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NUMERICAL PREDICTION OF THE EVAPORATION RATE OF A HORIZONTAL WATER SPAN

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1. ABSTRACT

A comprehensive analysis of the existing numerical models addressing the dynamics of water vapor flux across an air-water interface has been conducted. Additionally, we introduce a novel model based on the empirical friction velocity of the air over a water surface. This new model is used to predict evaporation rates in the context of wind tunnel experiments where water tanks are subjected to controlled drying conditions.

2. INTRODUCTION

Mass transfer between a water surface and the surrounding air is dominant in many situations, including industrial processes. Since the 19th century, several authors developed empirical correlations to predict the water evaporation flux from a horizontal water surface based on Dalton's law. This law relates the evaporation rate to the difference between the partial vapor pressure near the water surface and the ambient partial vapor pressure. These correlations are valid under certain conditions (on the geometry, wind velocity, temperature, and humidity range). Because of the range of validity of these correlations, it may be difficult to predict the water evaporation of a horizontal water span.

Some authors have studied the problem using numerical models, such as Raimundo et al. [1] and Blázquez et al. [2], to predict the water evaporation rate over a wider validity range. They both performed experimental setups and simulations to evaluate the evaporation of a water tank in a wind tunnel, each of them providing a (different) custom velocity boundary condition at the air-water interface. They obtained satisfactory results, but shown sensitivity to some parameters, such as the turbulent Schmidt number and the convection regime.

In the present work, we propose and implement a novel boundary condition to predict water evaporation from a horizontal water surface, which has been tested across multiple experimental setups documented in the existing literature. The main difference with the previous models lies in the computation of the mixture velocity near the air-water interface. In our approach, this velocity is estimated by the empirical friction velocity at the air-water interface [3]. Our work has already been published [4]. This

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work is fundamental to further deal with the prediction of the evaporation rate of other water surface drying cases, such as greenhouse drying water tanks.

3. METHODOLOGY

The studied configurations are wind tunnels with a water reservoir in front of the tunnel opening. Every setup we simulated was compared to an existing experimental setup [1, 2, 5].

The numerical model solves the classical mass, energy and momentum conservation equations. In addition to these equations, the water vapor concentration conservation equation is solved. The k-ω SST turbulence model is chosen to simulate the turbulent structures in the flow. The water surface is assumed to be a water-saturated air layer to avoid the use of a multiphase solver.

As mentioned above, the tangential velocity at the air-water interface is computed through the empirical friction velocity of the air on a water surface [3]. From this friction velocity, we can determine the tangential velocity gradient at the surface. There is also a normal velocity (because water is considered impermeable to air), which is computed in the same fashion as in Raimundo et al.'s work [1].

4. RESULTS

The figures 1 and 2 show the relative difference between the experimental results and those obtained by our numerical model in two and three dimensions, respectively. The average relative difference is 11.21% for the 2D cases and 12.3% for the 3D case. Different convection regimes have been studied in these simulations, and the model seems sensitive only to the transition to natural convection.

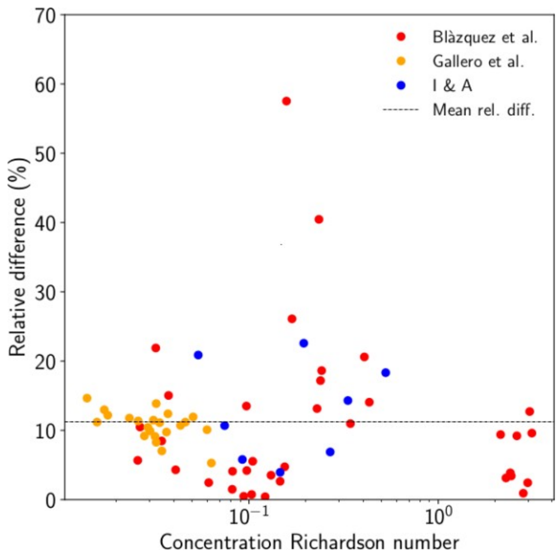

Fig 1 Relative difference between experimental and simulated data as a function of the concentration Richardson number, 2D cases

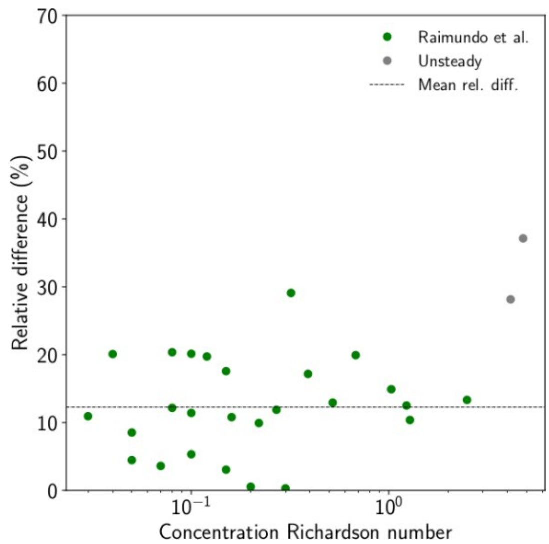

Fig 2 Relative difference between experimental and simulated data as a function of the concentration Richardson number, 3D case

5. CONCLUSIONS

A new near-water air velocity boundary condition was developed for the prediction of the water evaporation rate from a water tank. Numerical water vapor flux predictions from several experimental setups were compared with the experimental references. Over the mixed and forced convection regimes, an average relative difference close to 12% between experimental and simulated data was evaluated for both 2D and 3D simulations.

We are currently investigating the implementation of a radiative model to control the water surface temperature with solar energy. This implementation implies a modification of the previously used equations and boundary conditions. Little to no experimental data is available for this kind of setup.

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