



DESIGN RULE EVALUATION FOR MICRO-SCALE FLOW RESTRICTIONS: COMPARING EXPERIMENT AND THEORY

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Overview

- Purpose**
 - Describe pressure driven fluid flow in microchannels
- Methods**
 - Solutions to the Navier-Stokes equations are employed: Hagen-Poiseuille equation for rectangular channels; numerical solution for D-shaped isotropic etch channels
 - Photobleaching time-of-flight technique measures flow velocity
 - Experimental flow ratios are compared to those from theoretical expressions
- Conclusion**
 - Navier-Stokes equations hold for microchannels with dimensions of 1 μm or larger

Introduction

- In order to achieve rational design of passive flow control, an accurate model describing fluid flow in micron-scale devices must be available
- While solutions to the Navier-Stokes equations are quite accurate for dimensions above 10 μm, there is uncertainty as to their accuracy below 2 μm

Navier-Stokes Equations

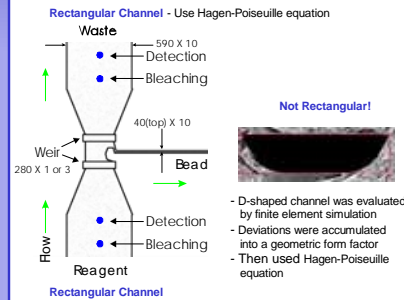
Hagen-Poiseuille equation, a solution to the Navier-Stokes equations for rectangular cross-section:

$$Q = \frac{W^2 D^3 F \Delta p}{4 \eta L} \quad (1)$$

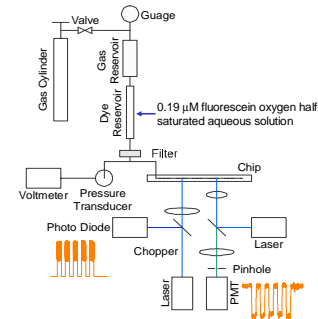
where Q is the volumetric flow rate, W the width, D the depth, and L the length of the channel, Δp the pressure drop across the channel, and η the viscosity of the fluid. F is the geometric form factor,

$$F = \frac{W}{3D} - \frac{64W^2}{\pi^2 D^2} \sum_{n=1}^{\infty} \frac{\tanh\left(\frac{(2n+1)\pi D}{2W}\right)}{(2n+1)^3} \quad (2)$$

Three-port device

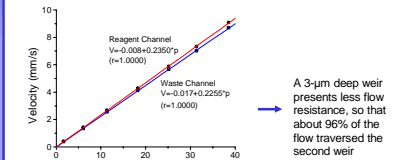


Photobleaching



- Velocities with a clear physical meaning can only be measured in Reagent and Waste rectangular channels
- Velocities were measured many entrance lengths downstream so as to make sure the bleach signal being fully developed
- Dual-point technique was employed

b) 3-μm deep weir

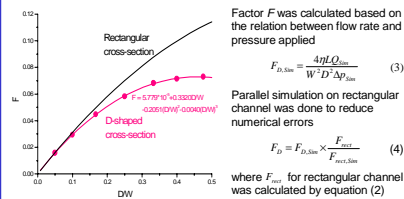


Comparison of the Experimental and Theoretical Flow Rate Ratios

Chip No.	Qw%(cal)	Qw%(exp)	ΔQw%
619 (1μm)	85.6	85.2	0.4
720 (1μm)	86.1	86.3	-0.2
819 (3μm)	96.8	95.9	0.9
820 (3μm)	98.2	98.5	-0.3

The measured and calculated flow percentages Q_w% to the Waste channel agree well!

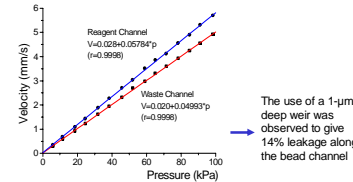
D-Shape Geometric Form Factor from Finite Element Method



Experimental Flow Rates

The cross-sections at the measurement points were the same, so the ratio of velocities is also the ratio of volume flow rates

a) 1-μm deep weir



Conclusion

- Calculate the geometric form factor by analytical equation for rectangular channels or by numerical solution for D-shaped channels
- Photobleaching technique measures flow velocity with a high accuracy
- Solutions to the Navier-Stokes equations provide an accurate means for predicting pressure driven flow within dimensions of 1 μm or larger
- Flow restrictor designs can be accurately modeled

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