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Performance Evaluation of Nano-Fluids in Solar Thermal and Solar Photovoltaic Systems

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Abstract*: The primary purpose of this paper is to offer a thorough analysis of the use of nanofluid in solar photovoltaic thermal (PV/T) systems, focusing on the importance of carefully selecting nanofluid parameters like concentration ratio, volume flow rate, volume fraction, high thermal conductivity, high rate of heat transfer, etc. This study focuses on the effects of nanomaterials on the thermal conductivity (k), latent heat, subcooling, phase change duration, phase change temperature, viscosity, and density of PCMs across a wide range of operating temperatures. This research is expected to shed light on the PV/T systems' underpinnings and popular conceptions, which in turn will improve the thermal performance of PV/T systems based on nanomaterials and combined with PCM or NEPCM. Incorporating nanofluids and NEPCM into a solar photovoltaic thermal system boosts the system's thermal, electrical, and overall efficiency.*

Keywords: Nanofluids, Solar energy, Renewable energy, Solar Photovoltaic-thermal system

I. INTRODUCTION

The ever-increasing number of people in the world necessitates ever-increasing amounts of resources, including power, water, shelter, energy, fuel, and food. The sun is the most accessible and widely available energy source on Earth. Solar energy (SE) has emerged as the leading renewable option when it comes to meeting the world's ever-increasing energy needs. As a result, the SE is seen as potentially fruitful because it ensures several extra benefits, such as lowering the need for fossil fuels, slowing the climate change rate, and so on (1). Since it doesn't pollute the air or water like traditional power plants, a photovoltaic cell can be used for various tasks. The photovoltaic system's numerous benefits include its simplicity, the absence of harmful greenhouse gas emissions, and the lack of groundwater pollution, the absence of fuel consumption, low maintenance cost, long life expectancy, portability, and reliability of the system (2, 3). As a result of the increased surface temperature (PVT module), the PV modules can become dangerously hot to the touch during the summer and in hot locations. The panel's lifespan is shortened by thermal stresses in the PV module brought on by an increase in (PVT module), and its ability to generate energy is diminished as a result (4). Using a non-combustible fluid that runs under the PV panel and acts as a heat exchanger, the thermal efficiency of the system is improved by lowering the temperature of the PV cells and reducing heat loss. Photovoltaic thermal (PV/T) systems are able to provide both thermal and electrical energy at the same time (5, 6). Water and oil, two common traditional fluids, are inefficient in solar photovoltaic thermal (PV/T) systems due to their low thermal conductivity and heat carrying capacity (7,8). Therefore, scientists and researchers are concentrating on making use of a novel fluid with increased thermal conductivity and heat-carrying capability. With these qualities, nanofluids are the top pick for a solar photovoltaic heating system. Researchers and scientists are concentrating on solar photovoltaic thermal (PV/T) systems that use nano-enhanced phase transition materials (9,10).PCM Paraffin wax has a large amounts of heat and storage over a broad temperature range, It's inexpensive, harmless, and eco-friendly; making it ideal for use in heat storage applications (11). The PCM's performance degradation over time is one of its disadvantages. The considerable increase in heat transfer rate owing to nanoparticles significantly raises the total recovered energy from the PCM (12). When added to paraffin wax, nanoparticles help increase recovered exergy by speeding up the solidification process, and the paraffin wax's thermophysical properties do not change after being subjected to 30 heating/cooling cycles (13).In order to provide a comprehensive overview, this review paper will focus on applying nanofluids and nano-enhanced phase transition materials in solar photovoltaic thermal (PV/T) systems. Nanofluids, phase-change materials, and neutrally charged phase-change materials (NEPCM) are all explored in depth, as are the impacts of various parameters on the thermal efficiency, electrical efficiency, and overall efficiency of PV/T systems.

Nanofluids

Many scientists define nanofluids as a combination of nanoparticles with diameters between 1 and 100 nm dispersed efficiently in a base fluid such as water, thermal oil, ethylene glycol, and many others [14, 15]. Nanofluid characteristics like viscosity, thermal conductivity, heat transfer coefficient, specific heat, and heat capacity all contribute significantly to the overall efficiency of the system. High thermal conductivity nanofluids improve heat transfer and, in turn, system efficiency [16, 17]. There are three main ways to categorize nanoparticles: (i) according to the metals, (ii) according to the carbons, and (iii) as nanocomposites. Figure 1 displays the nanoparticle classification scheme in great detail [18, 19]. The nanocomposites are the most effective at improving the base fluid's thermophysical properties, as their high thermal conductivity and heat-carrying capacity make them the most ideal of the three. The overall property of the system is improved due to the improved thermophysical characteristics, which reduces the operating cost of the system [20]. This is because nanofluids may soak up the excess solar energy that photovoltaic cells can't use, bringing the temperature down of the cells. As a result, nanofluids may serve as an optical filter for PV cells [21, 22, and 23]. Nanofluids present a problem because, compared to other fluids, the cost of producing and preparing nanofluids is relatively high [24]. Agglomeration of nanoparticles causes unstable behavior in nanofluids, lowering system performance [25]. Figure 2 is an SEM image depicting the aggregation of CuO nanoparticles under experimental conditions [26, 27]

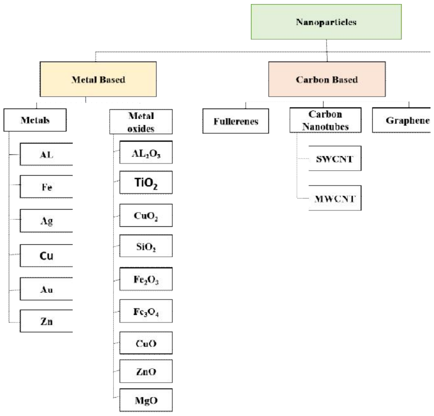

Fig.1.Nanoparticles and their categorization [19].

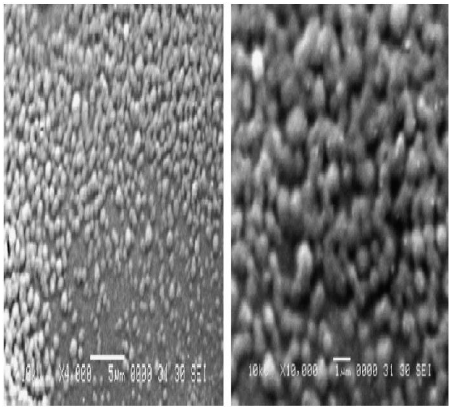

Fig. 2. Visualization of CuO nanoparticle Agglomeration through SEM [27].

Stability of nanofluid

As we've already established, nanofluid has better heat conductivity than conventional working fluid. The high thermal conductivity of the dispersed nanoparticles inside the lower thermal conductivity base fluid is responsible for the remarkable increase in the thermal conductivity of the colloidal suspension. The thermal conductivity of nanofluids declines, leading to a loss of performance when the nanoparticles agglomerate or separate from the base fluid due to the sedimentation of nanoparticles [28]. As a result, nanofluid stability is likely to be the most important factor to tweak. Figure 3 [29] illustrates the connection between the thermal conductivity of nanofluids and their stability. The stability of a colloidal suspension of nanofluids depends on three factors: the dispersion stability, the chemical stability, and the kinetic stability.[30]. When nanoparticles are suspended in a fluid, their dispersion stability determines how easily they will clump together. Chemical stability refers to the nature of the reaction that takes place between the nanoparticles and the surrounding liquid. When creating nanofluids at temperatures well below the chemical reaction temperature, for example, chemical stability can be ignored. The kinematic stability is a result of the dynamic motion, also called the Brownian motion, of nanoparticles scattered in the base fluid. Nanofluids thermophysical parameters (temperature, viscosity, density) and the type of surfactant used all have an impact on all three types of nanofluid stability (dispersion, chemical, and kinetic) [31]. For this reason, maintaining the integrity of nanofluids is a significant challenge for the scientific community. New methods for assessing nanofluid stability are now being developed by researchers and scientists. (i) Scanning electron microscopy, (ii) transmission electron microscopy, (iii) zeta potential, (iv) x-ray diffraction, (v) thermal gas analysis, (vi) differential scanning calorimetry, and (vii) femtosecond Fourier transform infrared spectroscopy [32–36]. TEM images of CuO nanoparticles are displayed in Fig. 4. Figure 4 shows that the stability of the nanofluids is clearly demonstrated by the reduced aggregation of the generated CuO nanoparticles and the uniform distribution of the nanoparticles.

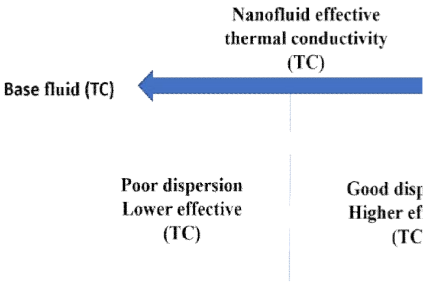

Fig. 3. Correlation between nanofluid stability and their thermal conductivity. [29].

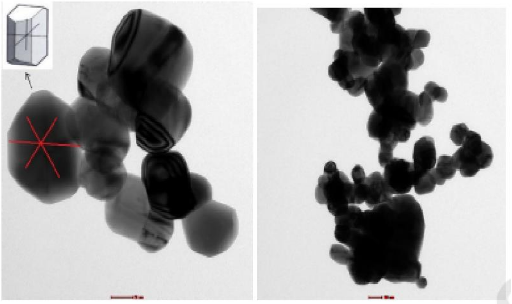

Fig. 4. TEM of CuO nanoparticles [37].

Nanofluid Preparation

Nanofluids are fluids with solid particles on the nanoscale scale dispersed throughout a liquid medium (liquid). Nanofluids can be prepared in two ways: Both a one-step and a two-step procedure. The two-step method is the most popular because it is easy to implement and inexpensive. First, the particles are made, and then they are dispersed in the base fluid shown in fig. 5. In a PV/T system based on nanofluids, the water would be replaced by the nanofluid. This is because the improved heat transfer provided by a PV/T collector is made possible by the superior thermophysical characteristics [38] of these fluids. Increased thermal and electrical efficiency is the result. The first step of the two-stage process is to collect the solid nanoparticles, typically in the form of a dry powder. After that, you'll need either sonication tools or a magnetic stirrer to mix the nanoparticles with the base fluid. Produced nanoparticles have a high surface activity, which causes them to be aggregated. To avoid undesirable outcomes like agglomeration and sedimentation, using a sonicator, such as an ultrasonic probe, is recommended for mixing. To achieve a stable, uniform, and continuous suspension [39], The nanofluid solution needs to be sonicated for long periods of time, typically 80 to 100 minutes, using ultrasonic shakers or vibration. To increase the nanofluid's thermal conductivity and stability, surfactant, also known as a dispersant, should be included [40]. Figure 6 depicts the procedure for the two-stage method, while Figure 7 depicts an ultrasonic shaker and a probe sonicator. Sardarbadi et al. [41] tested the effects of utilizing silica/water nanofluids as a coolant in a photovoltaic thermal unit (PV/T) to improve its thermal and electrical performance. The experiment utilized nanofluid concentrations of 1 wt% and 3 wt%. They discovered that a PV/T system operating with a 1 wt% silica/water nanofluid was 3.6% more efficient than one operating with pure water. Adding 3 weight percent of silica to water creates a nanofluid that increases overall efficiency by 7.9 percent. They found that increasing the silica/water nanofluid concentration from 1% to 3% increased the PV/T system's thermal efficiency by 7.6% and 12.8%, respectively. They found that adding a collector to a PV/T system boosted system exergy by 19.36%, 22.6%, and 24.3% when using pure water, 1 wt% silica/water nanofluid, and 3 wt% silica/water nanofluid, respectively. Hashim et al. [42] conducted experiments with Al_2O_3/water nanofluid as a coolant to test the electrical and thermal efficiency of a hybrid photovoltaic thermal system. At a constant mass flow rate of 0.2 l/s, they employed nanofluids of concentrations ranging from 0.1% to 0.5%. At a concentration ratio of 0.3, the solar panel's efficiency rises by 12.1% as the temperature drops to 42°C, but efficiency drops to 11.3% if the temperature of the PV system rises to 52°C. Khanjari et al. [43] employed an Ag/H_2O and Al_2O_3/H_2O nanofluid to analyze the fluid dynamics of a photovoltaic system. They concluded that increasing the nanoparticle volume percent improved system efficiency and the heat transfer coefficient. Compared to Al2O3/H2O, the increase in electrical efficiency of the system is greater for the Ag/H2O nanofluid scenario. The same author has also looked at how solar thermal photovoltaic systems interact with their natural surroundings [44]. Solar photovoltaic thermal system electrical efficiency was shown to decline with increasing solar radiation and fluid inlet temperature, while thermal efficiency was found to be relatively unaffected. They concluded that the Al2O3/H2O nanofluid used in the photovoltaic thermal system had higher electrical efficiency than plain water. Michael et al. [45] performed experiments on a solar photovoltaic thermal system using CuO and water nanofluids. The volume fraction of the nanofluids was 0.05%. Silicon cells have a thin copper sheet applied to them in place of the Tedlar layer. The electrical and thermal efficiency of the solar PV/T system experiments were run both with and without glazing. Fig. 8 depicts the experimental setup employed in this work. This study found that compared to using plain water as the "base fluid," glazing and nanofluid boosted thermal efficiency by 45% while decreasing electrical efficiency by 3%. Using Al2O3 as a nanofluid and paraffin wax as a phase change material, tested the efficiency of a solar photovoltaic system. They have set up three different configurations for testing: (i) a base fluid as a control, (ii) a PCM layer attached to the back of the photovoltaic thermal system, and (iii) a combination of the two. Compared to the reference configuration, they found that the third configuration improved PV/T system efficiency by 13.2%. The second setup is more efficient by around 5.7 percent.

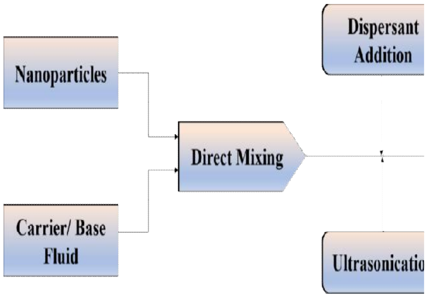

Fig. 5 Two-stage method methodology [38]

Fig. 6 Simulated, actual, and prepared silica nanofluid (a) before, (b) after, and (c) during an experiment. [39]

Fig. 7 Ultrasonic bath shaker [39]

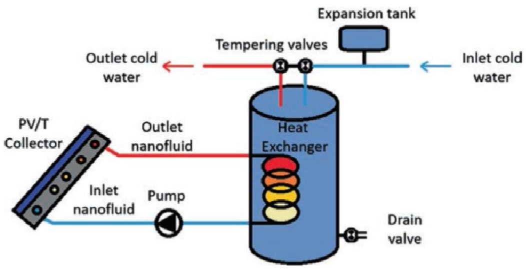

Fig. 8. Typical layout of a nanofluid-based PV/T system [45]

II. CONCLUSION

This research review paper offers a concise synopsis of current studies on solar power. The following are the findings of this review.

A hybrid PV and solar thermal system (PV/T) is a promising technology because photovoltaics (PV) alters the ultraviolet and visible parts of the solar spectrum. And while the solar thermal system used the sun's waste heat and the infrared spectrum, the PV system produced more energy than it needed. To summarize, a PV/T system is preferable to two separate electrical and thermal systems.

The increase in backside temperature of PV modules when exposed to solar irradiation is greatly attenuated in PV/T systems with a PCM layer, as compared to those without one..

By increasing the thermal conductivity of the base fluid, nanofluid is used to cool the cell of the PV/T system, resulting in greater electrical efficiency.

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