Numerical investigation of rotating cylindrical annulus with bi-directional temperature gradients

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In this work, numerical simulations of rotating cylindrical annulus with bi-directional temperature gradients are performed for a Rayleigh number, $Ra = 4.76 \times 10^8$, and Taylor number, $Ta = 6.5 \times 10^8$ (lowest), 1.5×10^9 (moderate), and 2.7×10^9 (highest). The present configuration is an improvement over the classical baroclinic annulus configuration as it provides both horizontal and vertical temperature gradients. The bi-directional temperature gradients are manifested by a localized heating zone (width = 5 mm) at the outer bottom periphery of the annulus. Assuming incompressible flow and Boussinesq approximation, the Navier-Stokes equations with Coriolis acceleration and the Energy equation govern the flow in the annulus. The working fluid is water. CFD toolkit OpenFOAM is used to solve these equations with second-order accuracy. The flow structures i.e. baroclinic waves and Columnar Convective Plumes (CCP) are studied using the Complex Empirical Orthogonal Function (CEOF) analysis. Baroclinic wave with four lobes is present in the annulus at the lowest Ta. At moderate Ta, the baroclinic wave deforms in shape, and at the highest Ta it completely disintegrates into eddies. The CCP is formed over the heating zone. At moderate Ta, the CCP gets thinner and it completely breaks down at the highest Ta. These large-scale structures affect the heat transport in the annulus. From the study of the turbulent temperature fluxes, $\mathbf{u}'T'$, we found that due to the presence of large-scale structures, the fluxes are larger at the lowest Ta. Temperature fluxes are smaller at moderate and highest Ta, because of the breaking of the flow structures. In addition at the lowest Ta, Ekman layer and the bulk region of the annulus play equal roles in transporting the heat in the radial direction. At moderate and highest Ta, Ekman layer plays an insignificant role in radial heat transport, and the bulk region is only responsible for radial heat transport. Overall our results explain the effect of large-scale structures on the heat transport dynamics in the annulus with bi-directional temperature gradients.

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