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A MODEL FOR LIQUID SLUG LENGTH DISTRIBUTION IN VERTICAL GAS-LIQUID SLUG FLOW*

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Abstract: The slug length and the trailing Taylor bubble velocity in an upward vertical slug flow were measured by using the optical probes and the EKTAPRO 1000 high speed motion analyzer. The correlation between the trailing bubble velocity and the length of liquid slug ahead of that bubble is derived from the experimental data. Based on this correlation as well as the bubble overtaking mechanism, a model for the slug length distribution at any designated locations along the pipe is proposed. The predicted results are in agreement with the experimental data.

Key words: gas-liquid, two-phase flow, slug flow, Taylor bubble, liquid slug

Nomenclature
B —Slug tail position
C —Coefficient
F —Slug front position
L —Length
N_f —Dimensionless inverse viscosity
n—Total number of liquid slugs
n_j —Number of liquid slug with $(j\pm0.5)D$ in length
t —Time
U —Velocity
x —Axial position
ρ —Density
η —Dynamic viscosity

Superscripts
i —Number of Taylor bubble
$'$—Trailing Taylor bubble

Subscripts
G —Gas phase
L —Liquid phase
Max —Maximum value
mean—Mean value
S —Mixture
SG—Superficial gas velocity
TB —Taylor bubble

1.Introduction

The flow field characterization at the near bubble wake region was studied and interesting results were

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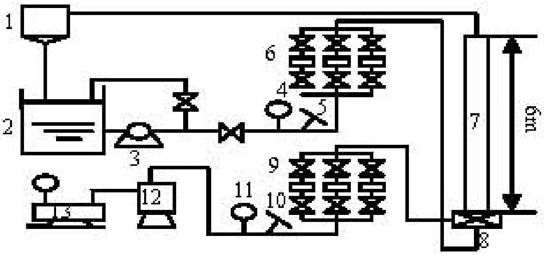
Biography: XIA Guo-dong (1965-), Male, Ph. D., Professor obtained by, for instance, Van Hout et al.[1] or Sotiriadis and Thorpe[2]. Experimental and numerical studies on the local phase structure of vertical downward and upward gas-liquid bubble flow were carried out by Kashinsky et al.[3] to examine the effect of gas-phase dispersion on the flow characteristics. Slug flow is one of the basic flow patterns and occurs over a fairly wide range of gas and liquid flow rates in small and medium sized tubes. It is characterized by large bullet-shape bubbles (referred to as Taylor bubbles), almost filling the tube, which are separated by liquid slugs. One may or may not find small bubbles in the slugs following the Taylor bubbles.

The length of liquid slug is an important parameter in the gas-liquid slug flow model. In the mixing zone, the momentum theory was employed and the mixing process between the film and slug was simulated by a two-dimensional wall jet entering a large reservoir to obtain the mixing length[4]. Experimental investigations in horizontal and upward vertical flows show that the mean slug length is relatively insensitive to the gas and liquid flow rates and depends mainly on the pipe diameter. Generally speaking, the liquid holdup increases with the increase of liquid converter velocity or liquid viscosity and decreases with the increase of gas converter velocity when other parameters remain unchanged[5]. In a vertical flow, the mean slug length is almost in the range of 8-25 pipe diameters[6]. The mean slug size was studied by many researchers[7,8]. For horizontal pipelines, experiments were conducted to study the characteristics of slug[9,10]. The measurements were made by conductivity probes to determine the liquid slug length distribution. The data cover both the slug and plug flow regimes. From experimental results, the mean liquid slug lengths were relatively insensitive to gas and liquid flow rates in a high mixture velocity range.

The first attempt to determine the probability distribution of the liquid slug length was made by Brill et al.[11] by fiting their field data with a log-normal distribution. Fractal statistics were used by Sather et al.[12] to analyze the stochastic fluctuations of slug lengths in a nearly horizontal flow. Based on a bubble overtaking mechanism, Barnea and Taitel[13] proposed a model for the slug length distribution at various positions along the pipe.

In the present work, the slug length and the trailing Taylor bubble velocity in a vertical slug flow were measured by using the EKTAPRO 1000 high speed motion analyzer. Based on the relation between the trailing bubble velocity and the length of liquid slug ahead of that bubble, a model is proposed to calculate the slug length distribution at any designated locations along the pipe. The calculated results for liquid slug length are in agreement with the experimental data.



1—Filter, 2—Tank, 3—Pump, 4—Pressure gauge, 5—Thermometer, 6—Water flow meter, 7—Test section, 8— Mixing chamber, 9— Air flow meter, 10—Thermometer, 11—Pressure gauge, 12—Stabilizer, 13— Air compressor
Fig.1 Schematic diagram of the experimental system

2. Experimental facility and procedure

2.1 *Experimental system*

Figure 1 shows the experimental system. Compared with the conventional experimental facility, a 10 m long transparent Perspex pipe with internal diameter of 24 mm[14], the test section of this system is made of a 6 m long Plexiglas tube with internal diameter of 30 mm. Air and water are used as the working fluids. Air is supplied by an air compressor, and water comes from a storage tank, which is fed into the experimental system by a pump. Their flow rates are adjusted by controlling valves and measured by flow-meters. These two fluids can be mixed in the mixing chamber at the bottom of the pipe. The length of the mixing chamber is about 0.4 m. The mixed fluid from the test section flows into the separator, from where recycled water returns to the storage tank, while air is released into atmosphere. The measuring stations are installed at positions 0.9 m, 2.4 m and 4.5 m above the inlet. The EKTAPRO 1000 high speed motion analyzer and the optical probes are used as measuring instruments. With the EKTAPRO 1000 high speed motion analyzer, the gas-liquid slug flow is measured non-invasively in order to obtain the Taylor bubble velocity and the leading liquid slug length accurately. The slug length at three axial locations is measured by the U-type optical probes. The signals are recorded and analyzed by a personal computer. The threshold value is determined by means of the synchronous measurement of the optical probe and the EKTAPRO high speed motion analyzer[15]. The experimental conditions are as follows:

System pressure: 0.1 MPa -0.3 MPa.
Superficial velocity of water: 0.032 m/s -1.2 m/s.
Superficial velocity of air: 0.1 m/s -1.6 m/s.

2.2 *High speed motion analyzer*

The frame rate of EKTAPRO 1000 high-speed motion analyzer can be selected in the range of 30-1000 fps. Different frame rates are used according