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# EFFECT OF SILICA NANOPARTICLES ON WATER EVAPORATION PROCESS

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## ABSTRACT

*This manuscript details an experimental study investigating the surface evaporation characteristics of a nanofluid composed of water and $SiO_2$ nanoparticles with an average diameter of 16 nm. The study evaluated the evaporation rates of nanofluids with varying nanoparticle mass concentrations (0.05 %, 0.1 %, 0.2 %, 0.3 %, 0.4 %, 0.5 %, 1 %, 3%, 5 %) using a STA PT1600 thermal analyser at a temperature of 40°C. Results indicate that $SiO_2$ nanoparticles initially reduce the evaporation rate of water up to a concentration of 0.1 mass %, but this effect reverses, with the evaporation rate increasing at intermediate concentrations (up to 0.5 mass%). At higher nanoparticle concentrations (1 mass % and above), the evaporation rate stabilizes and does not change significantly. These results demonstrate that the evaporation properties of water can be modulated by adjusting the nanoparticle mass concentration up to 1 %.*

Keywords: *nanofluid, evaporation, thermal analyser, $SiO_2$ nanoparticles.*

## INTRODUCTION

In recent years, the evaporation process in water-based nanofluids has gained significant scientific interest due to its fundamental importance in studying diffusion, surface properties, and various applications such as sensors, drug delivery, and water-based coatings [1 - 4]. Additionally, the rate of water evaporation holds economic significance in fields ranging from plant protection to drug production and coatings drying. Several methods have been proposed and explored to investigate the evaporation rate from liquid surfaces [5 - 8]. With advancements in nanotechnology, it is now possible to control the evaporation rate of water [4, 9] and liquid fuel [10 - 13] by incorporating nanoparticles (ranging from 1 nm to 100 nm) into the base fluid, creating what is known as a nanofluid. Nanoparticles possess a high surface area to volume ratio, thereby influencing the physical properties of the base fluid, including surface tension and viscosity [14 - 17].

Consequently, it is presumed that the presence of nanoparticles affects the evaporation of the liquid, with careful consideration of changes in the surface tension coefficient during analysis. Previous studies have demonstrated that the addition of nanoparticles to liquids can lead to varied effects on the evaporation rate. For example, the inclusion of aluminium nanoparticles in ethanol decreases the droplet evaporation rate compared to pure ethanol [10]. The impact of aluminium oxide nanoparticles in pure water was investigated by Madhusoodanan et al., showing increased surface tension and reduced evaporation rate compared to pure water [9]. In the study of Bair et al., the evaporation of nanofluid droplets containing silicon dioxide particles (10 nm, 0.1 % mass concentration) was examined, revealing slower evaporation compared to bulk liquid droplets [18]. However, conflicting findings regarding how nanoparticles alter vaporization properties have been reported in the literature. The inhomogeneity and instability of nanofluids pose challenges in obtaining reproducible samples [19]. At high nanoparticle concentrations, aggregation can occur due to Van der Waals forces, leading to changes in the microstructure or configuration [20]. This work aims to experimentally investigate the effect of nanoparticles on the evaporation rate of liquids at different concentrations, examining whether they enhance or reduce the evaporation process.

## EXPERIMENTAL

In this study, nanofluids were prepared by adding powder containing $SiO_2$ nanoparticles with an average size of 16 nm (Evonik Aerosil 200 - Fumed silica aerosol 200, Germany) to deionized water. The powder mass concentrations used were 0.05 %, 0.1 %, 0.2 %, 0.3 %, 0.4 %, 0.5 %, 1 %, 3 %, and 5 %. To achieve the desired nanoparticle concentration, precise measurements were performed using an EP 214C Explorer Pro electronic balance (Ohaus, USA) with an accuracy of 0.01 mg. Ultrasonic technology is widely used to determine the molecular mechanisms of processes in liquids and colloids, and in the case of high wave intensity, it is a reliable tool for the dispersion of nanoparticles [21 - 24]. The powder containing $SiO_2$ nanoparticles and base fluid were then mechanically mixed, and an ultrasonic disintegrator (UD-11 automatic, 100 W and 22 kHz) was employed to prevent initial agglomeration of the nanoparticles in water. The dispersal process was conducted for 20 min, which was determined to be the optimal duration for achieving uniform dispersion of the nanoparticles in the liquid volume [20].

The evaporation properties of the resulting nanofluid were investigated using an automated thermal analyser, specifically the STA PT1600 (LINSEIS, Germany). Thermogravimetric analysis was employed in this study, which is a widely utilized method for analysing mass changes and kinetics [25, 26]. This method involves evaluating the mass loss of the sample under specific temperatures or programmed temperature conditions [25]. Thermogravimetric analysis is an ideal tool for this research, as it enables accurate measurement of mass changes and allows for research even with small sample volumes. The device used in our study has a heating rate capability of 0.1 to 100°C $min^{-1}$. The sample container used has an internal volume of 0.12 mL. As the measurement took place in an insulated room and the initial sample temperature was approximately room temperature, no gas flow was introduced during the measurement. To conduct the measurement, the samples were placed inside a container, and the container lid was tightly closed. The mass loss of the samples was measured for a duration of 20 min, while maintaining a constant temperature of 40°C. It is crucial to handle the container with great care, as any damage to it would require replacement and subsequent re-calibration of the device. Regular measurements were performed using deionized water to ensure that the vessel remained undamaged and free from contamination throughout the measurement. This step was necessary to maintain the integrity of the measurements and ensure reliable results.

## RESULTS AND DISCUSSION

The automated system of the device provides controlled thermal energy to the sample. In the case of the studied liquid, which is deionized water, the system gradually increases its temperature from room temperature to 40°C at a rate of $1^{o}$ $min^{-1}$. This temperature increase is achieved over 100 s period. Once the temperature reaches 40°C, it is maintained at that level for the duration of the measurement, without any further changes (Fig. 1).

During the initial stage of the evaporation process, the saturated vapor pressure inside the sample container gradually increases. After a certain period, the saturated vapor pressure reaches a constant state. This equilibrium state results in a constant number of vapor molecules being released from the liquid surface over time, leading to a linear relationship on the graph (Fig. 2). To investigate the evaporation properties, a series of measurements were conducted in a closed and isolated system using both deionized and distilled water. The measurements were repeated 10 times to ensure consistency. Overall, the results indicated that the values of the evaporation rates differed considerably, with deionized water having approximately 4 times higher evaporation rate ($k_{deionized} = 3.5\ \mu g\ s^{-1}$) compared to distilled water ($k_{distilled} = 0.85\ \mu g\ s^{-1}$).

The evaporation rate of deionized water was used as a standard for comparison.

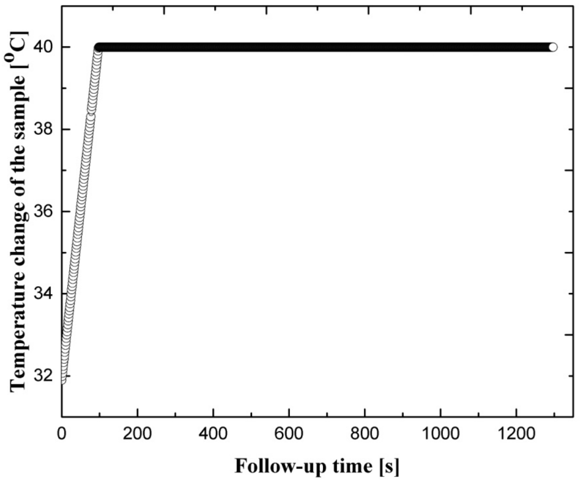

Fig. 1. Temperature of a sample in the container as a function of the time.

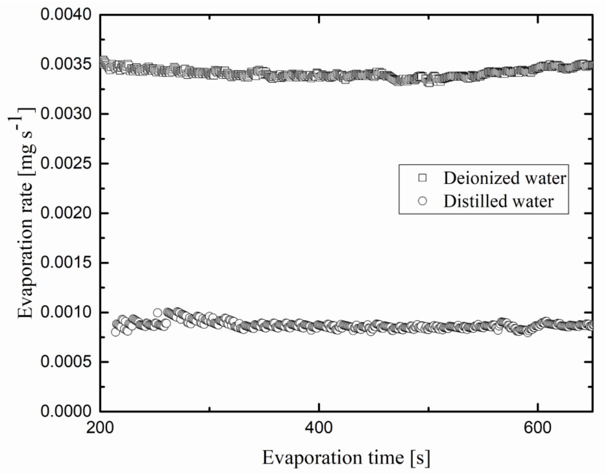

Fig. 2. Evaporation rate of distilled and deionized water at 40°C as a function of the thermal analyser scan time.

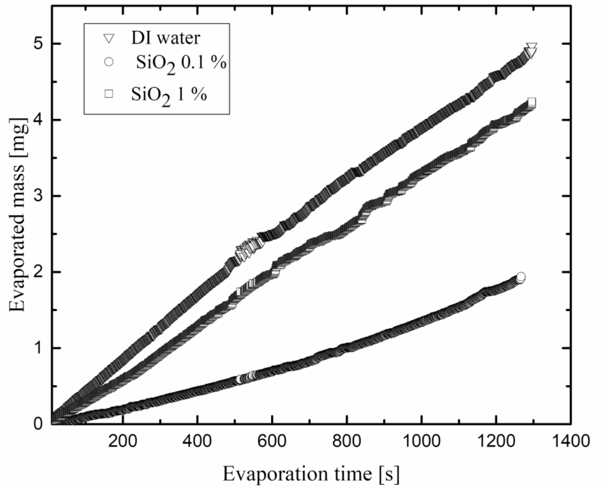

Fig. 3. Time-dependent vapor mass change of nanofluid with deionized water and $SiO_2$ nanoparticles.

Data collection was performed at one second intervals, resulting in minimal mass loss per second but with some jitter and noticeable noise in the data. It should be noted that the data at the beginning and end of the measurement period may not accurately represent the actual rate of water evaporation. However, measurements taken between approximately 200 and 800 s showed small deviations during the scanning process, indicating more reliable data with minimal scatter.

The thermogravimetric analysis method was calibrated for a deionized liquid and the mass loss due to evaporation in nanofluids containing silicon dioxide nanoparticles was measured. The measurements were carried out for a duration of 20 min, and the results obtained for some concentrations of nanoparticles are presented in Fig. 3.

After numerous measurements results for pure deionised water, it was observed that once a certain time has passed, the temperature of the sample remains constant (isothermal, T = const) at 40°C, as shown in Fig. 1. This indicates that the sample reaches a thermal equilibrium. Consequently, the pressure of the saturated vapor inside the container also remains constant (isobaric, P = const) after a certain time.

At this state, the mass loss during evaporation of the sample follows a linear law, represented by Eq. (1).

$$m = m_0 - kt \qquad (1)$$

In this equation, m represents the mass of the nanofluid after evaporation, $m_o$ is the initial mass of the sample, k is the evaporation rate, and t represents the time elapsed. The relationship between the evaporation rate and the time can be visualized as the angle formed by the 0X axis, which is equivalent to the value of k.

By calculating the evaporation rate (k) for each concentration case using Eq. (2):

$$k = \frac{\Delta m_i}{\Delta t} \qquad (2)$$

where $\Delta m_i$ represents the mass evaporated during the time interval Δt, the results were obtained and are presented in Fig. 4. These values provide insights into the evaporation behaviour of the nanofluid at different mass concentrations. The values of k for each mass concentration were determined and presented in Table 1 and Fig. 4.

Table 1. The value of evaporation rate depending on mass concentration.

| Mass concentration, % | Evaporation rate, µg $s^{-1}$ |
|---|---|
| 0.05 | 1.9 |
| 0.1 | 1.2 |
| 0.2 | 1.4 |
| 0.3 | 1.8 |
| 0.4 | 2.9 |
| 0.5 | 3.1 |
| 1 | 3.4 |
| 3 | 3.3 |
| 5 | 3.4 |
| Pure deionized water | 3.5 |

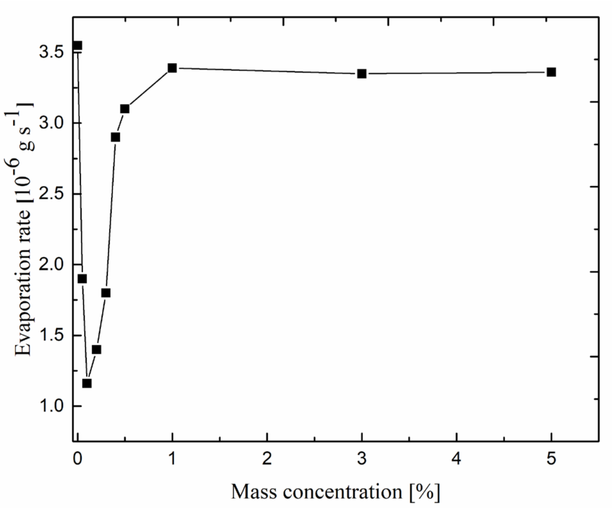

Fig. 4. The evaporation rate as function the mass concentration of $SiO_2$ nanoparticles in deionized water.

It was observed that $SiO_2$ nanoparticles decrease the evaporation rate of water up to a concentration of 0.1 mass % but exhibit an increased evaporation rate at intermediate concentrations (up to 0.5 mass %). However, at higher concentrations of nanoparticles (1 mass % and beyond), the evaporation rate remained unchanged. These findings suggest that the evaporation properties of water can be controlled by selecting mass concentration of nanoparticles up to 1 %.

## CONCLUSIONS

Based on the results obtained in this study it can be inferred that the evaporation rate of nanofluids with silicon dioxide nanoparticles varied depending on the concentration. The smallest observed evaporation rate was 1.2 µg $s^{-1}$ in the 0.1 % nanoparticle concentration, while the largest rate was 3.4 µg $s^{-1}$ in the 1 % concentration. Interestingly, no further change in the evaporation rate was observed beyond 1 % nanoparticle concentration. These findings suggest that the evaporation properties of water can be controlled by selecting the optimal concentration of nanoparticles. To gain a deeper understanding of the underlying mechanisms that influence the evaporation properties of water with nanoparticles, additional research is required. This research should focus on investigating the surface properties of both the nanoparticles and water. The analysis of water evaporation rate, using the coefficient of surface tension of the nanofluid, was performed on the results obtained from several measurements [27, 28]. By studying the physical processes and interactions between nanoparticles and water at the surface level, a clearer understanding of the evaporation properties can be achieved.

The effect of $SiO_2$ nanoparticles on the rate of water evaporation depends on a variety of factors and can be both direct (through film formation, alteration of surface tension) and indirect (through changes in thermal conductivity and heat capacity). Investigating these processes requires a comprehensive approach, including experimental work and theoretical modelling.

In conclusion, the addition of nanoparticles to water offers unique opportunities for controlling and optimizing evaporation processes, which is important for various applied fields, from industrial cooling to nanofluid sensors.

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***Authors' contributions:*** *A. P. conducted the research as part of a PhD dissertation in Physics. S. M., as the academic advisor, supervised the experimental work and contributed to the manuscript preparation. M. G. and Sh. N. provided scientific guidance and were involved in defining the research goals and objectives. B. A. participated in the research and in the analysis of scientific and technical literature.*

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