RESEARCHES ON WATER OXYGENATION USING MICROBUBBLES

***Mihaela* CONSTANTIN, *Nicolae* BĂRAN, *Beatrice* TĂNASE, *Rareș* PĂUN**

POLITEHNICA UNIVERSITY OF BUCHAREST, FACULTY OF MECHANICAL AND MECHATRONICS ENGINEERING, Bucharest, Romania

Abstract. Currently, water treatment plants use chlorine and compressed air introduced into water through various methods. The paper presents a new air distribution method, namely, using a microbubbles generator. It is known that as the air bubble diameter is lower the oxygen transfer speed to water is higher. Considering this, a microbubbles generator that has 152 orifices with Ø 0.1 mm was designed and developed; the air bubbles have 700 µm. The end of the paper presents the experimental stand and the experimental research results.

Keywords: water oxygenation, oxygen transfer speed, microbubbles generator.

1. INTRODUCTION

Water oxygenation is a fundamental process of thermodynamics namely, a process of mass transfer between air and water. The process is based on the transfer of oxygen from the air or pure oxygen transfer directly into a water body.

The water is subjected to aeration process in an aeration tank, in a lake or other free surface water as long as it has ”more or less" oxygen to saturation shortage. A pneumatic aeration plant injects the atmospheric air in the form of bubbles in water. Air bubbles are entrained in a hydrodynamic flow generated by the equipment forming air bubbles.

Pneumatic aeration has superior performance compared to other "mechanical" aeration systems. The performances of such pneumatic aeration system are defined by two parameters: the aeration efficiency and the oxygenation process performance. These parameters are determined by the compressed air production source efficiency and by the air dispersion architecture into the aeration tank.

The most advanced aeration systems are the ones that create fine air bubbles (Ø < 1 mm). Fine bubble aeration systems called fine bubble generators (FBG) can be classified in four categories [1] [2]:

I) FBG constructed of ceramic (ceramic diffusers);

II) FBG constructed of porous plastic material;

III) FBG constructed of perforated membrane;

IV) FBG constructed through spark-erosion or micro-drilling.

The advantages of fine bubble aeration systems are [3] [4]:

- Low hydraulic resistance, especially the IV category;
- Constructional simple;
- High efficiency;
- Superior life span;
- Easily adjustable (where applicable);
- Does not require frequent maintenance or constant supervision;
- Fit and easily removable and can be quickly replaced.

Pneumatic aeration efficiency of all systems is reduced with increasing water temperature because the oxygen solubility decreases at higher temperatures. The composition of the water has a profound influence in determining the oxygenation process efficiency because the performance is gradually reduced with the concentration of organic substances in water and pollution.

2. THE MICRO AIR BUBBLES GENERATOR CONSTRUCTIVE SOLUTION

The original constructive solutions for these new types of microbubbles generators (MBG) where the air injection orifices were constructed through spark-erosion or micro-drilling (on special CNC machines or using small drills with Ø < 0.5 mm).

According to specialized papers [1] [3], the main functional parameters that influence the oxygenation process performance are:

- The characteristics of microbubbles generators; the constructive characteristics are the microbubbles generators orifice diameter through which the air is released into water bodies, the distance between two orifices, the orifices distribution and the chosen constructive solution of the microbubbles generator. This refers to the dispersion plate shape, the plate thickness and the construction of the microbubbles generator body.

- The installation characteristics of microbubbles generators in the aeration tank. This refers to the installation distance from the tank foundation frame as well as their distribution in the aeration tank, the microbubbles generators connection manner to the compressed air network and the aeration tank shape.

The most important element of the microbubbles generators is the air dispersing element in water, or the orifice plate, which can be constructed with different shapes (circular, rectangular, tubular, spherical, etc.) and made of materials that fulfill certain operation criteria (metallic, glass, plastic, rubber, shape memory materials, etc.).

For the construction of performance microbubbles generator two conditions [5] [6] indicated by equations (1) and (2) are imposed:

* The first condition relates to the correlation between the plate thickness and the orifices diameter (Figure 1):

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

where: s- the plate thickness; d0 – the orifice diameter.

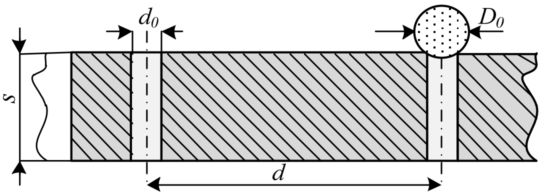

Fig. 1. Orifices placement in the MBG
d_0 – the orifice diameter, $D_0 = 2r_0$; d - the distance between the centers of two orifices. D_0 - the diameter of the gas bubble exiting the orifice (its detachment); s – the plate thickness

** The second condition refers to the relation between the distance between two successive orifices and the orifice diameter:

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

where: d - is the distance between two orifices.

Therefore, in order to obtain fine bubbles or microbubbles, the orifice diameter should be as small as possible ($d_0 < 1$ mm) and the orifices distribution in the plate must be uniform.

These two conditions can be achieved by using unconventional technologies or modern technologies as micro-processing:

- Spark-erosion processing;
- Electrochemical processing;
- Laser processing;
- Electron beam processing;
- Processing with micro- drilling machines with drills of Ø < 0.5 mm.

The microbubbles generator (MBG) has the dispersion element, a metal plate of a rectangular shape, referred to as rectangular MBG.

The plate thickness s = 2 mm, has 152 orifices with a diameter of 0.1 mm, the distance between the orifices is 2 mm, in compliance with the two previous conditions (relations 1 and 2):

$$\frac{s}{d_0} > 3 \rightarrow \frac{2}{0.1} = 20 \tag{3}$$

$$\frac{d}{d_0} > 8 \rightarrow \frac{2}{0.1} = 20 \tag{4}$$

From previous researches [7] [8], considering the water tank dimensions and the water layer height, an air exit section in the water equal to $1.2 \cdot 10^{-6}$ m^2 was selected. For $d_0 = 0.1$ m, the number orifices resulted:

$$n = \frac{A}{\left(\pi \cdot d_0^2\right)/4} = 152 \tag{5}$$

Figure 2 presents a plan view of the rectangular MBG.

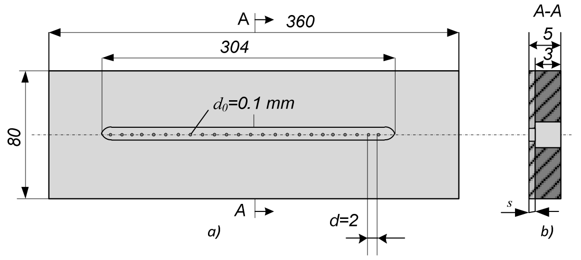

Fig. 2. MBG perforated plate
a) plan view; b) cross section

In Figure 3 one can observe the design of the microbubbles generator used in experimental researches.

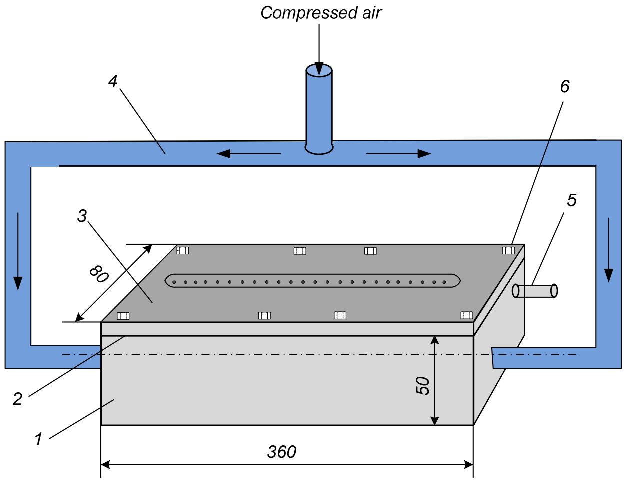

Fig. 3. Micro air bubbles generator
1 - compressed air tank; 2 - seal; 3 - orifice plate; 4 - pipe Ø 18 mm with compressed air;
5 - connection for measuring the air pressure in the tank; 6 - fixing screws of the perforated plate

The orifices in the perforated plate were created by micro-drilling with a machine KERN Micro. This machine has an accuracy of ± 0.5 mm and can process parts with a height of 220 mm and 350 mm diameter.

The achievement of this MBG which constitutes an original constructive solution took a theoretical and experimental basis revealed through [8] [9].

3. NUMERICAL INTEGRATION OF THE OXYGEN TRANSFER SPEED EQUATION

The oxygen transfer speed equation in water is [7] [8]:

$$\frac{dC}{d\tau} = a \cdot k_L \left(C_s - C\right) \tag{6}$$

where:

C - The dissolved oxygen concentration at the time τ;

ak_L -The volumetric mass transfer coefficient;

C_s -The oxygen concentration in water at saturation.

The values of ak_L and C_s are constant with time. If the boundary conditions are imposed $C = C_0$ for $\tau = 0$, the equation (6) can be integrated:

$$\int_C^{C_0} \frac{dC}{C_s - C} = \int_0^{\tau} a \cdot k_L \, d\tau \tag{7}$$

C_0- The dissolved oxygen concentration in water at the time $\tau_0 = 0$.

$$\ln\left(C_s - C\right)\Big|_C^{C_s} = a \cdot k_L \tau + 0 + ct \tag{8}$$

At $\tau = 0$:

$$\ln\left(C_s - C_s\right) - \ln\left(C_s - C\right) = 0 + 0 + ct \tag{9}$$

$$0 - \ln\left(C_s - C\right) = ct \tag{10}$$

Inserting (10) in (8):

$$\left(-\ln\left(C_s - C\right) = a \cdot k_L \cdot \tau - \ln\left(C_s - C_0\right)\right) \tag{11}$$

$$\ln\left(C_s - C\right) = \ln\left(C_s - C_0\right) - a \cdot k_L \cdot \tau \tag{12}$$

$$\ln\left(C_s - C\right) = \ln\left(C_s - C_0\right) + \ln e^{-a \cdot k_L \cdot \tau} \tag{13}$$

$$\ln\left(C_s - C\right) = \ln\left(\left(C_s - C_0\right) \cdot e^{-a \cdot k_L \cdot \tau}\right)$$

$$C_s - C = \left(C_s - C_0\right) \cdot e^{-a \cdot k_L \cdot \tau}$$

$$C = C_s - \left(C_s - C_0\right) \cdot e^{-a \cdot k_L \cdot \tau} \tag{14}$$

In the case studied the air is injected in the tank continuously for 120 ', so there is a non-steady state, will increase in time. In non-steady state, the measured value will be the dissolved oxygen concentration in time.

The water and air temperature, the gas flow rate introduced in the tank and the gas pressure in the MBG body are measured.

For the numerical integration of equation (14) a computer program was developed [7].

As input dates: C_0 = 5.84 mg / dm^3; H = 500 mmH$_2$O; t_{H2O}= 23.7 °C, t_{air}= 24.1°C; τ = 120 min.

After running the computer program the resulted values are showed in Table 1.

Table 1. Values of C = f (τ)

τ [min]	0	15	30	45	60	75	90	105	120
$\dot{V}_{aer} [dm^3 / h]$	600	600	600	600	600	600	600	600	600
$\dot{V}_{1,O_2} = 0,21 \cdot 600 = 126\ [dm^3 / h]$	126	126	126	126	126	126	126	126	126
$\dot{V}_{O_2}$ from other sources	0	0	0	0	0	0	0	0	0
t_{H2O} [^oC]	23.7	23.7	23.7	23.7	23.7	23.7	23.7	23.7	23.7
t_{air} [^oC]	24.1	24.1	24.1	24.1	24.1	24.1	24.1	24.1	24.1
C_0 [mg / dm^3]	5.84	5.84	5.84	5.84	5.84	5.84	5.84	5.84	5.84
C_s [mg / dm^3]	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4

Based on the data in Table 1, the function C = f (τ) (Figure 4) was plotted.

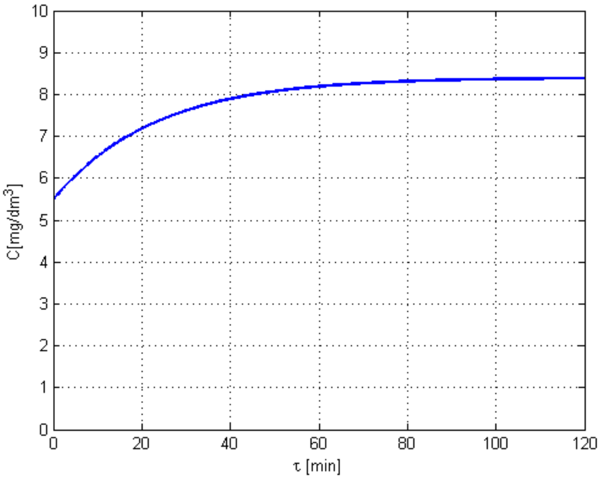

Fig 4. The graphical representation of the function C = f (τ) where atmospheric air is injected

4. EXPERIMENTAL INSTALLATION PRESENTATION

The scheme shown in Figure 5 provides the injection of air taken from the atmosphere in the microbubbles generator (MBG).

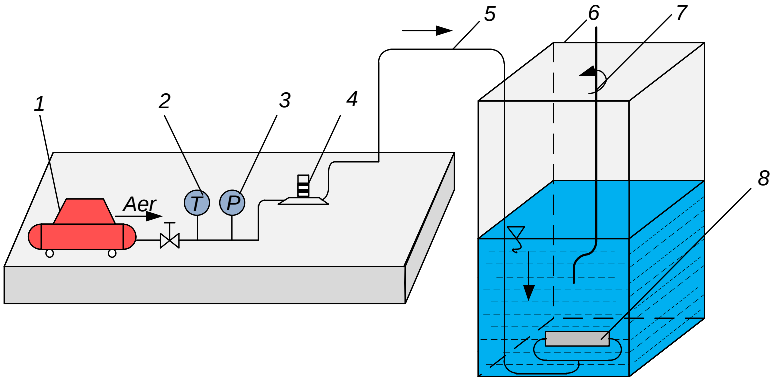

Fig. 5. Experimental installation scheme for atmospheric air injection into water
1 - air compressor; 2 - temperature measuring device; 3 - gas pressure measuring device; 4 - flow meter; 5 - compressed air supply line to the microbubbles generator; 6 - rectangular water tank; 7 - oxygen probe; 8 - microbubbles generator with 152 orifices Ø 0.1 mm

From Figure 5 one can observe that after compressing the air taken from the atmosphere, the temperature, pressure and air flow rate are measured; then air is introduced into MBG with the parameters: p=573 mm H_2O. The experiments time was 2 hours, while the dissolved O_2 concentration in the water will increase from C_0 to C_s.

The MBG is provided with a perforated plate with orifices of Ø 0.1 mm performed by micro-drilling [9]. In the right side of Figure 6 one can observe the plastic tank where the oxygen probe is introduced. In the central area of Figure 6 is a panel with devices: thermometer, manometer, oxygen meter.

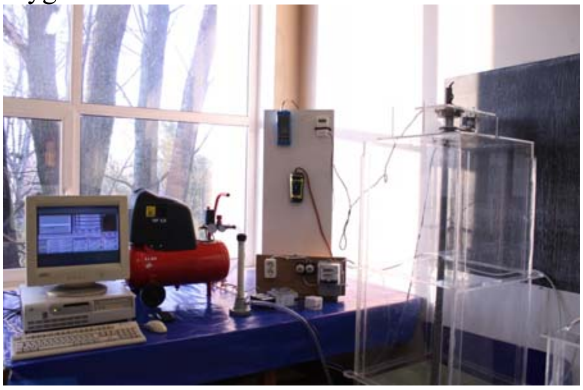

Fig. 6. Overview of the experimental installation in which the atmospheric air is used

In the left side of Figure 6 is a computer, an electro-compressor and a flow meter.

5. EXPERIMENTAL RESEARCHES

a) Researches purpose

The experimental researches conducted in the laboratory of the department of Thermo technics, Engines, Thermal and Frigorific Equipment from Polytechnic University of Bucharest followed:

-The experimental determination of the dissolved oxygen concentration variation in water versus time for the atmospheric air (21% O_2 + 79% N_2).

b) Researches methodology

Measurements involve the following steps:

1. Checking the functioning of the 152 orifices, that air is injected into the microbubbles generator;
2. Filling the tank with water up to H =500 mm H_2O;
3. Measuring C_0, t_{H2O}, t_{air};
4. Inserting the microbubbles generator and time counted (τ);
5. Every 15 minutes, the microbubbles generator is taken outside the tank, and the of dissolved O_2 concentration is measured;
6. When a horizontal level of $C = f(\tau)$ is reached the measurements stops with the condition: $C \approx C_s$;
7. In previous studies [10] [11] [12], the dissolved oxygen concentration in water tends towards saturation concentration after a period of two hours.

The oxygen concentration measuring will be done at: 0'; 15 '; 30 '; 45 '; 60 '; 75 '; 90 '; 105 '; 120 '.

8. At the end of the measurement the oxygen probe is cleaned and the water from the tank is removed.

Figure 7 shows the MBG in operation.

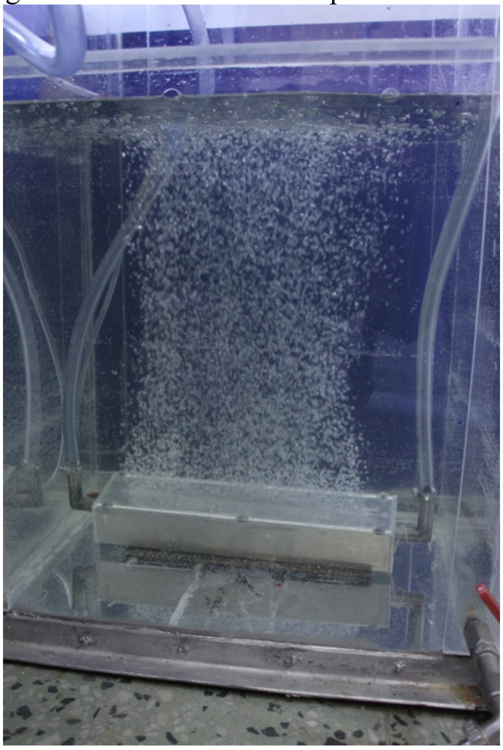

Fig. 7. MBG with 152 orifices Ø 0.1mm in operation

The columns of bubbles at the outlet of the perforated plate provide a curtain of bubbles, similar to that of a jet plane which is rectangular in cross section.

6. EXPERIMENTAL RESULTS

By injecting atmospheric air in water, following the measurements the dates of Table 2 were obtained.

Table 2. Values of C = f (τ)

τ [min]	0	15	30	45	60	75	90	105	120
$\dot{V}_{aer}[dm^3/h]$	600	600	600	600	600	600	600	600	600
$\dot{V}_{I,O_2} = 0,21 \cdot 600 =$ $= 126\ [dm^3/h]$	126	126	126	126	126	126	126	126	126
$\dot{V}_{O_2}$ from other sources	0	0	0	0	0	0	0	0	0
t_{H2O} [^oC]	23.7	23.7	23.7	23.7	23.7	23.7	23.7	23.7	23.7
t_{air} [^oC]	24.1	24.1	24.1	24.1	24.1	24.1	24.1	24.1	24.1
C_0 [mg / dm^3]	5.84	5.84	5.84	5.84	5.84	5.84	5.84	5.84	5.84
C_s [mg / dm^3]	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4
C [mg / dm^3]	5.84	6.89	7.65	8.01	8.10	8.26	8.31	8.35	8.39

Based on data from Table 2 the graph in Figure 8 was plotted.

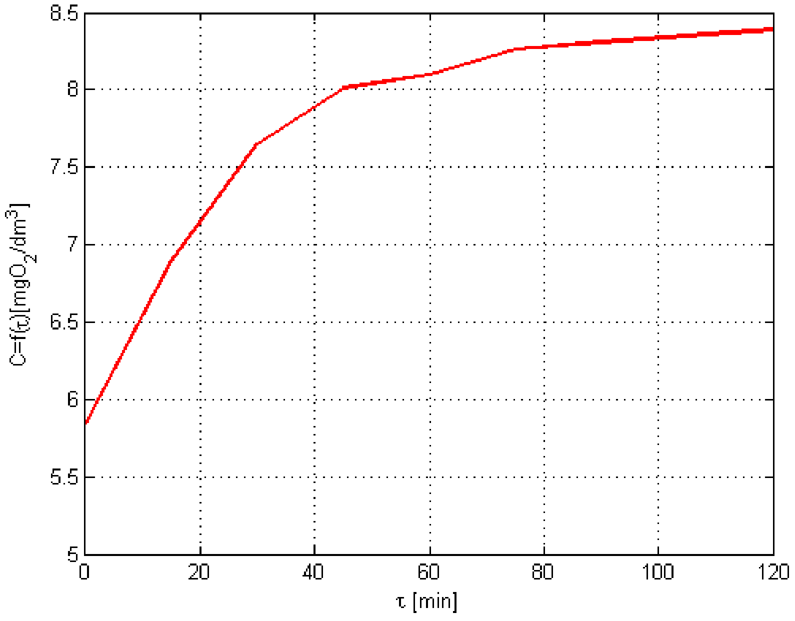

Fig. 8.The function $C_{0_2} = f(\tau)$

These results are in good accordance with those obtained in similar papers [13] [14].

Figure 9 shows two curves which reflect the results obtained by means of theoretical and experimental way.

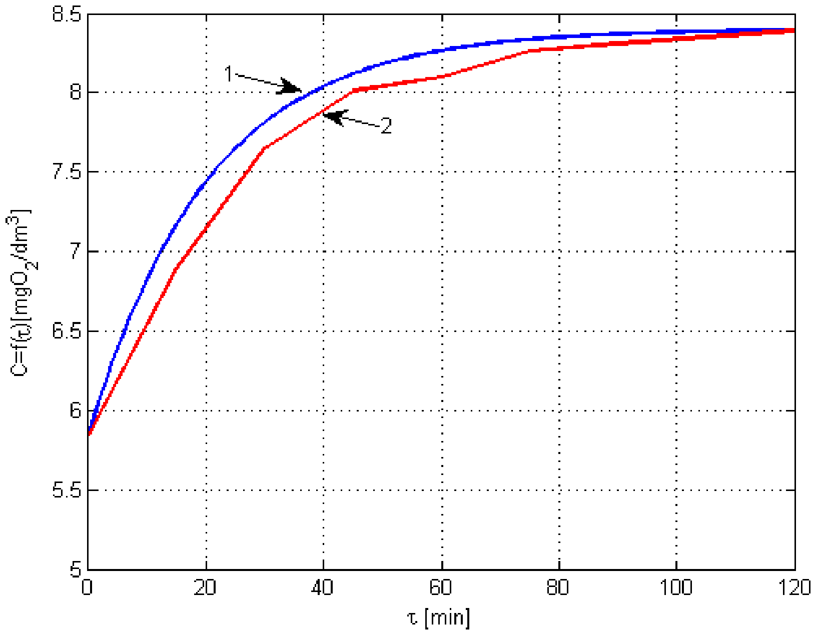

Fig. 9. $C_{0_2} = f(\tau)$ for atmospheric air

1- theoretical curve; 2- experimental curve

Figure 9 shows a good coincidence between the data obtained by means of theoretical and experimental way.

7. CONCLUSIONS

The study focused on the operation of a MBG having 152 orifices Ø 0.1 mm. The MBG with an original design has the following advantages:

1. It ensures a uniform distribution of air in water;
2. Knowing the air inlet section in water the exact airflow rate injected in water can be determined;
3. The orifices with Ø 0.1 mm, provides a working regime in the fine bubbles field, air bubbles in water having Ø = 0.7 mm = 700μm, known as "microbubbles";
4. The design and construction of the MBG with 0.1 mm orifices required collaboration with specialized institutes with unconventional technologies equipment's:

- Spark-erosion processing;
- Processing by micro-drilling.

5. The pressure drops of the air flowing through the microbubbles generator are much smaller than those of the porous diffusers [3] [15].

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