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OVERVIEW OF ALTERNATIVE DESIGNS FOR THERMALLY DRIVEN MICROPUMPS

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KEY WORDS

Knudsen pump, thermal transpiration, vacuum micropump, kinetic modeling.

ABSTRACT

The miniaturization trend in electromechanical systems has led to the development of several microfluidic applications, such as gas micro-pumps, which are required in a wide range of sensing and analysis related microsystems. The goal of the current investigation is to analyze a special type of vacuum pump, the so-called Knudsen pump, that has become an attractive candidate for miniaturization since it does not require any moving part to operate [1].

The Knudsen pump exploits the well-known thermal transpiration phenomenon, and is able to generate a macroscopic flow of gas by solely applying a tangential temperature gradient along a wall without any initial pressure gradient. Since the Knudsen pump allows gas movement only when the gas is under rarefied conditions, specific geometrical configurations need to be investigated to optimize the functionality of the pump in terms of its detailed geometry taking into consideration the operating pressure level in the system [2].

Several different designs of Knudsen pumps have been studied in the past years following the seminal work of Knudsen itself. The typical Knudsen micropump is based on a cascade system in which a basic unit is composed of a microchannel [3] or of a microporous medium [4] connecting two chambers with different temperatures, while various configurations have been numerically proposed in order to improve the efficiency and reliability of these Knudsen pump designs. The flow actuation in these alternatives designs can result either from longitudinal temperature gradients applied along microchannels with various shapes (serpentine, convergent/divergent tapered channels) [5] or from transversal temperature gradients between two asymmetrically structured surfaces [6].

One of the main concerns about the Knudsen pump is that, since the difference in pressure achieved in just one stage of the pump is rather small, a cascade system with successive stages is needed to obtain interesting performances to broaden the scope of practical applications. This setup causes difficulties related to microfabrication and optimization of these micropumps. In particular, the way in which the heating and cooling points are controlled has an important influence on the pump performances. Therefore, a brief qualitative overview of the more recent numerically studied designs [7] is presented in the following table:

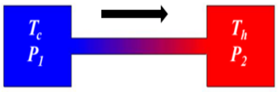
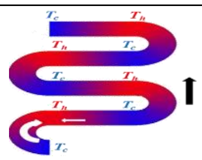
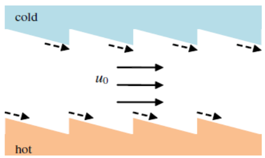
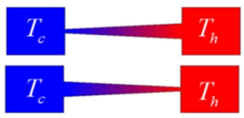
Design	Pump configuration	Advantages	Drawbacks
Straight channel		Robust design already fabricated and tested. Experimental data available for comparisons.	Non uniform temperature needed in reservoirs for a cascade pump, which requires big reservoirs compared to the channel size, to avoid counter flows.
Serpentine channel		No need of contrasted size between channels and reservoirs: the channel has a constant cross-section.	Lowest efficiency than in straight channel configuration. Tricky thermal control due to the small distances between heated and cooled points.
Ratchet surfaces		Relatively easy temperature control, constant on each surface. Mass flow rate can be tuned adjusting the misalignment between the upper and lower walls.	Thermal transpiration effect very sensitive to small geometry changes. Manufacturing of very regular saw-tooth like surfaces can be difficult.
Diode effect designs (e.g. tapered channel)		Various possible diode designs. Easy temperature control as the temperature is uniform in each reservoir. No need of big reservoir.	More complex flow structure than in other designs. Optimization requires higher computational effort.

Table 1: Qualitative comparison of alternative designs for Knudsen pumps

Based on these preliminary and more recent comparisons between different designs, the fabrication of an early prototype is expected to be achieved in the near future in collaboration with LAAS (Laboratoire d'Architecture et d'Analyse des Systèmes, Toulouse, France). Within the framework of the MIGRATE project, further research on various Knudsen pump designs as well as on alternative designs will be performed in order to develop and manufacture appropriate and optimized working Knudsen pumps to be tested during the project.

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