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INFLUENCE OF FINE BUBBLE GENERATORS NOZZLES DIAMETER ON THE DISSOLVED O_2 CONCENTRATION

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Abstract

This paper presents an experimental study regarding the influence of fine bubble generators (FBG) nozzles on the oxygen transfer rate from air to water, in case of pneumatic aeration processes of stationary (still) waters. This experimental study was conducted after three types of fine bubbles generators were previously computed, designed and constructed to satisfy the conditions imposed in order to provide valid experimental results. The three constructive versions were tested under similar operating conditions so that, the only parameter that influences the transfer of oxygen would be the nozzle diameter. It was found that, with increasing the air outlet diameter, the oxygen transfer rate into the water decreases.

Key words: fine bubble generators, nozzle diameter, stationary waters oxygenation

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1. Introduction

Some aspects concerning the influence of the constructive solution of fine bubble generators on the dissolved oxygen concentration in water and on the performances of this constructive solution can be found in a number of scientific papers (Miyahara et al., 1983; Oprina et al., 2009; USEPA, 1989). The constructive solutions of fine bubble generators and the materials from which they are produced are multiple and intensively studied. Băran et al. (2012) studied the efficiency of the water oxygenation process using a fine bubble generator (FBG). The study was carried out in non-stationary conditions using a fine bubble generator with a plate with 0.5 mm nozzle diameter. The authors found that the performance of the oxygenation process is reduced because the height of the water layer above the FBG is small (H = 500 mm H_2O); besides, the initial concentration of O_2 dissolved in water at $\tau = 0$ is high (C_0 = 5.12 mg/L). Moreover, they concluded that the oxygenation process is reduced because the nozzle diameter is large.

Recent research on the interphasic mass transfer with fine bubble generation focused on the following topics: sparger porosity and bubble diameter (Bouaifi et al., 2001; Luo et al., 1999; Shimizu et al., 2000), bubbles characteristics (Anabtawi et al., 2003; Forret et al., 2003; Veera et al., 2004), the flow regime and computational fluid dynamics (Tang and Heindel, 2004; Wang et al., 2003). The most important element of the fine bubbles generator is represented by the dispersion element of air in water, which can be built in different shapes (circular, rectangular, tubular etc.) and produced from materials that fulfill some functional criteria (metallic materials, glass, plastic, rubber, shape-memory materials etc.) (Miyahara et al., 1983; USEPA, 1989).

The control of bubble diameter is a very important technique. Many authors presented that

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bubble diameter depends on the generation method (Hirai et al., 2009). Sadatom et al. (2005) found an optimum diameter ratio of spherical body to pipe, and confirmed that the sparger could generate bubbles with a reduced energy consumption and increase effectively the dissolved oxygen levels.

This paper aims to study the constructive characteristics of fine bubbles generators (FBG) in terms of:

- nozzles diameter (d_0) of the fine bubble generator, through which compressed atmospheric air is introduced in the water mass;
- distance between nozzles (d).

For the construction of efficient fine bubble generators two conditions are imposed:

(i) the correlation between the plate height (s) in which the air output nozzles are manufactured and those nozzles diameters (d_0) is given by Eq. (1) (Oprina et al., 2009).

$$\frac{s}{d_0} > 3 \tag{1}$$

(ii) the correlation concerning the distance between two successive nozzles and the nozzle diameter is given by Eq. (2) (Căluşaru et al., 2012; Miyahara et al., 1983; Oprina et al., 2009).

$$\frac{d}{d_0} > 8 \tag{2}$$

We analyzed if the two conditions (i) and (ii) are fulfilled for three configurations of FBGs.

2. Material and methods

2.1. Constructive solutions of the FBG analyzed experimentally

In order to obtain fine or very fine bubbles, the nozzle diameter where air leaves the perforated plate must be as small as possible (d_0 < 1mm), and the nozzles distribution on the plate must be uniform. To establish the influence of the output nozzle diameter of the air bubbles in water we studied three FBG constructive versions.

Table 1. Design and operating conditions of the experimental spargers

FBG	*d_0 [mm]*	*$d=m\cdot d_0$ [mm]*	*A_0 [m]*
version I	0.3	6	$1.1775\cdot10^{-6}$
version II	0.4	8	$1.1775\cdot10^{-6}$
version III	0.5	10	$1.1775\cdot10^{-6}$

Notations: d_0 - the nozzles diameter; d - the network step (m=20); $\dot{V}$ - the air flow rate; A_0 -the air output section in water; H - hydrostatic load; τ - duration of the water oxygenation process.

The number of nozzles is given by Eq. (3):

$$n = \frac{A_0}{\frac{\pi}{4} d^2} \tag{3}$$

The A_0 value was chosen in order to have a reasonable length of the FBG for the experimental researches (Fig. 1).

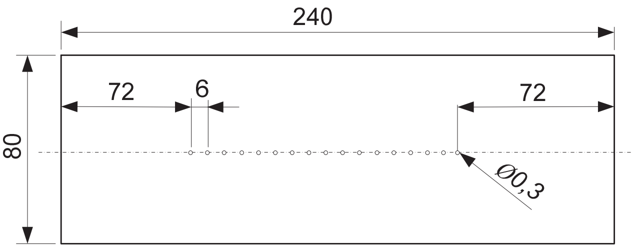


Fig. 1. The FBG plate (version I)

The dimensions for versions II and III are presented in Tables 1 and 2.

Table 2. Calculations results

FBG	*Condition (1)*	*n*
version I	7	17
version II	5	9
version III	4	6

The constructive shape of plate was rectangular; the bubbles coagulation risk is significantly reduced by using this shape (Fig. 2).

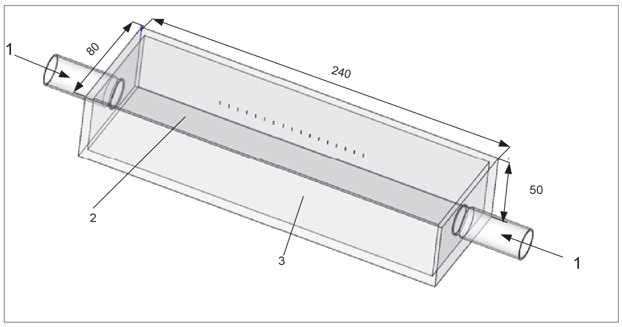


Fig. 2. The constructive version chosen for the fine bubble generator: 1- compressed air joint; 2- plate with nozzles; 3- body of the FBG

The nozzle diameter is the most important factor that influences the oxygen transfer rate in the pneumatic aeration systems with fine bubbles, because of its influence on the air bubble diameter.

2.2. Correlation between the diameter of FBG nozzle and the oxygen transfer into water

In order to obtain an efficient aeration, the air is introduced in the lower part of the water tank by using a certain FBG configuration. The fine bubble aeration is more efficient from mass transfer point of view than the aeration obtained with coarse bubbles, because the specific interfacial area (a) between air and water (Eq. 4) is larger (Oprina et al., 2009).

$$a = \frac{A}{V} \tag{4}$$

where: A - gas bubble area; V - the volume of the biphasic system (air + water).

The intensification of the oxygen mass transfer in water, meaning the increase of oxygen transfer rate in water ($\partial C / \partial \tau$) implies a maximal gas-liquid interfacial area between, which requires the development of air bubbles having a diameter as small as possible. There is a dependence relation between the nozzle diameter of the perforated plate (d_0) of the FBG and the diameter (D_0) of the generated air bubbles, which depends on the working regime: quasi static, dynamic, turbulent (Oprina et al., 2009).

The smaller is (d_0), the smaller (D_0) will be, the values (d_0) and (D_0) having the same order of magnitude. The size of the bubble also results from the balance between the gas pressure inside the bubble and the pressure corresponding to the hydrostatic column of liquid above the orifice plate. The transfer rate of oxygen into water is given by Eq. (5) (Pincovschi, 1999; Robescu and Robescu, 1999):

$$\frac{dC}{d\tau} = ak_L(C_s - C) \tag{5}$$

where: $\partial C / \partial \tau$ - the transfer speed of the oxygen [kg/m^3·s^{-1}]; ak_L - the volumetric mass transfer coefficient [s^{-1}]; C_s - mass concentration of dissolved oxygen at saturation [mg/L].

The volumetric mass transfer coefficient (k_La) can be calculated using Eq. (6) (Pincovschi, 1999).

$$k_La = \frac{ln\frac{C_s - C_1}{C_s - C_2}}{\tau_2 - \tau_1} \tag{6}$$

where: k_La – volumetric oxygen mass transfer coefficient at water's temperature [1/s]; C_1 – mass concentration of oxygen dissolved [mg/L] at the moment τ_1; C_2 – mass concentration of oxygen dissolved [mg/L] at the moment τ_2.

The values C_1 and C_2 will be specified after performing the measurements.

3. Experimental

The experimental researches were made in the Department of Thermotechnics, Engines, Thermal and Refrigeration Machines from the Faculty of Mechanical and Mechatronics Engineering, University Politehnica Bucharest. The measurement conditions were identical for all the three versions of the sparger. The compressed air delivered by the compressor passes through the rotameter where the air flow rate is measured.

The air temperature and pressure are measured; at the end, the air enters the FBG, which generates bubbles and disperses them in the water mass. The increase of the O_2 concentration in the water volume is measured using an oxygen meter - HI 9146 Portable Dissolved Oxygen Meter (www.hannainst.com) that measures up to 300% saturation or 45 ppm (mg/L) with temperature compensation and automatic calibration.

This instrument also allows altitude compensation up to 4000 m and the ppm and % saturation are both compensated for changes in solubility of oxygen in water and for permeability of the membrane as well as the temperature effect.

The included polarographic probe features built-in temperature compensation and removable protective membrane cover. The dissolved oxygen concentration the water was measured at the half of the water layer height by rotating the oxygen meter probe. During the measurements we maintained constant the air pressure in the tank; using the pressure reducer we maintained a constant pressure at the air input to the FBG. The height of the water level over the FBG is h_{H2O} = 500 mm, the probe is immersed at h_{probe} = 250 mm. The measured initial dissolved oxygen concentration is C_0 = 5.46 mg/L and the water temperature is of t_{H2O} =25°C. We measured the pressure (p) and the air flow rate ($\dot{V}$) of air that enters the FBG, maintained constant during the measurements. After a working time $\Delta\tau_1 = 15'$, the FBG is stopped and we measured the O_2 concentration by turning the probe in water, using the electromechanical driving system specially designed for this purpose (Băran et al., 2011). We started again the FBG and we introduce air during 15′ up to a total time of $\Delta\tau_2$=30'; we measured the O_2 concentration.

In the same way, we reached $\Delta\tau_3$=45', $\Delta\tau_4$=60', $\Delta\tau_5$=75', $\Delta\tau_6$=90', $\Delta\tau_7$=105', $\Delta\tau_8$=120'. The location of the fine bubble generator in the aeration tank and the measurement setup are presented in Fig. 4.

4. Results and discussion

The measurements were performed each 15′, from τ = 0 to τ = 120 min; the FBG was stopped during the measurement of the dissolved oxygen concentration in water using an oxygen meter. The FBG's operation can be observed in Fig. 5. For $\dot{V} = 600 dm^3/h$ and p ≈ 120 mbar the following values were obtained (Table 3).

Table 3. Values of k_La resulted by calculations using Eq. (6)

FBG	***k_La [1/s]***
version I	0.0462
version II	0.0416
version III	0.0389

The data collected during experiments allowed us to perform the following steps:

(i) computing k_La values for all three FBG;

(ii) plotting the dependence of dissolved oxygen concentration versus time for each sparger (Fig 6).

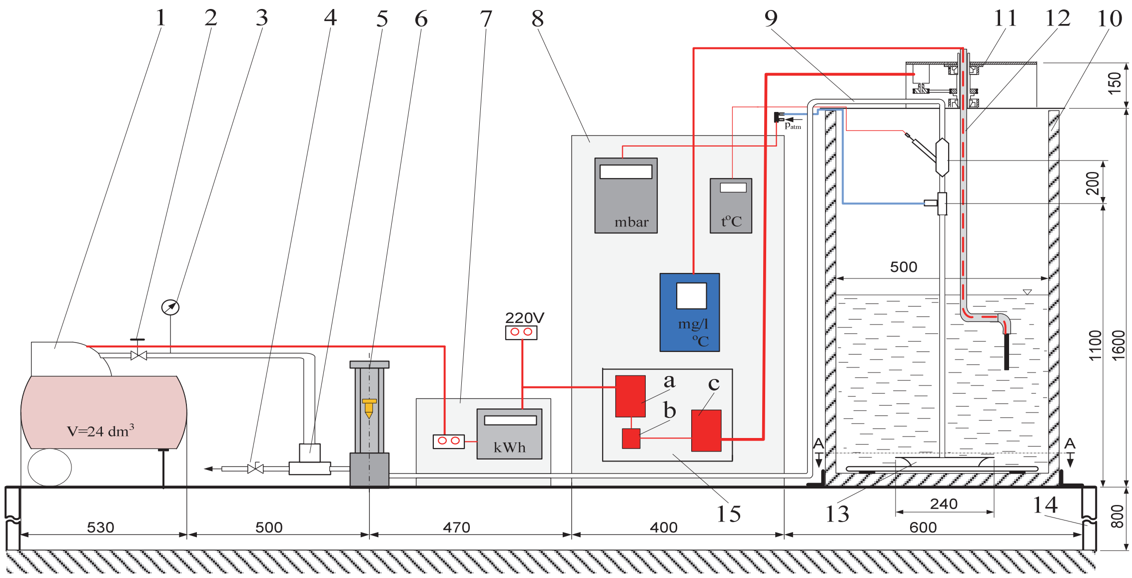
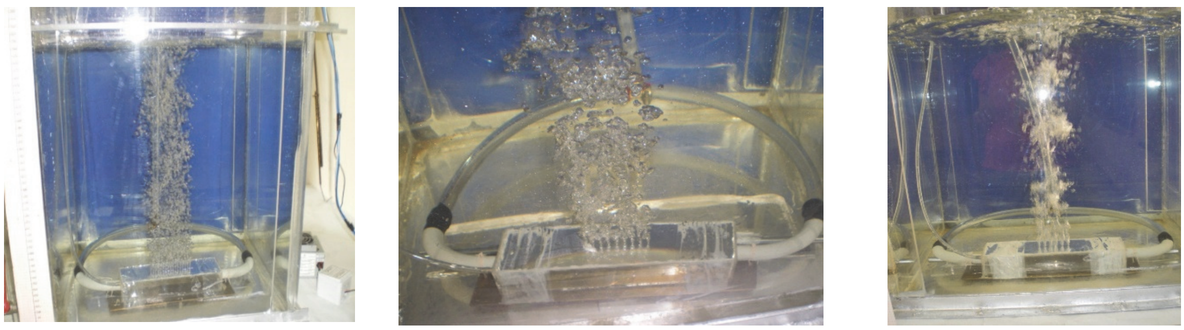


Fig. 4. The sketch of the setup for researches on water oxygenation: 1– electro compressor with air tank; 2 - pressure reducer; 3–manometer; 4–joint for exhausting of air in the atmosphere; 5– branch pipe; 6– rotameter; 7– electric panel; 8– measuring instruments panel; 9– pipe for the transport of the compressed air towards the FBG; 10– water tank; 11– mechanism for probe driving; 12– oxygen meter probe; 13– FBG; 14– holder for the plant; 15–control electronics (a – supply unit, b- switch, c- control element)



a) b) c)

Fig. 5. Fine bubble generators during working: a) FBG with 17 holes (Ø0.3mm); b) FBG with 9 holes (Ø0.4mm); c) FBG with 6 holes (Ø0.5mm)

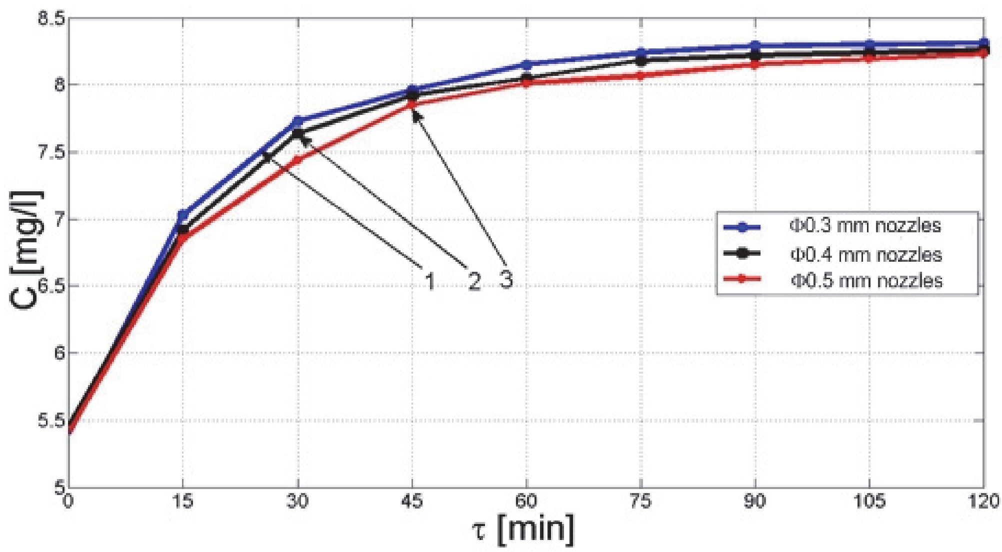


Fig. 6. The variation of the concentration of the oxygen dissolved into water function of time: 1 - FBG with perforated plate with Ø0.3 nozzles; 2 - G.B.F. with perforated plate with Ø0.4 nozzles; 3 - FBG with perforated plate with Ø0.5 nozzles

The results obtained show a satisfactory coincidence with other research results concerning the fine bubble generators (Băran et al., 2012). The bubble size is of the same order as the nozzle diameter, leading to a large rise velocity of the gas phase.Small orifice diameter plates enable the formation of smaller sized bubbles. The rise velocity of a single gas bubble depends on its size. Thus, the size and rise velocity of a bubble depend on each other and are affected by the same parameters. The final stage of oxygen transfer takes place as the air bubble breaks through the liquid surface. Surface turbulence is not required for good oxygen transfer with fine bubble diffusers. Coarse bubbles disturb the free surface due to the velocity of ascent to the surface. If this disturbance is sufficient, oxygen will be absorbed by the liquid passing through the air above the water surface.

5. Conclusions

The experiments performed in the laboratory of the Department of Thermotechnics, Engines, Thermal and Refrigeration Machines from the Faculty of Mechanical and Mechatronics Engineering, University Politehnica Bucharest led to the following conclusions:

a) The nozzle diameter of FBG influences the dissolved oxygen concentration and mass transfer rate of oxygen in water.

b) When the nozzle diameter increases in the range 0.3 mm →0.5 mm, the dissolved oxygen concentration in water decreases.

Acknowledgements

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