A Comprehensive Overview on the Applications of Nanofluids in Parabolic Trough Solar Concentrating Collector

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Ever-increasing demand of energy without degrading the environment has always been concern of scientific community. It is therefore important to go for reliable, cost effective and everlasting renewable energy source, and thus extraction of maximum thermal energy from solar energy is the most promising challenge. Based on the recent investigations, this paper gives a comprehensive overview about the use of Nanofluid as working fluid for enhancing the solar concentrating collector performance and efficiency. Advantages of Hybrid Nanofluids are identified. This review reveals that the application of Nano fluid increases the efficiency of the solar collectors due to its excellent performance.

***Key words*:** Nano fluids, Nano particles, parabolic trough solar collector, solar energy.

1. INTRODUCTION

Global energy crisis caused by the rapid world population and industrial growth as well as the rapid development of the society, increases day by day and may become a humanitarian crisis. Fossil fuels are the main energy sources for covering the worldwide energy needs. Moreover, Fossil fuels create serious environmental problems related with emissions of carbon dioxide i.e pollution, the global warming, the acid rain and the impact of the oil spill on the aquatic life [Pavlovic et al., 2018]. Increasing energy demands, limited and hazardous effect of fossil fuels, lead to go for renewable energy sources. Renewable energy generated from natural resources, such as solar, wind and geothermal energies, is a good alternative to the conventional fossil fuels**.** Solar energy is the most promising and abundant renewable energy source, which shows great potential to fulfill the world's total energy consumption. Solar energy can be converted either to useful thermal heat [with solar thermal collectors] or directly to electricity [with PV cells].

2. SOLAR COLLECTORS

The major component of any solar system is the solar collector. Solar thermal collectors are designed to absorb and convert solar irradiation into thermal energy. The energy is then transferred to a working fluid [typically air, water or oil] contained within the collector's structure. The circulating working fluid carries the energy away from the collector in the form of heat to be directly used or used to charge up a thermal storage tank. Therefore, higher the heat transfer to fluid means higher outlet temperature and higher the collector efficiency. Extraction of maximum thermal energy from solar energy is the most promising challenge. Solar collectors can be used for a variety of residential and commercial applications such as water heating systems in homes, solar space heating, solar desalination, solar drying devices, electricity production and small solar power plants. Basically there are several types of collectors, and they are classified by their concentration ratio and tracking motion. They are 1) Non concentrating collectors. 2) Concentrating collectors.

3. PARABOLIC TROUGH SOLAR COLLECTOR

Cylindrical Parabolic collector also called parabolic trough concentrator (PTC).is one of the best known solar concentrators. These are used for large scale power generation and small scale direct steam generation. It consists of a parabolic reflector, an absorber tube, a concentric tubular glass cover surrounding absorber with a gap which is evacuated, support structure. Cylindrical Parabolic reflector focuses all the incident sunlight onto a metallic tubular or flat absorber placed along its length in the focal plane. The heat transfer fluid is allowed to flow through the absorber that absorbs the heat transmitted through the pipe. A concentric glass cover around the absorber tube helps in reducing convective and radiative losses to surroundings .Fig1 shows the typical solar parabolic trough collector.

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Fig. 1.solar parabolic trough collector.

4. NANO FLUIDS

Fluids containing solid nanometer size particle dispersion are called "nanofluids". Usage of additives (nano particles) in the base fluid is one of the techniques applied to augment the heat transfer. Nano particles used in nanofluids are typically made of metals, oxides, carbides, or carbon nanotubes. Common base fluids include water, ethylene glycol, tri ethylene glycol and engine oil are some examples of base fluids. Choi from Argonne National Laboratory in Unites States was the first person who initiated this fluid in 1995 [Choi and Eastman, 1995] and observed experimentally that the addition of high thermal conductivities metallic/non-metallic nano - particles into the base fluid increases the thermal conductivity of these fluids dramatically and thus enhancing their overall heat transfer capability. Nano fluids with low viscosities, high thermal conductivities and superior photo thermal properties are highly desirable for the usage

Advantages of Nano fluids:

1. The extremely small particle dimensions make sure a high specific surface area i.e a large surface area makes a high heat transfer. 2. Size of the particles is very small, it fluidizes easily inside the base fluid and can move faster without any clogging and fouling. So, it can be used in micro channel applications. 3. Requirement of pumping power is low compared with other liquids.4. High effective thermal conductivity. 4. Thermal properties can be varied accordingly by changing the concentration of nano particles. 5. As the size of the particles is very small, erosion and clogging are negligible. 6. Nanofluid increases the efficiency of the system by storing large quantity of heat (decreasing the energy losses). 7. High stability of nanofluids makes them to stay in liquid phase for a long period of time.

4.1 USE AND APPLICATION OF NANO FLUIDS IN PARABOLIC TROUGH SOLAR COLLECTORS

Subramani et al [1] examined the use of TiO_2/DI-H_2O nanofluid in PTC for different concentrations [0.05%, 0.1%, 0.2% and 0.5%] at different mass flow rates under turbulent flow regimes. They found that TiO_2 nano fluid with a volume concentration of 0.2% at mass flow rate of 0.0667 kg/sec provides a maximum efficiency of 8.66% higher than water based nanofluid with an improvement in convective heat transfer coefficient by 22.76%.Figure2 gives the experimental setup of PTC. Figure3 gives the comparison of convective heat transfer coefficient for various mass flow rates at different concentrations. Subramani et al [2] examined the use of Al_2O_3/Deionized H_2O nano fluid for different concentrations [0.05-0.5%] at different mass flow rates [0.0083-0.05kg/s] under turbulent flow regimes. From results, they found that collector efficiency improved to 56% at a maximum volume concentration of 0.5% and maximum flow rate of 0.05kg/s and suggested a lower volume concentration of 0.2% is optimal for solar parabolic trough collectors

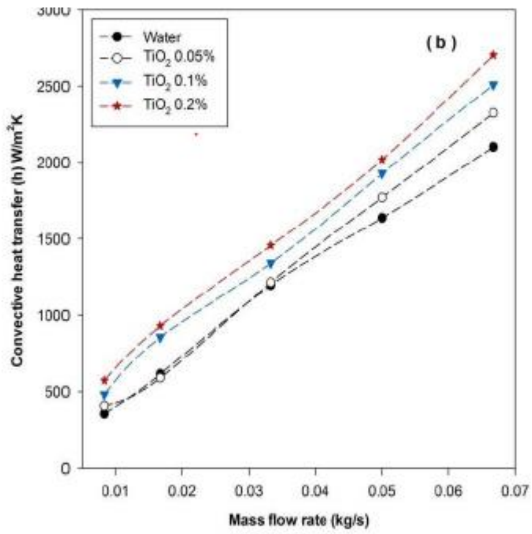


Fig.2. Picture of parabolic Trough Collector [1]. Fig.3.Comparison of convective heat transfer coefficient for various mass flow rates [1].

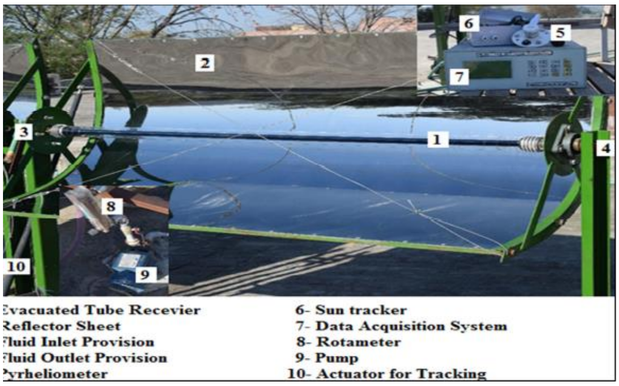
Ferraro et al [3] proposed a thermal model and implemented in MAT lab using Al_2O_3/Synthetic oil as nanofluid assumed in a great solar field of length 100m and concentrating surface area of 550m^2 and simulations are compared to the corresponding base fluid. They identified a better heat transfer rate at low temperatures, higher amount of dispersed particles.

Khakrah et al [4] investigated numerically by computational fluid dynamics inside a PTC using synthetic oil / Al_2O_3 nanofluid with 1%, 3% and 5% nanoparticles concentration. From the results they conclude 30° rotation of reflector surface can increase the conventional heat loss by about 123.2, 106.5, 95.7 and 86.1% for wind velocities of 5, 10, 15 and 20 m/s respectively, and the efficiency reduced by 1 to 3% by rotating the reflector 30° relative to wind direction, with a thermal efficiency enhancement of 12.4% obtained by 5% volume fraction of nano fluid.

Kasaeian et al [5] examined the use of MWCNT / thermal oil as the heat transfer fluid. A thermal model has been developed, finite difference method was adopted, and a code is created in MAT lab. From results, they revealed that the radiant losses were increased from 26.5 watts per meter at 30^{o}c to 57.3 watts per meter at 100°C, shows an increment of 116%, and the convective heat losses increased from 49.6 to 158.9 watts per meter shows an increment of 220% from 30-100°C. Finally they concluded that by adding 6% volume fraction of nano particle, there is an enhancement in convective heat transfer coefficient by 15%. Kasaeian et al [6] studied the optical and thermal performances of PTC by comparing four types of receiver coatings i.e black painted vacuum steel tube, a copper bare tube with black chrome coating, a glass enveloped non evacuated copper tube with black chrome coating using MWCNT as nanoparticles and mineral oil [instead of pure oil] as base fluid. From results they found that copper absorber tube, coated with black chrome has the highest absorptivity and thermal conductivity. Mwesigye and Meyer et al [7] studied numerically the thermal and thermodynamic performance of a PTSC using Cu-TherminolVP-1 nanofluid, using computational fluid dynamics tool together with Monte Carlo ray tracing. Results showed that the thermal efficiency increases by about 12.5% as the nano particle volume fraction in the base fluid increase from 0 to 6%.

Marefati et al [8] examined the use of water based with SiC, CuO and Al_2O_3 nano particles. Results show that Shiraz with an average annual thermal efficiency of 13.91% is the best region to use solar concentration system. They finally found that by using nano fluid can increase heat production, and the heat transfer increase with CuO nanofluid is more compared with Al_2O_3 and SiC, also finally concluded that, performance of solar system changes with geographical region

Rehan et al [9] studied the use of Al_2O_3/H_2O and Fe_2O_3/H_2O nano fluids used at three particles concentration of 0.2%, 0.25% and 0.3% by weight at flow rates of 1.0, 1.5, and 2.0 L/min. From the results they found that the temperature differences in the absorber tube increases with particle concentration and decreases at higher flow rates, and concluded that maximum thermal efficiencies achieved with Al_2O_3 and Fe_2O_3 nano fluids, at 2L/min are 13% and 11% higher compared to water Figure 4 gives the experimental setup of PTC. Figure 5 gives the comparison of collector efficiency with Al_2O_3 and Fe_2O_3 nano particles.



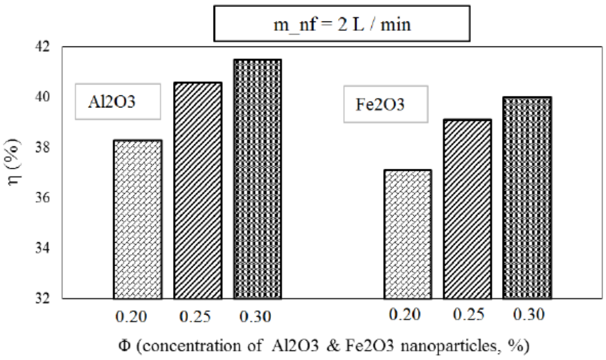


Fig. 4.PTC with evacuated tube receiver [4].

Fig. 5.comparison of collector η with Al_2O_3 and Fe_2O_3 nano particles

Coccia et al [10] performed experimental and numerical[using Wolfram mathematica] studies on a conventional Parabolic Trough Collector with six water based nano fluids [Fe_2O_3[5,10,20wt%], SiO_2[1,5,25wt%], TiO_2[1,10,20,35wt%], ZnO[1,5,10wt%], Al_2O_3[0,1,1.2wt%], Au[0.01wt%] at different weight concentrations. Results showed that Au, TiO_2, ZnO, Al_2O_3 nano fluid at lower concentrations present very small improvements compared to the use of water, while increasingly the concentrations of nanoparticles seems to be no advantage with respect to water. Tagle-salazar et al [11] designed a thermal model and validated with some experimental data. Engineering equation solver is used to simulate the model, using water/Al_2O_3 nanofluid with 1% nano particle concentration. Results indicated that, a small enhancement in heat gain of about 0.3w/m and thermal efficiency of about 0.03% by using nanofluid. Hatami et al [12] examined the use of Cu, Fe_3O_4, Al_2O_3 and TiO_2 nanoparticles with water as base fluid, also studied the use of porous material, which is filled by the absorber tube. Finite element method from

FlexPDE software is used for the analysis. From the results they concluded that maximum enhancement of nusselt number is possible at largest values of nanoparticles volume concentration and Rayleigh number; and Cu Nanoparticles shows most significant increase than Fe_3O_4, Al_2O_3 and TiO_2 nano particles.

Meenakshi reddy et al [13] examined the dispersion of Al_2O_3 in water at different flow rates of 2, 4, 6 ml/s with a volume concentration of 0.02%. From the results, they concluded that Nano Based Parabolic Trough Collector has higher efficiency than Water Based Parabolic Trough Collector. The thermal efficiency was enhanced by 5-10% and has higher efficiencies at higher flow rates. Khullar [14] carried out theoretical and numerical investigation regarding the use of nano fluid in parabolic trough collector, and developed mathematical modeling for heat transfer and flow aspects had been done by suspending Al nano particles in water. Results of the model were compared with experimental results of conventional concentric parabolic solar collector under similar conditions. They found that NCPSC has about 5-10% higher efficiency as compared to CPSC. K.S. Choudari et al [15] examined the dispersion of Al_2O_3 in water for operation in an uncovered parabolic trough collector with a double tube absorber, 0.1% weight fraction of nano particles and particle diameter of 40nm at a flow rate of 2 lit/min. Results revealed that nanofluid based parabolic trough collector has higher efficiency than water based parabolic trough collector with an enhancement of thermal efficiency by 7% and heat transfer coefficient by 32%.

Sokhansefat et al [16] studied numerically the mixed turbulent convection heat transfer of Al_2O_3/synthetic oil nanofluid in the receiver tube of a CPSC. Considering non uniform heat flux boundary condition using Monte Carlo ray tracing technique, examined the dispersion of Al_2O_3 in synthetic oil for various concentrations up to 5% at operational temperatures of 300K, 400K and 500K. The obtained results revealed that convection heat transfer coefficient has a direct dependency on the volume concentration of nano particles in the fluid. Zadeh et al [17] applied hybrid optimization method involving genetic algorithm and sequential quadratic programming and the methodology implemented involves Matlab, Fluent and Gambit. The thermal behavior of nano fluid Al_2O_3/synthetic oil throughout a PTC has been simulated. From results they conclude that heat transfer enhancement has a direct relationship with the nano particle concentration and inversely related with the operational temperature.

Basbous et al [18] studied numerically the use of Al_2O_3 synthetic oil i.e, syltherm 800 as a base fluid. The mathematical model used is based on energy balances of the collector element and validated with experimental data of SANDIA laboratories in USA. Results showed that nano particles improved the heat transfer coefficient between receiver and heat transfer fluid by about 18%. Basbous et al [19] investigated numerically the use of various nano particles [CuO, Cu, Ag & Al_2O_3] dispersed in syltherm 800 and carried up to 5% volume concentration. From the results, they concluded that the suspension of silver, Cu, CuO & aluminum oxide nanoparticles in the base fluid being about 36%, 33%, 27%, 18% increase in convection heat transfer coefficient and 21%, 18.5%, 14%, 8% decrease in overall heat loss coefficient. Maximum enhancement in thermal performance of PTC has been recorded for Ag nano particles.

Bellos et al [20] developed a thermal model in engineering equation solver and analyzed the use of various nanoparticles [Cu, CuO, Fe_2O_3, TiO_2, Al_2O_3 and Sio_2] dispersed in thermal oil [syltherm800]. From the results they found at a flow rate of 150l/min and 600k inlet temperature, the thermal efficiency enhancement was found to be 0.31, 0.54 and 0.74% for copper concentrations of 2, 4 and 6%, and concluded that copper is the efficient nano particle.

Mwesigye et al [21] designed a well validated numerical model with a typical heat flux profile on the outer walls of receiver's absorber tube, developed using a finite volume based computational fluid dynamics tool together with Monte Carlo ray tracing. They investigated the use of copper, silver and Al_2O_3 nanoparticles dispersed in therminol VP1.From the results they conclude that silver therminolVP1 nanofluid gives highest thermal performance and Al_2O_3therminolVP1 shows lowest thermal performance. Increase in thermal efficiency by 13.9, 12.5 and 7.9% for silver therminolVP1, copper therminolVP1 and Al_2O_3 therminolVP1 respectively. Mwesigye and Meyer et al [22] investigated the optimum thermal and thermodynamic operating conditions of a PTSC numerically using computational fluid dynamics tool together with Monte Carlo ray tracing .They examined the use of SWCNT/Therminol VP1 as working fluid. From results they found that heat transfer performance enhances by 234% as the nano particle volume concentration increased from 0 to 2.5% and reduction in entropy generation about 70%.

De los Rios et al [23] examined the use of alumina nanoparticles by dispersing in water with volume fraction of 1% and 3%. From the results they conclude that incident angle interval from 20^o to 30^o, nanofluid with 3% volume fraction reaches a maximum efficiency of 52.4% and for water it was 48%. Also, for incident angle of 10^0, nanofluid with 1% volume fraction reaches a maximum efficiency of 57.7% and for water it was 46.5%. Ajay and Kundan et al [24] examined the use of CuO-H_2O and SiO_2- H_2O experimentally and numerically using Computational fluid dynamics tool [Ansys Fluent14.5]. From results they found that improvement in efficiency by about 6.68 and 7.64% for SiO_2- H_2O and CuO-H_2O nanofluids at a volume concentration of 0.01% compared to water. Ghasemi and Ranjbar et al [25] studied numerically the use of CuO-water and Al_2O_3-water nanofluids using commercial software GAMBIT and computational fluid dynamic tool FLUENT- 6.2. Results showed that increasing nano particle volume fraction, increases nusselt number and friction factor for both nanofluids. At a volume concentration of 3%, heat transfer enhances by 28% for Al_2O_3 and 35% for CuO -water nanofluids. Table 1 shows the brief review of nano fluids in parabolic trough solar collectors.

4.2 USING HYBRID NANOFLUIDS

Hybrid nanofluids are new kind of nanofluids obtained by suspending at least two types of nanoparticles or composite nanoparticles in a base fluid. A hybrid material is a substance that coalesce physical and chemical properties of different materials simultaneously and provide these properties in a homogenous phase, which do not exist in the individual components.

Bellos & Tzivanidis et al [26] examined the idea of using mono and hybrid nanofluids in parabolic trough solar collector. Syltherm 800 is taken as base fluid and nanofluid used are 3% Al_2O_3/oil, 3% TiO_2/oil and 1.5% Al_2O_3-1.5% TiO_2/oil. From the results, they found that the hybrid nano fluid leads to higher thermal efficiency enhancement compared to other working fluid. The mean thermal efficiency enhancement with hybrid nano fluid was found to be 0.74% while with TiO_2 was 0.341% and with Al_2O_3 was 0.34%. Moreover it is important to state that heat transfer coefficient enhancement with hybrid nano fluid was found to be 142.1% while it was up to 35.2% for TiO_2 and 39.4% for Al_2O_3 nano fluid. They conclude that hybrid nanofluids are more efficient than mono nano fluids. Figure 6 shows the comparison of mono and hybrid nanofluids.

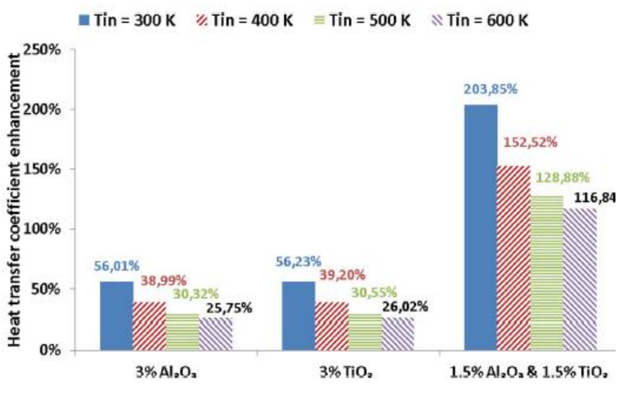


Fig. 6.Variation of heat transfer coefficient for mono and hybrid nanofluids at different Inlet temperatures [26].

Chen et al [27] investigated the synergistic effect of combining MWCNT and Fe_2O_3 nanoparticles on thermal conductivity of nano fluids. Moreover 0.05% MWCNT and different percentages of 0.01%, 0.02%, 0.04%, 0.08%, and 0.16% of Fe_2O_3 nanoparticles are considered. From results, they conclude that nano fluid containing 0.05% MWCNTS & 0.02%. Fe_2O_3 nanoparticles volume concentration have an enhancement in thermal conductivity of about 27.75% more compared with 0.2% single MWCNTS or Fe_2O_3 nanoparticles. Batmunkh et al [28] performed an experimental study by incorporating the newly synthesized flattened Ag particles [by planetary ball milling] into small [15nm] and large [300nm] TiO2 nano particle in an aqueous solution. Results conclude that thermal conductivity of TiO_2 nanofluid with a concentration of 1wt% enhanced from 601.4mw/mk to 609.4mw/mk with addition of only 0.5wt% of Ag nanoparticles. Fig.7. shows the SEM images of the (a) combination of 70% small/30% large TiO2, (b) the flattened “Ag” particle, and (c) Ag/TiO2 composite

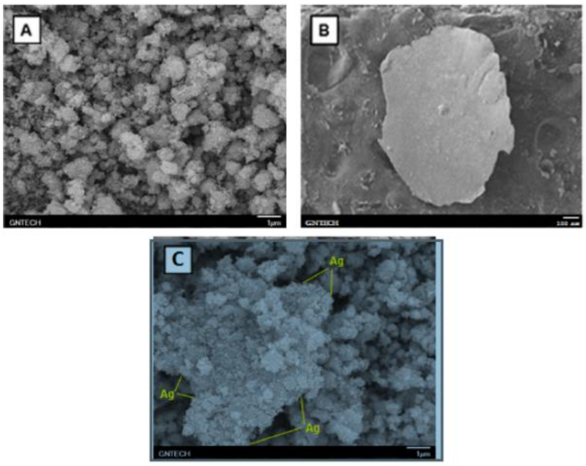


Fig. 7. SEM images of the (a) combination of 70% small/30% large TiO2, (b) the flattened “Ag” particle, and (c) Ag/TiO2 composite [28].

Botha et al [29] examined the use of silica and silver nanoparticles with transformer oil as base fluid are used. They found that nanofluids containing Ag supported on silica showed a lower viscosity compared to the nanofluid containing unsupported silica. They conclude that thermal conductivity increases with an increase in silver concentrations. An enhancement in thermal conductivity of 15% was observed when 0.6wt% silver was supported on 0.07wt% silica.

Madhesh et al [30] examined the use of copper-titania hybrid nanoparticles. Hybrid nanofluids are prepared by dispersing the surface functionalized and crystalline copper-titania hybrid nanoparticles in the base fluid, with volume concentrations using from 0.1 to 2%. From results, they found that the convective heat transfer coefficient, nusselt number and overall heat transfer coefficient were increased by 52%, 49%, and 68% respectively up to 1% volume concentration of Hybrid Nano Composite. An experiment work is done by sundar et al [31] with MWCNT-Fe_3O_4/water hybrid nano fluids. MWCNT--Fe_3O_4 nano composite was prepared by in situ method which includes the dispersion of carbohydrate carbon NTs in distilled water and mixing of ferrous chloride and ferric chloride with sodium hydroxide is used as a reducing agent to form hybrid nano composite. From the results, they concluded that at volume concentration of 0.3%, a maximum of 31.1% enhancement in nusselt number with a penalty of 1.18 times increase of pumping power at a Reynolds number of 22000. Finally concluded that the thermal performance of composite based hybrid nanofluids are superior compared to single particle based nanofluids such as Al_2O_3, TiO_2 & Fe_3O_4.

Esfe et al [32] investigated the effect of using Ag-MgO hybrid nano fluid with particle diameter of 40mm [MgO] and 20mm [Ag] and nanoparticles volume fraction of 50% Ag and 50%

MgO with concentrations of 0% and 2%. They developed an empirical correlation for thermal conductivity and dynamic viscosity. From results, they concluded that predictions of new developed correlations by comparing the predicted values with experimental data showed that new correlations are within a good accuracy.

Suresh et al [33] examined the use of Al_2O_3 – Cu hybrid nanoparticles synthesized by hydrogen reduction technique. From the results, they conclude that the thermal conductivity enhanced by 12.11% for a volume concentration of 2%. They showed that the thermal conductivity and viscosity of hybrid nanofluid increase with nanoparticles volume concentration. The use of three oxide based nano fluids [Al_2O_3, SiO_2, and TiO_2] and their hybrids are investigated by Minea et al [34].Mono and hybrid nanofluids are individually tested with various concentrations of combinations like [Al30, Al35, Al40, Al30t, Al35t, Al40t, HS1, HS2, HS3, MHS1, MHS2, MHS3, HT1, HT2, HT3, MHT1, MHT2, MHT3]. From the results it was concluded that the convective heat transfer coefficient of MHS3 hybrid nanofluid was enhanced by 257%. Moghadassi et al[35] developed a numerical model by CFD.Water based Al_2O_3 & Al_2O_3 –Cu hybrid nano fluid with 0.1% volume concentration and average particle size of 15 nm was considered. From the results, it was concluded that a higher convective heat transfer coefficient for hybrid nanofluids. Table2 shows the brief review of hybrid nanofluids.

5. CONCLUSION

This paper presented the literature studies about the utilization of mono and hybrid nanofluids in concentrating solar collectors. The theoretical and experimental studies prove that Nano fluids lead to higher thermal enhancements. Nano particles enhance the heat transfer coefficient of heat transfer fluids in PTCs system due to high thermal conductivity and density of metallic particles. Thermal performance of a solar collector depends on Particle size, shape of the nano particle, type of the base fluid, volume concentration and inlet fluid temperature. Increase in volume fraction of nanoparticles increases the thermal conductivity, convective heat transfer parameters, density, viscosity, and decrease in specific heat capacity. Increase in nano fluid viscosity lead to pressure drop results in increasing of pumping power. Hybrid nanofluids have been proved to be an excellent choice by the literature results leads to superior thermal properties compared with mono fluids.

6. FUTURE SCOPE

In the end of this work, it is important to state that the future trends of the nanofluid based solar systems. There are not enough studies regarding Hybrid and the Magnetic nano fluids that enhance the thermal properties compared with nano fluids .They Exhibit excellent properties at high temperature applications; Furthermore, there is a need for more experimental studies about solar selective coatings which increase the optical as well as thermal efficiencies .There is a need to develop cost effective method to have a coating on the absorber surface; Different shapes of cross section of absorber tube can be considered and their effects are recommended for further research; More experimental work should be done on nano fluids that have superior thermo-physical properties for a better heat transfer augmentation which in turn reduces the cost and size of the solar device .And development of low cost nano particle production techniques is crucial for nano fluid research.

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