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Vortex Flows under Effects of Buoyant-Thermocapillary Convection

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Abstract : A numerical investigation is carried out to analyze vortex flows in a free surface cylinder, driven by the independent rotation and differentially heated boundaries. As a basic uncontrolled isothermal flow, we consider configurations which exhibit steady axisymmetric toroidal type vortices which occur at the free surface; under given rates of the bottom disk uniform rotation and for selected aspect ratios of the enclosure. In the isothermal case, we show that sidewall differential rotation constitutes an effective kinematic means of flow control: the reverse flow regions may be suppressed under very weak co-rotation rates, while an enhancement of the vortex patterns is remarked under weak counter-rotation. However, in this latter case, high rates of counter-rotation reduce considerably the strength of the meridian flow and cause its confinement to a narrow layer on the bottom disk, while the remaining bulk flow is diffusion dominated and controlled by the sidewall rotation. The main control parameters in this case are the rotational Reynolds number, the cavity aspect ratio and the rotation rate ratio defined. Then, the study proceeded to consider the sensitivity of the vortex pattern, within the Boussinesq approximation, to a small temperature gradient set between the ambient fluid and an axial thin rod mounted on the cavity axis. Two additional parameters are introduced; namely, the Richardson number Ri and the Marangoni number Ma (or the thermocapillary Reynolds number). Results revealed that reducing the rod length induces the formation of on-axis bubbles instead of toroidal structures. Besides, the stagnation characteristics are significantly altered under the combined effects of buoyant-thermocapillary convection. Buoyancy, induced under sufficiently high Ri, was shown to predominate over the thermocapillay motion; causing the enhancement (suppression) of breakdown when the rod is warmer (cooler) than the ambient fluid. However, over small ranges of Ri, the sensitivity of the flow to surface tension gradients was clearly evidenced and results showed its full control over the occurrence and location of breakdown. In particular, detailed timewise evolution of the flow indicated that weak thermocapillary motion was sufficient to prevent the formation of toroidal patterns. These latter detach from the surface and undergo considerable size reduction while moving towards the bulk flow before vanishing. Further calculations revealed that the pattern reappears with increasing time as steady bubble type on the rod. However, in the absence of the central rod and also in the case of small rod length l, the flow evolved into steady state without any breakdown.

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