Review on Research Aspects of Evacuated Tube Heat Pipe Solar Collectors

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ABSTRACT

The global demand for hot water is rising exponentially due to population and industrialization. Solar water heaters are modern devices in which the incident solar radiation is absorbed by the absorbing surface and used to heat water. This research work focuses on the latest developments and advances with an overview of the reported use of nanofluids in solar heat pipe collectors. There is ample potential to improve the efficiency of the system significantly. Moreover, this review outlines future suggestions for improving the performance of evacuated tube heat pipe solar collectors. Attempts are made in this study to give an overview of current thrust research areas of Evacuated tube collector flow, heat transfer mechanisms, and heat pipes with different working fluids.

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

I. INTRODUCTION

Energy importers China, India, the United Kingdom, and the United States rely extensively on fossil fuels to supply their energy needs. In 2004, China's contribution to renewable energy increased by 25%, compared to 7% to 9% increase in electricity demand. China accounts for 40% of the world's collector area [1]. In terms of energy consumption, India is Asia's third most important country after Japan and China [2]. Traditional energy sources such as coal-fired power plants and mineral oil power plants provide the majority of India’s electricity, contributing significantly to greenhouse gas emissions [3]. Hence, in order to minimize emissions and meet the increasing energy demands, a paradigm shift is required to utilize renewable energy efficiently and effectively without damaging the environment. The Ministry of New and Renewable Energy (MNRE) in the Government of India reported that in the residential sector, the demand for hot water was about 129 million/day in 2017; however, it would be doubled by 2022 [4]. India has year-round access to plenty of sunlight, which makes solar water heaters an effective and reliable energy source. Utilizing solar energy can dramatically lower the power needed to heat water.

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

One of the cheapest collectors for water heating is the evacuated tube collector (ETC). The evacuated tubes are made up of two concentric glass tubes. Evacuation is formed in the annulus between the inner and outer pipes to limit heat loss. Various techniques are used to transmit heat absorbed by an absorber to the heat transfer fluid. One of the newest and most efficient technologies with extraordinarily high thermal conductivity is the heat pipe. Long service life, corrosion resistance, and temperature control are the main advantages of heat pipe evacuated tube solar collectors (HPETC).

A heat pipe is enclosed in a glass casing in the HPETC. The weather conditions have a considerable impact on the effectiveness of the collectors. Their performance suffers on cold, gloomy, and windy days [5]. Condensation, moisture and extreme weather cause the inner pipe materials to deteriorate prematurely, reducing the collector efficiency. Heat transfer through the common base fluid is also constrained. Additionally, due to the pump and its withdrawn power, additional space is required for the natural circulation system due to the necessary position restrictions. Night cooling due to the flow of chilled water, water freezing on cold nights, and pipe corrosion due to the use of water are all factors to considered. All of the above challenges can be resolved by using a heat pipe solar collector, (a high-efficiency heat conductor) inside an evacuated sealed pipe. The heat pipe solar collector is superior than the flat collector in terms of heat loss. Heat pipe solar collectors are available in two categories: single wall glass heat pipe and Dewar tube. A U-tube, heat pipe, or direct contact with liquid can be used to eliminate the major issues. [6]

II. SOLAR WATER HEATING SYSTEM (SWHS)

The SWHS is a water-heating device used for various home and commercial applications which are passive solar water heating systems (PSHWS) and active solar water heating systems (ASHWS).

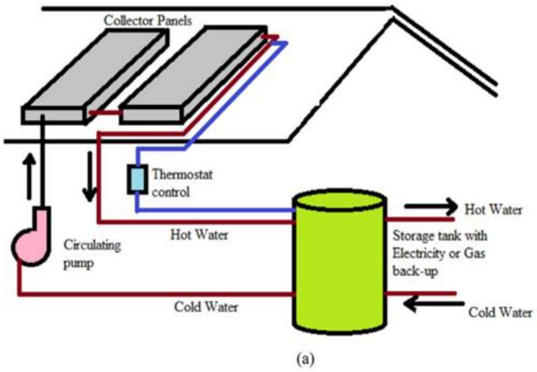

Figure 2: Active solar water heating system with direct circulation (ASWHS)

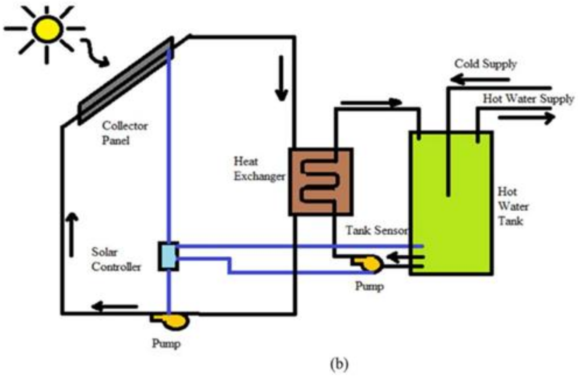

Figure 1 : Passive solar water heating system with indirect circulation (PSHWS)

ASWHSs are systems that use one or more pumps to move the working fluid. A basic diagram of the active ASWHS is shown in Fig. 1. The heat is transmitted to the water in the storage tank by the heat transfer fluid flowing through the heat exchanger between the collectors, which is referred to as direct circulation or open-loop circulation if the water is circulated directly from the collector to the storage tank. The working medium of direct circulation is highly sensitive to the freezing point; therefore, direct circulation SWHSs can only deliver hot water at 50-60 °C. To eliminate the freezing issues, ETC collectors were utilized for residential water heating, which gave outstanding results compared to FPC because of the lower convective heat losses in ETC. A V-trough SWHS is being developed and analyzed and has been found to give better results with economic benefits. In some cold areas, ethylene glycol is used within solar collectors and the heat is transported to the water in the storage tank via the heat exchanger due to its anti-freezing qualities.

The unique characteristic PSHWS of heat by natural convection distinguishes these systems from the other systems, as shown in Fig. 2. Various studies were carried out using different shapes of the tanks, e.g., cylindrical, rectangular, but the heat transfer rate has been increased by the use of cylindrical tanks SWHS. 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 are a kind of heat exchanger that absorbs solar energy and converts it to heat that can be used for a broad range of applications. An absorber is a component of a solar collector that absorbs all heat radiation and transports it to various liquids (air, water, etc.) depending on its use [8][9]. Various types of solar collectors can be used depending on the location, meteorological conditions, purpose, and operating temperature Fig. 3

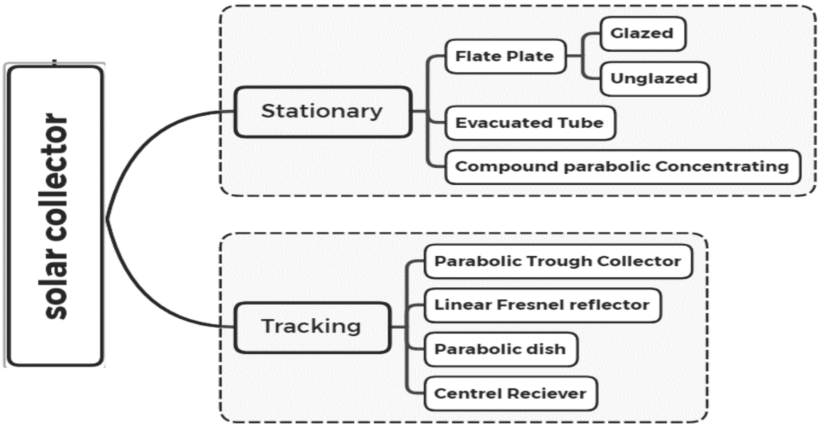

Figure 3:Classification of Solar Collector

B. Development Review of Evacuated Tube Solar Collector

Siegfried Godel and Edward Speyer developed the solar collector in 1963[10] and applied a selectively coated absorber to gain 100% of the radiation. To limit convective losses, envisioned the concept of evacuation around the absorber, Albert and Ivan developed the evacuated tube solar collector [11] and employed two concentric tubes, one with a selectively coated inner tube and the other with toughened glass, to separate two Evacuate separated concentric tubes. Due to the concentration of solar radiation, there was a risk of the glass tube shattering due to nonlinear heating of the opposite side of the glass tube. In 1963, Godel and Edward Speyer [12] used selectively coated absorbers to reduce convective losses. To transport thermal energy from the absorber to the storage tank, McConnell and Vansant [13] designed a glass tube that improves the capillary distribution of the liquid within the heat pipe. The heat pipe contains evenly distributed granulated glass particles. Dispersed glass particles enhance heat transfer. Zhiqiangt and Harding [14] developed an Evacuate tube solar collector to evaluate the variance in the heat transfer rate caused by the flow of liquid from the manifold using water as the medium. Ezekwe [15] evaluated the performance of a heat pipe absorber and discovered that the heat pipe system had a lower heat dissipation factor (FR) and a higher heat transfer ratio than similar systems. To establish the heat pipe system, which is a key factor in determining the amount of heat output found by Ali M. El-Nashar [16]. A comparison between two blocks and a solar panel was conducted using the dust impact on the glass cover. One block was cleaned once at the beginning of the year. During the year the second was not cleaned every month also found a 60% reduction in plant absorption of solar energy. When Zinian et al. [17] compared the optical performance of an evacuated tube with a flat plate vs. an evacuated tube with a semi-cylindrical absorber and found evacuated tube with a semi-cylindrical absorber absorbed 15.9% more solar energy. A flat plate absorber absorbs energy more efficiently. Benz and Beikirche[14] designed a flat-plate collector with an evacuated housing in order to minimize heat losses through gas conduction and convection and to generate steam. Also absorbed the air, argon, krypton and xenon between the glass cover and the absorber plate under Evacuate pressure and found that a flat-plate collector can generate steam at 150 °C with 50% efficiency. Mills used a reflector and n +1 absorber [19] functionality of reflectors and absorbers to reflect solar energy to absorbers. An evacuated tube served as the absorber, converting solar energy into thermal energy with minimal loss. Mills and Morrison [19] used a Fresnel lens to concentrate solar energy for large thermal energy in a smaller space also put 48 reflective mirrors on a tower house and found that a large amount of heat can be used to generate electricity at minimal cost.

Table 2 : Solar Water Heater Development

Development	Thermal Efficiency
Using concrete in the structure	40 %
Inserting honeycomb inside the FPC over the absorber plate by 3mm	46 %
Inserting transparent rectangle slats inside the FPC	49 %
Adding obstacles inside the FPC	50 %
Adding aluminum cans on the absorber plate with in order shape arrangement	59 %
Using a black colored sand under the double-glazing sheets	70 %
Adding aluminum cans on the absorber plate with zigzag shape arrangement	72 %
Two phases thermosyphon SWH	82 %

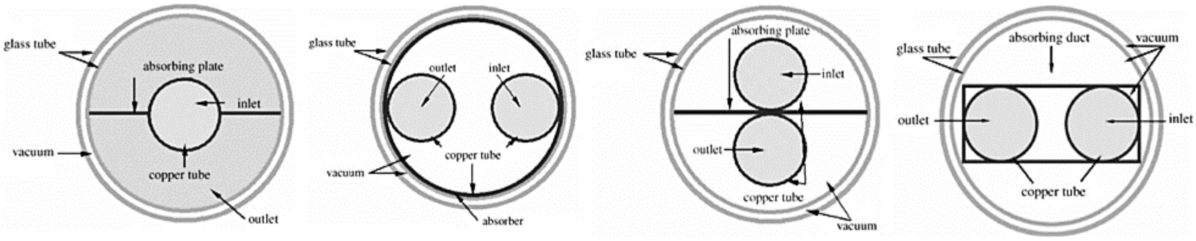

Figure 4: Differences in collector Centre Distance in ETC

Rakesh et al. [20] utilized an evacuated tube solar panel to heat a pressure cooker using12 pipes measuring 1.8 m in length and 63.5 mm in diameter evaporated 8 kg of water at ambient temperature in Delhi in roughly 100 minutes it was found that the system's effectiveness increased as the load increased. Yogev and Epstein [21] developed a solar system with highly reflecting primary and secondary reflectors in certain wavelength range. Primary reflectors reflect the solar radiation to the secondary reflector then reflects to the absorber. R-134a, R-407C, R-22, and water were tested as refrigerants in an evacuated tube, and R-407C performed the least. weather and the thermophysical parameters of refrigerant used in the heat pipe influenced the performance of the evacuated heat pipe solar collector. Zakhidov et al. [22] applied a phase change material which absorbed additional heat as latent heat, then transmitted as needed. Sabiha et al. [23] improved the thermal efficiency of an Evacuated tube solar collector by using carbon nanotube as nanofluid also revealed that single-wall carbon nanotube as nanofluids with volume concentration of 0.2 % had a 93.43% efficiency in Evacuated tube solar collectors. Using the TRNSYS software, Assilzadeh et al. [24] simulated an Evacuated tube solar collector employed a liquid filled heat pipe. The heat pipe liquid evaporates, transferring thermal energy to the manifold. For a solar absorption refrigeration system with the LiBr/H_2O absorption unit and concluded that for a 3.5 kW cold effect concept in Malaysia, a 35 m^2 absorber area of the Evacuated tube solar collector is required to minimize heat losses from the absorber plate to a working medium. 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. At water intake temperature and solar radiation, the effect of heat shields is essentially the same for various parameters including water flow, solar radiation, and ambient temperature.

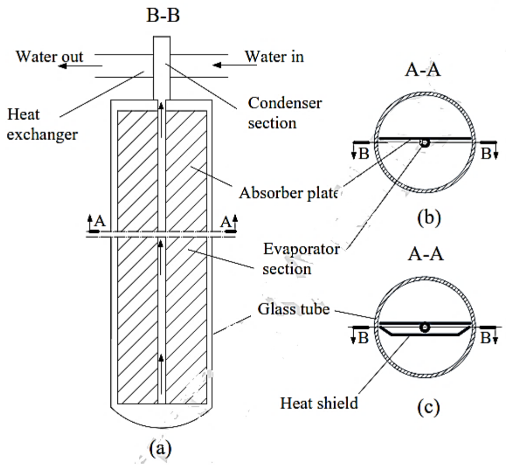

Figure 5: Heat Shielded ETC

Dannchelatebe Nkwetta et al. [27] compared two profiles of concentrated Evacuate tube heat pipe solar collectors made of single-sided and double-sided absorbers, as shown in Fig. 6, in which the double-sided absorber Evacuate heat pipe solar collector (DSACPC) performed better than the single-sided absorber Evacuate pipe heat pipe solar collector (SSACPC) due to its higher outlet temperature.

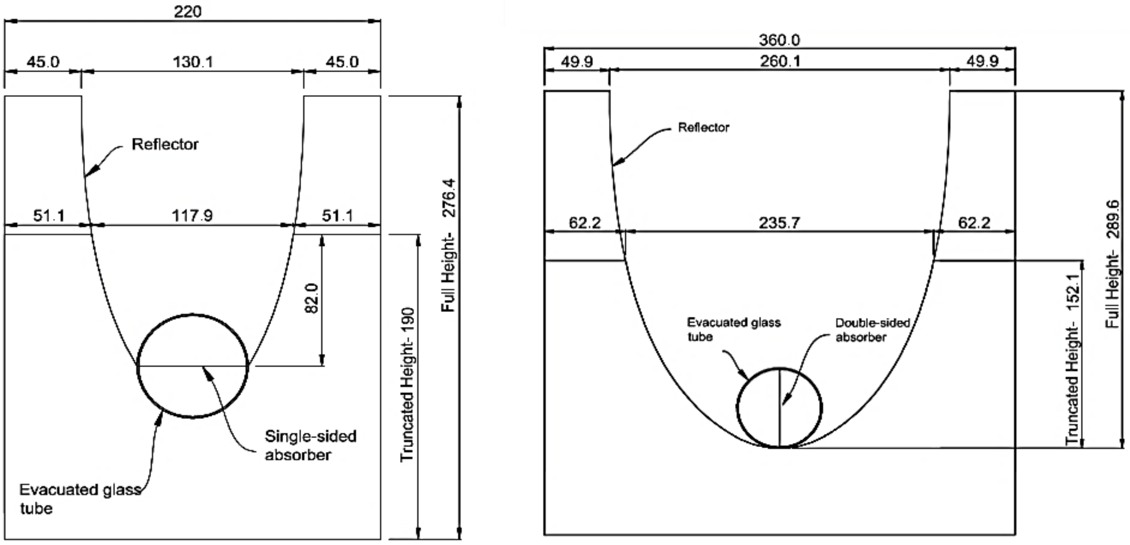

Figure 6 : Side Section view Of the Full and Truncated SSACPC & DSACPC Solar Collector

C. Change in condenser

E. Azad et al. [28] compared different condenser arrangements in solar collector as shown in Fig. 7it was found that type I provides better efficiency over the entire reduced temperature parameter range because the ribbed absorber plate behaves like a honeycomb.

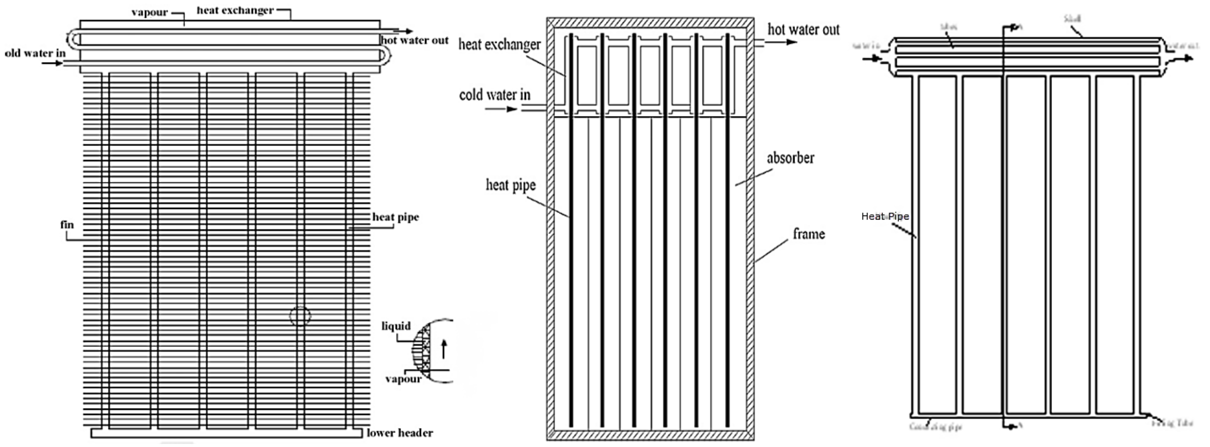

Figure 7 :Different Condenser Arrangement in Solar Collector

Yaxiong Wang et al. [29] found that the condensation heat transfer coefficient and condensation area both increased by a unique concentric condenser heat pipe design depicted in Fig. 8. The maximum heat transfer capacity of the heat pipe array is also influenced by the operating temperature, evaporator length, charge rate, and angle of inclination, notably at higher operating temperatures, as compared to traditional 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.

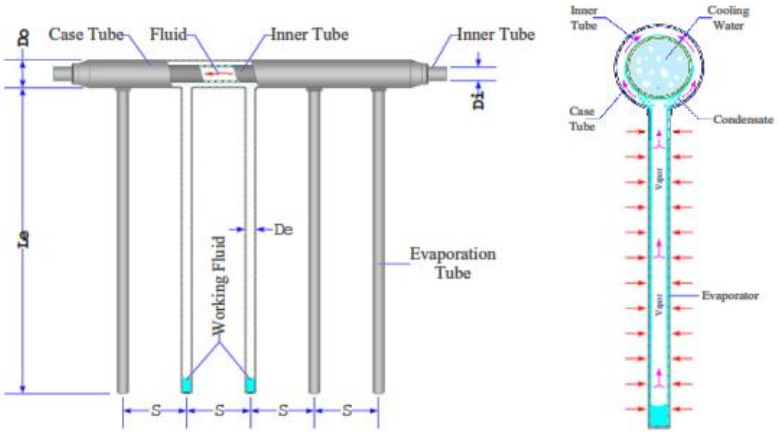

Figure 8 :Novel Concentrate Condenser

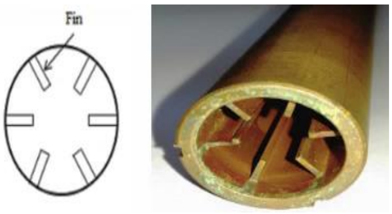

Figure 9: Additional Inner Fins Arrangement in Condenser

D. **Change in Filling Ratio**

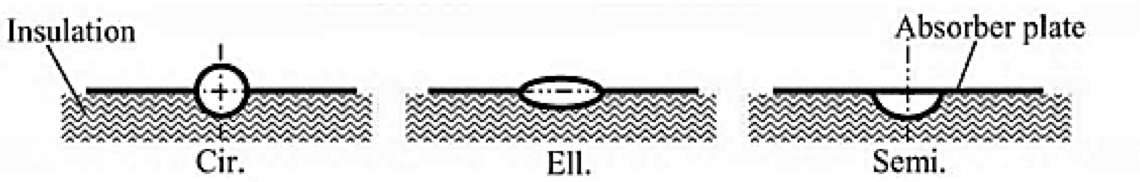

Figure 10 :Cross Sectional Views of Prototype Wickless Heat Pipe

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] concluded that replacing the circular cross-section of wickless heat pipes in Fig. 10 with an elliptical cross-section significantly improved the performance of flat-plate collectors with wickless heat pipes at low water fill levels significantly.

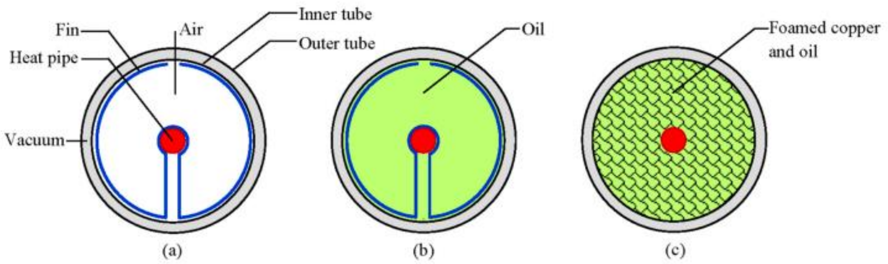

Figure 11:ETC Filling with (a) Air (b) Oil (c) Copper Foam

According to the findings of Mohamed S. Abd-Elhady et al. [33], filling the evacuated tubular heat pipe with oil and foamed copper instead of the fin depicted in Fig. 11 varied the type of heat transmission from pure conduction to conduction and convection. Compared to ribbed surfaces, foamed metals offer better contact between the inner tube of evacuated tube and the heat pipe. Filling air gaps with a good heat transfer medium increases the heat transfer rate. E. Kabeel et al. [34] took two distinct refrigerants, R-22 and R-134a, and charged them into the annulus of the heat pipe between two concentric pipes depicted in Fig. 12. Four distinct air mass fluxes, the degree of filling, and the type of refrigerant used in the experiments were used as variables that influenced the thermal performance of the modified heat pipe. As the mass flow rate is raised, the gain increases while the radiation and convection losses decrease.

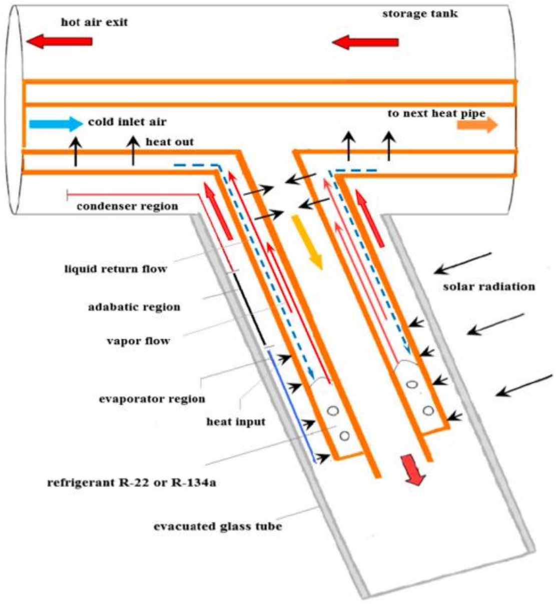

Figure 12: Double Concentratic pipe ETC

E. Change in Reflector

The compound parabolic collector (CPC) has a huge potential for increasing the photothermal performance of solar evacuated tube collectors and many application possibilities. Mcintire [35] developed a novel CPC reflector with V and W shaped to successfully remove loss between the circular absorber and the reflector while improving optical efficiency, although it would lose around 15% of the concentration ratio. Li et al. [36] proposed the development of lens-walled CPC based on mirror CPC, and the experimental results indicated that the lens-walled CPC had a more uniform flow distribution than the mirror CPC, which can significantly increase the PV performance. In the literature, there is a combination of an evacuate tube absorber and a CPC for optical and thermal performance. Under high temperature, Pei el. [37] tested evacuated U-tubes with mini-CPC and observed higher thermal efficiency than standard evacuated U-tubes. Liu et al. [38] carried out an experimental investigation on a low-cost, all-glass solar Evacuate tube steam generator with simplified CPC that generated 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. In order to increase the solar transmittance of the tubes to 0.94, Wang et al. [39] used an antireflection coating made of porous SiO_2 to reduce reflection and heat was supplied to the working fluid by joining copper U-tubes to aluminum fins through welding. A CPC made of aluminum was used to focus the sun's beams, resulting in an instantaneous solar thermal efficiency of 50.2% at 150 °C. Milani and Abbas [40] carried studies to analyse the role of flat diffuse reflectors on the ETC array to boost the heat capture rate. It was found that choosing the optimum configuration with diffuse flat reflector improved solar collector performance by 14.6%, 20.2%, 25.9%, and 27.9%, and saved energy annually by 95.8%, 91.3%, 81%, and 74% for zones 1, 2, 3, and 4. Avargani et al. [41] conducted a CFD study on a unique SWH with PTC arrays, showing that the position of the absorber pipe significantly impacts system efficiency. Abo-Elfadl et al. [42] assessed the effect of top, bottom and both reflectors with the ETSC-heat pipe system, finding a 20.3% increase in stored water temperature. Chai et al. [43] fabricated ETSC with inner focusing reflective coating and analyzed impact on thermal performance whereas found optimum coating, angle 180° and increasing eccentric distance improved the thermal performance. Naik et al. [44] evaluated the effectiveness of standard U-tube and parabolic reflector-fitted U-tube solar collectors, findings indicated that the parabolic reflectors increased collector capacity by 14.1%. Dinesh et al. [45] used flat and wavy diffused reflectors to improve the ETSC, raising water tank temperatures by 6 and 4 °C. Ma et al. [46] developed a medium-temperature selective coating for ETSC, achieving an instantaneous efficiency of around 0.46 at 150 °C. Zhang et al. [47] assessed the impact of receiver

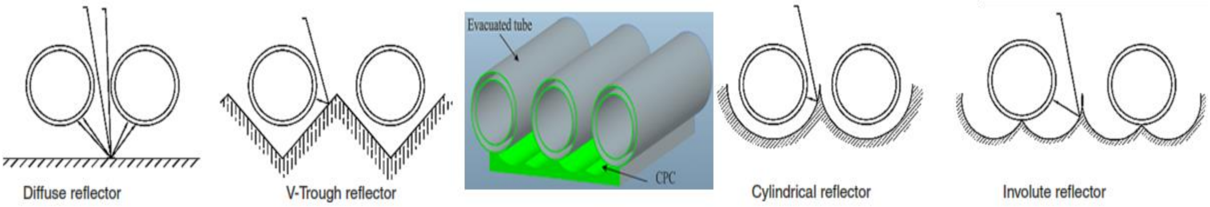

Figure 13: Different types of concentrator

installation error and azimuth-elevation axis tracking error of heat pipe evacuated tube-based PTC optical performance. The U-tube ETC had the highest thermal efficiency (50.2%) when an antireflection coating made of porous SiO_2 was applied to tubes outside surface.

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F. **Change in Working Fluid**

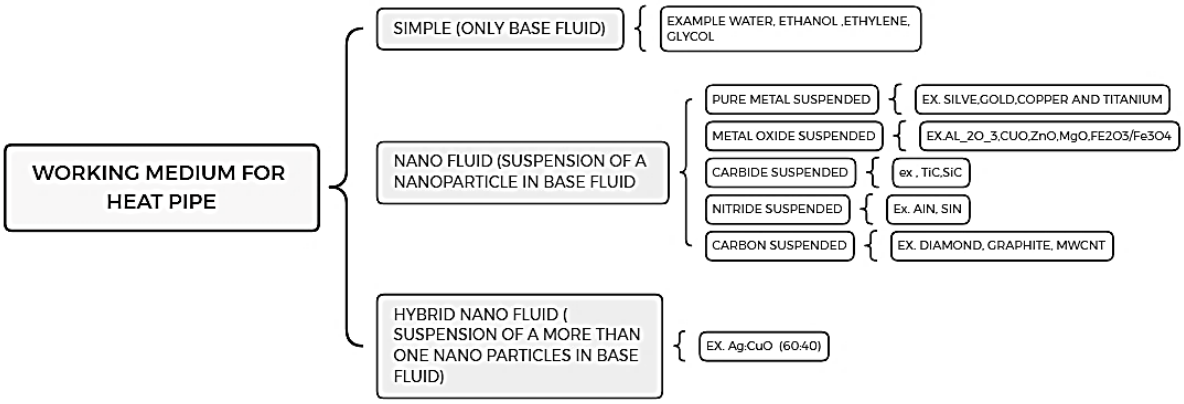

Figure 14: Working Fluids for Heat pipe

Water, ammonia, Freon compounds, and acetone are common working fluids in heat pipes, but their main disadvantage is their low heat conductivity. Recently, improvement in the thermal performance of ETSCs by using additional liquids with high thermal conductivity such as nanofluids are available.

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

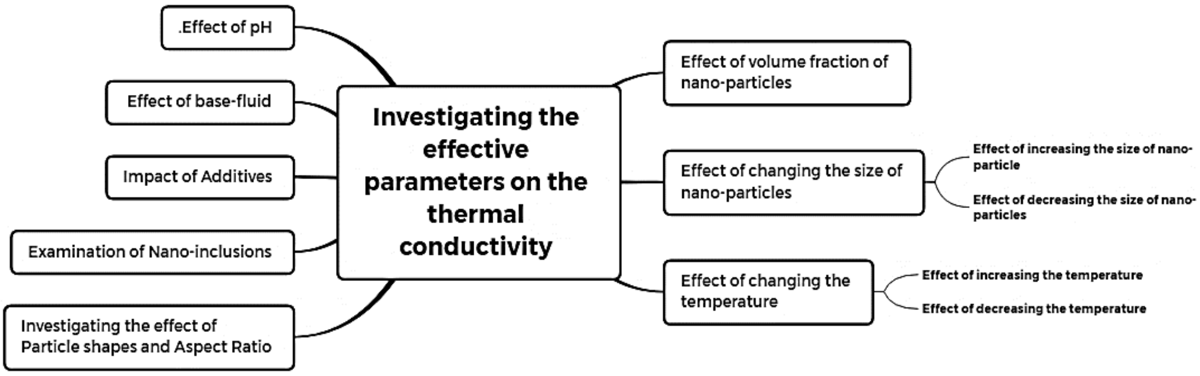

Figure 15:Effective Parameter on Thermal Conductivity of Working Fluid

Nanoparticles are extremely small particles with diameters measured in nanometers. Nanoparticles were eventually commonly used to describe these ultrafine particles. The heat transfer coefficient and hence the Nusselt number, enhanced with increasing nanoparticle concentration and nanofluid flow rate according to most cases. Better mixing of the particles observed as the flow rate of the nanofluid enhanced which improved the heat transport capabilities and caused an increase in the heat transfer rate. The increase in Nusselt number is due to increases in thermal conductivity, Brownian motion of nanoparticles, and particle migration owing to high volume percentage of nanoparticles. Experimental results showed a decrease in the rate of heat transfer for nanofluid. When the nanofluid's stability becomes compromised, particles begin to aggregate or settle, decreasing the fluid's thermal conductivity so temperature of the liquid input significantly affected heat transfer coefficient. The enhanced effect of liquid radiation on the inner wall of the pipes can be attributed to the improved thermophysical characteristics and increased effect of liquid radiation on the inner wall of the pipes. Various experiments have achieved the highest improvement in Nusselt number as a function of volume fraction. Carbon nanotubes / water nanofluid with concentration of 1% nanoparticles resulted in a maximum increase in Nusselt number of 90.76 %. Kim et al. [48] analyzed the use of four nanofluids in U-tube ETSC and found that the solar collector efficiency was optimum when MWCNTs (Multi-Walled Carbon Nanotubes) were used. Sharafeldin et al. [49] exemplifyed the effect of CeO_2 nanoparticles on the performance of ETSC and the results showed that the solar energy absorbed and the temperature difference between the inlet and outlet flow increased and the ETSCs photothermal properties improved by 34%. In the study by Lopez et al. [50] observed that the use of nanofluid as the working fluid resulted in significant reductions in the entropy generation rate. Specifically, viscosity effects, heat transfer and heat loss contributed to impressive decreases of 87.5%, 65.5%, and 14.71%, respectively. These findings highlight the considerable impact that nanofluids can have on minimizing entropy generation during the process. Liu et al. [51] found that the thermal performance of an evacuated tubular high-temperature air solar collector using an open thermosiphon with nanofluid. A two-step procedure used to create CuO water nanofluid with an average particle size of 50 nm. The efficiency of the system with nanofluid and the higher air outlet temperature was found to be higher than the system with pure water. In winter, with a volume flow of 7.6 m^3/h the air outlet temperature in the system with the nanofluid exceeded 170°C. Sabiha et al. [52] used single-walled carbon nanotube (CNT) nanofluids to evaluate the thermal performance of ETSC. A two-step technique using sodium dodecyl sulfate (SDS) surfactant at volumetric concentrations of 0.05 %, 0.1%, and 0.2 % used to make CNT water nanofluid. The thermal efficiency of all ETSCs that use both pure water and nanofluids improved when the cooling water mass flow rate increased. The nanofluid with volumetric concentration of 0.2% produced the maximum thermal efficiency in the ETSC. Furthermore, ETSCs with nanofluid had efficiencies that 0.1 percent higher than ETSCs with water with a volumetric concentration of 0.05 percent. Kim et al. [48] observed the effects of particle size and Al_2O_3 water nanofluid concentration on the thermal performance of a U-tube solar collector found a thermal power of solar collectors improved with decreasing particle size and nanofluids with volume concentrations of 0.5%, 1 %, and 1.5 % had the maximum thermal efficiency 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. Alshukri et al. [54] studied the use of nano enhanced PWax as a PCM system for thermal energy storage and incorporated micro-ZnO and nano-CuO particles, extending the hot water supply by 5 and 6.2 hours. The most efficient performance achieved with nano-CuO and paraffin wax in evacuated tubes and PCM tanks with efficiencies of 68.2%, 84.26%, and 88.5% at flow rates of 1, 2, and 3 l/h.

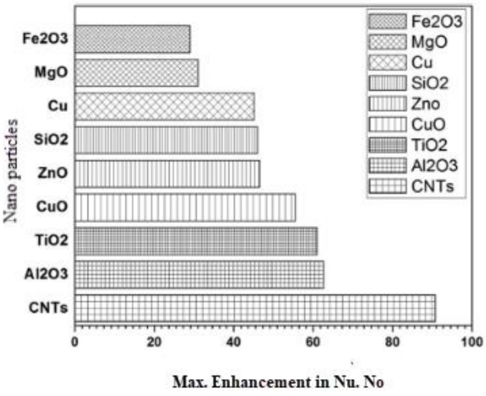

Figure 16 :Max. Enhancement in Nu no for Different Nanoparticles

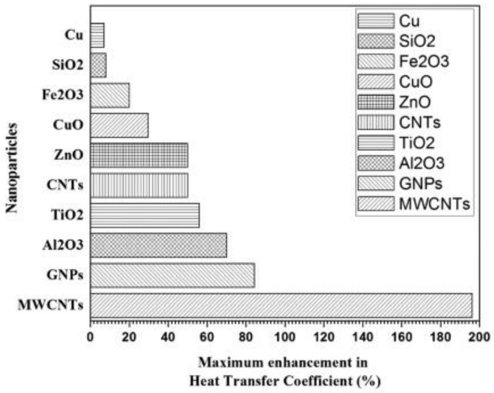

Figure 17: Maximum Enhancement in heat transfer coefficient (%)

b) Surfactant effect on heat pipes

Surfactants and other chemical additions are commonly utilized to increase nanoparticle dispersion without significantly affecting their thermophysical characteristics over time. However, various findings in the literature indicate that the type and concentration of surfactant have such a significant impact on the stability times as well as the thermophysical properties. Sarkar et al. [55] compiled the findings of a number of scholars working on nanocomposite synthesis, hybrid nanofluid creation, thermophysical properties, pressure drop, and heat transfer qualities and suggested more research on the uses and challenges of hybrid nanofluids based on the literature evaluation in order to better harness their exceptional thermophysical features.

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]
Al2O3/water	Two-step/bath/4 h	NSA	NR	24 h	[60]
Fe2O3/water	One-step	NSA	NR	NR	[61]
SiO2 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]
TiO2/water	TiO2–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]
Al2O3/CuO	Two-step/ultrasonic cell	NSA	NR	NR	[69]

2) Hybrid nano-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.

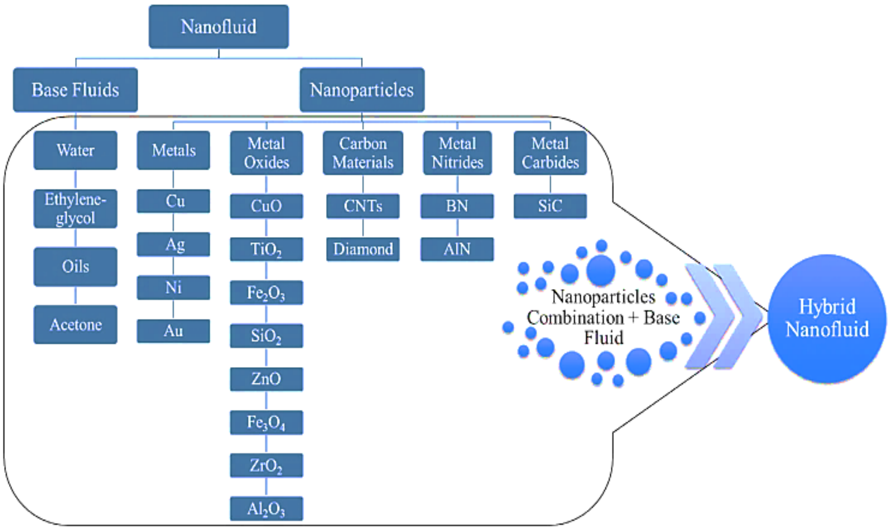

Figure 18 : Classification of working fluids

Owing to the development of carbon nanotube manufacturing technology. Since carbon is nano additive, suspensions are feasible due to its high heat capacity and its ability to increase thermal conductivity. Among the identified nanoparticles, nanofluids produced with carbon nanotubes were very often used due to the strong improvement in thermal conductivity. Kamble et al. [70] found that the thermal effect of copper heat pipes using an Al_2O_3-CuO / water hybrid nanofluid as the working fluid also found a drop in the heat pipe thermal resistance when the angle of inclination, particle volume concentration, and rate of heat input increased

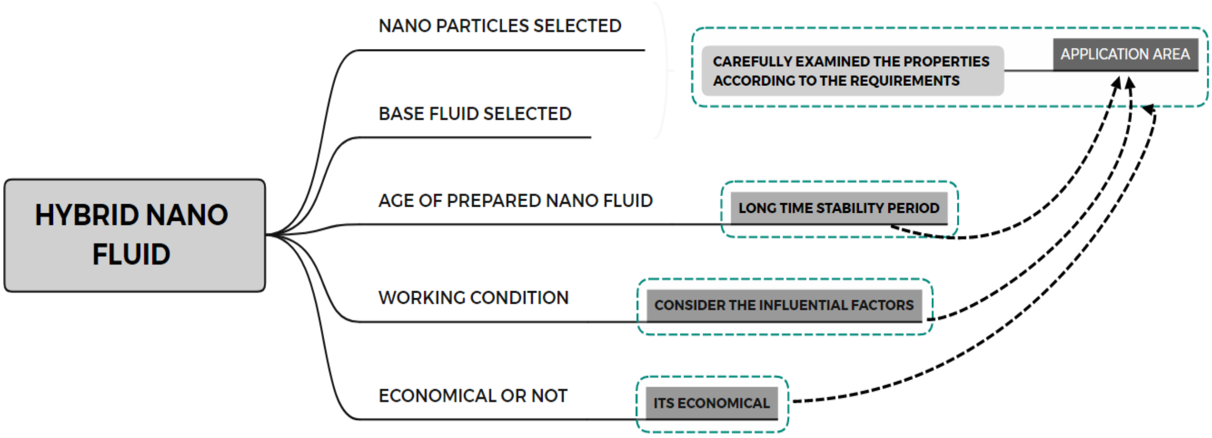

Figure 19: Schematic illustration of challenges that hinder the hybrid Nano-fluid application

By adjusting factors such as the angle of inclination, heat transfer rate, and particle concentration. Swapnil et al. [71] examined the thermal performance of heat pipes using hybrid nanofluid consisting of Al_2O_3 boron nitride (BN) / water. The thermal resistance decreased as the pipe inclination angle, heat transfer rate, and particle concentration increased, according to the findings. Chaudhari and Bhosale [72] examined the thermal performance of heat pipes with hybrid nanofluids composed of CuO-BN / H_2O and found thermal resistance reduces with increasing volume concentration, angle of inclination, and heat transfer evaluation. Ramachandran et al. [73] found that hybrid nano-liquids reduced thermal resistance in meshed wick heat pipes when compared to normal liquid (distilled water), uniform nano-liquid (Al_2O_3/DW), and binary liquid (Al_2O_3CuO/water). In contrast demonstrated the support of hybrid nanofluid in the form of enhanced heat pipe range in their analysis. Han and Rhi [74] compared the properties of numerous samples of uniform (Ag/water, Al_2O_3/ water) and hybrid nanofluids (Al_2O_3-Ag/water) nanofluids to assess heat pipe performance (Particle concentration, heat transfer rate, inclination angle, surface condition and temperature of the cooling water). The thermal resistance of liquid increased with the particle concentration and the hybrid nano-liquids degraded the system according to the findings and eventually arrived at a point where the uniform nanofluids performed admirably. The claim that hybrid nanofluids outperformed conventional nanofluids was not always true; it depended on the particle mix.

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G. **Phase change material (PCM)**

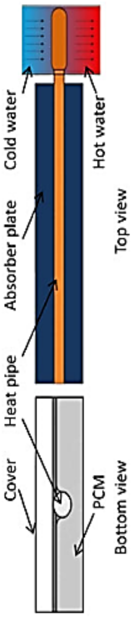

Figure 20:PCM in Heat Pipe Solar Collector

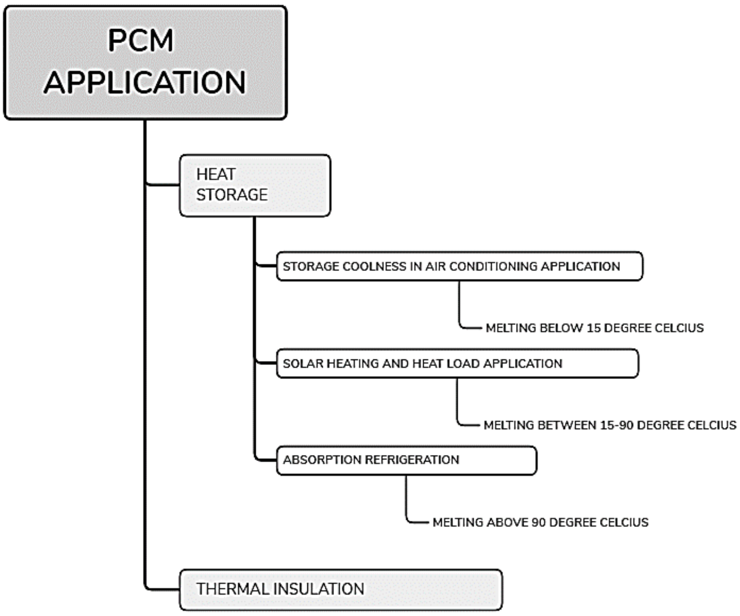

Figure 21:Different PCM Application

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.

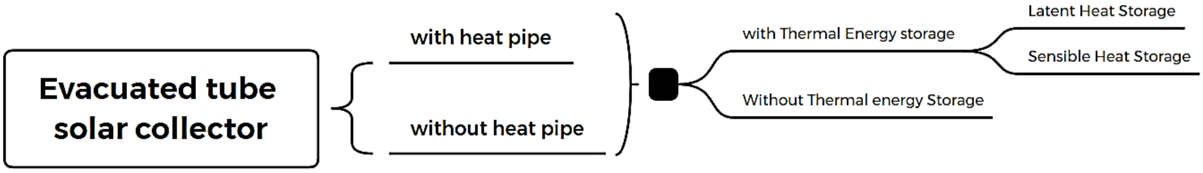

Figure 22 : PCM classification

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

Overview	PCM	key findings
Investigating 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.
A solar collector/storage heating system for mid-temperature applications was tested experimentally. [77]	Composite of Erythritol and expanded Graphite	• The composite PCM with 97 wt% erythritol and 3 wt% expanded graphite is the optimum material for mid-temperature applications. • The most acceptable forms of HPSC for integration with storage units are evacuated tubes with diameters of 58 and 47 mm.

Thermal analysis of domestic hot water system equipped with ETHPSC/S. [78]	Paraffin	• The increase of the annual solar fraction by 20.5% and the temperature of hot water inside the tank compared with conventional HPWH systems.
Examining the use of PCM in solar water heating systems, especially HPWH systems [79]	Various materials and composites	• The use of PCM for FPCs thoroughly researched, but further study needed for HPSCs and CPC collectors. • Using PCM boosts the energy capacity of a SWH system substantially. • More research needed for large-scale applications.
Creating a numerical model to simulate the thermal performance of HPs combined with PCM [80]	Cu-0.3Si	• Variable thermal input examined in order to achieve a precise boundary condition in solar applications. • A parametric study performed to determine the influence of heat transfer rate and PCM enclosure height. • Increasing the height to diameter ratio of the PCM enclosure enhanced PCM melting and lowered HP bottom wall temperature; using CPC raised PCM temperature on the shaded side of the HPSC.
Experiment on a solar water heater with a Nano composite phase change material. [81]	1 mass% of both Si and CuO was used in paraffin wax	• The energy efficiency of the systems without PCMs, with PCMs, and with a nanocomposite PCM was found to be 33.8%, 38.3%, and 41.7%, respectively.
Experiment with a heat pipe solar collector/storage heating system outfitted with CPC.[82]	Paraffin	• The use of CPC increased average charging efficiency and maximum charging efficiency by 5% and 9%, respectively.
An experimental evaluation of the thermal performance of a phase change material integrated heat pipe evacuated tube solar collector system.[83]	Stearic acid as a PCM	• The daily thermal efficiency of an evacuated tube solar collector with and without phase change materials assessed, with variations ranging from 42% to 55% and 79% to 87%, respectively. Surprisingly, when running at a flow rate of 20 liters per hour, both systems displayed their peak daily thermal efficiency.
An experimental study of a household solar water heater with solar collector linked phase-change energy storage conducted.[84]	$Ba(OH)_2\cdot 8H_2O$ as a PCM and BaCO3 used as a nucleant	• Solar radiation and beginning water temperature have an influence on system performance.
A parametric investigation on the efficiency of a solar evacuated tube collector employing phase change materials: A brief simulation [4].	RT-40	• Increasing the mass flow rate of HTF and the mass fraction of MWCNT nanoparticles may improve the thermal performance of ETC-PCM systems.
The thermal performance of an evacuated tube solar collector combined with phase change material was analysed. [4].	Paraffin wax	• The thermal energy process is improved by 20%, and the ideal charging and discharging diameter 6 mm.
Experimental analysis on solar water heater integrated with Nano composite phase change material (SiC and CuO) [81].	Pwax by mixing it with SiC and CuO nanoparticles	• The energy efficiencies for these three situations were 33.8%, 38.3%, and 41.7%, respectively, whereas the system's exergy efficiency was judged to be 1.78%, 2.1%, and 3.2%. When Pwax mixed with SiC and CuO nanoparticles, its thermal conductivity increased by 22.53%.

III. Thermal Performance of Collector

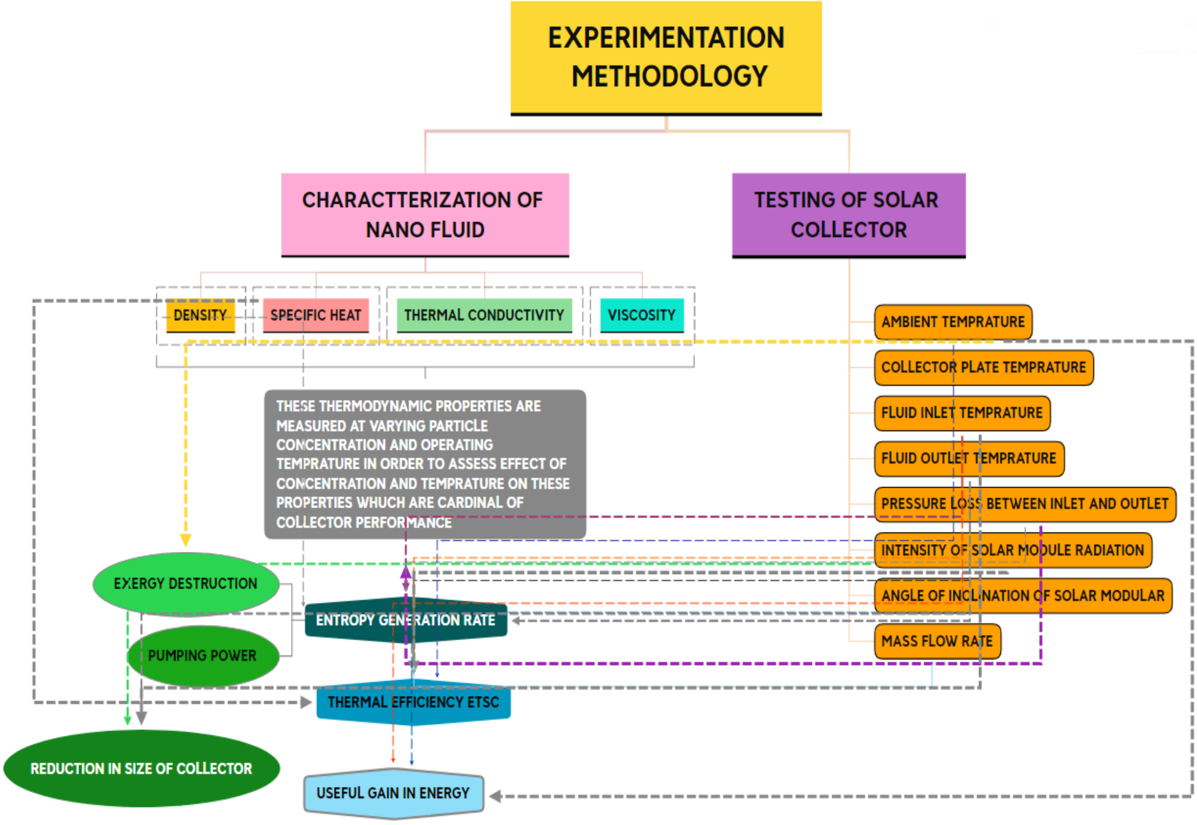

Fig. 23. Experiment methodology for ETC

The solar thermal collector's performance is determined by the amount of solar energy absorbed by the plate. The term "useful energy gain" or "collector efficiency" is used to describe this phenomenon. The solar collector receives Q watts of solar radiation.

$$Q=IA \qquad [1]$$

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

$$\boldsymbol{Q = I(\tau\alpha)A} \qquad [2]$$

The intensity of the solar radiation impacting on the collector is the transmission-absorption product. The temperature of the collector rises as the heat is absorbed, and the heat is discharged into the atmosphere by convection and radiation. The total heat transfer coefficient U, as shown, can be used to calculate the rate of heat loss.

$$\boldsymbol{Q_l = u_l A(T_C - T_a)} \qquad [3]$$

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

$$\boldsymbol{\eta = \frac{rate\ of\ useful\ energy\ extracted\ by\ the\ collector\ (Q_u)}{Total\ solar\ radiation}} \qquad [4]$$

Here, $Q_u = Q - Q_l$

$$\boldsymbol{\eta = \frac{I(\tau\alpha)A}{I(\tau\alpha)A - U_{lA}(Tc - Ta)}} \qquad [5]$$

IV. Conclusions

In enterprises, hotels, and hostels, solar water heating (SWHS) should be employed. When looking at the profitability of hybrid SWH, there is obviously a long way to go. The majority of studies are focused on the forced circulation system; therefore, there is a need to improve the thermosiphon circulation SWHS. The current article provides a complete summary of recent developments in nanofluid applications in heat pipe solar collectors. Future research should focus on the impact of nanofluid optical characteristics and fluid parameters other than thermal conductivity on HPC performance. In order to further reduce the costs of solar collectors based on nanofluids and satisfy market demands swiftly, future study must be devoted toward the invention of nontoxic and inexpensive nanoparticles. To optimize the efficiency of the nanofluid collector, the volume fraction of nanoparticles must be properly tuned.

V. Future scope

The use of heat pipes can extend the temperature range of evacuate tube collectors with reflectors from medium to high temperature applications. Nanofluids must be stable to work efficiently and innovative strategies to prevent agglomeration and sedimentation should be devised. More research is needed to make the production of nanofluids easier and more cost-effective. To alleviate this challenge, research should be conducted to improve pipe materials and hardness so that dependability can be improved without sacrificing performance. Because solar energy is intermittent, extensive study into the progress of PCMs in the 50-90 °C temperature range has been conducted. These materials with high latent heat can be used with evacuated tube collector system to store heat during the day and provide hot water/air at night for commercial and domestic applications. The surface area of the condenser section can be increased with a unique fin design. Although the coating on the absorber pipe of evacuated pipes has a 5-year lifespan, more research is needed to improve the coating stability. Cylindrically shaped heat pipes, which are most often used in industrial applications, have undergone substantial research due to their ease of fabrication, handling, filling, and refilling of the working fluid. The impact of heat load changes on heat pipe performance and the ideal heat pipe orientation and material could be developed in the future. 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

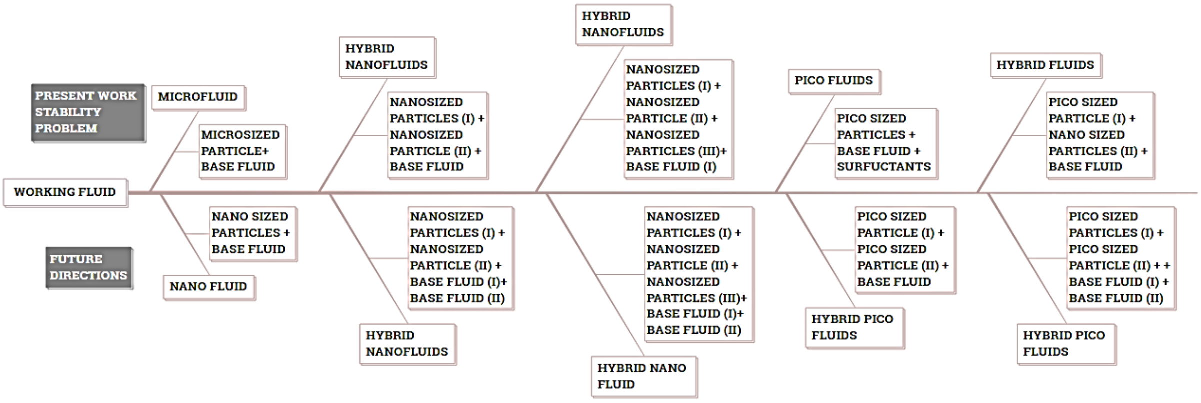

Figure 24 : Present and future recommendation for working fluid

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