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

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ABSTRACT

In comparison to horizontal and vertical two phase flow, very little information is available on the two phase flow phenomenon in upward inclined pipes. To explore and contribute to the current state of knowledge, the main objective of this work is to experimentally investigate the effect of upward pipe inclinations (horizontal to vertical upward) on gas-liquid two phase flow phenomenon. To accomplish this objective, experiments focused on flow visualization, void fraction, pressure drop and heat transfer measurements in non-boiling gas-liquid two phase flow are carried out in 12.7 mm I.D. polycarbonate and 12.5 mm I.D. stainless steel pipes using air-water as fluid combination. Different flow patterns are generated by varying the gas and liquid phase mass flow rates in a range of 0.001–0.2 kg/min and 1–10 kg/min, respectively. Experimental data for void fraction, pressure drop and heat transfer coefficient is analyzed for its dependency on phase flow rates and pipe inclination. Two distinct trends of the relation between these two phase flow variables and the phase flow rates or alternatively the flow patterns are observed. The experimental results show that increase in pipe inclination from horizontal significantly affects the void fraction, total pressure drop and heat transfer coefficient at low values of gas and liquid flow rates. With increase in the gas and liquid flow rates, effect of pipe inclination on two phase flow variables is observed to diminish. The issue of decreasing pressure gradient minimum in upward pipe inclinations is analyzed using non-dimensional form of gas and liquid flow rates. Finally, based on the heat transfer measurements, the circumferential variation of two phase heat transfer coefficient and its relation to the flow symmetry is discussed.

1. Introduction

Simultaneous flow of gas and liquid phase has extensive applications in petroleum (oil-gas transport), chemical (process engineering) and energy (nuclear, thermal, refrigeration) related industries. Consequently, for past few decades, substantial efforts have been expended on better understanding of two phase flow behavior using experimental and modeling techniques. However, most of these studies are focused on two phase flow in horizontal and vertical systems with little consideration given to this phenomenon in different pipe inclinations between horizontal and vertical. Owing to the wide use of deviated or undulating pipe lines carrying two phase flow in petroleum, chemical and thermal energy generation systems, it is intriguing to study the effect of pipe inclination on the gas-liquid two phase flow phenomenon. Two phase flow literature reports experimental work of Beggs [1], Nguyen [2], and Mukherjee [3] that focus on flow visualization and void fraction and pressure drop measurements for a range of upward and downward pipe inclinations. Beggs [1] and Nguyen [2] used air-water fluid combination to study two phase flow phenomenon in 25.4 mm and 45 mm I.D. pipes, respectively. Whereas, Mukherjee [3] studied two phase flow in deviated pipelines using air-kerosene and air-oil as fluid combinations in a 38 mm I.D. pipe. All these studies reported the pipe inclination to have a considerable effect on the two phase flow parameters and proposed empirical models to predict the flow pattern transition and estimate the void fraction and pressure drop. However, due to empiricism, these models are found to be restricted to a limited range of flow conditions. More recently, Perez [4] carried out liquid holdup and pressure drop measurements in 38 mm and 67 mm I.D. pipes inclined at $-20^\circ \leqslant \theta \leqslant +90^\circ$ from horizontal using air-water fluid combination. His work reported the liquid hold up to follow a decreasing and increasing trend with an inflection point at intermediate angles as the pipe is inclined from horizontal to vertical upward. With regards to the two components two phase flow, literature reports recent comprehensive work of Lips and Meyer [5] and Olivier et al. [6] based on condensing two phase flow of R134a

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