TWO PHASE FLOW IN LARGE DIAMETER PIPE

Abbas H. Sulaymon, Abdulah A. Kendoush, Ali A. Hassan, and Sami M. Zeboun
Chemical Engineering Department – College of Engineering – University of Baghdad – Iraq

ABSTRACT

Investigation of co-current vertical downward air-water flow was performed by using a 7.35 cm I.D. pipe. Three experimental distinct flow patterns were observed: annular, slug and bubbly. A flow pattern map was proposed and compared quantitatively with other three maps available in the literature to show the effect of tube diameter on the flow pattern map. The transition boundaries between the three flow patterns were found on the basis of void fraction values. Auto-transformer technique was used for void fraction measurement.

INTRODUCTION

There is a lack of published data concerning the flow patterns in vertical downward two-phase flow especially in large diameter pipes. Yamazaki and Yamaguchi [1] noticed the wispy-annular and the wetted wall flow in their 2.5 cm I D. pipe. Barnea, et al [2] produced two flow pattern maps, one for 2.5 cm I D. pipe and the other one for a 5.1 cm I D. pipe with only three patterns: annular, slug and dispersed bubbly flow. Troniewski and Spisak [3] proposed a flow pattern map for an air-mineral oil system and added two new flow patterns, core and stalactite flow. Kendoush and Al-Khatab [4] observed three distinct flow patterns: annular, slug and bubbly flow in their 3.8 cm I.D. pipe.

The aim of the present research is to standarize the flow patterns and produce a quantitative comparison with the literature to show the effect of tube diameter on the flow pattern map.

EXPERIMENTAL WORK

The schematic diagram of the experimental system [5] is shown in Fig. (1). It consists of an air compressor, a reservoir-separator tank, an air-water mixer, circulating pumps, a 7.35 cm I.D. and 3.25 m. long glass tube as a test section, and various other accessories. Tap water was circulated from the reservoir-separator tank, by means of four centrifugal pumps, to the test section through the air-water mixer. The reservoir-separator tank was opened at the top and contained one vertically fixed baffle and two fixed framed wire-mesh filters to completely achieved the air separation before water entering the pump section line. Care was taken to ensure the evaluation of entrapped air bubbles from the water flowing system. Air was supplied by the compressor and its flow rate was measured by a couple of calibrated rotameters connected in parallel. Water flow rate was measured by a calibrated turbine flow meter. The two-phase flow patterns were visualized for a wide range of flow rates (6-26 m^3/hr) and (0.2-11 m^3/hr) air. Absolute and differential pressure readings were taken by two pressure gauges located at the ends of the test section. The water and air used in the experiment were at ambient temperature (36 to 42 °C) and 136 kPa outlet pressure. The void fraction (α) was measured by an Auto-transformer technique which is a new method [6]. During the calibration of the Auto-transformer it was found that the optimum operating voltage (Vp.p) is 18v. The calibration of the Auto-transformer was achieved with stationary (no flow) system consisted of finite length glass test tube (the same diameter of the test section) Fig. (2) known geometrical size of empty plastic tube were inserted into filled tube with tap water to simulate the bubbles.

The flow pattern map, developed from direct visual observations, is shown in Fig. (3). Phase superficial velocities of water and air (Vsl and Vsg), respectively were used as coordinates (the superficial velocity is defined as the velocity that each phase would have if flowed at its specified mass flow rate through channel). Annular, slug and bubbly flow were observed distinctly. At low air flow rates, small bubbles were observed flowing randomly downward and tending to move away from the centerline of the tube. As the airflow rate increase at a constant water flow rate, bubble movement augments, and coalescence due to the more frequent collisions between them was noticed, and thus, larger bubbles were formed. Further increase of the airflow rates forces large slugs to move toward the central region of the tube, leaving a water film flowing down the walls of tube. Slugs pass alternately through a given station along the tube. It was noticed that the head of the bullet-shaped slug bubbles was pointed upward despite the downward direction of the flow. The length of the cylindrical slug bubble reached about 35 cm in some cases. Further increase in the airflow rate produced a fairly stable annular flow. The thickness of the water layer of the annular flow decreases as the flow rate increases.

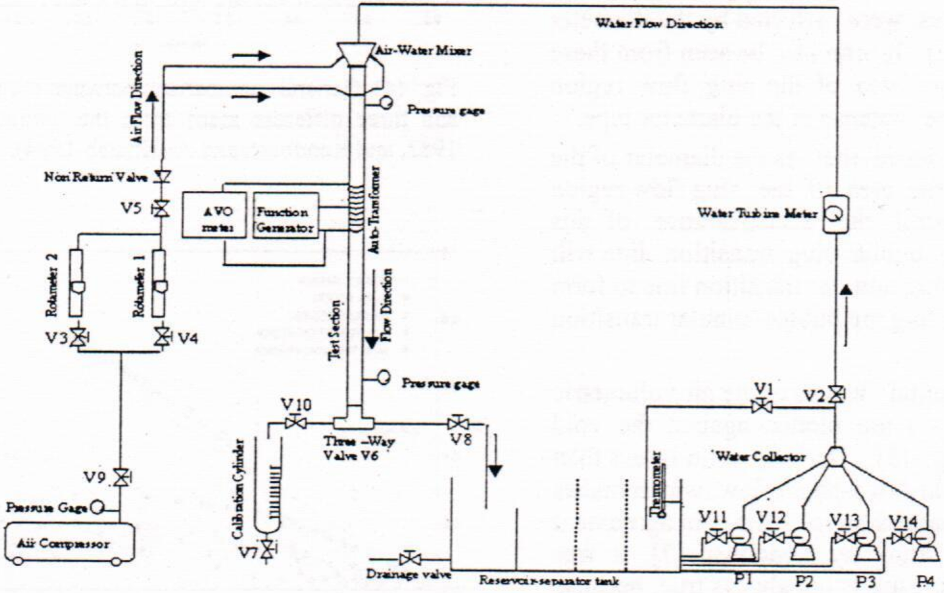

Fig. (1) Experimental arrangement of the auto-transformer used for void fraction measurement

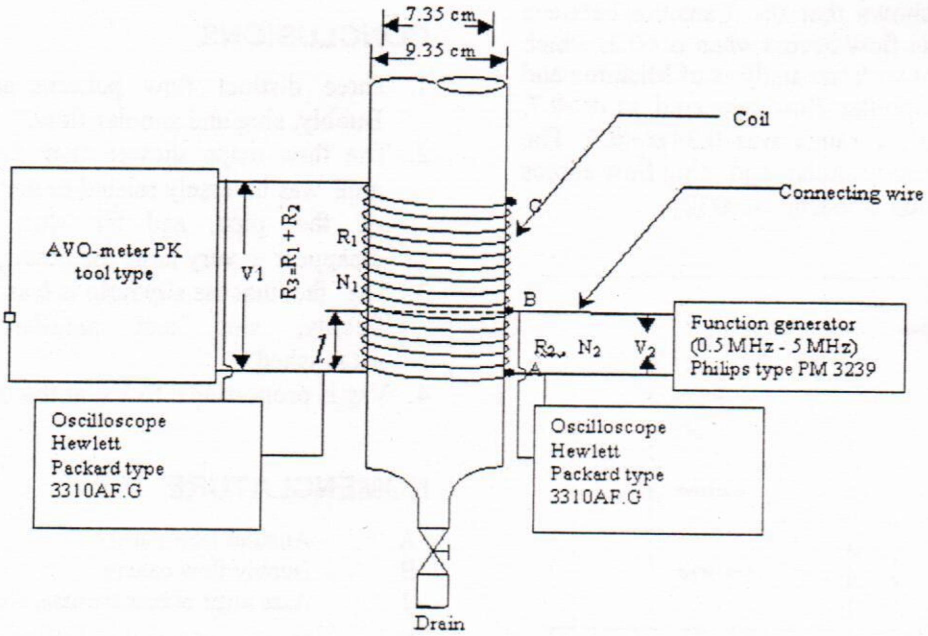

Fig. (2) The experimental arrangement of the auto-transformer used for void fraction measurement

RESULTS AND DISCUSSION

Figure (3) shows that the transition from bubbly flow to annular flow may occur directly without passing through slug flow in the case of lower water flow rates. At higher water flow rates, the transition requires high gas rate to take place.

Figure (4) shows a comparison between the present work and Barnea et al [2] and Kendoush and Al-Khatab results [4]. It is appeared that the general trends of the curves are approximately the same. The curves were affected by the diameter size of the pipes. It can also be seen from these Figures that the area of the slug flow region decreases with the increase of the diameter pipe.

It can be deduced that as the diameter of the pipe increases, the area of the slug flow region will decrease until the disappearance of this region (i. e. the bubble-slug transition line will combine with slug-annular transition line to form one line representing the bubble-annular transition bounding line).

The experimental values of the air volumetric flow fraction (β) are plotted against the void fraction (α) Fig. (5). The slip ratio is less than unity in downward two-phase flow, which makes values of α greater than β. This is in agreement with an earlier study by Kendoush [7]. It was noticed that this result is not always true, because in annular flow one can increase the airflow rate to any possible value to get a slip ratio ≥ 1.0. However, for the present experimental limited airflow rate used which was not enough to get this condition.

Figure (5) shows that the transition between bubbly and slug flow occurs when $\alpha = 0.3$, which is in agreement with the analysis of Mishima and Ishii [8]. The annular flow appeared at $\alpha > 0.7$, and the slug flow range was $0.3 < \alpha < 0.7$. The transition between annular and slug flow agrees with the prediction of Barnea et al [2].

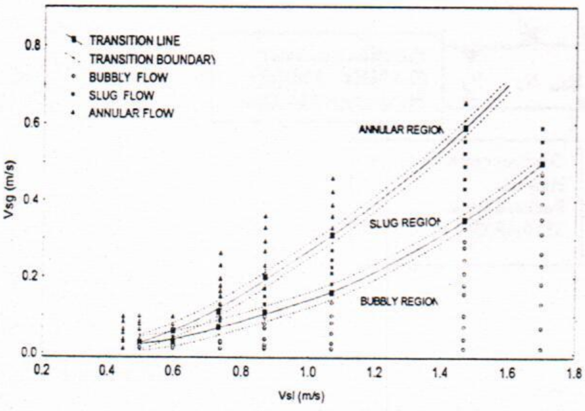

Fig. (3) Flow map of downloads two-phase flow

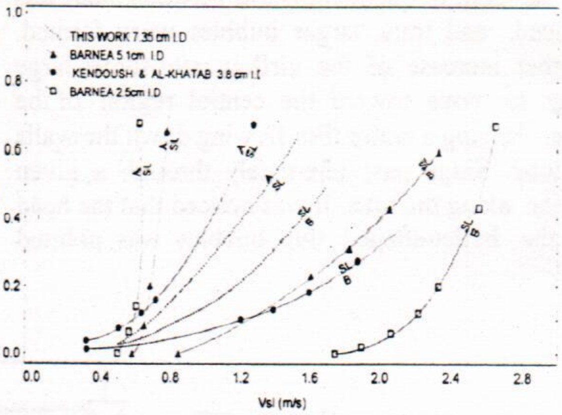

Fig. (4) General comparison between the present map and three different maps from the literature (Barnea 1982, and Kendoush and Al-Khatab 1994).

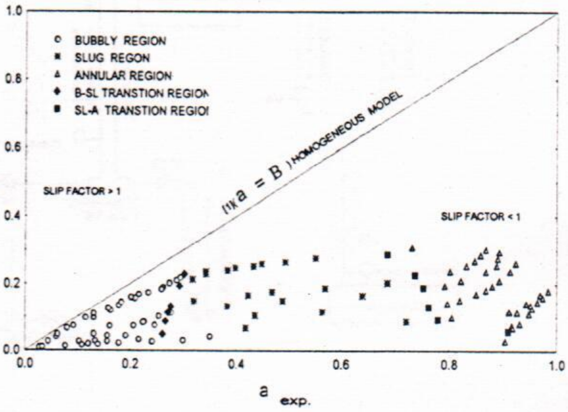

Fig. (5) β as function of α for different flow patterns

CONCLUSIONS

1. Three distinct flow patterns are observed: Bubbly, slug and annular flow.
2. The flow maps showed that the slug region area was inversely related to the diameter size of the pipe, and the slug pattern may disappear in very large diameter pipes.
3. The fact that the slip ratio is less than unity in bubbly, slug and annular flow was established.
4. Vsg is proportional to Vsl at the transition.

NOMENCLATURE

A	Annular flow pattern
B	Bubbly flow pattern
l	Axial length of input coil turns along test section, m
N_1	Number of output coil turns, dimensionless
N_2	Number of input coil turns, dimensionless
R_1	Resistance of output coil turns, Ω
R_2	Resistance of input coil turns, Ω

S	Slip ratio (= Vg / Vl), dimensionless
SL	Slug flow pattern
V_1	Potential difference across output lines, V
V_2	Potential difference across input lines, V
Vsg	Superficial air velocity, m/s
Vsl	Superficial water velocity, m/s

Greek Symbols

α	Void fraction, dimensionless
α_{exp}	Experimental void fraction, dimensionless
β	Volume dryness fraction, dimensionless

REFERENCES

1. Yamazaki, Y., and Yamaguchi,K, Characteristics of Co-current Two-Phase Downflow in Pipes, J. Nucl. Sci. Technol. 16, 245-255, 1979.
2. Barnea, D., Shoham, O., and Taitel, Y., Flow Pattern Transitions for Vertical Downward Two-Phase Flow, Chem. Eng. Sci. 37, 741-744, 1982.
3. Troniewski, L., and Spisak, w., Flow Patterns in Two-Phase Downflow of Gas and very Viscous Liquids, Internat. J. Multiphase Flow 13, 257-260, 1987.
4. Kendoush, A., A., and Al-Khatab, S., A. W., Experiments on Flow Characterization in Vertical Downward Two-Phase Flow. Experimental Thermal and Fluid Science Vol. 9, 1994.
5. Hassan, A. A., Two-Phase Flow in Large Diameter Pipe, M.Sc. Thesis, Depart. Chem. ,Coll. Eng., Univ. Baghdad, 2001.
6. Kendoush, A., A., and Sarkis, Z. A., A Nonintrusive Auto-Transformer Technique for the Measurement of Void Fraction, Experimental Thermal and Fluid Science, Vol. 139 pp.92-97, 1996.
7. Kendoush, A., A., Zaki, R. Y., and Shakir, B.M., Slip Measurement in Downward Two-Phase Bubbly Flow Using Cross-Correlation Technique, in Multiphase Transport: Fundamentals, reactor safety, Applications, T. N. Veziroglu, Ed., Vol. 5, pp. 2695-2707, Hemisphere Publishing, Washington, 1980.
8. Mishima, K., and Ishii, M., Flow Regime Transition Criteria for Upward Two-Phase Flow vertical Tubes, Internet. T. Heat Mass Transfer, Vol. 27, pp. 223-237, 1989.