

# Experimental Heat Transfer and Thermal Performance Analysis of a Direct Absorption Solar Collector Using CuO–Water Nanofluid

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**Abstract** - The increasing demand for energy due to industrialization, population growth, and technological advancement has intensified the depletion of conventional fossil fuels and raised serious environmental concerns. As a result, renewable energy sources have gained significant importance for sustainable development. Among them, solar energy is considered one of the most abundant and eco-friendly resources. Solar collectors are commonly used to convert solar radiation into useful thermal energy. However, conventional heat transfer fluids used in these collectors possess low thermal conductivity, which limits overall thermal performance. To address this issue, nanofluids have emerged as an effective alternative. Nanofluids are produced by dispersing nanoparticles into base fluids, improving thermal conductivity, heat transfer capability, and solar energy absorption. In this study, the thermal performance of a Direct Absorption Solar Collector (DASC) using CuO–H<sub>2</sub>O nanofluid was experimentally investigated. Unlike conventional collectors, DASCs absorb solar radiation directly within the fluid, leading to improved volumetric heat absorption and enhanced efficiency. Experimental results showed that the use of CuO–H<sub>2</sub>O nanofluid increased collector efficiency by approximately 4–6% compared to water at mass flow rates of 60–100 mL/hr. The study also found that nanoparticle concentration significantly affects performance. Lower nanoparticle volume fractions provided better stability and heat absorption, while higher concentrations caused agglomeration and sedimentation, reducing efficiency. Further improvement of 10–15% may be achieved through enhanced nanofluid stabilization and mixing techniques.

**Key Words:** Heat Transfer, Direct Absorption Solar Collector, Nanofluid Heat Transfer, CuO–Water Nanofluid, Solar Energy, Thermal Performance Analysis

## 1. INTRODUCTION

Solar energy has been available in immense quantities since ancient times and remains one of the most important energy resources for humanity. It serves as the primary source of energy for the entire solar system and forms the foundation of nearly all other energy sources, whether conventional or non-conventional, renewable or non-renewable. Sources such as wind energy and tidal energy are indirectly derived from the sun. One of the most remarkable facts about solar energy is that the amount of solar radiation received by the

Earth in a single day is nearly equal to the total global energy demand for an entire year. However, efficiently capturing and utilizing this enormous amount of energy remains a major challenge due to significant energy losses during conversion and storage processes [1].

When solar radiation reaches the Earth's surface, a part of it is absorbed, leading to an increase in surface temperature. As the temperature of the system rises, the surrounding atmosphere absorbs a considerable amount of heat, which is gradually lost from the surface at a higher rate. A steady-state condition is achieved when the rate of heat loss to the atmosphere becomes equal to the rate of solar heat absorbed by the system [2].

Extraterrestrial solar radiation refers to the solar energy received outside the Earth's atmosphere on a surface placed perpendicular to the incoming rays of the sun. The average intensity of this radiation at the mean distance between the Earth and the Sun is known as the solar constant. As solar radiation travels through the atmosphere, a part of it is reflected back into space, while another portion is absorbed by air molecules, dust particles, and water vapour present in the atmosphere. The remaining radiation is scattered in various directions before reaching the Earth's surface. The radiation that reaches the surface directly from the sun is called beam radiation, whereas the scattered radiation received from the sky is known as diffuse radiation [3]

### 1.1 Solar Energy Collector

Solar collectors are devices that are specifically designed to capture solar radiation and convert it into useful thermal energy. They operate by absorbing the sun's rays either directly or by concentrating them onto a particular surface. The absorbed solar energy is then transferred to a working fluid, such as water or air, which flows through the collector. The efficiency and overall performance of a solar collector mainly depend on its ability to effectively absorb solar radiation and transfer the generated heat energy.

Solar collectors are broadly classified into two major categories: non-concentrating or flat plate solar collectors, and concentrating solar collectors. Non-concentrating or flat plate collectors absorb solar radiation over a wide surface area without focusing the sunlight. These collectors are generally used for low and moderate temperature applications. On the other hand, concentrating solar

collectors use mirrors or lenses to focus solar radiation onto a smaller surface area. This concentration of sunlight produces higher temperatures and improves thermal efficiency, making them suitable for advanced and high-temperature applications [4].

### 1.2 Direct Absorption Solar Collector

A Direct Absorption Solar Collector (DASC) is designed to improve the thermal efficiency of solar energy systems by allowing the working fluid itself to absorb solar radiation directly. Unlike conventional flat plate collectors, where a separate absorber plate captures the incoming solar energy and transfers the heat to the fluid, a DASC eliminates the need for this intermediate absorber surface. In this system, the flowing fluid acts as the absorbing medium, resulting in direct volumetric absorption of solar radiation.

The main advantage of a DASC is the reduction in thermal resistance during heat transfer. In traditional flat plate collectors, heat must pass through multiple layers before reaching the working fluid, which increases thermal losses and decreases overall efficiency. However, in a direct absorption system, solar energy is absorbed directly by the fluid, minimizing heat transfer resistance and improving the collector's thermal performance.

These systems are particularly effective when advanced heat transfer fluids, such as nanofluids, are used due to their superior thermal and optical properties.

## 2. LITERATURE REVIEW

The literature review highlights the significant role of solar energy systems and nanofluids in improving thermal performance and energy efficiency of solar collectors. Various studies have investigated the behavior of conventional and direct absorption solar collectors (DASC) under different operating conditions such as solar radiation intensity, mass flow rate, temperature variation, nanoparticle concentration, and collector dimensions.

optimized volume fractions were observed to provide better thermal performance due to improved surface area and heat absorption capability.

Direct Absorption Solar Collectors were reported to perform better than conventional flat plate collectors because solar radiation is absorbed directly within the fluid volume, leading to volumetric heat generation and reduced thermal resistance. Research also showed that collector efficiency is influenced by collector height, length, flow rate, concentration ratio, and nanoparticle dispersion stability.

Proper optimization of nanoparticle concentration, particle size, and operating conditions is therefore essential for achieving maximum collector efficiency and sustainable solar energy utilization.

## 3. METHODOLOGY

This paper describes the methodology adopted for evaluating the thermal performance of a Direct Absorption Solar Collector (DASC) using CuO-H<sub>2</sub>O nanofluid as the working

medium. The experimental investigation was conducted according to ASHRAE Standard 93-77 to ensure accurate testing procedures, reliable measurements, and consistent efficiency calculations.

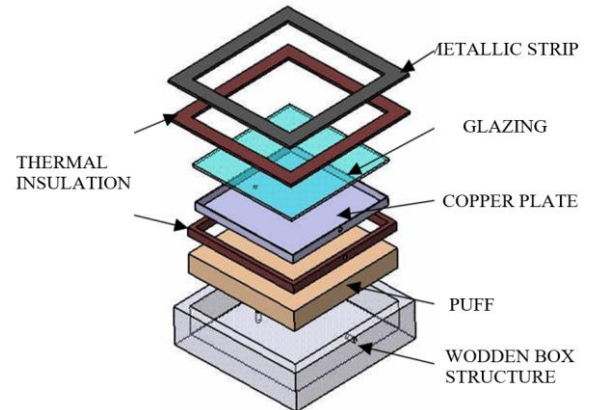


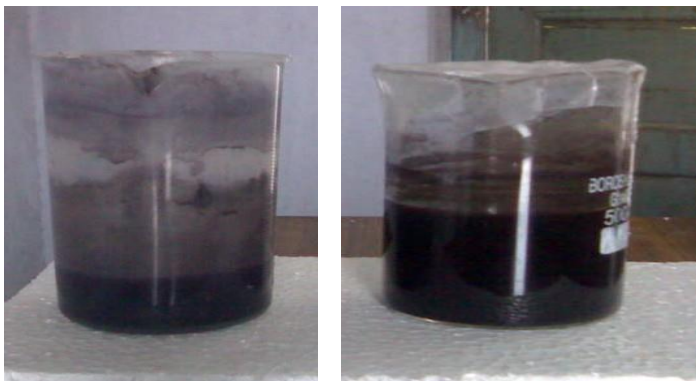
Figure 1 Exploded view of DASC

A small-scale experimental setup was designed and fabricated consisting of a solar collector, fluid circulation system, storage tank, measuring instruments, insulation, and data acquisition arrangement. The direct absorption method was employed, in which the nanofluid directly absorbs incident solar radiation, resulting in improved volumetric heat absorption and enhanced collector efficiency compared to conventional surface absorption collectors.



Figure 2: Top View of DASC

Several instruments were used for experimentation, including a pyranometer for solar irradiance measurement, digital temperature sensors for inlet, outlet, and ambient temperatures, a digital solarimeter for solar intensity measurement, and an infusion set for maintaining low and controlled flow rates. The collector was insulated using puff insulation and glass wool to minimize heat losses.



(CuO-H<sub>2</sub>O) Nanofluid - 0.005% volume Concentration (CuO-H<sub>2</sub>O) Nanofluid - 0.05% volume Concentration)

Figure 3 : volume Concentration



Figure 4. Setup installed by NIWE.

The methodology enabled accurate evaluation of the influence of nanoparticle concentration, solar radiation, and flow rate on the thermal efficiency and heat transfer performance of the DASC system.

#### 4. RESULTS AND DISCUSSION

This paper presents a detailed discussion of the experimental results and their analysis obtained during the investigation. The thermal performance of the Direct Absorption Solar Collector (DASC) was evaluated under different operating conditions, and the influence of Nano fluid on collector efficiency was thoroughly examined. The calculations related to the DASC performance are also included, followed by an analysis of the variations observed in collector efficiency throughout the experimentation.

Experimental observations were compared for both conventional water and CuO–H<sub>2</sub>O nanofluid to determine the improvement achieved through the use of nanoparticles. The results obtained from the experiments demonstrate the variation in collector efficiency with respect to operating conditions and nanoparticle concentration. The analysis confirms that the use of nanofluids improves the thermal performance of the collector due to enhanced thermal conductivity and superior solar radiation absorption characteristics of the nanoparticles.

#### 4.1 Solar Collector Performance Calculations

The experimental efficiency of the solar collector was evaluated using standard heat transfer and energy balance equations. The general expressions used in the analysis are given below.

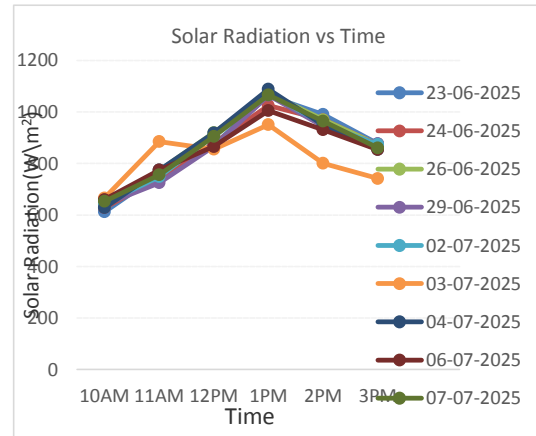


Figure 5. Solar Radiation Variation with time on different days

Therefore, the correction factor helps compensate for these unavoidable thermal losses and provides a more realistic estimation of the collector efficiency. By incorporating the correction factor into the analysis, the calculated performance of the Direct Absorption Solar Collector more accurately represents its actual operating behavior under outdoor environmental conditions.

#### 5.1.1 Solar collector efficiency using Water

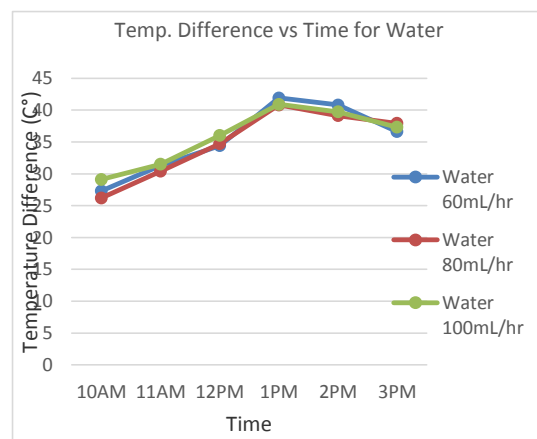


Figure 6. Temperature Difference vs Time for water

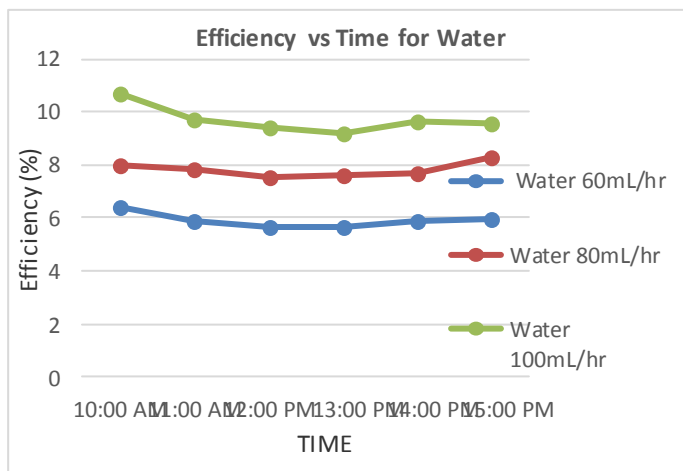


Figure 7. Efficiency vs Time

Figures 6 and 7 illustrate the variations in temperature difference and collector efficiency for the Direct Absorption Solar Collector (DASC) under different operating conditions. The experimental observations indicate that as the mass flow rate through the collector increases, only a slight variation occurs in the temperature difference between the inlet and outlet fluid temperatures, whereas the collector efficiency increases significantly. The primary reason for this behavior is that the percentage change in temperature difference is comparatively much smaller than the corresponding increase in useful heat transfer and energy collection rate. At higher mass flow rates, a larger quantity of fluid passes through the collector per unit time, which increases the overall heat carrying capacity of the system. After reaching peak solar conditions around midday, the incident solar radiation begins to decrease, resulting in a reduction in temperature difference.

#### 4.2 Solar collector efficiency using CuO nanofluid ( $\phi = 0.05\%$ ):

The reduction in effective specific heat at higher nanoparticle concentration indicates that although the thermal conductivity and heat absorption characteristics of the nanofluid improve, excessive nanoparticle concentration may influence fluid stability and flow behaviour.

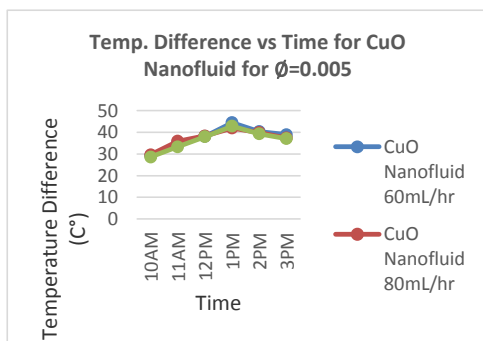


Figure 8. Temperature Difference Variation with Time for CuO Nanofluid (0.05%)

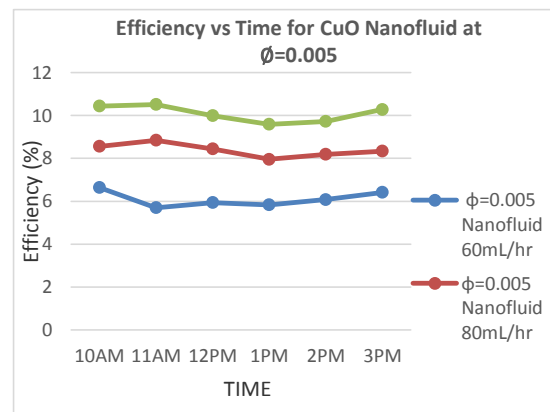


Figure 9. Variation of Efficiency with Time for CuO Nanofluid (0.005%)

Figures 8 and 9 show the variation of temperature difference and collector efficiency throughout the day for the CuO nanofluid having a volume fraction of 0.05%. The experimental results clearly indicate that the collector efficiency obtained using the CuO nanofluid is generally higher than that achieved using water as the working fluid. This improvement in performance is mainly attributed to the superior thermophysical properties of the nanofluid, such as enhanced thermal conductivity, improved heat transfer capability, and better solar radiation absorption characteristics.

#### 4.3 Solar collector efficiency using CuO nanofluid ( $\phi = 0.005\%$ ):

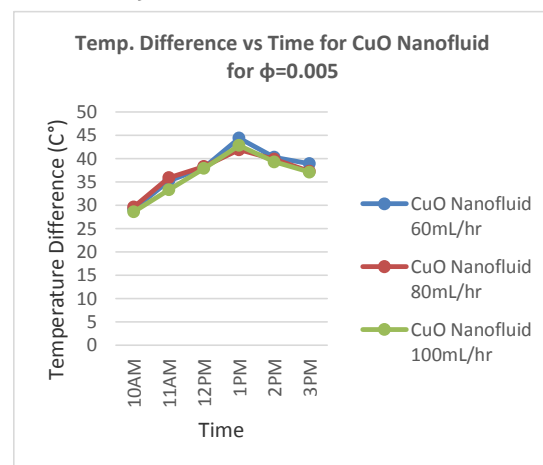
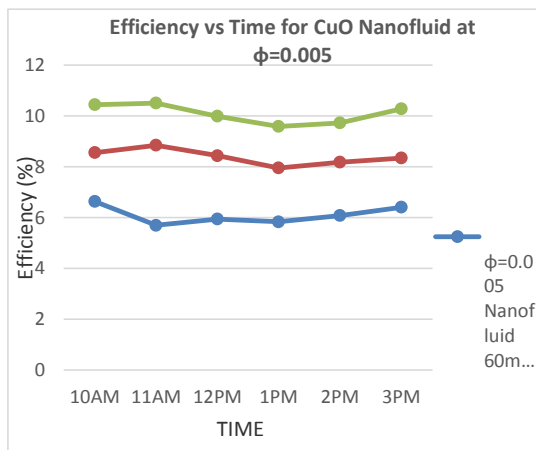


Figure 10. Temperature Difference vs. Time for CuO Nanofluid (0.005%)



**Figure 11.** Efficiency Variation with Time for CuO Nanofluid (0.005%)

Figures 10 and 11 illustrate the variation of temperature difference and collector efficiency throughout the day for the CuO nanofluid having a volume fraction of  $\phi = 0.005\%$ .

The experimental results show that both temperature difference and efficiency follow a similar trend during the daytime operating period. It can be observed that during midday, when the intensity of solar irradiation reaches its maximum value, the temperature difference between the inlet and outlet fluid temperatures becomes highest, whereas the collector efficiency attains its lowest value.

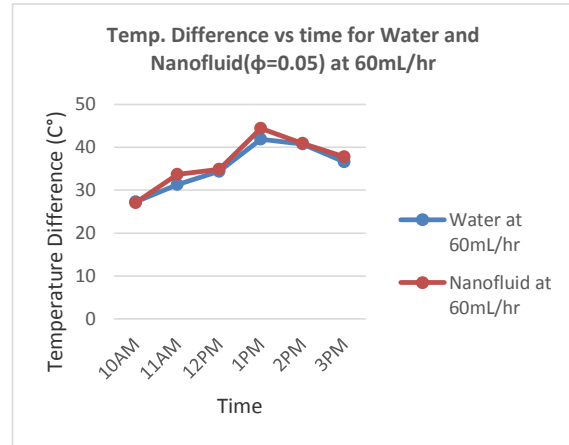
This behavior occurs because, although the collector absorbs a larger amount of solar energy during peak radiation hours, the increase in incident solar radiation is comparatively much higher than the corresponding increase in useful heat gain by the fluid. As a result, the efficiency ratio decreases despite the higher temperature rise within the collector.

The graphs clearly indicate that the thermal efficiency of the collector using CuO nanofluid with a volume fraction of  $\phi = 0.005\%$  is higher than that obtained using

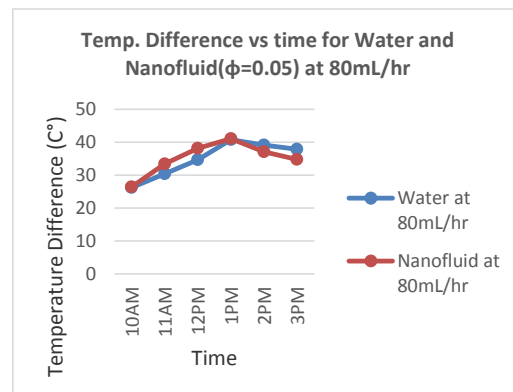
conventional water as the working fluid. The improved performance is mainly due to the enhanced thermophysical properties of the nanofluid, such as higher thermal conductivity and superior solar radiation absorption capability. In addition, the lower nanoparticle concentration provides better stability and more uniform dispersion of nanoparticles within the fluid, resulting in improved heat transfer characteristics and enhanced collector performance throughout the day.

#### 4.4 Performance Comparison Graph of Solar Collector

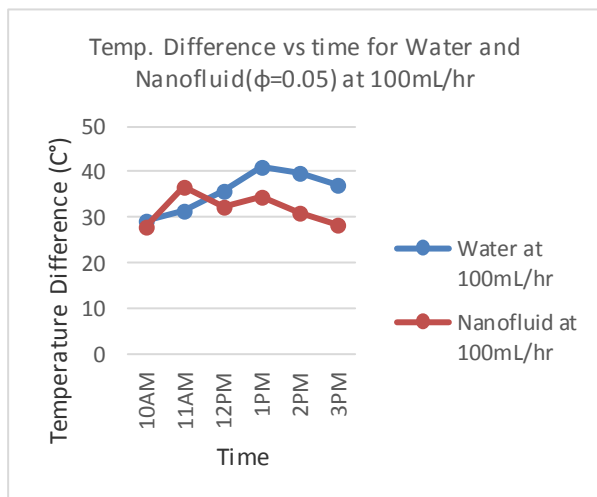
##### 4.4.1 Comparison graph between Water and CuO nanofluid ( $\phi = 0.05\%$ )



**Figure. 12.** Temperature Difference vs. Time at a Flow Rate of 60 ml/hr



**Figure. 13** Temperature Difference vs. Time at a Flow Rate of 80 ml/hr

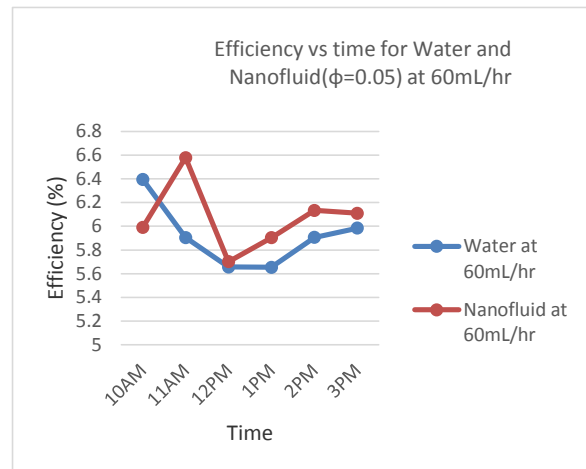


**Figure. 14.** Temperature Difference vs. Time at a Flow Rate of 100 ml/hr

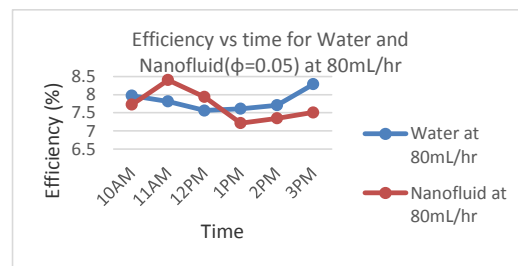
Figures 12, 13, and 14 present the comparison of temperature difference between water and CuO nanofluids under different operating conditions. The graphs clearly indicate that the temperature difference obtained using CuO nanofluids is higher than that observed with water as the working fluid. This improvement is primarily due to the enhanced thermal conductivity and superior heat transfer characteristics of the CuO nanofluid compared to conventional water.

The increase in temperature difference, however, is relatively moderate and generally lies within the range of 2°C to 3°C. Even this small increase is significant because it indicates better heat absorption and improved thermal energy transfer within the Direct Absorption Solar Collector (DASC). In Figure 14, the performance curve corresponding to the CuO nanofluid shows a decreasing trend. This reduction in temperature difference and collector performance can be attributed to lower solar radiation intensity on the particular experimental day. Since the available solar energy was comparatively less, the heat absorbed by the nanofluid also decreased, leading to a lower temperature rise and reduced thermal performance. Thus, the experimental results confirm that the efficiency and temperature difference of the collector are strongly influenced not only by the thermophysical properties of the nanofluid but also by the intensity of incident solar radiation.

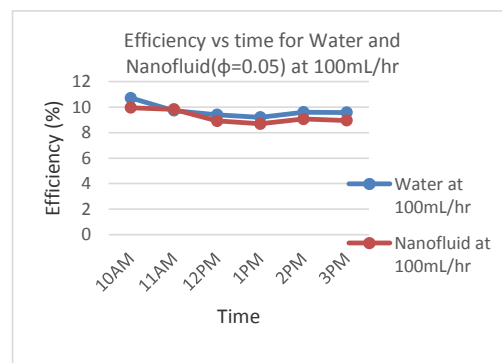
**4.4.2 Efficiency Comparison: -**



**Figure.15.** Efficiency vs. Time at a Flow Rate of 60 ml/hr



**Figure 16.** Efficiency vs. Time at a Flow Rate of 80 ml/hr



**Figure. 17** Efficiency vs. Time at a Flow Rate of 100 ml/hr

Collector efficiency depends mainly on two important parameters: the mass flow rate of the working fluid and the temperature difference between the inlet and outlet of the collector..

The experimental results indicate that CuO nanoparticles possess significantly higher density compared to water. Due to the presence of these nanoparticles, the effective thermophysical properties of the nanofluid are altered, resulting in enhanced heat carrying capacity and improved thermal performance of the collector. Consequently, the collector efficiency obtained using CuO nanofluid is generally higher than that achieved using water alone.

However, in some cases, the efficiency obtained with water was found to be slightly higher than that of the nanofluid. This behavior may be attributed to the coagulation or agglomeration of nanoparticles at higher mass flow rates and insufficient mixing duration. Agglomeration can reduce the stability of the nanofluid and decrease its effective heat transfer capability, thereby lowering the collector efficiency. Therefore, proper nanoparticle dispersion and adequate mixing are essential to maintain nanofluid stability and achieve optimum thermal performance in solar collector applications.

## 5. CONCLUSIONS

The present thesis mainly focuses on the experimental investigation and simplified analysis of the performance of a Direct Absorption Solar Collector (DASC) using CuO-H<sub>2</sub>O nanofluid as the working medium. Based on the experimental observations and analysis carried out during the study, the following conclusions can be drawn.

However, certain challenges associated with the use of nanofluids were also observed during the investigation. The primary issues include nanoparticle agglomeration, sedimentation, and the relatively high cost involved in nanoparticle preparation and nanofluid synthesis. These factors can affect the long-term stability and economic feasibility of nanofluid-based solar thermal systems. Therefore, further attention should be given to improving nanofluid stability, optimizing nanoparticle concentration, and reducing production costs.

The application of nanofluids in solar energy systems is still an emerging and rapidly developing research area. Although numerous theoretical and experimental studies have been conducted, variations still exist in the reported results and methodologies used by different researchers. Hence, further theoretical investigations and experimental studies are necessary to obtain more reliable and validated conclusions and to achieve greater efficiency enhancement in solar collector systems.

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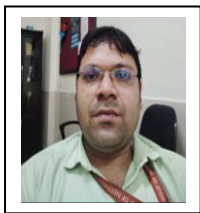
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#### **BIOGRAPHIES (Optional not mandatory)**



Shubham Pandey is an M. Tech scholar in Mechanical Engineering with a keen interest in solar technology, innovative engineering projects, research, and modern technological advancements.



Ajeet Kumar, Assistant Professor, is an academician and researcher in the field of Mechanical Engineering with expertise in innovative design and fabrication projects. He has guided various student research activities and technical projects focused on automation, renewable energy, and manufacturing technologies.