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A Review on Role of Nanofluids for Solar Energy Applications

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Abstract: The sun is a nature source of renewable energy. Solar energy consumption is very important in the backdrop of global warming and decrease of carbon dioxide secretion. Solar energy has been explored through solar thermal exploitation, photovoltaic power invention, and so on. Solar thermal consumption is the most accepted utilization surrounded by them. In conservative solar thermal collectors, plates or tubes coated with a layer of selectively absorbing material are used to take up solar energy, and then energy is carried away by working fluids in the form of warm. This type of collector exhibits several shortcomings, such as restrictions on incident flux density and relatively high heat losses. The shortage of fossil fuels and environmental considerations motivated the researchers to use alternative energy source such as solar energy. Therefore, it is essential to improve the effectiveness and recital of the solar thermal systems. In addition, some reported works on the applications of nanofluids in thermal energy storage, solar cells, and solar stills are reviewed. Dispersing outline amounts of nanoparticles into common base-fluids has a significant impact on the optical as well as thermo-physical properties of the base-fluid. Enhancement of the solar irradiance assimilation capacity leads to a higher heat convey rate resulting in more capable heat transmit. Nanofluids are suspension of nanoparticles in base fluids, a new challenge for thermal sciences provided by nanotechnology. Nanofluids have unique features different from conventional solid-liquid mixtures in which mm or µm sized particles of metals and non-metals are dispersed. Due to their excellent characteristics, nanofluids find wide applications in enhancing heat transfer. The aim of this appraisal manuscript is the study of the nanofluids in solar Energy applications. In order to overcome these drawbacks, direct solar absorption collector has been used for solar thermal exploitation.

Keywords: Nanofluid, Nanoparticle, Solar Water Heater, Thermoelectric Cells, and Solar Thermal Energy

1. Introduction

Nanofluids are the novel splitting up of fluids engineered by dispersing nanometer-sized materials (Nanoparticles, nanofibers, nanotubes, nanowires, nanorods, nanosheet, or droplets) in base fluids. In other words, nanofluids are nothing but the nanoscale colloidal suspensions which contains the diluted nanomaterials. There are two-phase systems in which one corresponds to solid phase and the other is related to liquid phase. Nanofluids have been initiated to acquire the improved thermo physical properties such as thermal conductivity, thermal diffusivity, viscosity, and convective heat transfer coefficients which were compared to those of base fluids like oil or water. It has been established with great impending applications in many fields.

The idea behind development of nanofluids is to use them as thermo fluids in heat exchangers for enhancement of heat transfer coefficient and thus to minimize the size of heat transfer equipments. The important parameters which influence the heat transfer characteristics of nanofluids are its properties which include thermal conductivity, viscosity, specific heat and density. The thermo physical properties of nanofluids also depend on operating temperature of nanofluids. Hence, the accurate measurement of temperature dependent properties of nanofluids is essential. Common fluids such as water, ethylene glycol, and heat transfer oil plays a momentous position in many manufacturing processes such as power generation, heating or cooling processes, chemical processes, and microelectronics. Though, these fluids have comparatively stumpy thermal conductivity and thus cannot reach elevated heat substitute rates in thermal engineering devices. An approach in the direction of rise above over this impenetrability in using ultra-fine solid particles balanced in frequent fluids to advance their thermal conductivity. The suspension of nano-sized particles (1–100 nm) in a conventional base fluid is called a nanofluid. Choi first used the term “nanofluid” in 1995 [1]. Nanofluids, compared to suspensions with particles of millimeter-or-micrometer size, show better stability, rheological properties, and considerably higher thermal conductivities. Researchers have in addition applied a selection of research methods, characteristics, and dissimilar models used for the computation of thermo physical properties of nanofluids (i.e., thermal conductivity, viscosity, density, specific heat capacity) [2–9]. Various investigators have also summarized the possessions of nanofluids on stream and heat transfer in usual and compulsory convection in different systems [10–13]. The improved thermal performance of nanofluids which can supply a starting point massive modernization of heat transfer intensification, which is of foremost significance to a measure of industrial sectors together with transportation, power generation, micro manufacturing, thermal therapy for cancer treatment, chemical and metallurgical sectors, as well as heating, cooling, ventilation and air-conditioning. Nanofluids are also important for the production of nanostructured materials for the manufacture of complex fluids as well as for clean-up oil from surfaces due to their exceptional wetting and spreading conduct [14]. An additional significance of the nanofluid stream is in the release of nano-drugs as suggested by Kleinstreuer et al. [15]. In recent years, the utilization of solar energy have amazing border. The apparent deficiency of fossil fuels as well as ecological considerations will confine the use of fossil fuels in the future. Therefore, researchers are motivated to find substitute sources of energy. This has been a turn out to be still an extra trendy as the cost of fossil fuels continues to ascend. Most solar energy applications are economically feasible whereas tiny system for entity use just a few kilowatts of power [16, 17]. It is appropriate to use solar energy to an extensive variety of applications and make available solutions through the alteration of the energy fraction, improving energy firmness, growing energy sustainability, and enhancing system effectiveness [18]. This paper presents a review of the application of nanofluids in solar energy applications. Therefore, this appraisal mainly investigates the special effects of nanofluids on the capability development of solar collectors as well as on profitable and environmental considerations concerning the handling of these systems. An additional application of nanofluids in thermal energy storage, solar cells, and solar stills are also reviewed.

2. Nanoparticles and Nanofluids Properties

Nanoparticles are sized between 1 and 100 nanometers. Nanoparticles may or may not exhibit size related properties that differ significantly from those observed in fine particles or bulk materials. Nanoclusters have at least one dimension between 1 and 10 nanometers and a narrow size distribution. Nanopowders are agglomerates of ultra-fine particles, nanoparticles, or Nanoclusters. Nanometer-sized single crystals, or single-domain ultra-fine particles, are often referred to as nanocrystals. Nanoparticles are of great scientific interest as they effectively form a bridge between bulk materials and atomic or molecular structures. A bulk material should have constant physical property regardless of its size, but at the nano-scale size- dependent properties are often observed. Thus, the properties of materials change as their size approaches the nanoscale and as the percentage of atoms at the surface of a material becomes significant. Suspensions of nanoparticles are possible since the interaction of the particles surface with the solvent is strong enough to overcome density differences, which otherwise usually result in a material either sinking or floating in a liquid. Nanoparticles also often possess unexpected optical properties as they are small enough to confine their electrons and produce quantum effects. For example, gold nanoparticles appear deep red to black in solution. Nanoparticles have a very high surface area to volume ratio, which provides a tremendous driving force for diffusion, especially at elevated temperatures. Sintering can take place at lower temperature, over shorter time scales than for larger particles. The fluids with nanosized solid particles suspended in them are called “nanofluids.” The suspended metallic or nonmetallic nanoparticles change the transport properties and heat transfer characteristics of the base fluid. Heat transfer enhancement in solar devices is one of the key issues of energy saving and compact designs. Solar energy is widely used in applications such as electricity generation, chemical processing, and thermal heating due to its renewable and nonpolluting nature. Most solar water heating systems have two main parts: a solar collector and a storage tank. The most common collector is called flat-plate collector but this suffer from relatively low efficiency. There are so many methods introduced to increase the efficiency of the solar water heater. But the novel approach is to introduce the nanofluids in solar collector instead of conventional heat transfer fluids (like water).

3. Preparation Methods for Nanofluids

3.1. Two-Step Method

Two-step technique is the mass extensively used technique for preparing nanofluids. Nanoparticles, nanofibers, nanotubes, or other nanomaterials used in this method. Initial method produced were dry powders by chemical or physical methods. Then, the nanosized powder will be detached into a fluid in the second processing step with the assist of exhaustive magnetic force agitation, ultrasonic agitation, high-shear mixing, homogenizing, and ball milling. Two-step method is the majority of economic technique to fabricate nanofluids in outsized scale, because nanopowder synthesis techniques have been already scaled up to industrial fabrication levels. Due to the high surface region and surface motion, Nanoparticles have the affinity to aggregate. The important technique to enhance the stability of Nanoparticles in fluids is in the use of surfactants. However, the functionality of the surfactants under high temperature is also a big concern, especially for high-temperature applications. Due to the difficulty in preparing stable nanofluids by two-step method, several advanced techniques are developed to produce nanofluids, including one-step method.

3.2. One-Step Method

To reduce the agglomeration of nanoparticles developed a one-step physical vapor condensation method to prepare Cu/ethylene glycol nanofluids [19]. The one-step process consists of simultaneously making and dispersing the particles in the fluid. In this method, the processes of drying, storage, transportation, and dispersion of Nanoparticles are avoided, so the agglomeration of Nanoparticles is minimized, and the stability of fluid is increased [20]. The one-step processes can be prepared uniformly dispersed Nanoparticles, and the particles can be stably suspended in the base fluid. The vacuum-SANSS (submerged arc nanoparticle synthesis system) is the capable technique to prepare nanofluids by means of dissimilar dielectric liquids [21, 22]. The different morphologies are mostly subjective and indomitable by a range of thermal conductivity properties of the dielectric liquids. The Nanoparticles prepared by this method exhibits needle-like, polygonal, square, and circular morphological shapes. This method avoids the undesired particle aggregation comparatively well. One-step physical method cannot manufacture nanofluids in large scale and the cost is also high, so the one-step chemical method is mounted rapidly. Zhu et al. offered a novel one-step chemical technique for preparing copper nanofluids by dropping $CuSO_4{\cdot}5H_2O$ with $NaH_2PO_2{\cdot}H_2O$ in ethylene glycol under microwave irradiation [23]. Well-dispersed and firmly balanced copper nanofluids were obtained. Mineral oil-based nanofluids containing silver Nanoparticles with a narrow-size distribution were also equipped by this method [24]. The particles might be stabilized by Korantin, which is synchronized to the silver particle surfaces via two oxygen atoms forming a dense layer around the particles. The silver nanoparticle suspensions were stable for about 1 month. Stable ethanol-based nanofluids containing silver Nanoparticles can be prepared by microwave-assisted one-step method [25]. In this method, polyvinylpyrrolidone (PVP) was employed as the stabilizer of colloidal silver and dipping agent for silver in solution. The cationic surfactant octadecylamine (ODA) is in addition of capable phase-transfer agent to produce silver colloids [26]. The phase shift of the silver nanoparticles arises owing to pairing of the silver nanoparticles with the ODA molecules in presence in organic phase through each coordination bond configuration or weak covalent interaction. Phase transfer method has been developed for preparing homogeneous and stable graphene oxide colloids. Graphene oxide nanosheets (GONs) were effectively transferred from water to n-octane following the alteration by oleylamine, and the schematic illustration of the phase transmit process is shown in Fig. 1 [27]. On the other hand, there are several disadvantages for one-step method. The most significant role is that the residual reactants are left in the nanofluids due to unfinished reaction or stabilization. It is complex to make clear the nanoparticle effect without eliminating this contamination effect.

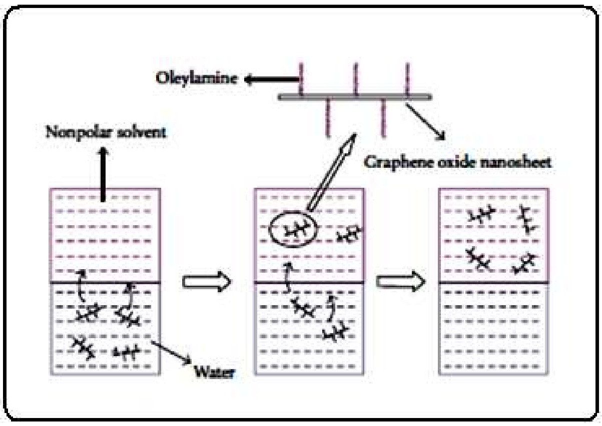

***Fig 1.** Schematic illustration of the phase transfer process[27]*

3.3. Other Novel Methods

Wei et al. developed a continuous flow micro fluidic micro reactor to synthesize copper nanofluids. By this method, copper nanofluids can be continuously synthesized, and their microstructure and properties can be varied by adjusting parameters such as reactant concentration, flow rate, and additive. CuO nanofluids with high solid volume fraction (up to 10 vol %) can be synthesized through a novel precursor transformation method with the help of ultrasonic and microwave irradiation [28]. The precursor $Cu\ (OH)_2$ is completely transformed to CuO nanoparticle in water under microwave irradiation. The ammonium citrate prevents the growth and aggregation of nanoparticles, resulting in a stable CuO aqueous nanofluid with higher thermal conductivity than those prepared by other dispersing methods. Phase-transfer method is also a facile way to obtain monodisperse noble metal colloids [29]. In a water cyclohexane two-phase system, aqueous formaldehyde is transferred to cyclohexane phase via reaction with dodecylamine to form reductive intermediates in cyclohexane. The intermediates are capable of reducing silver or gold ions in aqueous solution to form dodecylamine-protected silver and gold nanoparticles in cyclohexane solution at room temperature. Feng et al. used the aqueous organic phase transfer method for preparing gold, silver, and platinum nanoparticles on the basis of the decrease of the PVP's solubility in water with the temperature increase [30]. Phase transfer method is also applied for preparing stable kerosene based Fe_3O_4 nanofluids. Oleic acid is successfully grafted onto the surface of Fe_3O_4 nanoparticles by chemisorbed mode, which lets Fe_3O_4 nanoparticles have good compatibility with kerosene [31]. The Fe_3O_4 nanofluids prepared by phase-transfer method do not show the previously reported "time dependence of the thermal conductivity characteristic". The preparation of nanofluids with controllable microstructure is one of the key issues. It is well known that the properties of nanofluids strongly depend on the structure and shape of nanomaterials. The recent research shows that nanofluids synthesized by chemical solution method have both higher conductivity enhancement and better stability than those produced by the other methods [32]. This method is distinguished from the others by its controllability. The nanofluid microstructure can be varied and manipulated by adjusting synthesis parameters such as temperature, acidity, ultrasonic and microwave irradiation, types and concentrations of reactants and additives, and the order in which the additives are added to the solution.

4. Nanofluids in Solar Energy Applications

Initially, the application of nanofluids in collectors and water heaters are investigated for the efficiency, economic, and environmental aspects. Some studies conducted on thermal conductivity and optical properties of nanofluids are also briefly reviewed, because these parameters can determine the capability of nanofluids to enhance the performance of solar systems.

4.1. Collectors and Solar Water Heaters

A Nanofluid poses the following advantages as compared to conventional fluids which make them suitable for use in solar collectors: Absorption of solar energy will be maximized with change of the size, shape, material and volume fraction of the nanoparticles. The suspended nanoparticles increase the surface area and the heat capacity of the fluid due to the very small particle size. The suspended nanoparticles enhance the thermal conductivity which results in improvement in efficiency of heat transfer systems. Properties of the fluid can be changed by varying concentration of nanoparticles. Extremely small size of nanoparticles ideally allows them to pass through pumps. The fundamental difference between the conventional and nanofluids-based collector lies in the mode of heating of the working fluid. In the former case the sunlight is absorbed by a surface, where as in the later the sunlight is directly absorbed by the working fluid (through radiative transfer). On reaching the receiver the solar radiations transfer energy to the nanofluids via scattering and absorption. The nanofluid based solar water heater and collector are shown in Fig.2.

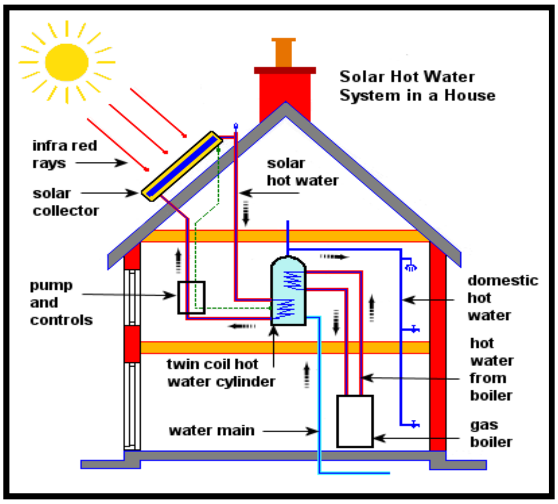

Fig 2. *The nanofluid based solar water heater and collector*

These devices absorb the incoming solar radiation, convert it into heat, and transfer the heat to a fluid (usually air, water, or oil) flowing through the collector. The energy collected is carried from the working fluid, either directly to the hot water or space conditioning equipment or to a thermal energy storage tank, from which it can be drawn for use at night or on cloudy days [33]. Solar water heaters are the most popular devices in the field of solar energy. Solar collector is used to collect the solar energy and transfers the collected solar energy to a fluid passing in contact with it, so it is always a matter of investigation to know that how efficiently solar collectors are converting solar energy into thermal energy. Solar collectors are classified as: Non-Concentrating or flat plate type solar collectors and Concentrating Solar Collectors. Flat plate collectors are very simple in construction and are mostly used as household equipment as water heater, air heater, and solar cooker whereas; concentrating solar collectors are mostly used for power generation, heating up water with higher mass flow rate. Concentrating Solar Collectors are more efficient then flat plate collectors, on the other hand they require a tracking system and require higher installation cost compared to flat plate collectors. The performance of solar collector depends upon the physical properties of the fluid flowing through it. It has been found that the conventional fluids used in solar collectors suffer from poor thermal properties. A new class of working fluids called “Nanofluid” can be used instead of conventional fluids, which have the improved thermal properties and thereby increase the thermal performance of the solar collector. Nonomaterial have unique mechanical, optical, electrical, magnetic and thermal properties in which average size of the nanoparticles is below 100 nm. A very small amount of nanoparticles when dispersed in any host fluids (e.g. water, oil, ethylene glycol) can improve the thermal properties of fluids dramatically. Commonly used material making nanofluids are as: oxide ceramics (Al_2O_3, CuO), nitride ceramics (AlN, SiN), carbide ceramics (SiC, TiC), metals (Cu, Ag, Au), semiconductors (TiO2, SiC), carbon nanotubes, composite materials ($Al_{70}Cu_{30}$). Nanoparticles can be manufactured by mainly two processes; those are Physical Processes and Chemical Processes. Physical Processes include Inert Gas Condensation (IGC) and mechanical grinding whereas Chemical Processes include Chemical Vapor Deposition (CVD), Chemical precipitation and micro emulsion. For making Nanofluids, nanoparticles are suspended in conventional heat transfer fluids by two methods called single step method and two step method. As described in section.3 above in single step method making and dispersion of nanoparticle happens simultaneously where as in two step method first nanoparticles are fabricated and then nanoparticles are dispersed into the base fluids.

4.2. 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. [34] stated that solar stills efficiency can be increased by using nanofluids. Their results showed that the efficiency is improved by 50% with addition of nanofluids. However, it was not clear that 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 improved by adding dyes in fluid [35] have reported that solar stills efficiency is increased by 29% by adding violet dye to water, which is remarkable. It is clear that nanofluids are more expensive than dyes. Hence, it is a 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. The solar stills illustrated in Fig. 3

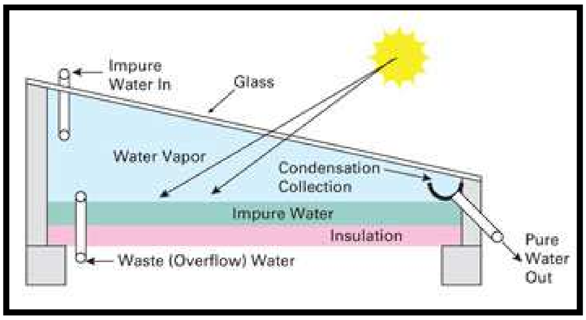

Fig 3. *Nanofluids based Solar Stills*

4.3. Solar Cells

Efficiency of solar cell can be improved by cooling solar cells (illustrated in Fig.4). Elmir et al. [36] numerically simulated the cooling a solar cell by forced convection in the presence of a nanofluid. The Al_2O_3 and water nanofluid was used for analysis purpose. The thermal conductivity and viscosity of the nanofluid are calculated using the models of Brinkman and Wasp respectively. It has been concluded that the average Nusselt number increase by use of nanofluids which leads to the improving the rate of cooling. But in whole analyses the thermal conductivity and viscosity of nanofluid was not considered.

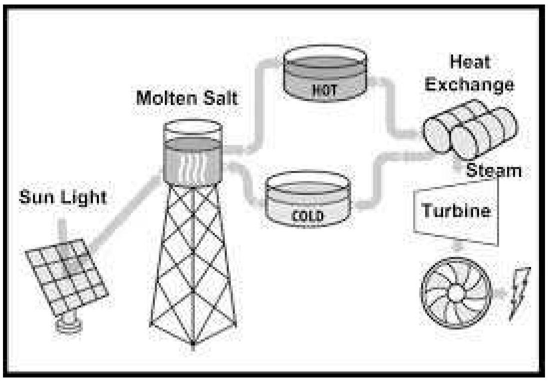

Fig 4. *Schematic diagram for solar cells*

4.4. Solar PANELS

Nanofluids are a simple product of the emerging world of nanotechnology. Suspensions of nanoparticles (nominally 1 to 100nm in size) dispersed in fluids such as water, oils, glycols and even air and other gases can rightly be called nanofluids. The first decade of nanofluid research was primarily focused on measuring and modeling fundamental thermo physical properties of nanofluids (thermal conductivity, density, viscosity, heat transfer coefficient). Due to its renewable and non-polluting nature, solar energy is often used in applications such as electricity generation, thermal heating, and chemical processing. Solar power plants with surface receivers have low overall energy conversion efficiencies due to large emissive losses at high temperatures. Nanofluids have recently found relevance in applications requiring quick and effective heat transfer such as industrial applications, cooling of microchips, microscopic fluidic applications, etc. The normal efficiency of the solar panels being used is recently found out to be 44.7% and the use of nanofluids it can be increased by 10-15%, also by Plasmonic Nanofluids by 20%.

4.5. 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 [37] stated that the abnormal improvement of specific heat capacity can be possible for high-temperature nanofluids than conventional one. It has been 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 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. Wua et al. [38] numerically simulate the thermal energy storage behavior of Cu/paraffin nanofluids PCMs. The results showed that with 1 wt.% Cu/paraffin, the melting time can be saved by 13.1%. Hence, it has been concluded that the use of nanoparticles is an efficient method to improve the heat transfer rate in latent heat thermal energy storage system as illustrated in Fig.5.

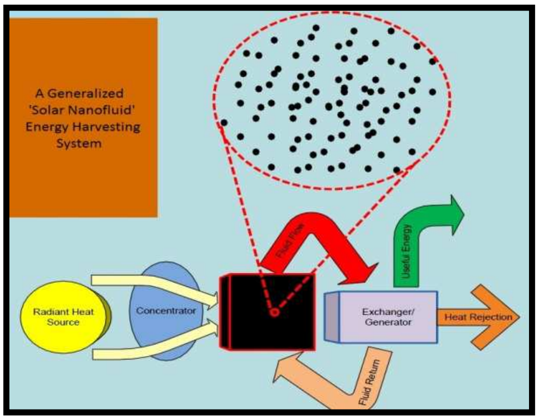

Fig 5. *Schematic diagram of Thermal energy storage*

4.6. Photovoltaic/Thermal Systems

A photovoltaic/thermal (PV/T) system is a hybrid structure that converts part of the solar radiation to electricity and part to thermal energy [39]. One can investigate experimentally the effects of using different nanofluids on the cooling rate, and, hence, the efficiency of the PV/T systems. The effects of different volume fractions, nanoparticle size on the efficiency of the system can be studied. A review of the literature shows that many researches have been carried out on the potential of nanofluids for cooling of different thermal systems such as electronic devices [40-42], automobile radiator [43], and micro channel heat sinks [44]. Therefore, using nanofluids to cool the PV/T system may be reasonable (illustrated in Fig.6).

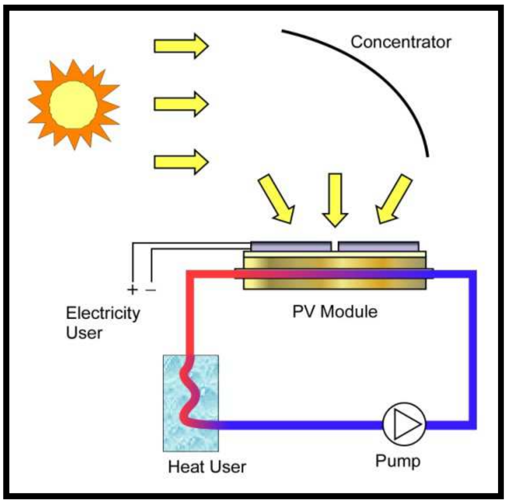

Fig 6. *Schematic diagram of Photovoltaic/thermal systems*

4.7. Solar Thermoelectric Cells

In recent years, interest in the development of solar thermoelectric systems has considerably increased [45]. 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. In this way the effects of different nanofluids with various mass flow rates on the efficiency of the solar thermoelectric cell can be studied (illustrated in Fig.7).

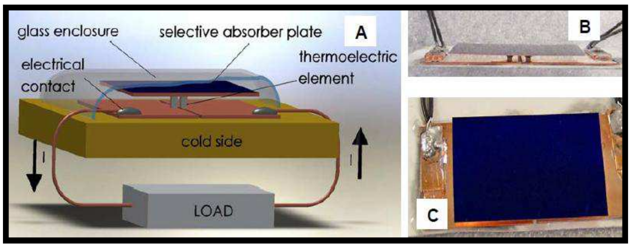

Fig 7. *Nanofluids based solar thermoelectric cells*

4.8. Thermal Conductivity of Nanofluids

Thermal properties of nanofluids very much depend on size as well as volume fraction of nanoparticles in the base fluid. The heat transfer characteristics of nanofluids also depend on the sonication time of nanoparticles and the quality of sonication used. So, as stated the higher value of thermal conductivity and thermo physical characteristics e.g. density, viscosity etc. enhance the heat absorption capacity, the specific heat capacity and heat carrying properties of nanofluids. It can be observed that same as the temperature difference collector efficiency of the nanofluid increases at lower volume fraction. Higher the volume concentration, higher will be the density, viscosity as well as heat capacity. It is known that thermal conductivity of solids is greater than liquids. Commonly used fluids in heat transfer applications such as water and ethylene have low conductivity when compared to thermal conductivity of solids especially metals. So the addition of solid particles in a fluid can increase the conductivity of liquids. When nanofluids are used as working fluids of the direct solar absorbers, the thermal properties of nanofluids are critical to the solar utilization. Photo thermal property is very important to the assessment of solar energy absorption of nanofluids because it directly reflects the solar absorption ability of nanofluids. Viscosity and rheological behaviors not only are essential parameters for nanofluid stability and flow behaviors but also affect the heat transfer efficiency of direct solar absorbers. Thermal conductivity is an important parameter for heat transfer fluids. It also affects the collectors' heat transfer efficiency. Great efforts have been made to the rheological behaviors and thermal conductivities of nanofluids, and these studies are helpful to research on nanofluids as solar absorption working fluids.

4.9. Electronic Applications

Due to higher density of chips, design of electronic components with more compact makes heat dissipation more difficult. Advanced electronic devices face thermal management challenges from the high level of heat generation and the reduction of available surface area for heat removal. Therefore, the reliable thermal management system is vital for the smooth operation of the advanced electronic devices. In general, there are two approaches to improve the heat removal for electronic equipment. One is to find an optimum geometry of cooling devices; another is to increase the heat transfer capacity. Nanofluids with higher thermal conductivities are predicted convective heat transfer coefficients compared to those of base fluids. Recent researches illustrated that nanofluids could increase the heat transfer coefficient by increasing the thermal conductivity of a coolant. Jang and Choi designed a new cooler, combined microchannel heat sink with nanofluids [46]. Higher cooling performance was obtained when compared to the device using pure water as working medium. Nanofluids reduced both the thermal resistance and the temperature difference between the heated microchannel wall and the coolant. A combined microchannel heat sink with nanofluids had the potential as the next-generation cooling devices for removing ultrahigh heat flux. Nguyen et al. designed a closed liquid-circuit to investigate the heat transfer enhancement of a liquid cooling system by replacing the base fluid (distilled water) with a nanofluid composed of distilled water and Al_2O_3 nanoparticles at various concentrations [47]. Silicon microchannel heat sink performance using nanofluids containing Cu nanoparticles was analyzed [48]. It was found that nanofluids could enhance the performance as compared to the use of pure water as the coolant. The enhancement was due to the increase in thermal conductivity of coolant and the nanoparticle thermal dispersion effect. The other advantage was that there was no extra pressure drop, since the nanoparticle was small, and particle volume fraction was low.

4.10. Energy Storage

The temporal difference of energy source and energy needs made necessary the development of storage system. The storage of thermal energy in the form of sensible and latent heat has become an important aspect of energy management with the emphasis on efficient use and conservation of the waste heat and solar energy in industry and buildings [49]. Latent heat storage is one of the most efficient ways of storing thermal energy. Wu et al. evaluated the potential of Al_2O_3-H_2O nanofluids as a new phase change material (PCM) for the thermal energy storage of cooling systems. The thermal response test showed the addition of Al_2O_3 nanoparticles remarkably decreased the super cooling degree of water, advanced the beginning freezing time, and reduced the total freezing time. Only adding 0.2 wt% Al_2O_3 nanoparticles, the total freezing time of Al_2O_3-H_2O nanofluids could be reduced by 20.5%. Liu et al prepared a new sort of nanofluid phase change materials (PCMs) by suspending small amount of TiO_2 nanoparticles in saturated $BaCl_2$ aqueous solution [50]. The nanofluids PCMs possessed remarkably high thermal conductivities compared to the base material. The cold storage/supply rate capacity increased greatly than those of $BaCl_2$ aqueous solution without adding nanoparticles. The higher thermal performances of nanofluids PCMs indicate that they have a potential for substituting conventional PCMs in cold storage applications. Copper nanoparticles are efficient additives to improve the heating and cooling rates of PCMs [51]. For composites with1wt%copper nanoparticle, the heating and cooling times could be reduced by 30.3 and 28.2%, respectively. The latent heats and phase-change temperatures changed very little after 100 thermal cycles.

4.11. Solar Absorption

Solar energy is one of the best sources of renewable energy with minimal environmental impact. The conventional direct absorption solar collector is a well-established technology, and it has been proposed for a variety of applications such as water heating; however, the efficiency of these collectors is limited by the absorption properties of the working fluid, which is very poor for typical fluids used in solar collectors. Recently, this technology has been combined with the emerging technologies of nanofluids and liquid-nanoparticle suspensions to create a new class of nanofluid-based solar collectors. Otanicar et al. reported the experimental results on solar collectors based on nanofluids made from a variety of nanoparticles (CNTs, graphite, and silver) [52]. The efficiency improvement was up to 5% in solar thermal collectors by utilizing nanofluids as the absorption media. In addition, the experimental data has been with a numerical model of a solar collector with direct absorption nanofluids. The experimental and numerical results demonstrated an initial rapid increase in efficiency with volume fraction, followed by a leveling off in efficiency as volume fraction continues to increase. Theoretical investigation on the feasibility of using a non-concentrating direct absorption solar collector showed that the presence of nanoparticles increased the absorption of incident radiation by more than nine times over that of pure water [53]. Under the similar operating conditions, the efficiency of an absorption solar collector using nanofluid as the working fluid was found to be up to 10% higher (on an absolute basis) than that of a flat-plate collector. Otanicar and Golden evaluated the overall economic and environmental impacts of the technology in contrast with conventional solar collectors using the life-cycle assessment methodology [54]. Sani et al investigated the optical and thermal properties of nanofluids consisting of aqueous suspensions of single-wall carbon nanohorns [55]. The observed nanoparticle-induced differences in optical properties appeared promising, leading to a considerably higher sunlight absorption. Both these effects, together with the possible chemical functionalization of carbon nanohorns, make this new kind of nanofluids very interesting for increasing the overall efficiency of the sunlight exploiting device.

5. Conclusion

Solar energy is one of the cleaner forms of renewable energy resources. The conventional solar collector is a well established technology which has various applications such as water heating, space heating and cooling. However, the thermal efficiency of these collectors is limited by the absorption properties of the working fluid, which is very poor for typical conventional solar flat plate collector. Recently, usage of nanofluids, which is basically liquid-nanoparticle colloidal dispersion as a working fluid has been found to enhance the thermal efficiency of solar flat plate collector by 30 percent. 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 solar energy applications. This paper presents an overview of the recent developments in the study of nanofluids, including the preparation methods. From the economic and environmental point of view, the review showed that using nanofluids in collectors leads to a reduction in CO_2 emissions and annual electricity and fuel savings. Many researchers have reported, works on the applications of nanofluids in solar cells, solar thermal energy storage, and solar stills are also reviewed. Hence it will be a promising effort to develop research projects on the use of nanofluids in different solar systems such as solar absorption, solar thermoelectric cells, and thermal conductivity of nanofluids, electronic applications, energy storage and solar absorption.

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