23rd ABCM International Congress of Mechanical Engineering
December 6-11, 2015, Rio de Janeiro, RJ, Brazil

BUBBLE EFFECT ON PRESSURE DROP REDUCTION IN HORIZONTAL PIPE FLOW

Jessica Lorrany Ferreira Barbosa
Diego Lourenço da Costa Felipe
Universidade Federal do Pará, Rua Augusto Corrêa, 01 – Guamá, Belém-Pará
lorrany-barbosa@hotmail.com
diego_felipe95@hotmail.com

Distefano Lima Martins Barbos
Marcelo de Oliveira e Silva
Danielle Regina da Silva Guerra
Universidade Federal do Pará, Rua Augusto Corrêa, 01 – Guamá, Belém-Pará
delimamb@gmail.com
mos@ufpa.br
daguerra@ufpa.br

Abstract. *In this paper, the bubble effect on the pressure drop caused by frictional losses in horizontal pipe flow was investigated. Pressure drop reduction in variable Reynolds numbers between 100 and 1000 and void fraction values between 0 and 0.8 was investigated on a 4m test section. The diameter of bubbles injected into the flow was almost 10cm and slug flow patterns was observed. Increasing Reynolds number in constant void fraction makes the bubbles move away from the up pipe and decreases the pressure drop reduction level. Increasing void fraction increases the bubbles effect on the frictional stress and decreases the pressure drop in the pipe. Furthermore, in lower Reynolds numbers, the void fraction effect on drag reduction is greater than its effect in higher Reynolds numbers. In the present study, the higher pressure drop reduction was observed in the maximum void fraction and least studied Reynolds number (1000). Even in very low void fraction, drag reduction was observed in greater Reynolds number. The obtained values of pressure drop reduction indicate that the bubble injection into pipe flow can be used to decrease the flow transfer costs.*

Keywords: *Slug Flow, Pipe Flow, Drag Reduction, Two phase flow.*

1. INTRODUCTION

Decrease drag by bubble injection to a turbulent boundary layer is one of the best methods of viscous drag reduction. This method was used at the first time by McCormick and Battacharyya (1973). Most research on drag reduction by micro-bubbles has included flows around a submerged body (McCormick and Bhattacharyya, 1973 and -b; Fontaine et al., 1999), fully developed and channel flow (Mazzitelli et al., 2003-a and –b; Takahashi et al., 1997; Guin et al., 1998; Kodama et al., 2000; Kanai & Miyata, 2001; Kawamura & Kodama, 2002; Marchioli & Soldati, 2002; Xu et al., 2002; Lu et al., 2005; Hassan & Gutiérrez-Torres, 2006; Gutiérrez-Torres et al., 2008; Nan-sheng & Bao-guo, 2011), and flows over flat plates (Madavan et al., 1985; Kato et al., 1999; Ferrante & Elghobashi, 2004; Jacob et al., 2010). Merkle and Deutsch (1989-a and -b), Kodama et al. (2000), Moriguchi and Kato (2002), and Hassan et al. (2005) investigated the effects of average void fraction of bubbles on the change of the flow. According to their work, the amount of drag reduction increases with increasing the average of void fraction. However, Kanai and Miyata (2001) validated this effect only for the conditions (retirei o in) which the rising of void fraction happens near the wall. In addition, when the mean void fraction remains constant, the location of the peak of local distribution of bubbles can affect turbulence changing level. Kawamura et al. (2002) examined flat plates with the same size of bubbles as those in Moriguchi and Kato's (2002) research. Kawamura et al.'s (2002) results showed that the larger bubbles tend to congregate near the wall and that the influence of larger bubbles on drag reduction is more pronounced. Shen et al. (2006) conducted experiments on a certain range of bubble diameters; According to their results, the bubble diameter does not have a large influence on drag reduction. Furthermore, Murai et al. (2007) investigated the effects of bubbles considered to be large relative to the shear layer on drag reduction in horizontal channel flows. They found that, when bubble sizes are larger than the boundary layer thickness, to a certain degree, the skin friction decreases independent of the flow velocity.

Investigating the previous works we can realize that few researches were performed about the bubbles effect on the pressure drop reduction on the pipe flow. In the field of effect of the other drag reduction methods in the pipe flow, Den Toonder et al. (1997) studied the pipe flow including polymer additives using LDV experimental method and DNS numerical method. Furthermore, Xueming et al.(2002) investigated the effect of polymer additives on drag reduction and turbulence characteristics in pipe flow by measuring LDA.

The aim of present work was empirical investigation of the probable influence of bubble injection into the pipe flow and on the pressure drop caused by frictional losses. Therefore, the pressure drop reduction value in the bubbly pipe was studied empirically, and the flow effect on the bubbles and accumulation place was studied. (não entendi a última parte)

2. EXPERIMENTAL SETUP(EU COLOCARIA "EXPERIMENTAL DEVICE")

The closed circuit used on empirical tests includes the following elements (figure1):

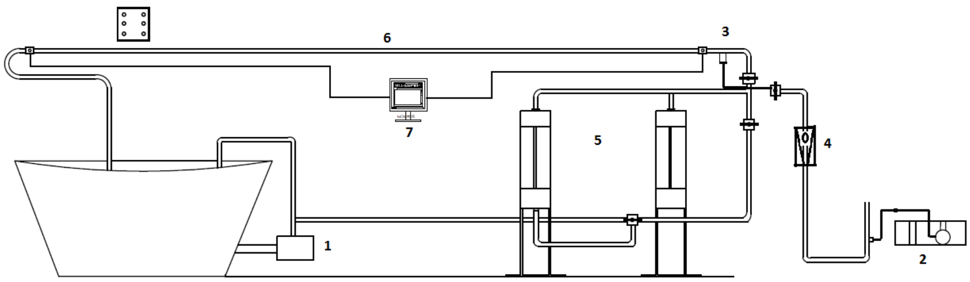

Figure 1 – Experimental setup.

1. Pump to circulate water in the circuit;
2. Air compressor to provide the required air to generate bubbles;
3. Bubble generator;
4. Air flow meter and valve to measure and regulate the bubble generator inlet air;
5. Water flow meter and valve to measure and regulate the water flow rate in the circuit;
6. Test pipe made of the flow; Test pipe made to observe the flow;
7. Pressure sensor to measure the pressure drop in pipe flow.

3. TEST METHODOLOGY AND RESULT

First, the air flow rate was assumed to be zero to investigate the performance of empirical test circuit. The pressure drop in the pipe was then measured for different Reynolds numbers by changing water flow rate, and the results obtained for single phase flow were compared with Moody diagram results. Then, the air flow rate increases to a defined value and the process of increasing Reynolds number of water at different flow rates is repeated. So, based on the obtained results, the pipe pressure reduction value was analyzed with constant Reynolds number for constant mean void fraction, as well Eq. (1).

$$\alpha = \frac{Q_{air}}{Q_{air} + Q_{water}} \tag{1}$$

The uncertainty of air flow rate is 0.02 according to air flow meter, and that of water flow rate is 0.04 in relative error. Therefore, the measurement uncertainty of the average void fraction is 0.04. Moreover, the uncertainty associated with pressure drop measurement and friction factor calculation are 0.015 (2.5%) and 0.02 (2%), respectively.

In horizontal pipe flow, total pressure difference between two measured point pressure drop caused by frictional losses. To investigate the bubble effect on the pressure drop caused by frictional losses.

3.1. Results obtained for single-phase flow compared with Moody diagram

The non-dimensional pressure drop or friction factor values which are calculated
As, Eq. 2:

$$f = \frac{D\Delta p}{2L\rho V^2} \tag{2}$$

D: Diameter of pipe,
L: Length of pipe,
ρ: Density of fluid,
V: Bulk velocity of flow.

The results obtained from empirical results with different Reynolds numbers were compared with Moody diagram results in figure (2). Based on this figure, there is a relatively good consistency between empirical results and Moody diagram results.

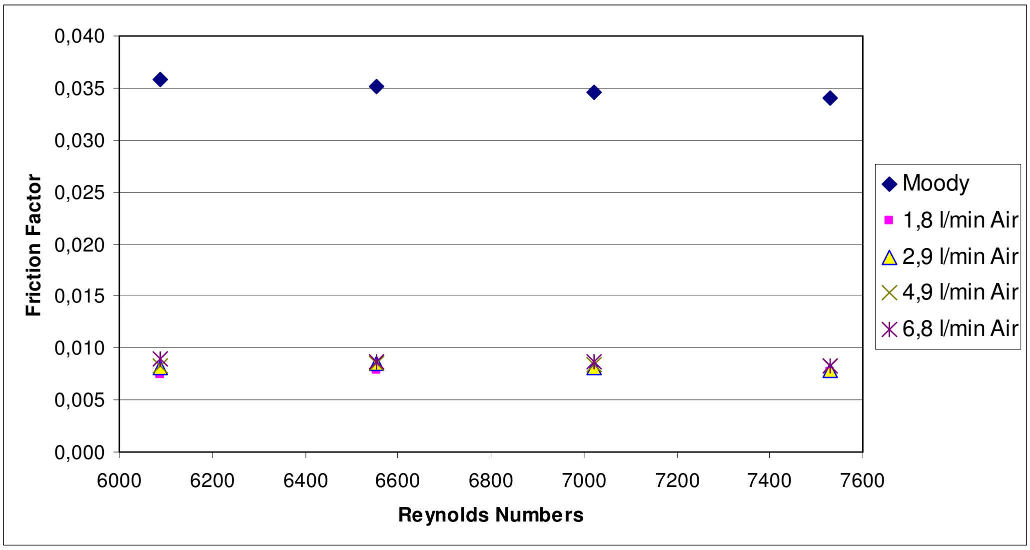

Figure 2 - Comparison between friction factors obtained from Moody diagram with empirical results of the present work versus Reynolds number.

3.2. Bubble injection and two-phase flow results

Drag reduction value defined as in Eq.

$$DR(\%) = \left(1 - \frac{\Delta p_{Two\ phase\ flow}}{\Delta p_{Single\ phase\ flow}}\right) \tag{4}$$

The equation above indicates the variations of pressure drop reduction caused by frictional losses. This value was shown in figure (3) versus void fraction for different values of Reynolds number. Based on the results, maximum pressure drop reduction observed in this work was 18% and was obtained for maximum void fraction, i.e. 53%, and minimum studied Reynolds number, i.e. 7500. It was also observed that with increasing void fraction from 0 to 50%, the pressure drop reduction value increases for all values of Reynolds number. This trend was observed in the work of other researchers such as Merkle and Deutsch (1989-a and -b), Kodama et al. (2000), Moriguchi and Kato (2002), andHassan et al. (2005). Increasing the pressure drop reduction level was due to increasing the number of bubbles in the flow, and therefore, increasing the number of effective bubbles near the wall. Furthermore, it was observed that in higher values of Reynolds number, increasing void fraction has a smaller effect on pressure drop. However, in lower

Reynolds numbers, increasing void fraction affects the frictional loss reduction noticeably. In many references such as Kanai and Miyata (2001) and Guin et al. (1996) it was noticed that the bubbles located near the wall are more active and effective in drag reduction process compared with the bubbles located far from the wall.
Therefore (troquei thus por therefore pois o primeiro é mais colloquial), increasing mean void fraction in lower Reynolds numbers increases the number of active bubbles near the wall, but in higher Reynolds numbers, it results in increasing inactive bubbles far from the wall. Therefore, as shown in figure (3), in higher Reynolds numbers, pressure drop reduction due to increasing bubbles void fraction is lower than the case of lower Reynolds numbers.

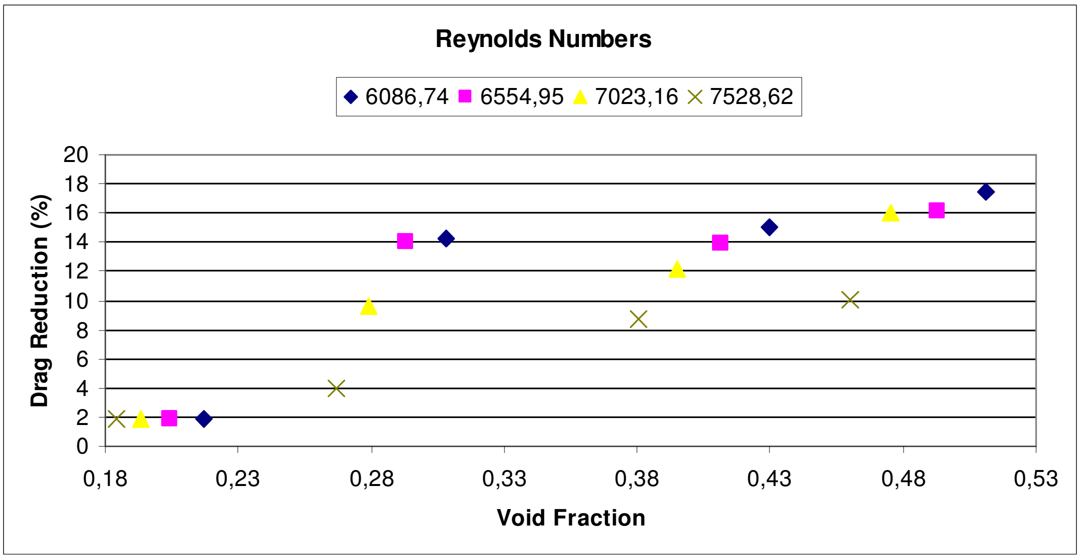

Figure 3 - Pressure drop reduction value versus void fraction in different values of Reynolds number

4. CONCLUSIONS

In this paper, the bubble effect on pressure drop reduction in upward pipe flow was studied empirically. The pressure drop value in two-phase flow containing bubbles was compared with single-phase flow, and pressure drop reduction value caused by the presence of bubbles in the flow was measured. Results obtained from the tests were as follows:

- Increasing Reynolds number in constant void fraction decreases the pressure drop reduction level. The observations indicate that increasing Reynolds number makes the bubbles move away from the wall. Therefore, the number of bubbles near the wall and their effect on the wall stress decrease.
- Maximum pressure drop reduction was 18% obtained in void fraction of 53% and Reynolds number of 7500. Even in very low values of void fraction like 0.18 considerable drag reduction of 2% was observed in Reynolds number of 6000.

The results indicate that micro-bubble injection method can be used applicably to reduce pressure drop in the pipe.

5. REFERENCES

Den Toonder, J. M. J.,Hulsen, M. A. , Kuiken G. D. C. &Nieuwstadt, F. T. M. (1997). Drag reduction by polymer additives in a turbulent pipe flow: numerical and laboratory experiments. J. Fluid Mech. 337, 193-231.

Ferrante, A. &Elghobashi, S. (2004). On the physical mechanisms of dragreduction in a spatially developing turbulent boundary layer laden withmicrobubbles. Journal of Fluid Mechanics, 503, 345-355.

Fontaine, A. A., Deutsch, S., Brungart, T. A., Petrie, H. L., &Fenstermacker, M. (1999). Dragreduction by coupled systems: Microbubble injection with homogeneous polymer andsurfactant solutions. Journal of Experimental Fluids, 26, 397-403.

Fujiwara, A., Minato, D., &Hishida, K. (2004).Effect of bubble diameter on modification of turbulence in an upward pipe flow. International Journal of Heat and Fluid Flow, 25, 481-488.

Guin, M. M., Kato, H., & Takahashi, Y. (1998). Experimental evidence for a link between microbubble drag reduction phenomena and periodically excited wallbounded turbulent flow. Proceedings of the International Symposium on Seawater Drag Reduction, 22-23, Newport, RI.

Guin, M. M., Kato, H., Yamaguchi, H., Maeda, M., &Miyanaga, M. (1996).Reduction of SkinFriction by Microbubbles and Its Relation with Near- Wall Babble Concentrationin a Channel. Journal of Marine Science and Technology, 1(5), 241-254.

Gutiérrez-Torres, C. C., Hassan, Y. A., & Jimenez-Bernal, J. A. (2008).Turbulence Structure Modification and Drag Reduction by Microbubble Injections in a Boundary Layer Channel Flow. Journal of Fluids Engineering, 130, 111304-111311.

Guo-zhen, L.,Yue-dong, Y.,&Shou-ping, D. (2007).Aphysical model for predicting the pressure drop ofgas-liquid slug flow in horizontal pipes.Journal of Hydrodynamics 19(6), 736–742.

Hassan, Y. & Gutierrez Torres, C. (2006).Investigation of Drag Reduction Mechanism by Microbuble Injection within a Channel Boundary Layer Using Particle Tracking Velocimetry. Nuclear Engineering and Technology, 38(8), 763- 778.

Hassan, Y. A., Gutíerrez-Torres, C. C. & Jimenez-Bernal, J. (2005).Temporal correlation modification by microbubbles injection in a channel flow. International Communications in Heat and Mass Transfer, 32(8), 1009-1015.

Jacob, B., Olivieri, A., Miozzi, M., Campana, E. F., &Piva, R. (2010). Drag reduction by microbubbles in a turbulent boundary layer.Physics of fluids, 22, 115104.

Kanai, A. & Miyata, H. (2001).Direct numerical simulation of wallturbulent flows with Microbubbles. International Journal for Numerical Methods in Fluids, 35, 593-615.

Kato, H., Iwashina, T., Miyanaga, M., & Yamaguchi, H. (1999).Effect of microbubbles on the structure of turbulence in a turbulent boundary layer. Journal of Marine Science and Technology, 4(4), 155-162.

Kawamura, T. & Kodama, Y. (2002).Numerical simulation method to resolve interactions between bubbles and turbulence. International Journal of Heat Fluid Flow, 23, 627-638.