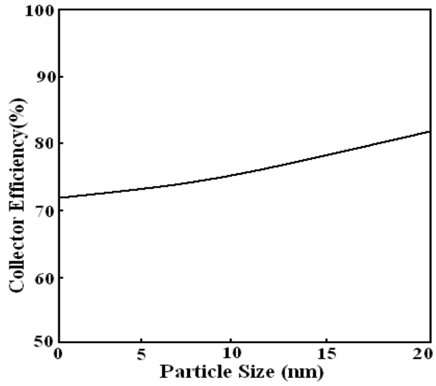


Fig 3 Collector efficiency as a function of the particle size[9]

They studied the effects on effectiveness of Triton X-100 used as a surfactant. Yousefi et al. [11] conducted the experiments using a schematic setup shown in Fig. 4. Their results are as follows:

1. The solar collector of 0.2% weight fraction (wt.) nanofluid has greater efficiency than water by 28.3%.
2. The effectiveness of collector with 0.2% wt. nanofluid is higher compared to 0.4% wt.
3. Efficiency enhance to 15.63% by using surfactant.

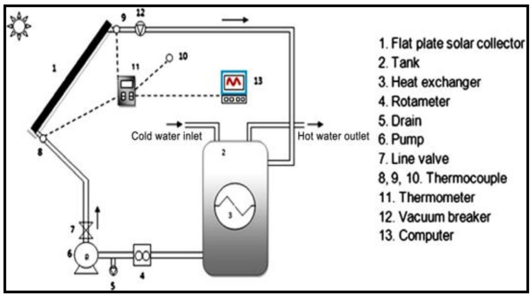


Fig.4. the schematic of Experiment of used by Yousefi et al.[11]

In further research,

Yousefi et al. [12], used the same experimental setup of the flat plate collector [11], to examine the effects on effectiveness of water Multi wall carbon nanotubes (MWCNT) + Water nanofluid.

Their results are:

1 MWCNT + Water nanofluid without surfactant for 0.4 wt. % nanofluid improve the efficiency of the collector as compared to water as the working fluid.

2 MWCNT + Water nanofluid without surfactant for 0.2 wt.% nanofluid decreases the efficiency of the collector compared to water as the working fluid.

3 The use of surfactant increases the efficiency of collector for 0.2 wt. % nanofluid compared to water.

In another experiment, Yousefi et al. [13], examine the efficiency of the flat plate collector with different pH of the

MWCNT + water nanofluid. They analyzed for 0.2 wt.% MWCNT with different pH values like 3.5,6.5 and 9.5. They also use surfactant Triton X-100. Their analysis shows by varying pH values of nanofluid and pH values of isoelectric point leads to increasing efficiency. The point at which the molecules carry no electrical charge is called isoelectric point. Fig. 5a and b shows that how pH values vary with the removed energy parameter and absorbed energy parameter of the solar collector. Fig. 5a shows that use of the nanofluid at increasing pH value increases the absorbed energy parameter. This shows for pH = 9.5 is highest absorbed energy parameter and for pH = 3.5 and 6.5 is almost still. Fig. 5b shows that at pH values 3.5 and 9.5 the removed energy parameter (F_RU_L) is decreased, but at pH = 6.5 the removed energy parameter is increased. Thus, the optimistic effect of MWCNT nanofluid at this pH is lesser than other pH values. Table 1 summarizes important results got from the previous works about the application of nanofluids to use in solar collectors.

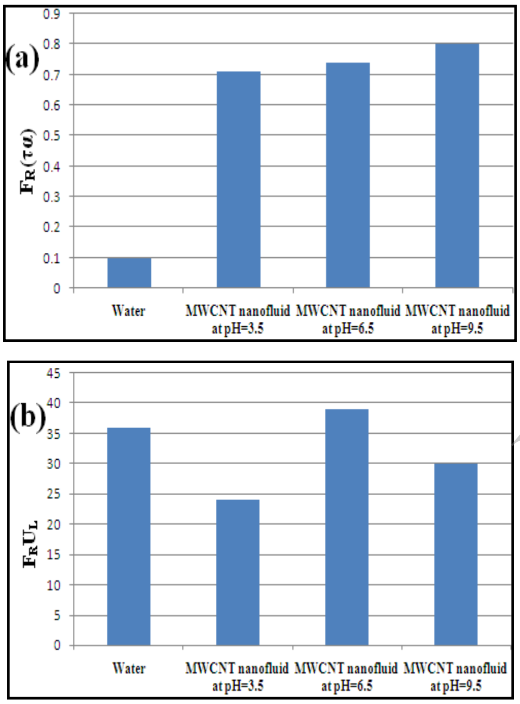


Fig. 5 $F_R(\tau\alpha)$ and FRUL of the flat-plate solar collector for water and nanofluids with various pH values.[13]

B. Other Application

Here we have reviewed other application on solar energy systems. Here we have studied solar still, solar cell and thermal energy storage.

1. Solar stills

A lot of research is carried out on solar stills and different methods are invented to improve their efficiency. In recent times, Gnanadason et al. [15] stated that solar stills efficiency can be increase by using nanofluids. They examined the effects of a single basin solar still by adding carbon nanotubes to the water. Their results showed that the efficiency improved by 50% with addition of nanofluids. However, they have not mentioned the exact amount of nanofluid added to the water for the solar still. As cost of nanofluid is so high, so the economic capability should be considered. It is also suggested that solar stills efficiency can be improve by adding dyes in fluid. Nijmeh et al. [16] concluded that solar stills efficiency increases by 29% by adding violet dye to the water, which is remarkable. It is clear that nanofluids are more expensive than dyes. Hence this is challenge to use nanofluids in solar stills. It can be used to minimize the production of greenhouse gas emissions from the production of fresh water.

2. Solar cells

Efficiency of solar cell can be improved by cooling solar cells. Nanofluids can be used as a solution for this problem. Elmir et al. [17] numerically simulate the cooling a solar cell by forced convection in the presence of a nanofluid. They considered the solar panel as an inclined cavity and solved the equations in Cartesian coordinate system. They used Al2O3 and water nanofluid for analysis purpose. The thermal conductivity and viscosity of the nanofluid are calculated using the models of Brinkman and Wasp respectively. They concluded that the average Nusselt number increase by use of nanofluids which leads to the improving the rate of cooling. But in whole analyses they did not consider the thermal conductivity and viscosity of nanofluid.

3. Thermal energy storage

Conventional solar thermal energy storage system needs the storage medium to have high thermal conductivity and heat capacity. But, very few materials are available with such properties and can be used in high temperatures. In recent times, Shin and Banerjee [18] stated the abnormal improvement of specific heat capacity can be possible for high-temperature nanofluids than conventional one. They found that the specific heat capacity of the nanofluid increase by 14.5% when Alkali metal chloride salt eutectic is doped with silica nanoparticles at 1% mass concentration . So this matter can be appropriate for the use in solar thermal energy storage system. Paraffin is the suitable because of its advantageous characteristics, since it has high latent heat capacity with minor super cooling and also low cost. Phase Change Material can also use for solar energy storage. S. Wua et al. [19] numerically simulate on thermal energy storage behavior of Cu/paraffin nanofluids PCMs. Their results exposed that with 1 wt.% Cu/paraffin, the melting time can be saved by 13.1%. Hence, they concluded that the use of nanoparticles is an efficient method to improve the heat transfer rate in latent heat thermal energy storage system.

CONCLUSION

In many thermal engineering systems nanofluids can be used to improve heat transfer rate of fluid. This paper presented a review of the applications of nanofluids in solar engineering. The experimental and numerical studies for solar collectors have been reviewed. It is observed that the overall efficiency of system increases by using nanofluids. It is suggested that to find out the optimum volume fraction of nanofluids, nanofluids in different volume fractions should be tested. It is seen that the theoretical results are varies from practical results for the effects of particle size on the efficiency of the collectors. It is important to carry out an experimental work on the effect of particle size on the collector efficiency. It also observed that some factors such as adding surfactant to nanofluid and a suitable selection of the pH of nanofluid improve the efficiency of collector. It is also concluded that the melting rate of paraffin is improved after adding Cu nanoparticles. We also reviewed applications of nanofluids in solar cells, solar thermal energy storage, and solar stills. It is suggested that some experimental studies can be performed on nanofluid based parabolic solar collector.

Table 1 Summary of previous works on the application of nanofluids used in solar collectors.

Author(s)	Collector type	Nanofluid type	Results
Tyagi et al.	Non-concentrating direct absorption	Aluminum + water	❖ For volume fraction less than 2% efficiency increases ❖ For volume fraction higher than 2% efficiency nearly remains constant
Khullar et al.	Parabolic Concentrator	Aluminum + Therminol VP-1	❖ Thermal efficiency of nanofluid based concentrating parabolic collectors is 5 to 10 % higher than conventional parabolic solar collector
Yousefi et al.	Flat plate	Al_2O_3+water, Triton X-100 is used as a surfactant	❖ The solar collector having 0.2% weight fraction (wt) nanofluid has 28.3% higher efficiency than water. ❖ Using the surfactant efficiency increases by 15.63%.
Yousefi et al.	Flat plate	Water-Multi wall carbon nanotubes /water Triton X-100 is used as a surfactant	❖ For 0.2 wt.% nanofluid efficiency of the collector decreases compared to water ❖ For 0.4 wt.% nanofluid efficiency of the collector increases compared to water ❖ For 0.2 wt.% nanofluid, using surfactant efficiency increases compared to water
Yousefi et al.	Flat plate	Water-Multi wall carbon nanotubes /water with various pH values:3.5, 6.5, and 9.5 Triton X-100 is used as a surfactant	❖ A bigger difference between the pH of nanofluid and pH of isoelectric point leads to higher efficiency

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