



Effect of geometrical parameters on slug behaviour and two phase pressure drop in microchannel T-junctions

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ABSTRACT

Geometric parameters of a microchannel such as cross-sectional area, shape and aspect ratio are important factors in determining the two phase flow characteristics. Two phase flow analyses were carried out experimentally for microchannel T-junction geometries at low values of capillary number. Three hydraulic diameters were used, namely 250, 400 and 550 μm , while the aspect ratio was varied between 0.1 to 1. Experiments were performed for the gas volume flow rate ranging from 2 to 30 ml/min while the liquid volume flow rate ranged between 0.1 to 10 ml/min. Slug length was estimated from the processing of high speed images of slug flow and pressure drop was simultaneously recorded. For constant mass flux in rectangular channels, an increase in the aspect ratio leads to an entrapment of continuous phase at the corner. This influences the transport characteristic of such channels. The effects of aspect ratio on slug length and pressure drop are reported. A simplified scaling model based on the geometric parameters of microchannels as well as gas and liquid flux is proposed which agrees reasonably well (within $\pm 15\%$) with the present experimental data as well as data available in literature. A flow based pressure drop prediction model was developed which agrees well (within $\pm 10\%$) with the experimentally measured two phase pressure drop. It is believed that *a priori* information on slug length and pressure drop in a given flow through a microchannel will help to design the flowing system better.

1. Introduction

Microchannel engineering has become one of the advanced applications in mechanical, biomedical and chemical industries. It has advantages of high efficiency in heat and mass transfer (due to large surface-to-volume ratio available for transport of energy and mass in a process), easy handling and less sampling size. Two phase flows in microchannels have been observed in both natural and man-made systems. Typical examples of artificial systems that employ such types of flows are microchannel heat sinks, micro-reactors and combustors, fuel cells and micro-therapeutic, diagnosis devices, etc. [1]. Over the past decades, many investigators have characterized gas–liquid flows in microchannels on flow pattern and regime, transition of regime and two phase pressure drop predictions for gas–liquid flows in microchannels [2–9]. The flow characteristics in channels of such length scales deviate from that observed in conventional channels such as shifting of flow transition [10], dominance of slug and slug-annular flow pattern [11,12].

The microchannels can be fabricated in many different ways such as conventional micromachining, chemical etching, and laser engraving

[13]. The conventional means of fabrication gives rise to planar cross-sectional geometries like square or rectangular whereas KOH etching gives trapezoidal or triangular cross-sectional areas. Many studies of two-phase flow were carried out with circular cross-section [2,14–16] while a few were performed in other geometries like triangular and trapezoidal [17,18]. In each of these geometries the wetted areas are different and the shape of slug or bubble depends on the cross-sectional area of the channel. Hence this aspect of the effect of geometry in two phase flow is reviewed now.

Triplett et al. [19] reported different flow regimes in such systems, namely bubbly, slug, churn and annular flows for a 1 mm diameter tube whereas Kawahara et al. [10] observed mostly slugs, Taylor bubbles and slug annular flows for a 100 μm hydraulic diameter (D_h) channel. Other than slug and Taylor bubble flows, there are a few different flow patterns observed in literature such as liquid ring flow, stratified flow, liquid or gas lumped flow [11,20]. Two phase pressure data were found to be well correlated with Lockhart-Martinelli's separated flow model. It has been reported that, due to the dominance of surface tension force, slug flow is the predominant flow regime in microchannels. In slug flow the dispersed phase is surrounded by a thin layer of continuous phase

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English*English*

a	width of channel, μm
b	depth of channel, μm
C	Chisholm parameter
Ca	capillary number
D	hydraulic diameter, μm
d	necking diameter
ΔP	pressure drop, Pa
Eu	Euler number
f	friction constant
f_r	frequency of slug, s^{-1}
G	mass flux, kg/s m^2
J	superficial velocity, m/s
$k(\infty)$	Hagenback's factor
L	length, mm
l	perimeter, mm
$\dot{Q}$	volume flow rate, ml/min
R^2	regression coefficient
Re	Reynolds number
t	time, s
V	volume, mm^3
x	void fraction
X^2	Martinelli parameter

Greek

α	aspect ratio
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α^*	fitting parameter
λ	Laplace constant
μ	viscosity, Ns/m^2
ρ	density, kg/m^3
σ	surface tension, N/m

Subscript

app	apparent
c	continuous phase
d	dispersed phase
$expt.$	experimental
g	gas
h	hydraulic
l	liquid
max	maximum
p	projected
s	slug

Superscript

$*$	non-dimensionalised
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Abbreviations

2ϕ	two phase
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which separates the slug from the wall. For the case of circular tube the continuous film will be of uniform thickness whereas for a rectangular cross-section it will be different due to the corner confinement [21]. The effect of cross-sectional area on Taylor bubbles were reported by Bi and Zhao [2] for three different types of minichannel cross-sections, namely, circular, rectangular and triangular. Chung and Kawaji [14] compared the flow patterns among the square and circular channels of size $100\mu\text{m}$. They observed flow map and reported that void fraction does not depend on the shape of channel. However, Choi et al. [22,23] reported the effect of aspect ratio on flow pattern for three different hydraulic diameter. They reported that the void fraction is dependent on the aspect ratio. Thus aspect ratio is an important parameter for two phase flow characterization in microchannels and the effect of aspect ratio on two phase flow pressure drop was rare. This demands a precise study on the effect of aspect ratio on flow characteristics in microchannels and forms the main objective of this work.

A large body of literature are available on two-phase pressure drop

prediction [2–9]. Chung and Kawaji [14] also noted transition of flow pattern changes with diameter and homogeneous flow model predicted two phase pressure drop reasonably well. Cubad and Ho [24] reported the flow patterns and two phase pressure drop for channels with hydraulic diameter of 200 and $525\mu\text{m}$. They scaled two phase pressure drop with single phase pressure drop and void fraction. Two phase flow pressure drop in rectangular channels were reported [25,26], and separated flow model was modified for 200 to $667\mu\text{m}$ rectangular channel. Most of the studies used separated flow models or had attempted modification of separated flow model with modified Chisholm parameter to predict two phase pressure drop. The two phase pressure drop prediction models were also proposed depending on flow pattern in the past [2,27–29]. These models are termed as flow based pressure drop model, which use the physical and local data, void fraction, slug velocity, and interfacial structure, to compute the pressure drop. These model use the local parameters and hence predicts two phase pressure drop more accurately [30]. The two phase pressure drop correlated well

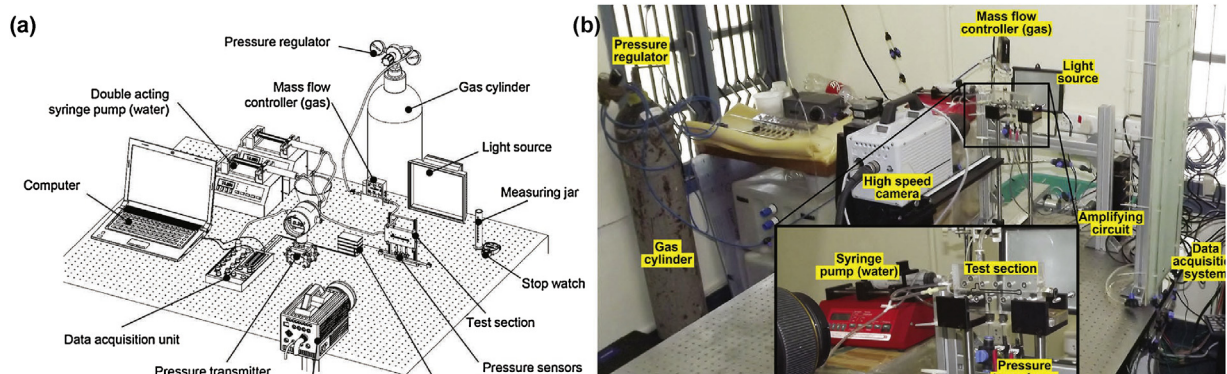


Fig. 1. Schematic (a) and photograph (b) of experimental setup.

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