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Review Article

A review on convective heat augmentation techniques in solar thermal collector using nanofluid

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ABSTRACT

Solar water heating system is convincing technology to convert solar energy into thermal energy. According to the survey, approximately 42% of refined crude oil is used in industries and commercial applications for heating processes. Fossil fuel is the main energy source that is depleting continuously. Solar energy is an environment-friendly energy source, which can fulfill energy demand. Solar thermal collectors are most popular in domestic as well as industrial sectors for water heating due to their ease of operation and simple maintenance. Extensive work is going on to improve the thermal performance of solar thermal collectors using passive techniques. Passive techniques include the use of nanofluid, twisted tape, Phase Changing Materials. Active and passive techniques have a significant contribution to solar thermal collector thermal performance enhancement. This paper reviews the work carried out and current progress to enhance the thermal efficiency of solar water heaters using nanofluid. In addition to this, a detailed discussion and limitations of existing research have made from this discussion, research gaps are identified and possible future modifications are suggested.

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INTRODUCTION

The world population is increasing dramatically by leap and bound. According to the population division of the department of economic and social affairs survey, the world population in 2000 was 6.1 billion and it becomes 8.9 billion in 2050. The industrial sector is expanding day by day to fulfill the needs of the population. The main energy source in industrial and commercial applications is fossil fuel. The industrial applications include heating processes like steam generation, cooling, heating, solvent extraction, distillation, food processing, boiler feedwater heating, and many other applications. The renewable energy source can

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be an alternate source to meet the energy demand due to scarcity and the continuous depletion of conventional fuels. Solar energy is the renewable energy source on earth, has the potential to fulfill energy demands without polluting the environment [1, 2, 3]. Solar energy can be harvested either by Photovoltaic panels or solar thermal collectors. Solar radiations are absorbed by collectors, which convert absorbed energy into heat and transfer this heat to working fluid [1, 2]. Solar collectors can be classified into the non-concentrating collectors and concentrating collectors. Non-concentrating collectors are classified as a flat plate and evacuated glass tube collector [4]. Evacuated glass tube collectors show outstanding thermal performance due to lower heat loss, easy transportability, and quick installation [1, 5]. Evacuated tube collectors are the most efficient solar collector in all weather conditions because the incident angle of sun rays on the evacuated tube is always 900 throughout the day [2]. An evacuated glass tube consists of the fused inner and outer tubes. The vacuum is created between both tubes to trap solar energy. The outer surface of the inner glass tube is coated with an aluminium nickel alloy to absorb more radiation.

Solar thermal energy is utilised in the industrial sector to meet the process heat requirements. Solar water heating is the most popular solar thermal system and accounts for 80% of the worldwide solar thermal market. Some of the technical problems, like low efficiency, high heat loss, poor solar energy harvesting capability, installations challenges, capital costs are barriers to the promotion of solar water heater in industrial applications. Extensive work is going on to minimize heat loss and enhance the thermal efficiency of solar thermal collectors. Existing research says enhance the overall performance of a solar thermal collector, changes are made in solar collector structure, glass tube coating, inclination, using active and passive augmentation techniques [6]. This paper presents a comprehensive review of the current status and technical developments in the field of solar water heating systems.

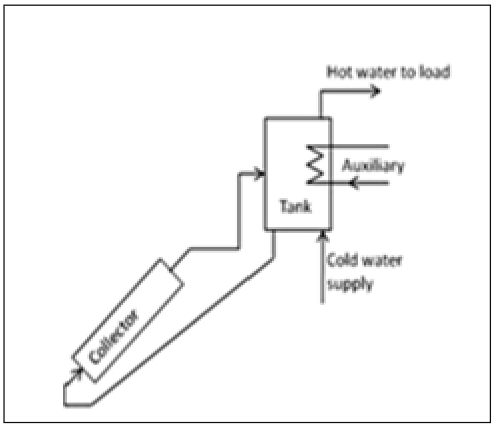

Figure 1. Passive system.

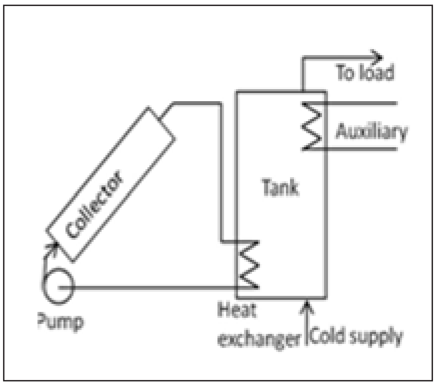

Figure 2. Active system.

CLASSIFICATIONS OF SOLAR WATER HEATER SYSTEM

Solar water heating systems are classified based on the pump requirement [7]. Passive solar water heaters systems are commonly used for domestic applications. Passive systems (Fig. 1) transfer hot water from the collector to the tank by natural circulation at 600C. The active system (Fig. 2) transfers thermal energy by using the pump. A differential thermostat is used to control the circulation of the water. A check valve is required to avoid the reverse circulation of water [8].

HEAT TRANSFER ENHANCEMENT TECHNIQUES IN SOLAR THERMAL COLLECTORS

In today's era, financial aspects and performance become basic, and crucial factors for commercialisation, hence Solar water heating systems are popular in domestic applications [7]. Solar system performance depends on solar irradiation. Variable climatic conditions are not suitable for industrial applications. Extensive work is going on for the augmentation of the convective heat transfer rate [7]. Continuous research work is going on to enhance unfavourable conditions performance by using active and passive augmentation techniques. A detailed review presented on the use of active and passive techniques by Jaishankar [9]. Active techniques use an external source as a prime mover. Passive methods use geometrical modifications, inserts, twisted tapes, curved tubes, helically coiled tubes, spirally coiled tubes [7]. The mode of heat transfer, type, and application decide the effectiveness of the system [7]. Twisted tape flattens the velocity profile at the centre of the pipe [10]. Wire coil and spiral tape insert give better performance at the surface of the conduit as it increases the velocity at the surface.

Khoshvaght et al. [11] examined the performance of agitated vessel U tube heat exchanger using spiky twisted tape and water-based metallic nanofluid. The effect of agitator speed tested at six different speeds. The optimum agitator speed obtained is 1300 rpm. Spiky twisted tape

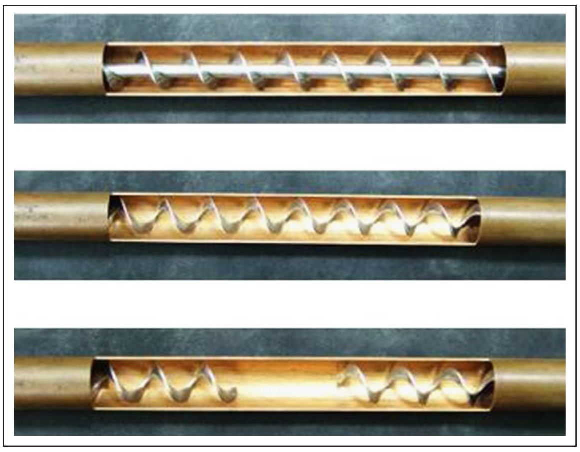

Figure 3. Twisted tape arrangements.

enhances the heat transfer coefficient at the cost of pressure drop. The spiky tape with angle α=β=0.33 is recommended for 33% overall performance enhancement. Metallic nanofluids exhibit a high heat transfer coefficient at the cost of pressure drop. Metallic nanofluids exhibit a high heat transfer coefficient at the expense of pressure drop. Among all metallic nanofluid water-based silver nanofluid gives better results [11]. The heat transfer coefficient increased by 18.2%, and the pressure drop by 8.5%. Sekhara et al. [12] studied Al_2O_3 nanofluid heat transfer coefficient variation, at different volume concentrations and twist tape ratios. At the same time, the twisted tape was placed in the fluid flow path. Constant heat flux condition maintained for experimentation. The heat transfer coefficient increased by 8-12% compared with water. The highest friction factor obtained at 0.5% particle concentration. Concluded Nusselt number and friction factor depends upon nanoparticle volume concentration. As Reynold's number of flow increases, Nusselt number increases, and friction factor decreases. The use of nanofluid improves heat exchanger efficiency and compactness. Keguang et al. [13] evaluated the performance of evacuated glass tube solar collector with twisted tape using CFD. He developed a numerical model for heat transfer and fluid flow inside a single collector tube. Results show that twisted tape insert reduces the velocity of flow and makes temperature a more uniform temperature field inside the pipe. The twisted tapes make the mixture more intense near the top and bottom half of the tube. It destroys the originally ordered flow and generates more eddy, which leads to a higher dissipation of mechanical energy and thus reduces velocity magnitude, at the same time, makes the temperature field more uniform. Sundar et al. [14] inserted tape geometry in Al_2O_3 nanofluid. Sunder and Sharma [15] performed with and without twisted tape in a tube in their study. For 0.3% vol. concentration heat transfer enhancement is 21%. It is further enhanced to 49.75% when the twisted tape of a twist ratio of 5 is used. The maximum friction penalty of 1.25 times observed. Sandesh et al. [16] work on flat plate collectors using water-based Al2O3 and CNT nanofluid with helical tape inserts. Tests were performed with different volume concentrations and twist ratios. The water-based CNT nanofluid with helical screw tape inserts shows higher thermal performance than water-based Al_2O_3 nanofluid. The maximum enhancement in heat transfer found at a 1% volume concentration of CNT with a helical tape twist ratio of 1.5. Literature reveals passive techniques increase eloquent heat transfer area and thermo-hydraulic performance by disturbing flow at the cost of pressure drop.

Phase change materials are one type of latent heat storage unit. It can absorb heat before reaching its melting temperature after energy storage it releases continuously. This heat transformation depends upon the situation. A phase change material having high latent heat of fusion can store and release a large amount of energy. Only solid to liquid and vice versa phase changes are possible for PCM's. Liquid to gas phase transformation is impractical because high volume and pressure required to store in the gas phase. The solid to solid-phase change is a too slow process and has a relatively low heat of transformation. Chopra et al. [17] used heat pipe in the evacuated tubes in the nadir or medium temperature applications. He found the integration of phase change materials in evacuated tube collectors influences its performance. His manuscript gives classification based on thermal energy storage, advantages, draw backs of evacuated technology, financial benefits, recent research, and recommendation for future improvement. Avinash et al. [18] tried to reduce the time required for storing and releasing heat in solar thermal applications. He used paraffin wax as phase-changing material, during operation phase change material melted, and solidified. In a concentric tube, heat storage unit longitudinal copper fins provided for charging and discharge of paraffin wax. The effects of fin height, Reynolds number, and Stefan number tested experimentally to analyse the system performance. At various locations, PCM temperatures observed. The observed Reynolds number, fin height, Stefan number increases the time required for the melting of PCM reduced. Avinash et al. [19] used PCM for heating and cooling application. The inner pipe is made of SS-316 and the outer of SS-304. The HTF flows from bottom to top in the HTF pipe. The temperature probe's accuracy was 0.1˚C. In the heat storage unit, four temperature probes set at positions of 100, 200, 300, 400 mm from bottom in the longitudinal direction, and 5, 14, 25 mm in a radial direction, from the outer wall of HTF pipe towards an inner wall to measure the temperature field in the PCM. The wall of the inner tube, then molten PCM ascended to the top part of the PCM container because of natural convection currents. 2. In the next two regions, the melted PCM zone in the liquid phase and the non-melted PCM zone in the solid phase coexisted during the charging process. 3. The conduction inside the solid matrix of the PCM was responsible for the heat transfer process in the frozen region 4. The PCM melting time is higher than the solidification. Though PCM shows good results, It has several challenges in manufacturing, usage, material compatibility, material properties, thermal performance, cost, availability, safety, disposal, conditioning, and packaging for use [20].

The determination of thermophysical properties of nanofluid, phase change material, experimentation is time-consuming and expensive. In the 21st century, these constraints are overcome by using soft computing techniques. Soft computing techniques include surface response methodology (RSM), artificial neural network (ANN), non-dominated sorting genetic algorithm (NSGA), particle swarm technology, computational fluid dynamics (CFD). These intelligent techniques can reduce the effort of the number of experimental runs and hypotheses. Arturo et al. [21] performed optimization of evacuated tube solar collectors using a combination of design of experiment simulated annealing method and computational fluid dynamics. Design of experiments and computational fluid dynamics model used to find geometrical and operational parameters, which affect the thermal performance of evacuated tube solar collectors. Simulated annealing optimization used to obtain a solution of 259 geometry modelled in CFD.

NANOFLUID

Nanofluids are 20thcentury, heat transfer fluids. In 1995 Choi used the Nanofluid term. The ordinary heat transfer fluid like water suffers from poor thermophysical properties. It limits collector performance. Nanomaterials have a wide range of materials like nanocrystalline materials, nanocomposites, carbon nanotubes. Nanofluid is a homogeneous mixture of base fluid and nanoparticles. Nanoparticle's size varies between 1 and 100 nm. The thin layer formed around nanoparticle called nanolayers acts as a thermal bridge between the base fluid and nanoparticles.

Nanofluids structure is represented by Figure 4. The nanofluid shows enhancement in thermal conductivity, thermal diffusivity, heat transfer coefficient, density, and viscosity of the base fluid. This enhancement depends upon

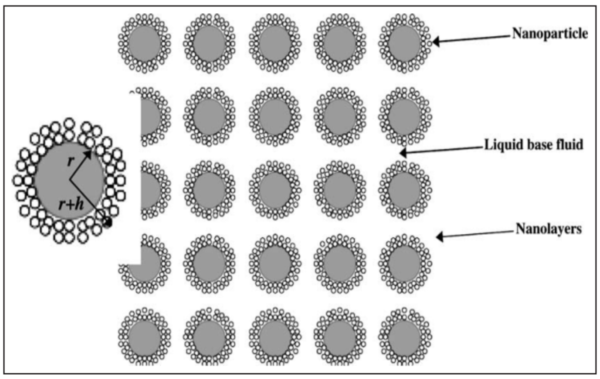

Figure 4. Nanofluid structure.

Table 1. Types of nanoparticle

Chemically Stable Metals	Gold, Copper
Metal Oxides	Alumina, Silica, Zirconium, Titanium
Oxide Ceramics	Al_2O_3, CuO
Metal Carbides	SiC
Metal Nitrides	AiN, SiN
Carbon In Various Forms	SWCNT, MWCNT, Graphen

particle shape, size, and volumetric fraction. Nanosize particles of the following materials used (Table 1) to improve thermal properties [1].

The base fluids include water, oils, organic liquids, bio-fluids, lubricants, polymeric solutions [22]. The next version of nanofluid is hybrid nanofluid, which developed by adding two or more types of nanoparticles in the base fluid. Table 2 shows the thermophysical properties of well-known nanoparticles. A Homogeneous mixture of hybrid nanofluid enhances physical and chemical properties [22]. Proper hybridisation of nanoparticles with fluid gives promising heat transfer enhancement.

Brownian diffusion and thermophoresis slip mechanism having a crucial contribution to heat transfer enhancement [27]. Ghiasi et al. [28] tried to model the slip mechanism of casson fluid flow over a fixed plate with a non-uniform source/sink and ohmic heating using the homotopy method. The Homotopy method is a semi-analytical method to solve a nonlinear differential equation. He states that the Harmann number affects the Nusselt number and skin friction coefficient. The homotopy analysis results show good agreement with previous studies. Ghiasi et al. [29] did an angular geometric surface, nonlinear, and thermomechanical analysis using homotopy analysis. The boundary layer equation derived by solving the conservation of mass, momentum, and energy equation. Ghaisi et al. [22] identified a gap in Navier-Stokes to determine the motion of the non-Newtanion fluid. An analytical optimal solution incompressible casson fluid flow over horizontal sheet under Lorentz force and ohmic heating investigated. Aristov et al. [30] derived numerical solutions to describe viscous incompressible fluid flow. He considered inertia and viscous force. Due to inertial force consideration, minimum boundary thickness exists where shear stress vanishes. Sarkar et al. [22] summarized challenges that engineers and researchers face while using nanoparticles compared with other techniques, in terms of stability durability, reliability, efficiency, safety, initial cost, life cost, size, weight, increase in pressure drop, pumping power, etc. Large size solid particles (more than 100 nm) sediments quickly in base fluid and forms a fouling layer on its surface, hence not recommended. This fouling layer affects the effectiveness of the

Table 2. Nanoparticles thermophysical properties

Sr. No.	Nanoparticle	Thermal Conductivity W/m k	Specific Heat J/kg. k	Density Kg/m^3
1.	Silver (Ag)	429	235	10500
2.	Zirconium oxide(ZrO2)	22.7	278	5890
3.	Zinc oxide (ZnO)	27.2	494	5630
4.	Titanium Oxide (Tio2)	8.4	710	4157
5.	Cerium Oxide (CeO2)	12	460	7220
6.	Alumina oxide(Al_2O_3)[23]	36	765	3970
7.	Copper Oxide (CuO) [23]	17.65	533	6500
8.	MWCNT[24]	3000	711	2100
9.	Magnesium Oxide(MgO)[25]	42	877	3580
10.	Silicon Oxide (SiO2)[23]	1.38	745	2220
11.	SWCNT[1]	6000	841	2100
12.	Tungsten Oxide(WO3)	1.63		7100
13.	Ferric Oxide (Fe3O4)[26]	17.65	104	5180
14.	Titanium Nitride	28.84	545.30	5240

base fluid. There is a lot of scope and challenges for research in the fields of preparation, characterization, stability, and applications of hybrid nanofluid [31].

Copper Oxide (CuO_2)

Copper (II) oxide or cupric oxide is the inorganic compound with the formula CuO. CuO is a black solid and a stable oxide of copper, and the other is Cu_2O or cuprous oxide, it is also known as tenorite. Ghaderian et al. [32] suspended Copper oxide nanoparticles in water. Nanofluid with different volume concentrations used in collectors throughout the study. The evacuated glass tube solar collector heat transfer enhancement is studied with different mass flow rates and volume concentrations. The efficiency enhanced to 51.4% with 0.06% and 41.9% with 0.03% of CuO. Michael et al. [33] examined the performance of flat plate collectors using water-based copper oxide nanofluid. Experimentation performed on a 100 LPD capacity system. Nanofluid thermophysical properties juxtapose analytically and experimentally. The Sodium Dodecyl Benzene Sulfonate (SDBS) and Triton X-100 selected as surfactants. The improvement in efficiency was observed more in thermosyphon circulation than forced circulations. At 0.1kg/s flow rate, maximum efficiency is obtained. Efficiency enhancement is possible if the heat exchanger placed inside the nanofluid thermal storage tank [33].

Zink Oxide (ZnO)

Huseyin Kaya et al. [34]the efficiency of an evacuated U-tube solar collector (EUSC determined solar collector efficiency. ZnO particles suspended in ethylene glycol and pure water. 50% of ethylene glycol and pure water used as base fluid. Found thermal conductivity of Zink oxide based nanofluid increases by increasing volume concentration of nanoparticle. ZnO nanoparticles added in base fluid at volume concentrations of 1.0%, 2.0%, 3.0% and 4.0%. Maximum collector efficiency found 62.87% for 3.0% concentration and 0.045kg/s mass flow rate. Barewar et al. [35] synthesized Ag/ZnO-glycol hybrid nanofluid to investigate thermophysical properties experimentally. Experimental results compared with a model developed by the artificial neural network (ANN). The correctness of the model is verified using R-squared value, mean square error, and average absolute relative deviation percent.

Aluminium Oxide (Al_2O_3)

Rajasekhara et al. [36] did an experimental analysis of Al_2O_3nanofluid to study the variation of heat transfer coefficient and pressure drop. Different volume concentrations of Al_2O_3 nanoparticles used in combination with twisted tapes. Due to small variations in viscosity at different particle concentrations, the Reynolds number changes, and these changes are within ±100. He found by using nanofluid, the heat transfer coefficient enhances at the entrance region [36]**.** The local heat transfer coefficient at X/D = 10 and 0.5% volume concentration is 26% and 22% higher than water in a plain tube [36]**.** The Nusselt number variation depends on the Reynolds number, particle concentration axial distance. Ghaderian et al. [37] investigated the thermal performance of solar collectors using aluminium oxide nanofluid. TritonX-100 surfactant used to avoid nanoparticle agglomeration. 40nm size nanoparticles used. Nanoparticles are added at 0.03% and 0.06% volume concentration for experimentation. The collector performance examined for 20 to 60 lpm. The maximum efficiency is 57.63% for 0.06% volume concentration and 60lph mass flow rate [37]. The collector efficiency depends upon the mass flow rate and volume fractions of Al_2O_3 nanoparticles. Concluded Al_2O_3 nanofluid convert maximum solar energy into thermal energy efficiently [37]. Gargee et al. [38] conducted experiments on the serpentine shape heat pipe of a flat plate collector. Aluminium oxide particle suspended in base fluid and nanofluid prepared with varying weight concentrations of 0.05, 0.25, and 0.5%. Collector tilt angles varied 18.53, 33.5, 40, 50, and 60°. The performance of the collector increases with coolant flow rate up to a limit, then decreases, the same trend seen for tilt angle. The maximum efficiency found at 50°. Rashmi et al. [11] performed a numerical simulation of Al_2O_3/water nanofluid in cylinder using computational fluid dynamics. The single-phase model analyses performance of nanofluid. Numerical simulation results compared with an experimental result at various values of Rayleigh number. The result shows with an increase in volume fraction that heat transfer decreases. Safikhani et al. [39] performed multi-objective optimisation ofAl_2O_3/water nanofluid in a flat tube using CFD, NSGA-II, and ANN. He used five independent design variable tube flattening (H), inlet volumetric flow rate (Q), wall heat flux (q), nanoparticle diameter (dp), nanoparticle volume fraction. In the first step, the heat transfer coefficient and pressure drop computed using the computational fluid dynamics two-phase mixture model. The first step numerical data utilised in a grouped method of data handling (GMDH) type ANN. The high accuracy of GMDH polynomials obtained used for multi-objective optimisation.

Graphene Nanoplatelets (GNP)/Distilled Water Nanofluid

Iranmanes et al. [3] measured the solar thermal collectors performance. Nanoparticle having surface area 750m2/g. Ultrasonication method used to prepare a stable and homogeneous graphene nanofluid. Transmission electron microscopy and field emission scanning electron microscopy used for the morphological characterisation of graphene nanoplatelets. ASHRAE standard 93-2003 referred for experimentation. Solar collector thermal efficiency enhanced to 90.7% at 1.5L/min flow rate. GNP nanofluid enhances thermal conductivity to 27.6%. Results show using graphene nanosheets the highest outlet temperature of the fluid obtained. Sadri et al. [13] did CFD modelling of a horizontal tube. The green functionalised graphene nanoplatelets (clove treated) under steady-state fully developed turbulent flow conditions. Nanofluid thermophysical properties obtained experimentally used as input for CFD simulation. TA shear stress transport model is selected to simulate turbulent flow. The convective heat transfer coefficient and friction factor evaluated for 0.0025%, 0.0075%, and 0.1% weight concentration of graphene nanoparticle. The tube thickness not taken into account only, fluid control volume considered. The grid generated by a module provided by Ansys fluent. The grid independence test carried out with 3 different sizes. Constant heat flux with no-slip boundary condition employed at a wall. Reynold number range 6371-15927. Simulation results validated with experimental results.

Multi-Walled Carbon Nanotube (MWCNT)

Sandesh et al. [40] determined the optimum volume concentration of carbon nanotube nanoparticle to enhance the performance of heat pipe solar collectors. The thermal performance of CNT nanofluid compared with pure water for different tilt angles and volume concentrations. Carbon nanotubes have a diameter of 10–12 nm and length 0.1–10 nm. SEM image of MWCNT captured by FESEM. Carbon nanotubes immersed in sulphuric acid and nitric acid (3:1) mixture. CNT treated in an ultrasonic bath. To neutralise the solution ammonium hydroxide used and cellulose acetate membrane used to filter. The carbon nanotube washed till the pH value of suspension reached 5.5. Nanofluids prepared for various volume concentrations of CNT. Kakavandi and Akbari [41] performed an experimental study on hybrid nanofluids made by suspending multi-wall carbon nanotube and silicon carbide in water plus ethyl glycol mixture. Scanning electron microscopy and X-ray diffraction methods used for the characterisation of a nanoparticle. Hybrid nanofluid stability measured by DLS test and thermal conductivity by KD2-Pro thermal analyser. The volume concentration range is 0–0.75% used. The general correlation developed to determine the thermophysical property of the nanofluid. Hamid et al. [42] performed sensitivity analysis and thermal performance optimisation of multi-wall carbon nanotube nanofluid charged U tube solar thermal collectors using a genetic algorithm. The mass flow rate, environmental condition, and collector length considered as a variable. Taffaroj et al. [43] predicted the performance of nanofluid charged parabolic trough solar thermal collected using computational fluid dynamics. Nanosilica and multi-wall carbon nanotubes used in ethylene glycol for experimentation. The CFD analysis performed for simulating processes and validating experimentation. A multi-layer perceptron neural network trained using the data obtained from the CFD model [43]. He states that artificial intelligence is an efficient algorithm for the optimisation and performance prediction of a solar thermal collector. He constructed the ANN model to predict process output.

Single-Wall Carbon Nanotube (SWCNT)

Sabiha et al. [1] used water-based SWCNT nanofluid in the heat pipe. Experiments performed according to

ASHRAE standard 93-2003 at the University of Malaya. Sodium dodecyl sulphate used as a surfactant. Nanofluid prepared with concentrations of 0.05, 0.1, and 0.2%. To overcome the SWCNT nanoparticle agglomeration of ultrasonication performed. The Performance of SWCNT nanofluid compared with water at different flow rates of 0.008, 0.017, and 0.025kg/s. The 93.43% efficiency found at 0.2%volume concentration and mass flow rate 0.025kg/s. The collector efficiency increases with SWCNT nanoparticle concentration and flow rate. He developed an empirical correlation between thermal efficiency and thermal conductivity. Mahbubul et al. [2] investigated collector performance using water-based SWCNT nanofluid experimentally. Experimental setup of solar-powered ammonia-water absorption refrigeration system for space cooling with an ice-storage facility developed at King Fahd University of Petroleum & Minerals, Dhahran, Saudi Arabia. The effective surface area of the collector was 42m^2. Water-based SWCNT nanofluids prepared at a concentration of 0.05%, 0.1%, and 0.2%. At 0.2% of SWCNT nanoparticles, maximum efficiency obtained. The results showed 56.7% efficiency obtained when the collector was operated with water and 66% of efficiencies 0.2% nanoparticle, respectively. Concluded nanofluids enhance the efficiencies of solar collectors significantly. Sandesh et al. [44] investigated thermosyphon heat pipe performance using water-based CNT nanofluid and pure water. Tests performed on varied range of CNT volume concentration of 0.15%, 0.45%, 0.60%, and 1% and tilt angle. Concluded;

- CNT nanofluid found more efficient than pure water for heat pipe.
- The efficiency of the solar heat pipe collector increases up to 0.60% volume concentration afterwards decreases. Maximum efficiency found 73% for 0.60% volume concentration of nanoparticle.
- The heat pipe collector efficiency increases with the tilt angle up to 50deg after this starts to decrease for water and nanofluids.

Cerium Oxide (Ceo2)

Ramesh et al. [45] prepared cerium oxide/water (CeO2/H2O) nanofluid. The thermal performance of flat plate solar water heater investigated experimentally, having capacity 100lpd. Polyvinyl pyrolidine used as a surfactant it shows better stability compared to pure water. The experiment performed on various mass flow rates to investigate heat transfer enhancement. For low volumetric fraction, significant performance improvement observed in forced circulation compared to conventional mode. Sharafeldin et al. [46] prepared stable water-based cerium oxide nanofluid. The stability measured by using Zeta potential machine. The mean diameter of the cerium oxide particle is 25nm. Experiments performed by varying volume concentration and mass flow rates. Nanofluid shows the remarkable temperature difference between inlet and outlet flow. For a 0.035% volume fraction and 0.017 kg/m3 mass flow rate, the maximum heat removable factor obtained. The solar corrector thermal loss coefficient is raised to 34.

Titanium Oxide (TiO_2)

Mahendran et al. [47] determined the efficiency of solar collectors using water-based titanium oxide (TiO_2) nanofluid. Experiments performed at flow rates of 2.0, 2.7, 3.0, and 3.5LPM. The efficiency of TiO2 charged solar thermal collectors at 0.3% volume concentration is 73%, and using water is 58%.

Titanium Nitride (TiN)

Satoshi Ishii et al. [48] according to the MANA survey, 55% of household energy consumption account for water and air heating. A research team of MANA scientists, (International Center for Materials Nanoarchitectonics) and NIMS, discovered nanoparticles of transition metal nitrides and carbides absorb sunlight very efficiently and confirmed experimentally. When titanium nitride nanoparticles, dispersed in water, quickly raised water temperature because of plasmonic resonance property. These nanoparticles are used for heating and distillation of water through efficient sunlight use. Titanium nitride nanoparticles absorb more sunlight than gold and carbon nanoparticles due to lossy resonances. When titanium nitride nanoparticles dispersed in water the evaporation and heating rates increased two to four times.

CONCLUSION

This paper gives an overview of nanofluid in the field of solar heating applications. Continuous research is going on to improve the performance of a solar thermal collector. The thermal performance of the solar water heating system depends upon inlet water temperature, solar radiations, atmospheric temperature, flow rate, collector inclination, storage tank height, wind speed, relative humidity, glass tube coating, and heat transfer coefficient. Convective heat transfer coefficient and pressure drop are considered major output parameters. Different active and passive techniques, like twisted tapes, phase change material, nanoparticles used to enhance thermal performance, but everyone having its constraint. The literature reveals, inserted swirl device generates turbulence in the flow path. The disturbed flow increases the heat transfer coefficient at the expense of pressure drop. Phase change materials are well known for heat storage ability, low thermal conductivity, energy storage, and release rate troubles. Nanofluids are recognised for thermophysical properties and suffer from sedimentation, synthesis, instability problem. Sedimentation and synthesis problems can be tackle using nanosize particles and surfactants. Grey areas of existing research were identified from the literature. The following areas are having a scope for improvement.

- Nitride-based nanoparticles having surface plasmonic properties. Its sunlight absorption capacity is more than carbon allotropes. It could increase collector efficiency significantly.
- Research in the field of boundary layer reduction in evacuated U tube solar collectors is still lacking. A boundary layer formed due to low velocity near a pipe wall.
- Modelling of Brownian diffusion, thermophoresis, and slip velocity is difficult in the heat transfer application.
- Optimization of a solar thermal collector using soft computing techniques.
- Preparation, synthesis and application of hybrid nanofluid is an emerging area.
- Ample research space is available for the study of nanofluids in combination with passive augmentation techniques in the solar collector for the betterment of society.

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