Analysis of A Thermal Transpiration Flow:

A Circular Cross Section Micro-tube Submitted to a Temperature Gradient Along its Axis

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IUVSTA
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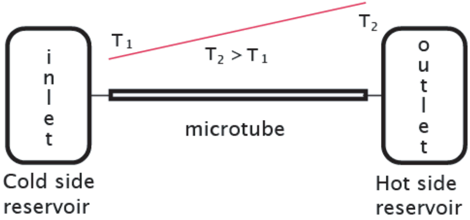
Outline

Thermal transpiration is the Macroscopic movement of particles due only to an imposed Temperature Gradient.

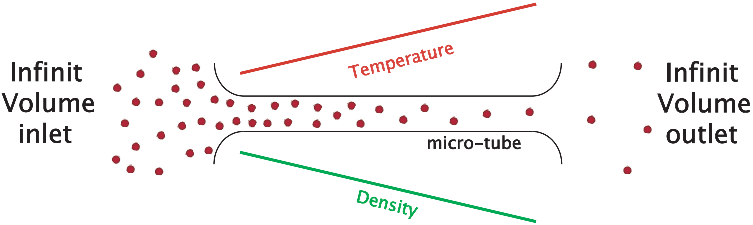


Objective: Measure the Mass Flow Rate along a tube induced by thermal transpiration.

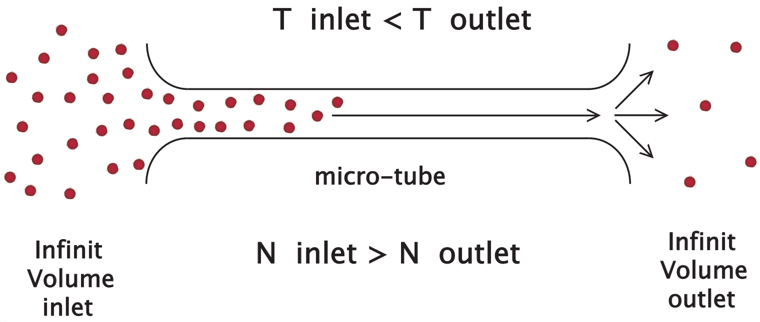
Thermal Transpiration

$$p_{outlet} = p_{inlet}$$

$$T_{outlet} > T_{inlet}$$



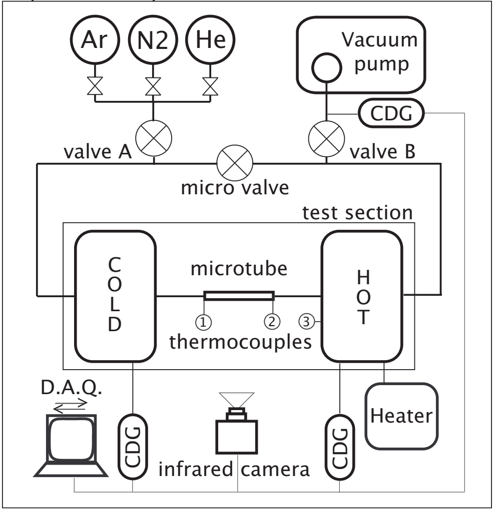
Macroscopic movement of gas particles:



Where are we?

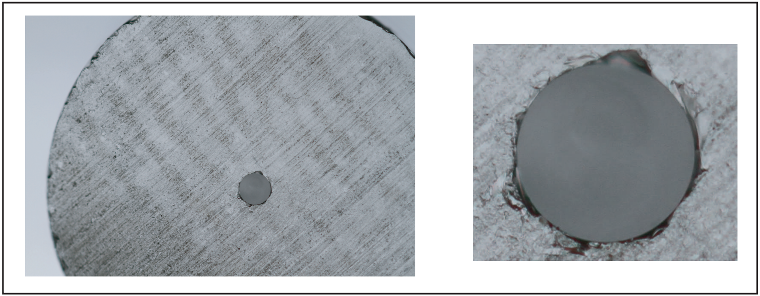
Experimental apparatus

experimental system



Micro-tube

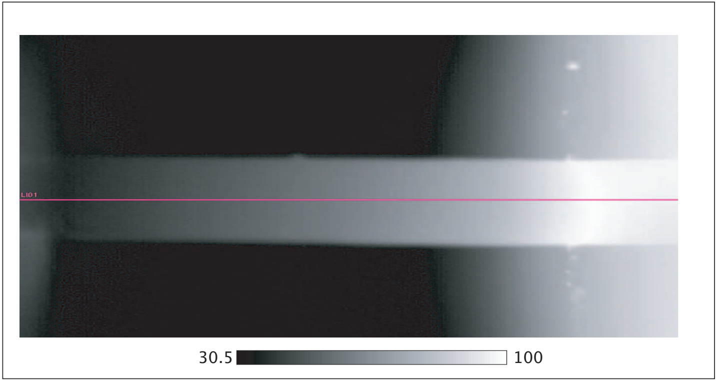
The circular cross-section glass micro-tube.



$$d_{tube} = 485\mu m \pm 1.2\% \; ; \; d_{ext} = 6.5mm \pm 0.1mm$$

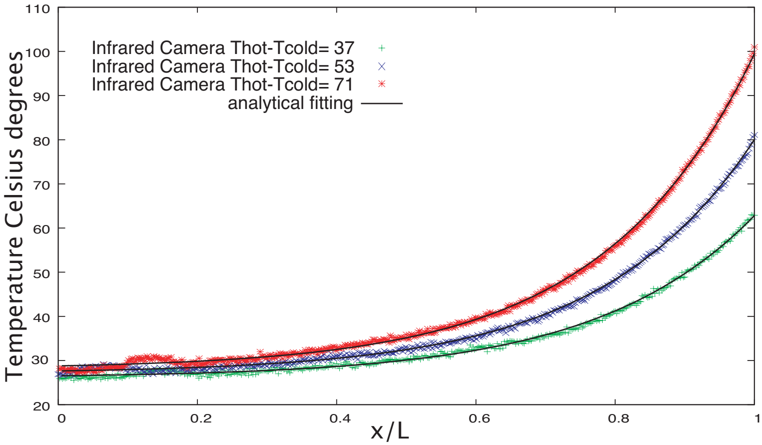
$$L_{tube} = 5.27cm \pm 0.01cm \; ; \; \Lambda = 1.14W/m^{\circ}C$$

Temperature gradient



Infrared camera caption of the temperature distribution along the external surface of the micro-tube.

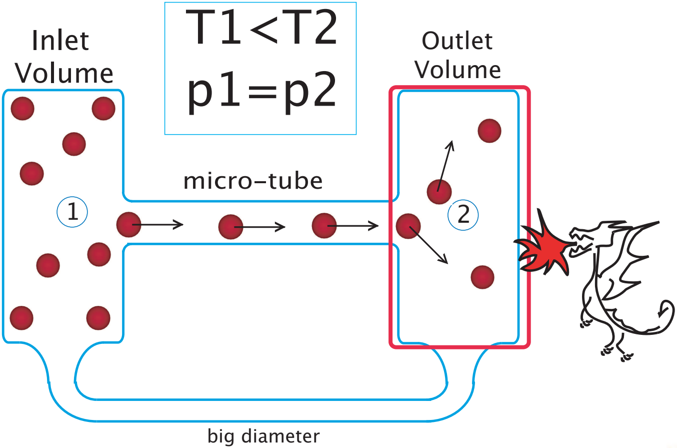
Temperature gradient



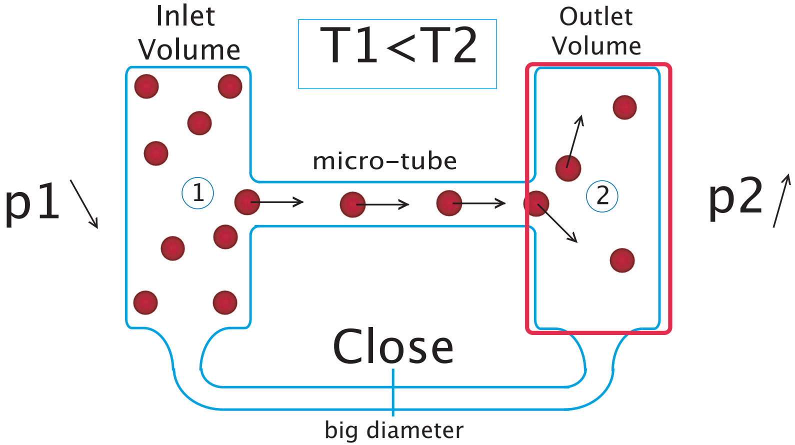
The temperature distribution along the external surface of the micro-tube.

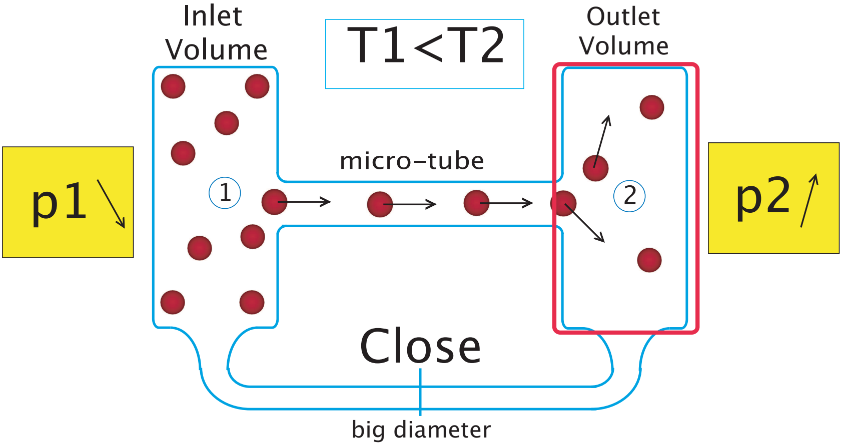
Where are we?

Initial conditions:

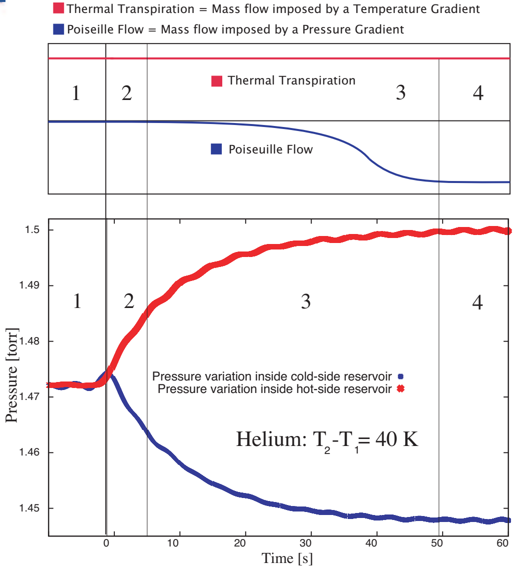


The experimental methodology

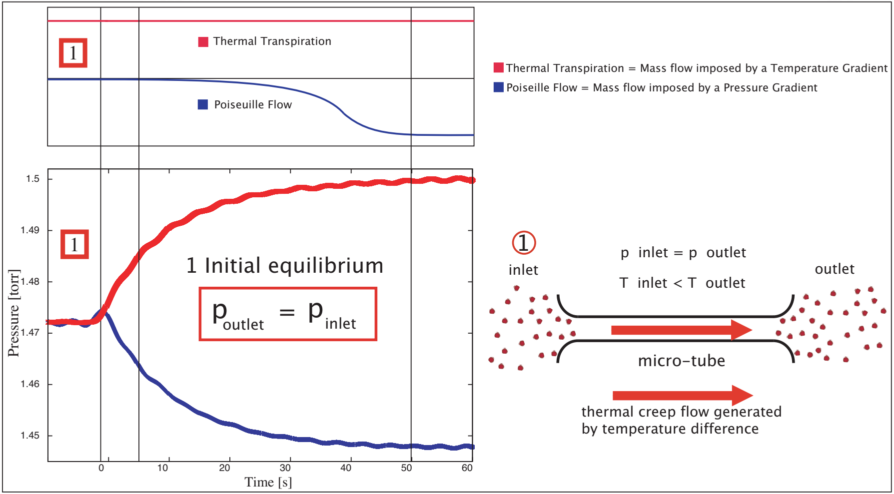



Inlet
Volume
T1<T2
Outlet
Volume
micro–tube
p1
1
2
p2
Close
big diameter

The experimental methodology



Stages of the experiment



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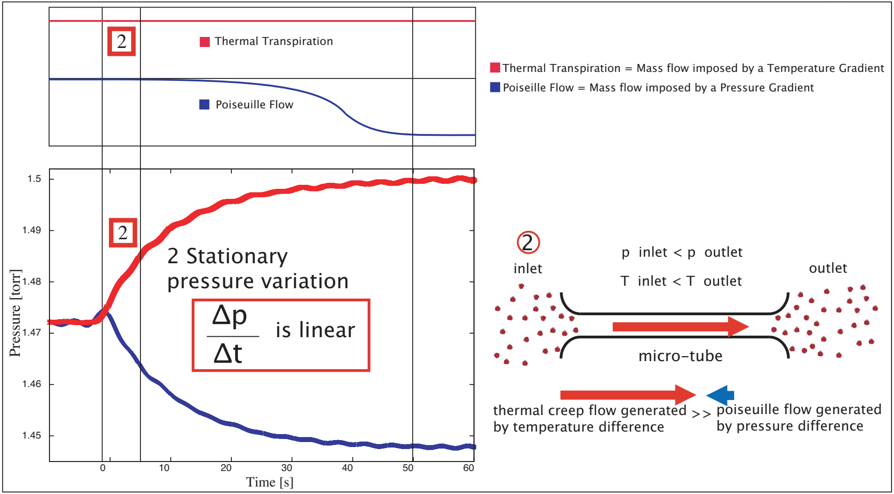
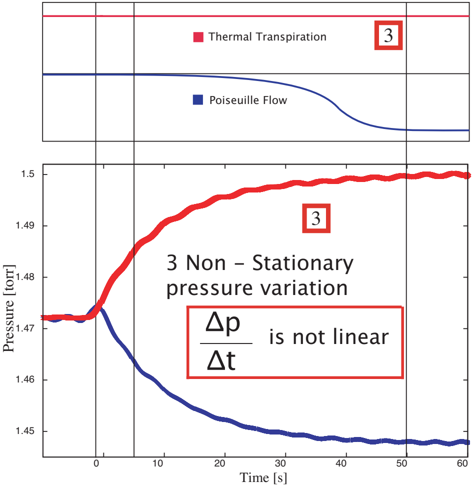
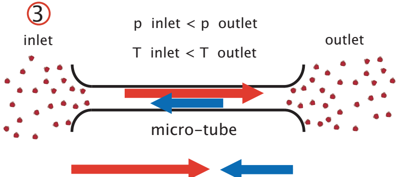


Stages of the experiment

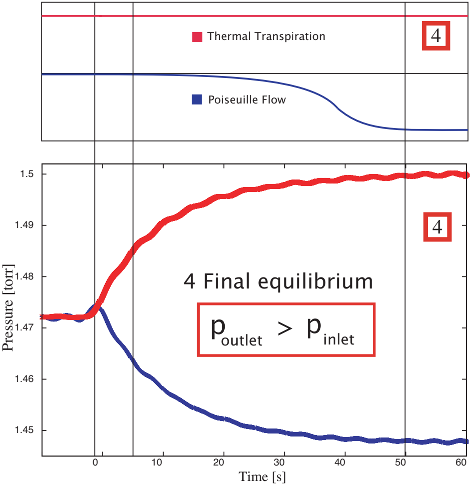


Thermal Transpiration = Mass flow imposed by a Temperature Gradient
Poiseille Flow = Mass flow imposed by a Pressure Gradient



thermal creep flow generated by temperature difference > poiseuille flow generated by pressure difference

Stages of the experiment



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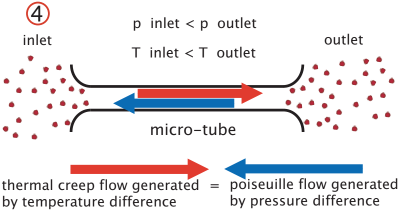
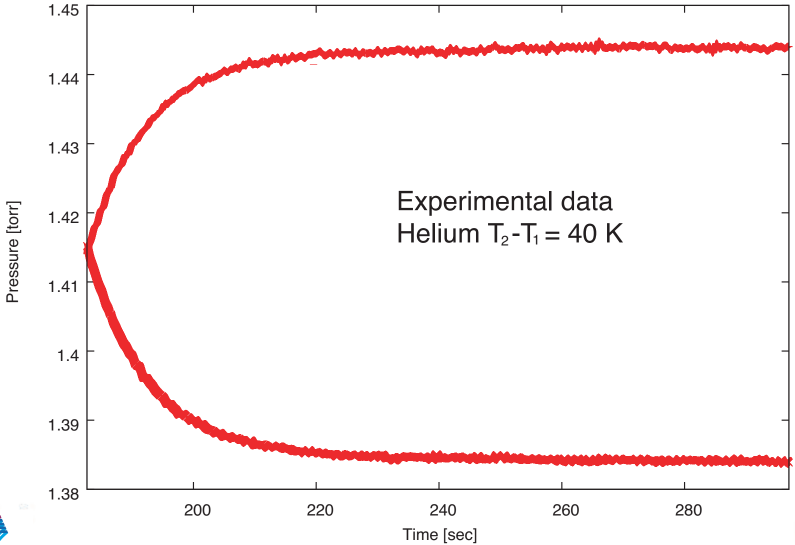


Exponential Behavior



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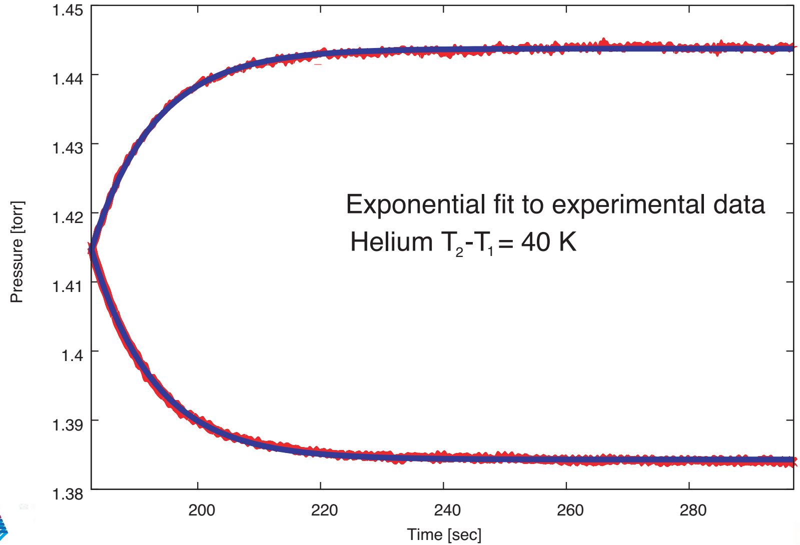
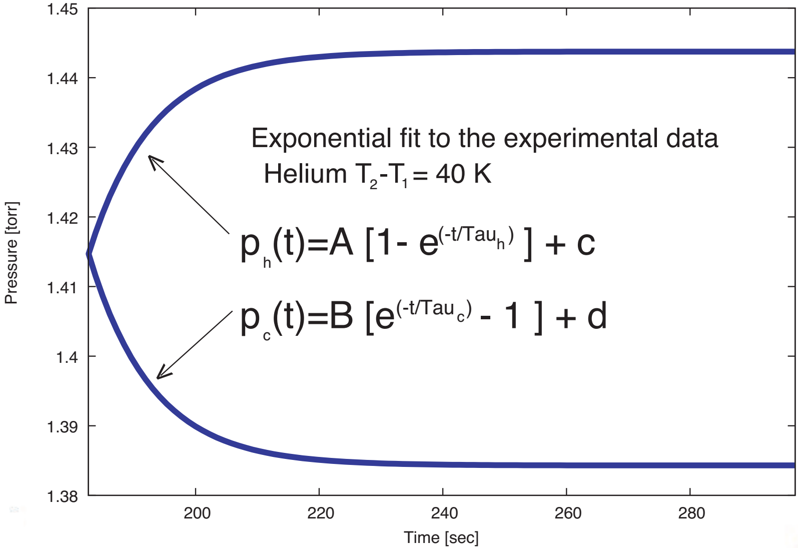
Exponential Behavior

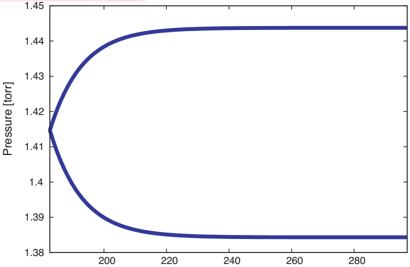


Exponential Behavior



Where are we?

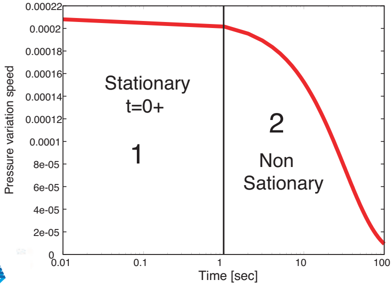
Stationary flow at t=0+



Exponential fit to the experimental data

Pressure variation in time:

$$p_h(t)=A\,[1-e^{(-t/Tau_h)}]+c$$



Stationary flow limit

Pressure variation speed:

$$\frac{dp_h(t)}{dt}=\frac{A}{Tau_h}\,[e^{(-t/Tau_h)}]$$

Mass flow rate

$$\rightarrow PV = mRT \quad \rightarrow \quad \frac{dP}{P} = \frac{dm}{m} + \frac{dT}{T}$$

Dividing by the experimental time length when the phenomenon is still stationary (Stage 2).

$$\frac{dm}{\Delta t} = \frac{V}{RT}\frac{dP}{\Delta t}(1-\epsilon)$$

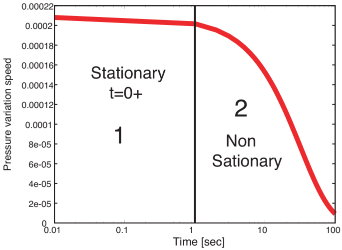
$$\rightarrow \epsilon = \frac{dT/T}{dP/P} \ll 1$$

Mass flow rate

$$\dot{M} = \frac{V}{RT}\frac{dP}{\Delta t}$$

$$\Delta t < 1[s] \quad \rightarrow \frac{dP}{\Delta t} \text{ is linear}$$

Stationary flow at t=0+



Stationary, not-perturbed flow

Pressure variation speed:

$$\frac{dp_h(t)}{dt} = \frac{A}{Tau_h}\left[e^{(-t/Tau_h)}\right]$$

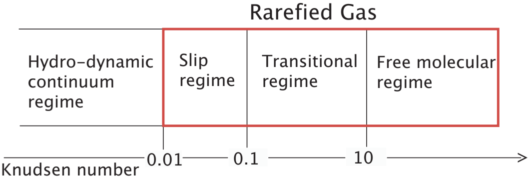
$$\dot{M} = \frac{V_h}{RT_h} \left. \frac{dp_h(t)}{dt} \right|_{t=0}$$

Where are we?

Working regimes

$$\delta = \frac{p \cdot (D_{tube}/2)}{\mu \cdot \sqrt{2 \cdot T \cdot R}}$$

$$\delta = \frac{\sqrt{\pi}}{2} \cdot \frac{1}{Kn}$$



$$0.44 < \delta < 15$$

Working regimes

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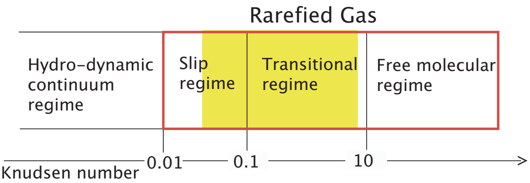
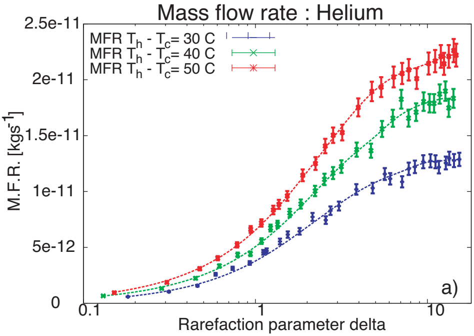
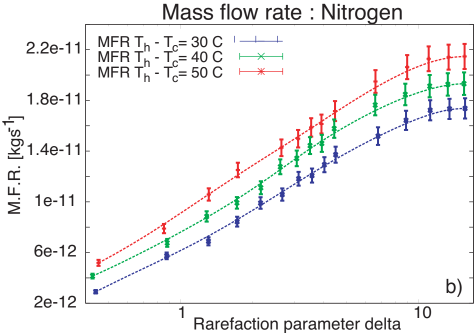
$$\delta = \frac{\sqrt{\pi}}{2} \cdot \frac{1}{Kn}$$



$$0.44 < \delta < 15$$

Mass Flow Rate





Where are we?

Conclusions

Conclusions:

- Still no efforts have been done to describe and analyze experimentally a mass flow rate induced by thermal transpiration: Here an original method is proposed.
- Thermal Transpiration can be introduced for high precision rarefied gas flow control systems.

Perspectives:

- The physics behind the exponential pressure variation in time will be explored: Divergences in function of the gas rarefaction, the temperature imposed gradient and the gas nature will be investigated.
- A new experimental setup will be installed, different geometries of the channel will be investigated.
- The experimental system will be equipped with interchangeable reservoir volumes in order to investigate the influence of the reservoirs in the system's time reaction.

Acknowledgments

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