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An Empirical Model to Predict the Transition Between Stratified and Nonstratified Gas–Liquid Two-Phase Flow in Horizontal and Downward Inclined Pipes

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The specific objective of this work is to develop an empirical model to predict the existence of stratified flow in horizontal and downward inclined gas-liquid two-phase flow. The proposed model is in nondimensional form and attempts to emulate the qualitative trend of the Taitel and Dukler mechanistic model. The key advantage of the proposed method is that it is explicit in nature and, unlike Taitel and Dukler, it does not require use of a graphical or iterative solution. The empirical parameters used in the proposed model account for the effect of pipe diameter, pipe orientation, and the liquid density on the transition line between stratified and nonstratified flow. The accuracy of the proposed model is verified against the flow visualization data collected from more than 16 data sources consisting of 8 fluid combinations, pipe diameter in a range of 8.9 to 300 mm, liquid density in a range of 780 to 1420 kg/m³, and all downward pipe inclinations including horizontal.

INTRODUCTION

Gas–liquid stratified flow predominantly exists in the horizontal and downward inclined pipes at low to moderate gas and liquid flow rates. Stratified flow is an inevitable flow pattern in large-diameter pipes, typically those involved in the oil and gas industry and several chemical engineering applications. Many flow assurance issues in the oil and gas industry are related to the incorrect estimation of the flow patterns and hence incorrect design and sizing of the two-phase flow systems. The stratified flow pattern also exists in evaporators and condensers associated with the refrigeration industry, and its correct estimation is always helpful in selecting flow-pattern-specific two-phase flow models for the design, sizing, and optimization of heat exchangers. The physical structure of stratified flow pattern is known to significantly affect the vital two-phase flow parameters such as void fraction, pressure drop, and heat transfer. In

comparison to downward pipe inclinations, stratified two-phase flow in horizontal pipes has received more attention from the two-phase flow community. Some of the available experimental work in studying the flow patterns and their transitions for the entire range of downward pipe inclinations include the work of Nguyen [1], Shoham [2], and Crawford et al. [3]. Additionally, for a narrow range of near horizontal downward pipe inclinations, Gibson [4], Kokal and Stanislav [5], and Kang et al. [6] have studied the stratified flow and its transition with other flow patterns.

A more recent experimental work of Lips and Meyer [7] (for condensing two-phase flow of R-134a) and Ghajar and Bhagwat [8] (for nonboiling air–water two-phase flow) studied stratified flow patterns in downward pipe inclinations. Their results show that in downward pipe inclinations, void fraction in stratified flow could be significantly higher (up to 120%) compared to other flow patterns in upward pipe inclinations. Also, in comparison to other flow patterns, the two-phase frictional pressure drop in stratified flow displays two significantly different trends, depending on whether the flow is buoyancy or inertia driven in nature. Moreover, Lips and Meyer [9] and Hossainy et al. [10] found that the existence of stratified flow in downward inclined pipes significantly affects (up to 40%) the two-phase heat

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