EXPERIMENTAL AND THEORETICAL STUDY OF SLUG LENGTHS IN HORIZONTAL AIR-WATER INTERMITTENT FLOWS

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Abstract. *The slug flow is a very common occurrence in gas-liquid two-phase pipe flow. Usually slug flow is an undesirable flow pattern since the existence of long lumps of liquid slug that moves at high speed is unfavorable to gas-liquid transportation, and considerable efforts have been devoted to the prediction of the slug hydrodynamics characteristics. In the literature, some approaches were proposed to determine the slug length distribution or frequency at any desired position along the pipe. Those models assume a random or uniform distribution of small slug length at the pipe inlet, and they calculate the increase or decrease in each individual slug length, including the disappearance of the shorts ones, as they move down. In this work, theoretical results were compared with experimental data from tests performed in a horizontal acrylic 34 mm ID pipe with 5m of length downstream from the mixing point. Experimental slug length distributions were obtained from several tests conditions of air-water slug flow by using a capacitance two-channel probe with concave electrodes. The results shown discrepancies between the theoretical and experimental data, which may requires deep research on the models development.*

Keywords. *Horizontal Flow, Slugs Length Distribution, Capacitance Probe, Experimental and Modeling.*

1. Introduction

The concurrent flow of gas and liquid has great importance in a huge variety of devices, including petroleum, chemical and food industries. When they are flowing concurrently in a horizontal pipeline, a number of different flow patterns or regimes may be present, depending largely on the superficial velocities of both phases (Taitel and Barnea, 1976). One of the most common flow pattern is the slug flow, which is characterized by an intrinsic unsteadiness due to alternating of liquid 'slugs' containing small bubbles and filling the whole pipe cross section, and of regions in which the flow consists of a liquid layer over a elongated gas bubble. Its intermittent behavior causes high fluctuations of pressure and flow rate, so that an extremely careful design of the pipeline (valves, orifices, etc.) is required. Moreover, the low-frequency values of the slugs (few hertz) may be in resonance with the characteristic frequency of the pipeline itself, causing serious damages if not taken into account. Thus, the correct prediction of the slug frequencies or length distribution is essential in all practical applications. Being the slug length and slug frequency interconnected properties and they are very often alternatively used (Nicholson *et al*., 1978).

Horizontal slug flow initiates at near to the gas-liquid mixing point when waves of a stratified liquid grow until they reach the top of the pipe. Once this has occurred, the gas propels a slug of liquid rapidly down the pipe. Immediately preceding the slug of liquid is scooped up from the stratified liquid layer, whilst behind the slug, the liquid level drops until the whole process is repeated (Dukler and Hubbard, 1975, Taitel and Dukler, 1977). Slugs tend to be only a few pipe diameters in length at near to the mixing point. However, such short slugs tend to collapse as a result of the trailing bubble moving faster than the slug front. Many previous investigators (Moissis e Griffith, 1962, Shemer and Barnea, 1987) have suggested that the bubble velocity is related to the local maximum velocity in the liquid ahead of the bubble. For relative short slugs, the velocity profile is not fully developed at the slug rear and the maximum velocity may be considerably greater than that found at rear of longer slugs. Thus, short slugs collapse as the bubbles on either side of it coalesce. During this process, the extra liquid shed at the trailing end of the short slug is collected by the following one, which subsequently grows as a result. As the series of slugs and bubbles progress down at pipeline, the random distribution of slug lengths evolve until all slugs are longer than a particular minimum stable slug length, when the rate of liquid picked up from the preceding film equals the rate of liquid shed at the rear of the slug, and no further collapse of slugs then takes place, the full-developed hydrodynamic condition.

The length of slugs to be expected under intermittent flow is important for two reasons. Firstly, the statistical distribution of the slug lengths and the maximum likely slug length are important in the design of the processing equipment, as discussed before, even the slug catches must be capable of handling the range of slug lengths that can be produced. Secondly, all existing mechanistic models such as those of Dukler and Hubbard (1975), Taitel and Barnea (1990) require an estimate of the void fraction into the bulk liquid slug and the slug average length (or frequency) as an input for pressure drop and hold up calculations. The void fraction can be estimated from empiric correlations (Gregory *et al.,*1977, Abdul-Majeed, 2000), while the minimum stable liquid slug length was proposed to be in a range of 12-30 *D* (pipe diameters), which occurs at about 300 *D* downstream from the pipe entrance (Nicholson *et al*., 1978, Nydal *et* *al*., 1992). A more complicate condition occurs distant from the full-developed flow condition, at 150 *D* from the pipe entrance for example. Therefore, the random nature of the slug lengths request for a special treatment (Tronconi, 1990).

Barnea and Taitel (1993) and Cook and Behnia (2000) proposed two similar theoretical models to calculate the slug lengths distribution at some distance from the pipe entrance. Hence, the models calculate parametrically at each small time step the rear and front position of the each liquid slug and elongated bubble along the pipeline. Therefore, it was assumed a random or uniform distribution of small slug length at the pipe inlet, and calculated the increase or decrease in each individual slug length, including the disappearance of the shorts ones as they move down.

In this work, theoretical results obtained by those models were compared with experimental data from tests performed in a horizontal acrylic 34 mm ID pipe with 5m of length downstream from the mixing point (about 150 *D*). Experimental slug length distributions were obtained from several tests conditions of air-water slug flow, by using a capacitance two-channel probe with concave electrodes. The results shown discrepancies between the theoretical and experimental data, which may requires deep research on the models development.

2. Experimental Installation

Figure 1 shows a schematic of the experimental flow loop. The air supply system is composed of a reciprocating compressor, producing 19.1 m^3/h at 830 kPa, an air reservoir, *AR*, of 400 liters, to reduce pressure oscillations downstream, an air filter and pressure regulator, two needle valves, *VC1* and *VC2*, one for fine flow adjustment, and two turbine flow meters, *TM1* and *TM2*, of 3/4 and 1 1/2 inches, for measurement of the airflow rate, Q_G, with ranges from 1.1 to 11.0 and 8.8 to 88.0 m^3/h, and calibrated measurement uncertainties of $\pm$ 0.14 m^3/h and $\pm$ 0.41 m^3/h, respectively. A type T thermocouple, *T1*, and an electronic pressure gauge, *P1*, were used to measure the air temperature and manometric pressure.

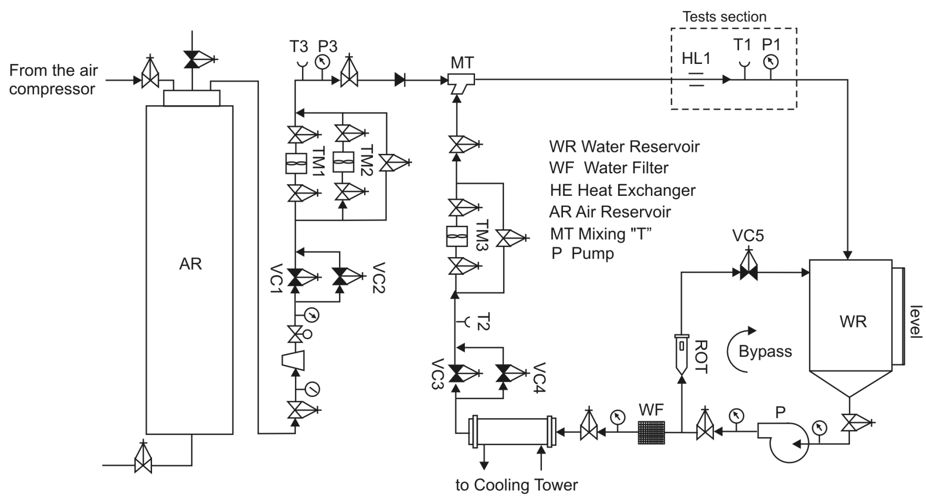

Figure 1. Experimental installation schematic

The water supply system was composed of a reservoir, *WR*, which also performed air-water separation; a centrifugal pump, *P*, with a capacity of 45 m^3/h at 274 kPa (75% efficiency); two water filters, *WF*, operating in parallel; a double tube heat exchanger, *HE*; two control valves, *VC3* and *VC4*, one for fine adjustment, and a turbine meter, *TM3* for measure the water flow rate, Q_L, which ranged from 3.0 to 45 l/min, with a measurement uncertainty of $\pm$ 0.23 l/min. A water-cooling system became necessary due to heating of the circulating liquid. A cooling tower supplied water close to the wet bulb temperature to the annular side of the heat exchanger. Tests were made with deionized water to avoid fouling the internal pipe walls, meters and valves. A type T thermocouple was used to measure the water temperature, *T2*.

The air-water flow system was composed by an 13 m long Plexiglas pipeline with an internal diameter, *D*, of 34 mm and a 3 mm of wall thickness, a junction with 45° branch arms, *TM*, which mixed air and water at the mixture point. The Plexiglas pipeline has about 5 m of length from *MT* to the tests section (150 *D*). Type T thermocouples were used to measure the temperature of air-water mixture, *T1*. A data acquisition system composed of a microcomputer, AT-MIO-16E10 board, connections block, and Labview 5.0, by National Instruments ™, was used to log all data from instruments.

3. Experimental Procedure

Tests were performed in several air and water flow rates and flow regimes, as shown in the flow map of Fig. 2 (Taitel and Barnea, 1976): test points 1, 2, 3, 4, 5, 6, 7, 8, and 9, which are on the external perimeter of the region represented by a dark gray polygon that is placed into the slug flow region on the map. Superficial velocities of air, $u_{GS} = Q_G / A$, from 1.3 to 6.0 m/s, and of water, $u_{LS} = Q_L / A$, from 0.20 up to 0.8 m/s were studied, where Q_G and Q_L are the flow rates of gas and liquid, and A is the internal pipe cross sectional area. As can be seen, some tests were near to the flow transition lines that were not studied on the subject of this work.

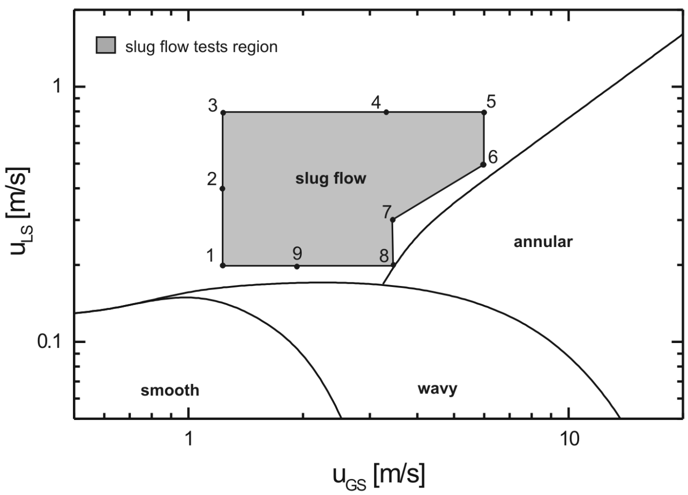

Figure 2. Tests flow map

Volumetric flow rates of air and water through *TM1* or *TM2* and *TM3*, shown in the Fig. 1, temperature of water *T2*, temperature of air, *T3*, manometric pressure and temperature of the air-water flow mixture, *P1* and *T1,* and signals from the capacitive probe, *HL1*, all these parameters were logged by the data acquisition system. Temperatures and manometric pressure measurements were used to determine de fluids properties as viscosity and density.

For each test, the number of samples, n, and the data acquisition rate, f, both were adjusted so that the acquisition time was always equal to 300 seconds (5 minutes). Therefore, the f values were equal to 800 Hz for test points 1, 2, 3 and 9, which had the smaller flow velocities (~1.5 m/s), 1500 Hz for points 4, 7 and 8, and 2500 Hz for points 5 and 6, which had the highest flow velocities (~6.5 m/s). This corresponded, for example, to n = 240000 samples acquired at 800 Hz. The use of high data acquisition rates was due to the temporal resolution of the probe data demanded by the cross correlation technique, as discussed below.

4. Slug Lengths Measurement Technique

The instrumentation adopted for this investigation to measure the liquid slug lengths is based on the capacitive method. The measurement device comprises a capacitive electrode system, a sinusoidal signal source and a capacitance transducer circuit, as shown in Fig. 3 (Reis and Goldstein Jr, 2003, Reis and Goldstein Jr, 2005). Two sensing electrodes, each connected to a capacitance transducer channel, and one source electrode, connected to the sinusoidal signal source, were used. By using two sensing electrodes, it was possible to determine the mean translational velocity of slugs, u_m, by applying the cross correlation technique to the logged voltage data from channels 1 and 2, shown in Fig. 4, which gives the mean time of delay between these signals, τ_m, (Yang *et al.,* 1997), and the mean flow velocity was calculated by $u_m = L / \tau_m$, where L is the distance between both thin sensing electrodes.

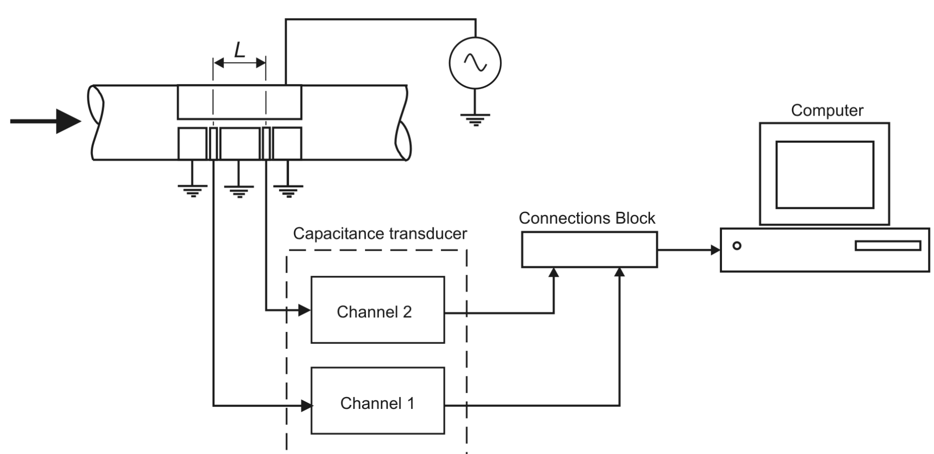

Figure 3. Schematic of the capacitive probe with two channels

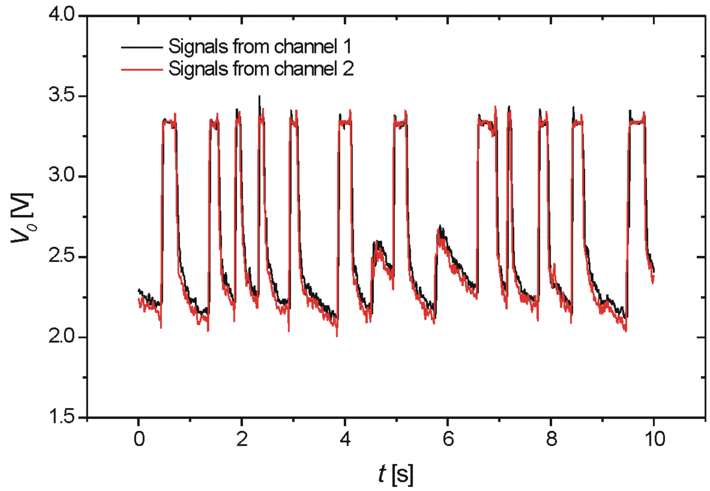

Figure 4. Output voltage signals from both probe channels with u_{LS} = 0.80 m/s and u_{GS} = 1.36 m/s

The voltage signals, V_o, from channel 1 at upstream can be converted in liquid film thickness measurements, h_L/D, as discussed by Reis and Goldstein Jr (2005). Simultaneously, another signal analysis technique to calculate the time interval, which each liquid slug passes through the measurement section, can be applied (Nydal *et al*., 1992, Mi *et al*., 2000). Since the probe signals are related to the liquid film thickness, their behavior during the elongated bubbles or liquid slugs passage are distinct so that it is possible to separate them in a time series, as shown in Fig. 5, where V_{aux} is an auxiliary variable which was defined as

$$\begin{cases} V_{aux} = 0 \quad if \quad \dfrac{h_L}{D} \leq \left(\dfrac{h_L}{D}\right)_b \\ V_{aux} = 1 \quad if \quad \dfrac{h_L}{D} > \left(\dfrac{h_L}{D}\right)_b \end{cases} \tag{1}$$

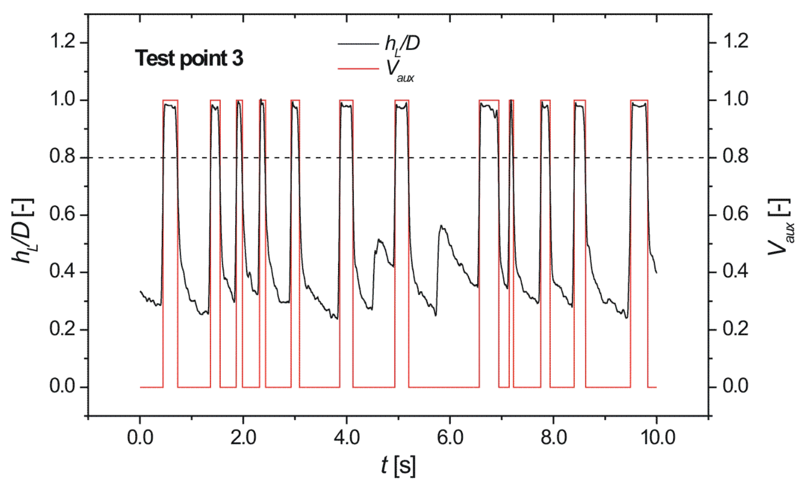

Figure 5. Graph of h_L/D and V_{aux} versus time t with u_{LS} = 0.80 m/s and u_{GS} = 1.39 m/s

The parameter $(h_L/D)_b$ was chosen analyzing a signal sample avoiding take larger waves as liquid slugs. For example, a 10 s signal sample acquired at test point 3 of Fig. 2 is shown in Fig. 5. A series of small and large waves gave their impressions on the probe signals, and at 6.0 s a larger wave could be considered as a liquid slug if $(h_L/D)_b$ = 0.5, which represent an error when computing the slugs. However, $(h_L/D)_b$ = 0.8 was used to calculate V_{aux} shown in the figure, which was distant from the signal peaks related to high waves into the body of the elongated bubbles. A computational program in FORTAN 90 was built to calculate the V_{aux} values related to each h_L/D sample given by Eq. (1), and the time interval Δt of passage of each liquid slug by considering the changes on the V_{aux} values from 0 to 1, slug head time t_i, and from 1 to 0, slug tail time t_f, and $\Delta t = t_f - t_i$ (Reis, 2003). Being the number of slugs registered during the test is $N_{S,total}$, the length of the slug number i, where i = 1, 2, 3, …, $N_{S,total}$, can be computed by

$$l_{s,i} = u_m \; \Delta t_i \qquad (2)$$

5. Results and Discussion

The experimental values of the mean flow velocities, u_m, were compared to an empiric correlation due to Bendiksen (1984) of the translational velocity of the elongated bubble, u_t, as shown in Fig. 6, where the gradient is equal to 1.2 for turbulent flow, and $u_S = u_{LS} + u_{GS}$ is the superficial velocity of the gas-liquid mixture. The figure show the comparison of u_m and u_t among the points 1 to 9. A good agreement was observed, except for points 6, 7, 8 and 9, which correspond to flow conditions near the flow pattern transition lines in the map of Fig. 2. This fact was related to the discontinuities of the velocity along the gas-liquid flow across the measurement section, that is, high and low velocities are present in the same flow test, where the higher velocities liquid slugs were followed by slower waves. These discontinuities in did not allow the cross correlation technique to determine a correct mean time delay between the signals from each probe channel. Therefore, in a general way, the cross correlation technique presented deficiencies when the flow was characterized by the presence of low velocity and large waves into the elongated bubbles region.

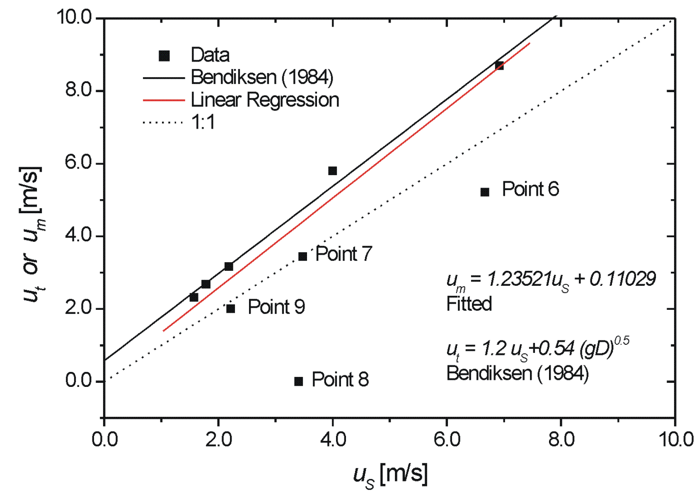

Figure 6. Mean slug flow velocity, u_t, for all test points and empirical correlation of Bendiksen (1984)

Figure 7 shown the graphs of h_L/D and V_{aux} of test point 5, which is similar to the Fig. 5 of test point 3, however, with $(h_L/D)_b$ = 0.6. It can be observed that, as the liquid slugs pass through, the signals do not reach h_L/D = 1.0, which represents the tube upper surface. This fact is associated with the high concentration of small gas bubbles present in the slugs, which cause a reduction in the effective dielectric permittivity of the phases between the electrodes of the capacitive probe. In this flow condition, the liquid slugs are shorter and highly aerated by small bubbles due to higher gas flow velocity; consequently, sharper signal peaks represent the liquid slugs.

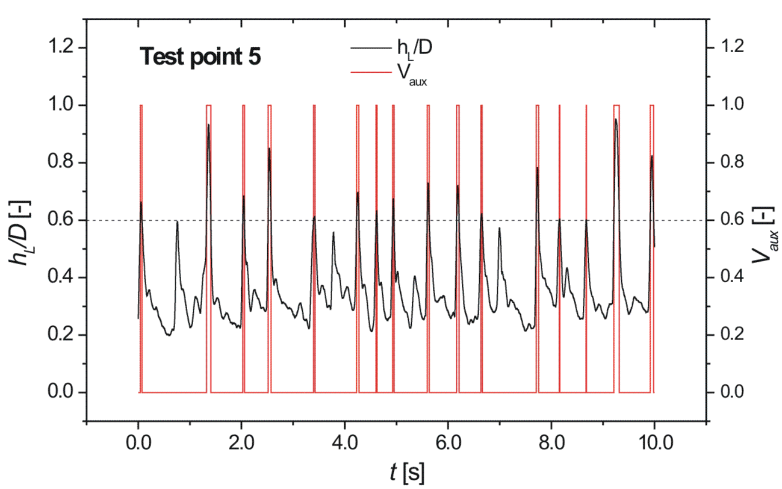

Figure 7. Graph of h_L/D and V_{aux} versus time t with u_{LS} = 0.79 m/s and u_{GS} = 6.13 m/s

Figure 8 is the same of Fig. 7, however, it was obtained at test point 7 with $(h_L/D)_b$ = 0.75. It shows the probe response signal corresponding to a condition near the wavy-slug flow transition line, as can be seen in Fig. 2. One can observe a sequence of elongated gas bubbles intercalated by liquid slugs, represented by sharp high peak signals, and the presence of small peaks of signal in the liquid slugs correspondent to large waves.

In the flow conditions presented in the Figs. 7 and 8, the liquid slugs are represented by sharp high peak signals that could be confused with larger waves. To avoid this erroneous condition in choosing the $(h_L/D)_b$ value that could also cause a erroneous calculation of the slug lengths distribution, some attempts were made to obtain a suitable histogram of these data, as shown in Figs. 9, 10 and 11, so that a normal or chi-square distribution of data was expected (Barnea and Taitel, 1993, Cook and Behnia, 2000), however, a large number of shorts slugs had place in the histograms if larger waves are computed as slugs, since these waves had sharper peaks and appeared as shorter slugs. Oppositely, the problem in choosing $(h_L/D)_b$ was not present in flow condition shown in Fig. 5 of test point 3, since the slugs passage was evident about h_L/D = 1.0.

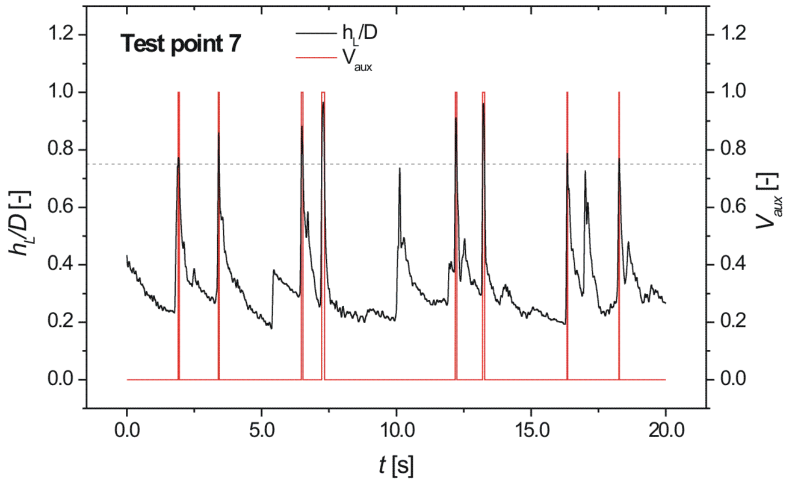

Figure 8. Graph of h_L/D and V_{aux} versus time t with u_{LS} = 0.30 m/s and u_{GS} = 3.17 m/s

Figures 9, 10 and 11 show the histograms of slug lengths over t_a = 300 s of data acquisition of test points 3, 5 and 7, respectively. The number of slugs of each interval or family in the vertical axis, N_S, was normalized by the total number of slugs, $N_{S,total}$. Even the non-dimensional lengths of slugs, l_S/D, among the intervals or families are present in the horizontal axis. It was given a series of data such as $N_{S,total}$ and $f_S = N_{S,total}/t_a$, and also the mean slug length, $l_{S,mean}$, and the standard deviation of the sample, S_{ls} on the right upper side of each graph.

In Fig. 9 of test point 3, the water flow rate was higher while the airflow rate was lower. This fact had produced long ($l_{S,mean}$ = 17.86 D) and low velocity (u_m = 3.17 m/s) slugs flowing through the pipeline. A number of 397 of them were computed having a 'normal' distribution of lengths, while their frequency of passage was about 1.32 slugs/s. From the test point 3 to 5 the airflow rate was increased by 440% while the water flow rate was the same, Fig. 10, the result was a decrease of the slug lengths ($l_{S,mean}$ = 11.30 D) and an increase of their mean velocity (u_m = 8.70 m/s). In this condition, a higher number of 429 slugs were computed with f_S = 1.43 slugs/s that was only about 8.1% greater than one of test point 3. From the test point 5 to 7, both the airflow and the water flow rates flow were decreased by about 45 and 62%, respectively as shown in Fig. 11, the result was a hard decrease of the slug lengths ($l_{S,mean}$ = 5.69 D), frequency of passage (f_s = 0.320 slugs/s) and their mean velocity (u_m = 3.44 m/s) near to the test point 3. Therefore, a low number of 96 slugs were computed. Besides the histogram of Fig. 11 shows a deformation of the 'bell shape' characterized by the 'normal' distribution, hence it gives a chi-square impression due to some slugs registered as having higher lengths about 17 D that is far away from the sample mean.

Table 1 presents experimental data of all test point, in which can be observed the values of $l_{S,mean}$ and S_{ls} having no significance in test 8 due to an erroneous calculated value of u_m, Fig. 6. Therefore, in a general way, $N_{S,total}$ and f_S increased while $l_{S,mean}$ and S_{ls} decreased when the flow rate of mixture was increased.

Theoretical models for the statistical evolution of liquid slugs along a pipeline (Barnea and Taitel, 1993, Cook and Behnia, 2000) calculate parametrically at each small time step the rear and front position of the each liquid slug and elongated bubble along the pipeline, as discussed in the item 1. Therefore, they assumed a random or uniform distribution of small slug length at the pipe inlet, and calculated the increase or decrease in each individual slug length, including the disappearance of the shorts ones as they move down. In addition, these models require an empirical correlation of the translational elongated bubble velocity as function of the liquid slug length ahead of it as an input.

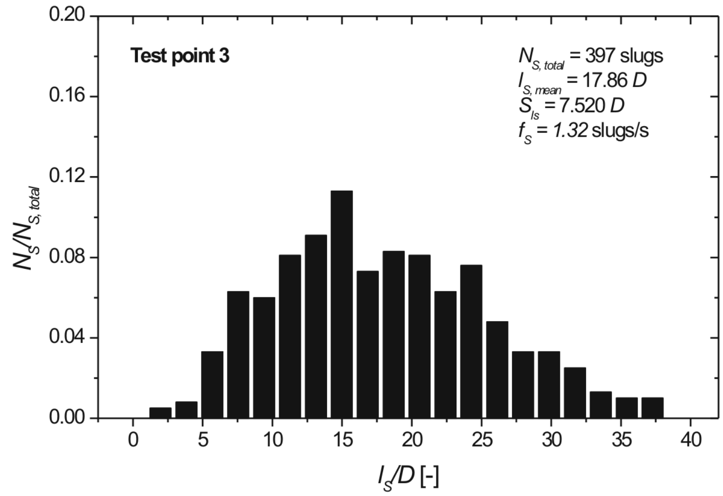

Figure 9. Slugs lenght histogram from experimental data with $u_{LS} = 0.788$ m/s and $u_{GS} = 1.392$ m/s

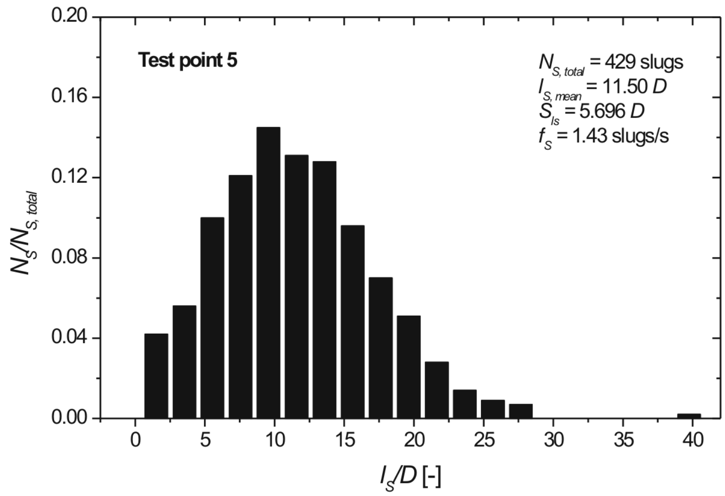

Figure 10. Slugs lenght histogram from experimental data with $u_{LS} = 0.788$ m/s and $u_{GS} = 6.131$ m/s

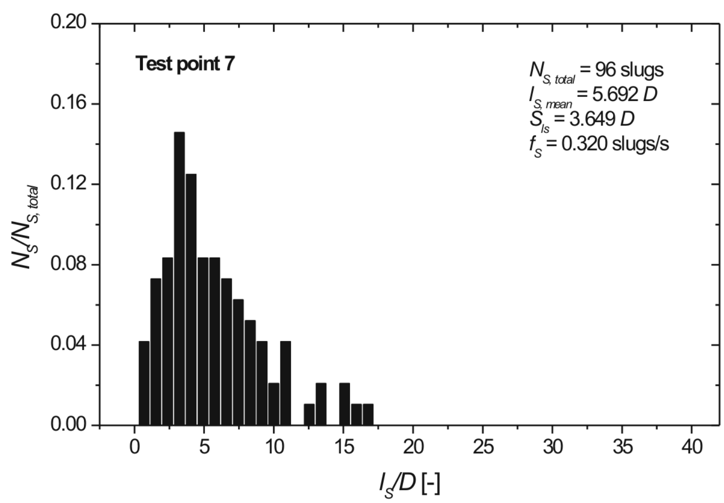

Figure 11. Slugs lenght histogram from experimental data with $u_{LS} = 0.198$ m/s and $u_{GS} = 1.371$ m/s

Table 1. Experimental data of tests 1 to 9

Test	$N_{S,total}$[slugs]	$l_{S,mean}$ [D]	S_{ls} [D]	f_S [slugs/s]
1	54	27.9	12.34	0.180
2	158	20.3	9.95	0.527
3	387	17.9	7.52	1.32
4	293	13.9	7.37	0.977
5	429	11.5	5.70	1.430
6	245	6.14	3.65	0.817
7	96	5.69	3.65	0.320
8	70	0.00581	0.00377	0.233
9	60	12.36	5.90	0.200

In early 60s, Moissis and Griffith (1962) studied the vertical upward gas-liquid flow and measured the rise velocity of trailing bubbles behind an elongated bubble. They expressed this velocity as a function of the separation between the leading and the trailing bubbles, and the authors suggested an exponential relation of the form

$$u_B = u_t\left[1+8\exp\left(-1.06\frac{l_s}{D}\right)\right] \tag{3}$$

where l_s is the slug length ahead of the bubble and u_t is the translational bubble velocity in full-developed hydrodynamic condition (Bendiksen, 1984). This equation is an average result for data taken primarily at low liquid and gas flow rates and pipe diameters in the range of 12 to 50 mm. Barnea and Taitel (1993) adopted this equation assuming the coefficients of the exponential term as 5.5 and –0.6, respectively, which was their fit to the Moissis and Griffith data. Cook and Behnia (2000) proposed a similar correlation; therefore, it was based in experimental results of bubbles motion in a 50 mm ID near to horizontal pipeline (+5°) with velocity below 3.0 m/s,

$$u_B = u_t\left[1+0.56\exp\left(-0.46\frac{l_s}{D}\right)\right] \tag{3}$$

In this work, the correlation of Cook and Behnia (2000) was adopted in the model for instance. A total of 500 slugs were introduced in the pipeline, which had a diameter of 34 mm installed at horizontal position (0°), as discussed before. A computational program in FORTRAN 90 was built, and a time step of 0.005 s was set and both uniform and normal statistical distribution between 2 and 8 D of slug length were taken at pipe inlet (Reis, 2003). Therefore, the same measured values of u_{LS} and u_{GS} were used in these calculations.

The histograms of simulations are shown in the Figs. 12-17 of the test points 3, 5 and 7 assuming both statistical distributions at inlet. When compared to the experimental histograms, Figs 9 to 10, they show the theoretical slug lengths of tests 3 and 5 smaller than their experimental ones, with both smaller $l_{S,mean}$ and S_{ls}. In opposition, theoretical data of test point 7 are greater than the experimental one, however, they are more precise and cover almost the same range of l_S/D with a quite difference of $l_{S,mean}$ and close values of S_{ls}, and the same had occurred in test 6, as can be seen in Tables 2, which shown the theoretical results of each test point taking a normal distribution of slugs at pipe inlet. Therefore, one can suppose that deviations should be associated to the value chosen of $(h_L/D)_b$ during the experimental data reduction stage, as discussed in the item 4, however, any long slug above 20 D were registered in both test points showing that all them as truly short.

Table 2. Theoretical data with normal distribution

Test	$N_{S,total}$[slugs]	$l_{S,mean}$ [D]	S_{ls} [D]
1	104	9.84	4.11
2	115	9.92	4.30
3	119	10.3	4.16
4	104	9.07	3.95
5	77	8.53	3.73
6	58	8.93	3.98
7	81	9.22	3.60
8	72	9.15	3.96
9	98	9.02	4.14

In a general way, theoretical data had few variations of $l_{S,mean}$ and S_{ls} if normal of uniform distribution are considered, having this parameter minimal influence on the results. It was also verified the same occurring if a range of slug at inlet is different from 2 to 8 D, as 4 to 6 D or 0 to 8 D. Consequently, it can observed the correlation of the bubble velocity as a function of the slug length ahead of it, Eq. 3, is of the primordial importance to the model. However, few correlations of this type are presented in the literature for horizontal flow (Rosa, 2004).

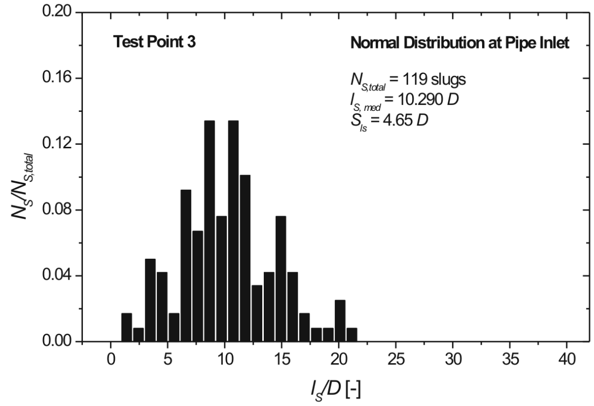

Figure 12. Normal distribution at pipe inlet. Test 3

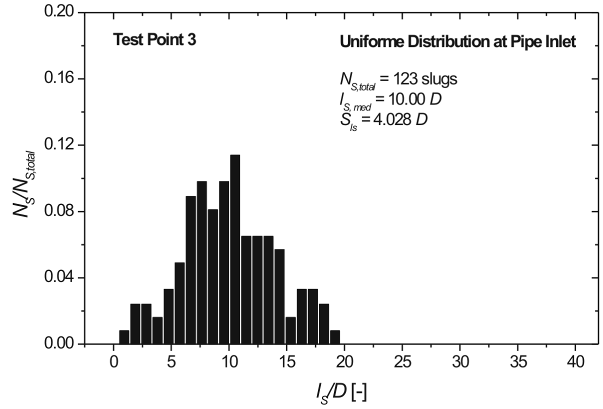

Figure 15. Uniform distribution at pipe inlet, Test 3

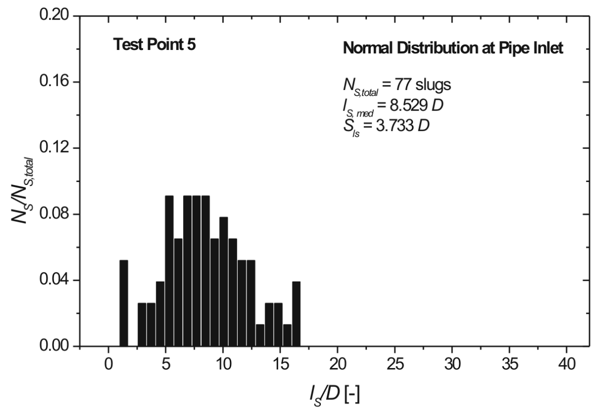

Figure 13. Normal distribution at pipe inlet. Test 5

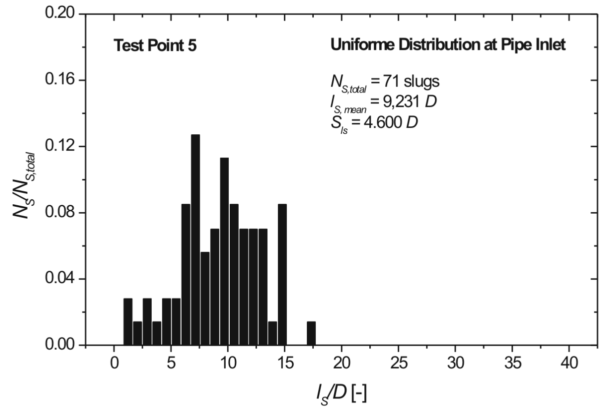

Figure 16. Uniform distribution at pipe inlet, Test 5

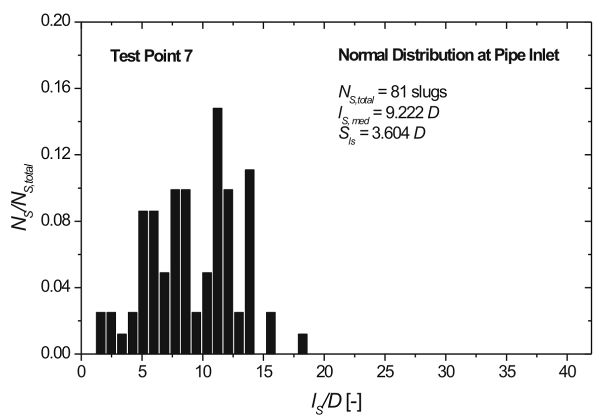

Figure 14. Normal distribution at pipe inlet. Test 7

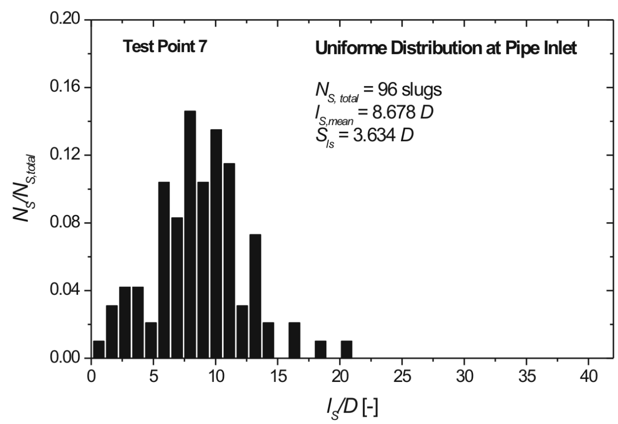

Figure 17. Uniform distribution at pipe inlet, Test 7

6. Conclusion and Remarks

This paper presents a study about the statistical distribution of slug lengths in a horizontal acrylic 34 mm of diameter pipeline at 150 *D* of length downstream from the mixing point, which characterized the slug flows as out of the full-developed hydrodynamic condition. Theoretical results obtained by model of Barnea and Taitel (1993) and Cook and Behnia (2000) with both normal and uniform short slugs distributions at pipe inlet were compared to experimental data, which were obtained by registering 300s of data from a capacitive two-channel probe at several slug flows under different superficial velocities of air and water. Being several of them at neat to the stratified-slug and annular-slug transition lines on the flow pattern map.

The main experimental results show some erroneous calculations of the mean velocity of the flow near o the transition lines, which were related to discontinuities of the velocity along the gas-liquid flow across the measurement section. This did not allow the cross correlation technique to determine a correct mean time delay between the signals from the capacitive probe. However, a good approximation was observed to the correlation of Bendiksen (1984) in general data. Experimental data also concerned about the importance of choosing an adequate value of the parameter $(h_L/D)_b$ during the data reduction stage, which must avoid to take larger waves as liquid slugs.

Theoretical results showed the short slugs distribution at pipe inlet having minimal influence on the results, and the same occurred if a range of slug at inlet. Consequently, the correlation of the bubble velocity as a function of the slug length ahead of it showed of the primordial importance to the model. Nevertheless, few correlations of this type are presented in the literature for horizontal flow.

Finally, when experimental and theoretical data were compared, no good agreements were observed, at least at two tests when the flow velocities were high and the slugs were short. Being in general the theoretical ones having slug lengths distribution with ranges smaller than those experimental ones, which indicates the necessity of improvements on the models mainly of its dependence on the correlation of the bubble velocity as a function of the slug length ahead of it.

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8. References

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