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THE INFLUENCE OF THE VELOCITY INDUCED BY AN AERATION GRID UPON OXYGEN TRANSFER

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The main objective of the paper is to determine the influence of the velocity induced by a grid of bubble columns on homogenization and mass transfer. The paper studies experimentally the flow field induced by a grid of porous diffusers placed in a tank and the interaction among the bubble columns. In the cylindrical experimental tank five diffusers are immersed and distributed at certain distances so that the columns to not interact. The diffusers are plates ø120, of sintered glass obtained from energetic wastes.

To evaluate the effect of the flow induced at different air flow rates, the variation of dissolved oxygen (DO) with time, for a constant water volume is experimentally determined. The two sets of measurements are simultaneously performed using specific devices. For determining instantaneous velocities at different points in the water volume, a MicroADV operating on Doppler principle is used. After data processing the evolution of average velocities with variation of the supplied air flow and with their spatial position is obtained. The controlled placement of the porous diffusers induces a circular flow between columns, which favours the mixing of aerated water and thus positively influences the mass transfer.

Keywords: induced velocity, diffusers grid, mass transfer

1. Introduction

The influence of flow induced by a grid of bubble columns (BC) is studied to establish the optimal layout of bubble diffusers (BD) in an aeration tank. The knowledge of the flow induced to water by buoyant bubbles is important in layout and sizing of aeration system and in determining optimal distance among BDs in tank. Aeration tank geometry influences essentially both efficiency of the aeration system and energy consumption for its operation. Thus, oxygenation efficiency is directly influenced by the convenient arrangement of BDs – a good aeration can be obtained by using a small number of BDs. The diffusers arrangement must be made so as to avoid interaction of the flaring bubble columns and presence of areas with water at rest. Is useful to know the water velocity distribution induced by the BC since it helps us to determine the maximum distance between BDs.

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This paper presents an experimental setup consisting in a cylindrical tank where five BDs with open controlled porosity of 250 ÷ 315μm are introduced. Water induced velocity is experimentally determined in 5 points, each located at two separate distances from the tank wall. All measurements are repeated for 3 different airflow rates. Measurements to evaluate the oxygen transfer from air into water are performed in parallel with measurements for the induced velocity determination. After the introduction of sodium sulphite and cobalt chloride catalyst in water to de-aerate it, continuous samples are taken during the re-aeration process for the 3 air flow rates, from a point located at 455 mm from the tank wall and 200 mm from the free surface. Measured data is processed and standard oxygen transfer rate and standard aeration efficiency are obtained.

2. Experimental research

Bubble columns induce to water a movement that depends on the injected air flow rate and on the water level in the tank.

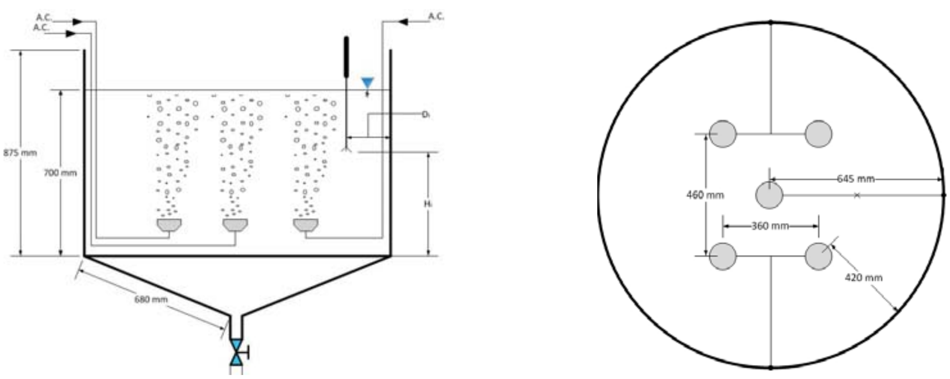

Fig. 1. Sketch of the experimental setup
1 – tank, 2 – bubble diffusers, 3– bubble columns grid, A.C. – compressed air

In order to experimentally determine the flow induced by a grid of BCs in a liquid at rest, a MicroADV SonTek device suitable for laboratory applications has been used. Its operation is based on Doppler principle and consists in recording real-time 3D components of water velocity in a measurement (sample) volume of about 0.3 cm^3. This volume is located at 5 cm from an acoustic transmitter fixed on a rod that is inserted into water. The measured velocities are discrete and measuring points have to be located at more than 50 mm from any wall, to not influence the measurement accuracy. A grid of 5 BDs, axially symmetric located, was installed in a cylindrical tank of 1.3 m diameter, at a hydrostatic head of 0.7 m (Fig. 1).

The experimental setup consists in: a cylindrical tank in which the BDs were placed and supplied with constant airflow rates from the flow distributor. It is connected to a PC where, with the Flow Control software, the air flow rates and the pressure introduced by each diffuser is separately controlled and adjusted. The air is provided by two compressors. The Micro ADV is connected to another computer that displays and records the velocities with the help of Sontek software. Simultaneously, the increasing levels of DO are continuously registered until saturation is reached. Thus, using a peristaltic pump, water is continuously sampled and sent to an oximeter connected to a computer that displays information concerning the evolution of DO, depending on time and temperature.

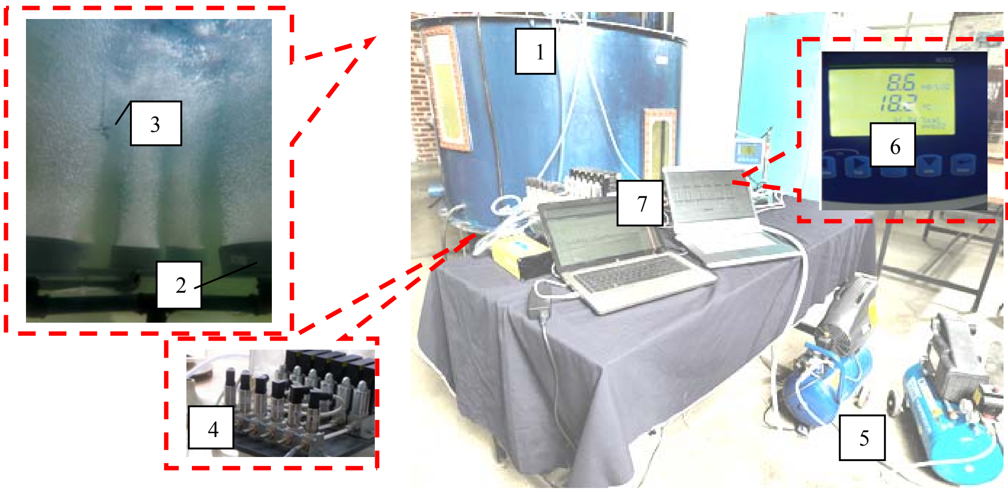

Fig. 2. Experimental setup and measuring devices (1-water tank, 2-grid of BDs, 3-Micro ADV, 4-airflow distributor, 5-compressors, 6-oximeter, 7- PCs equipped with three specific data acquisition software for: induced velocities, level of DO in water and airflow rates)

2.1 Induced velocities determination

The analysis and processing of data measured with MicroADV (Acoustic Doppler Velocimeter) devices is addressed in some recent works [1], [2]. The performance and limitations of this experimental method for measuring velocity induced in water by rising bubbles is highlighted and a procedure for the identification and separation of the values influenced by the presence of bubbles is proposed [1]. In [3] are presented the results of ADV measurements concerning the velocities induced by a pollutant plume (saline solution) in a liquid at rest.

The main method for processing the data acquired with ADV apparatus is to remove points with low correlation (usually under 70%). For the case of ADV devices for measuring the velocities in free surface flows, in the recent years [4] a new technique of processing that involves the 3D representation of the points (the realization of *Poincaré maps*) was developed; the measured values must fall within an ellipsoid; points outside it are considered “peaks” and are eliminated.

The acoustic receptors are located in the top of the 3 arms of ADV (fig. 3a and b). Each receptor shows one component of the velocity vector. Information is transmitted to processor and to a PC. Registration may be done continuously or by sampling at a defined timeframe; information can be taken within the range 2 ÷ 60 Hz. After setting the required parameters, information is viewed on-line and recorded. Samples of current measurements were taken at a frequency of 30 Hz.

Fig. 3a, Processor and stem sampling

Fig. 3b, Transmitter, acoustic receptors and their intersection in the measuring volume

To perform the velocity measurements, a seeding material (10-50 mg/l) was added into water; it is formed from spherical fluorescent particles of 10 ÷ 20 μm average diameter and density close to water. For the volume from the experimental setup (930 l), 10 g of *seeding material* was used. Water containing microparticles in suspension requires less seeding material than pure water.

The values indicated by MicroADV are:

- water velocity (cm/s) – the 3D velocity components (v_x, v_y and v_z) are collected using the acoustic receivers and are sent online to processor and to PC;

- Acoustic signal (dB) – (Signal-to-Noise Ratio – SNR) a low SNR (< 5-10dB) may increase noise in the measured data. SNR is a function that takes into account the amount of seeding material which is dispersed in water; thus, in very clean water, the MicroADV can not have a good measuring precision of velocity;

- Correlation (%) – it shows the quality/ accuracy of the measured velocities and depends on turbulence level and on the number of bubbles passing through the sample volume during registration. Thus, for laminar single-phase flow, correlation will be more than 90%, and for strong turbulent two-phase flow and low SNR, correlation will decrease. Generally, a correlation greater than 70% is sought. There are situations when correlation may decrease to 30-40%, giving good results but with high levels of noise (two-phase flow case) and to obtain the flow spectrum, the average velocity of the 3 components is used [4].

Samples were taken at 3 different air flow rates Q_i = 6, 8, 10 l/min and from 5 locations, H_i = 650, 550, 450, 320, 270mm (fig.1). All the five measuring points are located at D_i = 530 and 380mm respectively from the tank wall. The

MicroAVD rod was fixed and immersed into water at the desired depth and with a frequency of 30 Hz about 3000 samples were taken for each air flow rate. Near free surface, due to BCs flaring, a larger number of bubbles pass through the sample volume, decreasing correlation. It is necessary therefore to collect a larger number of data, to remain a sufficient number of samples with accuracy > 70% after processing. Only these samples were considered in the subsequent data processing to determine average velocity. v_x, v_y and v_z components were recorded from the locations H_i and D_i for each air flow Q_i. The errors of measurement (the correlation) increase with the air flow rate and as we approach the free surface; thus, were selected for further processing only those measurements where all the three components of velocity have a better correlation than 70%.

2.2 Determination of oxygen transfer

The importance of studying the pattern/distance between BDs is demonstrated by recent studies concerning the use of diffusers for liquids destratification [7] or to achieve the aeration in the tanks of wastewater treatment plants [8]. Also, the importance of studying the correlation between the induced velocity and mass transfer is illustrated by the undergoing research from U.S. [9] for designing the McCook basin and by the research carried out in situ [10] and compared with numerical simulations.

The main method for determining aeration systems performance, for isolated or network operation in water at rest is recommended by ASCE standard [6]; it is based on dissolved oxygen elimination from water, followed by re-oxygenation up to at least 98% of the saturation concentration. The chemical substances used for de-oxygentaion are sodium sulphite (minimum 7.88 mg/l) and cobalt chloride catalyst. For the water volume from the experimental setup (930 l) a quantity of 75 mg Na_2SO_3 was used. DO determination at a fixed air flow is achieved by continuously sampling water (during the re-aeration process, by using a peristaltic pump) and introducing it in the measuring cell of a Mettler Toledo oximeter. Data concerning the DO concentration variation with temperature and time is acquisitioned using specialized software and sent to a laptop. Thus, the DO variation curve with time, $C = f(t)$, is obtained.

2.3 Experimental data processing

After recording and saving data from MicroADV, they are processed and histograms representing the velocity density on 3 directions in the measurement points are plotted (fig. 4). From the sets of measurements were removed those having at least one velocity component with a correlation smaller than 70%; then, the average velocity on the three directions was calculated and also their resultant.

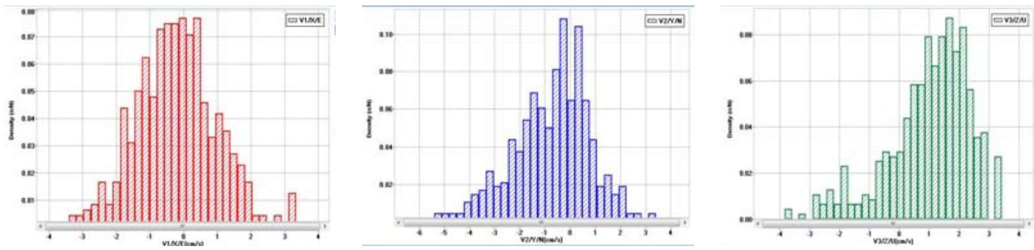

Fig. 4. Density histograms of velocity components at Q = 360 l/h and H= 320 mm

As seen in Table 1, the general sense of v_x and v_y components is negative near the bottom of the tank (deep); this trend is correct given that in the deep water tends to change its direction of motion. The sense of v_z is positive until near the free surface, where it becomes negative due to the circulation from the tank. The more we move towards the free surface and the more we increase the air flow rate, the greater the number of samples with a correlation lesser than 70%.

Table 1

Corrected average velocities in the measuring points

h **(mm)**	***D*** **(mm)**	***Q*** **(l/h)**	v_x **(cm/s)**	v_y **(cm/s)**	v_z **(cm/s)**	v **(cm/s)**	**No. of selected samples**
650	530	600	–0.93	0.02	4.30	4.40	1296
		480	–0.73	1.22	2.82	3.16	2722
		360	–1.55	0.23	2.67	3.10	1568
	380	600	2.62	1.00	–2.52	3.77	1000
		360	0.88	0.99	–6.85	6.91	886
		480	3.89	2.74	1.31	4.94	2414
550	530	600	–0.98	–0.25	4.82	4.93	2976
		480	–0.15	0.84	5.20	5.27	3060
		360	–0.45	–0.06	1.01	1.11	1813
	380	600	2.42	2.11	2.08	3.83	2750
		480	1.62	1.32	3.96	4.48	2960
		360	3.68	1.87	–5.23	6.67	1273
450	530	600	1.14	–0.76	4.75	4.94	3244
		480	0.11	0.33	5.35	5.36	3012
		360	0.14	–0.36	–0.15	0.42	1933
	380	600	0.29	–0.55	3.84	3.90	3067
		480	0.08	0.03	5.70	5.71	3043
		360	2.38	0.82	–3.47	4.28	2025
320	530	600	–0.38	–1.29	5.85	6.01	3024
		480	–1.12	0.13	5.13	5.25	3047
		360	–0.999	–0.89	3.41	3.66	2070

	380	600	0.40	–1.34	4.28	4.50	3059
		480	–1.06	0.46	6.88	6.98	3034
		360	–0.47	–0.01	2.55	2.59	2670
270	530	600	–1.26	–2.04	4.68	5.26	3009
		480	–1.72	–1.43	5.19	5.66	3017
	380	600	–0.08	–1.62	3.99	4.31	2732
		480	–1.39	0.26	6.15	6.31	3005

To determine the transfer of oxygen provided by the grid of diffusers, the experimental values of DO for the air flow rates Q = 360, 380 and 600 l/h are processed according to [6]. Thus, the curves C_{OD} = f(t) are analyzed and, if there is found an inflection point located at the bottom of the curves, the values situated before it are deleted and new curves of variation are obtained. To allow a proper comparison of the results, corrections of temperature and pressure are applied to the experimental data (t = 20°C, p = 1 bar). Next, linear regression is applied in order to estimate the parameters of the oxygen transfer model. Using standard formulas given in [6], the parameters evaluating the oxygen transfer performances of the tested grid of diffusers are calculated: standard oxygen transfer rate *SOTR*, standard oxygen transfer efficiency *SOTE* and standard aeration efficiency *SAE*.

Table 2

Oxygen transfer performances of the grid of diffusers in the measuring points

Q [l/h]	SOTE [–]	SOTR·10^3 [kg/h]	SAE [kg/kWh]
360	68.125	0.0272	39.561
480	62.890	0.0371	40.434
600	49.983	0.0379	32.984

By analyzing the data obtained, it can be easily seen that aeration efficiency registers a maximum in the range of 400 ÷ 500 l/h.

3. Conclusions

The analysis of data concerning induced velocities shows that the resultant velocity decreases with immersion depth and increases with air flow rate. Concurrently, due to sense change of the instantaneous velocity (Table 1), one can deduce existence of eddies, which grow in intensity by approaching free surface.

There was a decrease in the correlation of velocities when the phase of the sample volume changed (it was transited by bubbles). The decrease in correlation is emphasised in the proximity of free surface, where BCs flaring take place.

With MicroADV it can be determined, as order of magnitude, both the instantaneous and mean components of velocity vector and the resultant velocity vector averaged in a measurement point. Still, it is difficult to accurately capture the general evolution of the flow because can not be taken several samples consecutively. Furthermore, acoustic receptors don't have to be in the vicinity of walls. Discrete measurements don't describe the instantaneous unsteady flow but using the MicroADV one can evaluate the general aspect (tendency) of flow.

The performed experiments allowed determining the optimum operating air flow of the diffusers grid for the tested configuration: Q = 400 l/h. The operation of the diffusers at higher air flow rates leads to higher energy costs without improving the efficiency of oxygen transfer.

The velocities induced by BCs in water increase with air flow rate and also as we approach free surface, favouring mixing of the liquid and gaseous phases.

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REFERENCES

[1]. *D. G. Goring* and *V. I. Nikora*, "Despiking Acousting Doppler Velocimeter Data", J.Hydr.Engrg., **vol. 128**, Issue 1, 2002, pp. 117-126.

[2]. *K. D. Nielsen*, *L. J. Weber, M. Muste*, "Capabilities and Limits for ADV Measurements în Bubbly Flows", Proc. XXVIII IAHR Congress; Sustainable Water Resources Management at the Turn of the Millennium, Graz, Austria, 22-27 August, CD, (Reprint 1396), 1999.

[3]. *G. R. Tomasicchio*, "Capabilities and limits for ADVP measurements of breaking waves and bores", Coastal Engineering, **vol. 53**, 2006, pp. 27 – 37.

[4]. *C. Ying, M. J. Davidson, H. W. Wang and A. W. K. Law*, "Radial velocities in axisymmetric jets and plumes, Journal of Hydraulic Research, **vol. 42**, nr. 1, 2004, pp. 29-33.

[5]. *** YSI Environmental Company, SonTek ADVField - Acoustic Doppler Velocimeter, Technical Documentation, SUA, 2001.

[6]. *** ASCE standard no. ANSI/ASCE 2-91/1993, Measurement of Oxygen Transfer in Clean Water - 2nd Edition, 45 pages.

[7]. *K. Yum, S. H. Kim and H. Park,* "Effects of plume spacing and flowrate on destratification efficiency of air diffusers", Water Research, **vol. 42**, 2008, pp. 3249-3262.

[8]. *Florentina Bunea, Gabriela Oprina, Corina A. Băbuțanu, Irina Pincovschi and G. Lăzăroiu*, "Technical and economical aspects of the new waste water treatment technologies", 5th International Conference Management of Technological Changes, Alexandroupolis, Greece, August 25-26, **vol. 1**, 2007, pp. 363-368.

[9]. *C. L. Soga and C. Rehmann,* "Dissipation of turbulent kinetic energy near a bubble plume", Journal of Hydraulic Engineering, **vol. 130** (5), 2004, pp. 441-449.

[10]. *M. Gresch, M. Armbruster, D. Braun and W. Gujer*, "Effects of aeration patterns on the flow field in wastewater aeration tanks", Water Research, **vol. 54**, issue 2, 2011, pp. 810-818.