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Wave characteristics in gas–oil two phase flow and large pipe diameter

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ABSTRACT

An experimental study on wave characteristic has been carried out utilizing oil and air in a 0.1524 m ID horizontal and slightly inclined (±2°) pipe. A two-wire capacitance probe was developed to measure wave characteristics at the gas–liquid interface for two-phase flow in pipe. Wave celerity, amplitude and frequency have been determined from the capacitance time traces. The wave celerity increases with increase in superficial gas and liquid velocities. Although wave celerity was found to be dependent on inclination, the effect of inclination tends to diminish with increase in gas velocity. Wave amplitude and frequency did not show a particular trend for conditions studied. A new correlation for wave celerity for two-phase stratified flow using low viscosity fluids is proposed. The correlation was also compared with model prediction for wave celerity using mechanistic model proposed by others.

1. Introduction

Low liquid loading flow refers to flow conditions wherein the liquid flow rate is very small as compared to the gas flow rate. This condition is widely encountered in case of wet gas pipelines, where stratified wavy flow is the dominant flow pattern. In large diameter pipes (>0.3 m) annular flow could result due to deposition of entrained droplets at top of the pipe. This would need very high gas flow rates. Hence, for the case of wet gas pipelines stratified wavy flow with droplets entrained in the gas phase would be the most common flow pattern.

The entrainment fraction is strongly related to the waves occurring at the gas–liquid interface. There is a large amount of data and correlations for the prediction of entrainment fraction in literature. However, the entrainment predictions vary with different correlations resulting in uncertainties in multiphase system design and evaluation. Many correlations do not incorporate wave characteristics, which affects the entrainment fraction (Mantilla, 2008) prediction.

Andritsos and Hanratty (1987) divided the stratified flow pattern into stratified smooth, stratified wavy and stratified–atomization flows. Stratified–atomization flow occurs when the gas flow rate is high enough for entrainment of droplets but lower than that needed for annular flow to exist. Hewitt and Hall-Taylor (1970) observed a critical gas flow rate and a critical liquid flow rate below which entrainment ceases to exist. There is some uncertainty regarding criterion for onset of entrainment. Ishii and Grolmes (1975) defined it as the point at which first droplets appear at the gas–liquid interface. Hanratty and Hershman (1961) reported the presence of flow surges in the water layer for co-current air–water flow. These flow surges, which were called “roll waves”, are similar to large amplitude 2-D waves called “disturbance waves” reported by Hall Taylor et al. (1963), Woodmansee and Hanratty (1969) conducted a detailed photographic study on the initiation of roll waves and atomization in air–water co-current flow in rectangular channel. Since atomization of liquid droplets occurs by the breaking up of the interfacial waves, description of the wave characteristics, namely, celerity, wavelength, frequency and amplitude are very important for prediction and modeling the droplet entrainment.

Several experimental studies for understanding wave characteristics in vertical annular flow have been conducted. However wave behavior in horizontal and slightly inclined pipes is significantly different then in vertical pipe. The liquid film distribution is not uniform with bulk of the liquid flowing at the bottom of the pipe. Geraci et al. (2007) and Magrini et al. (2012) studied the effect of inclination on the disturbance wave characteristics in 38 mm and 76.2 mm diameter pipes, respectively. It was observed that, for inclinations close to horizontal, the disturbance waves exist only at the bottom of the pipe with thicker liquid film due to highly asymmetric distribution of the liquid film. However,

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with increasing inclination, the distribution becomes more and more symmetric, and the fraction of the pipe circumference covered by disturbance waves increases.

Paras and Karabelas (1991) reported measurements of axial velocity in the liquid layer for stratified–atomization layer using Laser Doppler Anemometry (LDA). Their results showed that large disturbance waves at the gas–liquid interface influence velocity distribution and turbulence intensity distribution in the liquid film. It was also observed that the axial velocity distribution and turbulence intensity resembles single phase flow only close to the wall ($y+ < 30$). Paras et al. (1994) conducted detailed wave characteristic and shear stress variation studies using parallel wire conductivity probes and flush mounted hot film anemometers. Wave celerity was found to be linearly dependent on superficial gas velocity while being independent of liquid flow rate. Moreover, the spectra of film thickness, shear stress and axial liquid velocity were found to display close similarities further confirming the effect of interfacial waves on wall shear stress.

Apart from the experimental study, numerical as well as mechanistic modeling of waves have been attempted by several researchers (Watson, 1989 and Johnson et al., 2009a,b). These models try to predict conditions leading to formation of waves and wave instability using linear stability analysis (Wallis, 1969; Andritsos and Hanratty, 1987; Barnea and Taitel, 1993) or nonlinear analysis and shallow water theory (Dressler, 1949; Hanratty and Hershman, 1961; Watson, 1989; Johnson et al., 2009a,b).

No studies on wave characteristics for oil–gas flow systems have been reported in the literature. Using a two-wire capacitance sensor, this study presents experimental results for wave characteristics in a 6-in horizontal and slightly inclined (±2°) pipeline. The results were compared with available correlations and mechanistic models.

2. Experimental program

The experimental program has been carried out at the Tulsa University Fluid Flow Projects (TUFFP) low pressure flow loop (see Fig. 1). Air supplied from a compressor and oil pumped from the oil tank enter the flow loop at the mixing tee (see Fig. 2). The test section details are shown in Fig. 3. After flowing through the loop the two phases are separated in a vertical separator. Air is vented to atmosphere while oil is re-circulated back to the oil tank. Two back-pressure valves at the outlet of the separator control the pressure in the flow loop. A more detailed description of the oper-

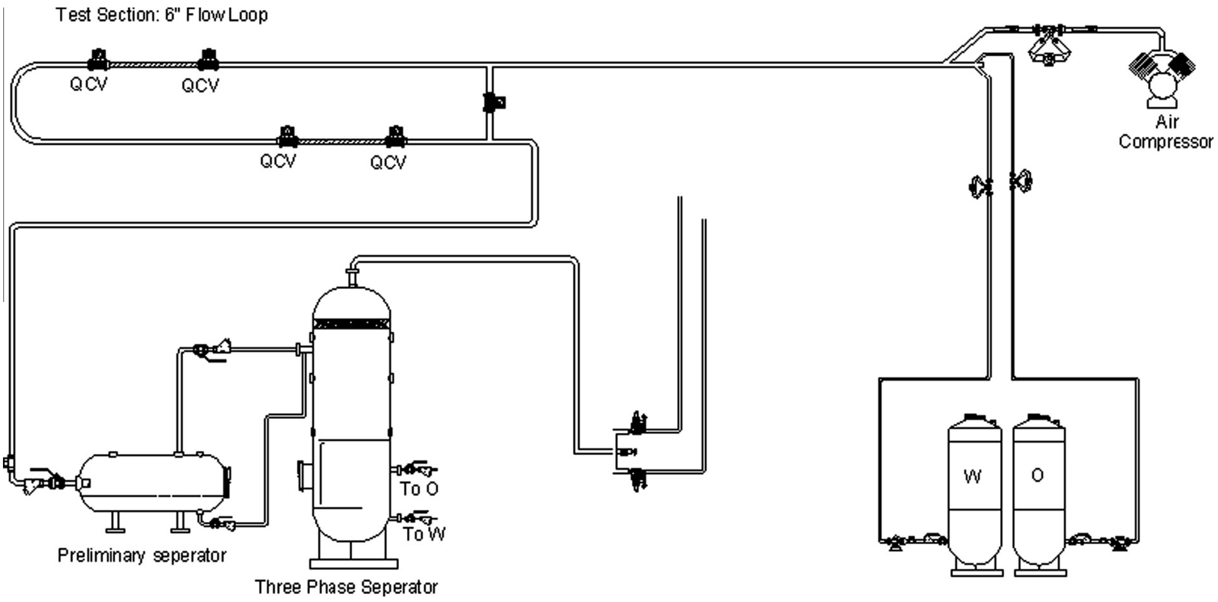

Fig. 1. Schematic of TUFFP 6-inch low pressure flow loop.

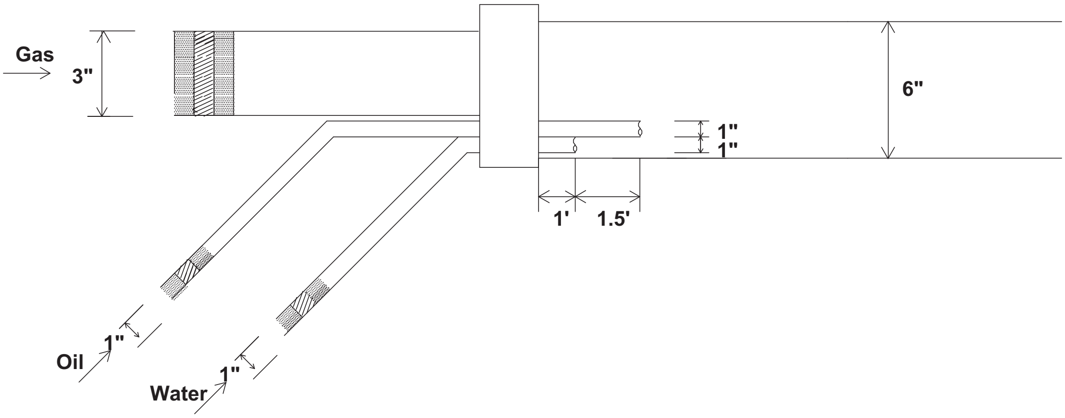

Fig. 2. Mixing tee.