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An Extensive Review on Applications of Nano Fluids in Various Solar Collectors and Heat Exchangers

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Abstract: Nano fluids refer to the distribution of nano particles within a fluid medium. It was first introduced in the late 20th century. This is evidenced by the increasing number of papers published annually that pertain to nano fluids. The increased interest in nano fluids stems primarily from their improved ability and thermo-physical properties to be incorporated into the number of thermal applications, including improving the potency of industrial solar energy and heat exchangers harvesting for renewable energy production. As research on nano fluids continues to expand, there is a need for a complete evaluation of the development and steps made in their application in heat transfer devices. This paper reviews advances in nano fluids production and applications of heat transfer devices heat exchangers and solar collectors. This study attempts to keep readers up to date on recent developments, stressing the prospects and problems for nano fluids as the fluids of the future for heat transfer. Eventually, a summary of the advantages and disadvantages of nano fluids is provided, along with suggestions for additional study to hasten the commercialization of nano fluids.

Keywords: Nano particles, Nano fluids, Heat transfer, Heat exchangers, solar collector.

1. Introduction

Before a system may do work, energy, a crucial quantitative property, must be exchanged. Heat or work can be used to transmit energy. When there is a temperature change between two systems, heat is transferred between them, moving from high to low temperatures [1]. Heat transfer is the science that details how and at what rate thermal energy is transmitted. Heat transfer applications can be seen in everyday life; for example, the human body emits heat at all times, and humans use clothing to alter their body temperature to fit external conditions. Heat transfer is also employed in our structures to control temperature and is required for cooking, refrigeration, and drying [2]. Heat transfer is used in spacecraft thermal control components and solar thermal collectors to convert solar energy into heat and power [3]. Many of these technologies require quick heat dissipation to ensure proper functioning and system efficiency [4]. Better heat management is required as technology develops and devices get smaller. In essence, the demand for effective cooling solutions increases with decreasing size [5]. As a result, heat transfer augmentation is a very significant topic in thermal engineering.

To improve the heat transfer coefficient between working fluids and their contact surfaces, a number of strategies have been put forth [6]. Conventional heat transfer fluids, such as water, thermal oils, and ethylene glycol/water, have considerable limits since their thermal characteristics are rather poor when compared to those of solids, as illustrated in Fig.1. The study of heat transfer fluids evolved as a result of the addition of nanoscaled particles, which enhanced the fluids' thermal characteristics. These solid particles' suspension in the base fluid enhances the fluid's ability to transmit energy, leading to improved heat transfer properties and increased thermal conductivity. The resulting fluids have been shown to have greater thermal conductivity [7]. Choi and Eastman [8] were the first to refer to such fluids as nano fluids. Nano -fluids are designed colloidal suspensions of nano -sized particles (10-100 nm) in a base fluid [9].

Usually, metallic oxides, metals, or other materials based on carbon make up these particles. More than hundred years ago, Maxwell [10] was the first to propose the suspension of micro-scaled particles in a fluid. Nonetheless, the rapid settlement of small particles in the fluid led to abrasion and occlusion in the flow channel, which restricted future studies on fluid suspensions. Furthermore, these fluids did not demonstrate the tremendous improvement seen today with the usage of nano fluids. Nano particles are more potent when dispersed in and tend to enhance the thermal characteristics of the fluids. Other aspects of nano fluids that make them suitable heat transfer fluids include Brownian motion of particles, particle/fluid nano layers, and lower pump power when compared to pure liquids for increased heat transmission.

Despite these advantages, nano fluids still have several application-specific constraints. Sedimentation and aggregation in the fluid have been reported, despite the use of ultrasonication, pH modulation, magnetic stirring, and surfactant addition to improve nano fluid stability [11].

Additionally, increasing the device's fluid circulation rate reduces the likelihood of sedimentation, albeit this may erode heat transfer in the flow stream or device. In certain systems, pressure loss has been noted due to the little increase in viscosity caused by larger particles, which may obstruct the flow channel.

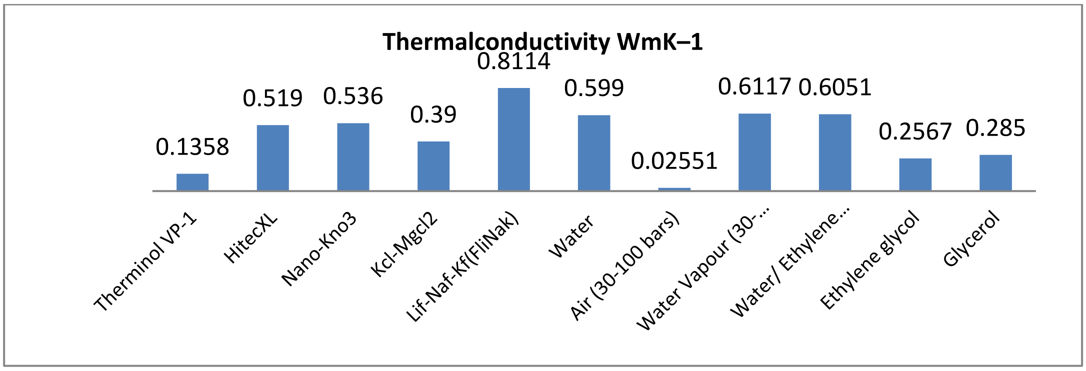

Fig. 1(a) Differences in bulk material thermal conductivity between widely used base fluids.

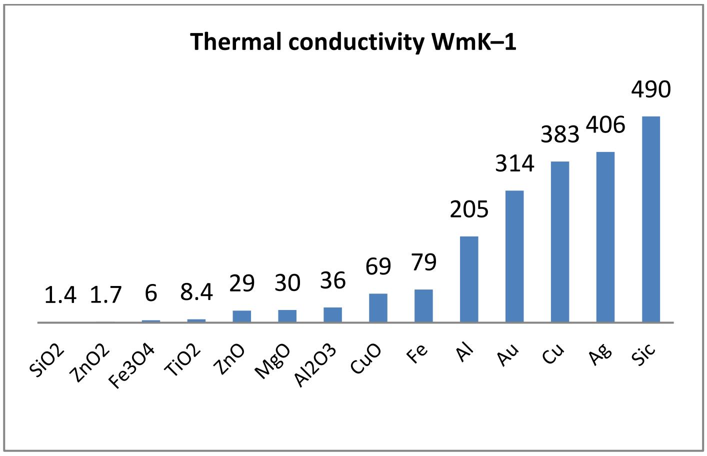

Fig. 1(b) Differences in bulk material thermal conductivity between widely used nanoparticles.

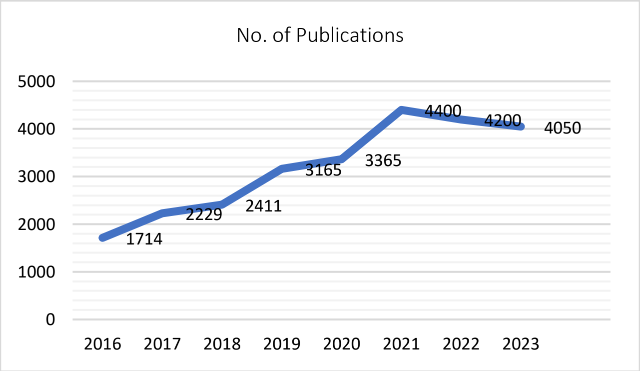

Fig. 2 publications pertaining to nanofluids throughout the last eight years

When studying the stability and thermophysical behavior of nanofluids, the technique utilized to prepare them is crucial [12]. The preparation stages are also critical in calculating the degree to which the nano fluids are used in heat transfer systems [13].

Properties of nano fluids

Nano fluids' thermo physical behavior has a direct impact on their application, particularly in heat transfer. Nano fluids' efficacy as heat transfer fluids is determined by properties such as density, specific heat capacity, thermal conductivity and viscosity,. Certain experimental approaches and standards have been utilized to measure the thermo physical properties of nano fluids.

The thermal comparator approaches transient and steady-state are the three primary methods for measuring the thermal conductivity of nano fluids. The transitory technique is more precise and dependable than the steady-state technique because it eliminates the effects of radiation and natural convection [14]. While many studies have employed the mentioned approaches to detect nano fluids' thermo physical properties, numerous other researchers have concentrated their efforts on developing an appropriate theoretical model to predict the thermo physical behavior of nano fluids.

Prior to the development of nano fluids, many scientists hypothesized about the effect of particle dispersal on the thermo physical properties of traditional heat transfer fluids. As previously noted, J. C. Maxwell proposed the thermal conductivity of particle dispersions in liquids in 1881 [15]. Einstein proposed the dynamic viscosity of particle dispersions in a liquid in 1905. Both studies reflect the first hypotheses about the thermo physical behavior of suspensions in fluids [16]. Many other scholars have presented models to predict the thermo physical behavior of suspensions in fluids. Classical models refer to theoretical models produced prior to nano fluid categorization. Table-1 depicts classical models for predicting the thermo physical characteristics of nano fluids. While traditional models were correct in a restricted range, they frequently failed to forecast the nano fluid's specific heat capacity, viscosity, and thermal conductivity, with sufficient accuracy.

Table.3 Standard formulas for fluid dispersions' viscosity and thermal conductivity

Model Year	Property	Formula
Maxwell model 1881	Thermal conductivity	$\frac{Keff}{Kf} = \frac{kp+2kf+2(kp-kf)\psi}{kp+2kf-(kp-kf)\psi}$
Hamilton–Crosse model 1962	Thermal conductivity	$K_{eff} = \frac{kp+(n-1)kf-(n-1)(kf-kp)\psi}{kp+(n-1)kf-(kf-kp)\psi} K_f$
Wasp model 1970	Thermal conductivity	$\frac{Keff}{Kf} = \frac{kp=2kf-2\psi(kf-kp)}{kp+2kf-\psi(kf-kp)}$
Bruggeman model 1935	Thermal conductivity	$\psi\ (\frac{(kp-keff)}{(kp+2keff)_{\psi}}) + (1-\psi)\ (\frac{(kp-keff)}{(kp+2keff)_{\psi}}) = 0$
Einstein model 1905	Viscosity	$\frac{\mu eff}{\mu f} = 1 + 2.5\psi$
Nielsen power law model 1970	Viscosity	$\mu_{eff} = (e^{\frac{\psi}{1-\psi m}})\ \mu_f$

Batchelor model 1977	Viscosity	$\mu_{eff} = (1 + 2.5\,\psi + 6.5\,\psi^2)\,\mu_f$
Mooney model 1951	Viscosity	$\frac{\mu eff}{\mu f} = e^{\frac{2.5\psi}{1-k\psi}}$
Krieger–Dougherty model 1959	Viscosity	$\frac{\mu eff}{\mu f} = 1-\frac{\psi^{\frac{-2.5\psi m}{\psi m}}}{\psi m}$

Where μ_f, μ_{eff}, k_{eff}, φ, k_p, φ_m and k_f, represent the fluid viscosity, effective viscosity, effective thermal conductivity, volume concentration, packing fraction and thermal conductivity of the particles and fluid, respectively.

Thermo-physical properties of fluid dispersion are influenced by factors beyond volume concentration and base fluid properties, as Einstein described them as "small rigid spheres suspended in a liquid" at the nano scale. However, research has shown that nano fluids' thermo-physical properties are influenced by a broader range of variables, including particle packing fraction, volume concentration, base fluid property, size, particle agglomeration, , fluid pH, particle distribution, nano layers, temperature, and mixture ratio (in hybrid nano fluids). Classical models' failure to account for these changeable factors limits their applicability to a small range of values. The physical parameters of the nano fluids play a crucial role in forecasting the heat transfer and friction factor behaviour of each nano fluid.

Mahian et al. [17] provided a summary of computational methods for solving the thermal transport model for nano fluid flow. These approaches include the finite volume, lattice Boltzmann methods, finite differential and finite element, among others. Lagrangian approaches include molecular dynamics and dissipative particle dynamics. Dadhich et al. [18] employed an artificial neural network to generate correlations for predicting the heat transfer coefficient of TiO_2 and Al_2O_3 water-based nano fluids flowing in an annulus at 1 bar. Their investigation used three input parameters: heat flow, mass flux and nano particle concentration. The results reveal that both nano fluids outperformed water. At a nano particle concentration of 0.2%, the heat transfer coefficient of TiO_2 nano fluid increased by 71.56% and that of Al_2O_3 nano fluid increased by 155.24% as compared to water. The friction factor and heat transmission behavior of hybrid nano fluids have also been studied. Hameed et al. [19] used experimental data to compare the heat transfer and pressure drop properties of alumina-CNT/water nano fluids and alumina-Cu/water nano fluids. Alumina-CNT/water improved convective heat transfer more than alumina-Cu/water hybrid fluid. At 0.3% volume fraction of CNT/water- alumina and Cu/water- alumina hybrid nano fluid, the Nusselt number increased by 30.65% and 20.48%, respectively. Their analysis found experimental correlations for both fluids. Yang et al. [20] studied dynamic stability. TiO_2 and CNT nano fluids exhibit sedimentation and time-dependent heat transfer properties. They discovered that a volumetric concentration of 0.3% TiO_2 and 0.1% CNT nano fluids increases the convective heat transfer coefficient by 17.84% and 19.31% respectively.

Factors influencing nano fluid stability and thermo physical properties:

The concentration and form of nano particles, aggregation in nano fluids, and the sonication duration utilized in their manufacture are the most important elements influencing their thermo physical properties. The stability of nano particles suspended in a fluid is a critical parameter that influences both the thermo physical and rheological properties of the resulting nano fluids. Brownian motion leads particles to collide with one another, resulting in cluster formation in the base fluid. These aggregations or cluster forms are influenced by a number of internal forces between the nano particles and the base fluid, including the Vander Waals forces of attraction between the particles [21]. The aggregates begin to crystallize when their density exceeds that of the base fluid, which influences the stability of the nano fluids. Over time, there has been an increase in interest in the use of nano fluids as coolants in heat transfer devices. This paper provides an in-depth analysis of research on the synthesis, thermo physical property assessment, and use of nano fluids in various thermal devices that need effective heat transfer. The use of various nano fluids in devices like solar collectors, electronics cooling, heat exchangers, and thermal storage, as well as the mechanisms underlying the enhanced thermal behaviors of these fluids, are some of the topics covered in the review. Other areas include thermo physical models used to determine the properties of the nano fluids. The study found that there appears to be no common approach for measuring stability, making it impossible to evaluate stability across articles. This is a concern because reported fluid stability varies significantly between investigations, ranging from days to months.

The size and volume of the nano particles utilized, the mixture's temperature, and the presence of surfactants all affect the thermo-physical properties of nano fluids. The thermal conductivity of grapheme oxide/water nano fluids with a mass concentration range of 0-1.5% was studied by Yang et al. [22]. Their findings demonstrated that the augmentation of thermal conductivity increased with the mass fraction of nano particles. Additionally, the nano fluids demonstrated their greatest stability and 48.1% increase in thermal conductivity at a pH of 8. This suggested that a key factor influencing its stability and thermal conductivity was pH. The enhanced thermal enhancement was explained by the authors as a result of the base fluid's molecules and particles moving more brownianly at higher temperatures. The thermal conductivity behavior of zinc nano powder in SAE 50 engine oil was also investigated by Yang et al. [23], who found that the thermal conductivity of the nano lubricant rose as the volume concentration of nano particles increased. They found that the largest thermal conductivity boost was 8.74%, which they attributed to the effects of the lubricant's particles moving more Brownian motion at higher temperatures. They also mentioned the influence of the thermophoresis effect on the improvement of thermal conductivity.

The thermal conductivity of CuO water/EG- GO (50:50) hybrid nano fluid was found by Rostami et al. [24] at 25–50 °C and 0.1–1.6% particle volume concentration. Their study shows a 46% increase in heat conductivity, more than the increase from utilizing a single nano material. The thermal conductivity of a hybrid nano fluid comprising GO/SiC (50:50) and water was studied by Mahyari et al. [25] at volume concentrations ranging from 0.05-1%. Their research indicates that the effect of raising temperature was not as substantial as the effect of nano particle volume concentration. Crucially, the research found that the hybrid nano fluid's increased thermal conductivity outperformed the thermal conductivity enhancements reported for SiC or GO alone. In addition to improving thermal conductivity, hybrid nano fluids also improve nano fluid stability.

Use of nano fluids in various thermal devices and Solar Thermal Collectors:

Using the principles of radiative, convective, and conductive heat transfer, solar collectors transform the Sun's radiant energy into electrical or thermal energy. A working fluid that circulates within the absorber of the collector helps it absorb solar energy from the sun. The most popular fluids for absorbing thermal energy include oils, salts, water and ethylene glycol (EG). There are restrictions on these working fluids that impact the overall effectiveness of certain collectors. Their poor heat conductivity is their primary drawback. It has been suggested and tested to employ nano fluids in various solar collectors to achieve increased thermal conductivity. This section examines the developments made in the use of nano fluids in different solar collectors. A classification of several solar collectors that are capable of using nano fluids as heat transfer fluids is shown in Figure. 3.

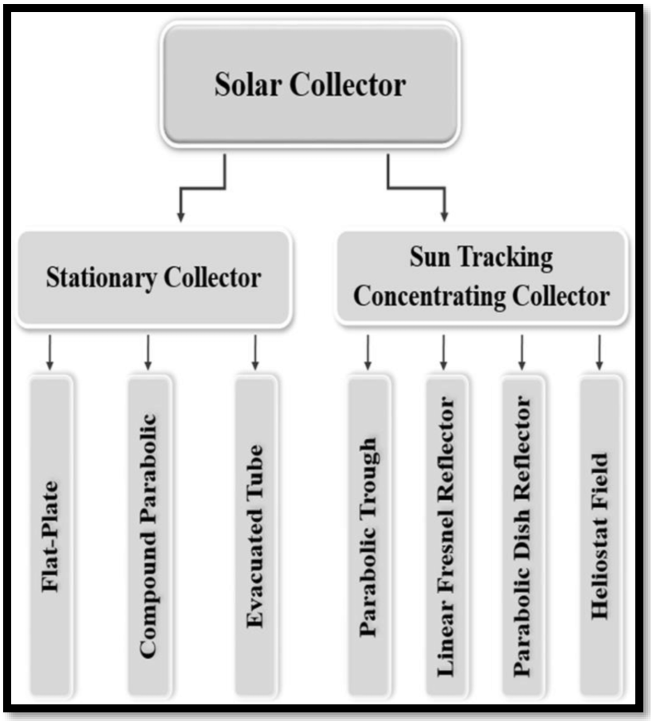

Fig.3 Types of solar collectors where nano fluids can be used

Flat plate collector (FPC)

The most popular type of solar collector is the flat plate collector. It is a rectangular tray with copper tubes (raisers) arranged along the surface of the absorber surface (plate). Conduction heat loss can be minimized by placing an insulating substance at the collector's rear. Radiative and convective heat losses can also be reduced by covering the collector's top with glass or other transparent glazing.

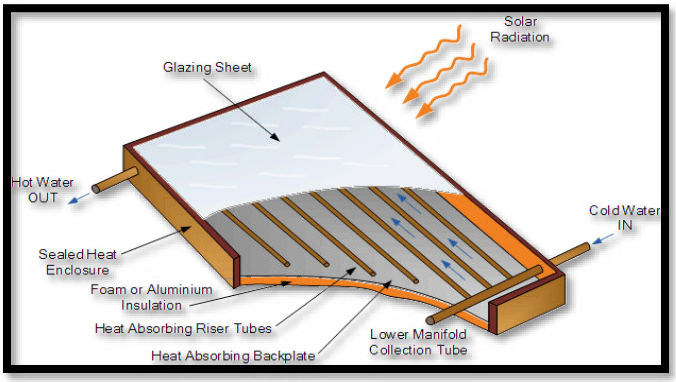

Fig. 4 Flat plate solar collector

Figure 4 displays a schematic of the flat plate collector. Nano fluids have been used in place of traditional fluids to increase the collector's efficiency. For example, Choudhary et al.'s study [26] examined the stability of MgO nano fluids intended for use in flat plate solar collectors, taking into account the impact of volumetric concentrations ranging from

0.08 - 0.4% on the nano fluid's long-term stability. The investigation proved that at 0.04% volumetric concentration, the nano fluids exhibited superior stability. When the nano fluids in the flat plate collector were tested, a 0.2% volumetric concentration and 1.5 lit-min^{-1} resulted in a maximum thermal efficiency of 69.1%.

Compared to EG/water, this number indicates a 16.36% improvement in thermal efficiency. Using TiO_2-water nanofluids as an agent fluid in a flat plate collector's outer absorber Ahmadlouydarab et al. [27] examined the overall thermal efficiency and thermal absorption capacity of a flat plate collector. By utilizing their high thermal capacity, the nano fluids in this design serve as thermal insulation. In order to improve the glass surface's ability to clean itself, TiO_2 nano particles were also applied to the collector's outer glass cover. The study found that at a volumetric concentration of 5% nano particles, the novel system design increased the collector's thermal efficiency by 49%. Saffarian et al. [28] used modified spiral, U-shaped, and wavy pipes to study the impact of a change in the flow direction of the flat plate collector using CuO–water and Al_2O_3 nano fluids. The study shows that substituting nano fluids for water enhanced the heat transfer coefficient. Although the heat transfer was much enhanced by the wavy and spiral shapes, using the wavy pipe resulted in greater pressure losses. According to the study's findings, the heat transfer coefficient rise by 78.25% when wavy pipes and CuO nano fluids at 4% volume concentration were used. Using Al_2O_3 and CuO nano fluids, Tong et al. [29] conducted an experimental analysis of a flat plate collector's thermal performance. It was shown that the maximum thermal efficiency gain of 21.9% was obtained at a volume content of 1% Al_2O_3. Moreover, employing CuO at 0.5 Vol.%, and Al_2O_3 at 1 Vol.% respectively, compared to water, energy efficiency improvements of 56.9% and 49.6% were noted. Using Al_2O_3-water nano fluids, Mondragon et al. [30] evaluated a flat plate collector's performance in laminar flow conditions. The study showed that a 2.3% improvement in heat transfer coefficient could theoretically be achieved at a 1% volume concentration of Al_2O_3 in the nano fluids. However, when the collector's efficiency was tested, the study found that employing Al_2O_3-water nano fluids reduced the collector's effectiveness from 47% when using water to 41.5%. The development of nano particle deposition layers on the absorber tube, which served as an extra layer of heat transfer resistance, was blamed for the decline. The low flow velocity of the nano fluids was assigned by the scientists as the cause of the creation of these layers.

Evacuated tube solar collector (ETSC)

Because vacuum insulation reduces heat losses in the ETSC relative to the FPC, This kind of collector has more efficiency than flat plate collectors. Convection and conduction losses can be minimized by creating a vacuum between the evacuated tube heat pipe and the glass tube. An anti freeze liquid is contained in a closed system within the heat pipe of the tube. This pipe then continues into the manifold, where the antifreeze condenses in the moving liquid and is then heated again by the heat pipe. Fig 5 illustrates this collection with pictures.

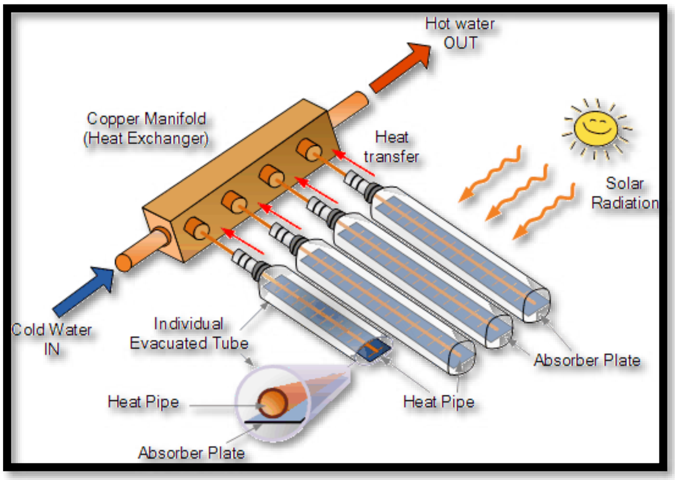

Fig. 5 Evacuated tube solar collector

It has been looked at whether using nano fluids can improve this collector's performance. For example, the effectiveness of an evacuated tube solar collector using a carbon acetone mix in the heat pipe was assessed by Sarafraz et al. [31]. The findings show that a thermal efficiency of 91% was attained, exceeding the mean thermal efficiency of 72.6% when acetone is used alone. An ETSC was experimentally tested by Natividade et al. [32] using water nano fluids based on multilayer graphene (MLG). Parabolic concentrators were part of the ETSC's apparatus. When compared to the base fluid, the MLG at concentrations of 0.00068 Vol. % and 0.00045 Vol.% enhanced the collector's thermal efficiency by 76% and 31%, respectively. A parabolic concentrator was also employed by Sadeghi et al. [33] to improve the efficiency of an ETSC using Cu_2O–water nano fluid. An ANN multilayer perception model was used to confirm the experimental configuration. At a flow rate of 50 liters per hour and 0.08 vol.% of Cu_2O, the highest thermal efficiency of 60% was reached. When compared to water, this result indicated an 87.5% improvement in the collector's performance.

Compound parabolic collectors (CPC)

Comparable to flat plate collectors, CPCs focus incident solar radiation on to the absorbers through parabolic optics mounted to each tube. CPCs can be stationary and still gather diffuse solar radiation, much like flat plate and evacuated tube collectors. As seen in Fig. 6, there are four different types of CPCs: wedge-like absorbers, tubular absorbers, flat one-sided absorbers, and flat two-sided absorbers. An absorber tube plus a parabolic collection surface makes up a tubular absorber. Under a laminar flow environment, Korres et al.'s [34] investigation focused on nano fluid-based CPC. A maximum and mean enhancement of the heat transfer coefficient of 17.41% and 16.16%, respectively, were shown in the investigation. The study found that the pressure drops seen were not a barrier to the use of the nano fluids and that employing CuO/ Syltherm nano fluids increased thermal efficiency by 2.76%. This was done after accounting for the effect of pressure losses resulting from the usage of nano fluids.

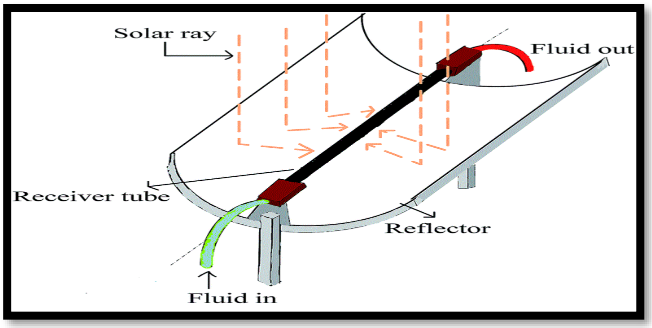

Fig. 6 Cross section of CPC tubular absorber

Linear Fresnel reflectors (LFR)

One concentrating solar collector that stands out from the others is the linear Fresnel reflector, which is less expensive due to its ease of assembly. To focus its rays onto the absorber tube, the LFR uses mirrors whose orientation revolves around a pivot that follows the Sun, as illustrated in Fig. 7 [35]. Applications requiring thermal energy at temperatures between medium and high can be met by this technology. Nevertheless, there are fewer research using LFRs as collectors with nano fluids because they are not as commonly installed collectors. A study was conducted by Ghodbane et al. [36] to evaluate the MWCNT-water nano fluid's performance in the LFR. The results show that more favorable thermal efficiency of 33.81% and MWCNT at 0.3 Vol.% produced the greatest pressure loss of 2.3 to 46 Pa when compared to the other fluids examined. The use of the nano fluids also showed that the system's rate of entropy creation was decreased.

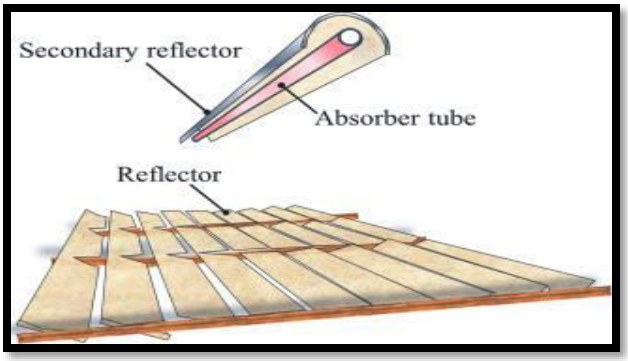

Fig. 7 A linear Fresnel reflector diagram

Parabolic trough solar collectors (PTSC)

The common researched and commercially used concentrating solar collectors now on the market are parabolic trough solar collectors. The collector uses a parabola-shaped mirror, as shown in Fig. 8, to reflect solar radiation from the Sun on to a cylindrical receiver. The receiver is made up of a glass cover surrounding a concentric absorber tube. The working fluid that passes through the receiver absorbs solar radiation, which is subsequently delivered to applications that require medium to high temperatures (50 °C to 400 °C). TiO_2 and zero-valent iron were synthesized by Okonkwo et al. [37].

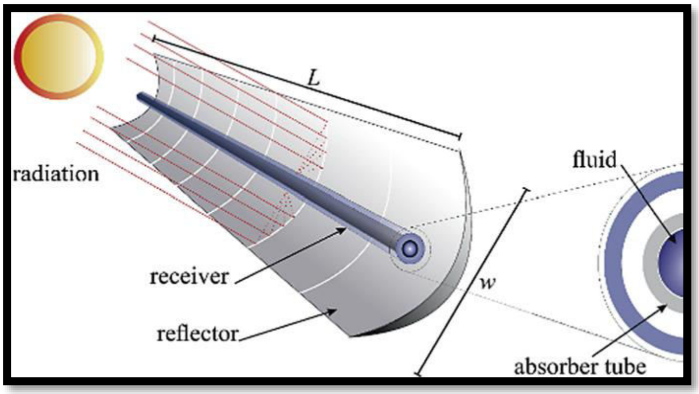

Fig. 8 parabolic trough solar collector

Olive leaf extract nano particles for solar parabolic trough collector use. Using Syltherm-800 as the foundation fluid, the nano particles were utilized to create nano fluids. When Syltherm-800/ TiO_2 and Syltherm-800/ZVI were used, the heat transfer coefficient increased by 42.9% and 51.2%, respectively, at a concentration of 3% nano particles in volume. The scientists reported that a thermal efficiency gain of 0.48% to 0.51% was still attained when utilizing Syltherm-800/ZVI and Syltherm-800/ TiO_2 nano fluids, despite the fact that the usage of the nano fluids caused an 11.5% drop in pressure. The energy, economic analysis and exergy of a PTSC running on water and Therminol VP1 as working fluids was investigated by Ehyaei et al. [38]. CuO and Al_2O_3 nano particles were added to these fluids, which were also utilized as base fluids. The PTSC's annual efficiency was measured using all four working fluids. The findings show that water has an energy and exergy efficiency of 10.64% and 9.07%, respectively, while the addition of CuO and Al_2O_3 to water at a volume concentration of 5% only slightly raised the PTSC's efficiency by 0.03% to 0.09%, respectively. Under an external magnetic field, Malekan et al. [39] examined the heat transport in a PTSC using Fe_3O_4 and CuO/Therminol-66 nano fluids. The findings showed that raising the concentration of nano particles improved the collector's heat transmission. When the volume concentration of Fe_3O_4/Therminol-66 nano fluids was 4% and the nano particle size was 10 nm, the highest enhancement of heat transmission was found. Despite the CuO nano particles' superior thermal conductivity, the Fe_3O_4/Therminol-66 nano fluid performed better in the presence of a magnetic field than the CuO/Therminol-66 nano fluid. Bellos and Tzivanidis [40] used Syltherm-800 as the base fluid to assess the performance of an LS-2 collector with six distinct nano particles (Cu, CuO, TiO_2, Fe_3O_4, Al_2O_3, and SiO_2). As demonstrated in Fig. 10, the concentration of the nano particles was adjusted up to 6%. The results indicated that the SiO_2 nano particles produced the least improvement in thermal efficiency, at 0.19%, while the Cu nano particles produced the most boosts at a 4% volume concentration, at 0.54%. The enhancements of the other nano particles, Al_2O_3, TiO_2, Fe_2O_3, and CuO, were 0.25%, 0.35%, 0.41%, and 0.46%, respectively.

Direct absorption solar collector (DASC)

In comparison to conventional solar collectors, a concentrated solar collector with lower thermal resistance is the direct absorption solar collector. It is possible for the working fluid to directly absorb solar energy by eliminating the absorbing surface. As seen in Fig. 9, the system's efficiency is now solely dependent on the working fluid's absorptivity and thermal characteristics, eliminating the conductive and convective resistance caused by the employment of a surface absorber. This alteration lowers the system's thermal losses.

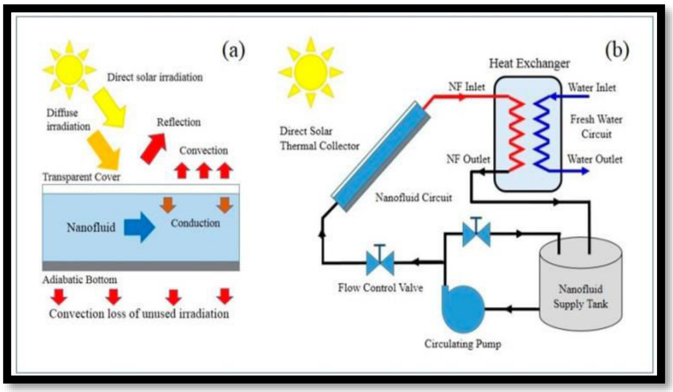

Fig. 9 Direct absorption solar collectors

Direct absorption solar collectors are 5-10% more efficient than standard parabolic trough collectors, according to Qin et al. [41]. Nonetheless, the problem with these systems still lies in the working fluids' poor absorption capabilities. On the other hand, the collector's efficiency may be raised by using nano particles diluted in these working fluids. The application of SiO_2/EG and MWCNT/EG nano fluids in a DASC was studied by Tafarroj et al. [42]. The results indicate that MWCNT/EG nano fluids produced the maximum output temperature of 346.1 K at 0.6% volume concentration of nano particles. Simonetti et al.'s CFD investigation on direct volumetric absorption was conducted in [43]. Solar collector using compound parabolic collectors and SWCNT/EG nano fluids, and compared its performance with a DASC integrated with it. According to the study's findings, the direct volumetric absorption solar collector outperformed it.

Photovoltaic thermal collectors (PVT)

High temperatures (~25 °C) have a negative impact on photovoltaic (PV) system cells because they diminish the effectiveness of the PV module due to excess heat from the sun. In addition to increasing the PV module's electrical output, technologies like the hybrid PVT system has been developed to capture this heat for potential use in other thermal applications. Fig. 10 makes this clear: the extra heat that the cells absorb is moved to a heat transfer fluid, which cools the collector and produces heat for use in other thermal applications.

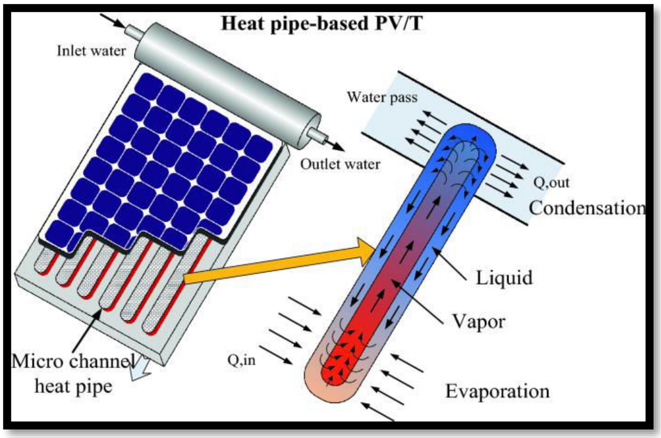

Fig. 10 Photovoltaic thermal collectors

Sangeetha et al.'s [44] experiments used various nano particles distributed in water to assess the effectiveness of a hybrid PVT system. The study assessed how well Al_2O_3, CuO and MWCNT, performed in water and showed that, in contrast to water, nano fluids increased the PVT's electrical efficiency. CuO nano fluids with MWCNTs reduced cell temperature by 19%. Al_2O_3, CuO, and MWCNT nano fluids increased the PV's electrical efficiency by 52%, 55%, and 60%, respectively. Likewise, grapheme nano platelets (GNPs) and MWCNT scattered in water as coolant in a PVT system were examined by Alous et al. [45]. According to the study's findings, the system's energetic efficiency increased with the inclusion of the thermal module by 53.4% when using water, 63.1% when using GNP-water and 57.2% when using MWCNT-water. GNP-water nano fluids were shown to increase energy efficiency in the PVT collector by 18.6%. This was the largest increase in energy efficiency that their analysis could find. Conversely, Fudholi et al. [46] investigated the application of TiO_2 water nano fluids on a PVT. According to the study's findings, the TiO_2 nano fluid outperformed water by 85–89% at a mass concentration of 1% at a mass flow rate of 0.0255 kg/s. Water outperformed water by 60–76%. In their investigation into the impact of optical filtration and nano-enhanced phase change materials (PCMs) on PVT collector performance, Abdel Razik et al. [47] found that both the application of nano PCM and optical filtration raised the collector's overall efficiency by 6–12%. It has been demonstrated that a PVT/PCM system with nano fluids works well as a cooler to increase the thermal conductivity of PVT collectors [48]. The photo thermal characteristics of several mono and hybrid nano fluids were examined in previous research on nano fluids in solar collectors [49], along with the effect of magnetic fields on the thermal performance of nano fluids in a solar collector [50]. The study investigated the enforced convection behavior of nanoparticles within a solar collector. [51]. More recently, artificial neural networks (ANN) models were utilized to predict the performance of nano fluids in solar collectors [52]. Table 2 presents additional research on the use of nano fluids in various types of solar collectors.

Nano fluids in heat exchangers

For transferring heat between two or more fluids, devices known as heat exchangers (HX) are used. The usage of nano fluids in various heat exchanger types has been looked at and is covered in the section below.

Double tube heat exchanger

In several sectors, double-tube heat exchange is a common technique. As seen in Fig. 11, this kind of heat exchanger is composed of two concentric tubes. Scholars have examined diverse approaches to enhance the effectiveness of these heat exchangers. Several of these involve changing the system's dimensions, designing much larger systems, and using a stronger pump. The use of nano fluids is a new technique that has lately gained popularity [53].

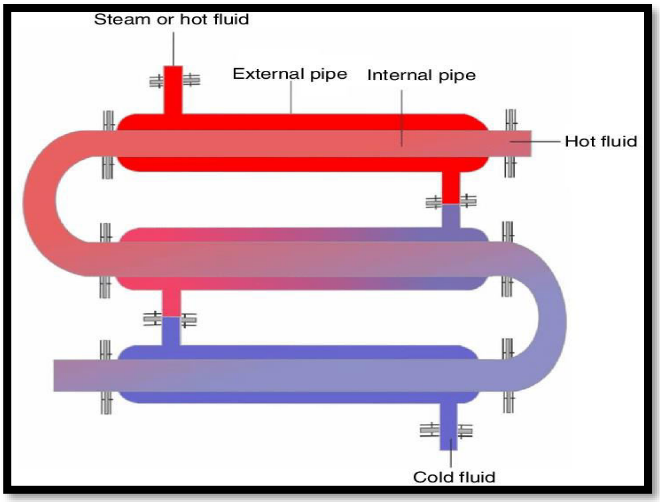

Fig. 11 Heat exchanger with two tubes

The potential of several nano fluids to enhance the double tube heat exchanger's performance has been studied. An experimental investigation of the performance of MWCNT-water nano fluids increased the heat transfer coefficient in the double-tube HX by 35%. TiO_2-water nano fluid in a double-tube HX shows 14.8% improvement in heat transfer rate, but a 51.9% increase in pressure drop. A double-tube HX using the Al_2O_3/water nano fluid also showed a higher favorable thermal efficiency of 16% as compared to pure water [53]. The heat transfer coefficient increased from 7% to 50%, according to a study that used silver-coated silica to examine heat transfer and pressure drop in the laminar flow regime [54]. Al_2O_3/water nano fluid turbulent flow was also studied, and it was found that the Nusselt number and Reynolds number increased by 23.2%, and 32.23% respectively [55]. Table2 (ext.).

Plate heat exchangers

One form of solid heat exchanger that is frequently used in businesses is the plate heat exchanger shown in Fig. 12. These days, a wide range of sectors are using this kind of heat exchanger. Nonetheless, there is a need to increase thermal efficiency and performance; using nano fluids promotes a greater rate of heat transfer within the same aspect. The application of nano fluids in plate heat exchangers is the subject of numerous investigations [56].

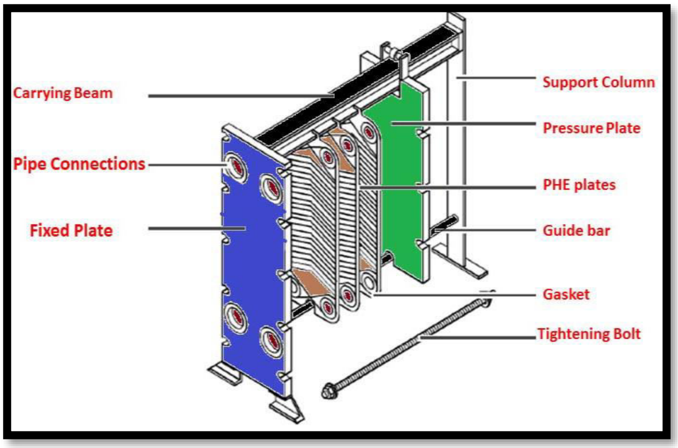

Fig. 12 A plate heat exchanger image.

In a numerical investigation of the impacts of hybrid nano fluids on plate HX performance [57], it was shown that the Al_2O_3–CuO/water nano fluid and the Al_2O_3–TiO_2/water nano fluid, respectively, enhanced heat transfer by roughly 16–27%. Nusselt number and heat transfer

Table 2: Investigation on the use of nanofluids in different types of solar collectors

References	**Type of study**	**Type of collector**	**Nanofluids used**	**Efficiency enhancement**	**Key outcomes**
[60]	Experimental	FPC	CuO-water	55.1%	For flow rates of 1, 2, and 4 L/min, CuO-water increased energy efficiency by 15.2%, 17.1%, and 55.1%, respectively.
[61]	Experimental	FPC	SiO_2/water	relative to water	For nanofluids with volume concentrations of 0.4% and 0.6%, the removed energy parameter decreases by 55.2% and 51.7%, respectively.
[62]	Experimental	FPC	CeO_2/water	28.07%	When compared to water, the nanofluids reduced CO_2 by 175 kg, saved 300.2 MJ of energy, and had a longer payback period of 2.12 years.
[63]	Numerical	FPC	CuO/water and Al_2O_3/water	17.98% and 14.51%, for CuO and Al_2O_3 respectively	It is discovered that using the CuO nanofluid as the HTF is more advantageous for enhancing cycle performance and lowering the energy-based cost of cooling.
[64]	Experimental	FPC	CuO + Al_2O_3/water, CuO/water and Al_2O_3/ water	50% for CuO-water	The optimal enhancement of 15%, 16%, 50%
[65]	Experiment	HPSC	CuO/water	47.6%	CuO nanofluid is more efficient than pure water. At 0.017 Vol%, the highest efficiency of 88.6% was achieved.

[66]	Experimental	FPC	Graphene nano platelets	13.30% performance	produced a 13.3% increase in thermal
[67]	Numerical	PTSC	SiO_2/water		ANN is a useful tool for forecasting PTC performance.
[68]	Experimental	FPC	MWCNT-water	35.20%	When compared to distilled water, nanofluids provide higher energy and energy efficiency in both forced and thermosiphon systems.
[69]	Numerical	FPC	Al_2O_3, SiO_2 and CuO water	4.47%, 4.65% and 5.22% for Al_2O_3, SiO_2 and CuO	With 4.47%, 4.65%, and 5.22% for Al_2O, SiO_2, and CuO nanofluids, respectively, the nanofluids outperformed
[70]	Experimental	FPC	Al_2O_3-Fe/water Al_2O_3/water	2.16% in enhancement using Al_2O_3/water	Al_2O /water increased efficiency by 2.16%, while hybrid nanofluids reduced efficiency by 1.79% when compared to water.
[71]	Experiment	HPSWH	Al_2O_3water	55%	The greatest increase in thermal efficiency, 19.34%, was achieved with nanofluid as opposed to 12.46% with distilled water.
[72]	Experimental	FPC	Graphene nano platelet-water nanofluids	18.20% performance	Utilizing environmentally friendly treated graphene nano-platelets and water nanofluids demonstrated improved

Table 2: (continued)

References	**Type of study**	**Type of collector**	**Nanofluids used**	**Efficiency enhancement**	**Key outcomes**
[73]	CFD	ETSC	Al_2O_3-water and CuO-water	6.8% for CuO-water	Heat transmission was enhanced by both nanofluids, however CuO-water performed better than Al_2O water.
[74]	CFD	FPC	Al_2O_3 + TiO_2, TiO_2 Al_2O_3, TiO_2, ZnO, ZnO + Al_2O_3	5.5% for nanofluids and 18% for hybrid	The nanofluid and hybrid nanofluid had maximum dynamic pressures of roughly 48% and 16%, respectively.
[75]	Numerical	ETSC	Ag, MgO and ZnO in EG/water	26.7% for Ag/EG-water	Coal, SO_2, and CO_2 emissions were decreased by 855.5 kg, 2241.4 kg, and 7.2 kg annually by 30 solar collectors that were erected using 4.0 Vol% Ag/EG-water nanofluids.
[76]	Numerical	LFR	Syltherm/CuO	1%	With a finned absorber, the thermal efficiency improvement at 4% nanofluid is 0.82%.
[77]	Experimental	ETSC	Graphene-methanol nanofluids	35%	There was a 95% increase in thermal efficiency.
[78]	Numerical	ETSC	water-TiO_2 Water-Al_2O_3, and water-CuO	13.8% higher with CuO	Found that the thermal efficiency of CuO-water, TiO_2-water, and Al_2O -water increased by 13.8%, 1.5%, and 1.3%, respectively.
[79]	Numerical and experiment	ETSC with parabolic concentrato	CuO/water	10%	At 0.08 volume fraction, the system's energy and exergy efficiency increased by 10% and 12.7%, respectively.

	al	r			
[80]	Experiments	ETSC	WO_3/water	23%	When compared to water, the improvement from using nanofluids ranged from 1.05 to 1.16.
[81]	Experimental	ETSC	CuO/water	7.20%	In the collector, smaller particles were more effective.
[82]	Experimental	ETSC	Cu/water		At concentrations of 0.01%, 0.02%, and 0.03%, respectively, the absorbed energy parameter rises from 0.55 when using water to 0.65, 0.76, and 0.83 when utilizing nanofluids.
[83]	Experiment	FPC	TiO_2/WATER	22%	A 22% improvement in the heat transfer coefficient was made.
[84]	Experiments	FPC	CNT/water		With nanofluids, the maximum water temperature was 75 °C, but without nanoparticles, it was only 68 °C.
[85]	Experiments	FPC	CeO_2/water	21.50%	CeO_2/water nanofluid improves solar water heater thermal efficiency by 78.2%.
[86]	Experiment	FPC	Al_2O_3-water	39.20%	achieved are 83.17% and 18.73% for nanofluids, respectively, at a flow rate of 3 lpm, in contrast to the highest energy and exergy efficiencies of 59.72% and 12.29% for water.

Table 2: (continued)					
References	**Type of study**	**Type of collector**	**Nanofluids used**	**Efficiency enhancement**	**Key outcomes**
[87]	Experimental	PTSC	CuO-water	11%	The high viscosity attained over 2.9 Vol% lowers the collector's efficiency relative to water.
[88]	Numerical	PTSC	Water + PEO + 1% CNT, PEO + 1%CNT and PEO + 0.2%CUO	19.68% for (water + PEO + 1%CNT)	Using nanofluids (water + PEO + 1%CNT, PEO + 1%CNT, and PEO + 0.2%CUO) results in improvements of 19.68%, 17.47%, and 15.1%, respectively.
[89]	Numerical	PTSC	TiO_2/water	0.27%	Minimization of entropy formation in a PTC with nanofluids
[90]	Experiment	DASC	Fe_3O_4-SiO_2/water nanofluid	21.7%	The increase in energy efficiency is 66.4%.
[91]	Numerical	PTSC	Silver, aluminum, gold, nickel and titanium dioxide water		Adding different quantities of the aforementioned nanoparticles improves the critical heat flux, which is higher for Au-water and Al-water nanofluids.
[92]	Numerical	PTSC	MWCNT/EG	8.60%	The vacuum-insulated enclosure has the best efficiency, and solar efficiency improves as particle concentrations rise.
[93]	Experiment	DAPTC	Ferrofluids	25%	Even at low concentrations, ferrofluids in the direct absorption

					solar collector exhibit good thermal and absorption characteristics.
[94]	Numerical	PTSC	Al_2O_3, CeO_2, CuO-Syltherm-800 Al_2O_3 CeO_2/Syltherm-800, Al_2O_3-CuO/Syltherm-800	1.09% using Al_2O_3-CeO_2/Syltherm-800	Using Al_2O -CeO_2/Syltherm-800, the maximum improvements in thermal and energy efficiency were 1.09% and 1.03%, respectively.
[95]	Experiment	PTSC	MWCNT-water	3%	With MWCNT nanofluids and water, the system's highest charging efficiency was 62% and 59%, respectively.
[96]	Experiment	PTSC	CuO, ZnO, Al_2O_3, TiO_2, Cu, Al and SiC using water and Therminol VP1		During turbulent flow, Cu-water and Therminol VP1-SiC nanofluids produced the greatest increases in heat transfer of 9.49% and 10.14%, respectively.
[97]	Numerical	PTSC	Al_2O_3 and TiO_2/water	34.51% for TiO_2/water	Using nanofluids as a heat transfer fluid can increase the collector's efficiency.
[98]	Numerical	PTSC	Al_2O_3-Therminol	15%	With nanoparticles, the collector's thermal efficiency can be increased by 15%, and the absorber tube temperature can drop by up to 64 K.

[99]	CFD	PTSC	Al_2O_3-Therminol	15%	At an inlet temperature of 600 K, the enhancement of thermal and energetic efficiency was 14% and 15%, respectively.

enhancement rates were found to have new relationships based on an experiment on a plate HX with Al_2O_3/water nano fluid [58].

According to a study looking into the improvement of heat transfer when using fly ash nano fluids as the working fluid, the rate of heat transfer was shown to rise by 6–20% with increasing concentration. A 2% mass concentration of nano particles was used to achieve the greatest boost [59].

Experimental research was done to determine how the particle sizes of three different metal oxide nano fluids— SiO_2-water with particle sizes of 20 to 30 nm, TiO_2/water with particle sizes of 10 to 25 nm, and Al_2O_3 water with particle sizes of 20 and 40 nm—affected plate HX. The largest boost in heat transfer was obtained when SiO_2-water nano fluid was applied at a mass concentration of 0.2%, whereas Al_2O_3-water nano fluid attained the minimum enhancement in heat transfer at a mass concentration of 0.1% [100]. Research was done on the characteristics of brazed plate HX and the application of carbon-based nano fluids [101]. At a mass concentration of 0.6%, the results shows that decrease in pressure and an increase in the heat exchange capacity and system efficiency factor of 9.19% and 7.28%, respectively

Shell and tube heat exchangers

In comparison to other forms of heat exchangers, the shell and tube heat exchanger permits a greater surface contact area. It is made up of bundles of inner tubes and a huge outer tube that serves as the shell. A schematic view of this kind of heat exchanger is shown in Fig. 13. These heat exchangers have a large contact surface, which increases the rate of heat transfer significantly. However, many of the heat transfer fluids employed have poor thermal conductivities, which make it possible to usehigher thermal conductivity nano fluids. A numerical investigation was conducted [100] to examine the heat transfer capability of carbon-based nano fluids on shell and tube HX.

The investigation found that while the pressure drop increased along with the particle volume concentration, the thermal performance was still enhanced by the nano fluid. An experimental investigation was conducted to examine the energy-saving and effectiveness of using non-Newtonian metallic oxide nano fluids in tube HX and shell. The greatest energy savings were obtained with CuO employing Al_2O_3, Fe_2O_3 and CuO nano particles with water serving as the base fluid [101].

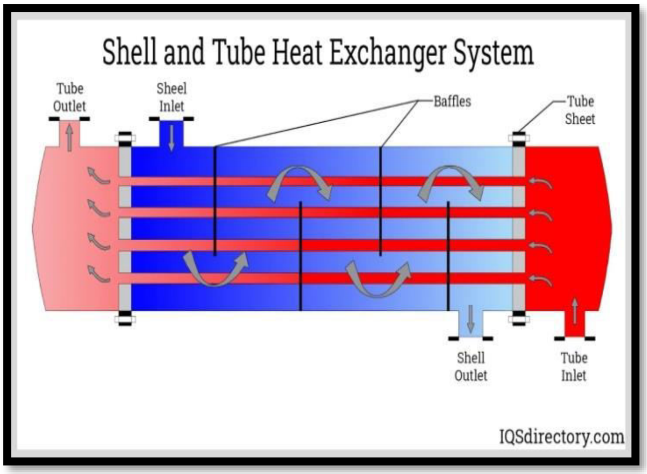

Fig. 13 Cross section of a shell and tube heat exchanger.

The heat transfer rate rises as volume concentration rise and flow, according to a study examining the heat transfer properties of TiO_2-EG nano fluids in a tube HX and shell [102]. The heat transfer rate was 0.277 J at 0.075% nano particle concentration and a volumetric flow rate of 0.6 l/min, according to the study's findings about the best volume concentration and flow rate for optimal heat transfer. CuO/water as a heat transfer fluid was studied experimentally and numerically by Said et al. [103]. The result shows a 7% and 11.39% increase in the convective and heat transfer coefficients, respectively. Furthermore, the area might be reduced by

Table 3: Investigation on the use of nanofluids in heat exchangers

References	**Method of study**	**Type of heat exchangers**	**Nanofluid used**	**Key outcomes**
[105]	Experimental	A rectangular channel	Al_2O_3-water	Maximum enhancement values of 54% in the transition flow regime and 11% in the turbulence regime were observed at a mass concentration of 1% of nanofluid.
[106]	Experimental	Concentric tube heat exchanger	SiC(P)/water, SiC(M)/water, SiC(P)/EG, and SiC(M)/EG	According to the experimental findings, SiC(M) has a greater heat transfer coefficient rate than SiC(P) in both the water and EG cases.
[107]	Simulation	Plate heat exchangers	TiO_2/water	The average improvement in the overall heat transfer coefficient from the TiO_2/water nanofluid was 6%, while the maximum improvement was 10%.
[108]	Experimental	Horizontal double-pipe mini-channel	Boehmite alumina (γ-AlOOH) nanoparticles	The highest thermal conductivity is found in nanofluids that contain platelet-shaped and cylindrical nanoparticles. Better heat transmission properties are shown by platelet form.
[109]	Experimental	Concentric tube	Al_2O_3 in water	The concentration of nanofluid volume improved the thermal properties and increased heat transfer the most.
[110]	Simulation	A spiral double-pipe	Water- Al_2O_3 and water-SiO_2	The ideal options are water- Al_2O and water-SiO_2 nanofluids for Reynolds numbers between 10,551 and 17,220 and 17,220 and 31,910, respectively.
[111]	Experimental	Plate heat exchanger	Al_2O_3-MWCNT hybrid	The heat transfer coefficient for MWCNT (0:5) nanofluid has improved by up to 15.2%, while the performance index has

			nanofluids	increased by 2.96% and the pump work has hardly increased by 0.02%.
[112]	Experimental	Heat exchangers	Aluminum and copper in ethylene-glycol and water	According to the findings, nanopowders can significantly increase wear by reducing ethylene glycol's anticorrosion properties through a synergistic erosion-corrosion mechanism.
[113]	Experimental	Counter-flow plate heat exchanger	Al_2O_3-SiC, Al_2O_3-AlN, Al_2O_3-MgO, Al_2O_3-CuO and Al_2O_3-MWCNT	For the Al_2O -MWCNT (4:1) hybrid nanofluid, a maximum improvement of about 31.2% has been noted in the heat transfer coefficient, with a minor improvement of 0.08% in the pump work and an improvement of 12.46% in the performance index.
[114]	Simulation	Plate-type heat exchanger	Al_2O_3 in water	As the concentration of the nanofluid increases, the overall heat transfer coefficient increases by 30% to 70%. At 0.75% volume concentration of Al_2O, the calculated hydraulic power (product of pressure drop and flow rate) showed a global minimum.
[115]	Simulation and experimental	Double-tube heat exchangers	Al_2O_3/water	The thermal efficiency of the Al_2O /water nanofluid was found to be 16% higher than that of pure water.

Table 3: (continued)

References	**Method of study**	**Type of heat exchangers**	**Nanofluid used**	**Key outcomes**
[116]	Experimental	Double-pipe counter-flow	TiO_2-water	Under the specified conditions, the volume concentration of 0.5 Vol% was 15% greater than that of the base fluid. Additionally, using the nanofluids resulted in a modest rise in pressure decreases.
[117]	Simulation	Counter-flow double pipe	MgO-oil based	As the pumping power and pressure drop increased, so did the heat transfer rate and heat transfer coefficient.
[118]	Theoretical	A helically coiled heat exchanger	rGO- TiO_2	The heat transfer coefficient's percentage improvement was approximately 35.7%.
[119]	Experimental	Concentric tube	TiO_2/Thermo Oil XT 32	As the volume proportion of nanofluids TiO_2/Thermo XT 32 oil grows, so does their convective heat transfer coefficient.
[120]	Experimental	Plate heat exchanger	CNT, Al_2O_3, surfactant with deionized water	They are useful in heat exchangers, which require large amounts of traditional fluids.
[121]	Simulation	Double-pipe heat exchanger	Al_2O_3/water	15% energetic efficiencies were achieved at 600 K as the inlet temperature.
[122]	Experimental	Plate heat exchanger	Kaolin-deionized water	A 9.3% increase in the mean heat transfer coefficient was attained.
[123]	Simulation	Pillow plate heat exchanger	Al_2O_3, CuO and TiO_2 in water	Among other nanofluids, the Al_2O_3-water with $\phi = 2\%$ at all Reynolds numbers and the TiO_2-water with $\phi = 5\%$ at higher Reynolds numbers perform better.

[124]	Experimental	Helically coiled tube heat exchanger	MWCNT/water	The pressure drop is determined to be 16%, 30%, and 42% higher than water, and the Nusselt number is 28%, 52%, and 68% higher than water.
[125]	Experimental	Plate heat exchangers	Kaolin/deionized water and TiO_2/deionized water	Using kaolin/deionized water and TiO_2/deionized water, the heat transfer rates were 18% and 12%, respectively.
[126]	Experimental	Compact heat exchanger	Al/water	At concentrations of 0.1 and 0.2%, the average Nusselt number value increased by 30.97 and 44.46%, respectively.
[127]	Experimental	Micro-heat exchanger	Zirconia nanofluids	At a mass concentration of 0.3%, the heat transfer coefficient and pressure drop were increased by 40.1% and 67%, respectively, in comparison to the base fluid.
[128]	Theoretical	Heat exchangers	Graphene-based and metal oxide nanofluids	For GNP, GNP2, alumina, and silicon dioxide nanofluids, the highest increase in Nusselt number was 84%, 72%, 26%, and 28%, respectively.

Table 3: (continued)

References	**Method of study**	**Type of heat exchangers**	**Nanofluid used**	**Key outcomes**
[129]	Experimental	A double-pipe HX, a shell and tube HX and, a plate HX	Al_2O_3/Water	The heat transfer coefficient for double-pipe HX was shown to have a maximum enhancement of 60%, whereas the plate HX showed a maximum enhancement of 11%.
[130]	Experimental	Helically coiled heat exchanger	Deionized water-based graphene	Heat transfer coefficient that is 21-25% higher than that of DI water
[131]	Simulation	Double-pipe U-bend	Fe_3O_4/water	For a nanofluid volume concentration of 0.06%, the Nusselt number is increased to 9.76% and 14.76%.
[132]	Simulation	Serpentine milli-channel heat exchanger	CuO/(60:40) % ethylene glycol and water	Between 42% and 47%, the pressure drop of nanofluids rises.
[133]	Experimental	Double-pipe and plate heat exchanger	Al_2O_3/water	The plate heat exchanger shows a mere 7% increase in the heat transfer coefficient, whereas the double-pipe HX has a maximum boost of 26%. For the plate type, the minimum pressure drop increase was 1%.
[134]	Experimental	Dimpled plate	Al_2O_3/water	Heat transfer coefficient for double-pipe HX can be enhanced by up to 26%, however the plate heat exchanger only shows a 7% increase in heat transfer coefficient. For the plate type, the minimum increase in pressure drop was 1%.
[135]	Experimental	Rough plate heat exchanger	Al_2O_3/water	Both the heat transfer rate and the pressure drop in the plate heat exchanger are improved by increasing the volume percentage of nanoparticles and surface roughness.

[136]	Simulation	Single-pass shell and tube	Al_2O_3-Cu/water	The hybrid nanofluid's heat transfer coefficient has increased by 25% compared to Cu/water nanofluid and 139% compared to water.
[137]	Simulation	Mini-channel hairpin	CNT/Fe_3O_4	Heat transfer rate, overall heat transfer coefficient (apart from at Reynolds number 500), heat exchanger effectiveness, and PEC all increase when the difference between the working fluids' inlet temperatures widens, but pumping power decreases as the inlet water temperature rises.
[138]	Simulation& experimental	Microchannels heat exchanger	SWCNTs	The convective heat transfer coefficient and the pressure drop increased with the concentration of SWCNTs.

6.81%. The utilization of Al_2O_3/water and TiO_2/water nano fluids to improve heat transfer and the thermal performance of tube HX and shell was investigated. Al_2O_3/water enhanced the heat transfer coefficient to a maximum of 41%, whereas TiO_2/water increased the heat transfer coefficient to a maximum of 37% [104]. Table 3 presents additional research on the use of nano fluids in heat exchangers.

Conclusions and recommendations

The utilization of nano fluids as coolants in heat transfer devices has won popularity over time. This article provides a comprehensive review of investigations on the manufacture, thermo physical property measurements and applications of nano fluids in a variety of thermal devices that require efficient heat transfer. Few topics covered include thermo physical models used to determine the properties of nano fluids, mechanisms that enable increased thermal behavior of nano fluids, and the usage of various nano fluids in devices such as heat exchangers and solar collectors and. Finally, more effort must be put into improving manufacturing procedures in order to address the issue of high manufacturing costs. Based on the various publications examined in the study, the following suggestions are made: On the preparation of nano fluids:

Some researches on the preparedness of nano fluids using the one-step method are known, although this method has been shown to be more stable than the two-step method. Many researches into the manufacture of nano fluids using the one-step process are required, since this could aid in the development of more cost-effective methods for large-scale nano fluid production.

Consideration of thermo physical properties of nano fluids:

- When the heat capacity of base fluids exceeds that of nano particles, increasing the volume concentration of nano particles reduces the specific heat capacity of nano fluids. Since coolants require a higher heat capacity, more research is needed to see how this phenomenon might be enhanced.
- More research is needed to understand the prevailing forces that influence the behavior of micro refrigerants in different flow configurations.
- The number of correlation models that explains the thermo physical properties of nano fluids has increased, as have the methodologies for building them. However, further correlation equations predicting the heat transfer and friction factor behaviour of numerous nano fluids are required. Regarding the mechanisms that change the properties of nano fluids.
- Nano fluids have been studied at temperatures ranging from 10 - 100 °C. The interaction mechanism of nano particles in base fluids for heat transmission at higher temperatures (>100 °C) and cryogenic settings warrants additional exploration.

- Our understanding of the impact of nano particle morphology and nano particle mixing ratio on heat transfer augmentation is incomplete. More research is needed to understand how they affect the performance of nano fluids in heat transfer devices.

Research on different heat transfer devices:

- Further research is needed, as there are conflicting findings on the influence of nano particle loading on pressure drop and increased pump power requirements. While few studies claim that particle loading raises the pressure drop and thus the system's pump power requirement, others plead that when the heat transfer rate obtained using nano fluids is compared to that of conventional fluids, nano fluids reduce pump power requirements.
- The finite volume method continues to be the most commonly used model in the literature for nano fluid simulations. Further research utilizing diverse methods
- In vehicle radiators and heat exchangers, the constant rate of heat transfer caused by the use of nano fluids reduces the heat transfer surface. This can lead to an improvement in the volume and size of these devices. Such enhancements would reduce drag forces in automobiles while increasing engine performance.
- Additional research is needed on the impacts of heat transfer erosion and flow channel corrosion caused by the usage of nano fluids, particularly at high temperatures. The short and long term effects of nano particle deposition and sedimentation on heat transfer device efficiency need to be investigated.
- There is few research on the environmental impact and production costs of nano fluids. Such characteristics pose significant barriers to the commercialization of nano fluids.

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