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USE OF CARBON NANOTUBES IN FLAT AND EVACUATED TUBE SOLAR COLLECTORS FOR THERMAL ENHANCEMENT: A REVIEW

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Abstract

Solar thermal collectors (STCs) are pollution-free and can be found in many parts of the world makes them a possible solution for both heating and cooling environments. The optimization of energy conversion is dependent on the improvement of the thermal efficiency of STCs. In light of this, the objective of this article is to present an overview of the utilization of carbon nanotubes (CNTs) for the aim of improving thermal performance in evacuated tube and flat plate solar thermal collectors from a technical standpoint. In accordance with the findings of the research that was carried out earlier, it was found that the utilization of carbon nanotubes (CNTs), both single-walled and multi-walled, was demonstrated to boost the efficiency of a solar thermal collector that was not evacuated and was flat. This article presents an in-depth investigation into the impact that carbon nanotubes (CNTs) could have on the prospective applications of STCs in flat and evacuated tube configurations.

Keyword: Carbon nanotubes; Solar energy; Flat plate solar collector; Evacuated tube solar collector; Thermal performance.

Nomenclature

SE	Solar energy
FPSC	Flat plate solar collector
ETSC	Evacuated tube solar collector
SAH	Solar air heater
SWH	Solar water heater
SWHS	Solar water heating syatem
STC	Solar thermal collector
ET	Evacuated tube
SC	Solar collector
AP	Absorber plate
HT	Heat transfer
TP	Thermal performance
NF	Nanofluid
h_t	Heat transfer coefficient
CNTs	Carbon noao tubes
MWCNTs	Multi-walled carbon nanotubes
SEM	Scanning electron microscopy
TEM	Transmissiom electron microscopy
η	Efficiency
η_c	Collector efficiency
η_c	Thermal efficiency

1. Introduction

Among all the renewable energy sources that are currently available all over the world, solar energy is the one that offers the greatest number of benefits and has the most potential. Through the utilization of photovoltaic cells as well as concentrating and non-concentrating solar collectors, it is able to transform solar energy into heat energy and electrical energy, respectively [1-2]. The SAH and SWH are two types of flat plate collectors that are utilized for low-temperature applications (below 100 degrees Celsius). These applications include crop yields, sun drying, room and water heating, and more. Both SAH and SWH have a number of drawbacks, the most significant of which are an insufficient heat transfer (HT) between the fluid and the absorber surface and an interrupted energy supply as a consequence of the intermittent nature of solar radiation. An investigation into the numerous roughness components, such as ribs, winglets, baffles, and so on, was carried out with the purpose of enhancing the HT. The roughness components provide the role of an extended surface, thereby increasing the surface area of the absorber plate that is in contact with the fluid in order to facilitate heat transfer. Additionally, the roughness elements that cause an increase in the intensity of turbulence and the reattachment effect, which causes the thermal boundary layer along the absorber surface to be broken [3-11].

In addition to the use of artificial roughness, there are also other effective methods that have been recommended for improving heat transmission. These methods include the utilization of jet and corrugated plates within the duct (SAH), which both increase the surface area for heat transfer and interrupt the laminar sub-layer. The use of the jet impingement strategy has been shown in a number of studies to improve the performance of the SAH. This approach results in the formation of a thin stagnant boundary layer and increases the amount of heat transfer that is confined near the stagnation zone of the impinging air jet. There have been a great number of studies that have been published that change the jet impingement method in order to raise the ht [12-18].

An STC that has a lot of potential is the ETSC, which is capable of managing a variety of different applications. One of the reasons for this is that it is capable of reaching temperatures that are even greater than one hundred degrees Celsius by utilizing a wide range of various fluids. Because of this, it is able to function with a diverse assortment of different systems. To ensure that the biggest amount of heat energy that is accessible at the absorber's inner surface is extracted, it is a well-established fact that when utilizing an ETSC with one end, one must employ a guiding mechanism that is both effective and efficient. This is necessary in order to ensure that the maximum amount of heat energy is extracted. The number of studies that have been conducted in this field is quite low; hence, a number of guiding techniques have been incorporated in order to boost the rate of heat transmission [19-21]. The most recent discoveries about the application of carbon nanotubes in SCs are presented in this article.

Carbon nanotubes (NFs) have been the subject of extensive research, with the primary objective being the creation of systems that provide enhanced heat transmission. According to the type of nanoparticles and the concentration that are utilized, the enhancement may either be in the applications for heating or cooling, depending on the specifics of the situation. The boost could be in either the cooling or heating applications, depending on the type of nanoparticles that are used and the concentration that is utilized. The use of nanofluid is required in a number of different areas of research, including those that include solar energy studies. Solar energy conversion can be classified as either solar thermal energy conversion, which involves the utilization of solar collectors, or solar electric energy conversion, which involves the utilization of solar photovoltaic panels to generate electric current. Both of these classifications are conceivable. According to the entirety of the research that was examined for this work. For the purpose of thermal argumentation, only a few research have documented the use of carbon nanotubes (CNTs) placed on flat plates and evacuated tube collectors. The research on solar energy that is based on CNT is still in its initial stages. The authors anticipate that this work will be beneficial in understanding the parameters that impact the thermal performance of these collectors, as well as the possible applications of hybrid carbon nanotubes (CNTs), which will have the effect of increasing the heat transfer (HT) in flat and ETSCs. The application of carbon nanotubes in evacuated and FPSCs is the only topic that will be covered in this review article on carbon nanotubes.

2. CNTs - Based Flat Plate Solar Collector

More than sixty years ago, the technology behind FPSCs was conceptualized. When it comes to other types of solar collectors, this practice is typical. Due to the fact that it is simple to operate and maintain, it is utilized extensively in the heating of air and water in both commercial and residential settings. Furthermore, the FPSTC's thermal efficiency is rather low due to the fact that the working fluid, which is the heat transfer fluid, has a low thermal conductivity. Figure 1 is an illustration of the performance analysis that Kim et al. [22] provided for an FPSC collector through their demonstration. To achieve the highest possible level of efficiency in terms of production costs, the glazing and absorber layers of the collector were developed with polymer materials that were not only affordable but also easily accessible and recyclable. Through the process of impregnating the polycarbonate with carbon nanotubes (CNTs), the optical and thermal properties of the polymers were enhanced. The findings of the experimental tests established that the incorporation of carbon nanotubes (CNTs) resulted in a substantial enhancement of the thermal performance of the polymer SCs and an improvement in the absorber's efficiency.

Fig. 1. Proposed PC + CNT solar collector [22].

In order to achieve the highest possible level of performance from the indirect sun dryer, Abdelkader et al. [23] make use of a shell and tube storage unit combined with an efficient SAH and paraffin wax that has been improved by carbon nanotubes (CNTs) to increase its heat conductivity. (Figure 2)... The results demonstrate that the thermal efficiency of the first and second trials consume a particular amount of energy, which is 6.545 kWh/kg and 30%, respectively. Taking this into consideration, it can be concluded that the dryer's overall thermal efficiency will improve as the amount of material being dried increases.

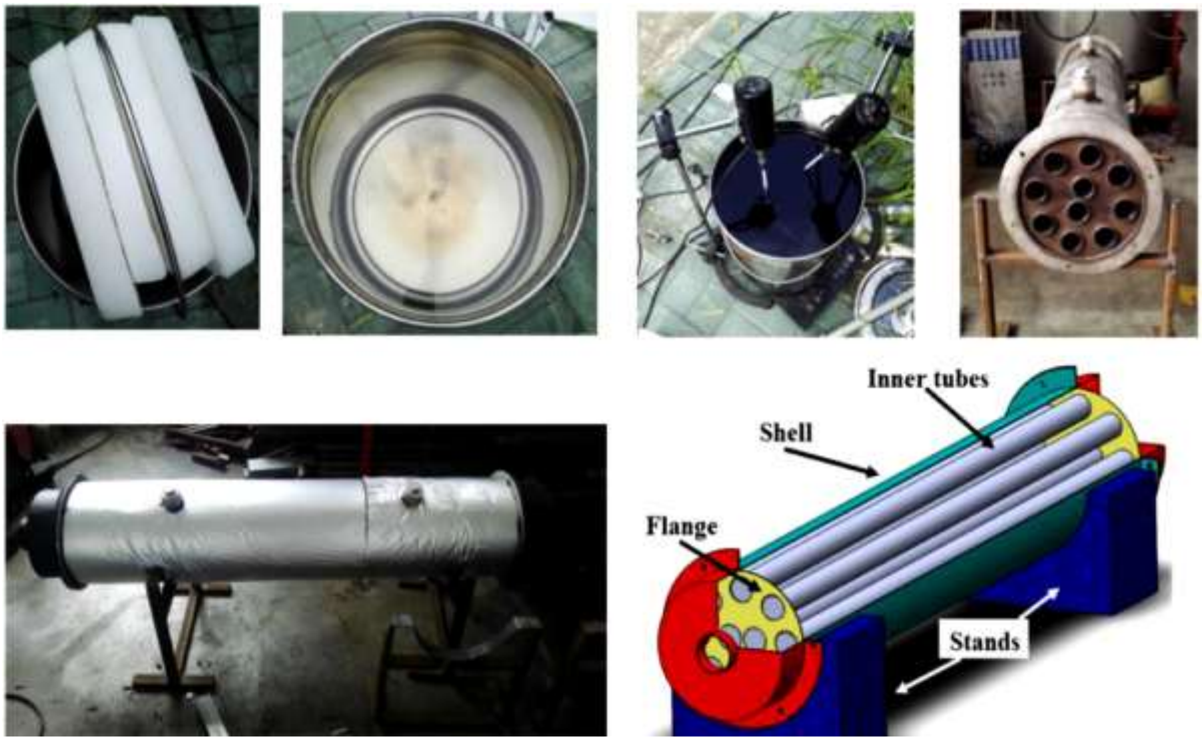

Fig. 2. Paraffin wax prepared for storage unit loading and diagrammatic and real shell-and-tube storage device [23].

Fan et al. [24] establish a straightforward and PCM-based SWHS that makes use of fins and MWCNTs in order to boost both heat transfer and light absorption. In research on photothermal conversion, the system that consists of PCM with multi-walled carbon nanotubes and fins is able to achieve a temperature of 70 degrees Celsius in the water. This represents an increase of 58.6% and 55.2%, respectively, in comparison to the original composite and the MWCNT-doped composite. According to analytical models, fins act as an interface between phase change material (PCM) and water, which speeds up the transmission of heat and increases the amount of thermal energy that can be stored for efficient SWHS. The proposed system is capable of keeping the water temperature at or above 40 degrees Celsius for a period of 51 minutes at a flow rate of 11.34 liters per hour. In the presence of ambient cooling, with an impressive efficiency of 89.2%, outperforming both FPSCs and ETSCs in terms of efficiency. The procedure for the preparation of PCCs is illustrated in Figure 3.

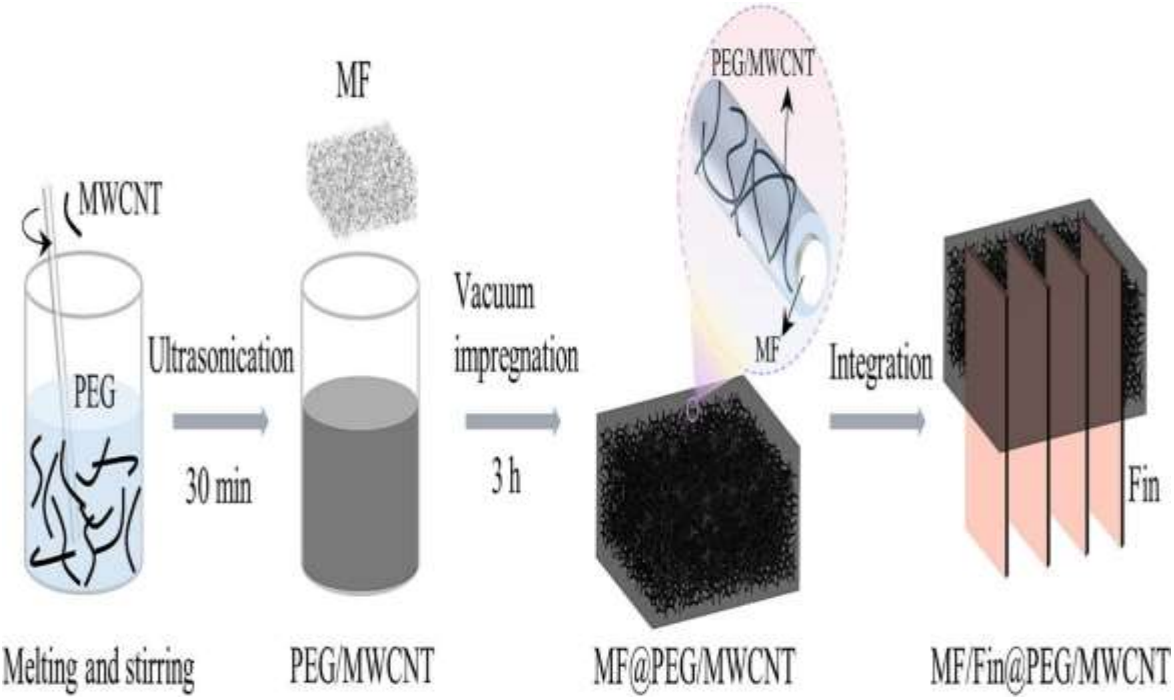

Fig. 3. Schematic of PCCs preparation [24].

According to Kumar et al. [25], a new hybrid system has been discovered that is capable of simultaneously heating water and air. This system also serves the dual goal of delivering both of these heat sources, as depicted in Figure 4. A procedure known as pressure shot blasting was utilized in order to roughen the inside surface of the rectangular duct that was constructed of aluminum in the SAH and the copper AP in the SWH. This was done in an effort to increase the total pressure. A further improvement in the performance of the convective heat transfer was achieved with the combination of solar glycol (SG) and MWCNTs focused nanofibers (NFs). The SEM and TEM images of the MWCNTs that were implanted in the virgin SG are displayed to the right in Figures 5a and 5b, respectively.

Fig. 4. Pictorial illustration of a hybrid SAH and SWH [25].

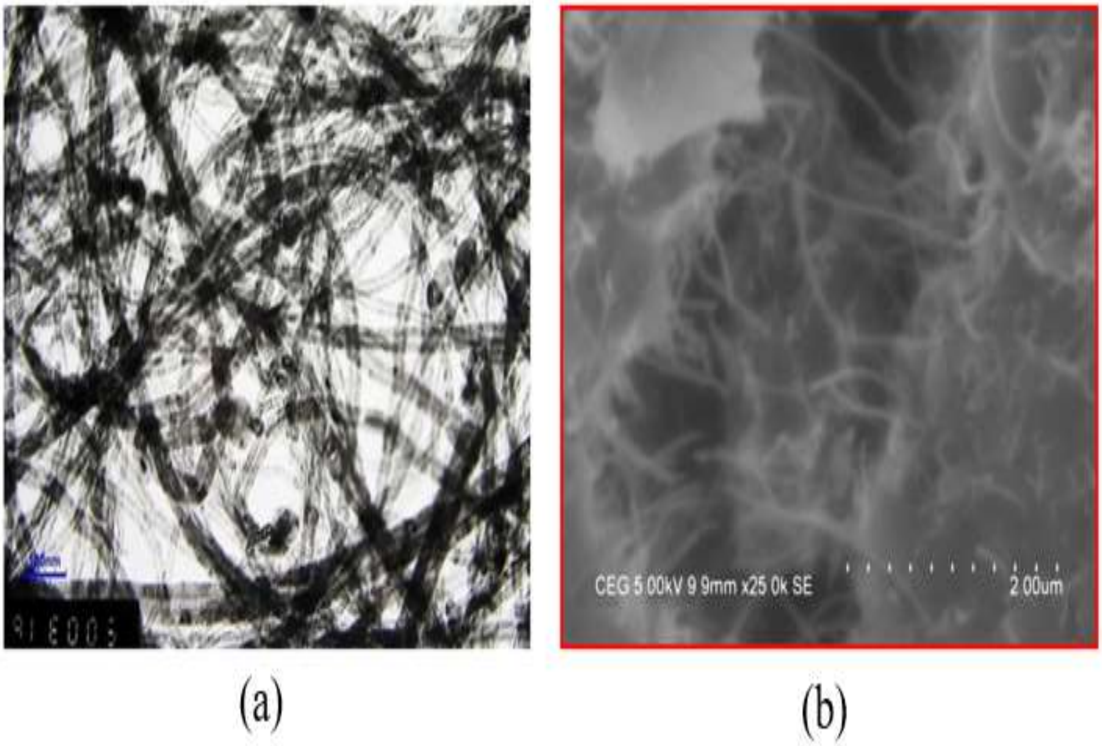

Fig. 5. (a) TEM picture of MWCNT (b) SEM picture of MWCNTs dispersed in SG (0.2 vol%) [25].

A new solar-selective coating that is light emitting and highly absorbent to solar radiation is used by Abdelkader et al. [26] to improve the TP of a solar-absorbent hybrid (SAH). This coating is constructed of carbon nanotubes (CNTs) and cupric oxide nanoparticles (CuO) that are embedded in black paint (Fig. 6). The data indicate that the 4% CNTs/CuO-black paint is the most solar selective of all coatings. This is because its solar absorptance and thermal emittance both reach 0.964 and 0.124, respectively.

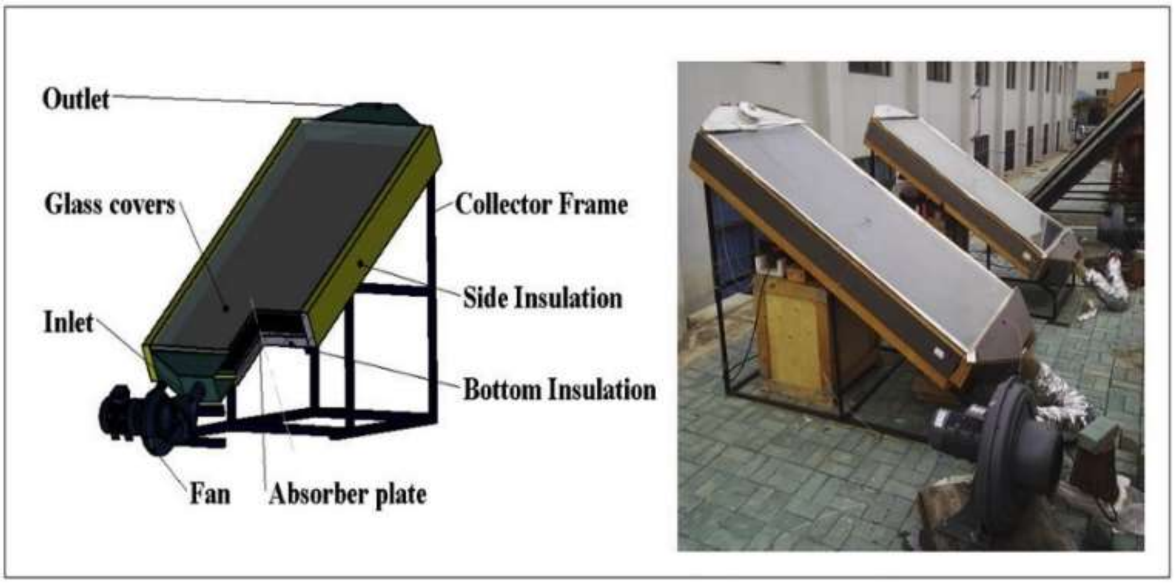

Fig. 6. Illustration, both schematic and pictorial, of the SAH [26].

Pugsley et al. [27] conducted an investigation into the effectiveness of solar water heating collectors (Fig. 7) that were made up of asphalt (ACNT) and Senergy polycarbonate (PCNT) carbon nanotubes. The investigation was conducted under controlled sunlight simulation settings. The unglazed ACNT collector was shown to be less effective in collecting than the single-glazed PCNT collector, which was proved to be more effective in every test scenario.

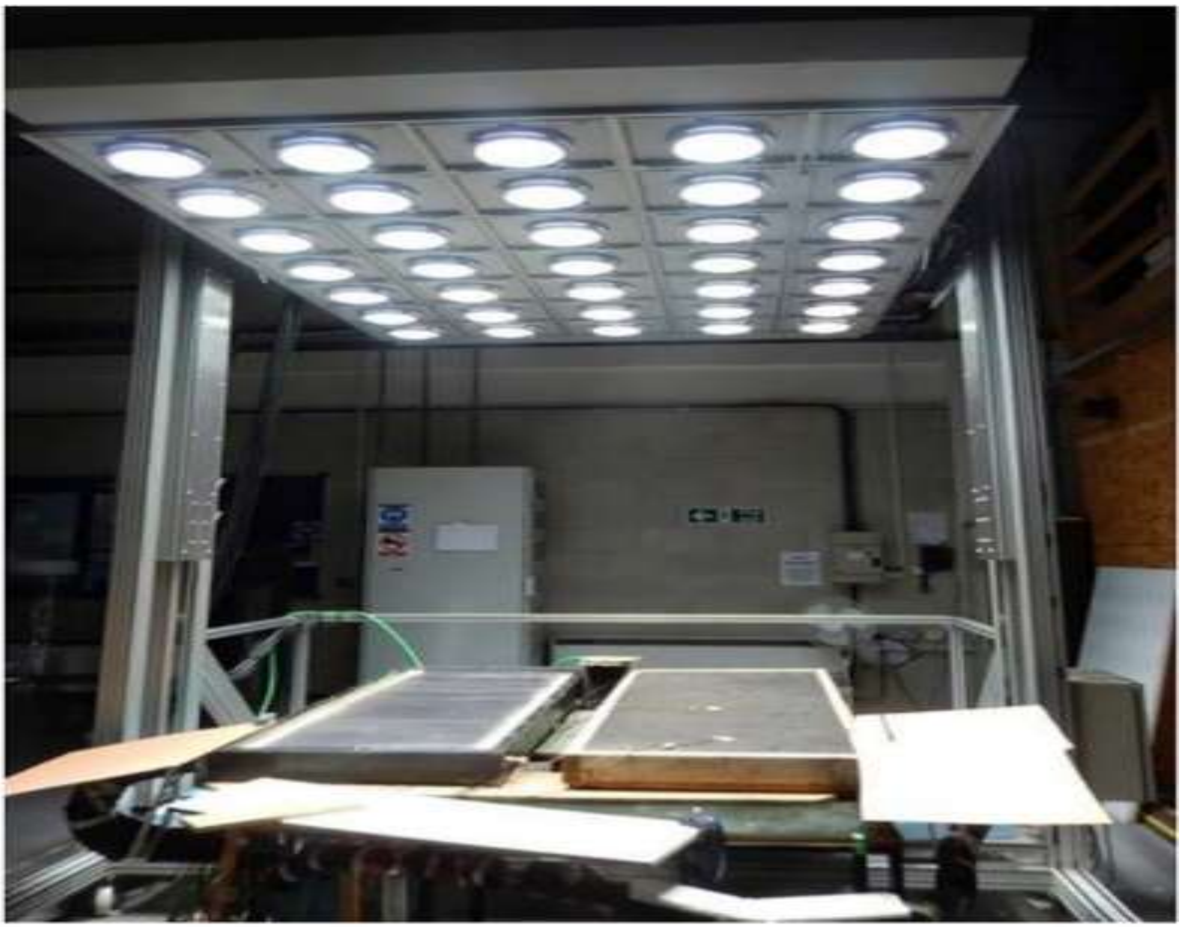

Fig. 7. Picture displaying the PCNT (left) and ACNT (right) collectors being examined under the solar simulator [27].

In order to investigate the TP of FPSCs, Hussein et al. [28] investigated the water-based CF-MWCNTs@TiO2 hybrid NF as well as its independent mono NFs. The results were compared with the base fluid. A comprehensive investigation was carried out in order to get a better understanding of how the hybrid NF influenced the FPSC's η_t under different fluid flow conditions. The findings demonstrated that the optimal conditions were satisfied by employing only "0.1 wt%" of TiO2/CF-MWCNTs and with a m_f of around 4 LPM. This resulted in a significant 84% increase in the efficiency of the FPSC. Figure 8 provides a comprehensive illustration of the molecular structure of the mixed nanoparticles that should be viewed.

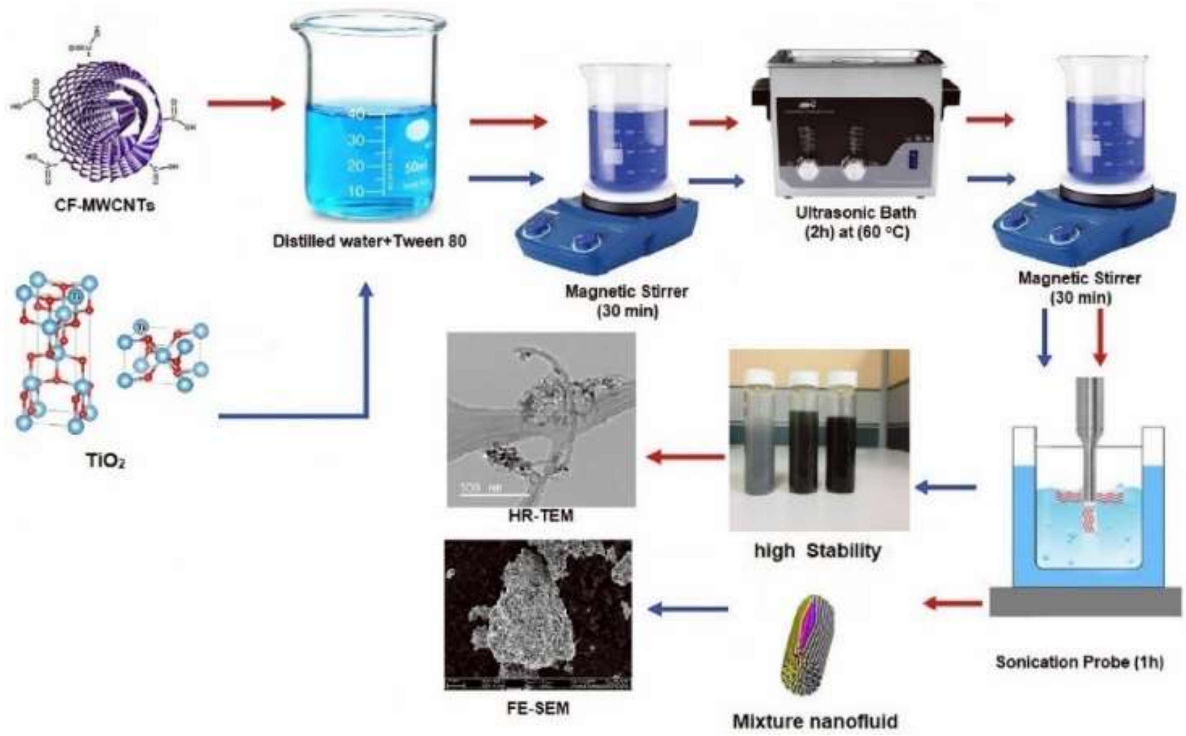

Fig. 8. Image of the TiO_2@MWCNTs nanocomposite mixture followed by the creation of nanofluid [28].

It is intended for use in the climate of Baghdad, Iraq during the winter months, and Habib et al. [29] provides a design for a SAH that is straightforward, effective, and cost-effective. In Baghdad, the average temperature during the summer months is between 38 and 58 degrees Celsius, while the average temperature during the winter months is between 0 and 10 degrees Celsius. Consequently, a SAH that utilized a composite material consisting of paraffin wax and CNTs with improved thermal conductivity was assessed in the winter conditions of Baghdad city. This evaluation allowed for the evaluation of the SAH. One of the waste products that has been added to the SAH is aluminum chip, which is a waste product of the forming processes. The shape of this chip is that of a multitude of little fragments. CNTs are coupled with locally produced paraffin that is supplied at a low price, which results in the creation of a novel approach that makes use of the latent heat of fusion and high thermal conductivity that is produced as a result of this combination.

3. CNTs - Based Evacuated Tube Solar Collector

The solar thermal collectors (STCs) are responsible for capturing solar radiation, which is then converted into thermal energy and transferred to an operating fluid once the process is complete. Because they are easy to move and can be set up in a short amount of time, the ETSCs provide great thermal performance. Additionally, they lose less heat than other cooling systems. Additionally, ETSCs are suitable for usage in circumstances that are not conducive to their overall performance. The vacuum that exists between the glass tubes in an ETSC serves to reduce the amount of conduction and convection losses, which in turn enables the collector to perform effectively at higher temperatures, as demonstrated in Figure 9 [30].

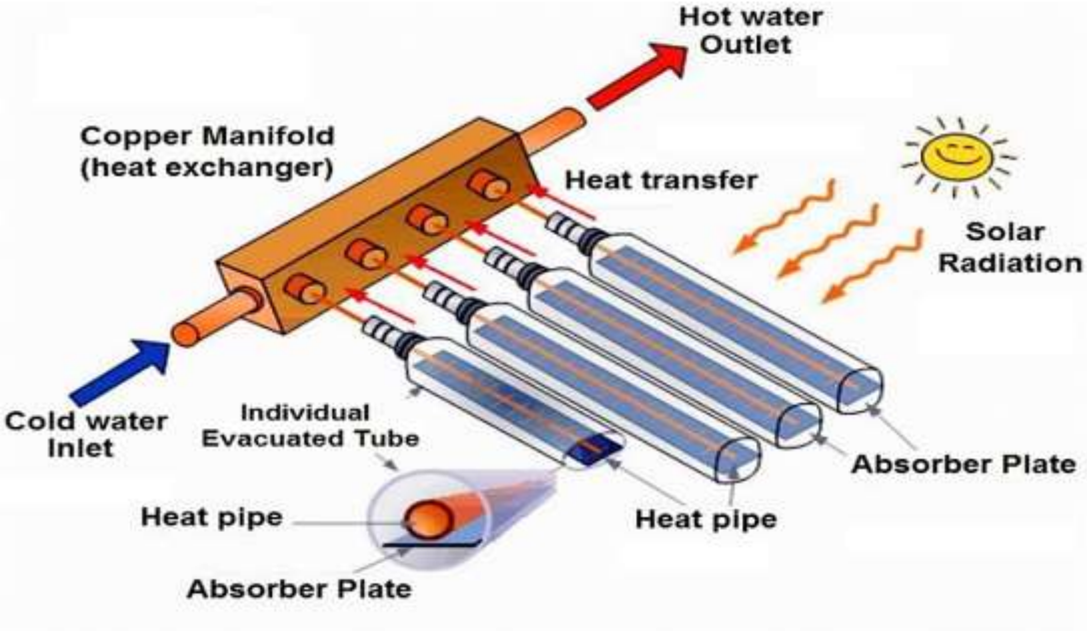

Fig. 9. Arangement of ETSC [30].

Through the utilization of MgO/MWCNT hybrid nanofluid, Henein and Abdel-Rehim [31] conduct an experimental investigation to investigate the energetic and exergetic η of the ETSC (Fig. 10). It has been discovered that significantly increasing the weight ratio of MWCNTs nanoparticles from 20% to 30% results in a significant enhancement of the improvement in η_c when compared to other hybrid nanoparticles. The results demonstrate that MgO/MWCNT (50:50) has improved performance at the entire m_f region and exhibits behavior that is more similar to that of MWCNT/water NF.

Fig. 10. ETSC [31].

Sabiha et al. [32] conducted an experiment to investigate the impact that single-walled carbon nanotubes (CNTs) based on water have on the thermal conductivity (TP) of an electrothermal sonic converter (ETSC) (Fig. 11). According to the findings, the utilization of single-walled carbon nanotubes (CNTs) with nanofluids as the working fluid, rather than water, resulted in an increase in the η_c. The greatest η value of 93.43% was observed for 0.2 vol.% single walled carbon nanotubes (CNTs) nanofibers when the m_f was 0.025 kg/s.

Fig. 11. ETSC [32].

A theoretical investigation into the application of MWCNT/water nanofluid in an ETSC (enclosed-type) was carried out by Tong et al. [33], as depicted in Figure 12. Based on the outcomes of the study, it was determined that the ht between the tube and the working fluid was largest for NF, which had a concentration of 0.24 vol% throughout the study.

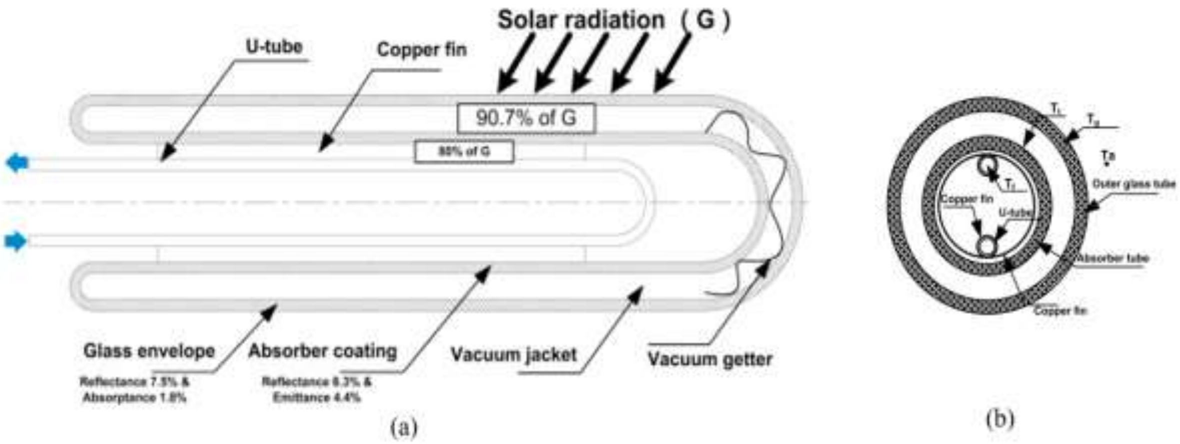

Fig. 12. Diagram showing the evacuated U-tube enclosed type [33].

In their study, Mahbubul et al. [34] analyze the impact that a single-walled carbon nanotube (CNT)-water nanofluid (NF) has on the magnetic field (η_t) of the collector. These comparative studies between collectors that operate with conventional water and those that operate with nanofluid are the basis for the evaluation of the enhancement of η_t efficiency. It has been discovered that the collector may achieve efficiencies of up to 56.7% and 66%, respectively, when it is operated with water or 0.2 vol% NF, among other things. See Figure 13. It is important to illustrate the image of the ETSC.

Fig. 13. Image of the ETSC [34].

Elshazly et al. [35] carried out a numerical analysis on distinct nanofluids to improve the ETSC TP. Three types of hybrid materials were examined: MWCNT, Al2O3, hybrid material made of 50:50 MWCNT and Al2O3. Out of the three distinct nanofluids fluids that were evaluated, the MWCNT showed the highest degree of efficacy overall. Hybrid Al2O3-MWCNT nanoparticles are shown in Fig. 14a, while the synthesis of the nanofluids is shown in Figs. 13b and c. Fig. 15 shows the ETSC complete system.

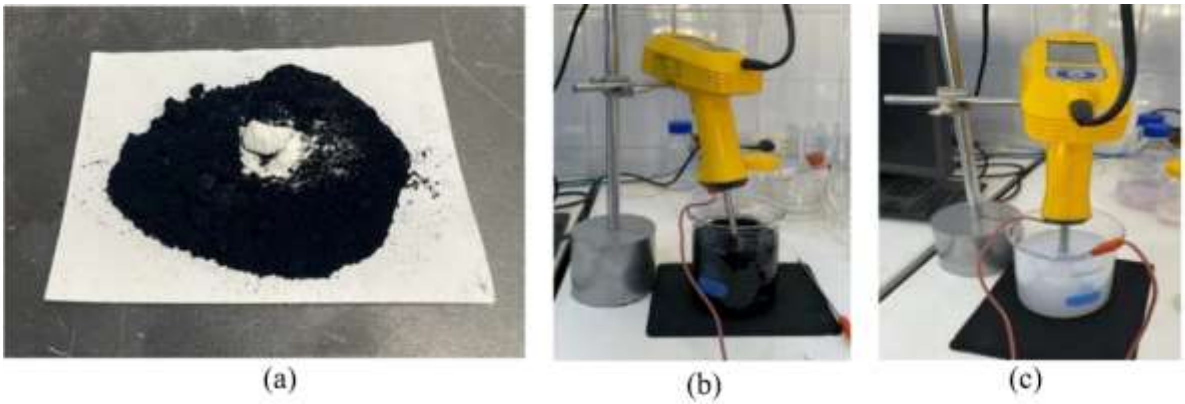

Fig. 14. a) Hybrid MWCNT/Al_2O_3 nanoparticles b) MWCNT/water c) Al_2O_3/water nanofluids making [35].

Fig. 15. ETSC complete system [35].

4. Conclusion and Remarks

The utilization of carbon nanotubes (CNTs) in SE for a variety of energy applications has been the subject of a significant amount of research. In the field of solar energy, carbon nanotubes (CNTs) have been utilized for a variety of applications, including solar thermal energy [22]. The commercial viability of carbon nanotubes (CNTs) showed that concentrated solar collectors with coatings made of CNTs would be both cost-effective and operationally efficient. In addition to this, it was found that carbon nanotubes are utilized in STC applications for the purpose of absorbing, converting, and storing devices [23].

This research focuses on the use of carbon nanotubes (CNTs) in all of their forms, including SWCNT and MWCNT, which are utilized in STCs [24,32]. It is impossible to deny the possible applications of carbon nanotubes (CNTs) in solar energy. Nevertheless, in spite of the fact that the utilization of nanofluid as an alternative might potentially enhance the effectiveness of STCs [33], it was indicated that this could be accomplished without adding to the cost of the collector design. It will be necessary to do additional research that is experimentally validated and adjusted in accordance with standards in order to determine the most effective method for incorporating CNTs into STCs.

Lastly, but certainly not least, hybrid nanofluids are named after the innovative combinations of two or more nanoparticles that have demonstrated potential in the field of high-temperature research [34, 35]. Carbon nanotubes (CNTs) are among the hybridized nanofluids that have demonstrated a good increase in both optical and convective heat transfer. This is due to the fact that CNTs have a great thermal conductivity.

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