EXPERIMENTAL ANALYSIS OF REFRIGERANT FLOW IN SMALL CLEARANCES

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SUMMARY

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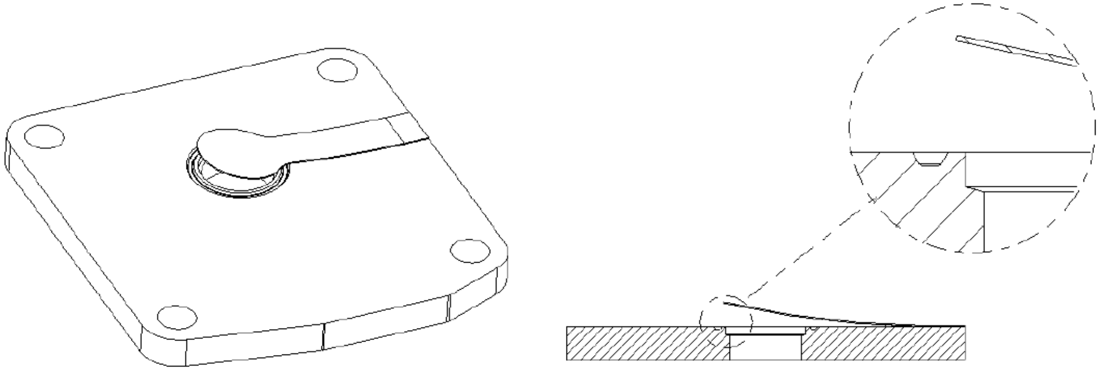
INTRODUCTION

Gas leakage is a well-known source of inefficiency of compressors:

- compression work is lost with the gas that leaks;
- increase of the gas suction temperature.

Recently, Silva and Deschamps (2012) found that the leakage caused by the incomplete sealing in reed valves of reciprocating compressors may significantly deteriorate the compressor performance.



(Silva, 2012)

In this case, characteristic length of these clearances can be of the same order of magnitude as the gas molecular mean free path and rarefaction effects can occur.

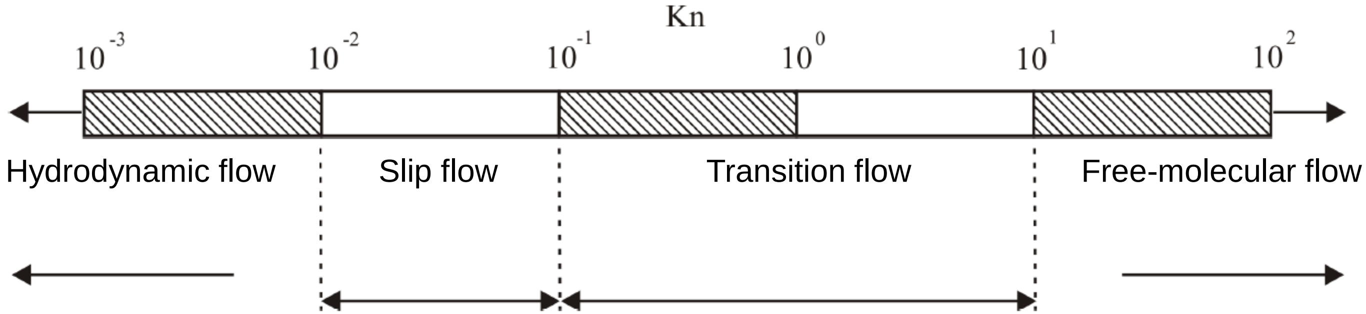
INTRODUCTION

Different rarefied flow regimes can be identified (hydrodynamic, slip, transitional, and free molecular flow) depending on the Knudsen number:

$$Kn = \frac{\lambda}{l}$$

A second parameter of use is the rarefaction parameter:

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



(Silva, 2012)

INTRODUCTION

In order to apply these theoretical methodologies, it is necessary to understand the gas/surface interaction. This interaction can be represented by means of physically meaningful coefficients, like the tangential momentum accommodation coefficient:

$$\sigma = \frac{\tau_i - \tau_r}{\tau_i - \tau_w}$$

- $\sigma = 0$ (specular reflection) $\rightarrow$ in a perfectly smooth surface the molecules do not change tangential momentum after collision with the walls;

- $\sigma = 1$ (diffuse reflection) $\rightarrow$ for rough surfaces molecules are reflected from the wall with an averaged tangential velocity that is equal to the one of the wall .

This experimental work aims to measure gas flows through micro-devices which closely reproduce the gas leaks through micro-metric clearances of compressors.

The device developed will provide means of:

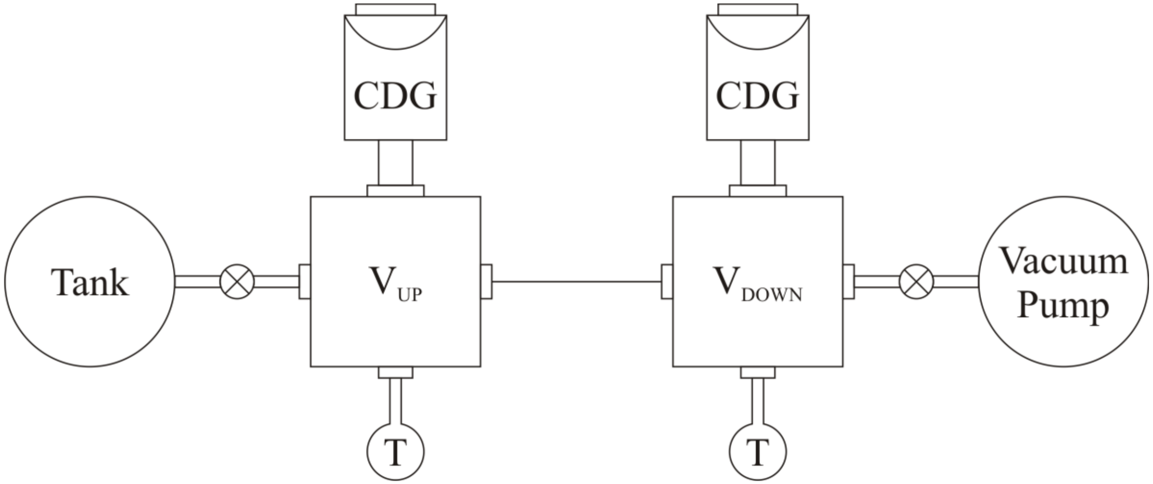
- obtaining slip coefficients;
- validating numerical models to predict gas-leakage in compressors.

EXPERIMENTAL APPARATUS

Different methods have been employed to measure the mass flow rate of gases through small channels:

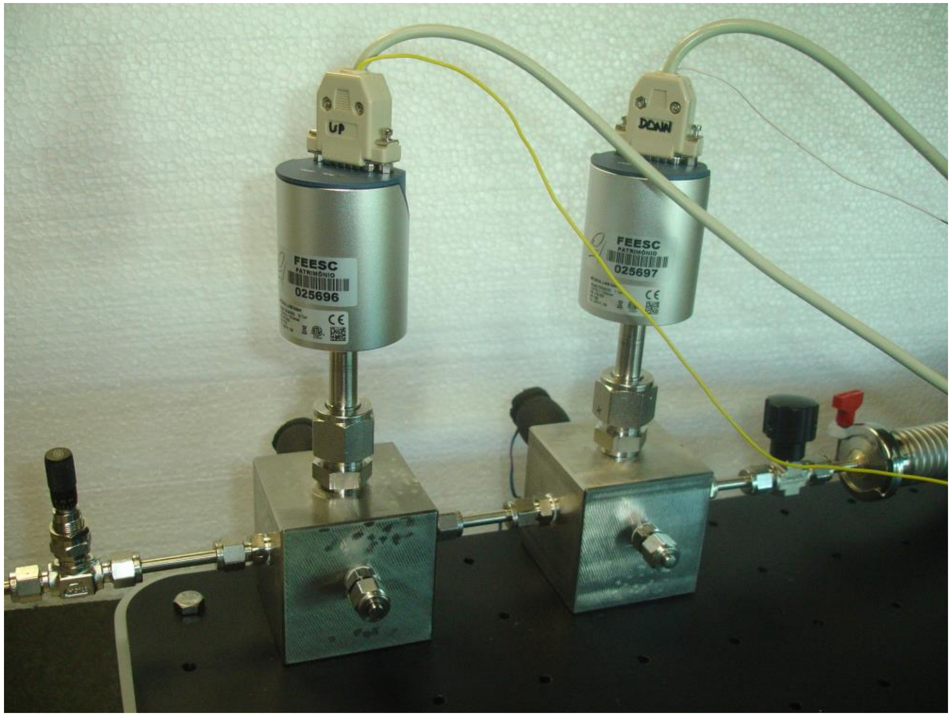
- Direct method (flow meters);
- Indirect method (constant-volume, constant-pressure, drop tracking).

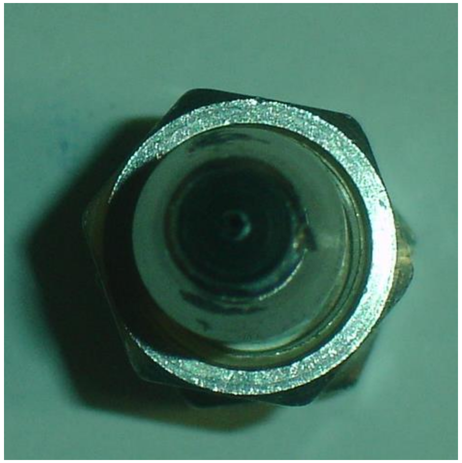
The constant volume technique consists in the tracking with time of the pressure variation inside two tanks which are positioned at the inlet and outlet of the micro-device studied. This pressure variation is associated to the mass flow rate through the microchannel.



EXPERIMENTAL APPARATUS

A micro-tube with nominal diameter of 0.42mm was manufactured in resin and it was positioned inside a stainless steel tube.

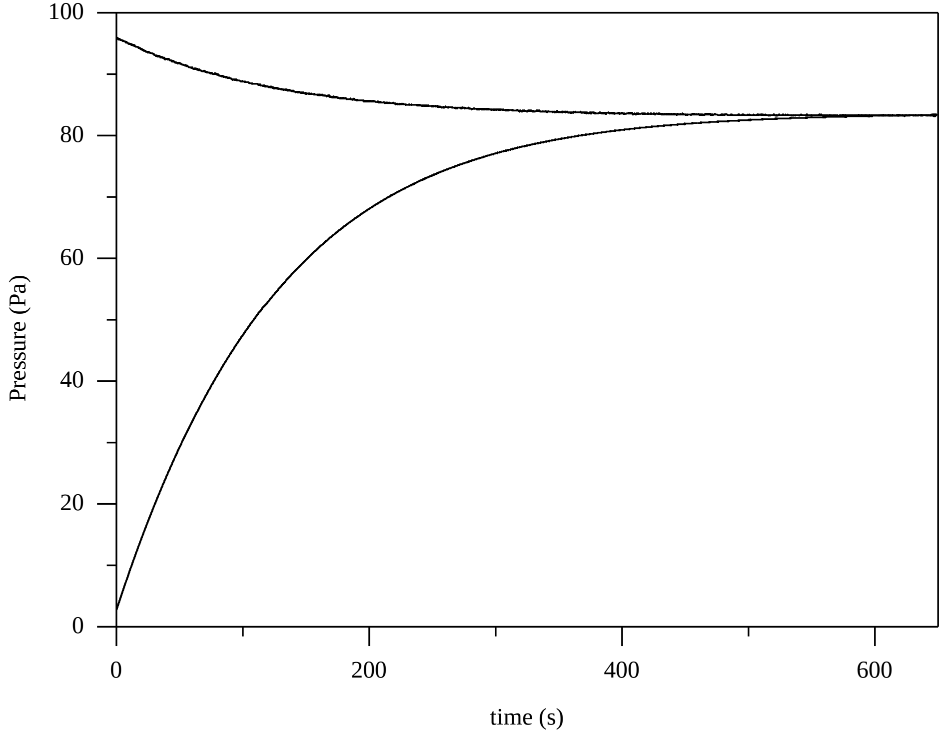




METHODOLOGY

A specific pressure difference between the reservoirs was adjusted and the system was let free to relax to its natural thermodynamic equilibrium configuration.

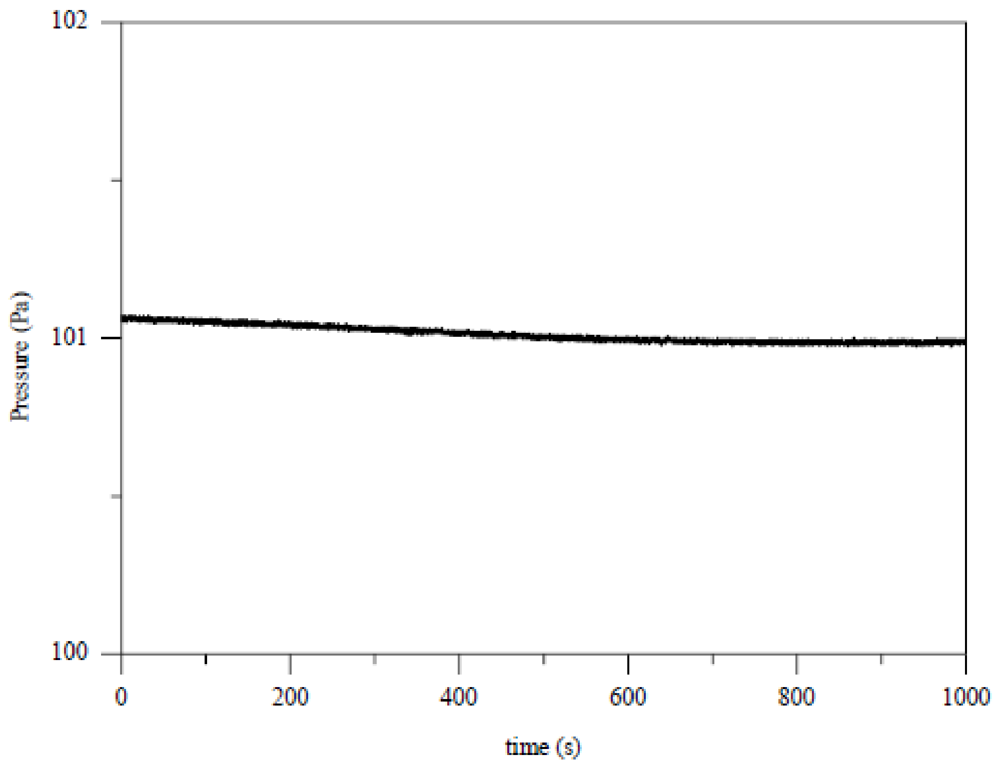
Mass flow rate in the micro-tube can be related to the pressure variation with time in the tanks by using ideal gas equation of state and assuming isothermal conditions.



$$\dot{m} = \frac{dm}{dt} = \frac{V}{\Re T}\frac{dP}{dt}$$

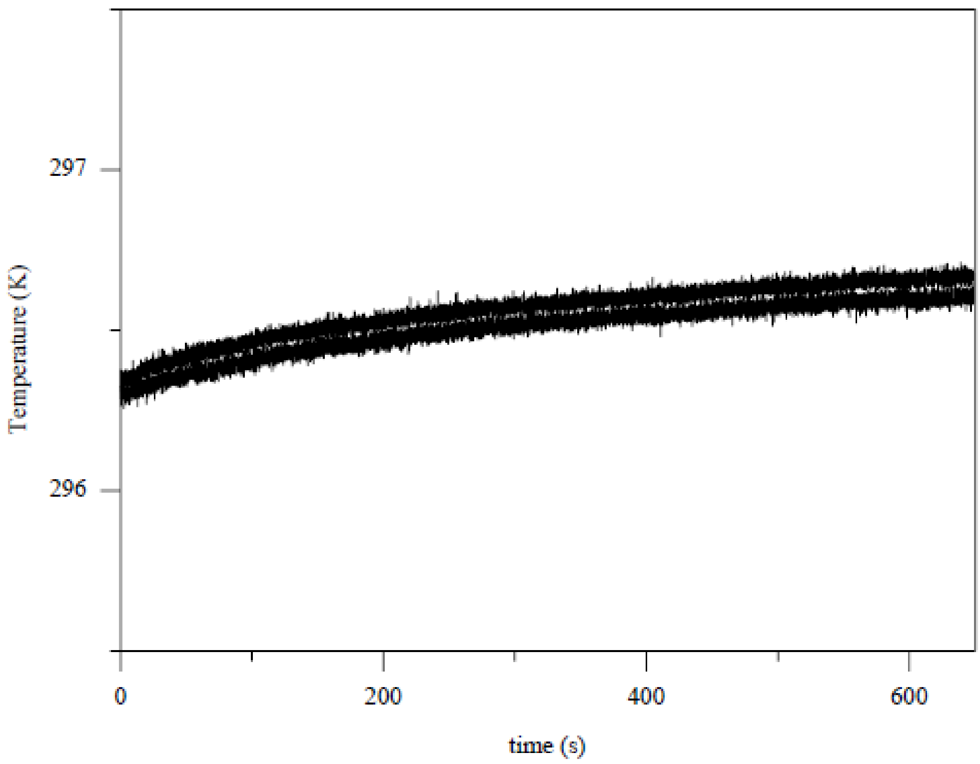
METHODOLOGY

Tests were carried out to assure that the test section was leak-free.



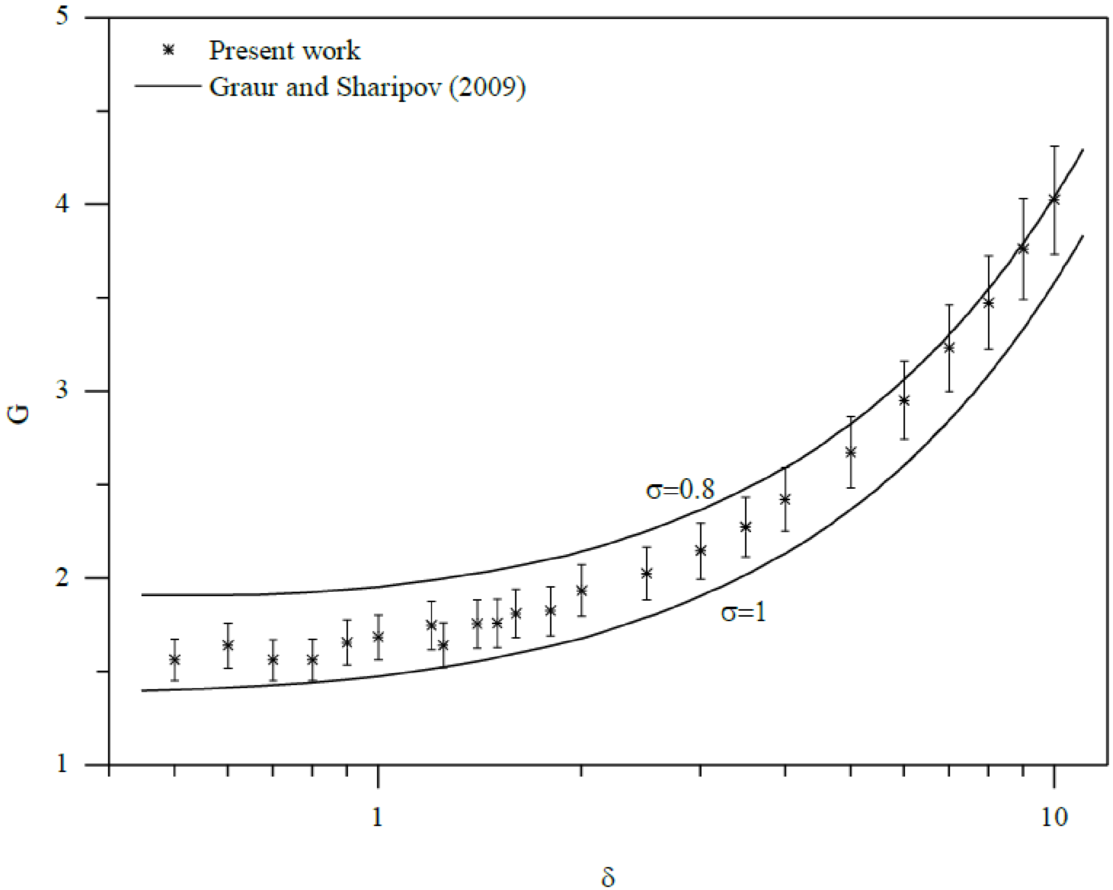
METHODOLOGY

Temperature fluctuations were estimated to be negligible in respect to the mass flow rate measurements effectuated since they were lower than $dT/T<5.10^{-4}$.



RESULTS

Numerical results obtained by Graur and Sharipov (2009) on the basis of the S-model kinetic equation are used for comparison with our experimental results.



$$G = -\frac{1}{\pi R^3}\frac{L}{\left(P_{up} - P_{down}\right)}\left(2\Re T\right)^{1/2}\dot{m}$$

CONCLUSIONS

- → The present work reported an experimental setup for the measurement of mass flow rates of gases through micro-devices.
- → Results for flows of nitrogen in a cylindrical microtube with 0.42mm of nominal diameter were compared with theoretical data and a good agreement was observed.
- → The differences between experimental and theoretical results was attributed to an incomplete accommodation of the gas at the walls or, more probably, to an imprecise value of the microtube diameter.
- → In the future the authors are preparing experiments to be performed with refrigeration fluid through microchannels with different cross-sections.
- → Experimental results obtained with this setup might be used for the validation of a previously existing numerical model to predict the leakage of refrigerant between valve and seat of compressors.

AKNOWLEDGEMENTS

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de ciência e tecnologia

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