Experimental Study of Slug/Plug Flow on Co-Current Downward Two Phase Flow in a Vertical Pipe

Franky S. Kusuma, Barlian, Indarto, Deendarlianto, and Adhika W.

Department of Mechanical and Industrial Engineering, Gadjah Mada University
Grafika Street No.2, Yogyakarta, 55281
franky.ina@gmail.com

Abstract

In oil and gas industry, slug/plug flow are generally unwanted because they can create significant pressure fluctuations, and they can also lead to gas and liquid arriving at the processing facilities unevenly, causing tanks to flood. Since gas has lower density and therefore lower heat capacity than liquid, gas cool faster, so the temperature reduction during periods of high gas content can more easily cause hydrates to form. The increased intermittent liquid velocity can also accelerate corrosion. To have a better understanding of this phenomenon, experimental investigation of downward slug/plug flow was carried out in a 0.0191 m diameter pipe and the length of pipe is 8 m with water and air as process fluid. The objective of this experimental study is understanding the characteristics of downward slug flow with measuring velocity profile, pressure drop, plug length and film thickness. The superficial velocity of gas flow is observed from 0.22 m/s to 0.55 m/s. The superficial velocity of liquid flow is observed from 0.44 m/s to 1.1 m/s. The obtained data are taken at 2 m height over the outlet using digital camera which can record visual data with the frame rate is 240 fps. The obtained visual data are processed by image processing with MATLAB to observe film thickness, plug velocity, and plug length accurately. Two nose form of plug is observed which is affected by two factors. The velocity of the liquid and the buoyancy induced velocity of the bubble. As a result, pressure fluctuations on low plug velocity is more significant than on high plug velocity. The nose of the plug tends to move towards the pipe wall if there is no entrainment bubbles after the nose of the plug.

Keywords: slug/plug flow, downward, image processing

Introduction

Flow pattern maps for downward flow for a wide range of experimental conditions were observed by previous researchers such as Bhagwat et al. (2011), Kendoush and Al-Khatab (1994), and Barnea et al. (1982). From all of flow patterns that were observed, slug/plug flow is one of the most complex flow patterns and is intrinsically unsteady.

Slug/plug flow is a two-phase flow pattern observed when gas and liquid flow simultaneously in a pipe over a determined range of flow rates and is characterised by long bullet-shaped bubbles, also called plug, which occupy nearly the entire cross-section of the pipe. The liquid moves around the bubbles in a thin film and in the bulk between successive bubbles. The slug flow observed in the co-current downward flow is quite different from that observed in the upward flow. The characteristic bullet-shaped bubble or plug with its nose directing toward the flow direction and staying near the center of the pipe is substituted by a highly distorted, offcentered plug, and the nose opposites to the flow direction. Griffith and Wallis (1961) were probably the first to report the unstable motion of cylindrical bubbles in downward liquid flow, eccentrically located towards the pipe wall.

One of the most non-intrusive technique to analyze two phase flow is image processing. Polonsky et al. (1999) mention an image processing procedure for the study of the motion of individual Taylor bubbles. Moreover, Mayor et al. (2007) developed an image analysis technique for the study of continuous co-current gas–liquid slug flow in vertical columns.

The principal interest of this study was to identify pressure drop fluctuation, plug velocity, and film thickness which occurring in downward slug/plug 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 Fluid Mechanic Laboratory, Gadjah Mada University. This setup is capable of doing flow visualization through transparent test section and measuring the pressure drop. The schematic of overall experimental setup is shown in Figure 1 respectively. In the present study two phase flow was analyzed for air-water fluid combination and flowing through 0.0191 m ID plexiglass pipe. The height of the plexiglass pipe is 8 m. The experimental loop was an adiabatic vertical air–water system. The total length of the test section was 1 m corresponding to L/D = 300. Water was supplied by a centrifugal pump and controlled by valves. The water flow rate was measured by a liquid rotameter. Air was supplied by a compressor with pressure maintained by a pressure regulator at 1 bar gage. The gas flow rate was measured by a gas rotameter. Absolute pressure readings were taken by pressure transducer installed 2.3 m from the outlet.

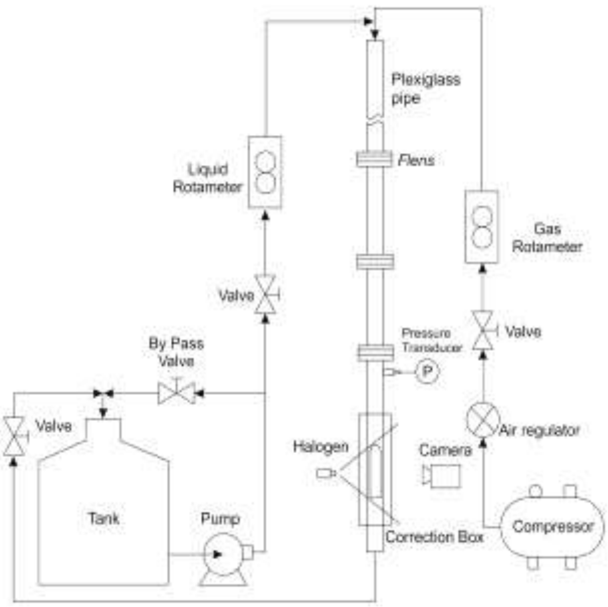


Fig. 1 Schematic of experimental set up

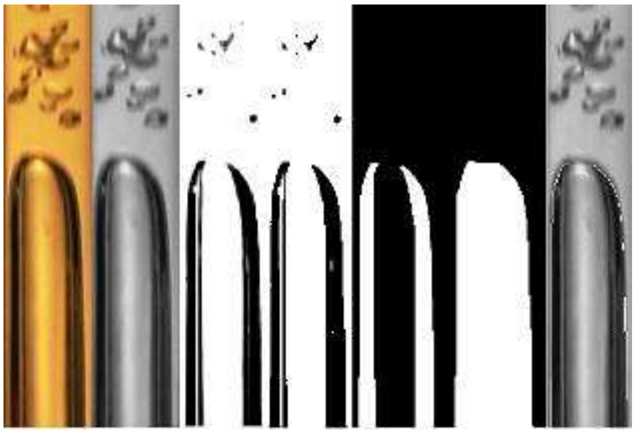
A rectangular transparent acrylic box (1 m long) filled with water was fitted to the column at the measuring test section, in order to reduce image distortion and heating effects from the light source (halogen) which is called correction box.

Images of slug/plug flow were recorded as videos using a Canon Power Shot 100S operating at a frequency of 240 Hz and producing images with the resolution 320 × 240 pixel. Each of the video files was loaded into the MATLAB workspace as a sequence of frames. Each frame corresponds to a snapshot of the camera field of view (a frame at each 0.0042 s corresponding to a frequency of 240 Hz).

Image Processing

In this present study, the procedures on image processing with MATLAB described below.

1. The images were loaded in 8 bit RGB format. This step is usually called image acquisition.
2. The images were converted from 8 bit RGB to 8 bit grayscale. The output images have 256 grey levels, ranging from 0 (black) to 255 (white). Further the images were cropped into desired size of the images.
3. The images were filtered to eliminate noise by implementing median filter technique. Median filter technique is similar to a uniform blurring filter which returns the mean value of the pixels in a neighborhood of a pixel.
4. The images intensity value or contrast was adjusted to get the better results when the images were converted into binary mode.
5. The images were converted into binary mode with tresholding technique. This technique consists in a reduction to two of the number of grey which one corresponding to black (0) and another corresponding to white (1).
6. The images were processed using morphology operation. In this operation, there were two techniques which used in this present study, Opening technique (a) and Closing techniques (b). Opening used to remove noise. Closing used to close the holes.
7. After binarization which created a black and white image that can be understood as a black background with white objects in the foreground, the images were labelled. The white objects were labelled using different grey levels to allow for easier observation of their positioning and dimensions. The aim of these process are to keep the desired objects and to remove noise. The outcome of every step of the procedure 1-7 is shown in the images of Fig. 2



(1) (2&3) (4) (5) (6a) (6b) (7)

Fig. 2 Sequential images in the image process

8. Post-processing the images. In this process, procedure to obtain plug film thickness was different with the procedure to obtain plug velocity profile. Tracing the

ISBN 978 979 8510 61 8

interfacial of the plug and calculating gap from the wall of the pipe was implemented to obtain film thickness data. Calculate the movement of nose and tail by using point reference from previous frame.

Results and Discussions

The plug form in co-current downward two phase flow was like bullet with its nose opposites the flow direction. Visual observation of the co-current downward slug/plug shape is necessary since limited information about it. The aim of the observation is to understand physical behavior and interfacial behavior of co-current downward slug/plug. Different superficial liquid velocity gave different shape of the plug as shown in Fig. 3. High superficial liquid velocity was presented by U_{sl} = 1.1 m/s. Low superficial liquid velocity was presented by U_{sl} = 0.44 m/s.

(a) (b)

Fig. 3 Two different shapes of the plug
(a) U_{sl} = 1.1 m/s and U_{sg} = 0.22 m/s
(b) U_{sl} = 0.44 m/s and U_{sg} = 0.22 m/s

At high superficial liquid velocity, the shape was not smooth and at several times, the plug was broken up as shown in Fig. 3(a). At this moment, the plug was not going straight down as like at low superficial liquid velocity, but was going down with zig-zag movement. At low superficial liquid velocity, the shape of the plug was smooth and unbroken as shown in Fig. 3(b).
There were two conditions where the nose of the plug followed by dispersed bubbles or not. It affected the nose form of the plug. The nose would be off-centered if the plug was not followed by dispersed bubbles. However the nose would be staying near center of the pipe if were followed by some bubbles. This phenomenon was shown in Fig. 4.

(a) (b)

Fig. 4 Two different nose forms
(a) U_{sl} = 0.77 m/s and U_{sg} = 0.22 m/s
(b) U_{sl} = 0.77 m/s and U_{sg} = 0.55 m/s

Figure 4 shows the influence of superficial gas velocity toward the nose form. At low superfial gas velocity there was just little of bubbles was formed. So the highest velocity of the liquid flow is in the center of the pipe. The liquid pushed the nose, so the nose form tends to the wall of the pipe. At high superficial gas velocity, there were some bubbles was formed upper the plug. The bubbles were like a barrier which obstructed the liquid flow before touching the nose. So, the inertia force from the liquid which was borne by the nose was less than if there was no bubbles followed the nose, and the nose formed concentric.
Figure 5 shows the results for the plug velocity,
for different background liquid flows, U_{sl}, and gas flows, U_{sg}.

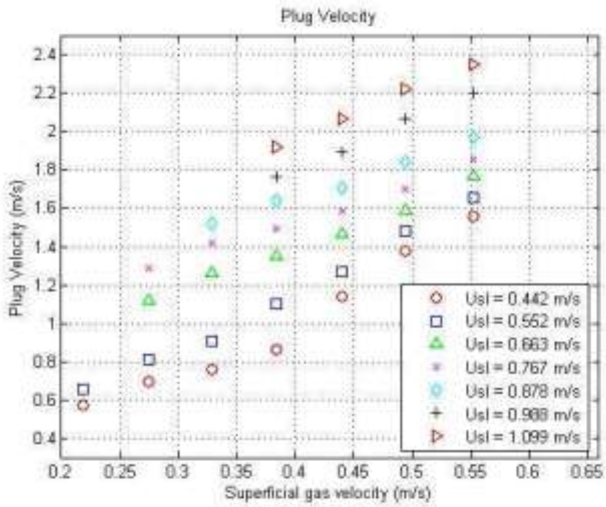


Fig. 5 Plug velocity profile

Before plug velocity data was obtained, nose velocity and tail velocity of the plug was measured by image processing using MATLAB. Plug velocity was obtained by calculating mean of nose and tail from each plug. Three until four representative plugs from each data variation was measured to obtain a valid data. As shown in Fig. 5, plug velocity data was observed from U_{sl} 0.442

ISBN 978 979 8510 61 8

m/s – 1.099 m/s and U_{sg} 0.22 m/s – 0.55 m/s. As the result, at a constant superficial liquid velocity, plug velocity increased as superficial gas velocity increased. At a constant superficial gas velocity, plug velocity also increased as superficial liquid velocity increased.

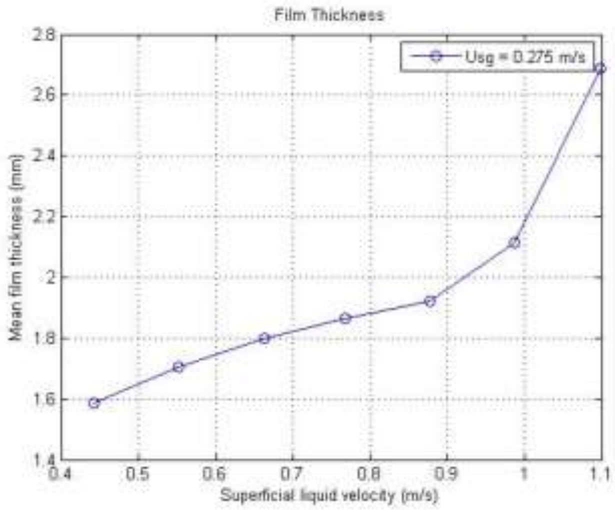


Fig. 6 Film thickness

Figure 6 shows the film thickness for the slug/plug flow at U_{sg} = 0.275 m/s as the function of superficial liquid velocity. Film thickness data was measured as mean of film thickness beside the body of plug which was processed by image processing using MATLAB. At a constant superficial gas, film thickness increased as superficial liquid velocity increased. The increase was not in linear curve since shear stress of the flow based on Newtonian fluid equation is not linear too as function of the width. However, at a constant superficial liquid velocity, film thickness was not in congruent with the descent of superficial gas velocity. It caused the friction at the wall of pipe was more considered than the descent of superficial gas velocity.

Figure 7 shows the fluctuation of the pressure drop for the slug/plug flow at U_{sg} = 0.22 m/s as the function of superficial liquid velocity. The experiment data was taken for 10 second and was completed with the visualization data to observe the physical phenomenon. The pressure transducer could take 667 pressure data per second. In this present study was observed that the amplitude of pressure drop was at peak on liquid slug form and was at valley on plug form. The upsurge of superficial liquid velocity was in congruent with the frequency upsurge of the plug. In the other hand, the upsurge of superficial liquid velocity was in congruent with the descent of pressure amplitude of the plug.

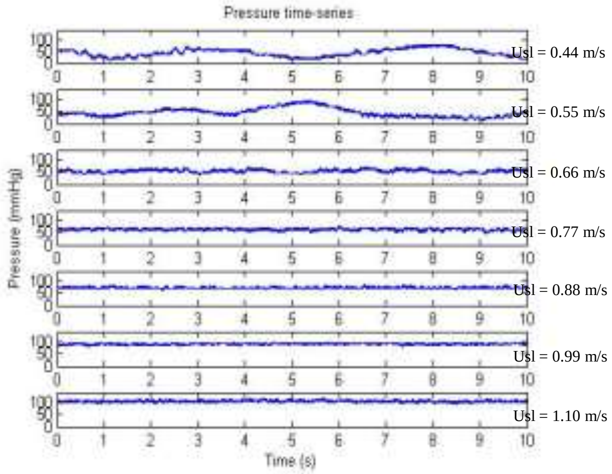


Fig. 7 Pressure drop fluctuation at U_{sg} = 0.22 m/s

Figure 8 shows the results for the pressure drop, for different background liquid flows, U_{sl}, and gas flows, U_{sg}. Pressure drop was obtained by calculating mean of pressure drop for 10 seconds. As shown in Fig. 8, pressure drop data was observed from U_{sl} 0.442 m/s – 1.099 m/s and U_{sg} 0.22 m/s – 0.55 m/s. As the result, at a constant superficial liquid velocity, pressure drop increased as superficial gas velocity increased. At a constant superficial gas velocity, pressure drop also increased as superficial liquid velocity increased.

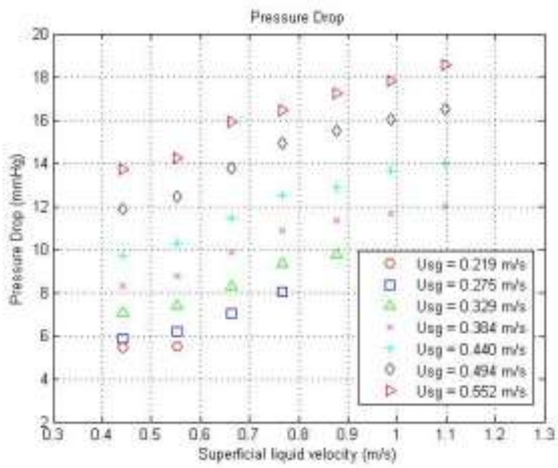


Fig. 8 Pressure Drop

As shown in Fig. 8, the change of superficial liquid velocity is more significantly affected pressure drop than the change of superficial gas velocity. It caused the density of gas is less than liquid.

Conclusion

An experimental study on the plug form, plug velocity profile, film thickness, and pressure drop in downward slug/plug flow made with an isothermal air-water system leads to the following main conclusions:

1. Two different shapes of the plug and two different nose forms were observed.

2. Plug velocity increased as superficial velocity increased.
3. Film thickness increased as superficial liquid velocity increased.
4. The upsurge of superficial liquid velocity was in congruent with the descent of pressure amplitude of the plug.
5. Pressure drop increased as superficial velocity increased.

Acknowledgements

The first author takes this opportunity to thank Shakti, Anindityo, Anggita, Akmal, and Hadiyan, for their invaluable assistance throughout this study.

Nomenclature

U_{sg} Gas superficial velocity (ms^{-1})
U_{sl} Liquid superficial velocity (ms^{-1})

Reference

Barnea, D., Shoham, O., Taitel, Y. Flow pattern transition for vertical downward two phase flow. Chemical Engineering Science, Vol. 37, pp. 741–744. (1982)

Bhagwat, S.M. & Ghajar, A.J. Flow patterns and void fraction in downward two phase flow. ECTC Proceedings ASME Early Career Technical Conference (2011)

Griffith, P., Wallis, G.B. Two-phase flow. Journal of Heat Transfer Vol. 83, pp. 307–320. (1961)

Kendoush, A.A. & Al-Khatab, A.W. Experiments on flow characterization in vertical downward two-phase flow. Experimental Thermal and Fluid Science, Vol. 9, pp. 34 – 38 (1994)

Mayor, T.S., Pinto, A.M.F.R., Campos, J.B.L.M. An image analysis technique for the study of gas-liquid slug flow along vertical pipes - Associated uncertainty. Flow Measurement and Instrumentation, Vol.18, pp. 139–147. (2007)

Polonsky S, Shemer L, Barnea D. The relation between the Taylor bubble motion and the velocity field ahead of it. International Journal of Multiphase Flow, Vol.25, pp. 957–975. (1999)