The Role of Wind Velocity in Saline Water Evaporation from Porous Media and Surface Salt Crystallization Dynamics

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1. Introduction

- Salt crystallization over evaporating porous media influences a wide range of environmental and engineering processes
- The evaporation of saline water is affected by factors such as the type and concentration of dissolved salts, inherent characteristics of the porous medium, and ambient conditions [1]–[3]
- Despite extensive research on salt crystallization dynamics and its effects on evaporation, the interaction between evolving salt crystals and overlying airflow remains understudied

Objective

- To investigate the effects of wind flow conditions (i.e., laminar and turbulent) on mass loss rates and salt crystallization dynamics in evaporating porous media

2. Materials & Methods

- We conducted well-controlled experiments in a laboratory wind tunnel, where the surface of sand columns saturated with NaCl solutions at concentrations of 0%, 10%, 15%, and 20% were subjected to wind flows of 0.5 m/s and 5 m/s (Fig. 1)
- Mass losses from the samples were measured using digital balances, while surface crystallization patterns were captured by optical imaging
- An image processing methodology was developed to analyze evolution of surface salt crystals

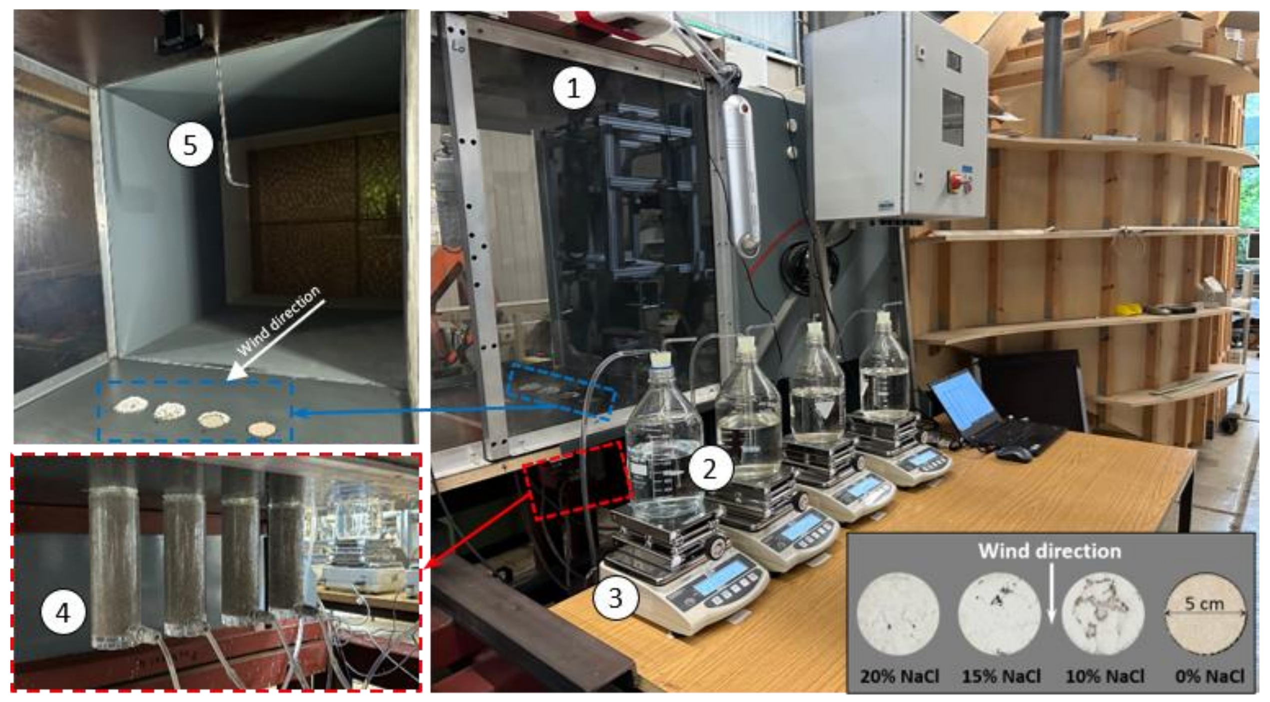
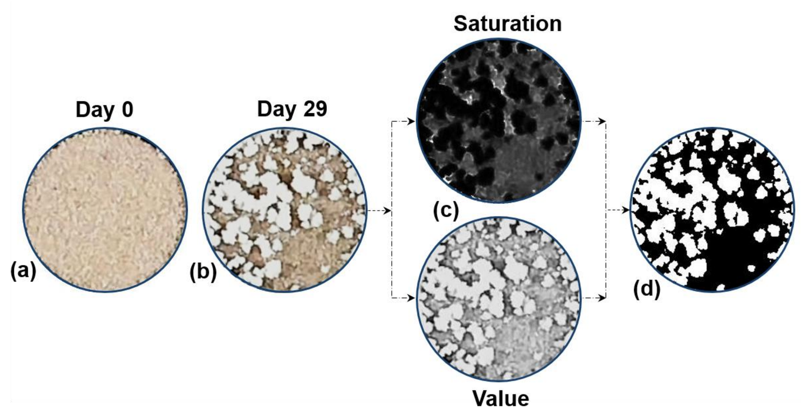


Fig. 1: Wind tunnel experimental setup: (1) Optical camera, (2) Mariotte bottles, (3) Balances, (4) Sample columns, and (5) Prandtl tube. The inset shows the surfaces of the samples exposed to a wind velocity of 5 m/s

Fig. 2: Image processing procedure. (a) Initial state of the sample surface. (b) Salt crystallization observed at the end of experiment. (c) Saturation and value channels extracted from the image, representing the intensity of color and brightness, respectively. (d) Binarized image generated by combining these channels for further analysis.



3. Results

Cumulative mass loss

- Higher wind speed increases evaporation by reducing the boundary layer thickness
- Increased salt concentration decreases vapor pressure, thereby diminishing evaporation rate
- In the sample with the highest NaCl concentration, the evaporation rate declined after four days at 5 m/s, due to the detachment of salt crust from the underlying sand matrix

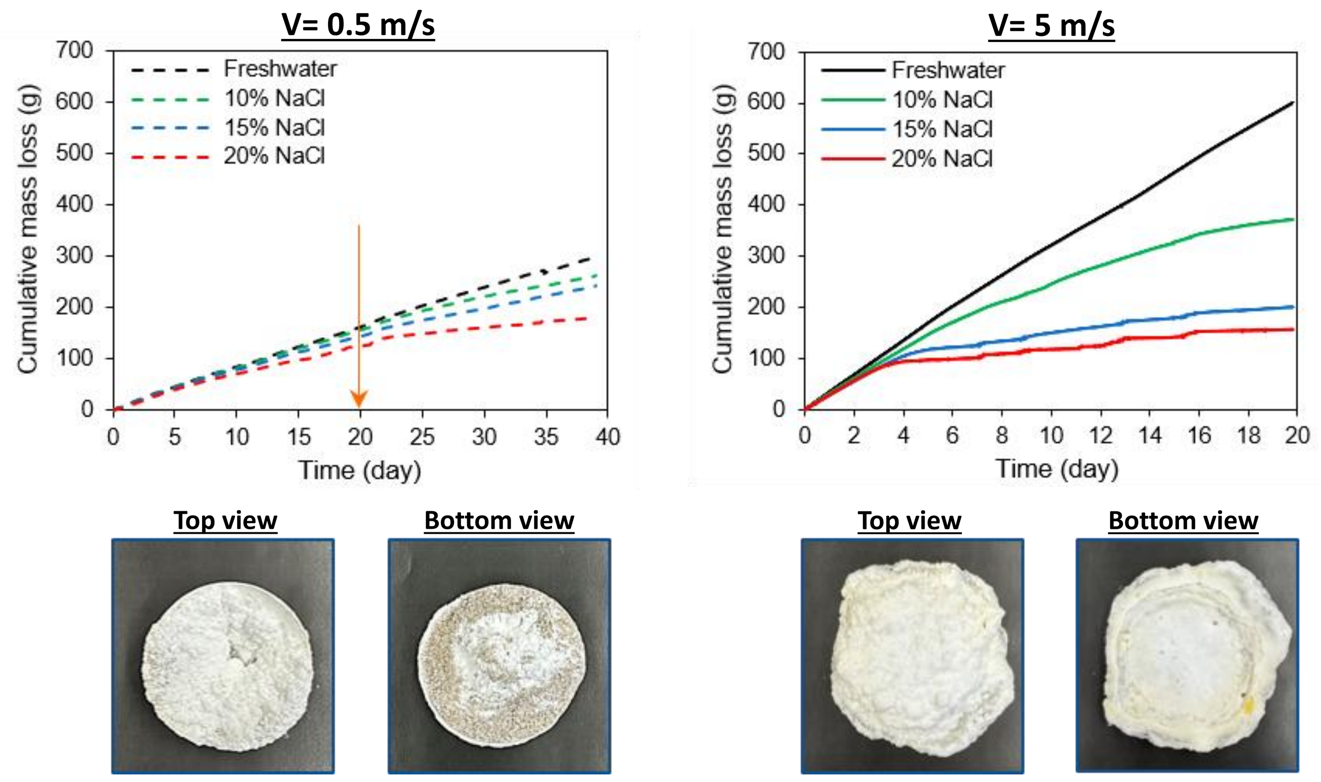


*Fig. 3: **(top)** Cumulative mass loss versus time for samples saturated with 0%, 10%, 15%, and 20% NaCl concentrations under wind velocities of 0.5 m/s, and 5 m/s. **(bottom)** The top and bottom views of salt crystals from samples saturated with 20% NaCl at the end of experiments at two wind velocities.*

Surface salt crystallization

- Crystallization patterns were highly influenced by wind flow conditions, with turbulent regimes leading to more extensive and uniform crystal deposition over the surface
- Salt crystals primarily nucleated at the leading edge of the sand samples at low wind speed of 0.5 m/s, while a uniformly distributed crystallization pattern was observed at high wind speed of 5 m/s

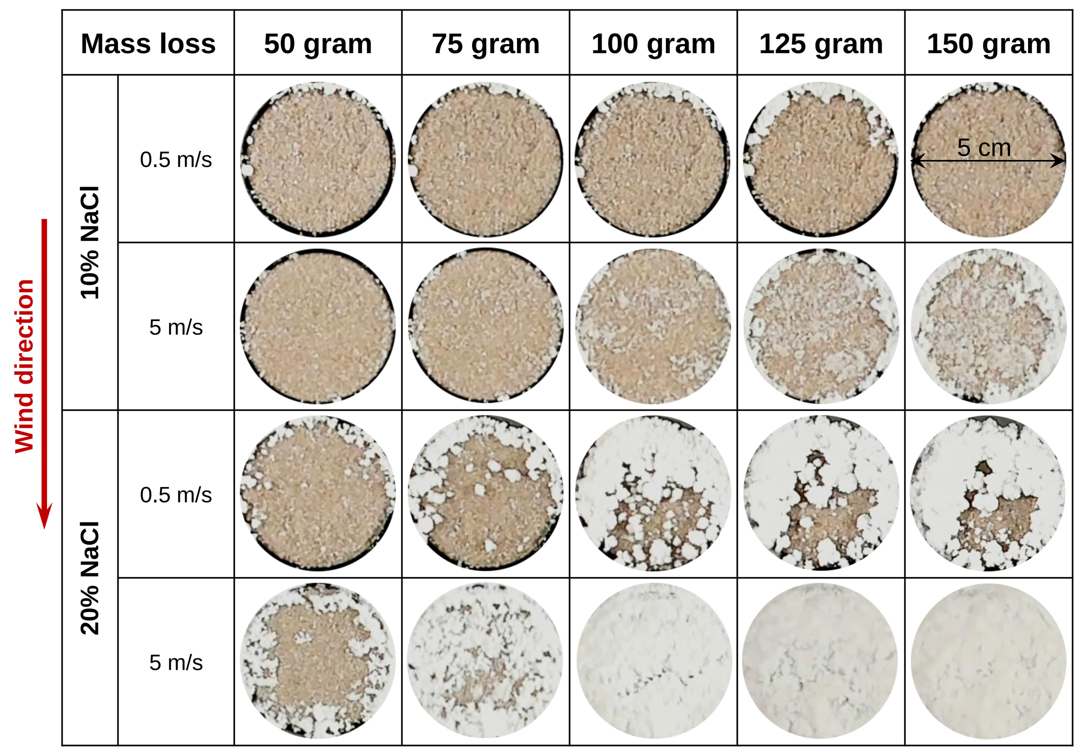


Fig. 4: Surface images of samples saturated with different NaCl solutions under wind velocities of 0.5 and 5 m/s, presented with their respective water mass loss.

Effect of wind velocity on crystallization dynamics

- Samples including higher salt concentrations reached the solubility limit with less evaporative water loss, facilitating efflorescence at crystallization sites and their interaction with overlying wind flow
- Increased wind speed led to greater salt crystal formation on the surface, driven by enhanced moisture transport and increased surface exposure to evaporation with crystal growth

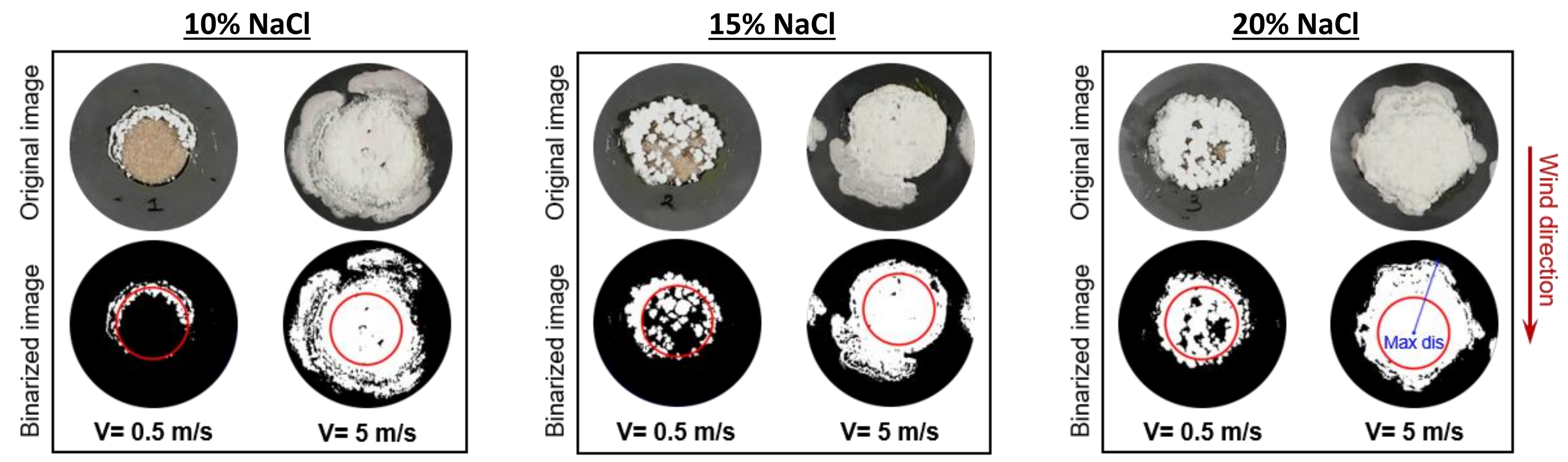


Fig. 5: Salt precipitation patterns of sample saturated with 10%, 15%, and 20% NaCl solutions under 0.5 m/s and 5 m/s wind velocities.

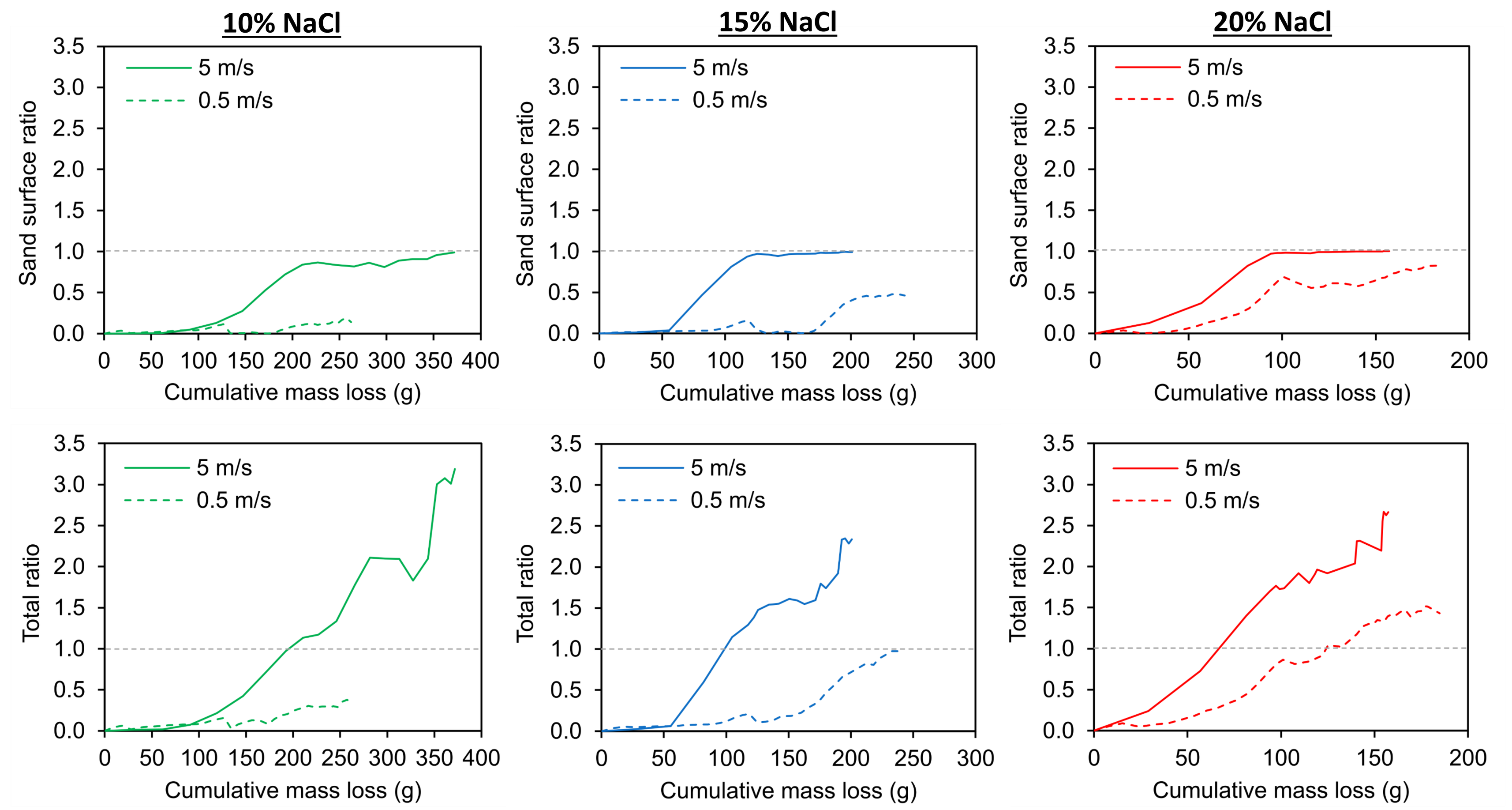


*Fig. 6: Evolution of salt crystal (projected) area as a function of cumulative mass loss for samples saturated with different NaCl concentrations, exposed to wind velocities of 0.5 m/s (dashed lines) and 5 m/s (solid lines): **(top)** coverage ratio over the sample surface; **(bottom)** coverage ratio over the combined sample surface and supporting plate (total). The coverage ratios are estimated based on the column surface area with a diameter of 5 cm.*

4. Conclusions

- The evaporation-crystallization interactions are influenced by surface roughness, turbulent eddies, and evolving porous salt crust
- Turbulent nature of the airflow at high wind speed of 5 m/s interacting with growing salt crystals resulted in a high cumulative mass loss from the samples

References

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Acknowledgments

We gratefully acknowledge the financial support provided by the German Research Foundation (DFG), grant 497539130, and the partial funding from DFG SFB 1313, project number 327154368. Furthermore, we extend our gratitude to Theodor Wassiliou and Axel Seils for their invaluable technical assistance in conducting the laboratory experiments. We also appreciate Ali Chaudhry from Forschungszentrum Jülich GmbH for his support in providing the essential equipment.

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Abstract

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