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THERMALY DRIVEN FLOWS IN LONG TAPERED CHANNELS

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KEY WORDS

Diverging and converging channels, diodicity, rarefied gas dynamics, thermal transpiration, linear kinetic modeling, Knudsen pump.

ABSTRACT

Due to the active interest in the development and manufacturing of thermally driven micropumps (Knudsen pumps) for use in gaseous microfluidic applications [1], thermal transpiration flows have received in recent years a lot of attention. The most prevalent designs feature a periodic temperature distribution applied at the walls of a cascade of channels. The need for this design rises from the fact that in order to achieve a considerable mass flow rate or pressure difference using a monotonous temperature distribution would require a very large temperature at the end of the channel. The main drawback however, since the temperature distribution is not monotonous, is a thermally driven flow in a direction opposite to the desired one and several modeling techniques have been proposed [2, 3]. The aim of the present work is to investigate the diodicity effect produced by converging/diverging channels, diminishing the flow in the opposite direction, and to evaluate the potential implementation of a cascade of such channels (Fig. 1a) in thermally driven micropumps.

Modeling is based on linear kinetic theory and more specifically on the infinite capillary theory. The linear Shakhov model equation is solved [4], assuming purely diffuse boundary conditions, for a large range of the rarefaction parameter (δ) and a database is filled with the kinetic coefficients $\left(G_P\right.$ and $\left.G_T\right)$, providing the dimensionless flow rates when a pressure or a temperature gradient is applied respectively. A mass conservation equation is solved, using those coefficients, in order to find the pressure distribution and the mass flow rate [4].

The geometric configuration consists of a channel with inclined walls so that the distance between the plates changes linearly in the flow direction (Fig. 1b,c). Three flow cases are distinguished [5]. In case 1 both ends of the channel are closed so that the net mass flow rate vanishes and a pressure difference is formed (thermo-molecular pressure difference). Case 2 consists of a channel with open ends held at the same pressure (zero pressure difference) and a mass flow rate is formed. In case 3 the channel ends are open and held at different pressures and therefore, both a pressure difference and a mass flow rate exist. This case is the most representative one and clearly demonstrates the pumping effect that a

converging/diverging channel configuration can produce. In all three cases a diodicity parameter is calculated, indicating the performance of the converging versus the diverging channel.

Simulations are conducted for a wide range of the inlet pressure and inclination ratio α and the pumping effect of such configurations is demonstrated. Indicative results are shown in Fig. 2. Based on the diodicity parameter and the values of the pressure difference or mass flow rate, the optimal operation conditions can be identified and some general guidelines for the design are provided. This work may be useful as an initial step in designing such pumps and help making engineering decisions.

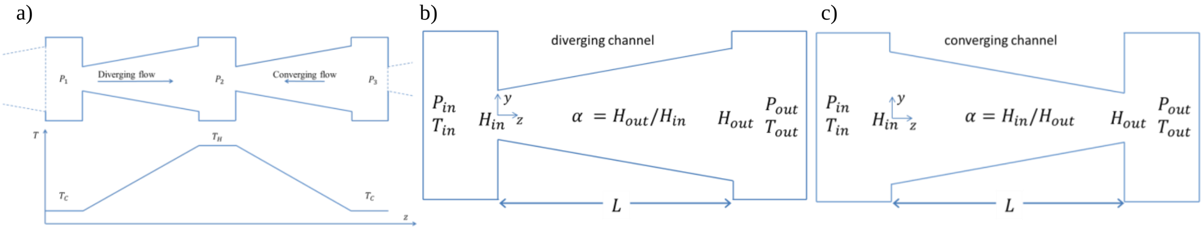

Figure 1: One pumping stage of a tapered channel Knudsen-type cascade pump along with the temperature variation (a); diverging (b) and converging (c) channels with the inclination ratio α .

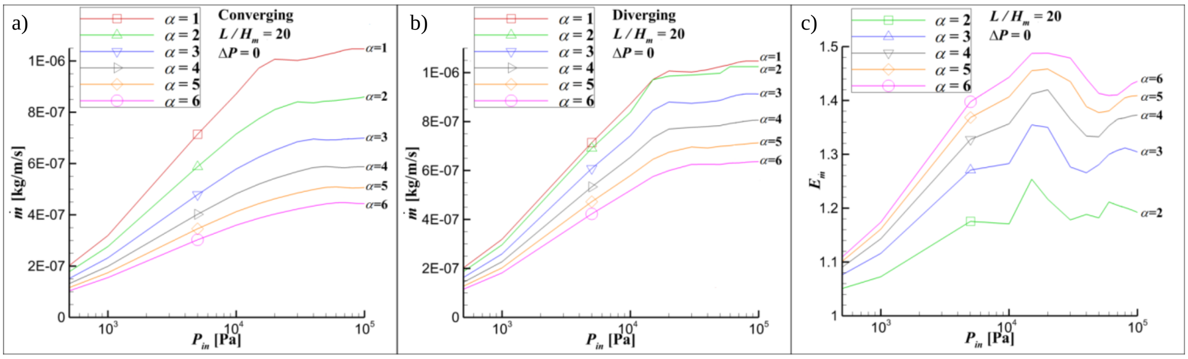

Figure 2: Mass flow rate for a converging (a) and a diverging (b) channel with zero pressure difference with the corresponding diodicity coefficient (c).

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