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Statistical assessment of experimental observation on the slug body length and slug translational velocity in a horizontal pipe

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ABSTRACT

In the present paper, the flow was examined experimentally using air and water as the working fluids. Various sets of experimental data were conducted by varying the superficial velocities within ranges of 0.7–3.84 m/s and 0.7–1.33 m/s for air and water, respectively. The slug characteristics were acquired and computed using non-intrusive optical based technique. Statistical analysis for the translational slug velocity and slug body length was conducted. It was observed that for fixed water velocity, the slug length was increasing with increasing the superficial air velocity while the slug frequency decreased. However, for fixed superficial air velocity, the slug length was decreasing with increasing the water velocity whiles the slug frequency increased. Also, it was found that when the superficial water velocity increased the slugs were formed and initiated far downstream from the pipe inlet section. Furthermore, the obtained results were found in a good agreement with the previous empirical correlation.

1. Introduction

Due to long transportation distances, time vary in production rates, large pipeline diameters and varying elevation profiles, slug flow is the most common flow regime in multiphase transportation pipelines [1]. It is a highly intermittent flow regime in which elongated gas bubbles flow alternately with liquid slugs at varying frequencies [2,3]. Moreover, it is also comprises very complex and diverse flow sub-patterns due to its irregular phase distribution nature in which the slugs liquid may be either of pure liquid or aerated with small bubbles [4,5]. The intermittency of slug flow causes severe unsteady loading on the pipelines carrying the fluids and on the receiving devices such as separators. Also, it may cause major variations in oil and gas flow rates at the inlet of downstream processing facilities which subsequently may cause catastrophic damages on the pipeline supports and connections due to mechanical vibrations induced by the liquid slugs.

Ref. [6] documented that the most important characterization parameters for the slug flow are slug length, slug frequency, volume fraction distribution, slug velocity, momentum and energy transfer at the interface. Due to the intermittent and irregular nature of the slug flow, these slug parameters usually vary with time. Hence, knowing the averaged values of these parameters may not be adequate for design purposes. Therefore, more comprehensive statistical analysis has been utilized, thus providing more insight into the phenomenon. Useful information is provided by the Probability Density Function (PDF) and Power Spectral Density (PSD) in addition to the mean characteristics. For instance, the maximum slug length is expected to influence the design of receiving equipment, e.g. slug catchers has to be designed based on the longest possible slug. Therefore, accurate predictions of slug characteristics have become extremely significant for the designers and engineers.

An increased number of studies have been conducted for decades to investigate slug flow. For horizontal flow, the mean liquid slug length increases and becomes nearly steady and stable at 30D–40D from the pipe inlet when the superficial gas velocity increases [7]. Also, Barnea and Taitel [8] mentioned that the slug length distribution varies substantially around the mean value. On the other hand, Fabre et al. [7] concluded that slug frequency decreased when the mixture velocity increased. Moreover, Wang et al. [9] mentioned that the mean slug frequency clearly increased as the liquid superficial velocity increased too. Hale [10] used two high speed cameras at a distances of 1.75 m and 5.60 m from the inlet to predict the slug frequency and observed a decrease in slug frequency value along the pipe. Ref. [11] conducted experiments of air–water to determine the slug frequency, and compared his results with other published correlations in the literature. He also

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concluded that the Taitel and Dukler [12] slug frequency model provides reasonable results but it need high computational effort; thus he developed a faster slug frequency correlation. Furthermore, he mentioned that the simple correlation developed by [13] to estimate the translational velocity provides results with satisfactory accuracy. Ref. [14] identified two significant parameters which play a major role on the slug formation. These parameters are the height of the stratified liquid film and the slip velocity.

Since the slug characteristics can be affected by various factor, most of the previous studies suggested that the developed correlations are limited to some experimental conditions; therefore the general applicability of these correlations is limited to the specific range of flow conditions used. Ref. [11] indicated that the slug characteristics can be affected by pipe diameter, pipe length, superficial gas and liquid velocities, fluid densities and viscosities. Moreover, from the conducted experiment in this work, it was observed that the inlet mixer configuration has a large effect on the slug initiation and growth, which subsequently affect the slug characteristics in general.

Although, many experimental and numerical studies have been conducted for investigating the slug flow, there is still not a complete clear understanding about the phenomenon and to date the precise prediction of the slug parameters remain a challenge [15]. Additionally, due to necessity of this statistical information during the design stage, a number of experiments should be executed under different boundary conditions and configurations in order to develop a robust correlations and models that can inherently represent the slug flow.

This study presents experimental investigation results of air and water slug flow in a horizontal pipe employing non-intrusive optical based technique. The purpose is to provide statistical data for the slug flow parameters such as translational slug velocity, j_S and slug length, L_S. The influence of different boundary conditions on the slug initiation and growth was also assessed. The experiments were conducted over a range of air superficial velocities, varying from 0.7 m/s to 3.84 m/s and water superficial velocities, varying from 0.7 m/s to 1.33 m/s. Moreover, the obtained results were compared against previously developed correlations.

2. Experimental set-up

Fig. 1 illustrates the schematic design of experimental facilities that were used to conduct air–water two phase flow test. The main test section consists of transparent pipe of 0.074 m diameter and 8 m length, this pipe was fixed to rigid steel supports in order to ban the vibration and ensure safe operation. Two tanks with 80 and 100 gallon capacity were used to store the water. Tank of 100 gallon capacity is connected to a pump (EBARA 3M 50-125/2.2) which pumped the water to the test section, while, 80 gallon tank was constructed to receive the water from the test section as well as to avoid supplying aerated fluid mixture to the pump along with the debris. Both tanks are connected using PVC pipe. The pump can provide a water with a maximum flow rate 1 m^3/min and 19 m pressure head. However, the water flow rate was measured using a calibrated ultrasonic flow meter with accuracy of ±0.5% of the scale reading. Solenoid valve was used to control the overall water supply to the loop. On the other hand, a central compressor (Ingersoll rand) which delivered maximum air of 42.5 m^3/min at pressure up to 0.85 MPa was used to supply the air to the test section and calibrated (Omega FMA-2600A) mass flow controller which measured air flow within the range from 0 to 2 m^3/min, with accuracy of ±0.05% of full scale reading, was utilized to measure the air flow rate. Air and water are flowing from their sources and inters into the mixer. The mixer was designed in such a way to separate the air and water from mixing at inlet. On other hand, the design of the mixer enhances the stratification level and prevents any perturbation that may affect the flow structure inside the pipe.

Phantom V 9.1 high speed video camera with full sensor resolution of 1632 × 1200 – 14 bit and 1000 fps (at full resolution) to 153,846 fps (@ 96 × 8 pixels was used to record the slug motion along the pipe. This camera has 24 gigabyte internal memory. In addition, it can record continuous video and continuous optional streaming of up to 500 fps for 8-bit and 350 fps for 12-bit. The duration of the recording time at full resolution is 3 seconds. However, in this work, 1000 fps and resolution of 480 × 960 pixels with a total recording duration of 13 s setting was selected. The record-

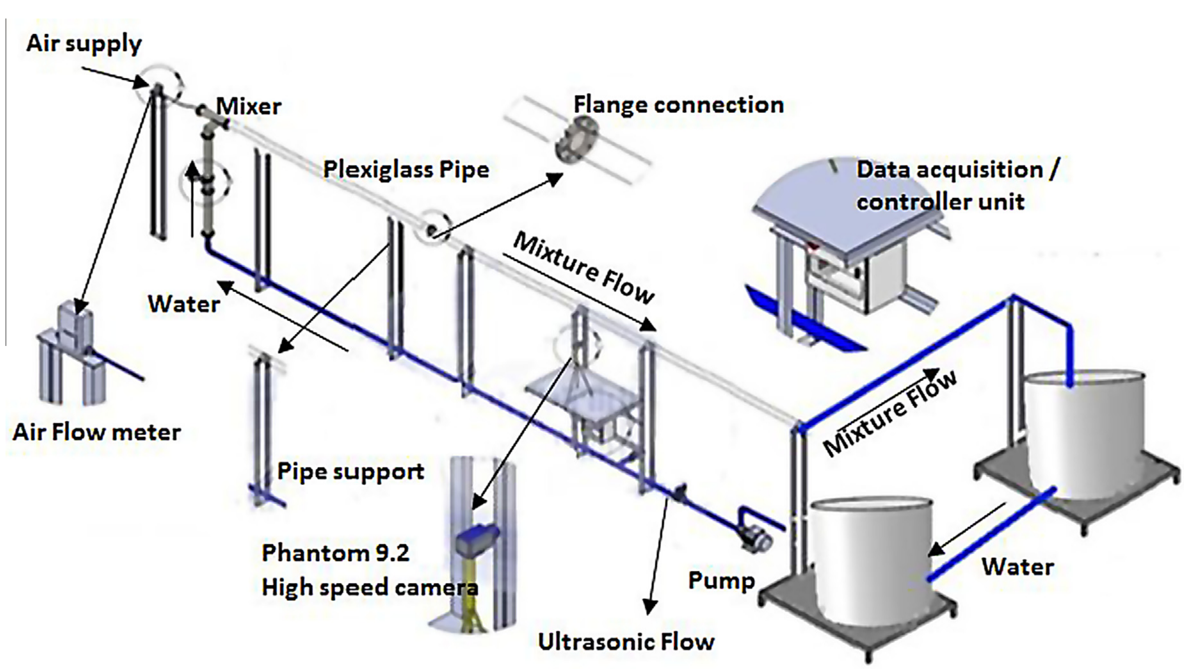

Fig. 1. Schematic of the experimental test facility.