# A Review on Augmentation of Convective Heat Transfer Techniques in Solar Water Heating

***Deshmukh K B*[1], *S V Karmare*[2]**
[1,2]*Professor*
*Department of Mechanical Engineering,*
[1]*Trinity College of Engineering, Pune, Maharashtra, India*
[2]*Government College of Engineering, Awasari, Maharashtra, India*
***Email:*** *dkishor21@gmail.com*
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***Abstract***
*Solar water heating system is an effective technology for converting solar energy into thermal energy. According to the ministry of petroleum and natural gas, approximately 42% of refined crude oil is used in industrial and commercial applications for process heating. Fossil fuel is the main energy source which is depleting continuously. Solar energy is environment friendly energy source, which can full fill energy demand. Solar water heaters are most popular in domestic as well as industrial sector due to its ease of operation and simple maintenance. Extensive work is going on to improve the convective heat transfer, thermal efficiency of solar water. Passive techniques like use of Nano fluid, twisted tape, Phase Changing Materials (PCM) are used to augment convective heat transfer. These techniques enhance thermal performance of solar water heating system significantly. This paper reviews the various techniques to enhance the thermal efficiency of solar water heaters. In addition to this, a detailed discussion and limitations of existing research have made. From this discussion research gaps are identified and possible modifications are suggested.*

***Keywords:*** *Nano fluid, passive techniques, phase changing materials*

## INTRODUCTION

World population is increasing drastically. India is 2nd largest country for its population. To full fill needs of population, industrial sector is expanding day by day. Fossil fuel is main energy source which is depleting continuously. Heating process in industrial and commercial applications, includes steam generation, cooling, heating, solvent extraction, distillation, food processing, boiler feed water heating, and many other processes. Renewable energy can be alternate energy source to meet the energy demand due to scarcity and continuous depletion of conventional fuels. Solar energy, the renewable energy source on earth, has potential to full fill energy demands without polluting environment [1-2]. Solar energy can be harvested directly with Photovoltaic panels; 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 non-concentrating collector and concentrating collector. Non concentrating collector classified as flat plate and evacuated glass tube collector. Evacuated glass tube collectors have outstanding thermal performance due to lower heat loss, easy transportability, and quick installation. The incident angle of sunrays on evacuated tube is always 90° throughout the day, hence evacuated tube collectors are the most efficient all-weather solar collector[2]. An Evacuated tube collector is made of parallel evacuated glass pipes. Each evacuated pipe consists of inner and outer tube. Outer tube is transparent, and aluminum nickel alloy coating is applied on inner tube. Inner and outer tubes have minimum reflection properties and fused together to create vacuum in order to increased heat transfer rate [3].

Solar thermal energy is utilized to meet process heat requirements in industrial sector and gain wide applications in industrial sector. Solar water heating is most popular solar thermal systems and accounts for 80% of worldwide solar thermal market. Some of the technical problems, like low efficiency, high heat loss and poor solar energy harvesting capability, challenges in installations and capital costs become barriers for promotion of solar water heater in industrial application. Extensive work is going on to enhance thermal efficiency, convective heat transfer coefficient, overall performance and minimize heat loss of solar water heaters heating. In order to enhance overall performance changes are made in solar collector structure, glass tube coating, glass tube inclination. Active and passive augmentation techniques are also used. This paper gives comprehensive review on current status and technical developments to enhance performance of solar water heating process [2].

**Classifications of Solar Water Heater**
Solar water heating systems is classified into passive and active system based on pump requirement. Passive system solar water heaters are commonly used for domestic applications. Passive systems (Fig. 1) transfer hot water from the collector to the tank by natural circulation at 60°C. In Active system (Fig. 2) water is circulated in the collector using pump. Active solar system transfers thermal energy by running the pump. A differential thermostat is used to control the circulation of the water. A check valve is required to avoid reverse circulation of water [4].

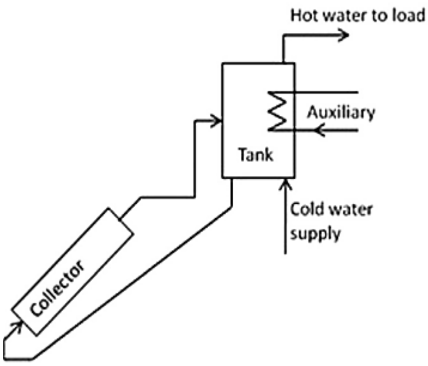


***Figure 1:*** *Passive system.*

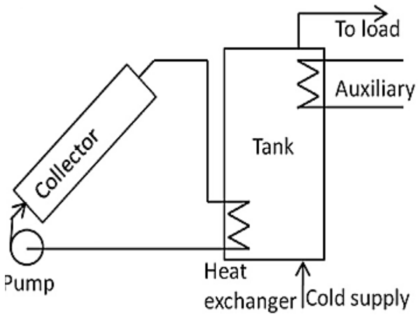


***Figure 2:*** *Active system.*

**Heat Transfer Enhancement Techniques in Solar Water Heating Systems**
Solar water heating system is popular in domestic application due to its low initial cost, low operational cost and short payback period. In today’s era, financial aspects and performance has become a basic and crucial factor for commercialization. Solar system performance depends on sun radiation, due to variable climatic condition not suitable for industrial application. Extensive work has been carried out for heat transfer augmentation by active and passive techniques. Continues research is going on to enhance performance by various augmentation techniques in unfavorable condition.. A detailed review has been presented on the use of active techniques

like electric field, vibration, acoustic and passive technique like special surface geometries, viz., twisted tapes, curved tubes, helically coiled tubes, spirally coiled tubes to improve the heat transfer did by Jaishankar [5].

***Nano fluid***

Nano fluids are the new class of nanotechnology based heat transfer fluids. Nano fluids term was first used by Choi in 1995. The conventional heat transfer fluid suffers from poor thermal and heat absorption properties. It limits collector performance. Nanomaterials have wide range of materials like nano crystalline materials, nano composites, carbon nano tubes. Nano fluid consists of the liquid base fluid, suspended solid Nanoparticles. nanolayer act as a thermal bridge in between base fluid and solid nanoparticles.

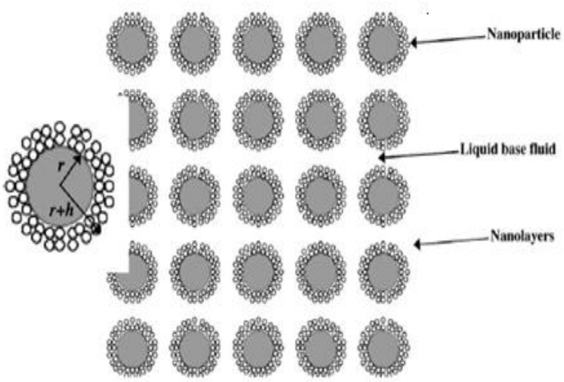


***Figure 3:*** *Nano fluid structure.*

Fig. 3 shows structure of Nano fluid. Nano fluids shows significant improvement in thermo physical properties like thermal conductivity, convective heat transfer coefficient, viscosity and thermal diffusivity. This improvement depends upon shape size and volumetric fraction, of nanoparticle.

Nanoparticles of following materials are widely used (Table 1) having size less than 100 nm are dispersed in conventional fluids to improve thermal properties[1].

***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 |

The base fluids includes water, oils, organic liquids, bio-fluids, lubricants, polymeric solutions[6]. Hybrid Nano fluids are next version of Nano fluids. These are prepared by suspending two or more than two types of nanoparticles in base fluid. A hybrid material shows physical and chemical properties enhancement in a homogeneous phase[6]. Proper hybridization of Nano fluid shows promising heat transfer enhancement. Jahar Sarkar et al. [6], summarized challenges and future application of hybrid Nano fluid. There is lots of scope and challenges for research in the fields of preparation, characterization, stability, and applications of Hybrid Nano fluid [7].

**Copper Oxide (CuO2)** Copper (II) oxide or cupric oxide is the inorganic compound with the formula CuO. CuO is a black solid and a stable oxides of copper, the other is Cu2O or cuprous oxide, it is also known as tenorite. Ghaderian et al. [8], suspended copper oxide nanoparticle in distilled water and prepared Nano fluid. This Nano fluid is used in collector with different volume concentrations throughout the study. The heat transfer enhancement in evacuated glass tube solar collector with variation of mass flow rate and volume concentration studied. The efficiency enhanced to 51.4% with 0.06% of CuO, and 41.9% with 0.03% of CuO. Michael et al. [9], examined water based copper oxide Nano fluid performance of flat plate solar water heater under natural and forced circulation mode. Experimentation performed on 100 LPD capacity system. Analytically and experimentally Nano fluid thermo physical properties are compared. Sodium Dodecyl Benzene Sulfonate and Triton X-100 surfactants are used. The improvement in efficiency was observed more in thermosyphon circulation than forced circulations. The highest efficiency of solar water heater is at flow rate of 0.1 kg/s. Further increase in efficiency is possible, if effectiveness of heat exchanger inside the thermal storage tank is designed for Nano fluid operation. [9]

***Zink Oxide (ZnO)***

Huseyin Kaya et al. [10] (2018), determined efficiency of an evacuated U-tube solar collector experimentally. Zink oxide particles are suspended in ethylene glycol and pure water. 50% of ethylene glycol and pure water used as base fluid. Found thermal conductivity of zinc oxide based Nano fluid 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 % volume concentration and 0.045 kg/s mass flow rate, it is 26.42% higher than pure ethylene glycol and pure water as a working fluid.

***Aluminum oxide ($Al_2O_3$)***

Rajasekhara et al. [11], did experimental analysis of convective heat transfer using $Al_2O_3$ Nano fluid inside horizontal circular pipe under constant flux boundary condition to study variation of heat transfer coefficient and pressure drop. Different volume concentrations of $Al_2O_3$ nanoparticles used in combination of twisted tapes. The Reynolds number changes due to small variations in viscosity at different particle concentrations, and these changes are within ± 100. It is found by using of Nano fluids, heat transfer coefficient certainly enhances especially in the entrance region.[12] Local heat transfer coefficient at X/D=10 and 0.5% volume concentration is 26% and 22% higher than water in plain tube.[12] The local Nusselt number increases with Reynolds number and particle concentration, and significant decrease in heat transfer enhancement with increase axial distance[12]. Ghaderian et al. [13], investigated experimentally the effect distilled water base aluminum oxide Nano fluid, on thermal efficiency of evacuated glass tube solar collector. Spherical coil immersed inside the horizontal tank. Triton X-100 was used as surfactant. Nanoparticles of 40 nm size at volume fraction of 0.03% and 0.06% used during experimentation. The collector performance using $Al_2O_3$ Nano fluid and water was compared for flow rate of 20 to 60 lph. It revealed that the maximum efficiency is 57.63% for 0.06% volume concentration of Nano fluids and mass flow rate of 60 lph [13]. The efficiency of collector increased by increasing flow rate and volume fractions of Al2O3 nanoparticles. Concluded Al2O3 Nano fluids can convert maximum solar energy into thermal energy efficiently[13]. Gargee et al. [14], conducted experiments on serpentine shape heat pipe in flat plate solar collector under real operating conditions. Found maximum efficiency was at 50° Distilled water used as base fluid. Aluminum oxide particle suspended in base fluid and Nano fluid prepared with varying weight concentrations of 0.05, 0.25 and 0.5%. Effect of coolant rate, nanoparticle concentration on performance of solar heat pipe collector studied experimentally. Collector tilt angles varied 18.53, 33.5, 40, 50 and 60°. Efficiency of the collector increases as coolant flow rate increases up to certain limit, then decreases, similar trend is observed for tilt angle.

***Graphene Nanoplatelets (GNP)/Distilled Water Nano fluid***

Iranmanesh et al. [15]**,** investigated evacuated tube solar collector water heater thermal performance experimentally. Nanoparticles having surface area 750 $m^2/g$ are used. The ultra sonication probe was used to prepare a homogeneous and stable GNP Nano fluid. Transmission of Electron Microscopy (TEM) and Field Emission Scanning Electron Microscopy (FESEM) were used to investigate the morphological characterization of graphene Nano platelets ASHRAE standard 93-2003 followed to calculate the efficiency of the collector. Solar collector thermal efficiency enhanced up to 90.7% at 1.5 L/min flow rate. GNP Nano fluids enhance thermal conductivity to 27.6%. Results shows using graphene Nano sheets highest outlet temperature of the fluid obtained.

***Multiwall Carbon Nanotube (MWCNT)***
Sandesh et al. [16], determined optimal volume concentration of CNT Nano fluid for better performance of heat pipe solar collector. The thermal performance of CNT Nano fluid is compared with pure water for varied range of tilt angle and CNT Nano fluid concentration. Carbon nanotubes have diameter 10–12 nm and length 0.1–10 nm. SEM image of MWCNT captured by FESEM. Caron nanotubes are immersed in mixture of Sulfuric acid and nitric acid (3:1). CNT treated in an ultrasonic bath. To neutralize the solution ammonium hydroxide used and cellulose acetate membrane used to filter. The carbon nanotube washed till the pH value of suspension reached to 5.5. Nano fluids were prepared for various volume concentration of CNT. Amir kakavandi et al. [17], performed experimental study on hybrid Nano fluid made by suspending multiwall carbon nano tube and silicon carbide in water plus ethyl glycol mixture. Scanning electron microscopy and X-ray diffraction methods used for characterization of nanoparticle. Hybrid Nano fluid stability measured by DLS test, and thermal conductivity by KD2-Pro thermal analyzer. Volume concentration range of 0–0.75% used. Thermal conductivity of Nano fluid rises to 33% relative to base fluid at volume concentration of 0.75%. The correlation developed to determine thermal conductivity of the Nano fluid.

***Single Walled Carbon Nanotube (SWCNT)***
Sabiha et al. [1], used SWCNT based Nano fluid as working fluid in heat pipe to convert solar energy into thermal energy. Experiments were performed according to ASHRAE standard 93-2003 at University of Malaya. Distilled water used as base fluid and Sodium Dodecyl Sulfate as surfactant. Nano fluid prepared with volume concentrations of 0.05, 0.1, and 0.2%. Solution sonicated to overcome agglomeration of SWCNT nanoparticles. Performance of SWCNT Nano fluid was compared with water at different flow rates of 0.008, 0.017, and 0.025 kg/s. The maximum efficiency found 93.43% for 0.2 % volume concentration and mass flow rate 0.025 kg/s. The collector efficiency increases by increasing volume concentration of SWCNT nanoparticles and flow rate. He developed empirical correlation between thermal efficiency and thermal conductivity. Mahbubul et al. [2], investigated collector performance using water based SWCNT Nano fluid experimentally. An Experimental setup of solar powered ammonia water absorption refrigeration system for space cooling with ice-storage facility developed at King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia. Collector effective surface area was 42 $m^2$. SWCNT water Nano fluids were prepared with volume concentration of 0.05, 0.1, and 0.2 %. By using 0.2 % of SWCNT nanoparticles with water 10% higher efficiency was observed. The results showed 56.7% and 66% of efficiencies when the collector was operated with water and 0.2% nanoparticle, respectively. Concluded Nano fluids enhance the efficiencies of

solar collectors significantly. Sandesh et al. [18], investigated thermosyphon heat pipe performance using water based CNT Nano fluid 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 1) CNT Nano fluid found more efficient than pure water for heat pipe. 2) The efficiency of solar heat pipe collector increases up to 0.60% volume concentration afterward decreases. Maximum efficiency found 73% for 0.60% volume concentration of Nano fluid. 3) The heat pipe collector efficiency increases with the tilt angle up to 50deg after this starts to decrease for water and Nano fluids.

***Cerium Oxide (Ceo2)***

Ramesh et al. [19]**,** prepared cerium oxide/water (CeO2/H2O) Nano fluid. The thermal performance of forced type flat plate solar water heater having capacity 100 lpd investigated experimentally. Polyvinyl pyrolidine (PVP) used as surfactant, and shown good 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. [20], prepared stable water based cerium oxide Nano fluid. The stability measured by using Zeta potential machine. The mean diameter of cerium oxide particle was 25 nm. Experiments performed with volume concentration of 0.015%, 0.025%, 0.35% and varying mass flow rates. Nano fluid shows remarkable temperature difference between inlet and outlet flow. For 0.035% volume fraction and 0.017 $kg/sm^2$ mass flow rate, maximum heat removable factor obtained. The thermal loss coefficient of solar corrector is raised up to 34.

***Titanium Oxide (TiO2)***

Mahendran et al. [21], determined efficiency of evacuated glass tube solar collector using water-based Titanium Oxide ($TiO_2$) Nano fluid. Experiments are performed at flow rates of 2.0, 2.7, 3.0 and 3.5 LPM. The efficiency of the collector using a $TiO_2$ Nano fluid at 0.3% volume concentration is about 73%, and for water is 58%. The efficiency is enhanced by 16.7%, compared to system working with water, when 30–50nm sized TiO2 nanoparticles dispersed in the water.

***Titanium Nitride (TiN)***

Satoshi Ishii et al. [22], According to MANA survey water and air heating accounts for 55% of household energy consumption. A research team of MANA scientist, (International Center for Materials Nano architectonics) and NIMS, discovered nanoparticles of transition metal nitrides and carbides absorb sunlight very efficiently, and confirmed experimentally that, titanium nitride nanoparticles, when dispersed in water, quickly raised water temperature because of plasmatic resonance property. These nanoparticles used for heating and distillation of water through efficient sunlight use. Titanium nitride nanoparticles are efficient sunlight absorbers than gold and carbon nanoparticles due to lossy resonances. Titanium Nitride nanoparticles were dispersed in water andit was found that the evaporation and heating rates increased by factors of two to four.

**Phase Changing Materials (PCM)**

A phase change materials having high latent heat of fusion, can store and release large amount of energy. Phase Change Material (PCM) is the medium used in Latent Heat Storage (LHS) unit[32]. PCM can melts and solidifies at a specific temperature. When material changes its phase from one form to other form heat may absorbed or released depending upon situation. PCM's are also known as latent heat storage units. Latent heat storage achieved by liquid to solid, solid to liquid, solid to gas and liquid to gas phase changes. Only solid to liquid and vice versa phase changes are possible for PCMs. Liquid to gas transitions having high heat transformation than solid to liquid transitions[33]. For liquid to gas phase changes large volumes or high pressures are required to store the materials in gas phase, hence it is impractical. Solid to solid phase changes are too slow and have relatively low heat of transformation. There are significant advantages of PCMs in thermal packaging applications. It has number of challenges in manufacturing and usage like, material compatibility, material properties, thermal performance, packaging for use, conditioning for use, cost and availability, health safety and disposal [34].

Chopra et al. [35]**,** carried out research on use of heat pipe in evacuated tube in low or medium temperature applications. Found integration of phase change materials in evacuated tube collector has the great impact on its performance. This manuscript gives classification based on thermal energy storage, advantages, drawbacks of evacuated technology, financial advantages, future recommendation for future improvement and recent research. Avinash et al. [36]**,** worked on to reduce the time required for storing and releasing heat in solar thermal application. 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. Effects of fin height, Reynolds number and Stefan number tested experimentally to analyze on performance of system. PCM temperature at various locations measured. The observed reynolds number, fin height, Stefan number increases time required for melting of PCM reduces. Avinash et al. [32], used PCM and HTF in Latent Heat Thermal Energy Storage system for heating and cooling application. The inner pipe made of SS-316 and the outer pipes of SS-304. The HTF flows from bottom to top in the HTF pipe. Temperature probes 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 longitudinal direction, and 5, 14, 25 mm in radial direction, from the outer wall of HTF pipe towards inner wall to measure the temperature field in the PCM. The following are the conclusions made: 1. Melting started near to the wall of the inner tube and then molten PCM ascended to the top part of the PCM container because of natural convection currents. 2. In next two regions the melted PCM region in the liquid phase and the non-melted PCM region in the solid phase coexisted during the charging process. 3. In the solid region, the conduction inside the solid matrix of the PCM was responsible for the heat transfer process.4. Time required for melting of PCM higher than solidification.

**Twisted Tape**

Heat transfer enhancement, augmentation deals with improvement of thermo hydraulic performance of system. Augmentation techniques are classified in to active and passive techniques. Passive augmentation techniques not require any external power source. Passive techniques generally use surface or geometrical modifications, inserts, additional device. Passive techniques increases effective heat transfer area. Passive techniques enhance heat transfer coefficients at the cost of increasing pressure drop by disturbing flow. Effectiveness of augmentation techniques depends upon mode of heat transfer, type and application. Twisted tapes are easy to prepare and effective to flatten velocity profile at center of pipe[40]. Wire coil and spiral tape insert are effective at surface of the pipe.

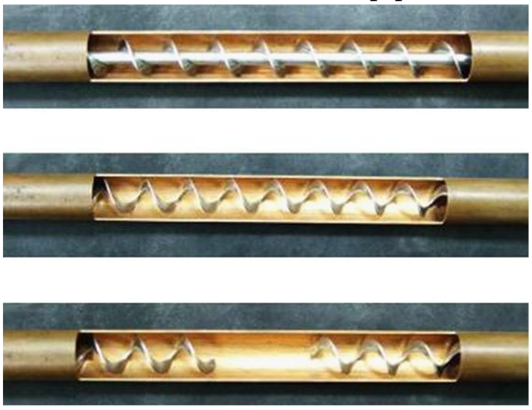

***Figure 4:*** *Twisted Tape Arrangements*

**Khoshvaght et al.** [41] examined the performance of agitated vessel U tube heat exchanger using spiky twisted tape and water based metallic Nano fluid. Effect of agitator speed was tested at six different speeds. The agitator speed of 1300 rpm was obtained as the optimum value. [41] Spiky twisted tapes improves the heat transfer coefficient of U tube heat exchanger at cost of pressure drop. The spiky twisted tape with α=β=0.33 is recommended for enhancement in overall performance factor by about 35% than the plain case. All metallic Nano fluids shown high heat transfer coefficient and pressure drop than base fluid, and Ag water based Nano fluid gives highest values is for. The augmentation in heat transfer coefficient is 18.2% and 8.5% in pressure drop. **Raja Sekhara et al.** [11] Studied heat transfer coefficient and pressure drop variation of $Al_2O_3$ Nano fluid, at different volume concentration and twist tape ratio. Different twisted tape and swirl generator inserted in the fluid flow path. Experimental analysis of convective heat transfer in horizontal circular pipe performed under constant heat flux condition. As compared with water, heat transfer coefficient increased by 8-12%. Highest friction factor obtained at 0.5% particle concentration compared with water. He drown conclusion Nusselt number and friction factor increases with increase in particle volume concentration. As Reynolds number of flow increases, nusselt number increases and friction factor decreases. Use of Nano fluid improves heat exchanger efficiency and compactness. **Syam Sundar et al.** [42] inserted tape geometry in Al2O3 Nano fluid. This study, performed with or without a twisted tape in tube. For 0.3% volume concentration and reynolds number of 13000 of Nano fluid heat transfer enhancement is 21%, further it is enhanced to 49.75% when a twisted tape of H/D = 5 is inserted in the tube. The maximum friction penalty of 1.25 times observed for 0.3% Nano fluid with H/D=5. The thermal effectiveness of collector is enhanced to 58%, further enhanced to 76% with a twisted tape of H/D=5 at a mass flow rate of 0.083 kg/sec and volume concentration 0.3%**. Sandesh et al.** [43] investigated convective heat transfer characteristics of water based $Al_2O_3$ and CNT Nano fluid with helical twisted tape inserts. Tests performed with range of particle volume concentration of 0.15%, 0.45%, 0.60% and 1% and helical tape inserts of twist ratio 1.5, 2.5 and 3.0. The performance of both Nano fluids increases with the increase in the particle volume concentration. The water based CNT Nano fluid with helical screw tape inserts exhibits higher thermal performance than water based Al2O3 Nano fluid. The maximum enhancement in heat transfer found at 1% volume concentration of CNT with helical tape twist ratio 1.5.

## CONCLUSION

Continuous research work is going on to improve thermal performance of solar water heaters. Literature revealed thermal performance of solar water heater depends upon inlet water temperature, solar irradiance, ambient temperature, flow rate, collector inclination, storage tank height, wind speed, relative humidity, glass tube coating and convective heat transfer coefficient. Insertion of swirl device creates turbulence in flow path and flow is disturbed. Addition of nanoparticle enhances base fluid thermal and optical properties. There is lot of scope to for the research in the field of Nano fluid with passive augmentation technique to enhance convective heat transfer coefficient and thermal performance of solar water heating system. Following gaps are identified from literature review

a) A large volume of published research discussed performance of metal oxide based Nano fluid in flat plate collector. Still there is scope for research in the field of nitride based Nano fluid. Titanium nitride (TiN) nanoparticle shows lossy plasmonic property. The sunlight absorption capacity of titanium nitride nanoparticle is more than carbon allotropes. Stable water base titanium nitride (TiN) Nano fluid convert sunlight into heat. It has having high efficiency to heat water and generate vapours. Titanium nitride nanoparticles can shows great possibility for better result in solar heat applications. Till date no studies were conducted on nitride based Nano fluid in solar collectors. it can increase collector efficiency significantly
b) Working fluid inside evacuated glass tube moves at a slow speed, boundary layer is formed near the wall. Research in field of reduction of boundary layer in ETC is still lacking.
c) None of the researcher investigated combine effect of Titanium Nitride (TiN) and twisted tape for evacuated glass tube in the field of solar water heater application. A system can be developed in order to minimize collector area and to maximize thermal performance.

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