ANALYTICAL AND NUMERICAL MODELING OF STRONGLY ROTATING RAREFIED GAS FLOWS

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Abstract: Centrifugal gas separation processes effect separation by utilizing the difference in the mole fraction in a high speed rotating cylinder caused by the difference in molecular mass, and consequently the centrifugal force density. These have been widely used in isotope separation because chemical separation methods cannot be used to separate isotopes of the same chemical species. More recently, centrifugal separation has also been explored for the separation of gases such as carbon dioxide and methane. The efficiency of separation is critically dependent on the secondary flow generated due to temperature gradients at the cylinder wall or due to inserts, and it is important to formulate accurate models for this secondary flow. The widely used Onsager model [3] for secondary flow is restricted to very long cylinders where the length is large compared to the diameter, the limit of high stratification parameter, where the gas is restricted to a thin layer near the wall of the cylinder, and it assumes that there is no mass difference in the two species while calculating the secondary flow.

There are two objectives of the present analysis of the rarefied gas flow in a rotating cylinder. The first is to remove the restriction of high stratification parameter, and to generalize the solutions to low rotation speeds where the stratification parameter may be *O(1)*, and to apply for dissimilar gases considering the difference in molecular mass of the two species. Secondly, we would like to compare the predictions with molecular simulations based on the direct simulation Monte Carlo (DSMC) method for rarefied gas flows, in order to quantify the errors resulting from the approximations at different aspect ratios, Reynolds number and stratification parameter. In this study, we have obtained analytical and numerical solutions for the secondary flows generated at the cylinder curved surface and at the end-caps due to linear wall temperature gradient and external gas inflow/outflow at the axis of the cylinder. The effect of sources of mass, momentum and energy within the flow domain are also analyzed [1, 2].

The results of the analytical solutions are compared with the results of DSMC simulations for three types of forcing, a wall temperature gradient, inflow/outflow of gas along the axis, and mass/momentum input due to inserts within the flow [1, 2]. The comparison reveals that the boundary conditions in the simulations and analysis have to be matched with care. The commonly used diffuse reflection boundary conditions at solid walls in DSMC simulations result in a non-zero slip velocity as well as a temperature slip (gas temperature at the wall is different from wall temperature). These have to be incorporated in the analysis in order to make quantitative predictions. In the case of mass/momentum/energy sources within the flow, it is necessary to ensure that the homogeneous boundary conditions are accurately satisfied in the simulations. When these precautions are taken, there is excellent agreement between analysis and simulations, to within 10 %, even when the stratification parameter is as low as 0.707, the Reynolds number is as low as 100 and the aspect ratio (length/diameter) of the cylinder is as low as 2, and the secondary flow velocity is as high as 0.2 times the maximum base flow velocity.

References:

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