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Experimental investigation of non-boiling gas-liquid two phase flow in downward inclined pipes

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ABSTRACT

This experimental work provides data on flow patterns, void fraction, pressure drop and heat transfer coefficient for non-boiling gas-liquid two phase flow in the entire range of downward pipe inclinations. The experiments are conducted in 12.5 mm I.D. pipe using air-water fluid combination over the entire range of downward pipe inclinations (horizontal to vertical downward). The thermofluidic measurements are performed over a wide range of gas and liquid phase flow rates that correspond to all the key flow patterns experienced during downward inclined gas-liquid two phase flow. The experimental results show a significant effect of the pipe inclination on two phase flow structure and the two phase flow variables at low values of gas and liquid flow rates. Especially, the void fraction and two phase heat transfer coefficient exhibit non-linear relationship as a function of downward pipe inclination. A significant effect of pipe inclination is also observed on the transition between stratified and non-stratified (slug, intermittent) flow patterns. At steeper pipe inclinations this transition is observed to be accompanied by the peculiar transient behavior of two phase flow. It is found that the two phase flow variable such as void fraction, pressure drop and heat transfer coefficient are significantly affected by the negative slippage at the gas-liquid interface governed by the buoyancy driven nature of the two phase flow. Whereas, the two phase flow phenomenon is apparently insensitive to the change in downward pipe inclination in the inertia driven region of the two phase flow.

1. Introduction

The downward inclined gas-liquid two phase flow, although not as common as horizontal or upward flow, is of a great practical significance in several applications such as undulating flowlines in oil-gas production, chemical process engineering, and downward inclined flow paths in A-framed and V-framed air cooled condensers in steam power generation. The simultaneous transportation of oil-gas in undulating pipe lines is usually at near horizontal upward and downward inclinations whereas the flow in chemical process engineering, A-framed and V-framed structures is at much steeper and near vertical downward pipe inclinations. In all these applications, correct determination of the two phase flow variables is of great importance for the sizing and optimization of the system. Void fraction in general is a pivotal two phase flow variable that is required in calculation of actual phase velocities, two phase pressure drop and heat transfer coefficients. Also, the pressure drop and heat transfer in two phase flow depend on the spatial variation of the two phase flow structure and hence alternatively on the flow pattern and void fraction. Thus, it is indispensable to have a correct understanding of the downward pipe inclination effect on the flow patterns and void fraction.

A comprehensive review of the two phase flow literature shows that most of the existing experimental and modeling efforts are dedicated to the study of two phase flow in near horizontal and vertical downward pipe inclinations. Relatively, little information is available about this phenomenon at intermediate and steeper downward pipe inclinations. Consequently, there are seldom any two phase flow models for void fraction, pressure drop and heat transfer applicable for all the two phase flow patterns in the entire range of downward pipe inclinations. The existing literature related to the experimental downward inclined two phase flow consists of the contributions by [1–9]. All of these experiments are performed with pipe diameters $D \geq 25.4$ mm with selected pipe inclinations and limited information on two phase flow variables. For instance, the work of Nguyen [2] is based only on five selected downward pipe inclinations whereas the experiments of Beggs and Brill [1] and Mukherjee [3] although cover several pipe inclinations in the range $0^\circ \geq \theta \geq -90^\circ$, their data mainly consists of intermittent and separated flow regions with very few data points measured for high liquid and low gas flow rates. The flow visualization experiments of Barnea et al. [4] provide information only on the flow pattern mapping and their transitions while the experiments of Crawford et al.

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