



Performance Enhancement In Heat Pipe Solar Collector

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Abstract: In recent years, there has been a significant surge in the demand for efficient and renewable energy sources. Solar energy has emerged as one of the most promising alternatives to meet this demand. Heat pipe solar collectors have gained considerable attention due to their ability to transfer heat effectively from the absorber to the heat exchanger. However, there is still ample room for improvement to enhance their performance. This paper presents a comprehensive review of the research conducted on enhancing the performance of heat pipe solar collectors through the implementation of nano composites.

Index Terms - Heat pipe, Evacuated tube solar collector, Base fluid, Nano fluid.

I. INTRODUCTION

Utilizing energy with low cost and high efficiency is paramount, particularly as India expands its renewable capacity, aiming to mitigate carbon dioxide emissions from coal and oil-based power generation. Solar energy, abundant and eco-friendly, presents a solution, despite challenges in engineering equipment due to its low flux density, necessitating larger collection areas for optimal utilization. Solar energy finds diverse applications in heating air, water, crop moisture removal, food processing, and cooling. With 31% of India's population residing in urban areas with higher energy demands, the adoption of solar technologies becomes increasingly imperative. Evacuated tube collectors serve as vital heat exchangers, transferring solar energy to heat transfer fluids. In industrial settings, where heat transfer is integral to numerous processes, optimizing heat transfer efficiency is crucial for energy recovery, process fluid heating/cooling, and overall operational efficacy. Enhanced heating or cooling not only conserves energy but also reduces process time, improves thermal ratings, and prolongs equipment lifespan. The pursuit of high-performance thermal systems for heat transfer enhancement aligns with the growing demand for efficient heat flow processes. Increasing the thermal conductivity of working fluids further improves heat transfer efficiency, contributing to sustainable industrial practices and energy conservation.

II. LITERATURE REVIEW

The literature surrounding performance enhancement in heat pipe solar collectors, particularly with a focus on evacuated tube collectors and the integration of nanocomposites, provides valuable insights into existing research, technological advancements, and potential avenues for further improvement. These studies collectively contribute to the understanding of thermal performance enhancement in evacuated tube solar collectors. They explore various approaches, including experimental analysis, theoretical modelling, and review of recent advancements, with a focus on integrating nanofluids and optimizing collector design. Such insights are crucial for advancing the efficiency and effectiveness of solar thermal systems, aligning with the growing demand for sustainable energy solutions.

1. According to In 2018, Mahboobe Mahdavi, Saeed Tiaria, and colleagues conducted an experimental analysis on a cylindrical copper heat pipe with a 12.7 mm diameter and a wick composed of four layers of copper screen mesh. The study focused on the effects of working fluid fill volume, inclination angle, and heat input on the heat pipe's thermal resistance. The findings revealed that in gravity-assisted orientations, where the condenser is positioned above the evaporator, the inclination angle had a negligible impact on the heat pipe's performance. However, in gravity-opposed orientations, with the evaporator above the condenser, increasing the inclination angle resulted in a higher temperature difference between the evaporator and condenser, thus increasing thermal resistance. Additionally, under-filling the heat pipe significantly decreased its capillary limit, which is essential for proper operation, while overfilling degraded performance due to excess liquid interfering with the evaporation-condensation mechanism. The experimental results were also used to validate a previously developed numerical model, showing very good agreement. This study provides valuable insights into the thermal performance of cylindrical copper-water heat pipes, highlighting the importance of optimal fill volume and orientation, and contributes to a better understanding of the operational limits and efficiency enhancements for heat pipe applications in thermal management systems.
2. Based on S.M. Fotukian and M. Nasr Esfahany study and examined the convective heat transfer and pressure drop characteristics of a very dilute CuO/water nanofluid flowing through a circular tube. Experimental measurements highlighted a significant increase in heat transfer coefficients upon the incorporation of nanosized CuO particles into the base fluid. On average, a 25% augmentation in heat transfer coefficient was observed alongside a 20% elevation in pressure drop. Interestingly, the enhancement ratio demonstrated consistency across varying concentrations of CuO within the examined range. Moreover, the study noted a noticeable rise in flow resistance even at very low CuO concentrations compared to the base fluid. The investigation specifically focused on exploring the convective heat transfer of CuO /water nanofluid in the turbulent regime within a tube, employing experimental methodologies.
3. According to In their 2017 paper, Ahmed Kadhim Hussein, Lioua Kolsi, et al. reviewed recent advancements in using nanofluids in heat pipe solar collectors. The review covered theoretical, numerical, and experimental studies, summarizing significant literature in Table 1, which highlighted how nanofluids enhance collector efficiency. The findings demonstrated a substantial increase in efficiency due to nanofluids and provided a comprehensive survey of recent advances, contributing to the understanding of this evolving field.

III. EXPERIMENTAL SETUP

The experimental system comprises a heat pipe integrated with copper oxide mixed with DI water to efficiently absorb solar energy. This absorbed solar energy is then transferred to recirculating water within the system, where it undergoes a conversion process into thermal energy, thus completing the energy cycle. Control over the mass flow rate at the inlet of the header is achieved through a rotameter, ensuring precise regulation of fluid flow within the system. Temperature measurements at both the inlet and outlet points are facilitated by thermocouples, providing accurate data regarding the thermal characteristics of the system throughout operation.

Sl. No.	Equipment's	Qty
1	Evacuated Tubes	4
2	Copper tube	4
3	Heat Pipe	4
4	Header for Heat Pipe	1
5	Inlet & Outlet Pipe	1
6	Water Recirculating Pump	3

TABLE 1- Equipment's detail

3.1 Design / CAD Model

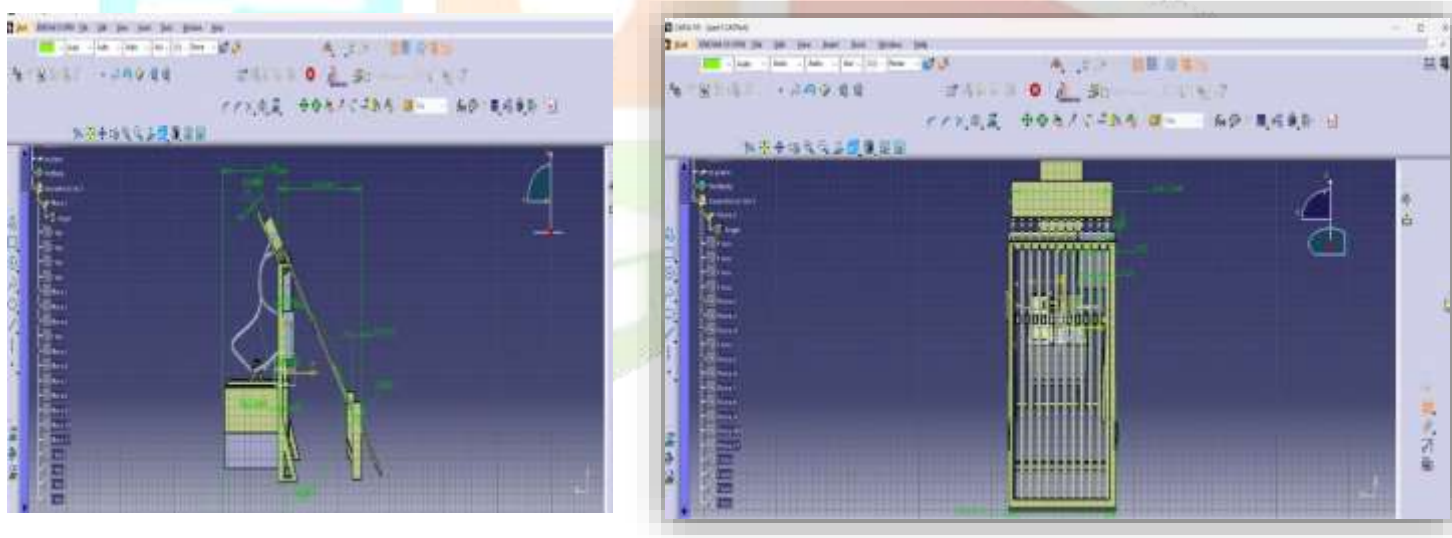


Fig 1 & 2 shows the Side and Front view of Experiment.



Fig 3 & 4 Shows Actual Front and side view of experiment.

IV. RESULTS AND DISCUSSION

4.1 Experimental Readings:

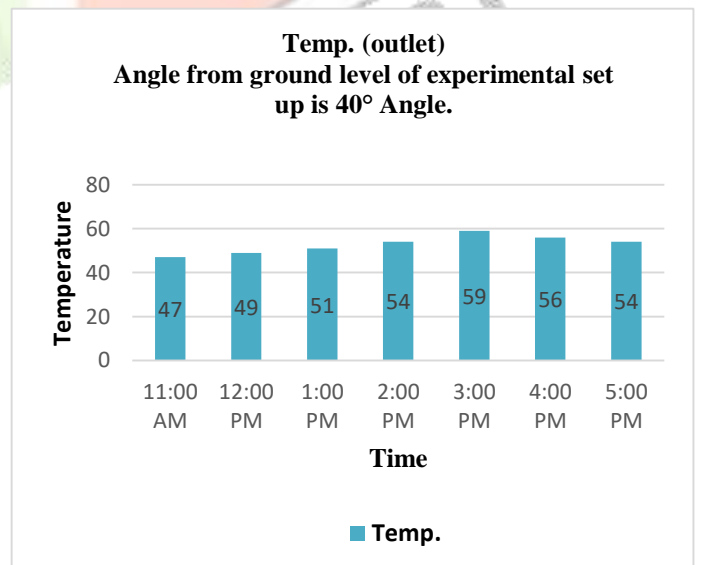
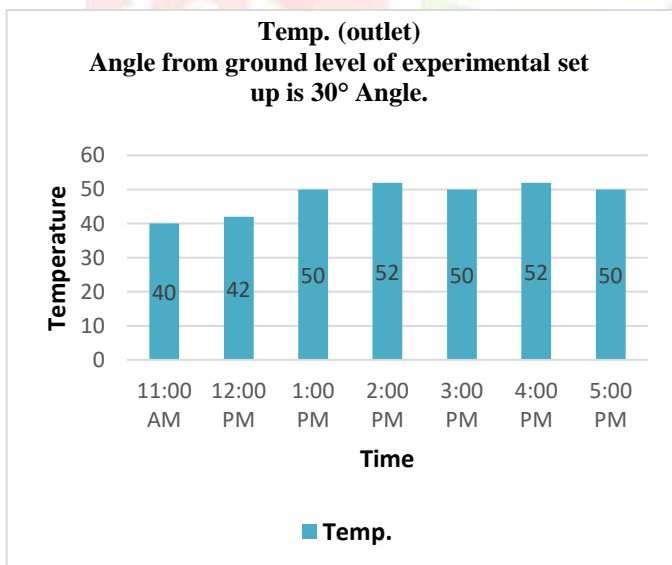


Fig 5 & 6 Shows the experimental reading of angle 30° and 40° from ground level.

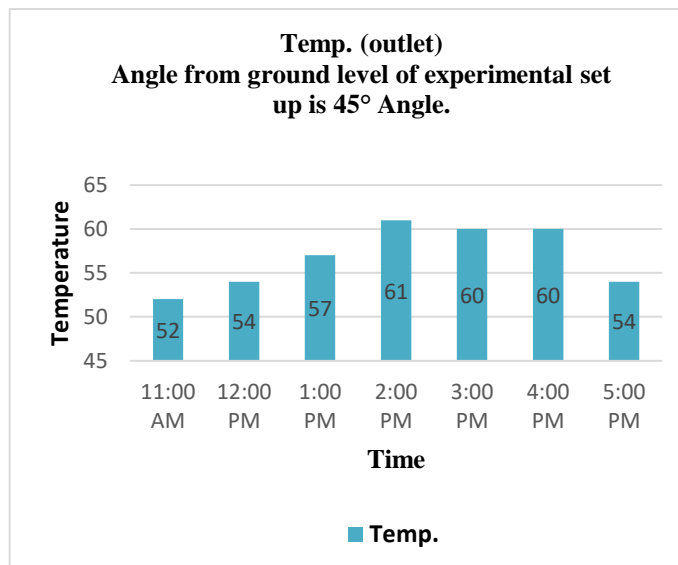


Fig 7 Shows the experimental reading of angle 45° from ground level.

Based on the analysis of the temperature differences (ΔT) between the inlet and outlet at various angles and times, the 45° angle shows the highest average ΔT , suggesting it is the most suitable angle for the experimental setup of the solar collector. This angle provides the best performance in terms of heat absorption and transfer, making it the optimal choice for enhancing the efficiency of the solar collector system.

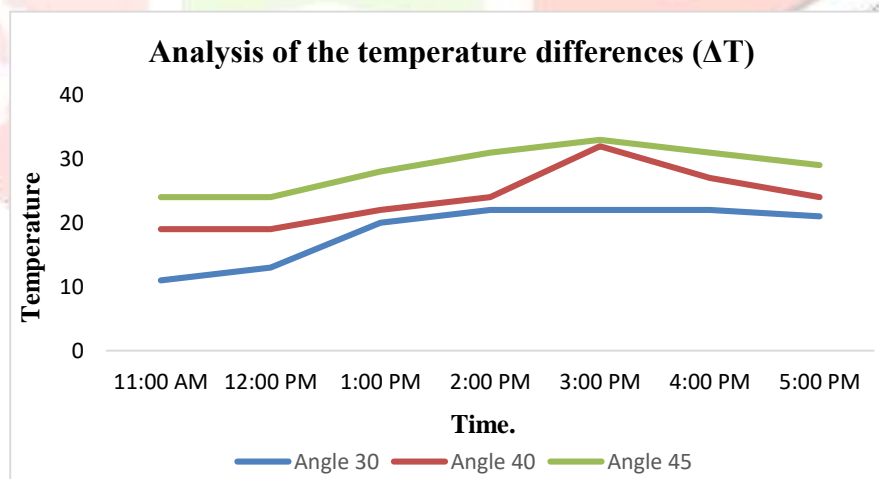


Fig 8 Shows Analysis of the temperature differences (ΔT)

The temperature variations of the designed evacuated tube solar collector are numerically calculated for a 5-liter system. To predict the numerical outlet temperature, solar radiation is measured hourly from 11:00 a.m. to 5:00 p.m. The outlet temperature is influenced by both solar radiation and the number of tubes integrated into the system. The maximum temperature obtained using this model is 61°C. This numerical analysis provides valuable insights into the thermal performance of the collector under varying solar conditions throughout the specified time period.

4.2 Comparison with Experimental Data of 45° Angle with Normal solar collector.

Time	Experimental ΔT (Nano Composite) Temp.	Normal ΔT (Standard) Temp.	Improvement (ΔT) Temp.
11 AM	24	7	17
12 PM	24	8	16
1 PM	28	9	19
2 PM	31	11	20
3 PM	33	10	23
4 PM	31	7	24
5 PM	29	6	23

Table 2- shows the difference between the Experimental Data of 45° Angle with Normal solar collector.

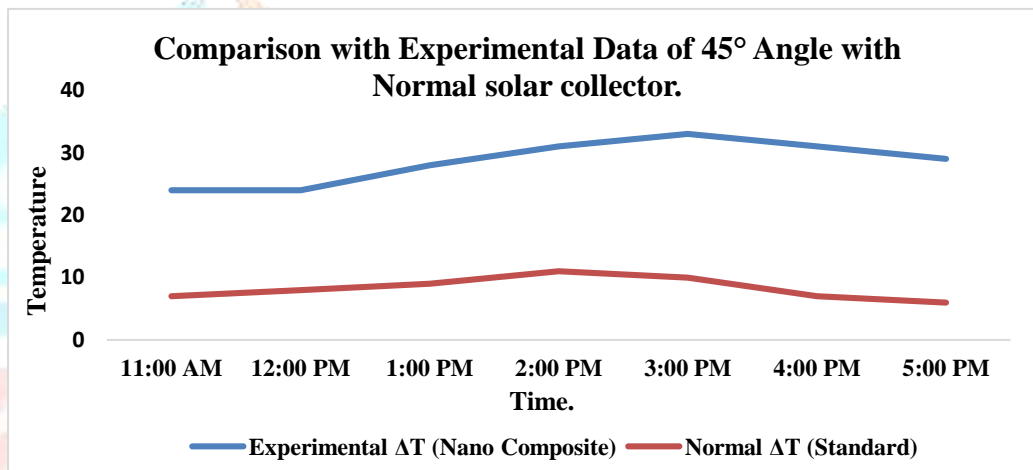


Fig 9 shows the Comparison with Experimental Data of 45° Angle with Normal solar collector.

A. 45° Angle:

Average Improvement in ΔT : $((17 + 16 + 19 + 20 + 23 + 24 + 23) / 7 = 20.29) ^\circ\text{C}$.

Based on the comparative analysis, it is evident that the nano composite-enhanced solar collector shows a significant improvement in temperature difference (ΔT) across all angles compared to a normal solar collector. The 45° angle exhibits the highest average improvement, making it the most effective angle for the experimental setup. Thus, integrating nano composite copper oxide materials in the solar collector at a 45° angle results in the best performance enhancement, offering the most substantial increase in heat absorption and transfer efficiency compared to standard solar collectors.

V. FUTURE SCOPE

1. Advanced Nano Composite Integration
2. Optimization of Collector Design
3. Long-Term Performance Studies
4. Integration of Multiple Nano Materials
5. Integration with Energy Storage Systems
6. Cost-Benefit Analysis
7. Scale-up for Industrial Applications & Home Appliances

VI. CONCLUSION

It is true that nanofluids have gained significant attention in the past decade due to their potential to improve heat transfer properties compared to conventional fluid suspensions containing milli meter and micro meter sized particles. The thermophysical properties of nanofluids are important for predicting their heat transfer behavior, and their enhanced thermal properties have generated great industrial interest for applications in industrial and energy-saving perspectives. Nanofluids have shown promise in enhancing heat transfer, and their development has the potential to contribute to more efficient industrial processes and energy conservation efforts.

- i. Improved Efficiency
- ii. Innovative Design
- iii. Enhanced Reliability
- iv. Heat Transfer Optimization
- v. Environmental Impact
- vi. Thermal Performance

VII. ACKNOWLEDGEMENT

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