Numerical study of natural convection of an air-water system with evaporation across the free surface

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In this talk, we present numerical simulations of natural convection of a two-phase system, in a cavity, consisting of liquid water and humid air separated by an evaporative free surface. Such configurations are encountered in geophysical systems, e.g. lakes or seas, and in industrial applications such as boilers and storage pools of spent nuclear fuel. In order to properly capture the dynamics of this complex system, the convective patterns in the water and the gas as well as the descent of the free surface must be solved simultaneously. Our simulations are based on a low-Mach number solver in a collocated grid arrangement recently developed by our team. This solver is based on a predictor-corrector scheme, combined with a projection method for the computation of the pressure and a flux-interpolation technique. Further, it treats the free surface as a flat interface, the descent of which is computed via the ghost-fluid method.

In the flows of interest, as the liquid water evaporates across the free surface, the height of the gas column increases and so does the Rayleigh number therein. Accordingly, the convective motions of the gas can become turbulent. One of the objectives of our study is to quantify the effect of increasing the turbulence intensity of the gas on the evaporation rate. To this end, several initial conditions have been considered by varying the height of the gas column hence the Rayleigh number therein. More specifically, the initial Rayleigh number in the gas side varied from 1.7×10^4 to 10^6 which implies laminar to weakly turbulent convection. On the other hand, the Rayleigh number in the water side was fixed at 7.5×10^5, which translates to weakly turbulent convection in that part of the cavity.

In this presentation, we discuss our numerical results for the evolution of the free-surface temperature, evaporation rate and Nusselt number in the gas side. Furthermore, we elaborate on the convective patterns in both liquid water and humid air, based on the analysis of mean streamlines and first and second-order statistics for the flow quantities. According to our simulations, an increase in the height of the gas column results in a decrease of the evaporation rate and an increase of the free-surface temperature. Furthermore, our study shows that the motion of the large convective structures in the two phases are correlated and herein we provide a plausible explanation of this phenomenon.

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