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RESEARCH PAPER

Flows of rarefied gaseous mixtures in networks of long channels

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Abstract A method is presented to calculate the steady flows of rarefied gaseous mixtures in networks of long channels. The approach is based on the kinetic level. First, the McCormack linearized kinetic model is solved to obtain the local flow properties in the channels in a wide range of gaseous rarefaction and mole fraction. Second, the global flow properties including the flow rates and the distribution of the pressure and the mole fraction are deduced. An integral equation is introduced in order to determine the flow rates as functions of the differences of the partial pressures between the two ends of each channel. The conservation of mass at the nodes of the network results into a system of linear algebraic equations. The overall mathematical problem is solved iteratively. Pressure driven flows of He/Xe and He/Ar through an example network of circular tubes are calculated at intermediate values of the gaseous rarefaction. The results of the flow rates and the pressures and the mole fractions at the nodes in the whole system and the representative distributions of the pressure and the mole fraction along the channels are presented and commented on.

Keywords Channel networks · Gaseous mixtures · McCormack kinetic model · Gaseous separation

1 Introduction

Over the last years, rarefied gaseous flows through long channels have attracted considerable interest in fluid dynamic communities. This interest can be justified by the appearance of gaseous micro- and nanofluidics (Kandlikar and Garimella 2006; Li 2008), as well as more traditional applications in vacuum science (Jousten 2008) or aerodynamics. Under rarefied conditions, the molecular details of the flow are nonnegligible, and its proper description should be based on the kinetic level and the velocity distribution function (Cercignani 1988).

The Boltzmann and model kinetic equations can be solved by either deterministic or probabilistic methods. In the deterministic approaches, like the discrete velocity method (DVM), the spatial and velocity spaces are discretized, and the resulting discrete equations are solved computationally. The DVM has extensively been used to solve linearized kinetic equations for flows of single gases and mixtures through long single channels with various cross-sections (Sharipov 1999; Szalmas and Valougeorgis 2010; Szalmas 2013; Naris et al. 2004a, b; Szalmas and Valougeorgis 2010). In these cases, the solution of the kinetic equation is typically carried out at a particular cross-section of the channel and yields to local moments of the velocity distribution function, for example velocity, shear stress, heat flow, and the flow rates as functions of the local driving terms. The deduction of the local flow problem can also be carried out by the probabilistic Direct Simulation Monte Carlo (DSMC) method in its variance-reduced form (Radtke and Hadjiconstantinou 2009; Szalmas 2012; Szalmas 2013), which solves the linearized version of kinetic equations in order to reduce the statistical fluctuations of the original DSMC in case of low-speed flows.

An additional treatment is necessary to deduce the global flow rate and the distribution of macroscopic quantities, like the pressure and the mole fraction for gas mixtures, along the channel. Such calculation is based on the conservation of mass along the channel (Szalmas and

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