Review on Research Aspects of Evacuated Tube Heat Pipe Solar Collectors

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ABSTRACT

The global demand for hot water is experiencing rapid growth, driven by factors such as population increase and industrialization. Solar water heaters represent modern devices designed to harness incident solar radiation, utilizing it to heat water. This research is committed to investigating recent progress and innovations, with a specific emphasis on the application of nanofluids in solar heat pipe collectors. There is considerable potential for a substantial improvement in system efficiency. Additionally, this review offers insights into future recommendations designed to enhance the performance of evacuated tube heat pipe solar collectors. In this study, we have endeavored to provide an overview of ongoing research areas pertaining to the flow within evacuated tube collectors, the mechanisms of heat transfer, and the utilization of different working fluids within heat pipes.

Keywords— Solar Collector, Evacuate Tube, Heat Pipe, Nanofluid

I. INTRODUCTION

Nations like China, India, the United Kingdom, and the United States, all prominent energy importers, have a substantial dependence on fossil fuels to fulfill their energy needs. It is worth highlighting that in 2004, China saw a remarkable 25% growth in its utilization of renewable energy sources, whereas its electricity demand only experienced a comparatively modest increase of 7% to 9%. Presently, China holds a dominant 40% stake in the global collector area [1]. India, on the other hand, ranks as Asia's third most significant country in terms of energy consumption, following Japan and China [2]. Traditional energy sources, such as coal-fired and mineral oil power plants, play a prominent role in India's energy landscape, contributing significantly to greenhouse gas emissions [3]. Consequently, a fundamental transition is essential to curb emissions and meet the increasing energy demands through efficient and environmentally friendly utilization of renewable energy sources. According to data from the Ministry of New and Renewable Energy (MNRE) under the Government of India, the residential sector's hot water usage was approximately 129 million/day in 2017 and is expected to treble by 2022 [4]. India enjoys abundant sunlight throughout the year, making solar water heaters a highly efficient and dependable energy solution. Harnessing solar energy can significantly reduce the energy required for water heating.

Table: 1 Solar Water Heating Potential in India (Cumulative Million m^2) ($1m^2$= 50 l /day)

Year	Residential/commercial	Hotel	Hospital	Others	Industries	Total
2010	2.58	0.19	0.10	0.18	0.19	3.24
2013	4.25	0.35	017	0.27	0.33	5.37
2017	7.68	0.61	0.27	0.39	0.57	9.52

Among the economically efficient choices for water heating, the evacuated tube collector (ETC) distinguishes itself. These evacuated tubes are constructed with two glass tubes arranged concentrically, creating a vacuum between the inner and outer tubes to reduce heat loss. Various techniques are employed to transfer the heat captured by the absorber to the heat transfer fluid. One of the most recent and efficient technologies, renowned for its outstanding thermal conductivity, is the heat pipe. Heat pipe evacuated tube solar collectors (HPETC) deliver substantial advantages, including an extended operational life, resistance to corrosion, and precise temperature regulation.

In the HPETC system, a heat pipe is enclosed within a glass casing. Weather conditions exert a notable impact on the performance of these collectors, resulting in decreased efficiency during cold, cloudy, and windy days [5]. Issues like condensation, moisture, and severe weather conditions can lead to premature deterioration of the inner pipe materials, further diminishing collector efficiency. Additionally, heat transfer through the conventional base fluid is restricted. Furthermore, the inclusion of a pump and the associated power requirements necessitate extra space for the natural circulation system, leading to placement constraints. Challenges such as night cooling from the circulation of cold water, water freezing during frigid nights, and pipe corrosion due to water usage must also be addressed.

All these challenges can be efficiently addressed by integrating a heat pipe solar collector, recognized for its exceptional heat conduction efficiency, into a sealed evacuated tube. Heat pipe solar collectors excel over flat collectors in their capacity to minimize heat dissipation. There are primarily two categories of heat pipe solar collectors: single-wall glass heat pipes and Dewar tubes. The means to mitigate these challenges include utilizing a U-tube, heat pipe, or direct contact with a liquid [6].

II. SOLAR WATER HEATING SYSTEM (SWHS)

The SWHS, commonly referred to as a solar water heating system, functions as a water heating device suitable for various residential and commercial purposes. These applications encompass both passive solar water heating systems (PSHWS) and active solar water heating systems (ASHWS).

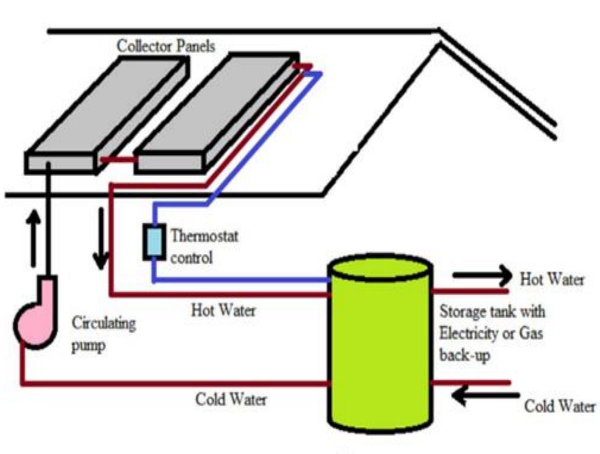


Figure: 1 Passive solar water heating system with indirect circulation (PSHWS)

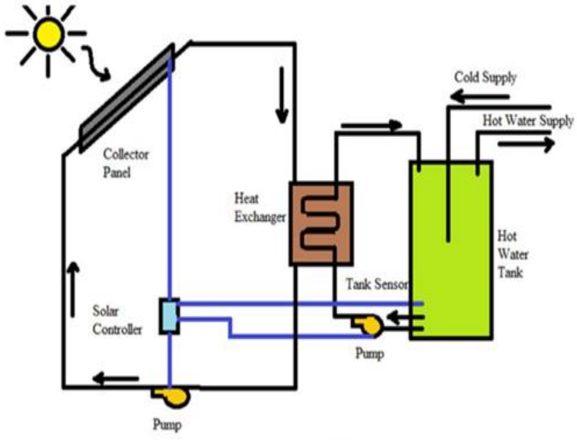


Figure: 2 Active solar water heating system with direct circulation (ASWHS)

ASWHSs are systems employing one or more pumps for the movement of the working fluid. A fundamental representation of an active ASWHS is illustrated in Figure 1. Heat is conveyed to the water within the storage tank by the heat transfer fluid coursing through the heat exchanger connecting the collectors. This process is known as direct circulation or open-loop circulation when water is directly moved from the collector to the storage tank. Direct circulation systems are highly susceptible to freezing issues, limiting them to supplying hot water at temperatures of 50-60 °C. To address freezing concerns, ETC collectors have been implemented for residential water heating, yielding superior outcomes in comparison to FPC due to reduced convective heat losses. A V-trough SWHS is currently under development and analysis, demonstrating enhanced results and economic advantages. In colder regions, ethylene glycol is introduced into solar collectors, and heat is transported to the storage tank's water via a heat exchanger, benefiting from its anti-freezing properties.

The distinct feature that sets PSHWS apart from other systems is their reliance on natural convection for heat, as depicted in Figure 2. Several studies have explored the use of different tank shapes, such as cylindrical and rectangular, but it has been observed that SWHS with cylindrical tanks exhibit an enhanced heat transfer rate. Reflectors were introduced to increase collector efficiency. Baffles have been employed to direct the flow of flowing fluid in a few investigations.[7]

A. Solar Thermal Collector

Solar thermal collectors function as heat exchangers, capturing solar energy and converting it into usable heat for a diverse range of applications. Within a solar collector, an absorber component is tasked with absorbing all heat radiation and transferring it to various fluids (such as air or water) depending on the intended application [8][9]. The selection of the solar collector type is contingent upon factors such as location, weather conditions, intended utilization, and operating temperature, as depicted in Figure 3.

B. Development Review of Evacuated Tube Solar Collector

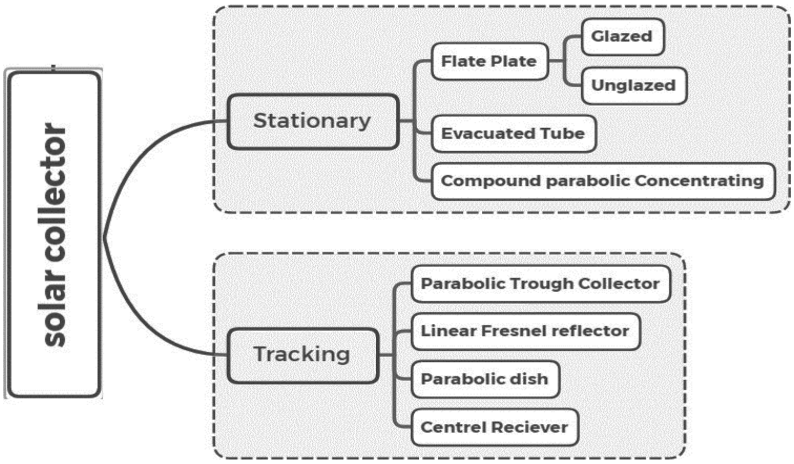


Figure: 3 Classification of Solar Collector

Siegfried Godel and Edward Speyer led the way in solar collector innovation in 1963. [10], developing an absorber with selective coating to maximize radiation absorption efficiency. Albert and Ivan presented the idea of putting the absorber inside an evacuated chamber to counteract convective losses, which eventually resulted in the creation of the evacuated tube solar collector. In [11]. This innovative design comprised two concentric tubes: one featuring a selectively coated inner surface and the other constructed with toughened glass, creating a vacuum-sealed gap between them. Nevertheless, the concentrated solar radiation presented a risk of glass tubing breakage because of uneven heating on the opposite side.

During that particular year, Godel and Edward Speyer [12] utilized selectively coated absorbers to reduce convective losses. McConnell and Vansant [13] introduced an enhanced glass tube with improved capillary distribution to promote the transfer of the storage tank receives thermal energy from the absorber. They were able to achieve this by adding evenly dispersed granulated glass particles to the heat pipe, which improved heat transfer. Using water as the heat transfer medium, Zhiqiangt and Harding [14] created an evacuated tube solar collector to investigate how differences in heat transfer rates are impacted by the flow of liquid from the manifold. Additionally, Ezekwe [15] conducted an assessment of the heat pipe absorber and found that this system displayed a lower heat dissipation factor (FR) and a higher heat transfer ratio compared to similar systems. Ali M. El-Nashar [16] conducted a significant study to establish the role of the heat pipe system as a crucial determinant of heat output. In their study, they conducted a comparison of the effect of dust accumulation on the glass cover of a solar panel and two distinct blocks. One of the blocks received a single cleaning at the start of the year, while the other block remained without cleaning for the entire year. Their results demonstrated a significant 60% decrease in solar energy absorption for the block that did not undergo monthly cleaning. Zinian et al. [17] examined the optical performance of different solar collectors in a different investigation. They carried out a comparison study between an evacuated tube with a semi-cylindrical absorber and one with a flat plate. Their findings revealed that the evacuated tube with a semi-cylindrical absorber exhibited a notably higher solar energy absorption rate, specifically 15.9% higher. Although the flat plate absorber was recognized for its efficient energy absorption, it was Benz and Beikirche [14] who devised a flat-plate collector featuring an evacuated enclosure to reduce heat losses caused by gas conduction and convection, resulting in steam generation. Their study also addressed the usage of gases between the glass cover and the absorber plate, including air, argon, krypton, and xenon. amid a scene of evacuation. Their results indicated that a flat-plate collector could achieve a remarkable 50% efficiency in steam generation at 150 °C. Mills [19] implemented innovative techniques that incorporated reflectors and absorbers to redirect and harness solar energy effectively. In order to ensure that there was as little energy loss in the conversion of solar energy into thermal energy, they used an evacuated tube as the absorber. Furthermore, Mills and Morrison [19] produced a significant amount of thermal energy in a small area by concentrating solar radiation using a Fresnel lens. They further enhanced energy capture by incorporating 48 reflective mirrors on a tower house, demonstrating the ability to cost-effectively generate electricity using abundant solar heat.

Table: 2 Solar Water Heater Development

Development	Thermal Efficiency
Incorporating concrete within the framework	40 %
Placing a honeycomb component within the Flat Plate Collector (FPC) above the absorber plate with a 3mm gap.	46 %
Incorporating transparent rectangular slats within the Flat Plate Collector (FPC).	49 %
Incorporating obstructions within the Flat Plate Collector (FPC).	50 %
Placing aluminum cans on the absorber plate in an orderly configuration.	59 %
Utilizing black-colored sand beneath the double-glazing sheets.	70 %
Incorporating aluminum cans onto the absorber plate in a zigzag arrangement.	72 %
Two-phase thermosyphon solar water heaters (SWH).	82 %

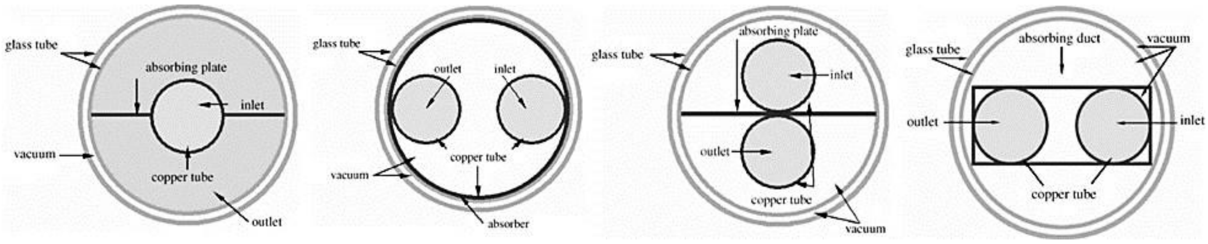


Figure: 4 Differences in collector Centre Distance in ETC

In their research, Rakesh et al. [20] utilized a vacuum tube solar panel equipped with 12 pipes, each measuring 1.8 meters in length and 63.5 millimeters in diameter, in order to warm up a pressure cooker. In Delhi, they were able to successfully evaporate 8 kilograms of water at room temperature in around 100 minutes. Notably, their results revealed that the system's efficiency demonstrated improvement as the load increased. In a separate inquiry, A solar system with main and secondary reflectors differentiated by strong reflectivity within particular wavelength ranges was devised by Yogev and Epstein [21]. The primary reflectors were responsible for redirecting solar radiation towards the secondary reflector, which, in turn, directed it towards the absorber. In an evacuated tube system, they conducted experiments with R-134a, R-407C, R-22, and water as refrigerants. R-407C was the focus of their work.

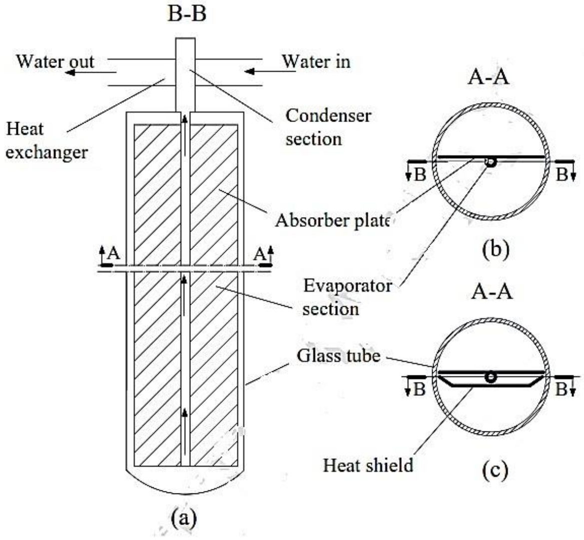


Figure: 5 Heat Shielded ETC

The functioning of the evacuated heat pipe solar collector is greatly influenced by the local climate as well as the thermophysical properties of the refrigerant used in the heat pipe. In research conducted by Zakhidov et al. [22], they introduced a phase change material capable of absorbing additional heat as latent heat and releasing it as needed. Sabiha et al. [23] achieved enhanced thermal efficiency in an evacuated tube solar collector by integrating carbon nanotubes as nanofluids. They discovered that single-wall carbon nanotubes with a volume concentration of 0.2% resulted in an impressive 93.43% efficiency in evacuated tube solar collectors. Utilizing the TRNSYS software, Assilzadeh et al. [24] simulated an evacuated tube solar collector equipped with a liquid-filled heat pipe. The heat pipe's liquid evaporated, transferring thermal energy to the manifold. Their research focused on a solar absorption refrigeration system that employed the LiBr/H2O absorption unit. It concluded that, to achieve a 3.5 kW cooling capacity in Malaysia, a 35 m2 absorber area for the evacuated tube solar collector was required to reduce heat losses from the absorber plate to the working medium.

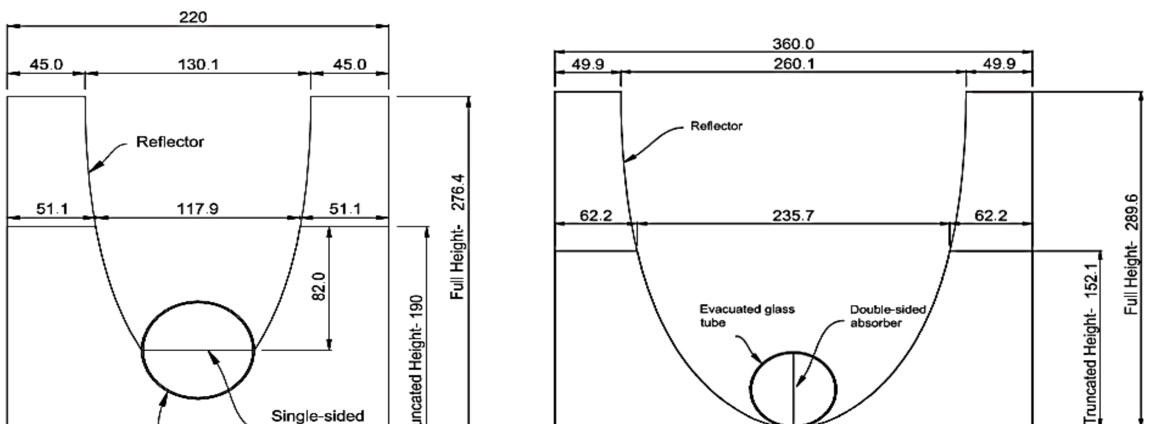


Figure: 6 Side Section View of the Full and Truncated SSACPC & DSACPC Solar Collector

Kim et al. [25] experimented with how the thermal output changes with varied collection pipe Centre distances, as shown in Fig. 4. As the collector's breadth is calculated, the number of collection pipes fitted decreases as the center distance increases. As a result, the absorption area shrank dramatically and the performance deteriorated. Although the shadow impact increased as the center-to-center distance decreased, the collector performance improved as the absorption area grew. Xiaona Huang et al. [26] examined whether the heat shields shown in Fig. 5 are successful at reducing heat gain. The effect of heat shields is constant for a range of parameters, including water flow, sun radiation, and ambient temperature, at the water intake temperature and solar radiation.Figure 6 shows the single-sided and double-sided absorber types of concentrated evacuated tube heat pipe solar collectors used in a comparative study by Dannchelatebe Nkwetta et al. [27]. The results showed that the ability to get a higher output temperature was the main reason why the double-sided absorber evacuated pipe heat pipe sun collector (DSACPC) performed better than the single-sided absorber evacuated pipe heat pipe solar collector (SSACPC).

C. Change in condenser

E. Azad et al. [28] conducted a comparison of various condenser arrangements within a solar collector, as depicted in Figure 7. Their findings indicated that type I exhibited superior efficiency across the entire reduced temperature parameter range. This superiority is attributed to the ribbed absorber plate, which functions similarly to a honeycomb structure.

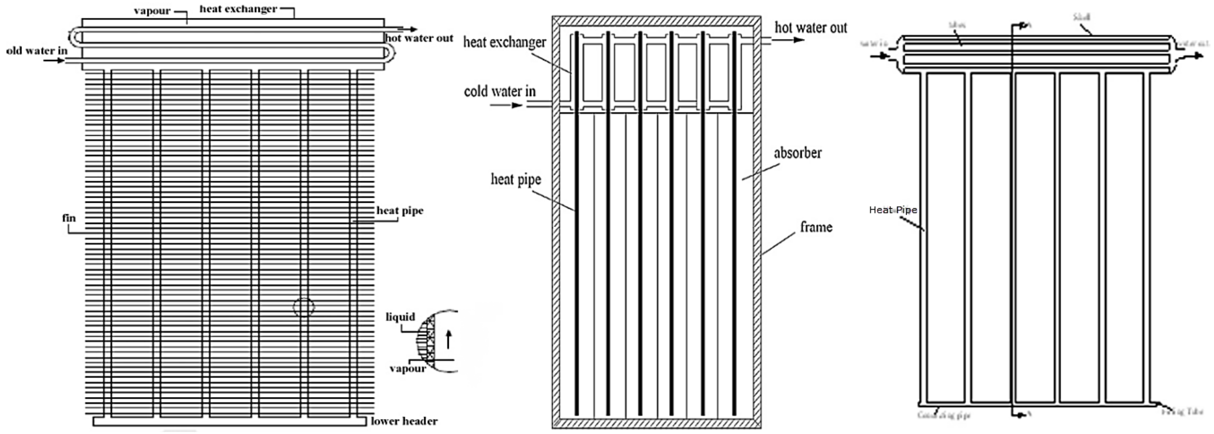
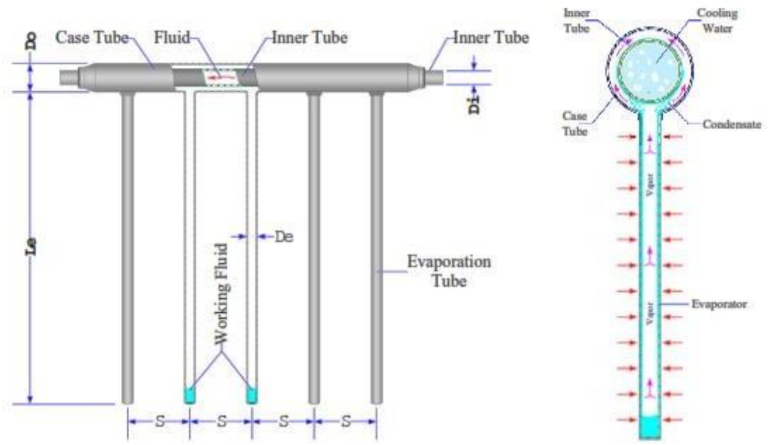


Figure: 7 Different Condenser Arrangement in Solar Collector

Yaxiong Wang et al. [29] noted that a unique concentric condenser heat pipe design, as depicted in Figure 8, resulted in an enhancement of both the condensation heat transfer coefficient and the condensation area. Factors such as operating temperature, evaporator length, charge rate, and angle of inclination also influence the maximum heat transfer capacity of the heat pipe array, particularly at higher operating temperatures, in comparison to conventional heat pipes. By enlarging the evaporator portion, the maximum heat transmission capacity improved. According to Naresh et al. [30] adding the fins shown in Fig. 9 improved condensation by 13%, lowering the fill ratio needed for maximum performance.



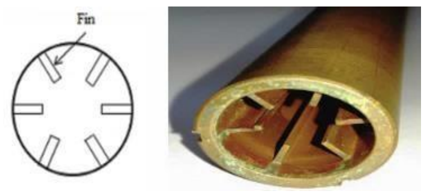


Figure: 9 Novel Concentrate Condenser

Figure: 8 Additional Inner Fins Arrangement in Condenser

D. Change in Filling Ratio

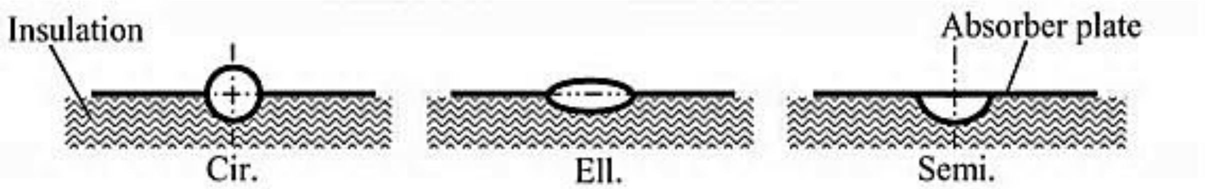


Figure: 10 Cross Sectional Views of Prototype Wickless Heat Pipe

Sang Lee et al. [31] studies indicated that if the charge ratio is low, heat pipe performs poorly because of the high capacity of the evaporator section, and the feed ratio was low. As a result, the lowest heat recovery value was obtained when the charge ratio was low while the maximum value was obtained when the charge ratio was high. Hussein et al. [32] found that, particularly at low water fill levels, the performance of flat-plate collectors fitted with wickless heat pipes was significantly improved by replacing the circular cross-section of the pipes in Figure 10 with an elliptical cross-section.

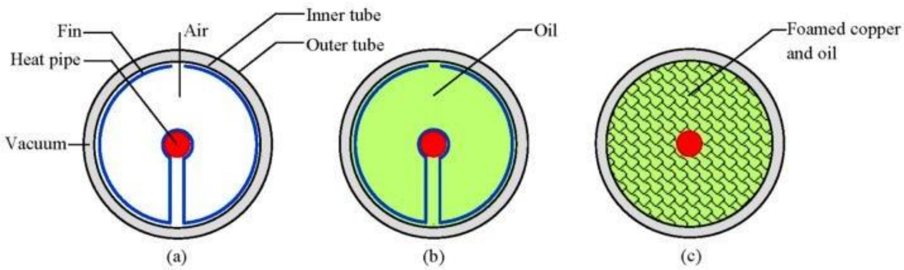


Figure: 11 ETC Filling with (a) Air (b) Oil (c) Copper Foam

As per the research conducted by Mohamed S. Abd-Elhady et al. [33], the modification of the evacuated tubular heat pipe composition to include oil and foamed copper, as illustrated in Figure 11, resulted in a transition from pure conduction to combined conduction and convection heat transfer. Foamed metals, as opposed to ribbed surfaces, promoted better contact between the inner tube of the evacuated tube and the heat pipe. The introduction of a heat transfer medium into the air gaps enhanced the overall heat transfer rate. In a distinct investigation, E. Kabeel et al. [34] examined the influence of using two different refrigerants, R-22 and R-134a, in the annulus of the heat pipe located between two concentric pipes, as shown in Figure 12. Various factors, including air mass flux, filling level, and refrigerant type, were considered as variables influencing the modified heat pipe's thermal performance. Thermal performance improved as the mass flow rate increased while radiation and convection losses decreased.

E. Change in Reflector

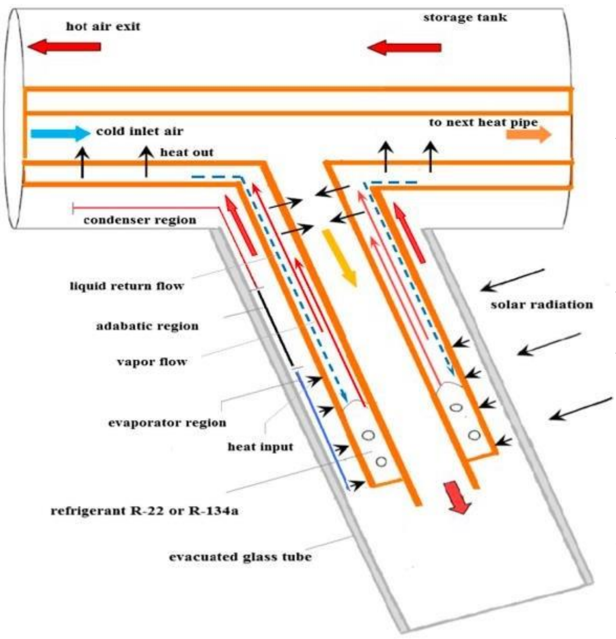


Figure: 12 Double Concentratic pipe ETC

The Compound Parabolic Collector (CPC) holds great potential for enhancing the photothermal performance of solar evacuated tube collectors and offers numerous application possibilities. In order to improve optical efficiency and minimize losses between the reflector and the circular absorber, A unique V- and W-shaped CPC reflector was created by Mcintire [35]. However, the concentration ratio is reduced by about 15% as a result of this design. Li et al. [36] proposed the development of a lens-walled CPC based on the mirror CPC concept. The lens-walled CPC significantly improved photovoltaic (PV) performance by providing a more equal flow dispersion than the mirror CPC, according to experimental results. In the literature, there have been instances of combining an evacuated tube absorber with a CPC to optimize both optical and thermal performance. Pei et al. [37] evaluated evacuated U-tubes with mini-CPC under high temperatures and found that they had a greater thermal efficiency than regular evacuated U-tubes. An experimental study by Liu et al. [38] used a simplified CPC in an all-glass solar Evacuate tube steam generator that produced high temperature air at 200 °C at 0.55 MPa. Kim et al. [25] designed, and tested on a stationary heat pipe CPC, and proposed arrangement outperformed other solar thermal systems without tracking in simulations and experiments, achieving a thermal efficiency of more than 40% above 200 °C. Wang et al. [39] used a porous SiO_2 antireflection coating to reduce reflection and increase the solar transmittance of the tubes to 0.94. By welding aluminum fins to copper U-tubes, heat was transferred to the working fluid. They concentrated solar beams using a CPC constructed of aluminum, which produced an immediate solar thermal efficiency of 50.2% at 150 °C.

Research was done by Milani and Abbas [40] to examine how flat diffuse reflectors in the ETC array affect heat capture rates. It was discovered that selecting the optimal configuration with a diffuse flat reflector improved solar collector performance by 14.6%, 20.2%, 25.9%, and 27.9%. This configuration also led to annual energy savings of 95.8%, 91.3%, 81%, and 74% for zones 1, 2, 3, and 4, respectively. In a Computational Fluid Dynamics (CFD) study, Avargani et al. [41] investigated a special SWH with PTC arrays and discovered that the absorber pipe's location had a major impact on the system's efficiency. When Abo-Elfadl et al. [42] assessed the impact of the top, bottom, and both reflectors with the ETSC-heat pipe system, the temperature of the stored water increased by 20.3%. Chai et al. [43] fabricated ETSC with inner focusing reflective coatings and analyzed their impact on thermal performance. They found that optimizing the coating, using an angle of 180˚, and increasing the eccentric distance all contributed to improved thermal performance. Naik et al. [44] assessed the effectiveness of standard U-tube and parabolic reflector-fitted U-tube solar collectors, discovering that the parabolic reflectors increased collector capacity by 14.1%. Dinesh et al. [45] employed diffused reflectors that were wavy or flat in order to enhance the ETSC. The water tank's temperature rose by 6 and 4 °C, respectively, as a result. A medium-temperature selective coating for ETSC was created by Ma et al. [46], who were able to achieve an immediate efficiency of roughly 0.46 at 150 °C. Zhang et al. [47] evaluated the impact of receiver position and reflector configuration on the performance of the ETSC.

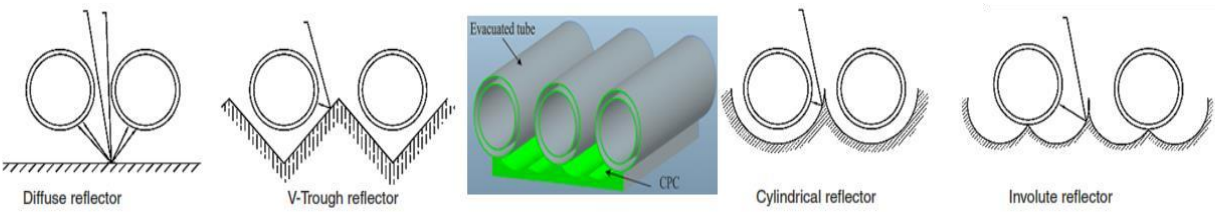


Figure: 13 Different types of concentrator

Errors in installation and inaccurate azimuth-elevation axis tracking can affect the optical performance of PTC systems based on evacuated tubes in heat pipes. Of these systems, the U-tube ETC had the maximum thermal efficiency (50.2%) when the outer surface of the tubes had a porous SiO_2 antireflection coating applied to it.

The compound parabolic collector (CPC) has considerable potential for improving the photothermal efficiency of solar evacuated tube collectors and presents various application opportunities. Despite a little decrease of about 15% in the concentration ratio, Mcintire [35] presented a novel CPC reflector design with V- and W-shaped configurations intended to successfully reduce losses between the circular absorber and the reflector while enhancing optical efficiency. The creation of a lens-walled CPC based on the mirror CPC idea was suggested by Li et al. [36]. According to experimental findings, the lens-walled CPC significantly improved PV performance because it had a more uniform flow distribution than the mirror CPC. In existing literature, there are instances of combining an evacuated tube absorber with a CPC to achieve improved optical and thermal performance, especially at high temperatures. When compared to conventional evacuated U-tubes, Pei et al.'s [37] studies on evacuated U-tubes with mini-CPC revealed increased thermal efficiency. A cost-effective, all-glass solar evacuated tube steam generator with a simplified CPC design that can produce high-temperature air at 200 °C under 0.55 MPa pressure was the subject of studies by Liu et al. [38]. Kim et al. [25] designed, evaluated, manufactured, and tested a stationary heat pipe CPC system. Their proposed configuration outperformed other solar thermal systems that lacked tracking, achieving a thermal efficiency exceeding 40% at temperatures above 200 °C. In order to reduce reflection, Wang et al.'s [39] application of a porous SiO_2-based antireflection coating increased the tubes' solar transmittance to 0.94. Aluminum fins were welded to copper U-tubes in order to efficiently transfer heat to the working fluid.

The sun's rays were focused using an aluminum-based CPC, which produced an instantaneous solar thermal efficiency of 50.2% at 150 °C. Milani and Abbas [40] looked into how flat diffuse reflectors affected the ETC array in order to increase heat capture rates. They discovered that selecting the optimal configuration with diffuse flat reflectors led to a 14.6%, 20.2%, 25.9%, and 27.9% improvement in solar collector performance, translating to annual energy savings of 95.8%, 91.3%, 81%, and 74% for zones 1, 2, 3, and 4, respectively. Avargani et al. [41] conducted a Computational Fluid Dynamics (CFD) study on a unique SWH equipped with PTC arrays, highlighting the significant impact of the absorber pipe's positioning on system efficiency. When top, bottom, and both reflectors are used in conjunction with the ETSC-heat pipe system, Abo-Elfadl et al. [42] found that the temperature of the stored water increased by a significant 20.3%. Chai et al. [43] manufactured ETSC with an inner focusing reflective coating and analyzed its impact on thermal performance. They determined that an optimum coating angle of 180° and increasing the eccentric distance led to improved thermal performance. Naik et al. [44] assessed the efficacy of standard U-tube and parabolic reflector-fitted U-tube solar collectors, finding that parabolic reflectors increased collector capacity by 14.1%. In order to improve the ETSC, Dinesh et al. [45] used diffused reflectors that were flat or wavy. As a result, the temperature of the water tank increased by 6 and 4 degrees Celsius, respectively. A medium-temperature selective coating was created by Ma et al. [46] for the ETSC, and at 150 °C, it produced an immediate efficiency of roughly 0.46. Zhang and colleagues' study [47] examined the effects of tracking error on the azimuth-elevation axis and receiver installation error on the optical performance of heat pipe evacuated tube-based PTCs. They discovered that when an antireflection coating consisting of porous SiO_2 was placed to the external surface of the tubes, the U-tube ETC displayed the maximum thermal efficiency (50.2%).

F. Change in working fluid

Water, ammonia, Freon compounds, and acetone are frequently utilized as working fluids in heat pipes; however, their primary drawback lies in their relatively low heat conductivity. In recent times, advancements in enhancing the thermal performance of ETSCs have emerged by incorporating supplementary liquids with superior thermal conductivity, such as nanofluids

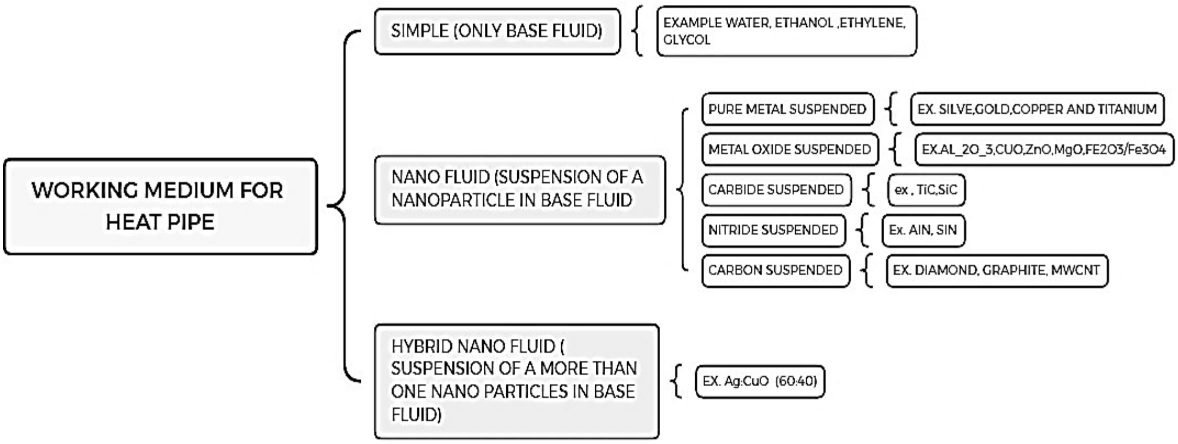


Figure: 14 Working Fluids for Heat pipe

1) Nano Fluid.

Nanofluids have shown to be an excellent complement to the novel heat transfer medium. Nanofluids, colloidal dispersion of nanoparticles in a base liquid, outperformed simple liquids in terms of thermal properties are available. Researcher have used the concentration of nanoparticles in the base liquid by using two methods: mass and volume concentrations

a) Effect on Thermophysical Properties of Nanofluid

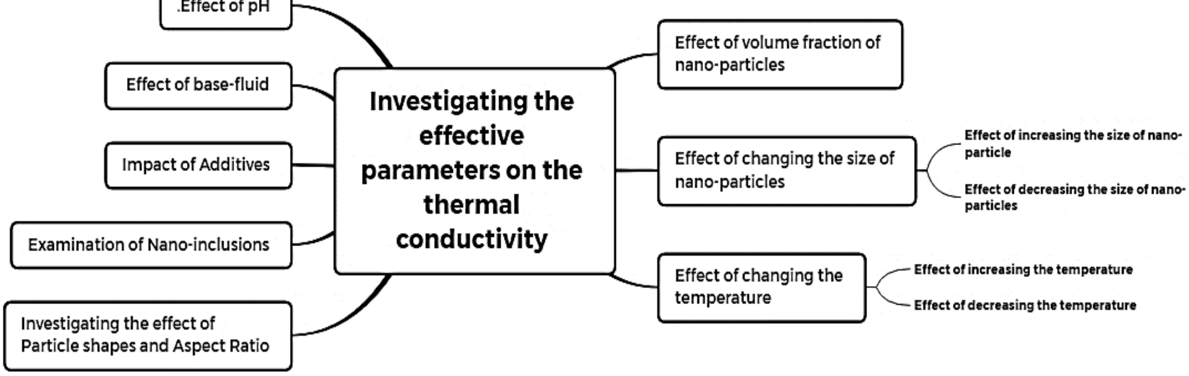
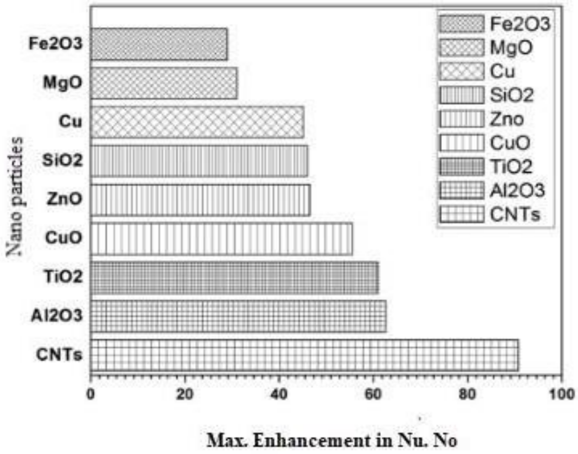


Figure: 15 Effective Parameter on Thermal Conductivity of Working Fluid

Nanoparticles refer to extremely small particles characterized by their nanometer-scale dimensions. Over time, the term "nanoparticles" has become widely accepted to describe these exceptionally fine particles. In most instances, there was an enhancement in the heat transfer coefficient, and consequently, the Nusselt number, with increasing nanoparticle concentration and nanofluid flow rate. Elevating the flow rates of the nanofluid resulted in improved dispersion of particles, which in turn augmented the heat transport capabilities, leading to higher heat transfer rates. The increase in the Nusselt number can be attributed to increased thermal conductivity, the Brownian motion of nanoparticles, and particle migration due to the high percentage of nanoparticles in the mixture.The heat transfer rate in nanofluids was shown to diminish when the stability of the nanofluid was disturbed, resulting in the settling or aggregation of particles, according to experimental results. The fluid's thermal conductivity decreased as a result of this event. Furthermore, the heat transfer coefficient was significantly influenced by the temperature of the liquid that entered the system. This higher radiation effect was a result of improved thermophysical qualities as well as increased liquid radiation influence on the inner wall of the pipes.
Several experiments have demonstrated the highest enhancement in the Nusselt number as a function of volume fraction. For instance, a nanofluid consisting of carbon nanotubes dispersed in water with a nanoparticle concentration of 1% resulted in a maximum increase in the Nusselt number of 90.76%. In a study conducted by Kim et al. [48], the use of four different nanofluids in U-tube ETSCs was analyzed, revealing that the solar collector efficiency was optimized when Multi-Walled Carbon Nanotubes (MWCNTs) were employed. Sharafeldin et al. [49] illustrated the effect of CeO_2 nanoparticles on the performance of ETSCs. The results indicated an increase in solar energy absorption and the gradient in temperature between the inflow and exit flows, resulting in a 34% improvement in the photothermal properties of the ETSCs. In a study conducted by Lopez et al. [50], the utilization of nanofluid as the working fluid demonstrated significant reductions in the entropy generation rate. Specifically, viscosity effects, heat transfer, and heat loss contributed to remarkable decreases of 87.5%, 65.5%, and 14.71%, respectively. These findings underscore the substantial impact nanofluids can have on minimizing entropy generation during the process. Liu et al. [51] investigated the thermal performance of an evacuated tubular high-temperature air solar collector using an open thermosiphon with nanofluid. They employed a two-step procedure to create CuO water nanofluid with 50 nm-sized particles on average. The effectiveness of the system using nanofluid and the higher air outlet temperature was found to be superior to that of the system with pure water. During winter, with a volume flow of 7.6 m3/h, the air outlet temperature in the system with the nanofluid exceeded 170°C.Single-walled carbon nanotube (CNT) nanofluids were used by Sabiha et al. [52] to evaluate the thermal performance of ETSC. To make CNT water nanofluid, they employed a two-step process utilizing sodium dodecyl sulfate (SDS) surfactant at volumetric values of 0.05%, 0.1%, and 0.2%. Increasing the cooling water mass flow rate led to improvements in the thermal efficiency of all ETSCs, regardless of whether they were employing nanofluids or pure water. Notably, the ETSC's maximum thermal efficiency was produced by the nanofluid at a volumetric concentration of 0.2%. Additionally, at a volumetric concentration of 0.05%, ETSCs containing nanofluid had efficiencies that were 0.1% higher than those containing water. The impact of particle size and concentration of Al_2O_3 water nanofluid on the thermal performance of a U-tube solar collector was examined by Kim et al. [48]. They discovered that when particle size decreased, solar collectors' thermal power increased, and the highest thermal efficiency was attained by using nanofluids with volume concentrations of 0.5%, 1%, and 1.5%. When compared to U-tube solar collectors with 1 vol percent Al_2O_3 -Water. Rezaeian et al. [53] studied using CuO nanofluid to improve the PTC efficiency and tested the performance index, thermal efficiency and pressure drop at different flow rates also evaluated higher mass flow rate and nanofluid percentages increased the performance index and thermal efficiency and highlights the potential of CuO nanofluids for optimizing PTC efficiency and performance. The application of nano-enhanced PWax as a PCM system for thermal energy storage was investigated by Alshukri et al. [54]. By incorporating nano-ZnO and nano-CuO particles, the hot water supply was extended by 5 and 6.2 hours, respectively. At flow rates of 1, 2, and 3 l/h, the most efficient results were obtained with nano-CuO and paraffin wax in evacuated tubes and PCM tanks, with efficiencies of 68.2%, 84.26%, and 88.5%.

a) Surfactant effect on heat pipes

Enhancements were observed as the cooling water, surfactants and various chemical additives are often employed to enhance the dispersion of nanoparticles while maintaining their thermophysical properties over an extended period. Nevertheless, numerous studies in the literature have suggested that the specific type and concentration of surfactants can significantly impact both the duration of stability and the thermophysical properties. Sarkar et al. [55] conducted a comprehensive review of the findings from numerous researchers who have been involved in studies related to nanocomposite synthesis, the creation of hybrid nanofluids, thermophysical properties, pressure drop, and heat transfer characteristics. They suggested that further research should be undertaken to explore the applications and challenges associated with hybrid nanofluids, based on the insights gathered from the literature review. This would help in better harnessing the exceptional thermophysical characteristics of these materials.



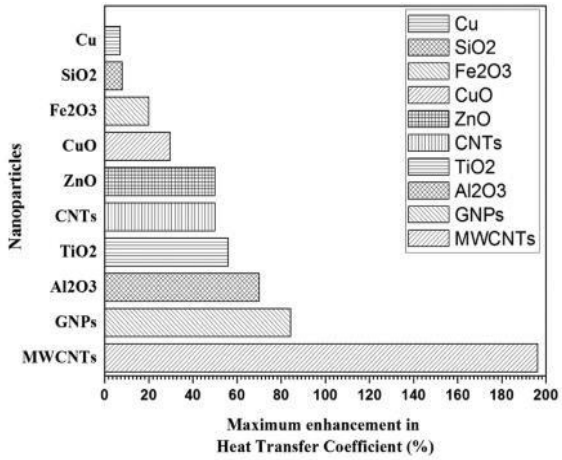


Figure: 16 Max. Enhancement in Nu no for Different Nanoparticles

Figure: 17 Maximum Enhancement in heat transfer coefficient (%)

Table: 3 Summary of surfactants used with working fluid

Nanoparticle/base fluid	Preparation method/sonication	Surfactant/NSA	Stability monitoring method	Stability time	Ref.
Al_2O3/water-ethylene glycol	Two-step/probe/100 min	PVP/0.1 vol%	Visual	45 days	[56]
Ag/water	Two-step/probe/120 min	PVP/1 vol%	SEM	40 days	[57]
Graphene functionalized (GNP)/water	Two-step/probe/10 min	SDBS/0.5:1 GNP	NR	30 days	[58]
CuO/water	Two-step/bath/2 h	NSA	NR	Several	[59]
Al_2O_3/water	Two-step/bath/4 h	NSA	NR	24 h	[60]
Fe_2O_3/water	One-step	NSA	NR	NR	[61]
SiO_2 functionalized with silanes groups/water	Two-step/bath/12 h	NSA	Visual	12months	[62]
MWCNT–Ag/water	Two-step/bath/45 min	NSA	NR	NR	[63]
MgO/water	Two-step/bath/8 h	Triton X100	NR	NR	[64]
TiO_2/water	TiO_2–Dilutions from W740X	PVP/1 mass%	NR	NR	[65]
Ag/water	Two-step/bath/12 h	Oleic acid/	NR	NR	[66]
GNP/water	NR/NR/NR	GA/0.5 mass%	NR	NR	[67]
Fly ash	Two-step/bath/NR	Triton X-100/	Visual	NR	[64]
CuO	Two-step/bath/10 h	NSA	NR	NR	[68]
Al_2O_3/CuO	Two-step/ultrasonic cell	NSA	NR	NR	[69]

2) **Hybrid nano-fluids**

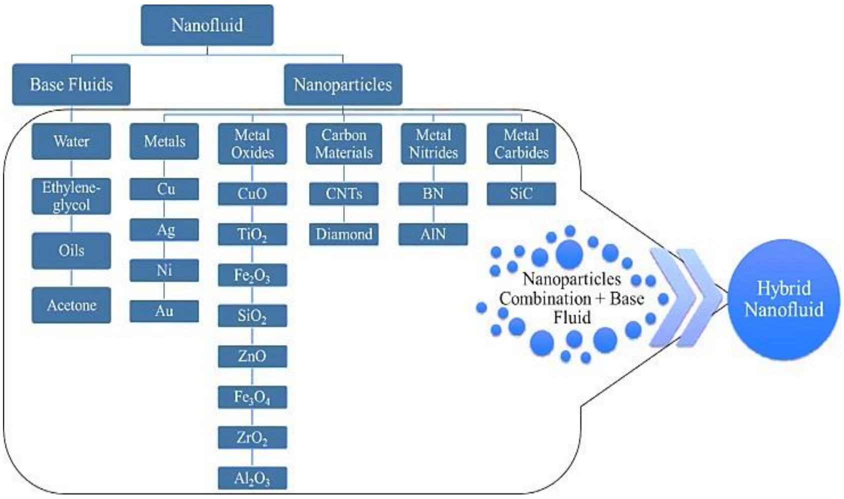


Figure: 18 Classification of working fluids

A hybrid nanofluid is a nanofluid that contains more than one nanoparticle. The hybrid nanofluids are created by combining multiple material qualities and the scientists found that diverse results were produced after examining these liquids. Its applicability in nanofluid heat transfer applications is particularly high in terms of high carbon heat capacity. While there is limited research due to the partial use of studies, the number of studies in this sector has lately increased exponentially.

Thanks to advancements in carbon nanotube manufacturing technology, the incorporation of carbon nanotubes into suspensions has become viable. This is primarily because carbon nanotubes possess high heat capacity and the ability to enhance thermal conductivity. Among the various nanoparticles studied, nanofluids containing carbon nanotubes have gained significant attention due to their remarkable capacity to improve thermal conductivity.

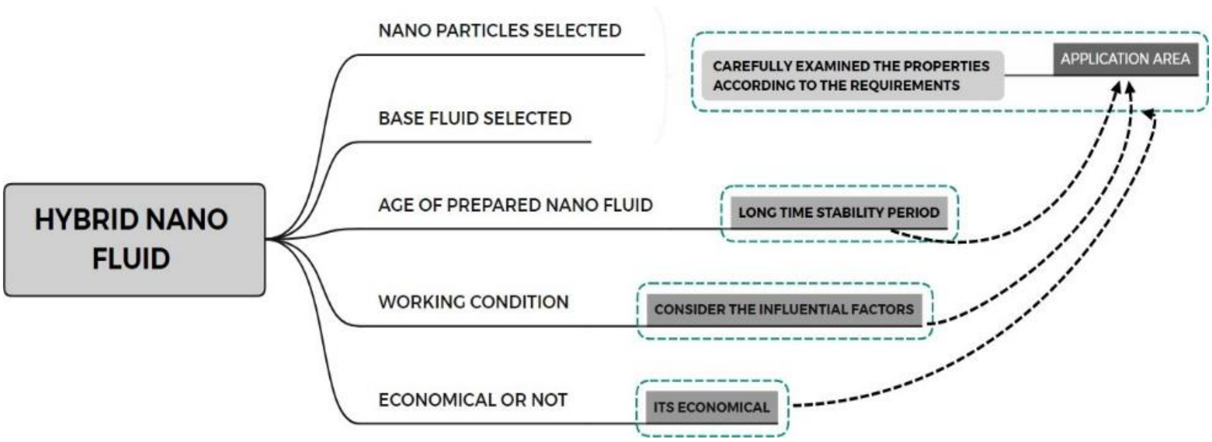


Figure: 19 Schematic illustration of challenges that hinder the hybrid Nano-fluid application

In their work, Kamble et al. [70] used an Al2O3-CuO/water hybrid nanofluid as the working fluid to examine the thermal performance of copper heat pipes. As the inclination angle, particle volume concentration, and heat input rate rose, they noticed a decrease in the heat pipe's thermal resistance.

In order to examine the thermal performance of heat pipes, Swapnil et al. [71] employed a hybrid nanofluid comprising boron nitride (BN) and Al2O3 in water. Their research shown that increasing the inclination angle, heat transfer rate, and particle concentration resulted in a decrease in thermal resistance. Similarly, Chaudhari and Bhosale [72] conducted research on the thermal performance of heat pipes using hybrid nanofluids containing CuO-BN in H2O. Their findings indicated that increased volume concentration, inclination angle, and decrease in thermal resistance was a consequence of the increase in heat transfer rate. Ramachandran et al. [73] also found that hybrid nano-liquids reduced thermal resistance in meshed wick heat pipes when compared to normal liquid (distilled water), uniformly dispersed nano-liquid (Al2O3/DW), and binary liquid (Al2O3-CuO/water). Their research demonstrated the advantages of hybrid nanofluids in terms of extending the heat pipe range.

However, Han and Rhi [74] conducted a comprehensive comparison of various samples of uniform nanofluids (Ag/water, Al2O3/water) and hybrid nanofluids (Al2O3-Ag/water) to assess heat pipe performance. Their findings indicated that the thermal resistance of the fluid increased with particle concentration, and the hybrid nano-liquids eventually deteriorated the system, reaching a point where uniform nanofluids performed better. This highlighted that the superiority of hybrid nanofluids over conventional nanofluids was contingent on the specific particle combination. Thanks to advancements in carbon nanotube manufacturing technology, the utilization of carbon nanotubes as nano additives has become increasingly viable. This is primarily attributed to carbon nanotubes' exceptional heat capacity and their capacity to significantly enhance thermal conductivity. Among the various nanoparticles recognized, nanofluids incorporating carbon nanotubes have gained widespread popularity due to their remarkable capacity to improve thermal conductivity. In their study, Kamble et al. [70] investigated the impact of employing an Al2O3-CuO/water hybrid nanofluid as the working fluid in copper heat pipes. Their findings revealed a reduction in the thermal resistance of the heat pipes as the inclination angle, particle volume concentration, and rate of heat input increased

G. Phase change material (PCM)

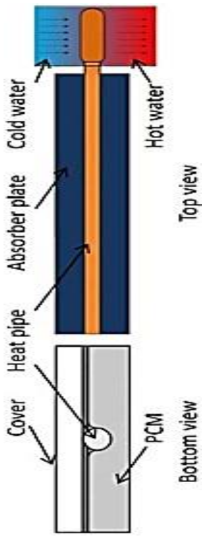


Figure: 20 PCM in Heat Pipe Solar

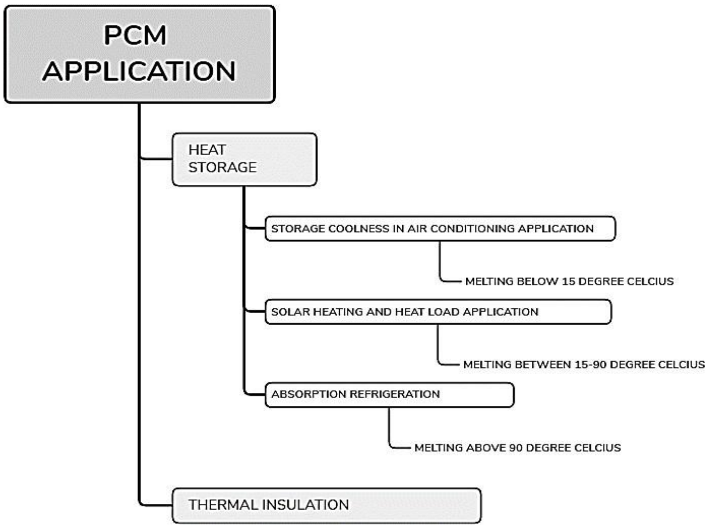


Figure: 22 Different PCM Application

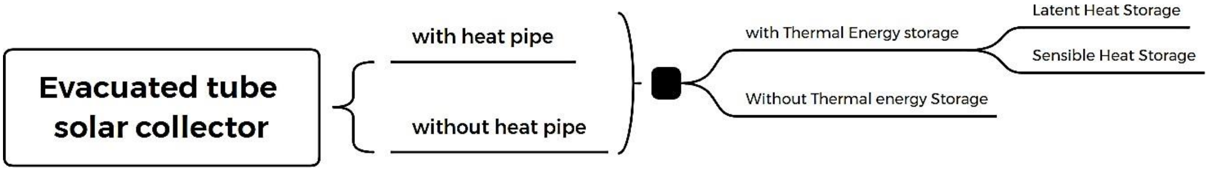


Figure: 21 PCM classification

Even if solar radiation is not accessible during the night or weekly radiation hours, the energy stored in the phase change material (PCM) can be utilized at any time. Tyagi et al. [75] found that ETCs with thermal energy storage (THES) had greater energy and energy efficiency than systems without THES. Furthermore, using paraffin wax-based system, both efficiencies are higher. In the temperature range of 40-80 ˚C, Fluid has employed several phase change materials and associated eutectics; these PCMs can be used with ETC.

Table: 4 Summary of recent studies involving evacuated tube heat pipe solar collector/storage systems

Overview	PCM	key findings
• Examining the experimental performance of a solar water heating system integrated with ETHPSC/S [76].	Tritracontane and Erythritol	• A 26% boost in efficiency over traditional ETHPSCs.
• An experimental test was conducted on a solar collector/storage heating system designed for mid-temperature applications [77].	Composite of Erythritol and expanded Graphite	• The ideal material for mid-temperature applications is the composite PCM consisting of 97 wt% erythritol and 3 wt% expanded graphite. • Evacuated tubes with diameters of 58 mm and 47 mm are the preferred forms of HPSC for integration with storage units.

• Thermal evaluation of a residential hot water system equipped with an Evacuated Tube Heat Pipe Solar Collector with Storage (ETHPSC/S) [78].	Paraffin	• Increasing the annual solar fraction by 20.5% and raising the hot water temperature within the tank compared to conventional HPWH systems.
• Exploring the use of PCM in solar water heating systems, with a specific emphasis on HPWH systems [79]. Top of Form	Various materials and composites	• While there has been extensive research on utilizing PCM for FPCs, there is a need for further investigation concerning HPSCs and CPC collectors. • The incorporation of PCM significantly enhances the energy storage capacity of a SWH system. • Further research is required, particularly for implementing PCM in large-scale applications.
• Developing a numerical model for simulating the thermal behavior of heat pipes in conjunction with phase change materials (PCM) [80].	Cu-0.3Si	• Investigating variable thermal input to establish precise boundary conditions for solar applications. • Performing a parametric study to evaluate the influence of heat transfer rate and the height of the PCM enclosure. • Increasing the height-to-diameter ratio of the PCM enclosure enhanced PCM melting and decreased the temperature of the lower wall of the heat pipe, while employing CPC raised PCM temperature on the shaded side of the HPSC.
• Performing an experiment utilizing a solar water heater incorporating a nanocomposite phase change material [81].	Paraffin wax was infused with 1 mass% each of Si and CuO.	• The energy efficiency of the systems lacking PCMs, incorporating PCMs, and employing a nanocomposite PCM was determined to be 33.8%, 38.3%, and 41.7%, correspondingly.
• Conducting an experiment utilizing a heat pipe solar collector/storage heating system equipped with CPC. [82]	Paraffin	• The utilization of CPC led to a 5% improvement in average charging efficiency and a 9% enhancement in maximum charging efficiency.
• Conducting an experimental evaluation of the thermal performance of a heat pipe evacuated tube solar collector system that incorporates a phase change material [83].	Stearic acid as a PCM	• The daily thermal efficiency of an evacuated tube solar collector was assessed, considering configurations with and without phase change materials. The efficiency for the system with phase change materials varied between 42% and 55%, while for the system without phase change materials, it ranged from 79% to 87%. Intriguingly, both systems attained their peak daily thermal efficiency when operating at a flow rate of 20 liters per hour.
• An experimental investigation was carried out on a residential solar water heater system that incorporated phase-change energy storage linked to a solar collector [84].	$Ba(OH)_2 \cdot 8H_2O$ as a PCM and BaCO3 used as a nucleant	• The system's performance is affected by both solar radiation and initial water temperature.

• Employing phase change materials, a quick simulation was run to do a parametric analysis of a solar evacuated tube collector's efficiency [4].	RT-40	• Increasing the mass fraction of MWCNT nanoparticles and the mass flow rate of the HTF may improve the thermal performance of ETC-PCM systems.
• The evaluation encompassed an assessment of the thermal performance of a solar evacuated tube collector that incorporated phase change material [4].	Paraffin wax	• The thermal energy process is enhanced by 20%, with an optimal charging and discharging diameter of 6 mm.
• An experimental exploration was conducted on a solar water heating system that incorporated a nanocomposite phase change material comprising SiC and CuO [81].	Pwax by mixing it with SiC and CuO nanoparticles	• The energy efficiencies in these three scenarios were recorded as 33.8%, 38.3%, and 41.7%, respectively. Additionally, the system's exergy efficiency was found to be 1.78%, 2.1%, and 3.2%. The inclusion of SiC and CuO nanoparticles in Pwax resulted in a notable 22.53% increase in its thermal conductivity.

III. Thermal performance of collector

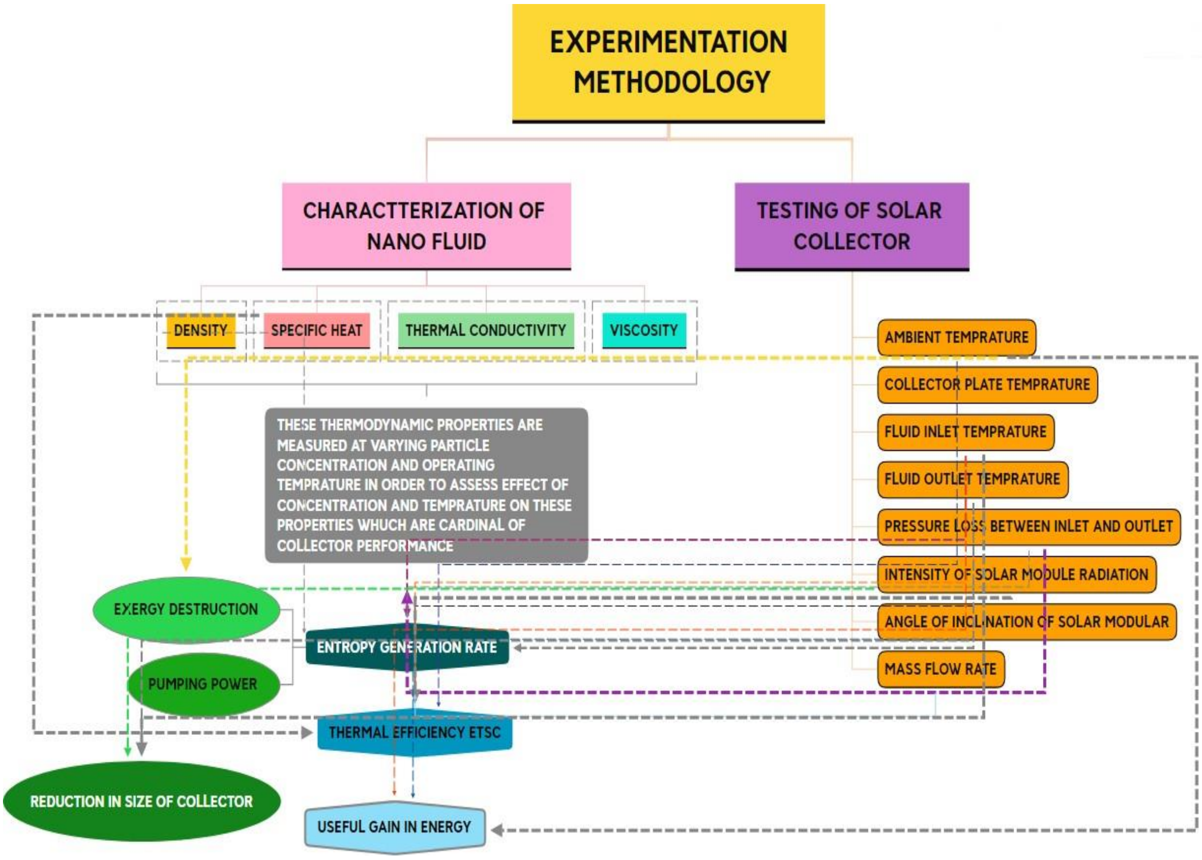


Figure: 23 Experiment methodology for ETC

The amount of solar energy that the plate absorbs determines how well the solar thermal collector works. The terms "useful energy gain" and "collector efficiency" are frequently used to describe this phenomenon. Q watts of sun radiation reach the solar collector.

$$Q=IA \tag{1}$$

Eq. (1) shows that I is the current solar radiation intensity in W/m^2, and A is the collecting area in m^2. Because some of this radiation is reflected back to the sky, the glazing absorbs some of it, while the remainder passes through the glazing and reaches the absorber plate as short-wave radiation. To acquire the actual current absorbed by the collector, a conversion factor is required. It is essentially the sum of the cover's transmission rate and the absorber's absorption rate. Eq. (2) can so be represented as

$$\boldsymbol{Q = I(\tau\alpha)A} \quad (2)$$

What affects the collector is the transmission-absorption product, which is the intensity of solar light. As the heat is absorbed, the collector's temperature rises, and convection and radiation release the heat into the atmosphere. The rate of heat loss can be determined using the total heat transfer coefficient U, as indicated.

$$\boldsymbol{Q_l = u_l A(T_C - T_a)} \quad (3)$$

where T_c is the average temperature of the collector and T_a is the ambient temperature. The efficiency of the collector can be expressed as

$$\boldsymbol{\eta = \frac{Rate\ of\ useful\ energy\ extracted\ by\ the\ collector\ (Q_u)}{Total\ solar\ radiation}} \quad (4)$$

Here, $Q_u = Q - Q_l$

$$\boldsymbol{\eta = \frac{I(\tau\alpha)A}{I(\tau\alpha)A - U_{lA}(Tc - Ta)}}$$

IV. Conclusions

Solar water heating (SWH) is recommended for use in various settings such as businesses, hotels, and hostels. When assessing the economic viability of hybrid SWH systems, it is evident that there is still significant room for improvement. Most research has concentrated on forced circulation systems, highlighting the need for enhancements in thermosiphon circulation SWHS. This article provides a comprehensive overview of recent advancements in the application of nanofluids in heat pipe solar collectors. Future investigations should prioritize understanding how nanofluid optical properties and fluid characteristics, beyond just thermal conductivity, affect the performance of these collectors. To further drive down the costs of nanofluid-based solar collectors and meet market demands efficiently, future research should concentrate on the development of non-toxic and cost-effective nanoparticles. Achieving optimal efficiency in nanofluid collectors will necessitate precise adjustments to the volume fraction of nanoparticles.

IV. Future scope

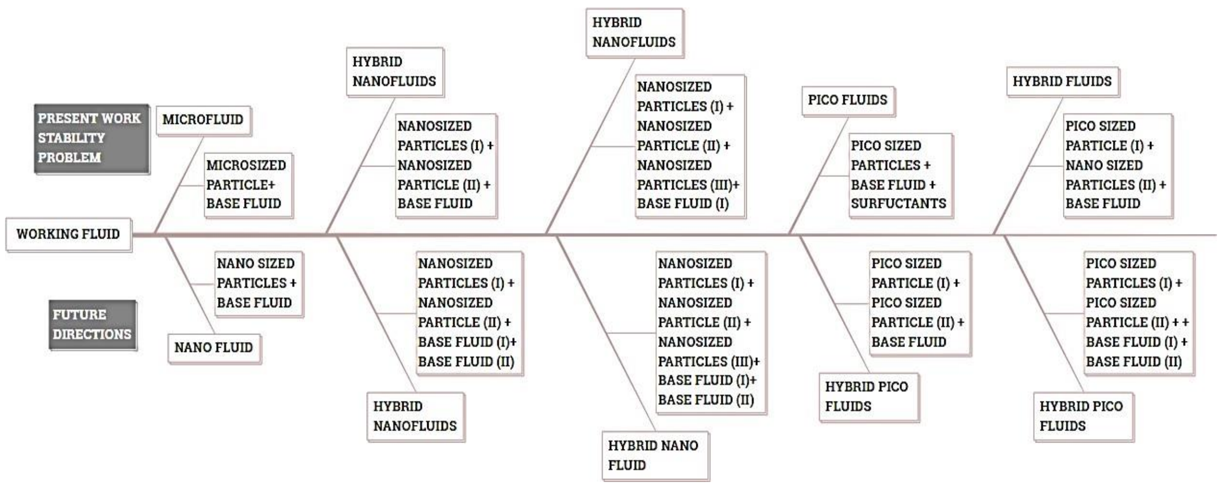


Figure: 24 Present and future recommendation for working fluid

Utilizing heat pipes can expand the temperature capabilities of evacuated tube collectors paired with reflectors, extending their applicability from medium to high-temperature scenarios. For effective operation, nanofluids must maintain stability, necessitating innovative strategies to prevent particle agglomeration and settling. Simplifying and cost-effectively scaling up nanofluid production remains an area requiring further investigation. Addressing this challenge involves enhancing the materials and robustness of heat pipes, aiming to enhance reliability without compromising performance. Given the intermittent nature of solar energy, substantial research has been undertaken to advance phase change materials (PCMs) suitable for the 50-90 °C temperature range. PCMs with high latent heat capacity can be integrated into evacuated tube collector systems, enabling daytime heat storage for subsequent nighttime use, catering to both commercial and residential demands. A unique fin design offers the potential to augment the surface area of the condenser section. While the absorber pipe coating in evacuated tubes typically boasts a 5-year lifespan, ongoing research is imperative to enhance coating durability. Since they are the most commonly utilized in industrial applications, cylinder-shaped heat pipes have been extensively researched because they are simple to fabricate, handle, fill, and refill with working fluid. Future research could determine the best orientation and material for heat pipes as well as the effects of variations in heat load on heat pipe performance.

An extensive study has been conducted on mono nanofluid as a working medium. The research covers subjects such as nanofluid types, wick construction, nanoparticle concentration, fill ratio, orientation, and heat load. There has been very little research on hybrid nanofluids and how to compare nanofluids in which individual nanoparticles are suspended. Hybrid nanoparticles could be used to explore the impact of various suspended nanoparticles, their proportions, concentrations, filling ratio, and surface morphology as well as their production technique on the thermal performance of heat pipes. The production of nanofluids and hybrid nanofluids is also a difficult task

References

[1] A. Kumar, Z. Said, and E. Bellos, "An up - to - date review on evacuated tube solar collectors," *J. Therm. Anal. Calorim.*, vol. 145, no. January, pp. 2873–2889, 2020.

[2] D. V. M. Renjish Kumar V K, "Energy consumption in India-Recent trends.," *Asia Pacific J. Res.*, vol. I, no. XXXVI, pp. 140–151, 2016.

[3] S. M. Lalwani M, *Conventional and renewable energy scenario of India: present and future.*, vol. I, no. VI. 2010.

[4] A. Uniyal *et al.*, "Recent Advancements in Evacuated Tube Solar Water Heaters: A Critical Review of the Integration of Phase Change Materials and Nanofluids with ETCs," *Energies.*, vol. 15, no. 8999, pp. 1–25, 2022.

[5] R. K. Mishra, V. Garg, and G. N. Tiwari, "Thermal modeling and development of characteristic equations of evacuated tubular collector (ETC)," *Sol. Energy*, vol. 116, pp. 165–176, 2015.

[6] W. Yu and H. Xie, "A review on nanofluids: Preparation, stability mechanisms, and applications," *J. Nanomater.*, vol. 2012, no.I, pp. 1-17, 2012.

[7] S. S. Abhishek Gautama, Sunil Chamolib, Alok Kumara, "A review on technical improvements, economic feasibility and world. scenario of solar water heating system," *Renew. Sustain. Energy Rev.*, vol. 68, no. July 2015, pp. 541–562, 2017.

[8] K. Huang, B. Su, T. Li, H. Ke, M. Lin, and Q. Wang, "Numerical simulation of the mixing behaviour of hot and cold fluids in the rectangular T-junction with/without an impeller," *Appl. Therm. Eng.*, vol. 204, no. 117942, 2022.

[9] H. Chang, Z. Han, X. Li, T. Ma, and Q. Wang, "Experimental study on heat transfer performance of sCO2 near pseudo-critical point in airfoil-fin PCHE from viewpoint of average thermal-resistance ratio," *Int. J. Heat Mass Transf.*, vol. 196, no. UNPUBLISHED, 2022.

[10] S. G. Edward S, *Solar collector*. 1963.

[11] W. I. Watkins AW, "U.S. Patent No," 4,987,883, 1991.

[12] S. G. Edward S, *Solar collector*, no. 1259. 2002.

[13] V. J. McConnell RD, "Glass heat pipe evacuated tube solar collector U.S. Patent," 4,474,170, 1984.

[14] W. B. Zhiqiang Y, Harding GL, "water-in-glass manifolds for heat extraction from evacuated solar collector tubes.," *Sol Energy.*, vol. 32, no. 2, pp. 223–30, 1984.

[15] Ezekwe CI., "Thermal performance of heat pipe solar energy systems.," *Sol Wind Technol.*, vol. 7, no. 4, pp. 349–54, 1990.

[16] El-Nashar AM., "The effect of dust accumulation on the performance of evacuated tube collectors.," *Sol Energy.*, vol. 53, no. 1, pp. 105–15, 1994.

[17] W. L. Zinian H, Hongchuan G, Fulin J, "comparison of optical performance between evacuated collector tubes with flat and semicylindric absorbers," *Sol Energy.*, vol. 60, no. 2, pp. 109–17, 1997.

[18] B. T. Benz N, "High efficiency evacuated flat-plate solar collector for process steam production.," *Sol Energy.*, vol. 65, no. 2, pp. 111–8, 1999.

[19] M. G. Mills DR, "Compact linear fresnel reflector solar thermal powerplants.," *Sol energy.*, vol. 68, no. 3, pp. 263–83, 2000.

[20] R. K. Bumataria, N. K. Chavda, and H. Panchal, "Heliyon Current research aspects in mono and hybrid nano fl uid based heat pipe technologies," vol. 5, no. March, 2019.

[21] E. M. Yogev A, Krupkin V, : "1996.," Patent No. 5,578,140., 1996.

[22] D. S. Zakhidov AA, Pozdin VA, Hassanipour F and P. A., "Integration of phase change materials inside evacuated tube solar collector for storage and transfer of thermal energy.," Application 14/455,766, filed, 2015.

[23] M. A. Sabiha, R. Saidur, S. Hassani, Z. Said, and S. Mekhilef, "Energy performance of an evacuated tube solar collector using single walled carbon nanotubes nanofluids," *ENERGY Convers. Manag.*, vol. 105, pp. 1377–1388, 2015.

[24] S. K. Assilzadeh F, Kalogirou SA, Ali Y, "Simulation and optimization of a LiBr solar absorption cooling system with evacuated tube collectors.," *Renew Energy.*, vol. 30, no. 8, pp. 1143–59, 2005.

[25] Y. Kim and T. Seo, "Thermal performances comparisons of the glass evacuated tube solar collectors with shapes of absorber tube," *Renew. Energy*, vol. 32, no. 5, pp. 772–795, 2007.

[26] X. Huang *et al.*, "Theoretical and experimental studies of impacts of heat shields on heat pipe evacuated tube solar collector," *Renew. Energy*, vol. 138, pp. 999–1009, 2019.

[27] mervyn smyth Dan nchelatebe nkwetta, “Performance analysis and comparison of evcuated tube heat pipe solar collectors.pdf,” *Appl. Energy*, vol. 98, no. 2012, pp. 22–32, 2012.
[28] E. Azad, “Assessment of three types of heat pipe solar collectors,” *Renew. Sustain. Energy Rev.*, vol. 16, no. 5, pp. 2833–2838, 2012.
[29] Y. Wang, X. Han, Q. Liang, W. He, and Z. Lang, “Experimental investigation of the thermal performance of a novel concentric condenser heat pipe array,” *Int. J. Heat Mass Transf.*, vol. 82, pp. 170–178, 2015.
[30] Y. Naresh and C. Balaji, “Thermal performance of an internally finned two phase closed thermosyphon with refrigerant R134a: A combined experimental and numerical study,” *Int. J. Therm. Sci.*, vol. 126, no. July 2017, pp. 281–293, 2018.
[31] J. S. Kim, S. J. Ha, S. Il Lee, and B. H. Jeong, “the Study of Evacuated Solar Collector Using Pulsating Heat Pipe,” *Front. Heat Pipes*, vol. 3, no. 4, pp. 196–200, 2013.
[32] H. M. S. Hussein, H. H. El-Ghetany, and S. A. Nada, “Performance of wickless heat pipe flat plate solar collectors having different pipes cross sections geometries and filling ratios,” *Energy Convers. Manag.*, vol. 47, no. 11–12, pp. 1539–1549, 2006.
[33] M. S. Abd-Elhady, M. Nasreldin, and M. N. Elsheikh, “Improving the performance of evacuated tube heat pipe collectors using oil and foamed metals,” *Ain Shams Eng. J.*, vol. 9, no. 4, pp. 2683–2689, 2018.
[34] A. E. Kabeel, M. M. Khairat Dawood, and A. I. Shehata, “Augmentation of thermal efficiency of the glass evacuated solar tube collector with coaxial heat pipe with different refrigerants and filling ratio,” *Energy Convers. Manag.*, vol. 138, pp. 286–298, 2017.
[35] Mcintire, W.R., “Design parameters for concentrators without gap losses.,” *Sol. Energy*, vol. 32, no. 3, pp. 439–441, 1984.
[36] S. B. Li, G.Q., Pei, G., Su, Y.H., Ji, J., Riffat, “Experiment and simulation study on the flux distribution of lens-walled compound parabolic concentrator compared with mirror compound parabolic concentrator.,” *Energy*, vol. 58, no. 1, pp. 398–403, 2013.
[37] Y. H. Pei, G., Li, G.Q., Xi, Z., Ji, J., Su, “Comparative experimental analysis of the thermal performance of evacuated tube solar water heater systems with and without a mini-compound parabolic concentrating (CPC) reflector (C < 1).,” *Energies.*, vol. 5, no. 4, pp. 911–924, 2012.
[38] Z. Liu, H. Li, B. Chen, J. Yang, and W. Liu, “Operational characteristics of flat type loop heat pipe with biporous wick,” *Int. J. Therm. Sci.*, vol. 58, pp. 180–185, 2012.
[39] X. H. Wang, H. C. Zheng, M. Q. Si, X. H. Han, and G. M. Chen, “Experimental investigation of the influence of surfactant on the heat transfer performance of pulsating heat pipe,” *Int. J. Heat Mass Transf.*, vol. 83, pp. 586–590, 2015.
[40] D. Milani and A. Abbas, “Multiscale modeling and performance analysis of evacuated tube collectors for solar water heaters using diffuse flat reflector,” *Renew. Energy*, vol. 86, pp. 360–374, 2016.
[41] M. D. Vahid Madadi Avargani, Amir Rahimi, “Coupled optical and thermal analyses of a new type of solar water heaters using parabolic trough reflectors,” *Sustain. Energy Technol. Assessments*, vol. 40, no. 100780, 2020.
[42] H. H. Saleh Abo-Elfadl, “Energy and exergy assessment of integrating reflectors on thermal energy storage of evacuated tube solar collector-heat pipe system,” *Sol. Energy*, vol. 209, pp. 470–484, 2020.
[43] Y. D. Shaowei Chai, Jian Yao, Jyun-De Liang, Yuan-Ching Chiang, Yao Zhao, Sih-Li Chen, “Heat transfer analysis and thermal performance investigation on an evacuated tube solar collector with inner concentrating by reflective coating,” *Sol. Energy*, vol. 220, no. May 2021, pp. 175–186, 2021.
[44] B. Kiran Naik, S. Premnath, and P. Muthukumar, “Performance comparison of evacuated U-tube solar collector integrated parabolic reflector with conventional evacuated U-tube solar collector,” *Sadhana - Acad. Proc. Eng. Sci.*, vol. 46, no. 3, 2021.
[45] R. A. P. S.N. Dinesh, S. Ravi, P. Manoj Kumar, Ram Subbiah, Alagar Karthick, P.T. Saravanakumar, “Study on an ETC solar water heater using flat and wavy diffuse reflectors,” *Mater. Today Proc.*, vol. 47, no. 15, pp. 5228–5232, 2021.
[46] Y. D. Guangbai Ma, Zhiqiang Yin, Xijie Liu, Jing Qi, “Developments of CPC solar evacuated glass tube collector with a novel selective coating,” *Sol. Energy*, vol. 220, no. 2021, pp. 1120–1129, 2021.
[47] R. T. Weiwei Zhang, Linzuo Duan, Jiabin Wang, Xuyang Ba, Zijing Zhang, “Influences of tracking and installation errors on the optical performance of a parabolic trough collector with heat pipe evacuated tube,” *Sustain. Energy Technol. Assessments*, vol. 50, no. 101721, 2022.
[48] H. Kim, H., Ham, J., Park, C., Cho, “Theoretical investigation of the efficiency of a U-tube solar collector using various nanofluids.,” *Energy*, vol. 94, pp. 497–507, 2016.
[49] M. A. Sharafeldin and G. Gróf, “Efficiency of evacuated tube solar collector using WO3/Water nanofluid,” *Renew. Energy*, vol. 134, pp. 453–460, 2019.
[50] J. M. B.-F. Oscar A. López-Núñez, J. Arturo Alfaro-Ayala, J.J. Ramírez-Minguela, Fernando Cano-Banda, B. Ruiz-Camacho, “Numerical analysis of the thermo-hydraulic performance and entropy generation rate of a water-in-glass evacuated tube solar collector using TiO2 water-based nanofluid and only water as working fluids,” *Renew. Energy*, vol. 197, pp. 953–965, 2022.
[51] 2017. Liu, Z.J., Li, H., Liu, K.J., Yu, H.C., Cheng, K.W., “Design of high-performance waterin-glass evacuated tube solar water heaters by a high-throughput screening based on machine learning: a combined modeling and experimental study. 142, 61–67.,” *Sol. Energy*, vol. 142, no. 1, pp. 61–67, 2017.
[52] M. S. Sabiha MA, Saidur R, Hassani S, Said Z, “Energy performance of an evacuated tube solar collector using single walled carbon nanotubes nanofluids. 2015; 105:1377–88.,” *Energy Convers Manag.*, vol. 105, no. 1377–88, 2015.
[53] S. S. Mohsen Rezaeian, Mohammad Shafiey Dehaj, Mostafa Zamani Mohiabadi, Masoud Salarmofrad, “Experimental investigation into a parabolic solar collector with direct flow evacuated tube,” *Appl. Therm. Eng.*, vol. 189, no. 116608, 2021.
[54] S. I. N. Mohammed J. Alshukri, Adel A. Eidan, “The influence of integrated Micro-ZnO and Nano-CuO particles/paraffin wax as a thermal booster on the performance of heat pipe evacuated solar tube collector,” *J. Energy Storage*, vol. 37, no. 102506, 2021.
[55] J. Sarkar, P. Ghosh, and A. Adil, “A review on hybrid nano fl uids: Recent research , development and applications,” *Renew. Sustain. Energy Rev.*, vol. 43, pp. 164–177, 2015.
[56] M. M. Sarafraz and F. Hormozi, “Experimental study on the thermal performance and efficiency of a copper made thermosyphon heat pipe charged with alumina-glycol based nanofluids,” *Powder Technol.*, vol. 266, pp. 378–387, 2014.
[57] M. M. Sarafraz, F. Hormozi, and S. M. Peyghambarzadeh, “Thermal performance and efficiency of a thermosyphon heat pipe working with a biologically ecofriendly nanofluid,” *Int. Commun. Heat Mass Transf.*, vol. 57, pp. 297–303, 2014.
[58] A. Amiri *et al.*, “Performance dependence of thermosyphon on the functionalization approaches: An experimental study on thermo-physical properties of graphene nanoplatelet-based water nanofluids,” *Energy Convers. Manag.*, vol. 92, pp. 322–330, 2015.
[59] S. Khandekar, Y. M. Joshi, and B. Mehta, “Thermal performance of closed two-phase thermosyphon using nanofluids,” *Int. J. Therm. Sci.*, vol. 47, no. 6, pp. 659–667, 2008.
[60] S. H. Noie, S. Z. Heris, M. Kahani, and S. M. Nowee, “Heat transfer enhancement using Al2O3/water nanofluid in a two-phase closed thermosyphon,” *Int. J. Heat Fluid Flow*, vol. 30, no. 4, pp. 700–705, 2009.
[61] G. Huminic, A. Huminic, I. Morjan, and F. Dumitrache, “Experimental study of the thermal performance of thermosyphon heat pipe using iron oxide nanoparticles,” *Int. J. Heat Mass Transf.*, vol. 54, no. 1–3, pp. 656–661, 2011.
[62] Y. J. Chen, P. Y. Wang, and Z. H. Liu, “Application of water-based SiO2 functionalized nanofluid in a loop thermosyphon,” *Int. J. Heat Mass Transf.*, vol. 56, no. 1–2, pp. 59–68, 2013.

[63] Z. hua Liu, X. fei Yang, G. san Wang, and G. liang Guo, "Influence of carbon nanotube suspension on the thermal performance of a miniature thermosyphon," *Int. J. Heat Mass Transf.*, vol. 53, no. 9–10, pp. 1914–1920, 2010.

[64] A. Sözen, T. Menlik, M. Gürü, A. F. Irmak, F. Kiliç, and M. Aktaş, "Utilization of fly ash nanofluids in two-phase closed thermosyphon for enhancing heat transfer," *Exp. Heat Transf.*, vol. 29, no. 3, pp. 337–354, 2016.

[65] T. Grab, U. Gross, U. Franzke, and M. H. Buschmann, "Operation performance of thermosyphons employing titania and gold nanofluids," *Int. J. Therm. Sci.*, vol. 86, pp. 352–364, 2014.

[66] H. R. Goshayeshi, M. Goodarzi, and M. Dahari, "Effect of magnetic field on the heat transfer rate of kerosene/Fe2O3 nanofluid in a copper oscillating heat pipe," *Exp. Therm. Fluid Sci.*, vol. 68, pp. 663–668, 2015.

[67] M. Azizi, M. Hosseini, S. Zafarnak, M. Shanbedi, and A. Amiri, "Experimental analysis of thermal performance in a two-phase closed thermosiphon using graphene/water nanofluid," *Ind. Eng. Chem. Res.*, vol. 52, no. 29, pp. 10015–10021, 2013.

[68] Z. Liu and Q. Zhu, "Application of aqueous nanofluids in a horizontal mesh heat pipe," *Energy Convers. Manag.*, vol. 52, no. 1, pp. 292–300, 2011.

[69] M. H. Buschmann and U. Franzke, "Improvement of thermosyphon performance by employing nanofluid," *Int. J. Refrig.*, vol. 40, pp. 416–428, 2014.

[70] D.P. Kamble, P.S. Gadhave, M.A. Anwar, "Enhancement of thermal performance of heat pipe using hybrid nanofluid, 17 (2014) 425–428.," *Int. J. Eng. Trends Technol.*, vol. 17, pp. 425–428, 2014.

[71] P. K. Swapnil, P. Dhananjay, Z. Gaurav, R. Anand, K. D, "heat transfer enhancement of circular heat pipe with AL2O3 BN/water hybrid Nanofluid," *Int. J. Curr, Eng. Technol. 138–143*, pp. 138–143, 2016.

[72] S. Y. B. A. Chaudhari, "Performance evaluation of circular heat pipe using (CuO +BN)/H2O hybrid nanofluid.," *Int. J. Eng. Manag. Res.*, vol. 6, pp. 315–321, 2016.

[73] R. N. Ramachandran, K. Ganesan, and L. G. Asirvatham, "The role of hybrid nanofluids in improving the thermal characteristics of screen mesh cylindrical heat pipes," *Therm. Sci.*, vol. 20, no. 6, pp. 2027–2035, 2016.

[74] W.S. Han, S.H. Rhi, "Thermal characteristics of grooved heat pipe with hybrid nanofluids, 15 (2011) 195–206, https://doi.org/10.2298/ TSCI100209056H.," *Therm. Sci.*, vol. 15, pp. 195–206, 2011.

[75] V. V Tyagi, A. K. Pandey, G. Giridhar, B. Bandyopadhyay, S. R. Park, and S. K. Tyagi, "Comparative study based on exergy analysis of solar air heater collector using thermal energy storage," no. February 2011, pp. 724–736, 2012.

[76] A. Papadimitratos, S. Sobhansarbandi, V. Pozdin, A. Zakhidov, and F. Hassanipour, "Evacuated tube solar collectors integrated with phase change materials," *Sol. Energy*, vol. 129, pp. 10–19, 2016.

[77] B. Li and X. Zhai, "Experimental investigation and theoretical analysis on a mid-temperature solar collector/storage system with composite PCM," *Appl. Therm. Eng.*, vol. 124, pp. 34–43, 2017.

[78] P. Feliński and R. Sekret, "Effect of PCM application inside an evacuated tube collector on the thermal performance of a domestic hot water system," *Energy Build.*, vol. 152, pp. 558–567, 2017.

[79] M. K. A. Sharif *et al.*, "Review of the application of phase change material for heating and domestic hot water systems," *Renew. Sustain. Energy Rev.*, vol. 42, pp. 557–568, 2015.

[80] N. Sharifi, A. Faghri, T. L. Bergman, and C. E. Andraka, "Simulation of heat pipe-assisted latent heat thermal energy storage with simultaneous charging and discharging," *Int. J. Heat Mass Transf.*, vol. 80, pp. 170–179, 2015.

[81] M. D. A. A.S. Manirathnam, M.K. Dhanush Manikandan, R. Hari Prakash, B. Kamesh Kumar, "Experimental analysis on solar water heater integrated with Nano composite phase change material (SCi and CuO)," *Mater. Today Proc.*, vol. 37, Part 2, no. ISSN 2214-7853, pp. 232–240, 2021.

[82] P. Feliński and R. Sekret, "Effect of a low-cost parabolic reflector on the charging efficiency of an evacuated tube collector/storage system with a PCM," *Sol. Energy*, vol. 144, pp. 758–766, 2017.

[83] K. Chopra, A. K. Pathak, V. V. Tyagi, A. K. Pandey, S. Anand, and A. Sari, "Thermal performance of phase change material integrated heat pipe evacuated tube solar collector system: An experimental assessment," *Energy Convers. Manag.*, vol. 203, no. July 2019, p. 112205, 2020.

[84] H. S. Xue, "Experimental investigation of a domestic solar water heater with solar collector coupled phase-change energy storage," *Renew. Energy*, vol. 86, pp. 257–261, 2016.