# EXPERIMENTAL STUDY OF GAS LIQUID FLOW AND REACTION IN MICROCHANNELS: EFFECT OF INLET CONFIGURATION, FLUID PROPERTIES AND FLUID FLOWRATES

by

**D. JEEVARATHINAM**

DEPARTMENT OF CHEMICAL ENGINEERING

Submitted

in fulfillment of the requirements of

the degree of Doctor of Philosophy

to the

**Indian Institute of Technology, Delhi**

Hauz Khas, New Delhi – 110016, INDIA

**MARCH, 2011**

# CERTIFICATE

This is to certify that the thesis entitled **"EXPERIMENTAL STUDY OF GAS LIQUID FLOW AND REACTION IN MICROCHANNELS: EFFECT OF INLET CONFIGURATION, FLUID PROPERTIES AND FLUID FLOWRATES"**, being submitted by D.JEEVARATHINAM to the Indian Institute of Technology, Delhi, for the award of the degree of Doctor of Philosophy in Chemical Engineering, is a record of bonafide research work carried out by him. D.JEEVARATHINAM has worked under our guidance and supervision and has fulfilled the requirements for the submission of the thesis.

The results contained in this thesis have not been submitted in part or in full to any other university or institute for the award of any degree or diploma.

**A. K. GUPTA**
Professor
Department of Chemical Engineering
I.I.T., Delhi

**RATAN MOHAN**
Professor
Department of Chemical Engineering
I.I.T., Delhi

# ACKNOWLEDGEMENTS

I express sincere gratitude and indebtedness to my supervisors Prof. A. K. Gupta and Dr. Ratan Mohan for their guidance and valuable suggestions throughout this research work and for their encouragement, support and cooperation.

I would like to express my inner sense of gratitude to Prof. B.Pitchumani, Prof A. N. Bhaskarwar and other faculty members of chemical engineering department, IIT Delhi, for their care and encouragement.

I wish to acknowledge my lab mate Mr. U.Vengateson for extending his help during the period of experimentation and thesis preparation.

I would like to express my sincere gratitude to my parents who have sacrificed a lot to bring me up to this stage.

Above all, I thank Almighty for bestowing good health to me and my family members throughout the course of the study.

D. JEEVARATHINAM
Entry No: 2005CHZ8077

# ABSTRACT

Gas-liquid flow through microchannels is of interest in connection with the design and operation of microreactors and microseparators. Under laminar flow conditions, bubbly and slug flow are two regimes generally found to exist in the system, with slug flow being predominant over a wider range. It has been reported in literature that slug flow provides high interfacial area, negligible axial dispersion and enhanced radial dispersion and high internal circulation in the liquid slugs. Thus high overall mass transfer coefficients are possible, compared to the values for conventional systems. In view of the potential beneficial features of the microreactor, flow hydrodynamics and reaction (nanoparticle precipitation) is studied in this work.

To study the hydrodynamics of gas-liquid slug flow, an experimental set up was fabricated with micro-capillaries of ID 0.83, 0.65, 0.5 mm combined with inlets of different shapes and sizes. From initial pressure drop measurements on the setup with single phase liquid flow, it became apparent that end effects are present and need to be quantified. The pressure loss due to end effects was quantified in terms of "excess equivalent length" ($L_{ee}$) and correlated as $L_{ee}= b*Re^{-c}$. The standard Hagen- Poiseuille equation was modified with $L_{ee}$ to predict the experimental pressure drop values. The end effect corrections obtained was also used in two phase flow analysis. Drop dynamics was found to be the main contributor for the excess pressure drop. The presence of Poiseuille flow was also verified with a modified setup using two capillaries of different lengths.

For the two phase gas-liquid slug flow, the characteristic parameters pressure drop and gas and liquid slug lengths were measured. It was observed that the gas slug length increases with increase with superficial gas velocity and decreases with increase in superficial liquid velocity. Similarly the liquid slug length was found to increase with increase in superficial liquid velocity and decreases in gas superficial velocity. Increase in liquid viscosity lead to decrease in gas and liquid slug lengths while increase in surface tension leads to increase in the slug lengths. The gas slug (bubble) frequency increases with increase in both gas and liquid flow rates. Empirical correlations proposed to estimate the gas and a liquid slug length predict the experimental data very closely. It was observed that the constants in the pressure drop correlation as well as the slug length correlations varied with the liquids used and also the experimental set up configurations. The constants values also differed from those given in earlier studies in literature, as the present channel geometries and some of the liquids are different.

For the reaction studies, $BaSO_4$ particles (down to 250 nm) were synthesized using the present experimental setup. The effect of gas and liquid stream flow rates on the mean size and distribution of the particles was studied.

# CONTENTS