Nano World Journal

https://doi.org/10.17756/nwj.2023-s1-075

Review Article

Open Access

Nano Fluid and Phase Change Materials Practice in Evacuated Tube Solar Collector: A Review

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Received: November 24, 2022
Accepted: April 19, 2023
Published: April 20, 2023

Citation: Bhalavi J, Gupta B, Soni S, Chouhan OP. 2023. Nano Fluid and Phase Change Materials Practice in Evacuated Tube Solar Collector: A Review. *Nano World J* 9(S1): S385-S389.

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Abstract

Solar thermal technology applied to utilize the thermal energy coming from the sun in various applications with the help of solar thermal collectors. Different types of solar collectors such as flat plate, evacuated tube, concentrating collectors, and pitched roof solar collectors are available in practice. Among them, evacuated tube solar collectors are widely used due to their lower convective losses and higher efficiencies. Researchers put great effort to enhance the efficiency of ETSCs by applying various enhancement techniques like integration of fins and reflectors; incorporation of different thermal energy storage materials, nanofluids, PCMs, etc. The purpose of this article is to summarize the effect of nanofluids (ZnO, CuO, Al_2O_3, and CNTs) and different PCMs (Tritriacontane Paraffin and Erythritol) as energy storage options in practice on the efficiencies of evacuated tube collectors. PCMs with melting temperature (90 - 180 °C) have been successfully practiced in ETSCs.

Keywords

Evacuated tube solar collectors, Nanofluids, Phase change materials, Thermal efficiency

Abbreviations

PCM: Phase change material; ETC: Evacuated tube solar collector; TiO_2: Titanium oxide; ZnO: Zinc oxide; CuO: Copper oxide; Al_2O_3: Aluminum oxide; CNTs: Carbon nanotubes; CeO_2: Cerium oxide; GNP: Graphene nanoplateletes; $CuCeO_2$: Copper-cerium oxide nanocomposite; WO_3: Tungsten oxide; Ag: Silver nanoparticle.

Introduction

The development of mankind is related to energy consumption. As the human race is developing, the consumption of energy is also increasing. "The Global Energy Report-2018" says that energy consumption will increase by 33% by the end of 2040 [1]. To meet the increasing energy needs, it has become very necessary to find other means of obtaining energy. Solar energy is very beneficial amongst the unconventional sources of energy. Solar collector is an eminent device to harvest solar power. It is a heat exchanger that converts the energy received by the sun into thermal energy [2]. Solar collectors are generally categorized as: flat plate, evacuated tubes, and concentrating types [3]. Figure 1 shows the classification of solar collectors. The flat plate collector is very popular in the market due to its simple design, but the evacuated tube collector is prevalent due to the cost factor of concentrating solar collectors. The Evacuated Tube Collector (shown in figure 2) is very low cost as compared to flat plate collectors, and it gives very good performance throughout the year, even in low radiation.

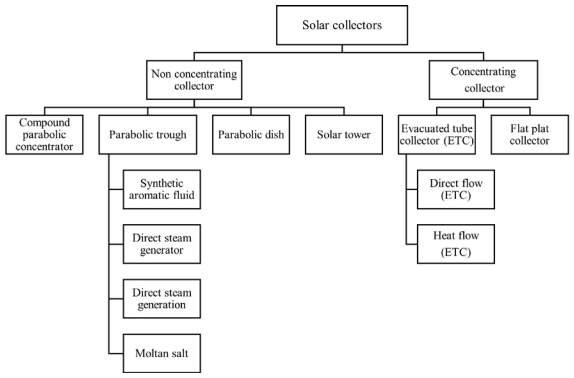


Figure 1: Classification of solar collectors.

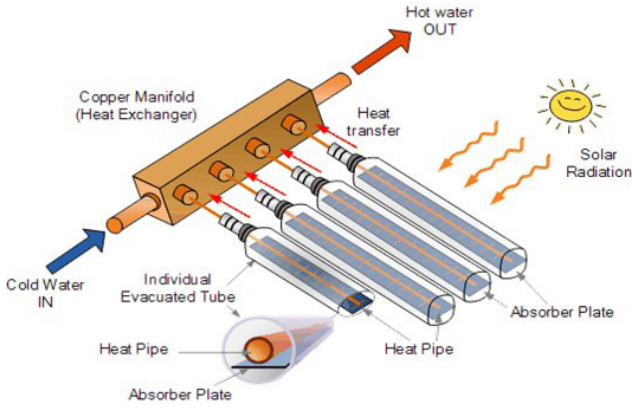


Figure 2: Evacuated tube solar collector [32].

Performance enhancement can be done by increasing the heat transfer properties of working fluid in the solar collector. For this purpose, nanofluids and heat storage materials also called PCMs have been proved very helpful. This article covers the various approaches used by researchers to enhance the efficiency of evacuated tube solar collectors using nanofluid and energy storage materials.

Evacuated Tube Solar Collector with Nanofluids

Utilization of nanofluid is an advanced approach in current scenario to boost the solar collector's performance. The high thermal properties of nanofluid help to utilize solar energy in a proper way. Figure 3 shows beneficial qualities of nanofluid. By keeping these properties in mind various researchers have used nanofluid to increase the performance of solar collectors through various experiments. Lu et al. [4] used water/

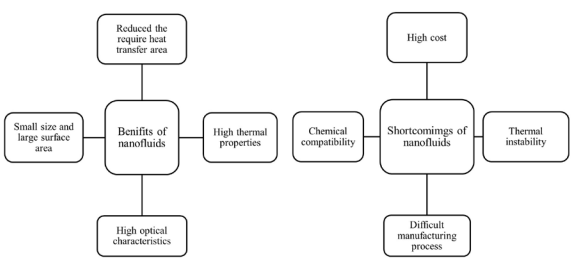


Figure 3: Benefits and limitations of nanofluids [7].

CuO nanofluid as working fluid, they found a 30% increment in heat transfer coefficient as compared to deionized water. Ghaderian et al. [5] found the effect of nanofluid (distilled water/CuO) on evacuated tube solar collector. They concluded that below 0.01% concentrations of CuO nanoparticles there is no effect on the temperature. However, the mean output temperature increased 14.5% approximately at 0.03% to 0.06% concentrations range. Yan et al. [6] found increased heat transfer rate with water/SiO_2 nanofluid they concluded that, longer retaining time makes nanofluid easy to accumulate and heat transfer properties became weak. Kim et al. [8] did experiment with U-pipe ETSC, which is employed with Al_2O_3 nanofluid. The effect of size and nanofluid concentration was found on the collector, at 1.0 volume% Al_2O_3 nanofluid and at 0.048 kg/s mass flow rate highest efficiency obtained was 24.1%. Tong et al. [9] worked with water/ MWCNT nanofluid in U-pipe ETSC. They resulted in a more than 4% increase in efficiency of collector. Simulation of this work has revealed that CO_2 and SO_2 emissions can be reduced by 1500 kg and 5.4 kg per year in this case. Kim et al. [10] found the behavior of a U-pipe ETSC using different types of nanofluid. They concluded, 50 solar collectors incorporating nanoparticles are spread over the working fluid, the coal consumption might be annually dropped around 40.6 - 132.4 kg. CO_2 and SO_2 emission can also be reduced as compared to solar collectors, having water as base working fluid. Table 1 gives a summary of various numerical and experimental studies done on ETSC incorporating various nanofluids.

Evacuated Tube Solar Collector with Phase Change Materials

PCMs are also called latent heat storage materials, the energy is absorbed as latent heat during phase transition process. Table 2 gives various phase change materials along with their melting temperatures. Table 3 represents various properties of phase change materials useful in the selection process. PCMs can be used in different ways to enhance the performance of ETSC. The key purpose of using PCMs is to increase the density of heat storage [19]. Algarni et al. [20] did experiment in U-pipe ETSC. They mix paraffin wax with copper nanoparticles; this mixture is used in the evacuated tubes. They concluded 33% enhancement in the system efficiency. Koca et al. [21] did energy and exergy analysis with ($CaCl_2.6H_2O$) and found 46% energy efficient solar collector. Abokersh et al. [22] experimented with two configurations finned and unfinned type in a compact U-pipe ETSC which was integrated with paraffin wax they found 14% increased efficiency. Varol et al. [23] did experiments with $Na_2CO_3.10H_2O$ as PCM to forecast the thermal characteristics of thermal collectors. Different software-based computing techniques were used by them to estimate the performance characteristics of STCs. They applied ANN, SVM methods and ANFIS. They found solar collectors with PCM were more efficient than conventional solar collectors. Chopra et al. [24] did a comparative experimental investigation in evacuated tube solar collectors with and without phase change materials. They resulted 79 - 87% thermal efficiency of ETSC with PCM as compared to 42 - 55% without PCMs. Wang et al. [25] develop a phase change

Table 1: Summary of various numerical and experimental studies on ETSC incorporating various nanofluids.

Year	Nanofluid	Model	Size (nm)	Volume by %	Remarks	Reference
2010	Water/Cu	Numerical	100	0 to 0.05	Nusselt number and mass flow rate increment in 30% at 15° - 35° tilt angle.	[11]
2012	Water/TiO_2	Experimental	30 - 50	0.3	Efficiency increased 16.8% at 0.3% volume maximum efficiency obtained 73%.	[12]
2013	Water /CuO	Experimental	50	0.8 to 1.5	30% increment in heat transfer coefficient.	[4]
2015	Water/SWCNT	Experimental	1 - 2	0.05, 0.1, and 0.2	At 0.2% volume Highest effectiveness was 93.53% at 0.026 kg/s flow rate.	[13]
2016	Water / TiO_2	Numerical	-	0.05 and 1	Nusselt number was average, thermal conductivity of fluid was Improved.	[14]
2016	Water/Al_2O_3	Experimental	50, 100	0.5, 1, and 1.5	24% efficiency increased at 1% volume, highest efficiency 72% obtained.	[10]
2018	Water/ TiO_2	Experimental	21	0.01 to 0.05	7.2% increment found in thermal conductivity and entropy generation decreased 17.5%.	[15]
2019	Water/CuO	Experimental	50	0.01, 0.02, and 0.03	51% increment in efficiency.	[16]
2019	Distilled water/Cu_2O	Experimental and Numerical	50	0.01, 0.02, and 0.03	Output temperature found 50 °C and 51% increment in efficiency.	[17]
2017	Distilled Water /CuO	Experimental	40 - 60	0.03 to 0.06	14% efficiency increased at 0.03% volume.	[5]
2020	Water/Al_2O_3 Water/ CuO Water/TiO_2	Experimental	-	0.0 to 4	More efficiency found with water/CuO nanofluid as compared to Water/Al_2O_3 and Water/TiO_2.	[18]

Table 2: PCMs with melting point.

Melting point	Phase Change Materials
26 °C	PC210
53 - 58 °C	Sigma Aldrich
57 - 60 °C	Stearic acid ($CH_3(CH_2)_{16}COOH$)
60 - 62 °C	ALEX WAX 600
62 °C	C58
62 °C	Alexandria Wax
69.3 °C	Stearic acid
78 °C	$(BaOH)_2.8H_2O$
100 °C	RT70HC
121 °C	Erythritol
156.7 °C	Paraffin wax

material by mixing β-AlN with poly-ethylene glycol and silica gel. They found 156.5% thermal conductivity as compared to 30.32%. Kim et al. [26] made silver nanoparticles/paraffin composites (Ag/PW) by dissolving 0.5, 1.0, 1.5, and 2.0 % by weight and found 19.78% increase in thermal conductivity. Table 4 further summarizes phase change materials that are experimentally incorporated in ETSC efficiently.

Conclusion

This article covers various available works exploring the possible applications of nanofluid and phase change materials in ETSC based on various methodologies. Main consequent from this study is given below:

- Integration of PCMs in ETSC has been proved to be a practice technique to enhance its efficiency.
- TiO_2, CuO, and Al_2O_3 are the most practiced nanoparticles in ETSCs, while CeO_2, GNP, $CuCeO_2$, WO_3, and Ag are less practiced.
- The average size of nanofluids practiced is between 1 - 25 nm in 40% experimentation, While size between 25 - 50 nm in 34% cases and in the rest cases the nanofluid size are between 50 - 100 nm.
- PCMs with melting temperature (90 - 180 °C) have been successfully practiced in ETSCs.
- Paraffins (60 - 80 °C), Acetamides (82 °C), $Mg(NO_3)_2.6H2O$ (90 °C), and $MgCl_2.6H_2O$ (117 °C) have been practiced experimentally in ETSCs.

Table 3: Properties of PCM.

Thermal	Physical	Chemical	Kinetic	Other
Higher latent heat	High density	Non-corrosive	Good nucleating properties	Economical
Higher specific heat	Small vapor pressure	Non-flammable	No sub-cooling	Ease of available
Higher thermal conductivity	Small phase change	Non-toxic	No super-cooling	Reusable
Desired phase change temperature	Density difference	Chemically stable	No phase segregation	-

Table 4: Summary review of PCMs incorporated in ETSC.

Year	PCM	Method	Model	Result	Reference
2015	Paraffin wax	PCM is filled in manifold	Experimental	Maximum efficiency found 75.3%	[27]
2016	$(BaOH)_2.8H_2O$ and $BaCO_3$	Evacuated tube is filled with PCM	Experimental	Efficiency increased 21%	[28]
2017	ALEX WAX 600	Evacuated tube is filled with PCM	Experimental	Efficiency increased 14%	[22]
2018	Alexandria Wax	Evacuated tube is filled with PCM	Experimental	Efficiency increased 21.8%	[29]
2019	Stearic acid	PCM is filled in manifold	Experimental	Maximum efficiency found 75.53%	[30]
2020	CeO_2-nano-embedded PCM	PCM is filled in storage tank	Experimental	Efficiency increased 11%	[31]
2020	Stearic acid	Evacuated tube is filled with PCM	Experimental	Efficiency increased 30-53%	[24]

- Out of all practiced, dual PCM as Tritriacontane Paraffin and Erythritol (72 °C and 118 °C) proved most effectively and safely.
- The practice of nanofluids and PCMs both in solar collectors supports the green energy revolution that might discourage the use of coal and leads to emission reduction of CO_2 and SO_2 for sustainable healthy environment.

Future Scope

Only a small number of researchers used nanofluids as base fluid in their study, with the majority of their work using pure water. Use of nanofluids seems to be more effective because of their thermal properties. Finding the ideal concentrations of nanoparticles for nanofluids must be the next stage of research on ETSCs.

Acknowledgements

None.

Conflict of Interest

The authors declare no conflict of interests that are relevant to the content of this article.

Credit Author Statement

Jyoti Bhalavi: Conceptualization, Methodology, Writing - original draft preparation; Bhupendra Gupta: Conceptualization, Writing - review and editing, Supervision; Sanjay Soni: Visualization, Supervision; O.P. Chouhan: Writing - review and editing, Supervision. All the authors read and approved the manuscript.

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