U.P.B. Sci. Bull., Series D, Vol. 79, Iss. 4, 2017 ISSN 1454-2358

AIR FRACTIONS IMPACT OVER PRESSURE DROP IN AIR-WATER MIXTURE FLOW

Corina BONCESCU[1], Diana ROBESCU[2]

The pressure drop in air-water mixture flow is one of the fundamental design parameters closely related to the performance of the two-phase flow systems. This article shows air impact on local and linear pressure drop, in air-water mixture flow through a pipe with the diameter of 0.036 m. The pipe includes a vertical to horizontal 90^0 elbow bend, a horizontal to vertical 90^0 elbow bend and a diaphragm. Experimental research and mathematical modeling were carried out for three situations: water, air-water mixture with 0.04 air volume fraction and air-water mixture with 0.07 air volume fraction.

Keywords: pressure drop, air-water mixture, 90^0 elbow bend, diaphragm

1. Introduction

In many practical engineering systems, two-phase flow is transported through horizontal and vertical channels, interconnected by various systems, or changing the pipe diameter, flow and direction, that significantly alter the pressure. A two-phase pressure drop is one of the fundamental design parameters closely related to the performance of the two-phase flow systems. Researches were conducted since the 80^s [1] and they indicated that local pressure drop depends largely on the size and location of the jam. There were decreases in higher pressures, higher hurdles or obstacles located in the mix with greater impetus.

Over time several studies were developed on the matter. The latest researches regarding local pressure drop were made for two-phase mixture flow in pipes with diameters from 3 mm [2] to 50.3 mm [3] and elbows of 45^0, 90^0 [4] and 180^0 [5,6, 7].

The studies of P.L. Spedding (2007) [4] focused on the pressure drop in a 26 mm pipe diameter with 90^0 elbow bend. The pressure drop in the vertical intake pipe, followed by 90^0 elbow bend, showed significant differences compared to a vertical right pipe. This was the result of fluid pressure accumulation in the vertical segment of the pipeline. Seungjin Kim (2010) [3] investigated the effects of

[1] PhD Student, Dept. of Hydraulics, Hydraulic Machinery and Environmental Engineering, University POLITEHNICA of Bucharest, Romania, e-mail: corinai05@yahoo.com
[2] Prof., Dept. of Hydraulics, Hydraulic Machinery and Environmental Engineering, University POLITEHNICA of Bucharest, Romania, e-mail: diana.robescu@upb.ro

geometrical structure consisting of a 90^0 elbow bend followed by a 45^0 elbow bend on pressure loss in horizontal flow in a 50.3 mm inner diameter tube. Experimental data has shown that the pressure drop is influenced by the distance between the two elbows and it grows with increasing flow rates of gas and liquid. P. M. de Oliveira (2013) [5] studied air-water mixture flow in a 26 mm diameter pipe with an 180^0 elbow bend. In the studied configuration, the elbow is in the upright position and the two-phase flow can be modified. The results have shown that flow direction influences pressure loss in the elbow, in particular in the upward flow, when the gravity plays an important role.

This article aims to evaluate the pressure drop in air-water mixture flow in a 36 mm diameter pipe. The pipe includes a vertical to horizontal 90^0 elbow bend, a horizontal to vertical 90^0 elbow bend and a 28 mm diameter diaphragm. Experimental research and mathematical modeling were carried out for air-water mixture flow with 0.04 air volume fraction and 0.07 air volume fraction, respectively for water flow.

2. Experimental setup

The experimental setup consists of a transparent pipe with inner diameter 0.036 m and length 10.22 m. In order to ensure the necessary water flow a pump with maximum flow rate 6 m^3/h was used. The installation was filled with tap water through the upper valve and after the system was filled, the valve was closed and the pump was opened to recirculate water in the pipe. The measurements were made at water temperature of 15ºC. In figure 1 is presented schematic of the experimental setup. The measurements were made in five segments: upward flow (1i-1o), vertical to horizontal 90^0 elbow bend (2i-2o), diaphragm (3i-3o),horizontal to vertical 90^0 elbow bend (4i-4o) and downward flow (5i-5o). Pipe segments can be observed in Figs. 1 2, 3, and 4. The pressure drop was determined with liquid differential pressure gauge like in figure 5.

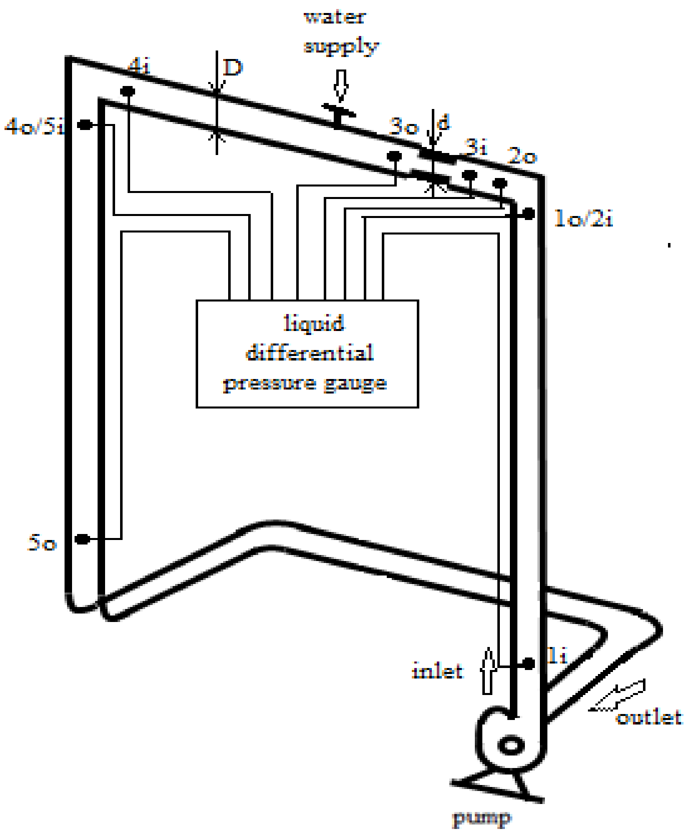

Fig. 1. Schematic of the experimental setup

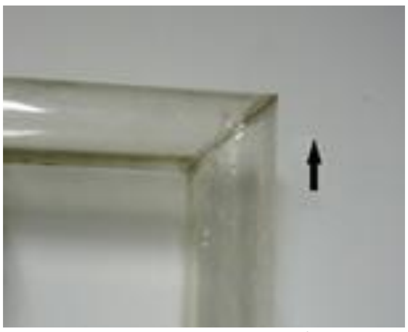

Fig. 2. Vertical to horizontal 90^0 elbow bend

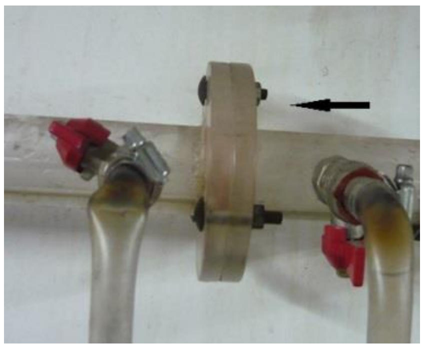

Fig.re 3. Diaphragm

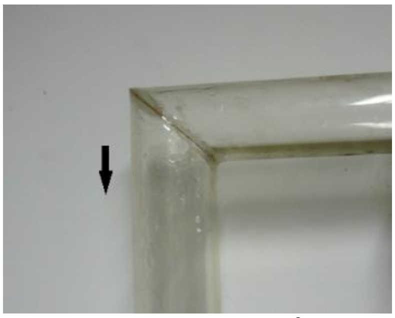

Fig. 4 Horizontal to vertical 90^0 elbow bend

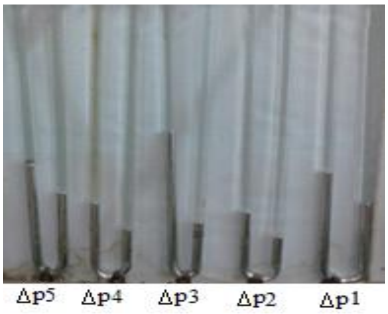

Fig. 5. Liquid differential pressure gauge for pressure measurements

The regime flow was determinate by calculating the Reynolds number, using the relations (1), (2) and (3). In the literature [8] critical value of the Reynolds number is 2300. If the Reynolds number is less than 2300 is laminar flow regime and if it is bigger than 2300 is turbulent flow regime. In these researches, for pump maximum flow rate, 6 m^3/h, was calculate value of water velocity 1.63 m/s and value of Re number 5084. For pump minimum flow rate, 2.5 m^3/h, was calculate value of water velocity 0.7 m/s and value of Re number 21724. According to the results, turbulent flow regime was obtained.

$$Q = 3600 * \mu * \frac{\pi * d^2}{4} * \sqrt{2 * g * \Delta h} \quad (1)$$

$$v = \frac{4 * Q}{\pi * D^2} \quad (2)$$

$$Re = \frac{v * D}{\vartheta} \quad (3)$$

where, Q $[m^3/h]$ - flow rate, $\mu=0.4$ aperture flow coefficient (experimentally determined), d $[m]$ - diaphragm diameter, $g=9.81$ $[m/s^2]$ - gravitational acceleration, Δh $[mH_2O]$ - level difference determined using differential pressure gauge with liquid, v $[m/s]$ - velocity, Re - Reynolds number, D $[m]$ - pipe diameter, $\upsilon=1.16*10^{-6}$ $[m^2/s]$ - kinematic viscosity of water at 15°C.

3. **Mathematical model**

Mathematical modelling and simulation of multiphase fluid dynamics is an important factor for obtaining the best solution for practical problems. In air-water mixture flow computational fluid dynamics was used in many analysis, such as describing the behavior of air-water mixture flow in pipe bends [9], in horizontal pipes [10] and simulate bubble rising in water column [11]. In this paper CFD was used to identify air fraction impact on pressure drop in air-water mixture flow in vertical pipe and 90^0 below bends.

Mathematical modelling and simulations were conducted in Fluent software. Gambit was used for elaborating the simulation domain and the 0.01 step mesh (figure 11, 12, 13). For the simulation study the following hypothesis were considered: no outside source, no mass exchange between the two phases, three directional flow in the turbulent regime, unsteady state regime, the movement is achieved due to pumping pressure, the air volume fraction in the mixture is known, static pressure was null in relation to reference pressure.

Considering the simulation steps presented by Robescu (2009) [12] and the hypotheses above VOF and k-ε models were used [13]. The convergence criterion was chosen as residual values below 10^{-3}. The residuals were obtained by solving the equations which govern this phenomenon: fraction volume equation, conservation of mass and momentum equations (Navier-Stokes).

Boundary conditions were set for the entrance area (pressure inlet), outlets (pressure outlet) and walls. The initial total pressure in the inlet is of 149 kPa and the reference pressure is of 101.325 kPa. The pressure drop was determinate as the pressure difference between two points in the considered segments in the experimental setup. For evaluating the pressure values during mathematical modelling, equations 4-6 were used.

$$p_m = p_{s,m} + \frac{1}{2}\rho_m|\overrightarrow{v_m}|^2 \tag{4}$$

$$\vec{v}_m = \frac{\alpha_l\rho_l\vec{v}_l+\alpha_g\rho_g\vec{v}_g}{\rho_m} \tag{5}$$

$$\rho_m = \alpha_l\rho_l + \alpha_g\rho_g \tag{6}$$

where, p_m *[kPa]* - pressure of mixture flow, α_l, α_g - volume fraction of water and air, respectively $\alpha_l + \alpha_g = 1$, $p_{s,m}$ *[kPa]* - static pressure of the mixture, ρ_m *[kg/m³]* – density of mixture, ρ_l, ρ_g *[kg/m³]* - density of water and air, respectively, $\vec{v}_m$ *[m/s]* – vector velocity of mixture, $\vec{v}_l$, $\vec{v}_g$ *[m/s]* – vector velocity of water and air, respectively, g*=9.81 [m/s²]* - gravitational acceleration.

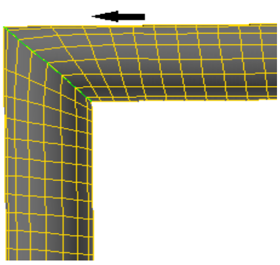

Fig. 6. Mesh of horizontal to vertical 90^0 elbow bend

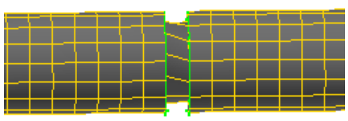

Fig. 7. Mesh of diaphragm

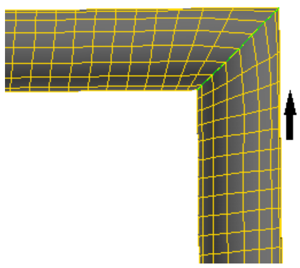

Fig. 8. Mesh of vertical to horizontal 90^0 elbow bend

4. Results and discussions

Laboratory experimental researches represented the first step, where the pressure drop for five water flow rates ranging between 2.5 m^3/h and 6 m^3/h were determined in turbulent regime. Pressure measurements (Δp) were made in five segments: upward flow (segment 1 of the pipe), vertical to horizontal 90^0 elbow bend (segment 2 of the pipe), diaphragm (segment 3 of the pipe), horizontal to vertical 90^0 elbow bend (segment 4 of the pipe), and downward flow (segment 5 of the pipe) (fig. 9, 10 and 14).

The experimental results had shown the direct proportionality between the pressure drop and flow rate, as it is well-known. As can be seen in figure 9, the pressure drop in the upward flow pipe segment is comparable with the one in the downward flow pipe segment. At the same time, having the 90^0 elbow bend changing the flow direction from vertical to horizontal or the other way didn't have a significant impact on the pressure drop. On the other hand, it resulted that local pressure drop in the 90^0 elbow bends was higher than linear pressure drop.

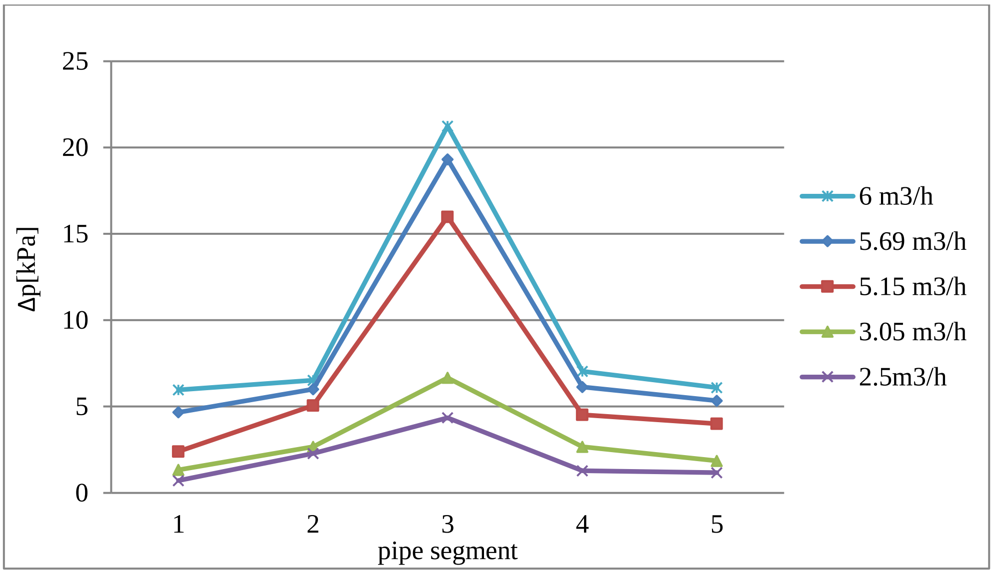

Figure 9. Pressure drop in all five segments for five water flow rate, between 2.5-6 m^3/h, in turbulent regime

The second step consisted in mathematical modelling and simulation. The water flow rate was considered 6 m^3/h. The simulation results, compared to the experimental ones, can be seen in figure 10. The simulation results was similar to the experimental ones and it led to the conclusion that the model and hypothesis were valid.

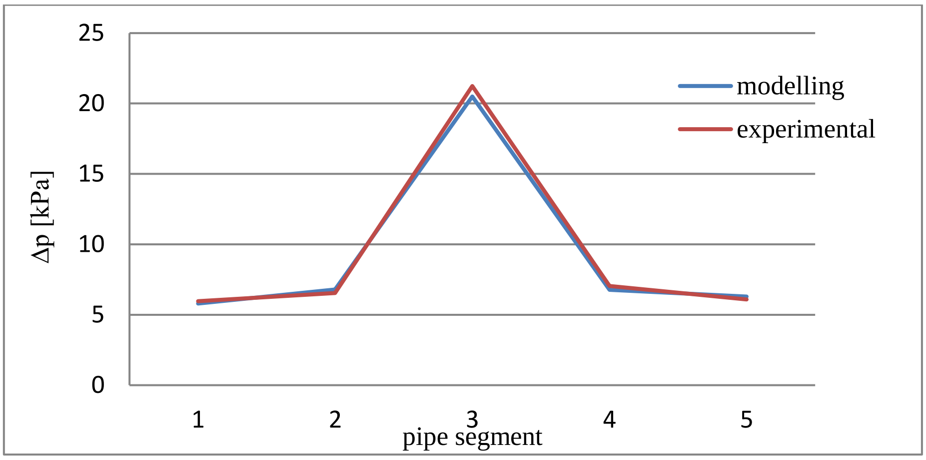

Fig. 10. Comparison between experimental and modelling results, all five segments, for water flow rate 6 m^3/h in

The validated mathematical model was used in simulating two air-water mixture flows: 0.04 air fraction volume and 0.07, respectively. The aim was to determine air to pressure drop impact in five points. Figures 11-13 show pressure distribution in cross sections of the pipe, upstream and downstream of the three segments (vertical to horizontal 90^0 elbow bend, diaphragm, horizontal to vertical 90^0 elbow bend) for evaluating local pressure drop. Three situations are compared: water flow (a), mixture flow with 0.04 air fraction volume (b) and mixture flow with 0.07 air fraction volume (c).

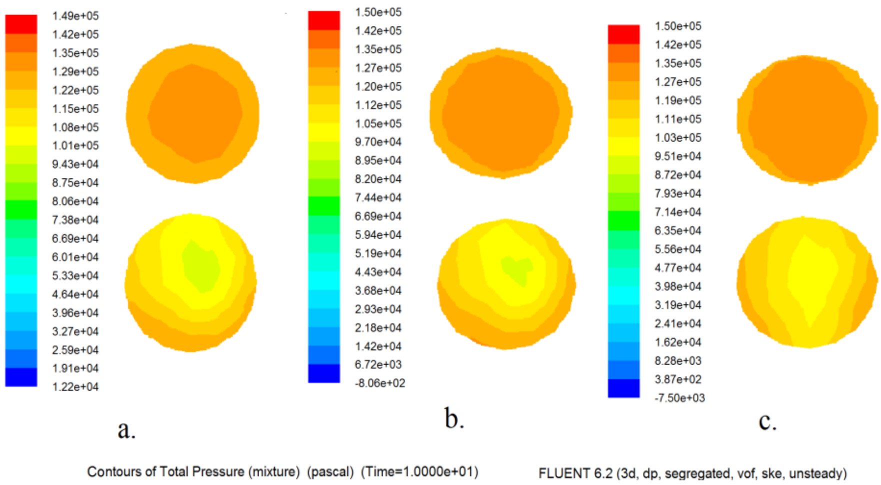

Fig. 11. Total pressure distribution on the cross sections in the upstream and downstream of the vertical to horizontal 90^0 elbow bend for water flow (a), mixture flow with 0.04 air fraction volume (b) and mixture flow with 0.07 air fraction volume (c) at a 6 m^3/h flow rate

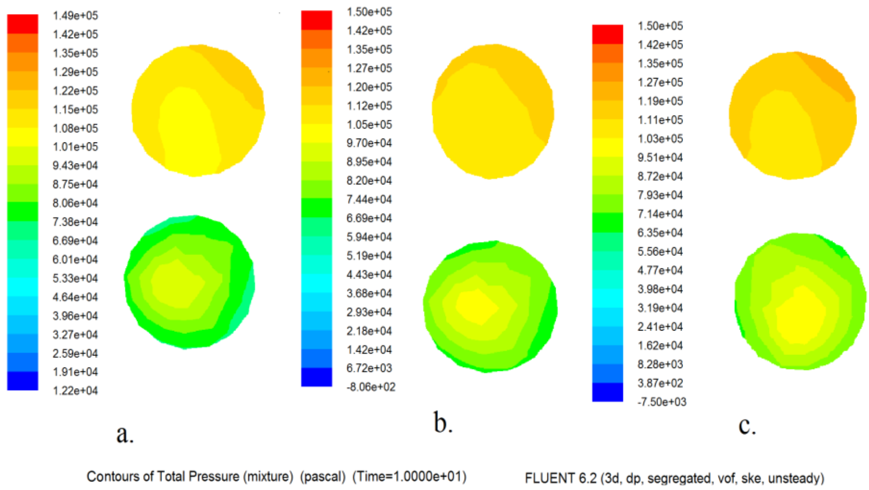

Fig. 12. Total pressure distribution on the cross sections in the upstream and downstream of the diaphragm for water flow (a), mixture flow with 0.04 air fraction volume (b) and mixture flow with 0.07 air fraction volume (c) at a 6 m^3/h flow rate

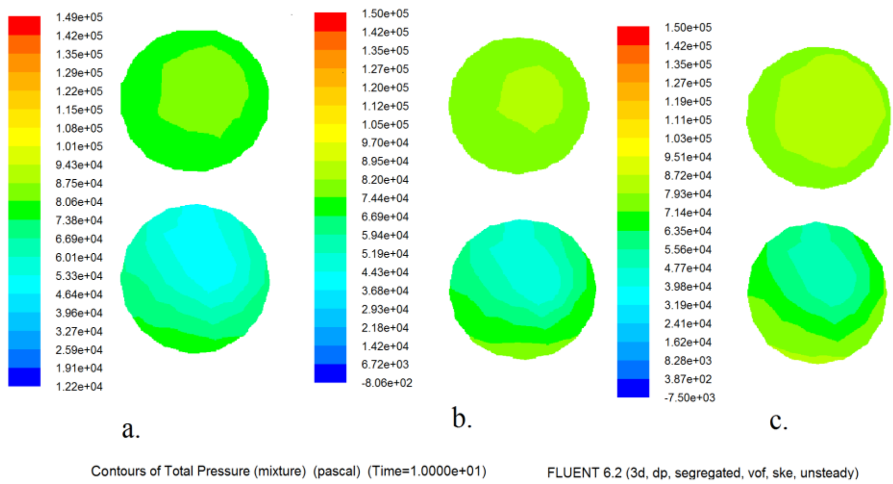

Fig. 13. Total pressure distribution on the cross sections in the upstream and downstream of the horizontal to vertical 90^0 elbow bend for water flow (a), mixture flow with 0.04 air fraction volume (b) and mixture flow with 0.07 air fraction volume (c) at a 6 m^3/h flow rate

Mathematical modelling and simulation study revealed the fact that air presence causes an increase in pressure drop. The results, presented in figure 14, show that in the upward flow pipe segment, the pressure drop was reduced when compared to the one in the downward flow segment. Due to the density difference between air and water in the studied mixture air tends to float. This leads to a difference between gravitational and buoyancy forces, named friction force. In the downward flow pipe segment, the friction force was higher than in upward one and this has a significant impact on the pressure drop.

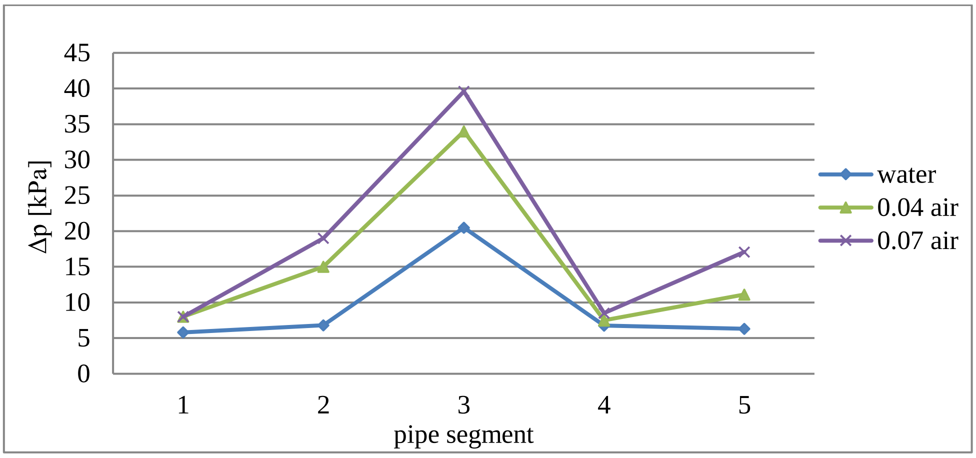

Fig. 14. Pressure drop in all five segments for water flow (a), mixture flow with 0.04 air fraction volume (b), mixture flow with 0.07 air fraction volume (c), for a flow rate of 6 m^3/h

In air-water mixture flow the direction change in 90^0 elbows was important. In the case of vertical to horizontal 90^0 elbow bend, the pressure drop was double of the one in horizontal to vertical 90^0 elbow bend. Also, it was observed a significant increase in pressure drop in the diaphragm.

5. Conclusions

This paper presents the results obtained for evaluating air contents in air-water mixture flow impact on local and linear pressure drop values. Experimental researches were carried out for turbulent water flow regime and rate between 2.5-6 m^3/h. Mathematical modelling and simulations were elaborated for water flow and air-water mixture flow with air volume fractions of 0.04 and 0.07, respectively, only for flow rate of 6 m^3/h. Measurements were made in five segments: upward flow, vertical to horizontal 90^0 elbow bend, diaphragm, horizontal to vertical 90^0 elbow bend and downward flow.

The experimental results have shown the direct proportionality between the pressure drop and flow rate. At the same time, having the 90^0 elbow bend changing the flow direction from vertical to horizontal or the other way didn't have a significant impact on the pressure drop in the case of water, things resulting different in the case of mixtures. The simulations also led to the conclusion that in downward flow pipe segment the friction force between air and water was bigger than in the upward flow one and this determined pressure drop increment. The highest pressure drop was obtained in the diaphragm.

The research will continue with mathematical modelling and simulations for values of air volume fraction and flow rate bigger than 0.07 and 6 m^3/h, respectively. In the same time, it will be study the impact of distance between two 90^0 elbow bend over pressure drop in air-water mixture flow.

R E F E R E N C E S

[1]. *M. E. Salcudean, L.K.H. Leung,* Two-phase pressure drop through obstructions. Nucl. Eng. Des. 105 (1988), 349–361.

[2]. *C. C. Wang, I.Y. Chen, Y.W. Yang, R. Hu*, Influence of horizontal return bend on the two-phase flow pattern in small diameter tubes, Exp. Therm. Fluid Sci., 28 (2004), pp. 145–152

[3]. *S. Kima, G. Kojasoyb, T. Guob*, Two-phase minor loss in horizontal bubbly flow with elbows: 45◦ and 90◦ elbows, Nuclear Engineering and Design 240 (2010) 284–289

[4]. *P. L. Spedding, E. Benard,* Gas–liquid two phase flow through a vertical 90 elbow bend, Experimental Thermal and Fluid Science 31 (2007) 761–769

[5]. *P. M. de Oliveira, J. R. Barbosa Jr.,* Phase distribution and pressure drop in air–water flow in a 180º return bend, 8th World Conference on Experimental Heat Transfer, Fluid Mechanics, and Thermodynamics, June 16-20, (2013), Lisbon, Portugal

[6]. *C. C. Wanga, I. Y. Chenb, Y.T. Linc, Y.J. Changa*, A visual observation of the air–water two-phase flow in small diameter tubes subject to the influence of vertical return bends, chemical engineering research and design 8 6 (2008) 1223–1235.

[7]. *M. Abdulkadir, D. Zhao, A. Azzi, I.S. Lowndes, B.J. Azzopardi*, Two-phase air–water flow through a large diameter vertical 180º return bend, Chemical Engineering Science 79 (2012) 138–152

[8]. *J. Flore, D. Robescu, T. Petrovici, D. Stamatoiu,* Dinamica fluidelor polifazate şi aplicaţiile ei tehnice (Multiphase fluid dynamics and technical applications), Editura Tehnică, Bucureşti, 1987

[9]. *S. S. Amornkul, F.R. Steward, D. H. Lister*, Modelling Two-Phase Flow in Pipe Bends, J. Pressure Vessel Technol 127(2), 204-209, 2004

[10]. *F. Vásquez, M. Stanko, A. Vásquez, J. De Andrade, M. Asuaje,* Air–water: two phase flow behavior in a horizontal pipe using computational fluids dynamics (CFD), WIT Transactions on Engineering Sciences, Vol 74, 2012 WIT Press

[11]. *S. S. Rabha,V.V.Buwa*, Volume-of-fluid (VOF) simulations of rise of single/multiple bubbles in sheared liquids, Chemical EngineeringScience, 65, 2010, 527-537

[12]. *L. D. Robescu*, Modelarea proceselor biologice de epurare a apelor uzate (Modelling biological processes of wastewater treatment), Editura Politehnica Press, Bucureşti, 2009

[13]. ANSYS Fluent Theory Guide, 2013