U.P.B. Sci. Bull., Series D, Vol. 75, Iss. 1, 2013 ISSN 1454-2358

STATISTICAL ANALYSIS OF THE FLOW INDUCED BY THE INJECTION OF AIR

Talida Mirona CIRLIORU[1], Florentina BUNEA[2], Gabriel Dan CIOCAN[3], Valeriu PANAITESCU[4]

Anumite aplicaţii, în fluide bifazice, necesită cunoaşterea simultană a caracteristicilor dinamice ale celor două faze, în cazul de faţă lichidă şi gazoasă. Pentru a putea caracteriza o coloană de bule, este necesar să se determine viteza indusă de gaz în fluid, viteza ascensională a bulelor, zona de influenţă a coloanei de bule în lichid precum şi caracteristicile bulelor: diametru, factor de formă, etc.

Acest articol prezintă o metodă de tratament statistic a datelor obţinute printr-o tehnică de măsură Particle Image Velocimetry (PIV). Pentru determinarea zonei de influenţă a coloanei de bule în lichid autorii propun o metodă originală de utilizare a parametrilor statistici de asimetrie şi de formă. Precizia măsurătorilor este determinantă de utilizarea acestor parametri, prezentându-se metoda de tratare a datelor.

Some applications require knowledge of simultaneity of two-phase flow characteristics: liquid and gaseous. In case of a bubble column, for its complete characterization is necessary to determine the flow velocity induced by the column of bubbles in the liquid phase, the bubble ascension velocity, and bubble characteristics: diameter, diameter fluctuations, shape factor.

This paper presents a statistical treatment method of experimental data obtained by a Particle Image Velocimetry (PIV). The authors propose an original approach by using the statistical moment skewness and flatness to discriminate the bubble column influence zone. The accuracy of the measurement results is an important parameter in this approach.

Keywords: PIV, two phase flow, bubble column, skewness, flatness

1. Introduction

Experimental measurements of biphasic flows into aeration columns, using the PIV technique, can be found in the international literature (Deen et al. [1],

[1] PhD Student, University POLITEHNICA of Bucharest, Romania, e-mail: talida.cirlioru@gmail.com
[2] PhD, National Institute for R&D in Electrical Engineering ICPE-CA, Bucharest, Romania, e-mail: buneaflorentina@yahoo.com
[3] Asoc. Prof., Laboratoire de Machines Hydrauliques, Université Laval, Québec, Canada, e-mail: gabriel.ciocan@gmc.ulaval.ca
[4] Prof, University POLITEHNICA of Bucharest, Romania, e-mail: valeriu.panaitescu@yahoo.com

Tomiyama [2], Lain [3]), where velocity profiles of the two phases are presented, for certain configurations of the flow or bubble size distribution, Laakkonen et al. [4] and the comparison of PIV measurements from literature with numerical simulations, Zhang [5]. PIV technique began being used in recent years also in the case of biphasic flows in hydraulic turbines - see Ciocan et al., [6, 7], Iliescu et al.[8, 9] and Houde et al.[10].

The object of this experimental study is the determination of the velocity field induced by a bubbles column in liquid. In order to establish this, the PIV technique was used in the water flow induced by a bubbles column.

The study focuses on development of the velocity field induced to water by different flow rates of injected air, through a metallic perforated plate with holes of 0.2 mm (MP0.2), in a rectangular tank filled with water. The measuring method is described in detail in Ciocan et al.,[6]. Using these experimental measurements, the velocity fields are analysed by statistical means. The skewness and flatness of statistical moments are used to discriminate the influence zone of the induced velocity by the bubble column. The accuracy of the different statistical moments is established.

2. Experimental set-up

The measurements were made in a rectangular tank (1100x300x300 mm), made from transparent Plexiglas, in which a sparger was installed – see Fig. 1. The height of the water column, between the surface of the sparger and the free surface (hydrostatic head) is 800 mm. The sparger is situated at a 90 mm height from the bottom of the tank, in order to avoid the influence of the wall on the induced flow.

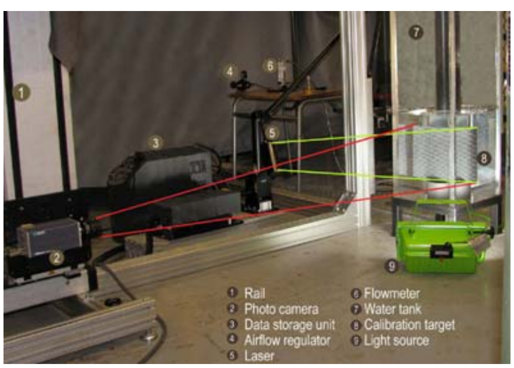


Fig. 1. a) Measurement set-up, b) Emissions of bubbles by perforated plates MP0.2.

The sparger has a diameter D = 44 mm; the orifices diameters d are placed at a distance $7d$ in order to avoid the bubbles coalescence and an orifice length of

6*d* in order to neglect the contraction coefficient of the orifice. Four air flow rates are considered: Q = 3, 6, 8 and 12 l/min.

The PIV set-up, the calibration and data processing was described in Ciocan et al., [6].

3. Experimental characterization of flow

A specific post-processing methodology is developed to extract the relevant flow features from the PIV measurements. The developed algorithms use background intensity correction, contrast enhancement, and optical distortion compensation to isolate the bubble contours and the particle locations within each image. The relative grey levels of the bubbles and background vary for each individual acquisition, thus an adaptive threshold value was set for each image.

3.1. Velocity processing

A measurement consists in a pair of images acquired at a certain time interval of 10 to 18 ms. The velocity field induced in the fluid phase by the bubble column is determined. The raw data processing treatment is performed in the instrument-specific software Flow Manager, while the subsequent data validation and visual representations are made using Matlab routines.

The instantaneous velocity fields in the liquid phase are obtained by cross-correlation of the acquired image pairs and further validation based on local velocity range criteria. As seen in Fig. 2, the effective portion of the velocity field is located on the left side of bubble column, in the direction of the incoming laser sheet. On the right side, scattering from the seeding particles is drastically reduced due to the lower energy quantity of incident light past the bubble column. Dispersion, adverse scattering on the bubbles' surface and absorption are some of the factors that contribute to the light intensity diminution on the right side of the image. Therefore, less reliable statistics are issued in this area.

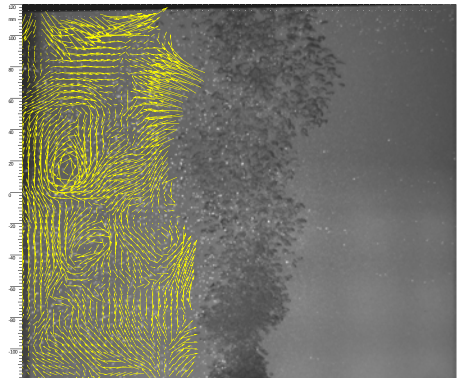


Fig. 2. Instantaneous velocity field (Q=8 l/min, MP0.2, plan1) superimposed on the original image Ciocan et al. [6].

The statistical convergence is checked for the average value of the velocity. The accuracy of the average value is estimated at 5%. At this time the other order values (standard deviation, skewness and flatness) are not considered.

An example of final results for the average velocity field induced in water by the rising bubbles is presented in Fig. 5. Only the bottom measurement section is shown here, near the sparger's exit.

3.2. Skewness and flatness processing

Skewness, the asymmetry parameter of the axial velocity is calculated by:

$$Sk_v = \frac{1}{n} \cdot \frac{\sum_{i=1}^{n} (v_i - \bar{v})^3}{S_v^{\ 3}}. \tag{1}$$

According to the value of this parameter we can have a positive or negative asymmetry.

Flatness, the form parameter of the axial velocity (Kurtosis/ flatness) is defined according to:

$$K_v = \frac{1}{n} \cdot \frac{\sum_{i=1}^{n} (v_i - \bar{v})^4}{S_v^{\ 4}}. \tag{2}$$

For this statistical analysis the number of the acquired data and the treatment applied for the velocity processing are not enough to obtain a good accuracy, see § 3.3 and Fig. 4 - unfiltered fields, and for skewness and flatness a large dispersion can be observed. A difference can be also observed between the right and left side of the image. The number of acquisitions in the left side is less important like in the right side due to the shadow of bubbles – see § 3.1.

A second validation procedure, based on Gaussian filtering, was developed in Matlab and applied to vector-field series for both velocities components. Considering a 95 % confidence level, the filtered values lie within the bounds:

$$\bar{v} - 2S_v < v_{filt\ i,j} \leq \bar{v} + 2S_v \tag{3}$$

with $v_{filti,j}$ - filtered velocity, n number of samples; v_i – axial instantaneous velocities; $\bar{v}$ – axial average velocities.

$$f(v) = \frac{1}{S_v\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{v-\bar{v}}{S_v}\right)^2} \quad (4)$$

Fig. 3 shows the Gauss distribution curves described by equation (4), with all data and validated (filtered) data within the selected range. This filter does not have a significant incidence on the average value of the velocity – less that the accuracy of the measure, but are significant for the hi-order moments – see Fig. 4.

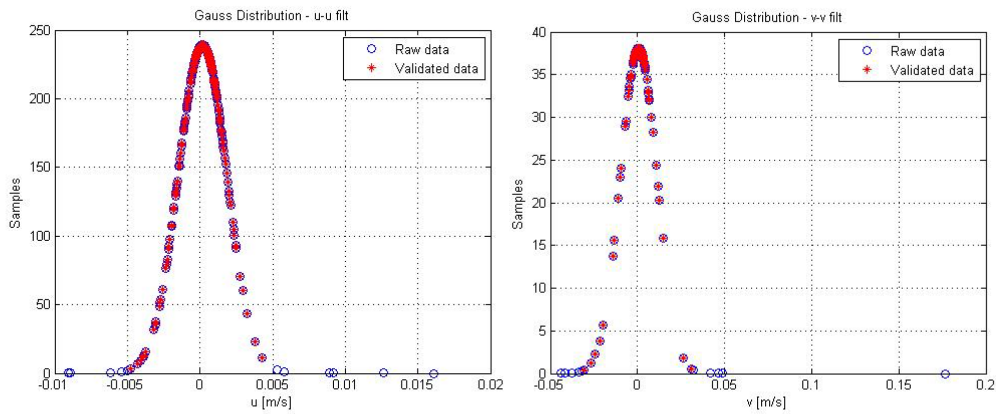


Fig. 3. Overlapping Gauss distribution curves for instantaneous and filtered velocities u and v.

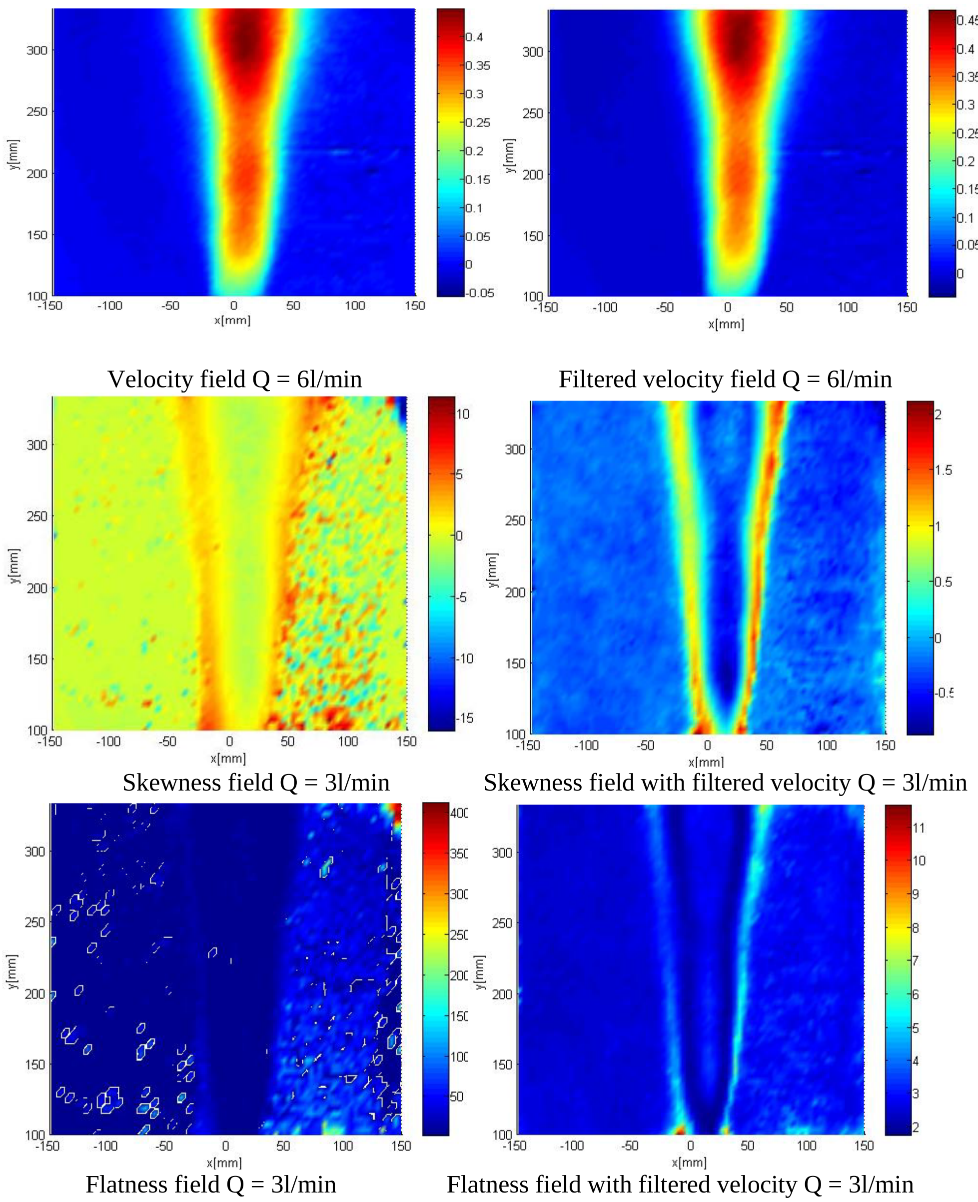
The statistical moments are also calculated only with validated velocities. The use of this filter does not have a significant incidence of the velocity field, but improves significantly the accuracy of the statistical moment's skewness and flatness – see Fig. 4.

3.3. Influence zone of the bubble column

An important parameter in the induced flow by a bubble column is its influence zone. Many methods can be used to define this boundary and to discriminate the influence zone of the bubble column from the no influence zone: a velocity mean isovalue near 0, consider a gradient value, etc. All this methods contain the subjective criteria that will be chosen.

The flow is basically unsteady. The maximum of the statistical moments skewness and flatness can be an excellent criterion to discriminate, in average value, the boundary of the bubble column influence.

According to this, the statistical parameters like the probability and normal distribution are used. In general, the normal distribution is characterized by the "bell form". In terms of the value of the asymmetry parameter we can establish if the measured values are symmetric or not, if the average value is analyzed.



Velocity field Q = 6l/min

Filtered velocity field Q = 6l/min

Skewness field Q = 3l/min

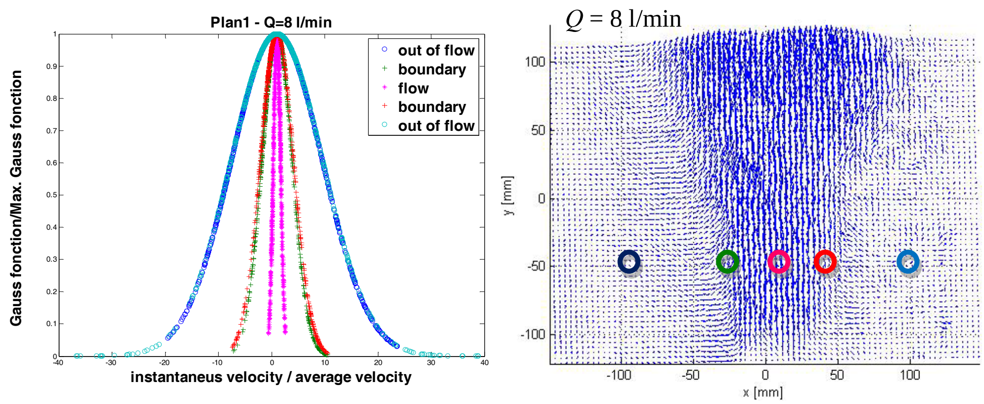
Skewness field with filtered velocity Q = 3l/min

Flatness field Q = 3l/min

Flatness field with filtered velocity Q = 3l/min

Fig. 4. Statistical moments before and after using the Gauss filter.

If this parameter is near the zero value ($Sk = 0$), then most of the measured values are symmetrically arranged. From the skewness distribution is clearly observed an area of maximum asymmetry. These areas correspond to the shear layer between the fluid without induced flow and induced flow by the bubble column. In this way, the skewness is an excellent criterion to discriminate the two areas. The importance of the accuracy of the data used for this criterion is evident – see Fig. 4. These considerations are related to the average velocity, because in this area the flow is unsteady: the velocity varies around the zero value.



Gauss function distribution *Average velocity field*

Fig. 5. Gauss function distribution for spatial points in the induced velocity zone, boundary and out of induced flow area.

The flatness parameter shows another flow characteristic – see Fig. 5. In the central zone the velocity variation around the mean value is reduced. In opposite, outside the induced flow zone, the flow variation is very large around an average near 0 – is a recirculating area.

4. Conclusions

A combination of standard PIV, LIF and shadowgraphy was employed to study an air column evolution in a water tank.

The investigation was done in 3 separate zones covering the whole longitudinal cross-section of the water tank and for 4 air flow rates. The velocity field is determined with an accuracy of ~5%.

An original approach is proposed to discriminate the boundary of the region impacted by the induced flow of the bubble column: the use of the statistical moment’s skewness and flatness. A Gauss filter was applied to improve the accuracy of the moment’s calculation. This approach is explained with the physical behaviour of this flow configuration.

Acknowledgment

The work has been funded by the Sectorial Operational Program Human Resources Development 2007-2013 of the Romanian Ministry of Labour, Family and Social Protection though the financial Agreement POSDRU/88/1.5/S/60203. The measurement was performed at Laval University – Laboratory for Hydraulic Machines.

R E F E R E N C E S

[1] *N. G, Deen, T. Solberg, B. H. Hjertager,* "Large eddy simulation of the gas-liquid flow în a square cross-sectioned bubble column", Chem. Eng. Sci., **vol. 56**, 2001, pp. 6341-6349.
[2] *A. Tomiyama,* "Drag, lift and virtual mass forces acting on a single bubble", 3rd Int. Symp. on Two-Phase Flow Modeling and Experimentation. Pisa, Italy. 22-24 Sept, 2004.
[3] *S. Laín,* "Large eddy simulation of gas-liquid flow in a bubble column reactor", El Hombre y la Máquina No. 32 • Enero-Junio de 2009.
[4] *M. Laakkonen, M. Honkanen, P. Saarenrinne, J. Aittamaa*, "Local bubble size distributions, gas–liquid interfacial areas and gas holdups in a stirred vessel with Particle Image Velocimetry", Chem. Eng. Journal, **vol. 109**, 2005, pp. 37–47.
[5] *D. Zhang,* "Eulerian modeling of reactive gas-liquid flow în a bubble column", PhD thesis, University of Twente, Netherlands, ISBN 978-90-365-2560-2, 2007.
[6] *G.D. Ciocan, M.S. Iliescu, T.C. Vu, B. Nennemann, F. Avellan,* "Experimental study and numerical simulation of the FLINDT draft tube rotating vortex", Journal of Fluids Engineering-Transactions of the ASME, **vol. 129**, pp. 147 – 158, 2007.
[7] *G.D. Ciocan, M.S. Iliescu,* "3D PIV Measurements in two phase flow and rope parametrical modeling", 24th IAHR Symposium, Brazil, October 27-31, 2008.
[8] *M. Iliescu*, "Analysis of large scale hydrodynamic phenomena în turbine draft tubes", Ph.d. Thesis no. 3775, École Polytechnique Fédérale de Lausanne, 2007.
[9] *M.S. Iliescu, G.D. Ciocan, F. Avellan*, "Two phase PIV measurements of a partial flow rate vortex rope in a Francis turbine", J. of Fluids Eng., ISSN 0098-2202, **vol. 130**, Issue 2, pp. 146-157, 2008.
[10] *S. Houde, M. S. Iliescu, R. Fraser, S. Lemay, G. D. Ciocan, C. Deschênes, "*Experimental and numerical analysis of the cavitating part load vortex dynamics of low-head hydraulic turbines", Proceedings of ASME-JSME-KSME, Hamamatsu, Japan, July, 2011
[11] *F. Bunea, S. Houde, G.D. Ciocan, G. Oprina, G. Băran, I. Pincovchi,* "Aspects concerning the quality of aeration for environmental friendly turbines", Institute of Physics (IoP Publishing), Earth and Environment Science, **vol. 12**, 012035, 2010.
[12] *G.D. Ciocan, F. Bunea, S. Houde, C. Deschênes,* "Measurement technique for air-water disperse system study", University Politehnica of Bucharest Scientific Bulletin, Ed. Politehnica Press, serie D, **vol. 74**, nr. 1, ISSN 1454-2358, 2012, 2012.