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The Use of Microtechnology's for the Construction of Some Devices Necessary for Water Aeration

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ABSTRACT

The first part of the paper analyzes the differential equation of the oxygen transfer rate to water and indicates the ways to increase this speed. One way would be to use fine bubble generators, which in their construction contain a plate with orifices through which air enters the water subjected to aeration. The smaller the orifices diameter, the more efficient the aeration process. The constructive solution of a fine bubble generator is presented, in which the perforated plate has orifices with a diameter of 0.1 mm. The technology of the execution of these orifices is exposed and the theoretical and experimental results regarding the increase of the dissolved oxygen content in the water are presented, by using this type of fine air bubble generator.

Keywords: *Water aeration, Fine air bubble generators, Microtechnology's.*

1. INTRODUCTION

In a water treatment plant, about 50% of energy consumption is used to aerate the water. By water aeration is meant the introduction of atmospheric air (21% O_2 + 79% N_2) into water; from the air introduced into the water, some of the oxygen is transferred to the water and this oxygen, which is free in the water, is called dissolved oxygen (DO) in the water (figure 1). Dissolved oxygen is formed by the presence of those oxygen molecules free from water.

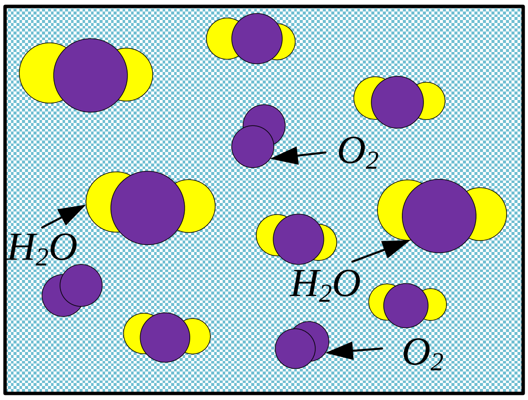

Fig.1. Oxygen Dissolved in Water

In figure 1, one can observe that oxygen appears in two forms:

- *O_2 bound to H_2*

- *Free O_2 called dissolved oxygen in water.*

By introducing atmospheric air into the water, a certain concentration of dissolved oxygen (DO) in the water is ensured. The existence of different life forms in water, such as: bacteria, plants, crabs, fish, etc., is ensured by the presence in certain quantities of oxygen dissolved in water.

The oxygen dissolved in water, necessary to ensure life, is as follows:

- *fish need 4 ÷ 15 mg / dm^3;*

- *oysters, crabs need 1 ÷ 6 mg / dm^3.*

If the dissolved oxygen (DO) level falls below 3.0 mg / dm^3, the fish may die due to lack of oxygen. If dissolved oxygen (DO) levels rise above 9 mg / dm^3, it can also be fatal for fish [2].

The water aeration process can be performed in three ways [1], [2], [3]:

A) By mechanical aeration

B) By pneumatic aeration

C) By mixed aeration.

Mechanical aeration provides the operation of aerators, performing a surface aeration.

Pneumatic aeration is more efficient and provides the introduction of air below the free water level.

Pneumatic water aeration systems are divided into three classes [4], [5]:

I) Perforated pipes placed on the water tank radiator;

II) Porous diffusers made of ceramic materials, elastomer membranes, etc.;

III) Fine bubble generators (FBG) having as dispersion element a flat plate provided with orifices; this case will be studied in this paper.

The advantages of using fine bubble generators are the following:

1. FBG shall ensure a uniform distribution of air columns entering the water, as specified by the installation designer.

2. It is possible to determine precisely the air flow rate introduced into the water.

3. The pressure drop when air passes through the FBG is lower than for porous diffusers [1] [6].

4. FBGs have increased reliability and easy maintenance.

In the laboratory of the Faculty of Mechanical and Mechatronics Engineering, a fine bubble generator (FBG) was designed and built, in which the rectangular perforated plate contains a number of 152 orifices with a diameter of 0.1 mm.

2. THE NECESSITY OF USING MICROTECHNOLOGY’S TO THE CONSTRUCTION OF THE FINE BUBBLES GENERATORS

The transfer oxygen rate to water is given by the relation [1]:

$$\frac{dC}{d\tau} = a \cdot k_L \cdot \left(C_s - C_0 \right) \; [kg / m^3 s] \rightarrow \textbf{(1)}$$

relations where:

$$a = \frac{A}{V}\left[\frac{m^2}{m^3}\right] \rightarrow \textbf{(2)}$$

A = gas bubbles area [m^2].

V = volume of the biphasic system (air + water) [m^3].

k_L = mass transfer coefficient [m / s].

Relation (1) indicates the change in oxygen concentration in time as a result of the molecular diffusion of O_2 from the high concentration area to the low concentration area.

From relation (1), one can observe that in order to increase the transfer rate of O_2 to water it is necessary:

I. the increase of a, k_L and C_s

II. the reduction of C_0

Conditions I and II are set out in Table 1.

Table 1. Solutions for Increasing $\frac{dC}{d\tau}$

No.	The pursued goal	The theoretical solution	The practical solution
1	The increase of C_s	Increasing the O_2 concentration in the air introduced into the water.	Introduction of oxygen, ozone (O_3) into water
2	The decrease of C_0	Minimum values for C_0 depending on the nature of the micro-organisms present in the water	Decreased initial water temperature; Introduction of C_0-reducing substances into water.
3	The increase of k_L	Intensification of turbulence	FBG rotation Using mobile FBG
4	The increase of a	Decrease the gas bubble diameter	Decreasing of the FBG orifices diameter.

From table 1 it results that, in order to increase the dissolved O_2 concentration in water, it is necessary to decrease the diameter of the FBG orifices, therefore, implicitly to decrease the diameter of the air bubbles immersed in water.

If the air bubble is considered as a small sphere, then relation (2) becomes:

$$a = \frac{4\pi R^2}{\frac{4}{3}\pi R^3} = \frac{3}{R} = \frac{3}{\frac{d}{2}} = \frac{6}{d} \rightarrow \textbf{(3)}$$

Where: R = the sphere radius; d = the sphere diameter.

From relation (3), one can observe that the value of "a" will increase if the diameter of the gas bubble decreases.

The increase of "a" implicitly leads to an increase in the oxygen transfer rate to water (1).

Figure 2 shows a classification of gas bubbles according to their diameter.

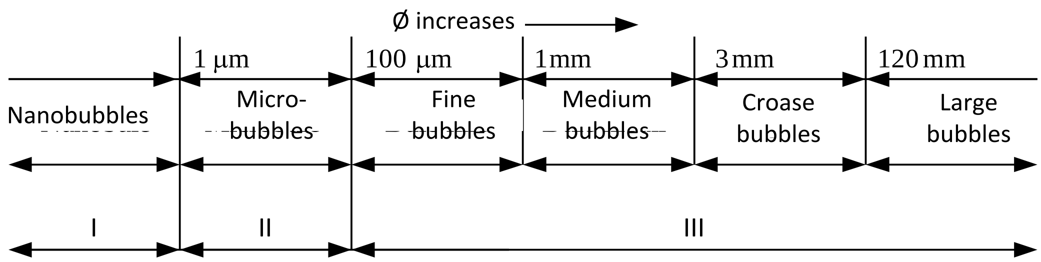

Fig.2. Classification of Gas Bubbles According to their Diameter (Ø)

I - the area where the gas bubbles can be observed under the microscope; II - the area where gas bubbles can be observed with difficulty; III - the area where gas bubbles can be observed with the naked eye.

In the present paper, the FBG has a plate with orifices with a diameter of 0.1 mm, so, the air bubbles emitted by it will fall into domain III, in the category "fine bubbles".

3. THE PRESENTATION OF THE CONSTRUCTIVE SOLUTION OF THE FINE BUBBLE GENERATOR AND OF THE EXPERIMENTAL INSTALLATION

Figure 3, presents the orifice plate.

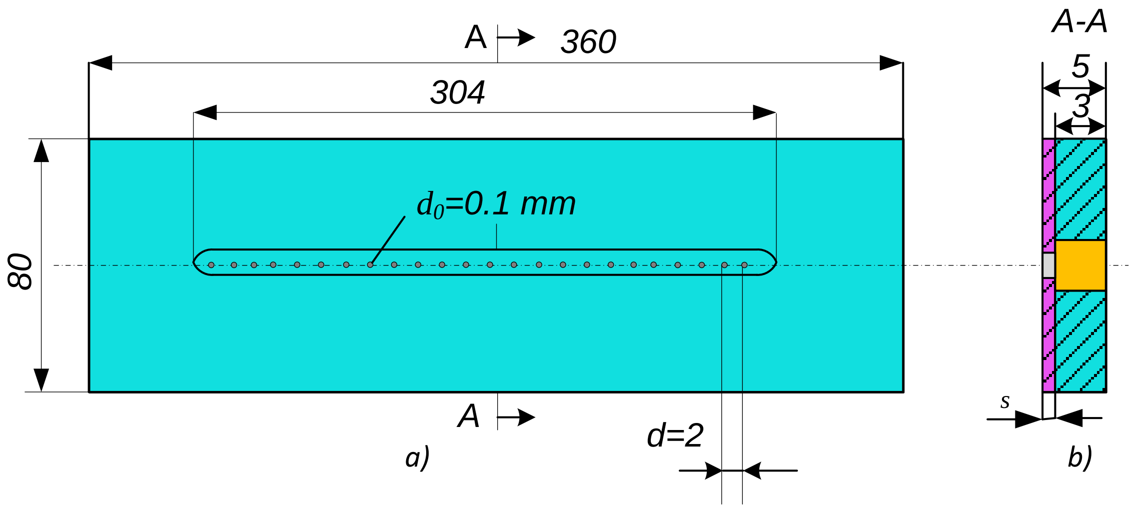

Fig.3. Perforated Plate of the Microbubble Generator

a - plan view; b - cross section

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In order to perform the orifices in the plate (fig.3), a cell (channel) 3 mm deep and 304 mm long was created. Subsequently, with the help of a C.N.C. (numerical control machine), special machine for microprocessors type KERN Micro [7] [8][9], 152 orifices with Ø 0.1mm were made in channel. This machine has an accuracy of ± 0.5μm, which ensured the creation of an FBG, which is an original constructive solution.

Figure 4 shows the constructive solution of the FBG.

The microbubble generator has as a dispersion element a rectangular metal plate, it being called FBG in rectangular shape. Considering the size of the water tank and the height of the water layer, a section of air outlet in water equal to $1.2 \cdot 10^{-6}$ m^2 was chosen. For d_0 = 0.1 mm, a number of orifices result:

$$n = \frac{A}{\left(\pi \cdot d_0^2\right)/4} = \frac{1{,}2 \cdot 10^{-6}}{\frac{\pi \cdot \left(0{,}1 \cdot 10^{-3}\right)^2}{4}} = 152\, orifices \rightarrow \textbf{(4)}$$

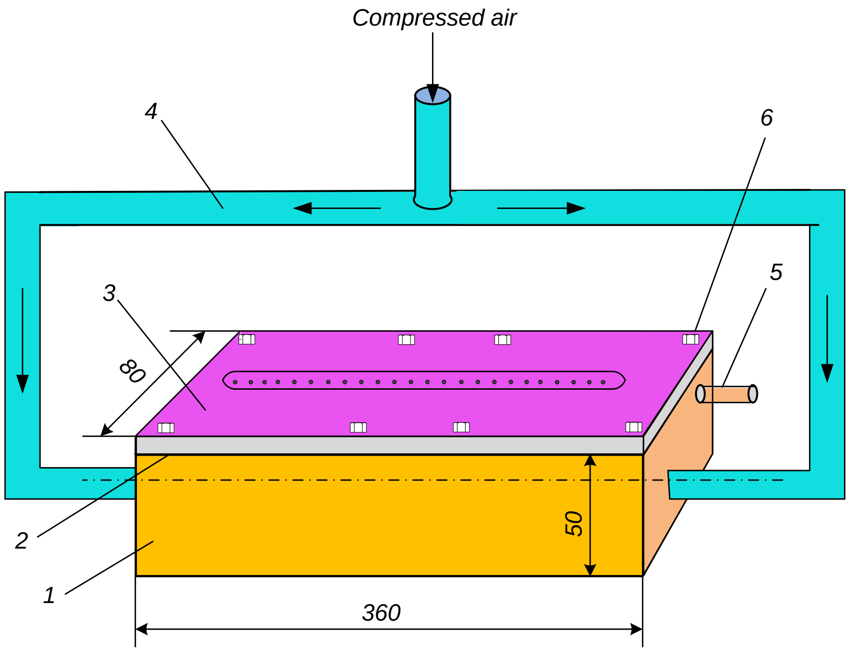

Fig.4. Air Microbubble Generator

1 - compressed air tank; 2 - sealing gasket; 3 – orifices plate; 4 - pipe Ø 18 mm with compressed air; 5 - connection for measuring the air pressure in the tank; 6 - screws for fixing the perforated plate

The fine bubble generator was fitted in an experimental installation of original design (figure 5).

The air compressed by the electro compressor (1), passes through the pressure reducer which keeps its pressure constant; subsequently, the air passes through the rotameter (6) and enters the fine bubble generator (13).

On the panel (8), the following devices are seen:

- electronic manometer that measures the air pressure in the FBG

- electronic thermometer that measures the air temperature

- oxygenometer which, through the probe (12), measures the dissolved oxygen concentration in water.

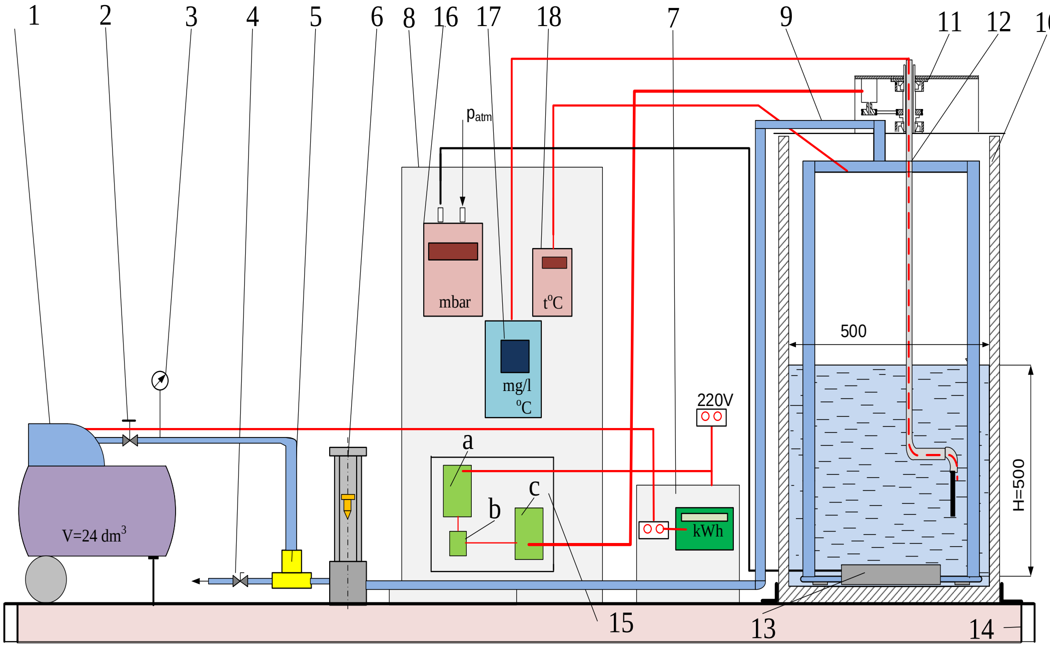

Fig.5. Scheme of the Experimental Installation for Researches on Water Oxygenation

1 - electro compressor with air tank; 2 - pressure reducer; 3 - manometer; 4 - connection for evacuating air into the atmosphere; 5 – T-joint; 6 - rotameter; 7 - electrical panel; 8 - panel with measuring devices; 9 - pipe for transporting compressed air to the FBG; 10 - water tank; 11 - mechanism of actuation of the probe; 12 - oxygenometer probe; 13 - FBG with orifices Ø 0.1mm; 14 - support for installation; 15 - control electronics: a - power supply, b - switch, c - control element, 16 - digital manometer; 17 – oxygenometer; 18 - digital thermometer.

4. THEORETICAL DETERMINATION OF THE VARIATION OF THE DISSOLVED OXYGEN CONCENTRATION IN WATER

The dissolved oxygen transfer rate in water has the form [10]:

$$\frac{dC}{d\tau} = (a \cdot k_L) \cdot (C_s - C) \; [kg / m^3 s] \rightarrow \textbf{(5)}$$

Where:

- ak_L - oxygen transfer coefficient [s^{-1}];

- C_s - mass oxygen concentration at saturation [kg / m^3];

- C - current mass oxygen concentration of in water at time τ [kg / m^3].

The boundary conditions $C = C_0$ imposed for $\tau = 0$ and by integration one can obtain:

$$\frac{dC}{C_s - C} = a \cdot k_L \, d\tau \rightarrow \textbf{(6)}$$

$$-ln(C_s - C) = a \cdot k_L \cdot \tau + ct \rightarrow \textbf{(7)}$$

$C = C_0$ for $\tau = 0$, one can obtain:

$$ct = -ln(C_s - C_0) \rightarrow \textbf{(8)}$$

Introducing (8) in (7) one can obtain:

$$-ln(C_s - C) = a \cdot k_L \cdot \tau - ln(C_s - C_0) \rightarrow \textbf{(9)}$$

Results:

$$C = C_s - (C_s - C_0) \cdot e^{-a \cdot k_L \cdot \tau} \rightarrow \textbf{(10)}$$

Starting from equation (10), a computation program was built (figure 6) to determine the variation in time of the dissolved oxygen concentration in water.

As initial data are specified: $C_0 = 5.84$ mg / dm^3; $C_s = 9.02$ mg / dm^3; $ak_L = 0.0427$; h = 1; $\tau = 120$ min.

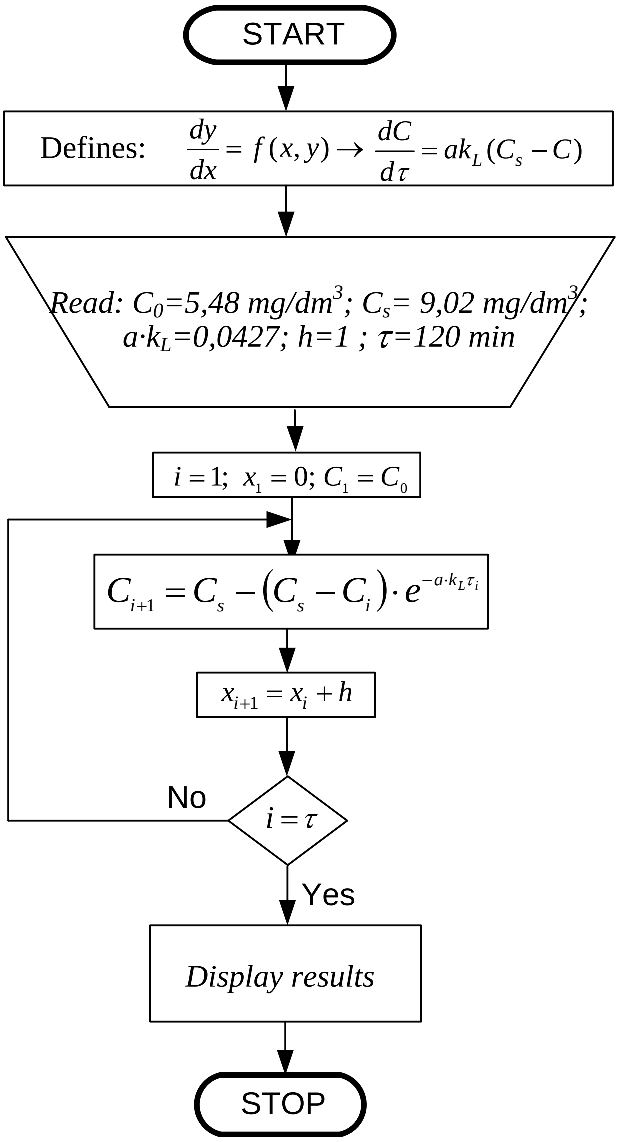

Fig.6. Logical Computation Scheme for Determining the Variation of the Dissolved Oxygen Concentration in Water, as a Function of Time C = f(τ)

Following the running of the program presented in figure 6, the values presented in table 2 resulted.

Table 2: Values of the Function: C = f (τ)

τ [min]	**0**	**15**	**30**	**45**	**60**	**75**	**90**	**105**	**120**
$\dot{V}_{air}\ [dm^3/h]$	600	600	600	600	600	600	600	600	600
$\dot{V}_{IO_2} = 0.21 \cdot 600 = 126\ [dm^3/h]$	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} **[°C]**	23.7	23.7	23.7	23.7	23.7	23.7	23.7	23.7	23.7
t_{air} **[°C]**	24.1	24.1	24.1	24.1	24.1	24.1	24.1	24.1	24.1
C_0 **[mg/dm³]**	5.84	5.84	5.84	5.84	5.84	5.84	5.84	5.84	5.84
C_s **[mg/dm³]**	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4
C **[mg/dm³]**	5.84	6.89	7.65	8.01	8.10	8.26	8.31	8.35	8.39

Based on the values in Table 2, the variation of the dissolved oxygen concentration in water as a function of time was plotted (Figure 7).

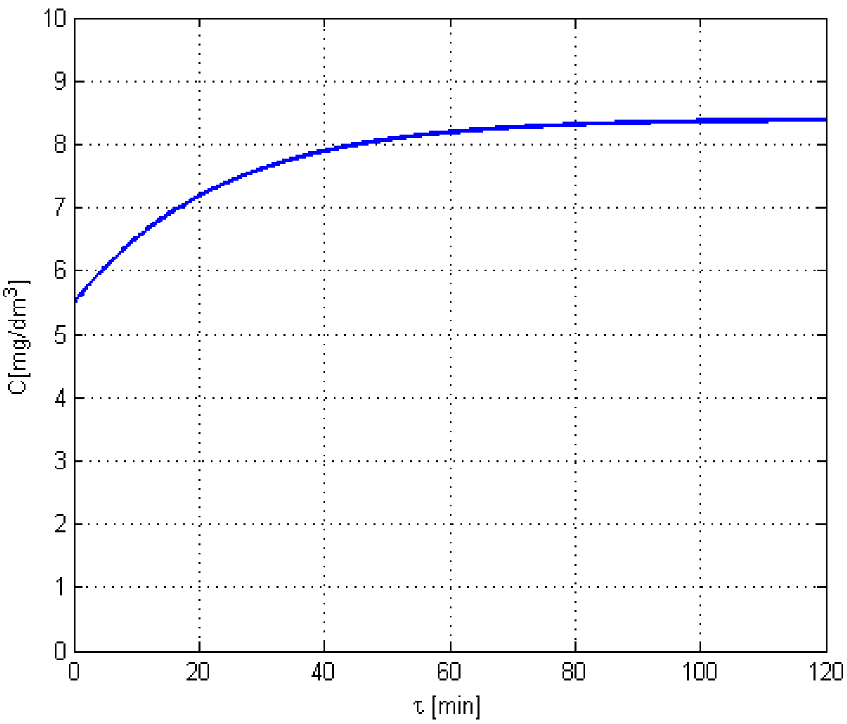

Fig.7. The Variation of Dissolved Oxygen Concentration in

Water as a Function of Time: C = f (τ)

The figure shows that after two hours the C_0 value tends to C_s [11][12].

5. THE COMPARISON OF THEORETICAL DATA WITH THOSE EXPERIMENTALLY OBTAINED

In figure 8, two graphs are observed: graph 1, is taken from figure 7 and represents the variation of the concentration of dissolved oxygen in water as a function of time.

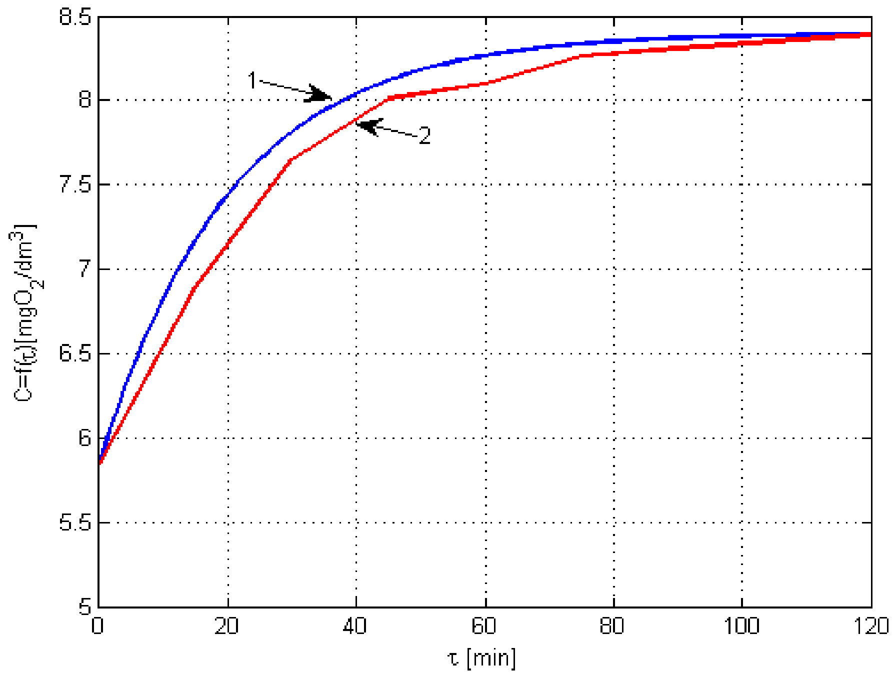

Fig.8. Variation of the Dissolved Oxygen Concentration in

Water as a Function of Time

1 - Curve Drawn Based on Theoretical Data; 2 - Curve Drawn Based on Experimental Data

Graph 2 is built on experimental data and shows the same variation.

6. CONCLUSION

1. The use of fine bubble generators (such as those presented in the paper), for water aeration, is an original solution to increase the oxygen transfer rate to water.

2. Pressure losses when the air flows through the FBG are smaller than the pressure losses when the air flows through the porous diffusers.

3. The designing and construction of the FBG from the paper required the collaboration with ICPE which has equipment for unconventional technologies, such as micro drilling.

4. The literature [13][14][15] confirms that the smaller the orifice diameter, the more efficient the aeration.

5. The experimental installation for the FBG designed in an original way, allows the exact measurement of the increase of the oxygen concentration in the water tank, depending on the time.

6. From the diagram of the experimental installation, it can be seen that this original solution comprises modern measuring instruments, of increased precision, with digital indication.

7. From the comparison of theoretical and experimental data on the dissolved oxygen concentration in water, a good coincidence results, which reveals the scientific level of the paper.

Declarations

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Competing Interests Statement

The authors declare no competing financial, professional and personal interests.

Consent to participate

Not Applicable

Consent for publication

We declare that we consented for the publication of this research work.

Availability of data and material

Authors are willing to share data and material according to the relevant needs.

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