**MIGRATEWS2016-06**

# MEASUREMENTS OF THE TEMPERATURE GRADIENT DRIVEN FLOW FOR VARIOUS GASES

**Hiroki Yamaguchi[1], Pierre Perrier[2], Minh Tuan Ho[3],**

**Tomohide Niimi[1] and Irina Graur*[2]**

[1]MDepertment of Micro-Nano Systems Engineering, Nagoya University, Furo-cho, Chikuza, Nagoya, Aichi 464-8603, Japan
hiroki@nagoya-u.jp, niimi@mech.nagoya-u.ac.jp
[2]Aix-Marseille Université, CNRS, IUSTI UMR 7343, 5 rue Enrico Fermi, 13453 Marseille, France
pierre.perrier@univ-amu.fr, irina.martin@univ-amu.fr
[3]James Weir Fluids Laboratory, Department of Mechanical and Aerospace Engineering, University of Strathclyde, james Weir Building, 75 Monotrose Street, Glosgow G1 1XJ, UK
minh-tuan.ho@strath.ac.uk

## KEY WORDS

Micro-/nano-fluid dynamics, non-continuum effects, rarefied gas flow

## ABSTRACT

The gas movement from the cold reservoir to the hot one through a porous media and small capillaries, called thermal transpiration phenomena, was observed many years ago by Reynolds, Maxwell and then by Knudsen [1-3]. Some experimental data were collected from these time, especially on the final pressure difference achieved by the Knudsen compressor effect [4-10].

The measurements of the temperature gradient driven mass flow rate mass flow rate through a rectangular channel made of PEEK with a height of $H = 0.22 \pm 0.01$ mm, width of $W$ = 6 mm and length of $L$ = 73 mm are carried out. The temperature gradient along the microchannel was created by two blocks with gas reservoirs inside placed at each end of the microchannel, whose temperatures were controlled by an electrical heater for the hot side and a circulating water for the cold side, respectively. The temperatures of the blocks were monitored by K-type thermocouples (TC) placed on the outside of the blocks.

Temperature for the hot reservoir $T_H$ and that for the cold reservoir $T_C$ were maintained to realize two cases of the temperature difference $\Delta T$: 1) $T_H = 347.1 \pm 0.5$ K, $T_C = 289.2 \pm 0.2$ K, where $\Delta T = 57.9$ K and 2) $T_H = 337.0 \pm 0.6$ K, $T_C = 299.6 \pm 0.4$ K, where $\Delta T = 37.4$ K. These temperature conditions were chosen to have the same mean temperature for two cases as $T_m$ = 318K. Here, twice of the standard deviation was used as an uncertainty of the temperature conditions.

The hot and cold reservoirs were connected directly by a tube with a large diameter forming a circuit with insertion of a micro valve (Parker Hannifin). When the micro valve is open, there is the stationary thermal creep flow through the microchannel from the cold to hot sides; while the flow through the large diameter tube maintains pressures equally at both reservoirs by compensating the

thermal creep. By closing the micro valve, the flow in the large diameter tube is blocked, and there is only the thermal creep flow inside the microchannel. With time evolution, the pressure difference occurs between the cold and hot reservoirs as a result of the thermal creep flow, inducing a pressure driven flow in the opposite direction to the thermal creep flow.

## Results

The thermal slip coefficient in the slip flow regime and the reduced flow rate in the transitional flow regime were obtained for five noble gases in the rectangular cross section geometry from the experimental measurement of a pure thermal creep flow. The mass flow rate was compared with the numerical result by solving the S-model kinetic equations, showing good agreement for all cases in all flow conditions. Then, the numerical simulation was employed to validate the assumptions for involved methodology. The thermal slip coefficient, very useful when the continuum simulation in the frame of the Navier-Stokes equations is used, is derived from the mass flow rate measurements.

## Acknowledgements

The microchannel and the blocks were fabricated at Institute for Micro Process Engineering (IMVT), Karlsruhe Institute of Technology (KIT) in the framework of the European Community's Seventh Framework Program (FP7/2007-203 under grant agreement n 215504). This study was partially supported by the Overseas Visits Program for Young Researchers by Nagoya University Venture Business Laboratory and the program “Creation of Materials, Processes and Systems Provided with New and High Functionality” in the fund “Institutional Program for Young Researcher Overseas Visit” sponsored by JSPS. This work has been carried out in the framework of the Labex MEC (ANR-10-LABX-0092) and of the A*MIDEX project (ANR-11-IDEX-0001-02), funded by the “Investissements d’Avenir” French Government program managed by the French National Research Agency (ANR).

## References and Citations

[1] Reynolds, O. (1879). On certain dimensional properties of matter in the gaseous state. Parts I and II, *Philos. Trans. R. Soc. London* **170**, 727-845.
[2] Maxwell, J. (1879). *On stresses in rarified gases arising from inequalities of temperature, Philos. Trans. R. Soc. London* **170**, 231-256.
[3] Knudsen, M. (1934). The kinetic theory of gases. Some modern aspects, *J. Phys. Chem.* **39**, 307.
[4] Annis, B. K. (1972). Thermal creep in gases. *J. Chem. Phys.*, **57** (7), 2898–2905.
[5] Porodnov, B., Kulev, A. N., & Tuchvetov, F. T. (1978). Thermal transpiration in a circular capillary with a small temperature difference. *J. Fluid Mech.*, **88** (4), 609–622.
[6] Han, Y., Muntz, E. P., Alexeenko, A., & Young, M. (2007). Experimental and Computational Studies of Temperature Gradient-Driven Molecular Transport in Gas Flows through Nano/Microscale Channels. *Nanoscale Microscale Thermophys. Eng.*, **11** (1), 151-175.
[7] Gupta, N. K., & Gianchandani, Y. B. (2008). Thermal transpiration in zeolites: A mechanism for motionless gas pumps. *Appl. Phys. Lett.*, **93**, 193511.
[8] Rojas-Cárdenas, M., Graur, I., Perrier, P., & Méolans, J. G. (2011) Thermal transpiration flow: A circular cross-section microtube submitted to a temperature gradient. *Phys. Fluids*, **23**, 031702.
[9] Yamaguchi, H., Rojas-Cárdenas, M., Perrier, P., Graur, I., & Niimi, T. (2014) Thermal transpiration flow through a single rectangular channel. *J. Fluid Mech.*, **744**, 169–182.
[10] Yamaguchi, H., Perrier, P., Ho, M. T., Méolans, J.G., Niimi, T., & Graur, I. (2016) Mass flow rate measurement of thermal creep flow from transitional to slip flow regime. *J. Fluid Mech.*, **795**, 690-707.