RESEARCHES REGARDING WATER OXYGENATION WITH FINE AIR BUBBLES

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In the field of water oxygenation it is known that as the bubble diameter of the gas (air) is smaller, the oxygen transfer rate to the water is higher. In this regard, the paper presents the results of theoretical and experimental research on the performance of fine bubble generators built through special technologies. The orifice plate of fine bubble generators were performed by micro-drilling. Through micro-drilling, three types of perforated plates with orifices of Ø 0.1 mm, Ø 0.3 mm, Ø 0.5 mm, were performed. The results of the experimental researches on the increased dissolved oxygen concentrations in water function of time for the three constructive versions are presented.

Keywords: water oxygenation, fine bubble generators, micro-drilling.

1. Introduction

The paper aims to establish the influence of fine bubble generators architecture on the aeration (oxygenation) plant performance. The studies were performed using a special constructed experimental installation to establish the performance of new types of fine bubble generators in the laboratories of POLITEHNICA University of Bucharest. Water oxygenation is a process of mass transfer between air and water; the process is based on the oxygen transfer from air to water or pure oxygen in a water volume. The water volume is subject to the aeration process in a basin, a lake or other water volume of free surface, as long as it has a shortage of oxygen compared to the saturation state. Aeration plants are equipped with pneumatic compressors that introduce atmospheric air bubbles in water. By using modern oxygenation technologies is possible to reduce the energy consumption, which leads to high performance results of oxygenation plants.

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The paper presents a new type of fine bubble generator (FBG) that in comparison with porous diffusers made of ceramic materials, has the following advantages:

− Ensures a uniform distribution of air bubbles in the water mass;

− All bubbles emitted by the fine bubble generator have the same diameter;

− The pressure loss at the air passage through this type of FBG is lower than at porous diffusers;

− The orifices placement in different networks is imposed by the designer, which guarantees a certain air flow for water oxygenation.

According to the size of the gas bubbles that appear into the water mass bubble generators are classified as follows [1] [2]:

a) Fine bubble generators emitting gas bubbles with a diameter $D_0 < 1$ mm;

b) Medium bubble generators that provides gas bubbles with $D_0 = 1...3$ mm;

c) Large bubbles generators with $D_0 = 3 ... 120$ mm.

The size of the air bubble is determined by the diameter of the orifice through which the air is inserted into the water; the paper presents three constructive solutions of FBG with the orifice diameter $d_0 < 0.5$ mm.

The present paper represents a comparison between a new version of GBF with 0.1 mm orifice and two versions of GBF previously built by the authors with orifice of 0.3 mm and 0.5 mm (see Constantin et al. [15] for the 0.5 mm version).

2. The influence of the orifice diameter on the variation of dissolved oxygen concentration in water

The orifice diameter will influence the bubble diameter emitted in the water mass. The initial gas bubble diameter (D_0) emerging from the orifice is computed with the relation [3] [4]:

$$D_0 = \sqrt[3]{\frac{6 \cdot \sigma \cdot d_0}{(\rho_l - \rho_g) \cdot g}} \ [m] \tag{1}$$

The value of D_0, depends on: d_0 - orifice diameter; σ - surface tension coefficient; ρ_l - liquid density; ρ_g - gas density; g- gravity acceleration.

Are known [5]: $\sigma = 7.3 \cdot 10^{-3}$ N/m; $g = 9.81$ m/s^2; $\rho_l = 10^3$ kg/m^3; $\rho_g = 1.2$ kg/m^3.

For the three versions, by replacing in equation (1), d_0 with $0.1 \cdot 10^{-3}$ m, $0.3 \cdot 10^{-3}$ m, $0.5 \cdot 10^{-3}$ m, $D_{0,I} = 0.0007$ m, $D_{0,II} = 0.0010$ m, $D_{0,III} = 0.0013$ m, are obtained. It is noted that d_0 and D_0 are in the same magnitude order, $D_0 \cong 2 \cdot d_0$.

In the paper, researches concerning orifices with Ø 0.1; Ø 0.3; Ø 0.5 mm are performed, so, the maximum bubble diameter is $D_0 \approx 1 \ mm$, i.e., the research is performed in the field of fine bubbles.

In the case of pneumatic aeration equipment's, the oxygen transfer rate to water is given by [6] [7]:

$$\frac{dC}{d\tau} = a \cdot k_L \left(C_s - C \right) \left[\frac{kg}{m^3} \cdot \frac{1}{s} \right] \tag{2}$$

where: a– specific interfacial area $[m^2/m^3]$ k_L – global mass transfer coefficient $[s^{-1}]$; C_s – mass concentration of oxygen in water at saturation $[kg/m^3]$; C – current mass concentration of oxygen in water $[kg/m^3]$.

From the specialty literature [8] [9], it is known that the specific interfacial area (a) significantly decreases as the gas bubbles diameter grows. As a result, there is a need to create a network of air dispersion in water through bubbles with small diameter. The mass transfer coefficient (ak_L) computation method is presented in the paper [4].

3. Fine bubble generators architecture

With the notations in Figure 1, when designing and constructing the FBG the following two conditions [10] [11] I, II must be fulfilled:
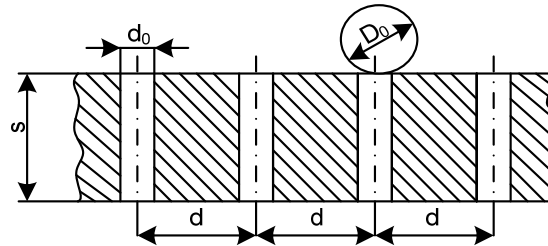

Fig. 1. Orifices plate for air dispersion in the water
d_0 - orifice diameter, $d_0 = 2r_0$, D_0 - gas bubble diameter at the orifice exit (at the detachment time);
s - perforated plate thickness

$$\text{I. } s/d_0 > 3 \tag{3}$$

$$\text{II. } d/d_0 > 8 \tag{4}$$

Within the experimental research, for the three versions, the following are obtained:

$$\text{I. } d_0 = 0.1 \text{ mm}; \ s/d_0 = 2/0.1 = 20; \ d/d_0 = 2/0.1 = 20 \tag{5}$$

$$\text{II. } d_0 = 0.3 \text{ mm}; \ s/d_0 = 2/0.3 = 6.66; \ d/d_0 = 6/0.3 = 20 \tag{6}$$

$$\text{III. } d_0 = 0.5 \text{ mm}; \ s/d_0 = 2/0.5 = 4; \ d/d_0 = 10/0.5 = 20 \tag{7}$$

It is noted that for the three versions, the ratio $s/d_0 > 3$ and the ratio $d/d_0 = 20$. From previous research conducted by the authors [12] [13] and

considering the plant architecture for experimental research on FBG, the air exit section of an area $A=1.2 \cdot 10^{-6}$ m^2 was chosen.

The orifice number for the three versions, results:

$$\text{I. } d_0 = 0.1 \text{ mm}; \; n_{0.1} = \frac{A}{\left(\pi \cdot d_0^2\right)/4} = 152 \tag{8}$$

$$\text{II. } d_0 = 0.3 \text{ mm}; \; n_{0.3} = \frac{A}{\left(\pi \cdot d_0^2\right)/4} = 17 \tag{9}$$

$$\text{III. } d_0 = 0.5 \text{ mm}; \; n_{0.5} = \frac{A}{\left(\pi \cdot d_0^2\right)/4} = 6 \tag{10}$$

The authors propose a new generation of FBG where the air dispersion orifices in water are processed by micro-drilling (Ø0.1 mm, Ø0.3 mm, Ø 0.5mm). This new type of FBG has the paper introduction described advantages. Other types of FBG obtained by unconventional technologies are presented in [9] [14].

The following provides the three versions of FBG, namely:

I. Version I: FBG where the perforated plate has 152 orifices Ø 0.1 mm;

II. Version II: FBG where the perforated plate has 17 orifices Ø 0.3 mm;

III. Version III: FBG where the perforated plate has 6 orifices Ø 0.5 mm.

I. Version I presentation

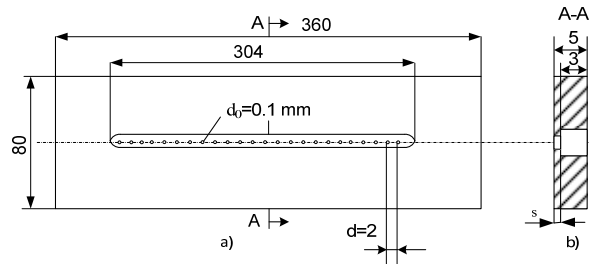Fig. 2 presents the FBG perforated plate.

Fig. 2. The FBG perforated plate
a) plan view; b) cross section

In order to create the orifices in the plate (Figure 1), a recess (a duct) of 3 mm deep and 304 mm long has been created; the air exit orifice has a thickness of 2 mm. Subsequently, by using a CNC which have a special type micro processing machine KERN Micro, into the duct, 152 holes of 0.1 mm, has been performed. This machine has an accuracy of ± 0.5 μm which ensured the design of a FBG constituting an original constructive solution.

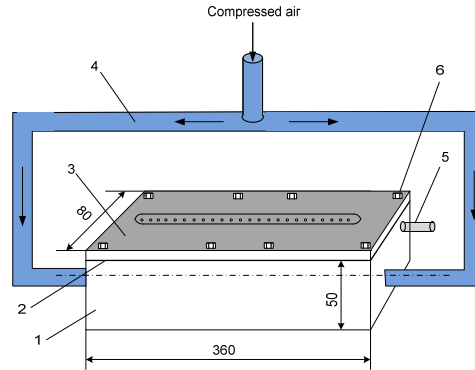Fig. 3 shows the constructive solution of the FBG in version I.

Fig. 3. Fine air bubble generator
1 - compressed air tank; 2 - gasket; 3 - orifice plate; 4 - compressed air supply pipe Ø 18 mm;
5 - connection for measuring the air pressure in the tank; 6 - plate fixing screws

II. Version II presentation

As a constructive form, a rectangular shape plate was chosen. A sketch of this plate is shown in Figure 4:
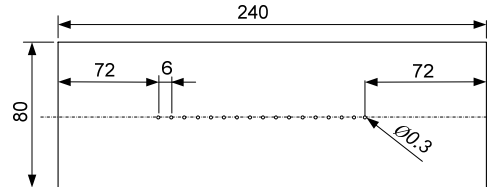

Fig. 4. Perforated plate with 17 orifices of Ø 0.3 mm

The distance between the orifices is 6 mm, and the aluminum plate thickness is 2 mm.

III. Version III presentation

As a constructive form, a rectangular shape for the orifice plate was selected. A sketch of this plate is shown in Figure 5 [15]:
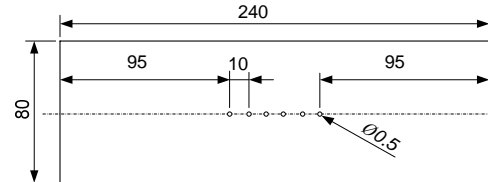

Fig. 5. Perforated plate with 6 orifices of Ø 0.5 mm

For this version the distance between the orifices is 10 mm, and the aluminum plate thickness is 2 mm.

4. The experimental plant presentation

The research aims is to determine the dissolved O_2 concentration variation in water for the 3 versions of FBG. The experimental stand consists of [10]:

- Compressor (1), to produce compressed air with the following operating parameters: maximum discharge pressure p = 8 bar, aspirated flow rate = 200 dm³/min, electric motor power P = 1.1 kW at rpm n = 2850 rpm/min, tank volume (V = 24 dm³). The compressor is equipped with a manometer 0-16 bar to show the pressure in the compressor tank and a pressure reducing valve (2) for the establishment of the pressure in the piping system.

- Air pipes for the delivery of the compressed air, made of plastic, with the inner diameter of Ø15 mm and a wall thickness of 2 mm; its supplies the fine bubble generator with air and ensures the evacuation of the excess air supplied by the compressor to the atmosphere.

- The aeration tank constructed of Plexiglas plates with thickness of 5 mm, having the dimension, $0.5 \times 0.5 \times 1.5$ (W × L × h); the tank was filled with tap water.

- Fine bubble generator.

- The mechanism for the probe actuation.

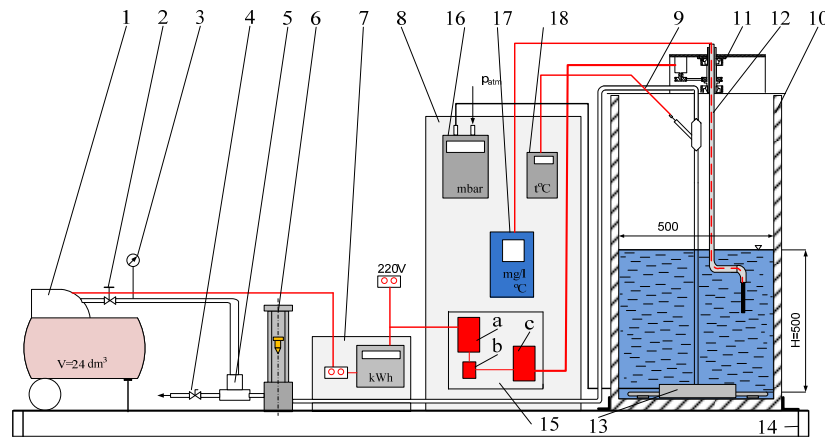The sketch of the stand used for the experimental researches is presented in Fig. 6.

Fig. 6. Sketch of the experimental plant for researches regarding water oxygenation
1-electro compressor with air tank; 2– pressure reducer; 3–manometer; 4– connector for air exhaustion in the atmosphere; 5– T-joint; 6– rotameter; 7–electrical panel; 8- panel with measuring devices;9- pipe for the transport of the compressed air to the FBG; 10– water tank; 11- mechanism for the probe actuation; 12– oxygen meter probe; 13– FBG; 14- installation holder; 15–electronics control: a– supply unit, b- switch, c- control element; 16–digital manometer; 17– oxygen meter; 18–digital thermometer.

On the tank cover (10) a mechanism that drives the oxygen meter probe (12) in rotation at a speed of 0.3 m/s is located. The oxygen meter probe is located at the half of the height H=500 mm and at 125 mm towards the tank walls.

5. Experimental research methodology

The experimental researches were conducted as follows: the water tank is filled: H = 500 mm; the water temperature in the tank and the initial dissolved O_2 concentration (C_0 at $\tau = 0$) in the water are measured; C_s (t_{H2O} [23.7^{o}C]=8.5 mg/l); the compressor is turned on and the compressed air temperature is measured; the FBG is inserted in the tank and the time (τ =0) is noted; every 15 minutes, the dissolved oxygen concentration in water is measured; the duration of the experiments is 120 minutes, ie eight measurements set are performed.

6. Experimental research results

I) For version I where the FBG has 152 orifice of Ø 0.1 mm (Fig. 3) the data in Table 1 were obtained, the dissolved oxygen in water was noted DO.

Table 1

Determined values

Nr.crt	0	1	2	3	4	5	6	7	8
τ [min]	0	15	30	45	60	75	90	105	120
t_{H2O}[^{o}C]	23.7	23.7	23.7	23.7	23.7	23.7	23.7	23.7	23.7
t_{aer}[^{o}C]	24.1	24.1	24.1	24.1	24.1	24.1	24.1	24.1	24.1
DO[mg/l]	5.48	7.39	7.85	8.01	8.26	8.30	8.35	8.37	8.39

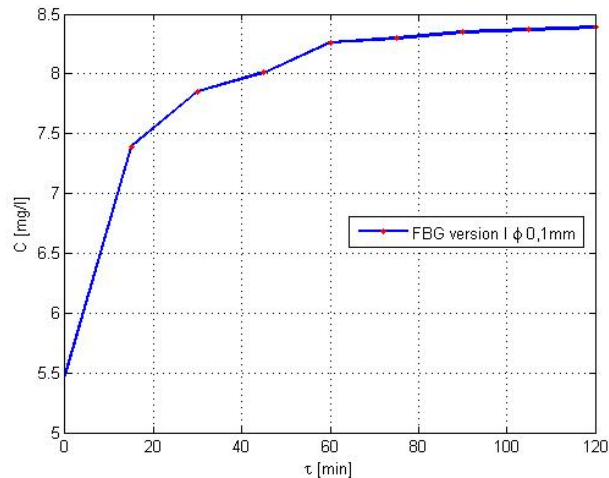Based on the results in Table 1, the graphs C=f(τ) in Fig. 7 was plotted.

Fig. 7. The variation of dissolved oxygen concentration in water function of time; version I

The operation of FBG in version I is observed in Fig. 8. II) For version II, the operation of the FBG is shown in Fig. 9.
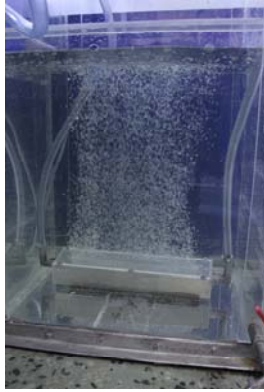

Fig. 8. FBG with 152 orifices Ø 0.1 mm
in operation

Fig. 9. FBG with 17 orifices Ø 0.3 mm
in operation

Following the measurements, the data in Table 2 was obtained.

Table 2

Experimental data obtained by testing the FBG with 17 orifices

Nr.crt	0	1	2	3	4	5	6	7	8
τ [min]	0	15	30	45	60	75	90	105	120
t_{H2O}[^{o}C]	24,6	24,6	24,6	24,6	24,6	24,6	24,6	24,6	24,6
t_{aer}[^{o}C]	27,2	27,2	27,2	27,2	27,2	27,2	27,2	27,2	27,2
DO[mg/l]	5.46	7.03	7.73	7.96	8.15	8.24	8.29	8.30	8.31

Based on the data of Table 2 to graph C = f (τ) (Figure 10) presents the variation of dissolved oxygen concentration in time, for the FBG in version II.
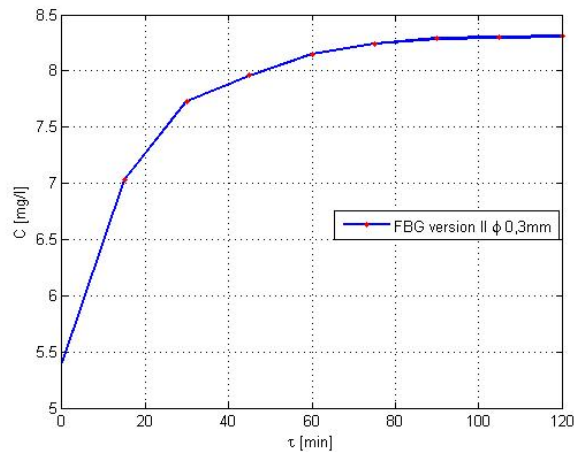

Fig. 10. The variation of dissolved oxygen concentration in time C = f (τ)

III) For version III, measurements were performed with an FBG with 6 orifices of Ø 0.5 mm. The experimental researches are performed similarly as in the case of the other described above FBG's. The present measurements were performed in February, while those presented by Constantin et al. [15] were performed in July.

Fig. 11. FBG with 6 orifices Ø 0.5 mm in operation

The values of the experimental measurements are shown in Table 3.

Table 3

Experimental data obtained by testing the FBG with 6 orifices

Nr.crt	0	1	2	3	4	5	6	7	8
τ [min]	0	15	30	45	60	75	90	105	120
$t_{H2O}[^{o}C]$	24	24	24	24	24	24	24	24	24
$t_{aer}[^{o}C]$	27	27	27	27	27	27	27	27	27
DO[mg/l]	5.41	6.85	7.44	7.85	8.01	8.07	8.15	8.19	8.23

Based on the experimental data from Table 3 the graph of the dissolved oxygen concentration in water $C = f(\tau)$ Fig. 12, was plotted:
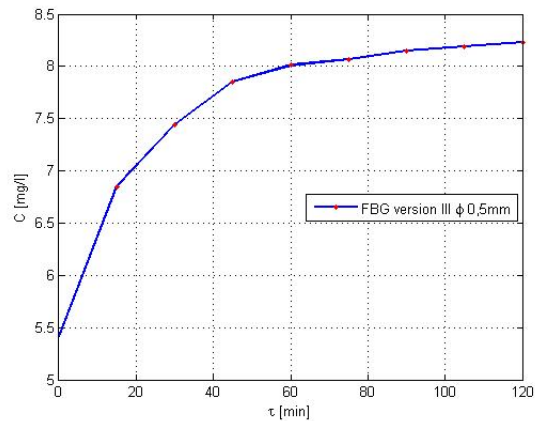

Fig. 12. The variation of dissolved oxygen concentration in time $C = f(\tau)$

Fig. 13 presents the functions $C_{O_2} = f(\tau)$ for the three versions of FBG.
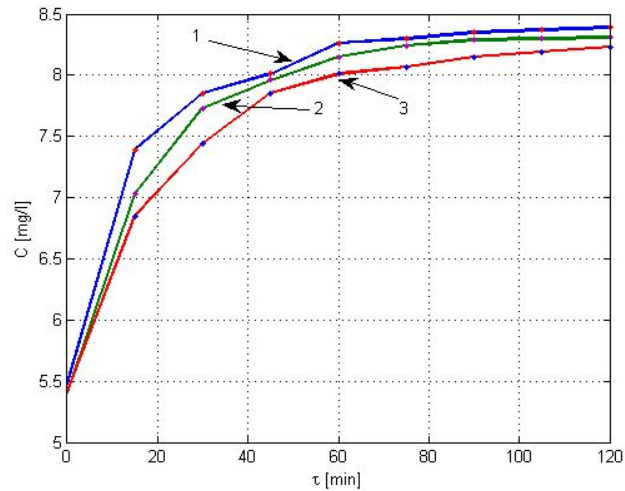

Fig. 13. The variation of dissolved oxygen concentration in time
1. Version I: Ø 0.1 mm; 2. Version II: Ø 0.3 mm; 3. Version III: Ø 0.5 mm.

From Fig. 13 it is noted that the FBG version I, has the most efficient operation. It is confirmed that, as the orifice diameter is smaller, the water oxygenation process is more efficient.

7. Conclusions

1. The issue presented in this paper contains a series of determinations and original contributions:
− Design and construction of new types of FBG;
− Experimental testing of new prototypes of FBG;
− The hydrodynamic FBG performance determination.
2. Bubble generators with perforated plate that contains orifices of Ø 0.1 mm, Ø 0.3 mm, 0.5 mm, fall within the category of fine bubble generators that provides a fast and efficient wastewater oxygenation.
3. The paper emphasizes the importance of cooperation and implementation of mixed teams of researchers in the fields of: mass transfer, micro-processing, electrical drives, electrochemical measurements, etc.

4. The design and the achievement of a FBG which has perforated plate with orifice of Ø 0.1mm is an original achievement of the authors. It is a clear progress due to the fact that the plate provides a controlled and uniform distribution of the air in the water tank. By contrast, porous diffusers [16], although emitting air bubbles with a diameter less than 0.1 mm, create a distribution that is uneven and chaotic.

5. The FBG constructed by micro-drilling or spark-erosion [17] provides a lower pressure loss than the FBG with porous diffusers, which leads to an energy saving in the air compressing station.

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