Visualization, Mapping Flow Patterns, Plug Length and Plug Velocity Measurement for Air-Water Downward Two Phase Flow in Vertical Pipe

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Abstract: The two phase flow is of significant interest in chemical, nuclear and petroleum industries. The two phase flow in horizontal and vertical upward pipe orientation has been studied extensively in the literature. However, limited information is available in the literature on the downward two phase flow. To have a better understanding of this phenomenon, experimental investigation of downward two phase flow was carried out in a 0.019 m diameter tube and the length of tube is 8 m with water and air as process fluid. The objective of this experimental study was flow visualization and measurements of the plug velocity. The superficial velocity of gas flow is observed from 0.25 m/s to 1.06 m/s. The superficial velocity of liquid flow is observed from 0.34 m/s to 0.45 m/s. Data has been taken at 2 m height over the outlet. Two flow patterns were observed in this research there are annular flow and slug or plug flow. Plug velocity measured by light sensor and compared with visual velocity. Visualization of the flow has been taken by digital camera to measure plug length. Flow pattern was mapped and compared with several previous researcher's maps.

Key words: *light sensor, flow pattern.*

Introduction

Multiphase flow is a simultaneous flow of more than one phase, occurs in many facets such as petroleum industry, chemical industry, and nuclear reactor. Two phase flow being the simplest case of multiphase flow with distinguished interfaces which separates one phase from another. The complexity in the two phase flow is primarily due to turbulent mixing of the two phases and the compressible nature of the gas phase. In the present study we are concerned with two phase air-water flow in vertical downward orientation. The research done so far in the field of two phase flow can be classified in terms of flow visualization, void fraction, pressure drop and mapping flow patterns. Most of research is dedicated to horizontal and vertical upward two phase flow whereas limited information is available in the literature over the analysis of the vertical downward two phase flow.

According to research has been done by Bhagwat and Ghajar (2011), the type of flow pattern in the downward two phase flow consisted of bubbly flow, slug/plug, annular, froth, falling film. However different observation made different type of flow pattern like the research by Omer and Indarto (2005) found three kinds flow pattern in their research, they are falling film, slug, and bubble. Generally, slug/plug flow should be avoided as it can cause corrosion in the pipes.

The principal interest of this study was to identify the major flow patterns, plug velocity, and plug length which occurring in downward two phase flow followed by the analysis of the available gas superficial velocity (U_{sg}) and liquid superficial velocity (U_{sl}) correlations.

Experimental Setup

The experimental setup used in present study is located at the Hydrodynamic Lab, Gadjah Mada University. This setup is capable of doing flow visualization through transparent test section and measurement of the plug length and plug velocity. The schematic of overall experimental setup and the dimensional details of the flow visualization and plug velocity sensor are shown in Figures 1 and 2, respectively. In the present study two phase flow was analyzed for air-water fluid combination and flowing through 0.019 m ID plexiglass pipe. The height of the plexiglass pipe which was the section test is 8 m.

Plug velocity sensor tool based on light sensor that detect intensity of light. Two set of sensor was attached in two different height of the pipe. The first set of sensor was attached on the pipe of test section with 2 meters height over the output. The second set of sensor was attached on the pipe of test section with 6 meters height over the output.

Before measuring the plug velocity data it was necessary to calibrate the sensor with test tube to indicate data digital when the light refracted through the body of plug, tail of the plug, and head of the plug. Calibrating of the air rotameter and water rotameter was necessary too before measuring volumetric flow rate. Visualization data such as videos and photos was taken by use Canon 60D camera. A set of plug velocity sensor consist of two LED and two photodiodes which connected with ADC(Analog to Digital Converter) and showed the data digital in microsoft excel.

phases across the pipe cross section. The present experimental study was carried out for constant liquid flow rates starting from low gas flow rates and then moving towards the higher gas flow rates. Two distinct flow patterns were observed namely, annular flow and slug/plug flow. However, at a height of 6 meters only found annular flow pattern because the flow was still developed so the data in 6 m height was not discussed in this research deeply.

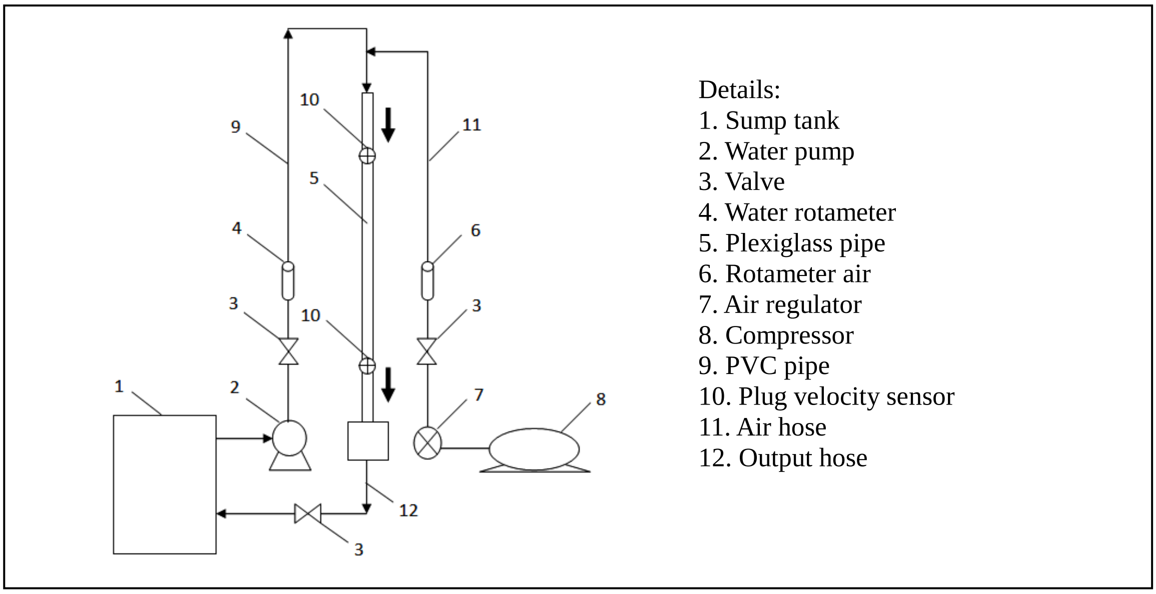


Figure 1. Schematic of experimental set up

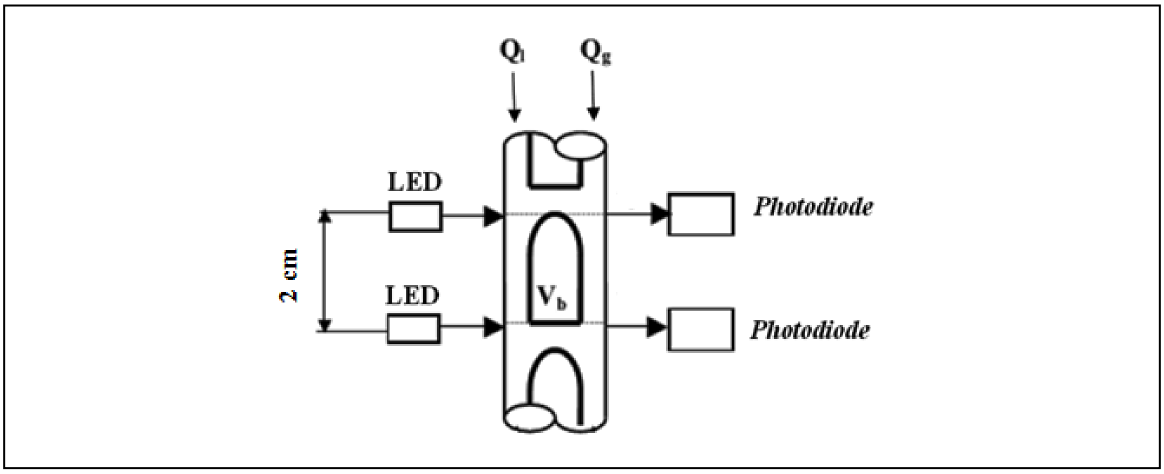
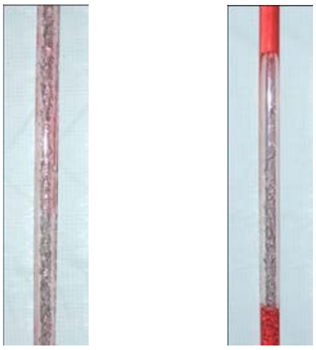


Figure 2. Schematic of a set of plug velocity sensor

Experimental results

Visual observations of the flow patterns was necessary in the present study since the two phase flow parameters like pressure drop and void fraction. Different flow patterns exist in downward two phase flow depending upon the distribution of the individual

The superficial velocity data of gas flow was taken from 0.25 m/s to 1.06 m/s. The superficial velocity data of liquid flow was taken from 0.34 m/s to 0.45 m/s. Annular flow was happened in low liquid superficial velocity. At annular flow, the distribution of the two phases in the pipe cross section is similar to the falling film flow except the slow moving liquid film along the pipe wall is replaced by the fast moving agitated liquid film. Plug/slug flow was happened in high superficial liquid velocity. Plug/slug flow is flow pattern with gas and liquid flowing alternately through the pipe cross section. At constant gas superficial velocity and increased liquid superficial velocity from 0.34 m/s to 0.45 m/s, there will be a transition flow pattern from annular flow to plug/slug flow as shown in Figure 3.



U_{sl} = 0.34 m/s U_{sl} = 0.45 m/s
U_{sg} = 0.49 m/s U_{sg} = 0.49 m/s

Figure 3. Flow pattern transition from annular to slug/plug flow at two meters height.

Mapping flow patterns is one of the important thing to know characteristic of the air-water downward flow. In Figure 4, U_{sl} is ordinate axis and the axis of abscissa is U_{sg}. Slug/plug flow was occurred on U_{sg} 0.25 m/s with the U_{sl} 0.38 m/s - 0.45 m/s and the U_{sg} 0.49 m/s - 0.78 m/s with U_{sl} 0.4 m/s - 0.45 m/s and the U_{sg} 1.06 m/s with the U_{sl} 0.43 m/s - 0.45 m/s. Annular flow was occured on U_{sg} 0.25 m/s with the U_{sl} 0.34 m/s - 0.36 m/s and the U_{sg} 0.49 m/s - 0.78 m/s with U_{sl} 0.34 m/s - 0.38 m/s and the U_{sg} 1.06 m/s with the U_{sl} 0.34 m/s - 0.4 m/s.

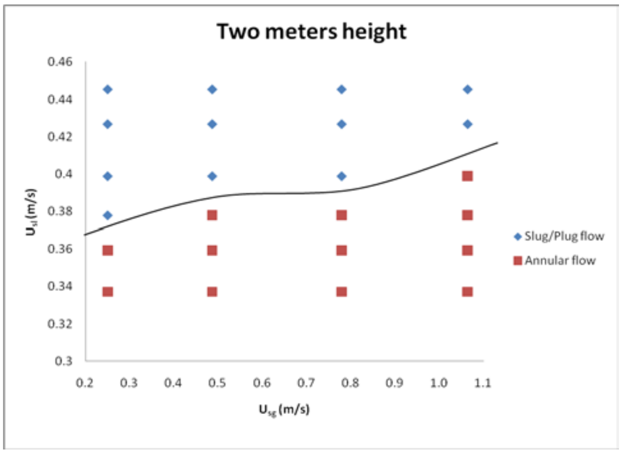


Figure 4. Mapping flow pattern of the air-water downward flow.

Flow pattern map in this experiment was compared with flow pattern map from Kendoush and Al-Khatab (1995) as shown in Figure 5. Flow pattern map which observed in this experiment has different position of of slug/plug - annular transition line.

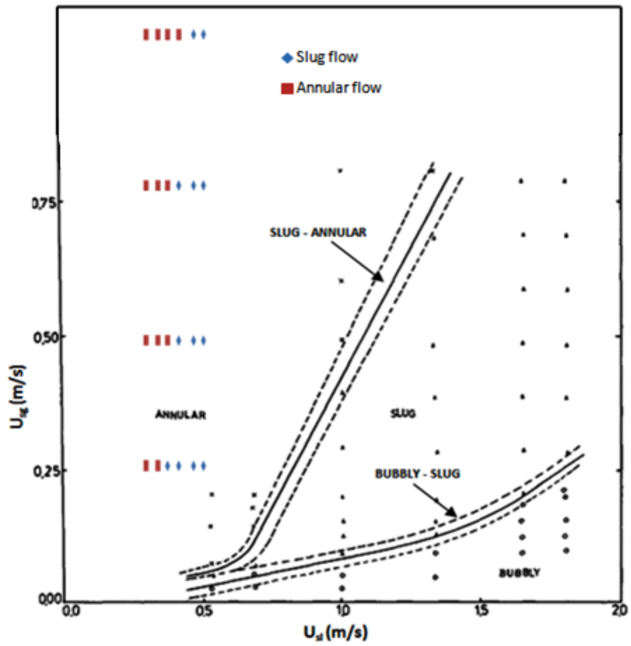
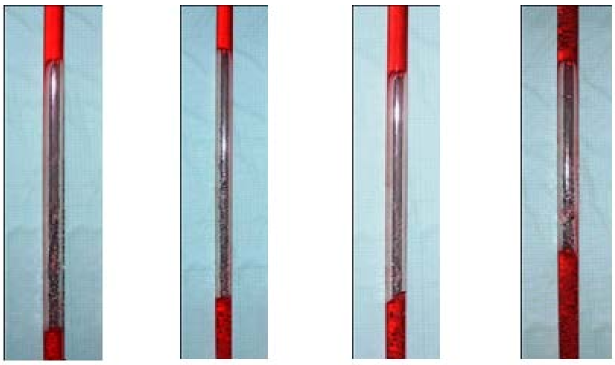


Figure 5. Mapping flow pattern at two meters height in Kendoush and Al-Khatab (1994) map.

Plug length is determined by the distance from head of plug to tail of plug. In Figure 6 shows that with increasing superficial liquid velocity on the gas superficial velocity is constant then the plug length decreases. This is because with the increase in liquid superficial velocity, then the fluid volume was also increased so that the volume of fluid is more dominant, therefore the plug length decreases, and vice versa.



U_{sg} = 0.25 m/s U_{sg} = 0.25 m/s U_{sg} = 0.25 m/s U_{sg} = 0.25 m/s
U_{sl} = 0.38 m/s U_{sl} = 0.4 m/s U_{sl} = 0.43 m/s U_{sl} = 0.45 m/s
L = 0.40 m L = 0.34 m L = 0.28 m L = 0.25 m

Figure 6. Plug length effect of increasing superficial liquid velocity at constant superficial gas velocity.

Plug velocity is measured from the chart digital voltage data as a function of time results of the reading of the sensor. Plug rate increases with superficial gas velocity increases at a constant superficial liquid. Plug velocity also increases with superficial liquid velocity increases at a constant superficial liquid as shown in Figure 7.

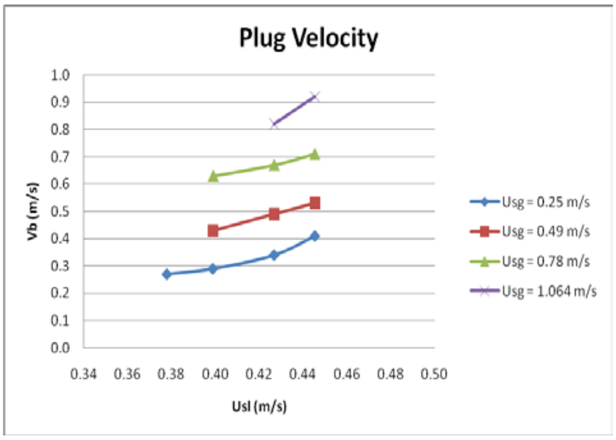


Figure 7. Plug velocity effect of increasing superficial liquid velocity at various constant superficial gas velocity.

Validation plug velocity data needed to determine the accuracy of velocity sensor, which is the way the data from the sensor compared to the video data. As Shown in Figure 8 that plug velocity data from sensor is quite accurate with plug velocity data from video.

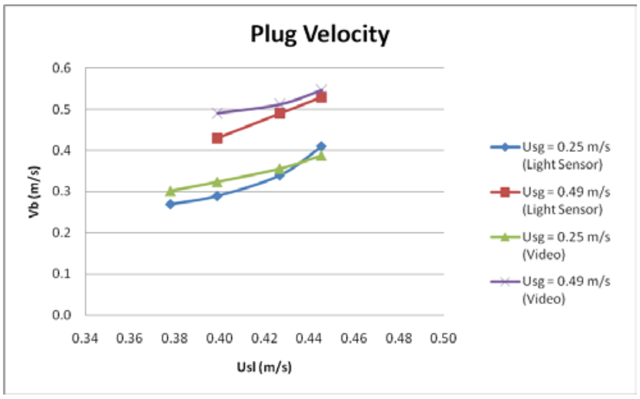


Figure 7. Plug velocity data from sensor compared with plug velocity data from video.

Conclusion

An experimental study on the flow patterns, measuring plug length and plug velocity in downward two-phase flow made with an isothermal air-water system leads to the following main conclusions:

1. Two distinct flow patterns were observed, slug/plug flow and annular flow.
2. Flow pattern map in this experiment is different and renew the map from previous researcher.
3. Plug velocity increases with increasing superficial gas and liquid velocity.
4. In a constant liquid superficial velocity, the plug will be more elongated along with increasing superficial gas velocity, and vice versa.

Acknowledgements.
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Nomenclature

U_{sg}	Gas superficial velocity (ms^{-1})
U_{sl}	Liquid superficial velocity (ms^{-1})
L	Plug length (m)
V_b	Plug velocity (ms^{-1})
Q_g	Gas flow rate (m^3kg^{-1})
Q_l	Liquid flow rate (m^3kg^{-1})

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