Local resistance of fluid flow across sudden contraction in small channels

Hang GUO, Ling WANG, Jian YU, Fang YE, Chongfang MA, Zhuo LI

Abstract The pressure drop caused by flow area contraction in microchannels has been experimentally studied in this paper using the tiny gap pressure measurement method. The working fluid was deionized water at room temperature at near-atmospheric pressure. Three test sections with area ratios of 0.284 and 0.274 and at different tube diameter sizes were used. The experimental results show that the abrupt contraction coefficient \( K_c \) decreases with the Reynolds number increasing, and it is much higher than that of conventional tubes in laminar flow. The widely-applied correlation \( K_c = 0.5(1 - \sigma)\alpha^{0.75} \) could not predict the contraction coefficient of turbulent flow in the micro tubes. The \( K_c \) decreases as the tube diameter increases. The transition from laminar to turbulent flow is not obvious when the diameter of the small tube is 0.32 mm.

Keywords microchannels, pressure drop, abrupt contraction, loss coefficients

1 Introduction

The applications of micro electro mechanical systems (MEMS) have been increasing in many fields in recent years. Devices with dimensions of the order of microns are developed for micro-electronic cooling systems, bipolar plates of fuel cells and compact heat exchangers, etc. So far, a lot of research has been conducted on micro-flow, most of which are focused on flow characteristics in straight channels due to frictional resistance.

Wu and Little [1], as pioneer investigators, studied the gas flow characteristics in rectangular glass channels \((d_h = 45.5 – 83.1 \mu m)\) and silicon channels \((d_h = 55.8 – 72.4 \mu m)\). The gas friction factors obtained were substantially higher (about 10%–30% higher in silicon channels and 3–5 times higher in glass channels) than those predicted by the Moody chart. Peng et al. [2] investigated the flow characteristics of water flowing through rectangular channels with a hydraulic diameter of 133–367 \(\mu m\). It was found that the flow friction behavior for both the laminar and turbulent flow dramatically deviated from the classical correlations. The geometric parameters, hydraulic diameter, and the aspect ratio were found to be the most important parameters which had significant effects on the fluid flow through microchannels. Kohl et al. [3] studied compressible gas (air) flow and water flow in the silicon channels, with hydraulic diameters ranging from 25 \(\mu m\) to 100 \(\mu m\). The relative roughness for the tested channels was between 0.29% and 1.3%. The experimental results suggested that friction factors for microchannels can be accurately determined from the data on standard large channels. Tang et al. [4] investigated flow characteristics of nitrogen and helium in stainless steel microtubes \((d = 119 – 300 \mu m)\), fused silica microtubes \((d = 50 – 201 \mu m)\) and fused silica square microchannels \((d_h = 52 – 100 \mu m)\). The experimental results showed that the friction factors were in good agreement with the theoretical predictions for conventional-size channels except that the friction factors in stainless steel tubes were much higher than the theoretical predictions for tubes of conventional size. This discrepancy resulted from the large relative surface roughness in the stainless steel tubes.

Besides the frictional resistance in straight channels or pipes, the local resistances in expansion, contraction, divergence, convergence and elbow also influence the total pressure drop in microchannels. However, experimental studies on flow through a sudden flow area contraction in micro/mini channels are still lacking in the literature. Abdelall et al. [5] performed several experiments to investigate pressure drops caused by abrupt flow area contraction in microchannels. The theoretical predictions for tubes of conventional size were in good agreement with the experimental results.
expansion and contraction in small circular channels, using air and water as working fluids at room temperature and near-atmospheric pressure. The diameters of larger and smaller tubes were 1.6 mm and 0.84 mm, respectively. The experimental results for water showed that approximately constant expansion loss coefficients occurred in experiments for turbulent flow in the smaller channel. The contraction loss coefficient for water was approximately 0.5 while that for air in turbulent flow was a constant and matched well with theoretical predictions. However, the expansion loss coefficients for air were not reported. Chalfi and Ghiaasiaan [6] measured pressure drops caused by flow area expansion and contraction under low flow conditions using air and water. The test section consisted of two capillaries with 0.84 mm and 1.6 mm diameters. The experimental expansion loss coefficients for air conformed to be a constant 0.8 at least for $Re \geq 5000$. For $Re < 600$, however, the expansion coefficients for air and water had a sharp increase as the Reynolds number increased. The contraction loss coefficient for air in turbulent flow and water in laminar flow had a minor increase with the Reynolds number increasing. Yu et al. [7] and Li et al. [8,9] conducted experiments with nitrogen and water, and investigated single-phase and gas-liquid two-phase pressure drops caused by a sudden contraction in microtubes at room temperature and atmospheric pressure. The diameter of the smaller tube was 330 μm. In single-phase flow experiments, the contraction loss coefficients for water were larger than the experimental results from conventional tubes in the laminar flow. Meanwhile, in turbulent flow, the contraction loss coefficients were slightly smaller than those from conventional tubes and were predicted accurately by $K_c = 0.5(1 - \sigma)^{0.75}$.

In this paper, local pressure drops due to sudden flow area contractions in small circular channels are experimentally studied and analyzed.

## 2 Experimental

The experimental setup is shown schematically in Fig. 1. The water was pumped from a tank by a metering pump with a flow rate range of 0–80 mL/min and a micro pump with a flow rate range of 80–200 mL/min, respectively. In order to prevent any particles or bubbles from flowing through and blocking the tubes, a 10 μm filter was installed at the outlet of the pump. Each experiment was repeated at least three times to ensure the consistency of the results. The pressure drop was measured by two 1151DP pressure transmitters (ranges: 0–30 kPa and 0–150 kPa; accuracy:...