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EFFECT OF MINOR LOSSES ON DETERMINATION OF FRICTIONAL BEHAVIOR OF SHORT MINI TUBES

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KEY WORDS

Pressure drop, Inlet Pressure Loss, Exit Pressure Loss, Darcy Friction Factor

Introduction

Frictional characteristics of mini and micro tubes have been extensively analyzed during the past decades both for gas and liquid flows. Even if different channel cross sections and different inlet geometries have been tested [12,] especially for micro heat exchangers, not much focus has been given to the quantification of inlet and outlet minor losses in the literature. Currently, authors who consider minor losses in their experimental results utilize constant loss coefficients $K_{in/out}$ developed for macro flows. Therefore this study is motivated to quantify the effect of minor losses in large and short mini-channels systematically with the aim to verify in which conditions the loss coefficients validated for macro flows can be used in microfluidics. This analysis will be conducted by coupling experiments to Computational Fluid Dynamics (CFD) using the commercial ANSYS CFX finite volume solver.

Experimental Setup and Data Reduction

A series of experimental tests have been made using nitrogen as working fluid with the help of the test rig shown in Figure 1. Nitrogen is stored in a high pressure flask (200 bar) (1) and is brought to approximately 11 bars and ambient temperature before entering into a 7μm particle filter (2, Hamlet®), used to prevent possible impurities from clogging the microchannels or the flow controller. A three-way valve (3) directs the flow to the proper flow controller, as the facility is equipped with three Bronkhorst EL-Flow E7000 flow transducers operating in the 0-50 Nml/min (4a), 0.500 Nml/min (4b) and 0-5000 Nml/min (4c) ranges respectively. These flow controllers are able to impose the mass flow rate by means of a computer-steered valve which allows to impose a certain mass flow rate in order to achieve desired Reynolds number. Gas is then allowed to enter the test section (5), that allows to test microtubes of varying length (1 to 100 cm) and variable inner diameter, given that they have same external diameter, namely 1/16’’. Outlet of the microtube is open to atmosphere. The total pressure drop between the inlet and the outlet of the microtube is measured by means of a differential pressure transducer (6, Validyne DP15) with an interchangeable sensing element that allows accurate measurements over the whole range of encountered pressures. Mass flow controller and pressure sensors used in current experimental campaign have accuracy of ±0.5% of their full scale (FS) values. To measure the temperature at the entrance of the microtube a K-type, calibrated thermocouple is used (7). The typical uncertainty associated with temperature measurement is ±0.25% FS.
Considering ideal gas approximation for gas flow through microchannel and knowing the total pressure drop ($\Delta p_{ch}=p_{in}-p_{out}$) in microchannel, Darcy friction factor (f_D) for isothermal flows can be calculated using Eq.(1) [3].

$$f_D = \left(\frac{D_h}{L}\right)\left[\frac{{P_{in}}^2-{P_{out}}^2}{RT\left(\dot{m}/_{\Omega}\right)^2} - 2ln\left(\frac{P_{in}}{P_{out}}\right)\right], \tag{1}$$

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where D_h and L are hydraulic diameter and length of channel respectively. P_{in} and P_{out} represent the absolute pressures at inlet and outlet of channel, $\dot{m}$ is the gas mass flow rate flowing through cross sectional area Ω of the channel, R is the gas constant and T is average bulk temperature of the fluid. Total pressure drop measured (ΔP_{meas}) includes minor losses at the inlet (ΔP_{in}) and exit (ΔP_{out}) and therefore such losses should be subtracted from total measured pressure drop in order to obtain the pressure drop linked to the average value of the friction factor along the channel:

$$\Delta P_{ch} = \Delta P_{meas} - [\Delta P_{in} + \Delta P_{out}], \quad (2)$$

Minor losses are present due to sudden contraction at the inlet and expansion at the outlet of the microchannel and are estimated as:

$$\Delta P_{in} = K_{in} \frac{\rho {u_{in}}^2}{2}; \Delta P_{out} = K_{out} \frac{\rho {u_{out}}^2}{2}, \quad (3)$$

where u is average axial velocity at a specific cross section of the channel, ρ is the fluid density and K_{in}, K_{out} are loss coefficients dependent on geometry of inlet and outlet respectively.

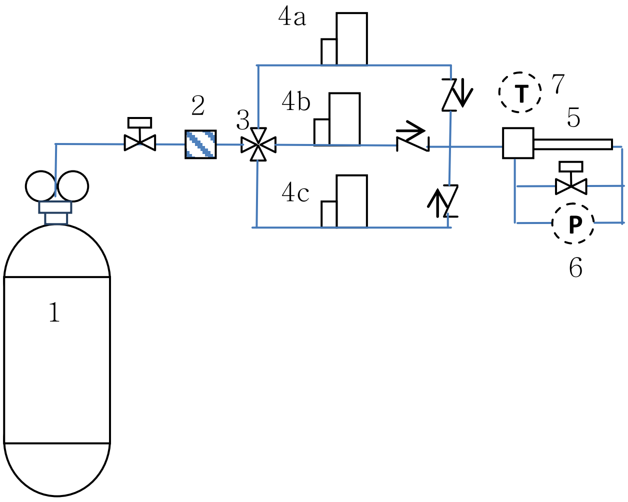

Figure 1: Schematic of test-bench

Results

In Figure 2 the experimental results obtained by testing a commercial tube from Upchurch(R) having inside diameter of 1 mm with L/D_h ratio of 100 are shown. Additional tests are ongoing with other channel geometries. K_{in} and K_{out} for sudden contraction and expansion are given as 0.5 and 1 respectively [4]. Using classical values of loss coefficients developed for macro-flows, minor losses in short mini channel flows account for 15-20% with respect to the total pressure drop and therefore should be dealt with care in data reduction. In the paper CFD results will be used in order to numerically estimate inlet and outlet minor losses after validation of computational model using experimental results.

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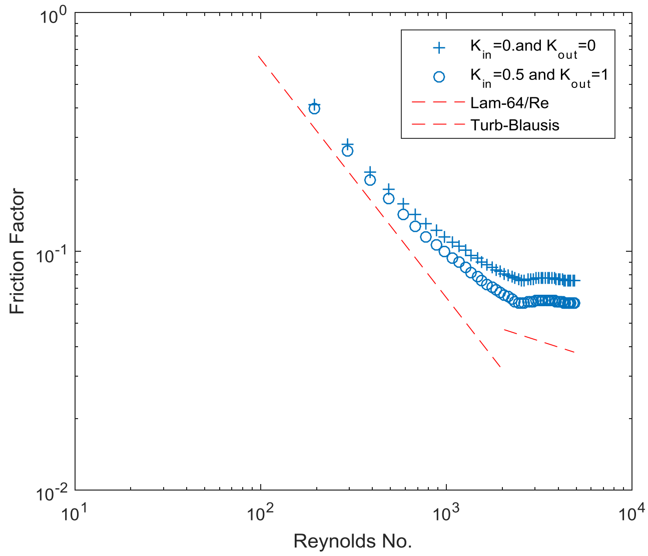
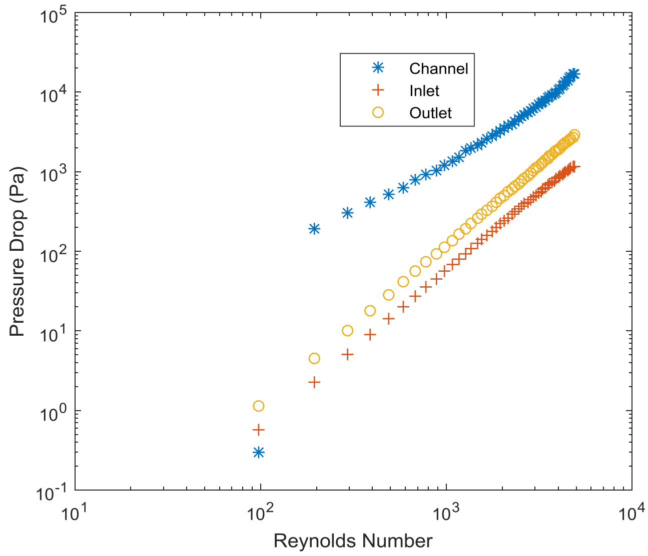


(a)



(b)

Figure 2: Friction factor (a), total pressure drop and minor pressure losses for 1mm (b)

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