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Slip ratio in dispersed viscous oil–water pipe flow

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ABSTRACT

In this article, dispersed flow of viscous oil and water is investigated. The experimental work was performed in a 26.2-mm-i.d. 12-m-long horizontal glass pipe using water and oil (viscosity of 100 mPa s and density of 860 kg/m^3) as test fluids. High-speed video recording and a new wire-mesh sensor based on capacitance (permittivity) measurements were used to characterize the flow. Furthermore, holdup data were obtained using quick-closing-valves technique (QCV). An interesting finding was the oil–water slip ratio greater than one for dispersed flow at high Reynolds number. Chordal phase fraction distribution diagrams and images of the holdup distribution over the pipe cross-section obtained via wire-mesh sensor indicated a significant amount of water near to the pipe wall for the three different dispersed flow patterns identified in this study: oil-in-water homogeneous dispersion (o/w H), oil-in-water non-homogeneous dispersion (o/w NH) and Dual continuous (Do/w & Dw/o). The phase slip might be explained by the existence of a water film surrounding the homogeneous mixture of oil-in-water in a hidrofilic–oilfobic pipe.

1. Introduction

Two-phase liquid–liquid flow is common in several industrial processes; however it has not been studied as intensively as gas–liquid flow. The interest in liquid–liquid flow has increased recently mainly due to the petroleum industry, where a mixture of oil and water often flows through pipes for long distances during the production and transportation processes. In addition, there are only a few works particularly dedicated to the study of liquid–liquid dispersed flows (where one phase is dispersed as droplets into a continuous phase). Dispersed flow has not yet been studied to the same extent as separated flows, usually annular and stratified, or intermittent flow patterns such as slug flow. Moreover, the existing literature in liquid–liquid dispersed flow covers mainly the investigation of flows involving oil with low viscosity (close to the water viscosity), with few references to viscous oil–water flows. In the present study the oil is a hundred times as viscous as water.

The homogeneous model [1] is a candidate route for the prediction of the flow properties at high mixture velocities. The mixture may be treated as a pseudo-fluid with averaged properties that obey the usual equations of single phase flow. The main assumption of the model is the no-slip condition between the phases. However, phase slip has been detected in some experimental studies on oil–water dispersed flow, indicating that one of the phases is flowing faster. Trallero [2] reported values of slip ratio (s, defined as the oil–water *in situ* velocity ratio) greater than 1 in dual continuous flow (both phases retain their continuity while there is interdispersion of the phases) in a 50-mm-i.d. acrylic pipe using water and oil (884 kg/m^3 of density and 28.8 mPa s of viscosity) at mixture velocities from 0.9 m/s to 1.3 m/s, indicating the oil as the fastest-flowing phase. He suggests that the slip ratio could be related to the pipe material. Angeli [3] performed experiments in acrylic and steel pipes using oil (801 kg/m^3 of density and 1.6 mPa s of viscosity) and water as test fluids. At mixture velocities varying from 1.3 m/s to 2.2 m/s and 50% oil cut the slip ratio in most of the cases was less than 1 for the experiments performed in the acrylic pipe. The acrylic is preferentially wetted by oil, which would affect the contact area of the oil drop with the pipe wall. On the other hand, the slip-ratio values for the experiments performed in the steel pipe were close or greater than 1. Different properties of the fluids and pipe material could affect the distribution of the phases in a pipe's cross-section and subsequently the slip ratio.

Lovick and Angeli [4] investigated oil–water dual continuous flow in a 38-mm-i.d stainless steel test section, using water and oil (828 kg/m^3 of density and 6 mPa s of viscosity). They observed that the slip ratio increases with increasing oil cut. A change of the interface shape could explain this behavior. Cross-sectional images of the pipe cross-section showed that at low oil cuts the oil forms a thin continuous layer at the top of the pipe with a rel-

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