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Experimental analysis of water evaporation rates: influence of fan configuration on evaporation efficiency

Su buharlaşma oranlarının deneysel analizi: fan konfigürasyonunun buharlaşma miktarına etkisi

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Abstract

This study experimentally investigates the effect of fan configuration and air velocity on evaporation rates. Four different fan configurations were tested under controlled experimental conditions: central opposite blowing, one-sided blowing, top blowing, and strong fan blowing from the short side. The results indicate that opposite blowing significantly enhances evaporation, while one-sided blowing has limited effectiveness due to reduced air-water contact. Top blowing and the use of strong fans also notably increase evaporation rates. These findings provide valuable insights for optimizing water management practices and contribute to strategies aimed at reducing water losses.

Özet

Bu çalışma, fan konumlandırmasının ve hava hızının su buharlaşma hızları üzerindeki etkisini deneysel olarak incelemektedir. Kontrollü deneysel koşullarda yapılan çalışmada dört farklı fan konfigürasyonu test edilmiştir: merkezden karşılıklı üfleme, tek taraflı üfleme, üstten üfleme ve kısa kenardan güçlü fan üflemesidir. Sonuçlar, karşılıklı üflemenin buharlaşmayı önemli ölçüde artırdığını, tek taraflı üflemenin ise hava-su temasının azalması nedeniyle sınırlı etkili olduğunu göstermiştir. Üstten üfleme ve güçlü fan kullanımının ise belirgin bir şekilde buharlaşma hızlarını artırdığı görülmüştür. Bu bulgular, su yönetim uygulamalarını optimize etmek için değerli içgörüler sunmakta ve su kayıplarını azaltma stratejilerine katkıda bulunmaktadır.

INTRODUCTION

The water cycle describes how water evaporates from Earth's surface into the atmosphere, condenses into clouds, and falls back as precipitation. Water collects on land in rivers, lakes, soil, and rocks, with much returning to the oceans. This constant movement affects Earth's weather, emphasizing the importance of water management. Access to clean water isn't a luxury but a basic need, especially for our future and descendants. Urban growth, climate change, industry, and agriculture strain water sources, highlighting the need for efficient use and management. The rational and sustainable use of water resources can be achieved through the coordination and integration of spatial and inter-sectoral planning and decision-making processes. Sustainable water use involves ensuring efficient utilization of water in a manner that is harmonious with the environment, without wasting even a single drop. This concept brings to mind the water masses that evaporate annually from reservoirs. Various models and coefficients can be used to predict evaporation over a lake. Studies have shown that these coefficients vary with wind speed (Yu et al. 2017). This information is crucial for understanding the water cycle and managing water resources effectively. Particularly, it is of great importance for the planning of dams and the management of water storage. New modeling techniques offer promising improvements in evaporation predictions. For example, the modified Coactive Neuro-Fuzzy Inference System (CANFIS) algorithm can perform exceptionally well in different

climates (Allawi et al. 2021). Such advancements can help in more accurately assessing and managing water resources. Additionally, the impact of groundwater on evaporation should not be overlooked. This allows global models to produce more accurate results. For instance, the GLEAM-Hydro model predicts groundwater interaction globally, providing a more realistic representation of evaporation under water-limited conditions (Hulsman et al. 2023). In addition to evaporation, understanding soil water resources is important. Studies using stable isotopes of hydrogen and oxygen contribute to a better understanding of soil water resources in arid and semi-arid regions (Li et al. 2023). Furthermore, the use of modern techniques such as artificial intelligence can improve evaporation predictions. For example, a study using data from a treatment plant in Iran showed that artificial neural networks outperformed other methods (Izady et al. 2017). Different approaches exist for predicting evaporation rates in humid environments using meteorological data. Improving the accuracy of evaporation predictions can be achieved by forecasting daily equilibrium surface temperatures, focusing on models that relate to the relationship between potential and actual evaporation (Szilagyi and Jozsa 2008). A method has also been developed to determine floating tray evaporation rates in small wetlands. A study conducted in a wetland in Norman, Oklahoma, showed that floating tray evaporation rates were significantly lower than those of land trays (Masoner et al. 2008). Predicting global reservoir evaporation losses is challenging, but new datasets like the Global Reservoir Surface Area Data Set and the Global Reservoir and Dam Database can address this gap (Tian et al. 2022). According to data from the Nansihu Lake Evaporation Station, conversion coefficients for free water surface evaporation vary for different evaporators and exhibit a similar pattern throughout the year. The installation and structures of evaporators affect evaporation rates (Fu et al. 2004). When studying micro-droplet evaporation, it was observed that changes in surface energy between different surface materials and temperatures ranging from 25-250 °C affected contact line dynamics. The evaporation rate was linearly scaled with the contact radius, and a sticking-slipping contact line was observed. A maximum evaporation rate of around 35 µg/s was determined for all materials (Putnam et al. 2012). Studies examining different surface materials to enhance micro-evaporator performance revealed that in two different evaporation regimes, namely non-wetted and wetted regimes, different surface properties affected evaporation. In the non-wetted regime, the P-SiO_2 (Phosphorus-doped Silicon Dioxide) surface showed the highest performance, while in the wetted regime, the P-SiNW (Phosphorus-doped Silicon Nanowire) surface was the most efficient (Azarkish et al. 2015). Soil evaporation is a process that varies depending on atmospheric conditions, with factors such as environmental air temperature and relative humidity being crucial. As temperature increases, evaporation rate increases but the evaporation duration decreases exponentially (Ben Neriah et al. 2014). Instead of traditional methods, a maximum evaporation model can be used to approximate potential evaporation (EP). Applying the maximum evaporation model to all global land surfaces resulted in higher EP estimates compared to the Priestley-Taylor model. This difference increases with decreasing surface moisture, relying on increased net radiation despite obtaining lower Ts (surface temperature) (Tu and Yang 2022). The long-term average evaporation of 3415 reservoirs in Texas has a significant impact on water budgets and management. This corresponds to 61% of agricultural water use or 126% of municipal water use in the state. Therefore, developing strategies to reduce evaporation effects in water management is crucial (Wurbs and Ayala 2014). The interaction between soil and atmosphere provides thermal and hydraulic soil surface conditions that maximize evaporation. This theory links surface energy flows to temperature and soil moisture, supported by experiments (Gao et al. 2023). These findings play a crucial role in water resource management and sustainable use. Therefore, the importance of research on evaporation is increasing.

Climate change has significant effects on water resources. Particularly, the uneven distribution of water resources, extreme rainfall, and droughts pose threats to water security (Abbas et al. 2022, Wang and Liu 2023). Some important studies conducted to understand the effect of

wind speed configurations in determining water evaporation rates. Wind speed has an effect on evaporation rates (Yu et al. 2017). Similarly, it is shown how water evaporation prediction models can be improved by specifically considering wind speed (Yu et al. 2017, Allawi et al. 2021). Effective and sustainable management of water resources, including reducing the loss of water through evaporation, is vital to understanding and controlling the water cycle. Reducing evaporation from dams is an important goal to increase the efficiency of water reservoirs and protect water resources. This study aims to investigate the impact of wind as a strategy to reduce evaporation from dams. In the experiment, the effect of wind is simulated by placing water in a container and using a fan at different angles and speeds. Factors such as the speed of the fan and the distance between the water surface and the fan are also considered. The main objective is to measure the amount of water evaporating under different wind conditions to determine the effect of wind on evaporation. This information will contribute to more efficient water resource management and reduce losses in water reservoirs. The overall goal is to develop solutions that support the sustainable use of water resources and minimize water losses.

EXPERIMENTAL SETUP

Laboratory techniques and measurement methods are crucial for assessing water evaporation rates, providing essential data for models such as SWAT-MODFLOW used in water resource management (Abbas et al. 2022). To experimentally investigate the impact of fan position and speed on water evaporation, a transparent glass container filled with water was observed under controlled conditions. Water temperature was measured using a thermometer, and the laboratory's ambient humidity levels were monitored using national meteorological data. Various fan positions and speeds were tested to observe changes in evaporation rates. These changes were recorded at regular intervals using a timer, yielding valuable data for subsequent analysis.

RESULTS AND DISCUSSIONS

Case 1: Two Facing Fans

In the initial experimental setup, two fans were positioned diametrically opposite each other at the center of a long side of a water-filled container, generating airflow at a velocity of 8 m/s. This configuration facilitated a concentrated air movement directly across the water surface. Over a period of 7 days, the evaporation process was monitored, and the reduction in water level was precisely measured using a mechanical caliper.

The findings from this experiment indicate a significant increase in the amount of water evaporated when the fans were placed facing each other. This observation suggests that the opposite orientation of the fans enhances evaporation by creating a focused airflow that maximizes air-water interaction at the surface. The controlled environment ensured stable conditions for humidity and temperature, minimizing external factors that could influence the evaporation rates observed.

This experimental approach provides empirical evidence supporting the hypothesis that optimizing fan placement and airflow direction can effectively enhance water evaporation rates. Such insights are crucial for developing efficient strategies in water resource management and environmental engineering applications, aiming to mitigate water loss and improve overall system efficiency.

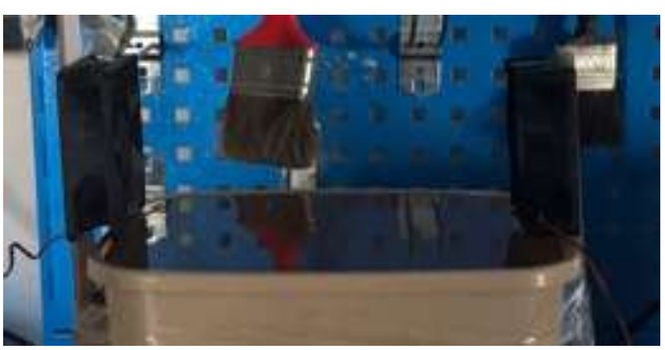


Figure 1. Two fans opposite blowing position

Table 1. Results when two fans blow oppositely from the sides

	Air velocity (m/s)	Time (hour)	Evaporation(g)
Still water	0	168	170
Air blown water	8	168	419

Case 2: Single Fan Blowing From The Side

In the second experimental configuration, a single fan was positioned at the center along one of the long sides of a water-filled container, generating airflow at a velocity of 8 m/s. This setup allowed for unidirectional air movement across the water surface. Over a period of 7 days, the evaporation process was monitored closely, and the reduction in water level was measured using a precise mechanical caliper.

The experimental results indicate that the amount of water evaporated was significantly influenced by the direction and placement of the fan. When the fan blew individually along the long side of the container, the observed evaporation rate was lower compared to the configuration where two fans were blowing towards each other. This suggests that one-sided airflow, despite the same velocity and environmental conditions, results in less effective air-water interaction and consequently reduces the evaporation rate.

The controlled laboratory conditions ensured stable humidity and temperature levels, minimizing external variables that could affect the experimental outcomes. These findings underscore the importance of airflow dynamics and fan placement in optimizing evaporation rates. Understanding these factors is essential for designing efficient systems in water management and environmental engineering, aiming to maximize evaporation processes and mitigate water loss effectively. Such insights contribute to the development of sustainable water conservation strategies and technological advancements in related fields.



Figure 1. Single fan one-side blowing position

Table 2. Results in case of one-side blowing

	Air velocity (m/s)	Time (hour)	Evaporation(g)
Still water	0	168	170
Air blown water	8	168	375

Case 3: Air Blowing From The Top

In the third experimental configuration, different fan setups were tested to investigate their impact on water evaporation from a water-filled container under controlled laboratory conditions. Specifically, three configurations were evaluated: first, two fans positioned at the center blowing towards each other at a speed of 8 m/s; second, a single fan blowing directly downwards onto the water surface at a speed of 13 m/s; and third, no

fans (control group). Each configuration was maintained for a period of 7 days, during which the decrease in water level was measured using a precise mechanical caliper.

The results of the experiments demonstrate distinct variations in the evaporation rates depending on the fan configuration. When two fans were blowing towards each other from the center along the long side of the container, the evaporation rate was observed to increase significantly compared to the control group where no fans were used. This configuration facilitated enhanced air-water interaction due to the converging airflow, thereby promoting greater evaporation from the water surface.

Conversely, when a single fan was positioned directly above the water-filled container, generating a downward airflow at a higher velocity of 13 m/s, the evaporation rate also increased noticeably compared to the control group. The focused airflow directly onto the water surface promoted more intensive air-water mixing, leading to accelerated evaporation over the 7-day observation period.

The controlled laboratory environment ensured consistent humidity and temperature levels throughout the experiments, minimizing external factors that could influence the results. These findings underscore the critical role of fan placement, directionality, and airflow velocity in modulating water evaporation rates. Such insights are instrumental in optimizing evaporative processes for various applications in water management, agricultural practices, and environmental engineering, aiming to enhance efficiency and sustainability in resource utilization.



Figure 2. Single fan top blowing



Figure 3. Two fans top blowing side by side

Table 3. Results in case of single and two fans blowing from the top

	Air velocity (m/s)	Time (hour)	Evaporation(g)
Still water	0	168	170
Air blown (single fan)	13	168	963
Air blown (two fans)	8	168	305

Case 4: Side Blowing Along The Short Side

In the fourth experimental setup, the influence of different fan configurations on water evaporation from a water-filled container was systematically investigated under controlled laboratory conditions. Three distinct fan setups were examined: first, two fans positioned centrally along the long side of the container, blowing towards each other at a velocity of 8 m/s; second, a single fan positioned directly above the water surface, blowing downwards at a higher velocity of 13 m/s; and third, a control setup with no fans operating. Each configuration was maintained for a duration of 7 days, during which the reduction in water level was meticulously measured using a precise mechanical caliper.

The experimental findings revealed notable variations in the rates of water evaporation depending on the fan configuration. When two fans were positioned centrally, directing airflow towards each other along the container's long axis, a significant increase in the evaporation rate was observed compared to the control condition without fans. This configuration facilitated enhanced air-water interaction due to the converging airflow patterns, resulting in accelerated evaporation from the water surface.

Conversely, the setup with a single fan blowing directly downwards onto the water surface at 13 m/s also exhibited a pronounced increase in the evaporation rate relative to the control group. The higher velocity and focused airflow of the single fan promoted intensified air-water mixing and turbulence directly above the water, thereby enhancing the evaporation process over the 7-day experimental period.

The controlled laboratory environment ensured consistent ambient conditions, including humidity and temperature levels, throughout the experiments, thereby minimizing external variables' impact on the results. These findings underscore the critical role of fan placement, directionality, and airflow intensity in modulating water evaporation rates. Such insights are instrumental for optimizing evaporative processes in diverse applications, including water resource management, agricultural practices, and environmental engineering, with the goal of improving efficiency and sustainability in resource utilization strategies.



Figure 4. Side blowing along the short side



Figure 5. High air speed with a single side fan

Table 4. Side blow results along the short side

	Air velocity (m/s)	Time (hour)	Evaporation(g)
Still water	0	168	170
Air blown (single fan)	13	168	782
Air blown (two fans)	8	168	445

The position and speed of fans affecting water evaporation have been examined through laboratory experiments and modeling. Such studies demonstrate how fan configurations can be adjusted to optimize water evaporation (Abbas et al. 2022, Wang and Liu 2023).

Contributions Of Experimental Findings To Evaporation Estimation

The experimental findings from this study significantly contribute to the estimation and control of evaporation in natural and artificial reservoirs, lakes, and similar water bodies. Accurate estimation and reduction of evaporation are critical for sustainable water resource management. These findings offer potential benefits in several key areas:

Development of Evaporation Prediction Models: The experimental data obtained can be utilized to enhance the accuracy of evaporation models. These models could incorporate the effects of material properties, as well as environmental and climatic factors, leading to more precise estimations of water loss in reservoirs and lakes.

Evaluation of Evaporation-Reducing Materials: The findings enable an assessment of the effectiveness of materials designed to mitigate evaporation. This includes solutions such as surface coatings or floating platforms deployed on water surfaces, which may significantly reduce evaporation rates and water loss.

Analysis of Environmental and Climatic Influences: The data acquired facilitate a deeper understanding of how various environmental and climatic conditions impact evaporation processes. Through the analysis of factors such as temperature, humidity, and wind speed, strategies can be developed to manage these variables effectively and reduce evaporation.

Formulation of Water Management Strategies: The results contribute to the development of strategies for sustainable water resource management. By minimizing evaporation, more efficient utilization of water resources is ensured, particularly in regions experiencing water scarcity.

In summary, the results of this study offer important insights into the estimation and control of evaporation in reservoirs and lakes. The minimization of evaporation is crucial for conserving and efficiently utilizing water resources, and the findings of this research can guide future efforts in this area.

Recent studies highlight the escalating impacts of climate change on water resources and emphasize strategies aimed at mitigating these effects (Wang and Liu 2023). The findings contribute valuable insights into optimizing water management practices through the strategic deployment of fans to enhance evaporation rates, thus supporting sustainable water resource management strategies in varying environmental contexts.

NUMERICAL SETUP

Evaporation, the process by which molecules transition from the surface of a liquid to the gas phase, is a fundamental phenomenon encountered in both natural occurrences and industrial applications. It plays a pivotal role in the water cycle, as well as in various industrial processes where accurate estimation and control of evaporation rates are crucial. Understanding and quantifying evaporation rely heavily on a set of mathematical equations that describe the underlying mass and energy transfer mechanisms.

The equations used to model evaporation are essential tools in assessing the amount of water vapor leaving the liquid surface and the associated heat transfer dynamics.

Mass transfer equations are employed to calculate the rate of evaporation from the liquid surface into the surrounding medium. These equations take into account factors such as temperature, humidity, and air movement, which influence the evaporation rate. They provide insights into how environmental conditions affect the evaporation process.

Conversely, energy transfer equations focus on determining the amount of energy required for water molecules to transition from the liquid to the vapor phase. This involves calculating the latent heat of vaporization, which is the amount of heat absorbed by water molecules during evaporation. These energy equations are crucial for understanding the thermodynamics of evaporation and for quantifying the heat flux involved in the process.

The application of these equations extends across various domains, from industrial settings where controlling evaporation impacts production efficiency and resource management, to environmental studies where understanding natural evaporation rates informs ecological models and water resource management strategies. In industrial processes, for instance, precise calculations of evaporation rates aid in optimizing energy consumption and reducing water usage. In environmental sciences, these equations are instrumental in predicting water loss from natural reservoirs, lakes, and rivers, thereby supporting sustainable water resource management practices.

Overall, the mathematical models and equations used to analyze evaporation are indispensable tools in scientific research and engineering applications. They enable researchers and engineers to quantify and predict evaporation rates under different conditions, leading to improved management strategies and enhanced efficiency in various sectors that rely on water and energy resources. Thus, a comprehensive understanding of these equations is essential for advancing both theoretical knowledge and practical applications related to the complex phenomenon of evaporation.

Air density: $$\rho\left[kg/m^3\right]=348.1x\frac{P}{273+T}$$

Air heat conductivity:

$$k\left[W/mK\right]=0.02418x\left(\frac{273+T}{273}\right)^{0.85},$$

Applied -40÷140 °C

Dynamic viscosity of air:

$$\mu\left[kg/ms\right]=1.724x10^{-5}x\left(\frac{273+T}{273}\right)^{0.77},$$

Applied -20÷160°C

Saturation pressure of water:

$$P_{doyma}\left[kPa\right]=\left[0.782+2.962\left(\frac{T}{100}\right)+6.29x\left(\frac{T}{100}\right)^{2.325}\right]^2$$

Enthalpy of evaporation of water:

$$h_{fg}\left[kJ/kg\right]=2501.64-2.364xT-7.80\left(\frac{T}{100}\right)^{2.2}$$

Diffusion coefficient of water vapor in air:

$$D\left[m^2/s\right]=\frac{2.336}{P}x\left(\frac{273+T}{273}\right)^{1.81}$$

Temperatures are in [°C] and saturation pressure and evaporation enthalpy are valid between 0-100 °C. P in the diffusion coefficient equation is atmospheric pressure in N/m^2.

Solution can be applied:

If we write the heat and mass equations together on the box,

$h(T_y-T_\infty) + hm\left(m_{1y}-m_{1\infty}\right)h_{fg} = 0$

This means that heat will be removed from the surface by convection and evaporation. Since there is blowing with a fan, there is forced convection because there is air velocity. Reynolds number will be used to determine the flow regime.

$$m_{1y}=\frac{\emptyset_y.P_{yd}.M_{H2O}}{\emptyset_y.P_{yd}.M_{H2O}+(P_a-\emptyset_y P_{d)}\,M_{hava}}$$

$$m_{1\infty}=\frac{\emptyset_\infty.P_{\infty d}.M_{H2O}}{\emptyset_\infty.P_{\infty d}.M_{H2O}+(P_a-\emptyset_\infty P_{d)}M_{hava}}$$

$$h_{fg}\left[kJ/kg\right]=2501.64-2.364xT-7.80\left(\frac{T}{100}\right)^{2.2}$$

Reynold number: $\frac{\rho V_{ort.D}}{\mu}$

Schmidt number: $\frac{\mu}{\rho.D}$

Prandtl number: $\frac{Cp.\mu}{k} = \frac{\gamma}{\alpha}$

For heat transfer;

Nusselt number: $\frac{h.D}{k} = C.Re^{m}.Pr^{1/3}$

For mass transfer;

Sherwood number: $\frac{\rho.hm.D}{D}$ = $C.Re^{m}.Sc^{1/3}$
According to this

$\mathrm{hm}\left(\mathrm{m}_{1\mathrm{y}} - \mathrm{m}_{1\infty}\right)$: The equation actually tells us the amount of mass evaporated from the surface;

$\mathrm{hm}\left(\mathrm{m}_{1\mathrm{y}} - \mathrm{m}_{1\infty}\right)\mathrm{h}_{\mathrm{fg}}$: The equation will give the amount of heat absorbed by this mass while evaporating (Incropera and DeWitt 2002).

CONCLUSION

The experimental investigation aimed to assess the influence of varying fan configurations—position and speed—on the rate of water evaporation. Firstly, the scenario involving two fans blowing in a opposite configuration demonstrated a notable increase in evaporation. This effect was attributed to enhanced air movement over the water surface, facilitating a more uniform distribution of water vapor and accelerating the overall evaporation process. The opposite blowing between fans likely promoted a significant rise in the evaporation rate by facilitating a more homogeneous evaporation environment.

In contrast, the case involving a single fan blowing from the side showed an observable but less substantial increase in water evaporation compared to the opposite blowing configuration. Side blowing appeared to limit direct air-water contact, thereby restraining the potential for a more pronounced evaporation rate increase as observed in mutual blowing scenarios.

The third experimental setup involved directing fan airflow directly onto the water surface, whether from a single fan or two fans concurrently. This arrangement led to a significant enhancement in water evaporation rate. The direct airflow from fans promoted faster evaporation by directly interacting with the water surface, thereby accelerating the phase transition of water molecules into vapor. Notably, the combined blowing effect of two fans demonstrated a more pronounced increase in the evaporation rate, suggesting a synergistic effect in promoting evaporation.

Furthermore, the use of a powerful fan was observed to further intensify the evaporation rate. Even when positioned along the shorter side of the water container, a powerful fan still increased the evaporation rate significantly. This outcome can be attributed to the high velocity of air flow and its direct impact on the water surface, facilitating quicker evaporation of water molecules.

Overall, the experimental findings underscored that mutual and top blowing configurations of fans provided the most substantial enhancements in water evaporation rate. Conversely, side blowing configurations showed a more limited increase in evaporation rate. These results emphasize the critical role of fan position and speed in influencing the dynamics of water evaporation.

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