TEZĂ DE DOCTORAT

PhD. Thesis

Cercetări privind aerarea apelor stagnante sau în curgere prin conducte

Researches regarding the aeration of stagnation waters
or flowing waters through pipes

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Annexes

REZUMAT

1. Introduction

The term "water aeration" is used when only atmospheric a ir (21% O_2 + 79% N_2) is introduced into the water volume.

When it comes to water oxygenation one refers to the introduction gaseous mixture into the water volume consisting of:

a) Atmospheric air and oxygen obtained from the cylinder;

b) Air with a low nitrogen content (95% O_2 + 5% N_2), air delivered by devices called oxygen concentrators;

c) Air and ozone, ozone being supplied by ozone generators, devices generically called ozonizers;

Aeration or oxygenation of water aims to increase the coefficient of dissolved oxygen (DO) which has a major contribution on water quality. If the dissolved oxygen concentration decreases, anoxic conditions may develop, which reduces the body's ability to sustain life.

Oxygenation equipments are based on the dispersion of one phase in the other phase, for example gas in liquid, or liquid in gas, a process that takes place with energy consumption.

Aeration or oxygenation of water is used for:

a) improving the quality of wastewater that has a low level of dissolved oxygen, prior to their discharge into the network of collector or sewer channels;

b) biological cleaning of wastewater either by the process with activated sludge or with biofilters or aerated lagoons;

c) removal of chemical elements found in water (manganese, iron, copper, etc.) or dissolved inorganic substances;

d) the process of separation and collection of emulsified fats from wastewater;

The topic addressed in the content of each chapter of this thesis is briefly presented below.

Chapter 1. Current state of art of water aeration researches

This chapter presents some general considerations regarding dissolved oxygen in water as well as a classification of aeration installations [1] [2].

At the end of the chapter, the objectives of this thesis are presented.

Thesis objectives:

The elaboration of this paper was based on known data on the process of water aeration, namely: the height of the water layer in the tank, air temperature, water temperature, the flow rate and the air pressure introduced in water, the initial dissolved oxygen concentration in water and the water volume to be aerated [3] [4].

Based on the data presented above, the author intends to pursue the following objectives:

a) Carrying out a study on the equipments that ensures an efficient aeration of the waters;

b) Analysis, based on a calculation program, of the change in the dissolved oxygen concentration in water;

c) Studying the factors that influence the change in the dissolved oxygen concentration in water;

d) Presentation of solutions to increase the dissolved oxygen concentration in water;

e) The use of microtechnologies in the design and construction of fine air bubble generators in order to aerate stagnant or flowing water through pipes;

f) The design and construction of the two experimental installations in which the perforated plate for the two versions will be:

- Version I: perforated plate with 113 orifices with a diameter of Ø 0.1 mm.

- Version II: four circular plates each with 113 orifices with a diameter of Ø 0.05 mm, representing a total of 452 orifices.

g) Experimental researches to demonstrate which version is more efficient and advantageous;

h) Presentation of the conclusions, the original contributions, as well as perspectives for the development and continuation of future researches;

Chapter 2. Mass transfer interface, air - water

The equations of mass transfer that take place between two environments are presented, and then customized for the transfer of oxygen to water [5] [6].

The equation of the oxygen transfer rate to water is numerically integrated and a calculation program is developed to determine the change in the dissolved oxygen concentration in water.

The factors that influence the change in the dissolved oxygen concentration in the water are analyzed.

Chapter 3. Formation and evolution of air bubbles from fine bubble generators (F.B.G.).

This chapter presents how bubbles are formed by means of several devices: a classification of gas bubbles according to their diameter is carried out; the relationship between the diameter of the hole in the perforated plate and the diameter of the gas bubble entering the water, as well as the change in the diameter of the gas bubble in its upward movement in water [7] [8].

Chapter 4. Analysis of the mathematical relationship that establishes the link between the diameters of the air bubble immersed in water and the concentration of dissolved oxygen in the water.

In this chapter, the equation of the transfer rate of oxygen to water is analyzed, considering the specific interphase contact surface, the current mass concentration, the mass transfer coefficient and the mass concentration at saturation of oxygen in the liquid phase. The relationship that determines the diameter of the air bubble at the entrance to the water, depending on the diameter of the hole, the coefficient of surface tension and the density of the water, the gravitational acceleration, is presented.

The mathematical relationship that links the diameter of the air bubble at the exit from the hole to the variation of the concentration of dissolved oxygen in the water as a function of time is analyzed and presented, establishing that when the diameter of the hole entering the air into the water decreases, the value of the concentration of dissolved oxygen in water grows.

It is mathematically demonstrated that the size of the diameter of the air bubble immersed in water obviously influences the change over time in the concentration of dissolved oxygen in the water, in the sense that with the decrease in the size of the diameter of the air bubble entering the water, there is an increase in the concentration of oxygen dissolved in water.

The equation for the rate of oxygen transfer to water is rewritten as follows:

$$C = \frac{C_s - \left(C_s - C_0\right)}{e^{a \cdot k_L \cdot \tau}} = C_s - \frac{C_s - C_0}{e^{a \cdot k_L \cdot \tau}} \tag{4.13}$$

The value of the interfacial area, considering the bubble as a small sphere of radius R is [76]:

$$a = \frac{A}{V} = \frac{4\pi R^2}{\frac{4}{3}\pi R^3} = \frac{4\pi (d_b/2)^2}{\frac{4}{3}\pi (d_b/2)^3} = \frac{6}{d_b} \tag{4.14}$$

where: d_b is the air bubble diameter.

Relation 4.13 becomes:

$$C = C_s - \frac{C_s - C_0}{e^{\frac{6}{d} \cdot k_L \cdot \tau}} \tag{4.15}$$

The fraction numerator is dimensionless:

$$\frac{6}{d_b} \cdot k_L \cdot \tau \rightarrow \frac{1}{m} \cdot \frac{m}{s} \cdot s \text{ or } \frac{1}{m} \cdot \frac{m}{min} \cdot min$$

Given that C_s, C_0, k_L are constants, the relation 4.15 can be written as:

$$C = C_{t,1} - \frac{C_{t,2}}{e^{C_{t,3} \cdot \frac{\tau}{d_b}}} \tag{4.16}$$

When db decreases the size $e^{C_{\tau_3} \cdot \frac{\tau}{d_b}}$ increases which makes the fraction in the relation (4.16) decrease during the aeration , so C increases during the aeration if db decreases.

It is thus mathematically demonstrated that the size of the diameter of the air bubble immersed in the water obviously influences the change over time in the concentration of dissolved oxygen in the water, in the sense that with the decrease in the size of the diameter of the air bubble entering the water, there is an increase in the concentration of oxygen dissolved in water.

Thus, it is mathematically demonstrated that when the air inlet is reduced the value of the dissolved oxygen concentration in the water will increase [9] [10] [11].

Chapter 5. The realization of two variants of fine bubble generators (F.B.G.), variant I and variant II, intended for researching the efficiency of stagnant water aeration.

In this chapter, considering that both variants must operate under the same air and water temperature conditions, under the same hydrostatic load, with the same insufflation air flow rate, the same infusion area and inlet air pressure as well as the same concentration initial oxygen in water, two constructive variants of fine bubble generators are presented, namely one of rectangular shape with the diameter of the holes of Ø 0.1 mm and one consisting of four circular plates with the diameter of the holes of Ø 0.05 mm [12] [13].

The details, constructive and dimensional, related to Variant I are presented, in which the compressed air is dispersed by means of a rectangular plate with 113 holes, specifying that the holes for dispersing the air in the water, with a diameter of 0.1 mm, are processed by micro-drilling (with a special machine for micro-machining, type KERN Micro, which has an accuracy of ± 0.5 µm).

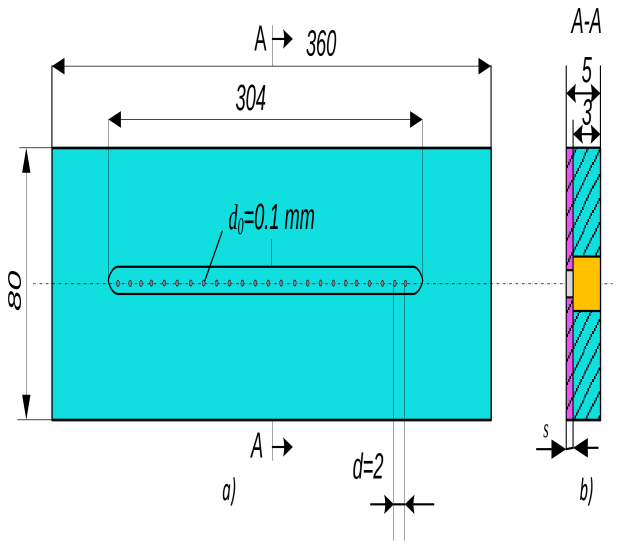


Fig. 1. Plate with holes of G.B.F. of air

a) plan view; b) cross section

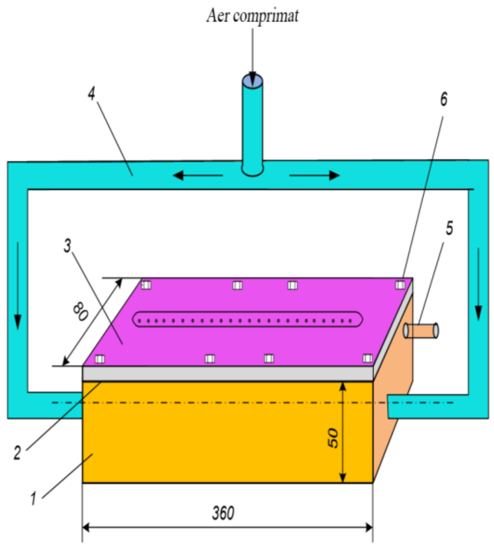


Fig. 2. Generator of fine air bubbles

1. compressed air tank; 2 - sealing gasket; 3 - plate with holes Ø 0.1 mm; 4 - G.B.F. compressed air supply pipe; 5 - connection for air pressure measurementtablet; 6 - tank plate fixing screws;

In Variant II the compressed air is dispersed through four circular plates, each having 113 holes with a diameter of 0.05 mm. Details of making the 0.05 mm holes are given (with the modern Sixis and Tripet MUS 100 micro-drilling machines, equipped with special Gühring drills).

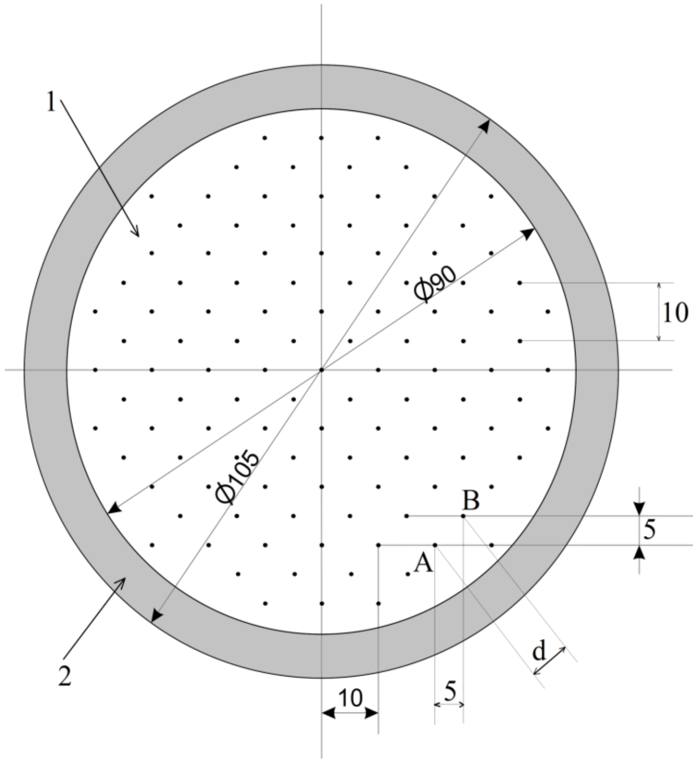


Fig. 3. Plate with holes: n = 113; Ø 0,05 mm

1 – plate with holes; 2 – the frame for fixing the plate

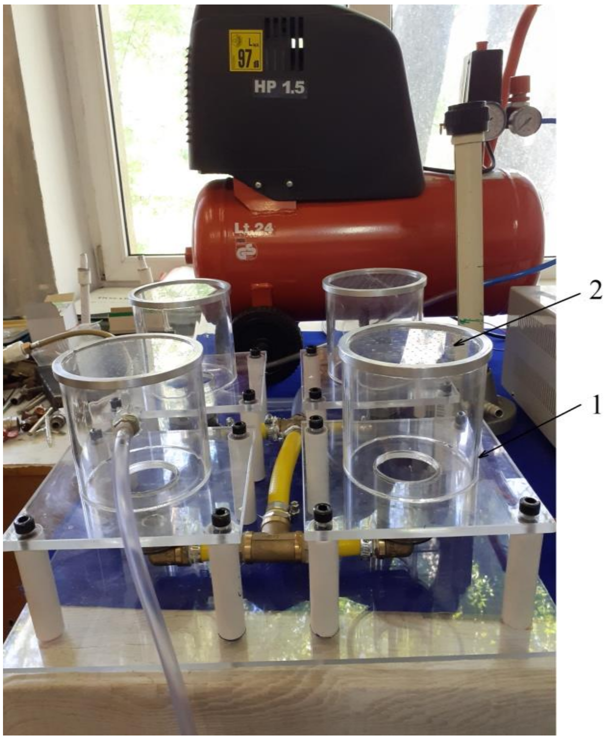


Fig. 4. Side view a F.B.G.

1 – cylinder with an outher diameter Ø 105 mm;

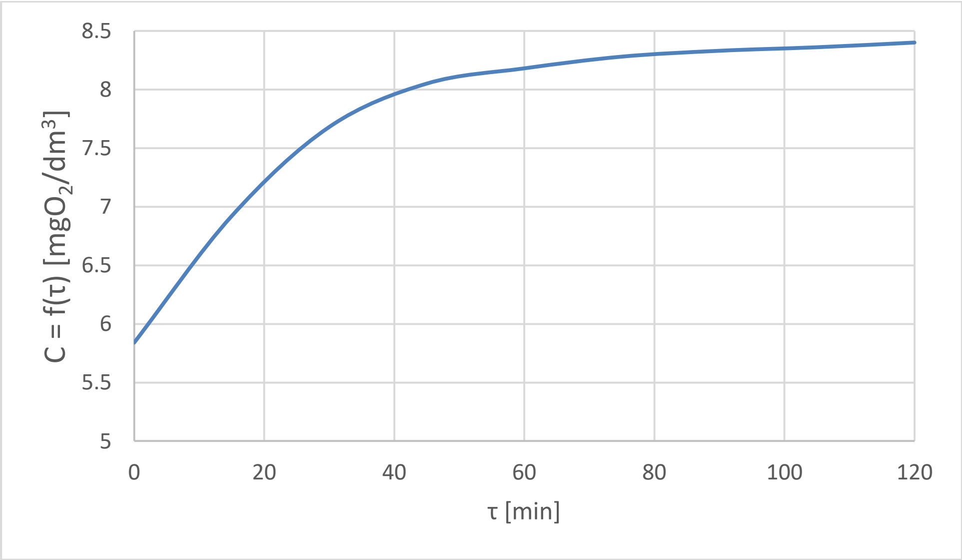
2 – perforated plate with 113 holes Ø 0,05 mm

Starting from the input data: C_0 = 5.84 mg / dm^3; H = 500 mmH_2O; t_{H2O} = 240C; τ = 120 min; C_s = 8.4 mg / dm^3, $V^{\cdot}$ = 600 dm^3 / h; V_{H2O} = 0.125 m^3 and using the calculation program developed in Chapter 2 the following theoretical results are obtained:

Theoretical calculation results regarding the increase of the dissolved oxygen concentration in water for **version I** – F.B.G. with orifices Ø 0.1 mm are shown in table 1 and graphically represented in figure 5.

Table 1. Theoretical operating conditions of the fine bubble generator in **version I**

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
t_{H2O} [^{o}C]	24	24	24	24	24	24	24	24	24
C_s [mg/dm^3]	8,4	8,4	8,4	8,4	8,4	8,4	8,4	8,4	8,4
C_0 [mg/dm^3]	5,84	6,92	7,68	8,05	8,18	8,28	8,33	8,36	8,40



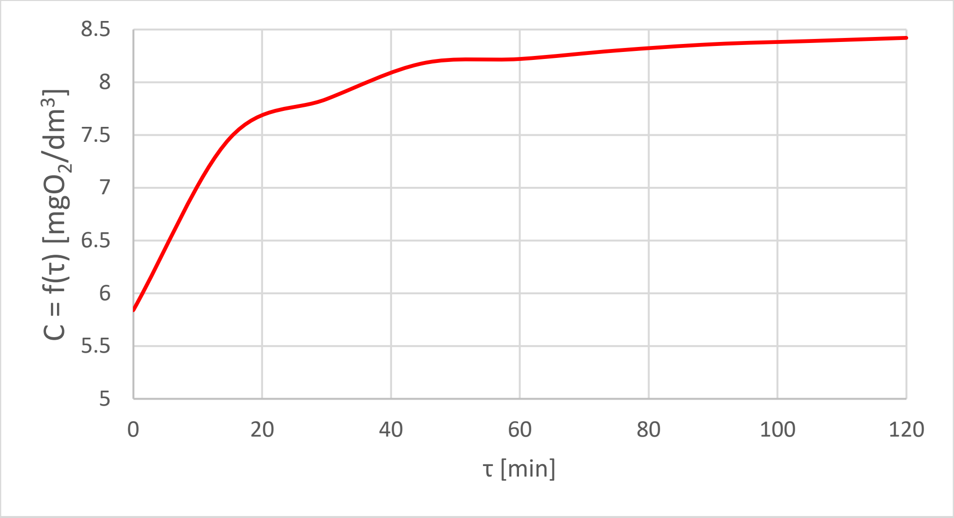
C = f (τ) theoretically, Ø = 0.1mm

Fig.5. Variation in the dissolved O_2 concentration in water as a function of time for F.B.G. in **version I**, Ø 0.1 mm

Theoretical calculation results regarding the increase of the dissolved oxygen concentration in water for **version II** – F.B.G. with 4 circular plates with orifices Ø = 0.05 mm, are shown in table 2 and graphically represented in figure 6.

Table 2. Theoretical operating conditions of the fine bubble generator in **version II**

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
t_{H2O} [^{o}C]	24	24	24	24	24	24	24	24	24
C_s [mg/dm^3]	8,4	8,4	8,4	8,4	8,4	8,4	8,4	8,4	8,4
C_0 [mg/dm^3]	5,84	7,47	7,84	8,18	8,22	8,30	8,36	8,39	8,42



C = f (τ) theoretically Ø = 0.05 mm

Fig. 6. Variation in the dissolved O_2 concentration in water as a function of time for F.B.G. in **version II**, Ø 0.05 mm

Starting from the same theoretical operating conditions, the calculation program for numerical integration of the differential equation of the transfer rate of oxygen in water calculates the value of the concentration of oxygen dissolved in water for each integration step separately, obtaining the values in table 3 , values that allow a comparative graph of the theoretical results obtained for the change over time in the concentration of dissolved oxygen in stagnant water (fig.7.).

Table 3. Theoretical results obtained for two versions of fine bubbles generators studied

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
t_{H2O} [^{o}C]	24	24	24	24	24	24	24	24	24
C_s [mg/dm^3]	8,4	8,4	8,4	8,4	8,4	8,4	8,4	8,4	8,4
C_0 [mg/dm^3] – theoretically version I	5,84	6,92	7,68	8,05	8,18	8,28	8,33	8,36	8,40
C_0 [mg/dm^3] – theoretically version II	5,84	7,47	7,84	8,18	8,22	8,30	8,36	8,39	8,42

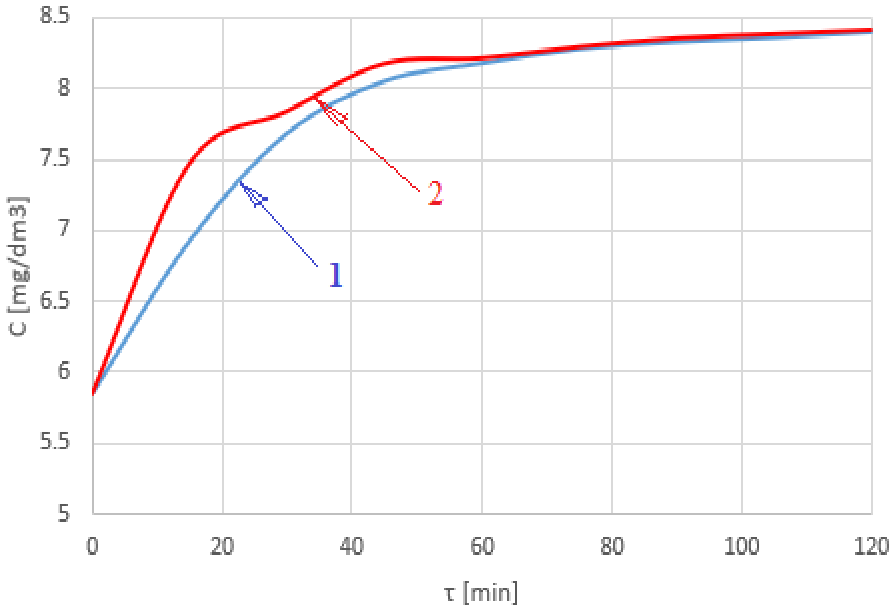


Fig. 7. The graphic representation of the theoretical variation of the variation of the dissolved oxygen concentration in water as a function of time $C = f(\tau)$ for the two variants of G.B.F. :
1 - F.B.G.- Ø 0,1 mm; 2 - F.B.G. – Ø 0,05 mm;

Chapter 6. Design, implementation and construction of experimental installations for the two studied versions

This chapter presents the two studied versions, respectively version I, introducing compressed air into water by means of a rectangular bubble generator with orifices diameter of Ø = 0.1 mm and version II, introducing compressed air into water with the help of a circular fine bubble generator with orifices diameter of Ø = 0.05 mm.

The scheme of the experimental installations for the two study verions are presented and their component elements are specified, figures 8, respectively 9.

The equipments and measuring instruments used in the experimental researches are also presented.

Figure 8. shows the scheme of the experimental installation for water oxygenation in verion I - fine bubbles generator of rectangular shape with orifices diameter of Ø = 0.1 mm.

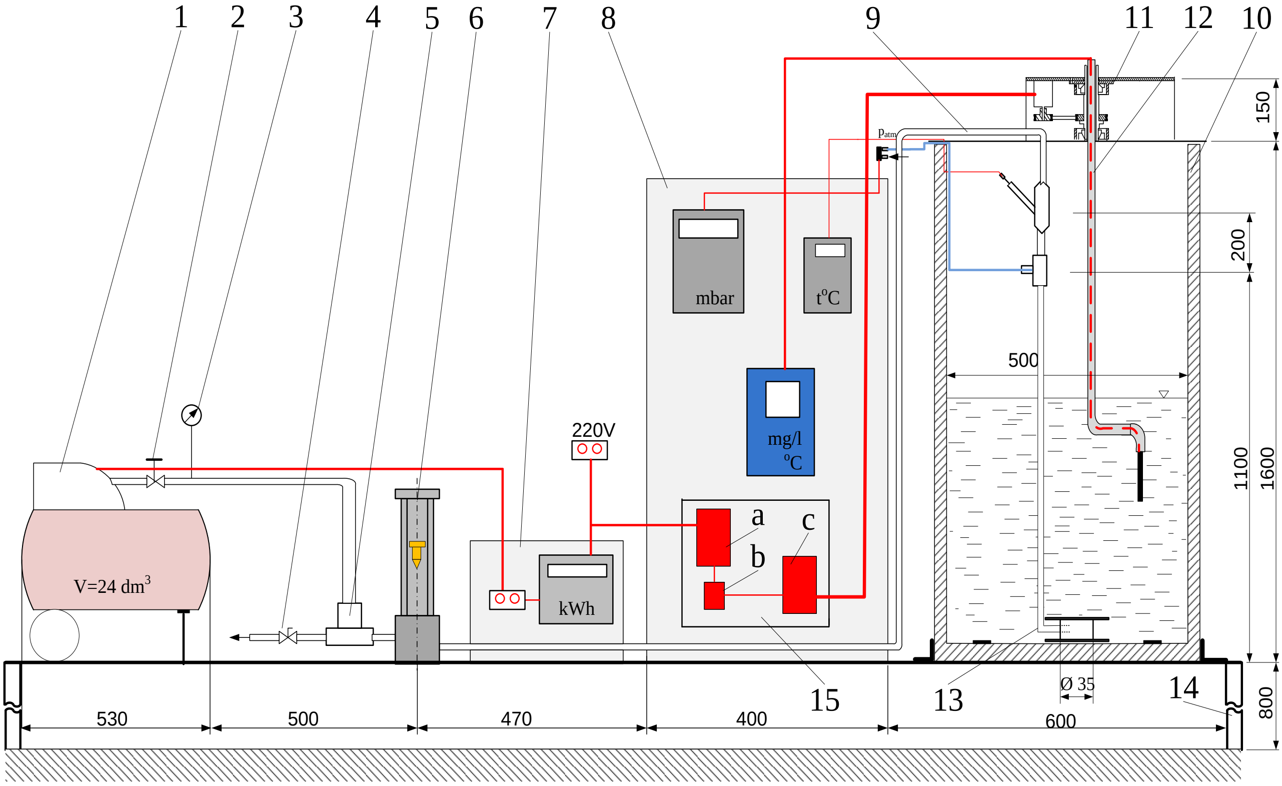


Fig. 8. The scheme of the experimental installation for researches on water oxygenation with F.B.G. with orifices of Ø = 0.1 mm

1– electrocompressor 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 F.B.G.; 10– water tank; 11– mechanism of actuation of the probe; 12– oxygenometer probe; 13– F.B.G.; 14– support for installation; 15 – control electronics: a - power supply, b - switch, c - control element

In **version I**, the compressed air supplied by a compressor (1) passes through a rotameter (6) so that through the pipe (9) it reaches the F.B.G. (13).

Figure 9 shows the scheme of the experimental installation for water oxygenation in **verion II** - fine bubble generator with four circular perforated plates with orifices of Ø= 0.05 mm.

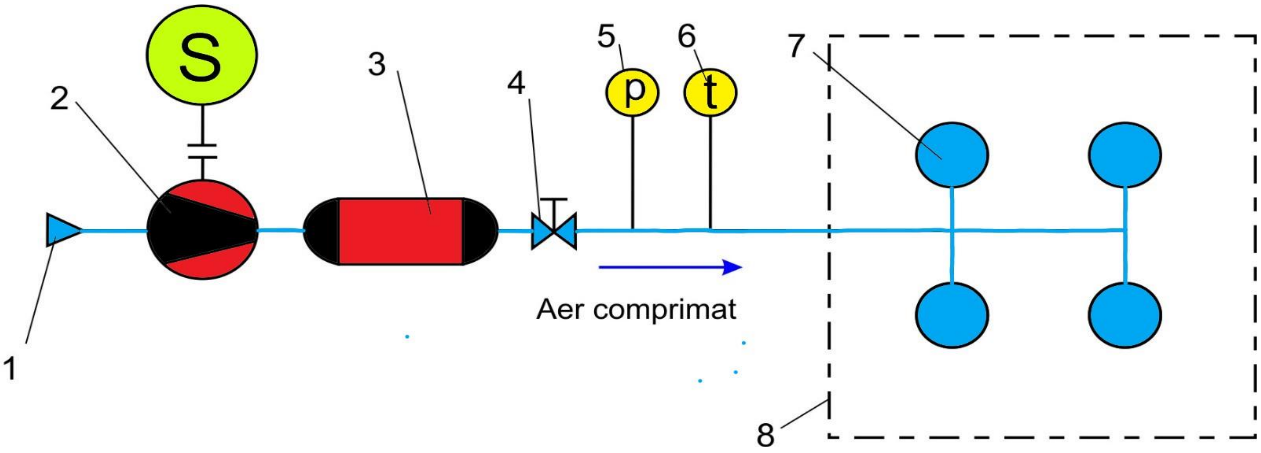


Fig. 9. The scheme of the experimental installation for water aeration with F.B.G. with four perforated plates in shape circular with orifices of Ø 0.05 mm.

1 - air filter; 2 - electrocompressor; 3 - compressed air tank; 4 - pressure reducer; 5 - pressure measuring device; 6 - temperature measuring device; 7 - set of four fine bubble generators; 8 - the contour of the tank with water

In vesion II, the compressed air supplied by a compressor (2) passes through the pressure (manometer) and temperature (thermometer) (5), (6) measuring devices to later reach the set of four F.B.G. (7).

Chapter 7. Conception, design and practical implementation of the experimental installation for the study of aeration of water flowing through pipes.

This part deals with the flow of biphasic fluid through pipes, the scheme of the water aeration installation is presented, as well as the design and construction of the air introduction spiral into the pipe.

Figure 10 shows a cross section through the pipe where the spiral is located.

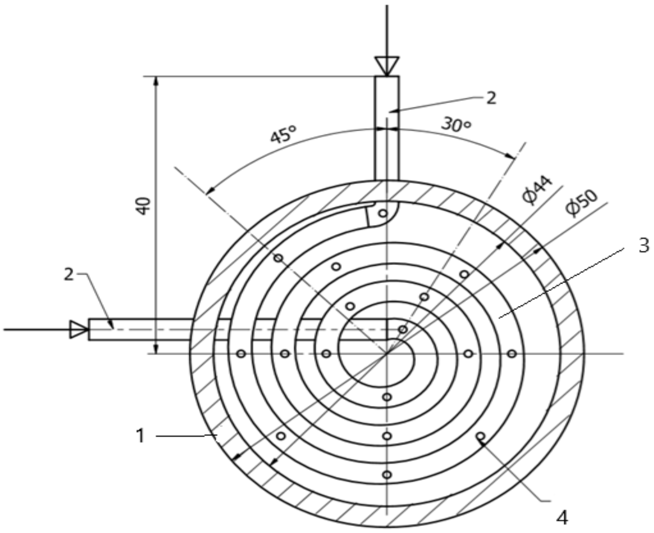


Fig. 10. Cross section through the pipe where the spiral is located

1– pipe Ø - 50 x 3 mm; 2 - compressed air inlet connections; 3 - spiral; 4 – orifices

Figure 11 shows the arrangement of the holes on the three circles of the spiral.

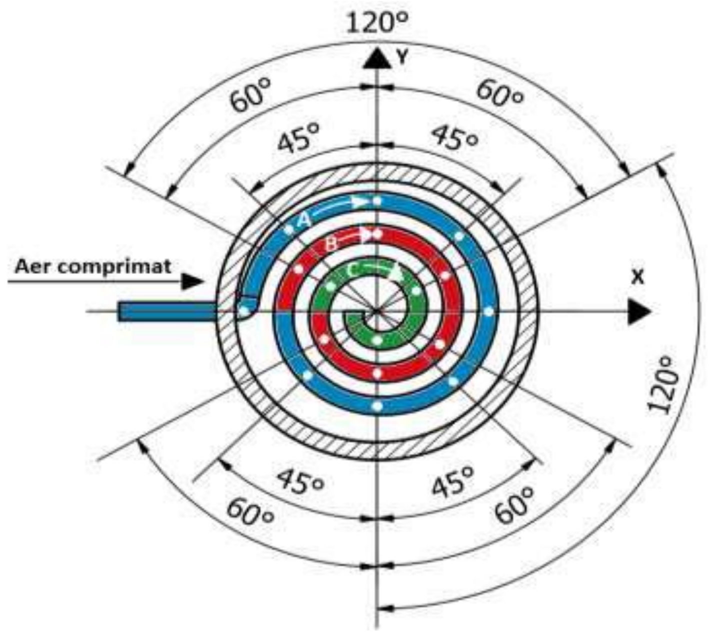


Fig. 11. The arrangement of the holes on the three circles of the spiral

A –the blue area – 8 holes arranged at 45°; B – the red area – 6 holes arranged at 60°;

C – the green area – 3 holes arranged at 120°;

The scheme of the experimental installation specifies the component elements for the study of the change in the dissolved oxygen concentration in water flowing through pipes:

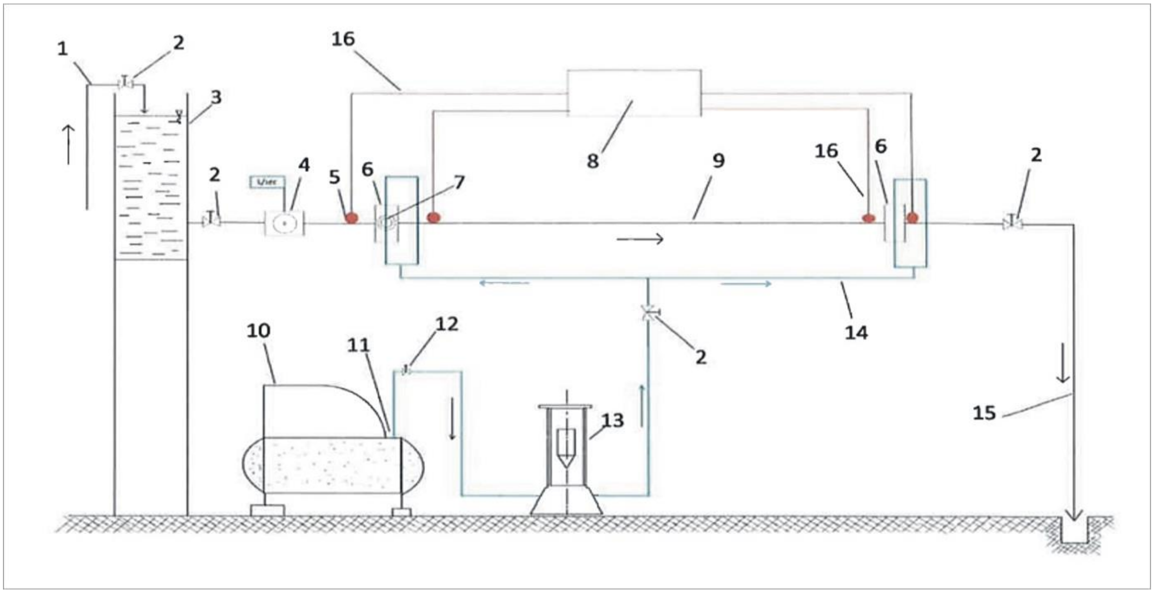


Fig. 12. Sketch of the experimental installation

1– water supply pipe; 2 - tap; 3 - water tank; 4 - flow meter; 5 - light insulating spot; 6- flanges; 7 - spiral; 8 - oxygenometer; 9 - transparent plexiglass pipe; 10 - electrocompressor; 11 - compressed air tank; 12 - pressure reducer; 13 - rotameter; 14 - compressed air pipes; 15 - water drainage pipe to the sewerage network; 16 - optical fiber

Figure 13. shows the transparent plexiglass pipe in which the spiral is mounted.

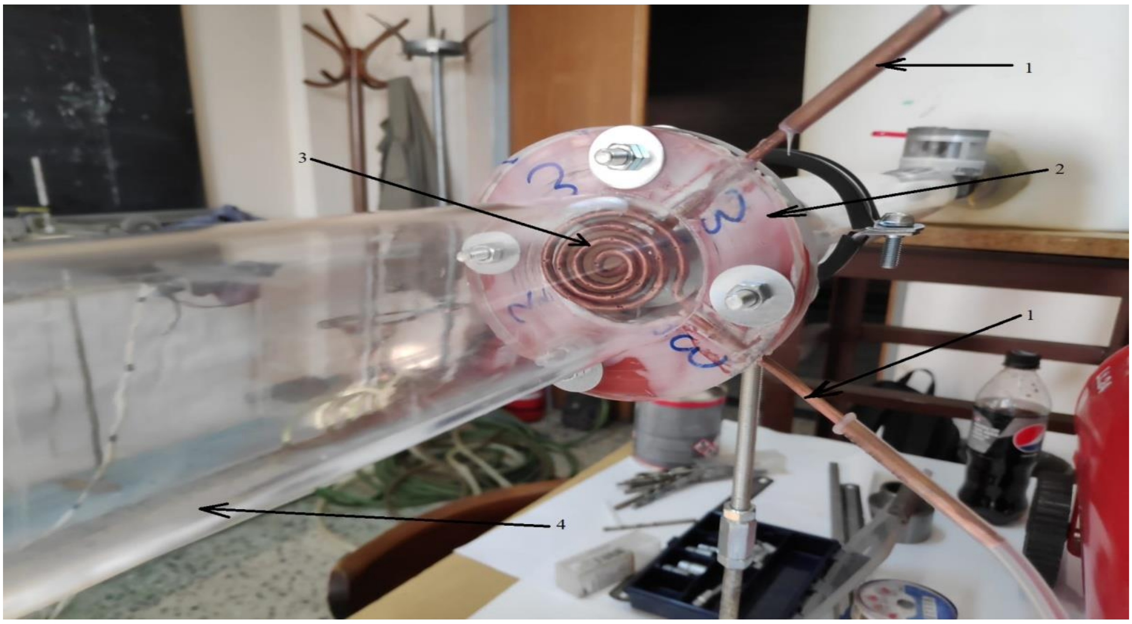


Fig. 13. The spiral placeed inside the pipe

1 - compressed air connections; 2 - flange; 3– spiral; 4 - transparent plexiglass pipe

Determination of dissolved oxygen concentration value in water can be done with the latest measuring method which is a non-invasive method and has applications in the food and beverage industry.

The determinations are made with high precision and are carried out by means of a sensor applied to a transparent surface such as a transparent plastic material (plexiglas) or glass (fig. 14.).

Fig. 14. Non-invasive device for measuring dissolved oxygen concentration

NomaSense portable oxygen meter is presented (fig. 15.), as well as how to measure the concentration of oxygen dissolved in water by the non-invasive method (fig. 16.).

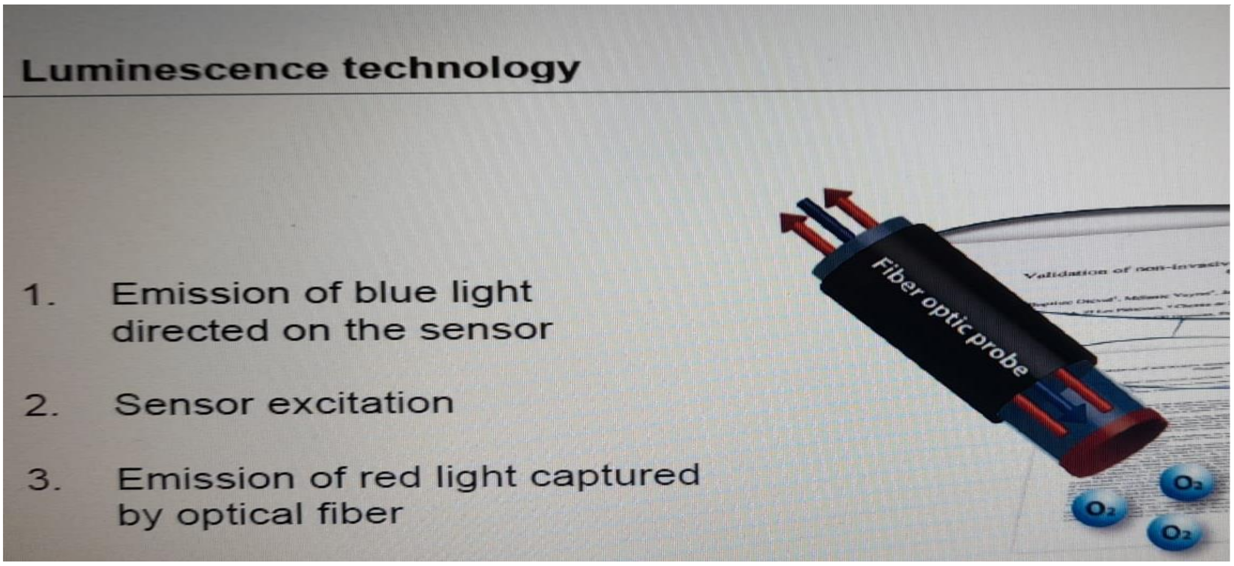
Fig. 15. NomaSense portable oxygen meter

Fig. 16. How to measure the concentration of dissolved oxygen in water with the NomaSense portable oxygen meter

Also presented is the principle underlying these measuring devices, the principle of oxo-luminescence.

The signal emitted by the sensor is transmitted to the oxygen meter by means of the optical fiber.

Figure 17 shows the operating principle of the oxygen meter, which non-invasively determines the concentration of dissolved oxygen in a liquid flowing through pipes.



Luminescence technology

1. Emission of blue light directed on the sensor
2. Sensor excitation
3. Emission of red light captured by optical fiber

Fig. 17. The principle of operation of the oxygen meter by the non-invasive method

Also, to measure the liquid flow, the installation is equipped with an electronic flow meter with a flow sensor.

The way of measuring the flow of water passing through the plexiglass pipe of the experimental facility is shown in figure 18.

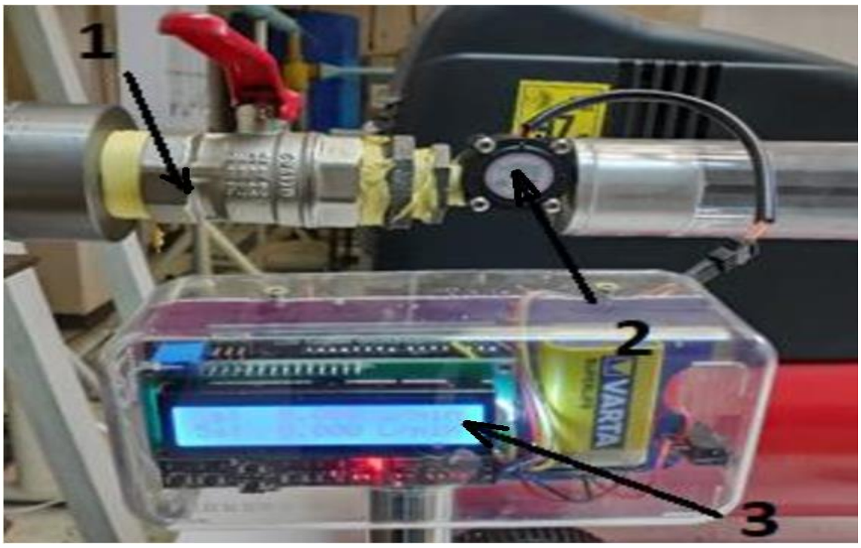


Fig. 18. Measurement of the flow of water passing through the pipeline plexiglass of the experimental facility

1 – water flow regulation valve; 2 – flow sensor; 3 – electronic flow meter;

Chapter 8. Experimental researches

This chapter presents the purpose of the experimental researches, the methodology of their realization, the experimental obtained results, as well as a comparative analysis of the results for the two studied verions.

Performing the measurements involves the following steps [14] [15] [16]:

1. Check that the 113 orifices function, i.e., the atmospheric air is introduced into the bubble generator;

2. Fill the tank with water up to H = 500 mm H_2O;

3. Measure C_0, t_{H2O}, t_{air};

4. Insert the fine bubble generator into the water tank and note the time (τ);

5. Every 15 minutes, take the fine bubble generator out of the tank and measure the dissolved oxygen concentration; subsequently, reinsert the fine bubbles generator in the water tank.

6. When a horizontal level of the function $C = f(\tau)$ is reached, the measurements stop, with the condition: $C \approx Cs$;

7. From previous researches, the dissolved oxygen concentration in water tends to saturate after two hours. So, the measurement of the oxygen concentration will be performed at the moments: 15, 30, 45, 60, 75, 90, 105, 120 minutes.

8. At the end of the measurements, clean the oxygenometer probe and drain the water from the tank.

Then repeat the above steps for verion II with the set of four plates each with 113 orifices Ø - 0.05 mm.

Initial data for the two analyzed verions

Initial data for experimental measurements include [17] [18]:

1.) The water volume V_{H2O} tank = 0.125 [m^3];

2.) Hydrostatic load (height of the water layer in the tank) H = 500 [mmH_2O];

3.) Water temperature t_{H2O} = 24 °C;

4.) The value of the saturation concentration of dissolved oxygen in water for the temperature of t_{H2O} = 24 °C, results from table 2.1 as C_s = 8.4 mg / dm^3;

5.) Air temperature t_{air} = 24.1 °C;

6.) The air flow rate introduced into the water $\dot{V} = 600\ \mathrm{dm^3/h}$;

7.) Initial concentration of dissolved oxygen in water C_0 = 5.84 [mg / dm^3];

The duration in which the experimental measurements are performed for τ = 120 min.

In **version I,** atmospheric air (21% O_2 and 79% N_2) is introduced into the water tank in a flat, rectangular bubble generator (F.B.G.) with a plate with 113 orifices Ø 0.1 mm [19] [20].

For verion I, the results of the measurements performed are presented in table 4.

Table 4. Experimental values of dissolved oxygen concentration in water depending on the time, C_{O_2} = f(τ) in the case of **version I**

No.	τ [min]	0	15	30	45	60	75	90	105	120
1	C [mg/dm^3]	5.84	6.89	7.65	8.01	8.10	8.26	8.31	8.35	8.39
2	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 experimental data obtained, the graph of the function C_{O_2} = f (τ) was drawn for verison I as shown in figure 19.

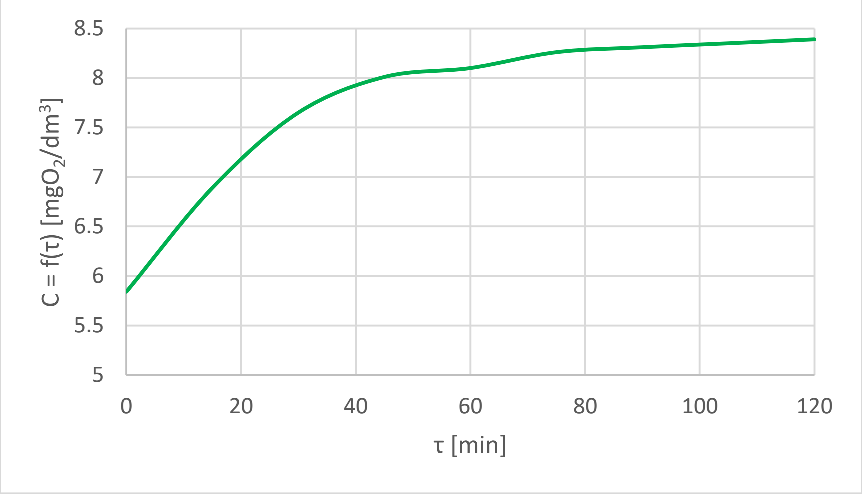


Fig.19. Graphical representation of the function C_{O_2} = f (τ) for **version I,**

1 – C_{O_2} = f(τ) for F.B.G. with ø = 0,1 mm;

In order to make a comparison between the theoretical and the experimental results in the case of **variant I,** the obtained results are highlighted in table 5, and their comparative situation is presented graphically in figure 20.

Table 5. Theoretical and experimental values of the dissolved oxygen concentration in water as a function of time, in the case of version I.

Nr. Crt.	τ [min]	0	15	30	45	60	75	90	105	120
1	*C teoretic* Var.I [mg/dm^3]	5,84	6,92	7,68	8,05	8,18	8,28	8,33	8,36	8,40
2	*C* experimental Var.I [mg/dm^3]	5.84	6,89	7,65	8,01	8,10	8,26	8,31	8,35	8,39
3	C_S [mg/dm^3]	8,4	8,4	8,4	8,4	8,4	8,4	8,4	8,4	8,4

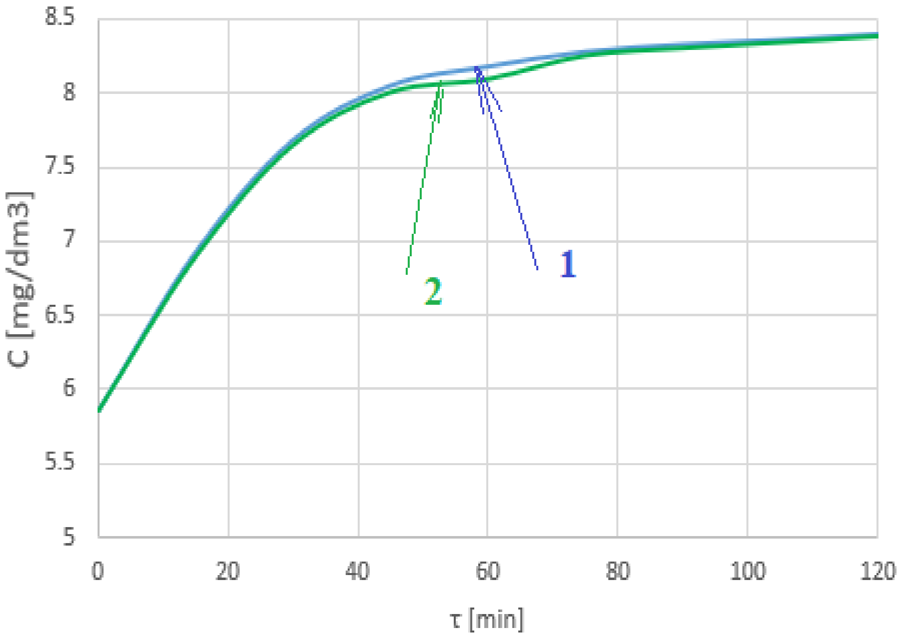


Fig. 20. Comparative graphic representation of the function C = f(τ) for **version I,**

1– C = f(τ) theoretical, for G.B.F with Ø 0,1 mm;

2– C = f(τ) – experimental, for G.B.F with Ø 0,1 mm;

Figure 21 shows the generator of fine, rectangular bubbles during experimental research.

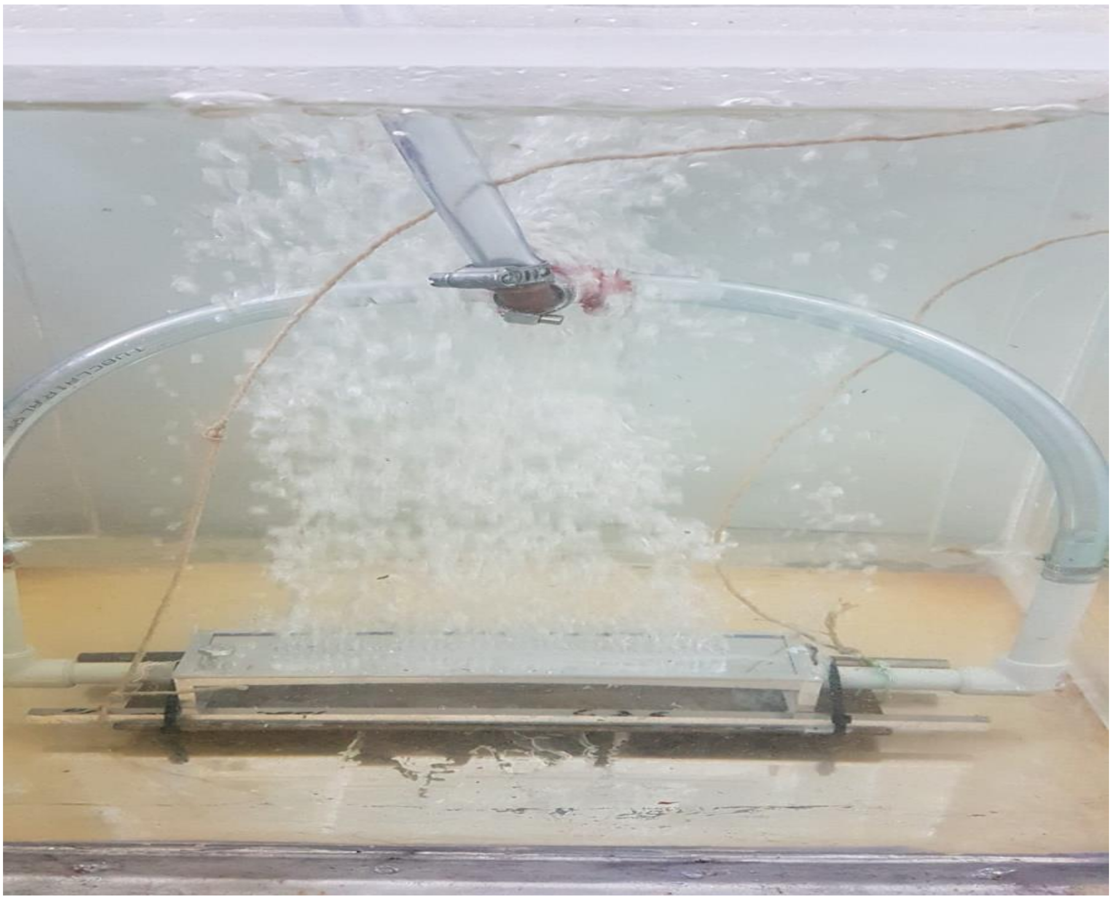


Fig. 21. Bubble curtain emitted by the fine bubble generator in operation

In **version II**, atmospheric air (21% O_2 and 79% N_2) is introduced into the water tank by means of an installation whose compressed air distribution element is a platform containing four fine bubble generators provided with circular perforated plates with a number of 113 orifices Ø 0.05 mm on each plate.

Figure 22 shows the set of four cylindrical bodies that form the F.B.G. and in figure 23 the F.B.G. is presented during experimental research.

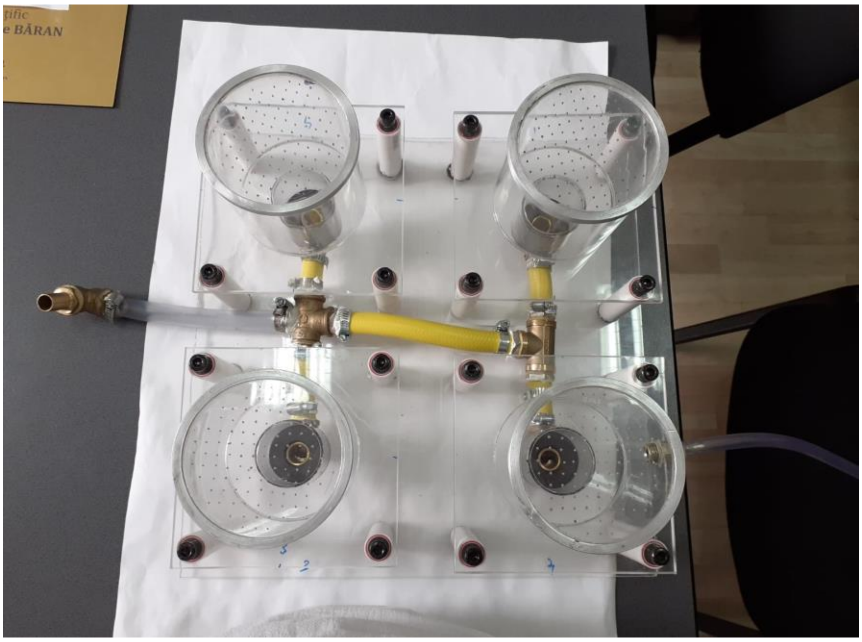


Fig. 22. Overview of the F.B.G. - verion II, orifices Ø 0.05 mm

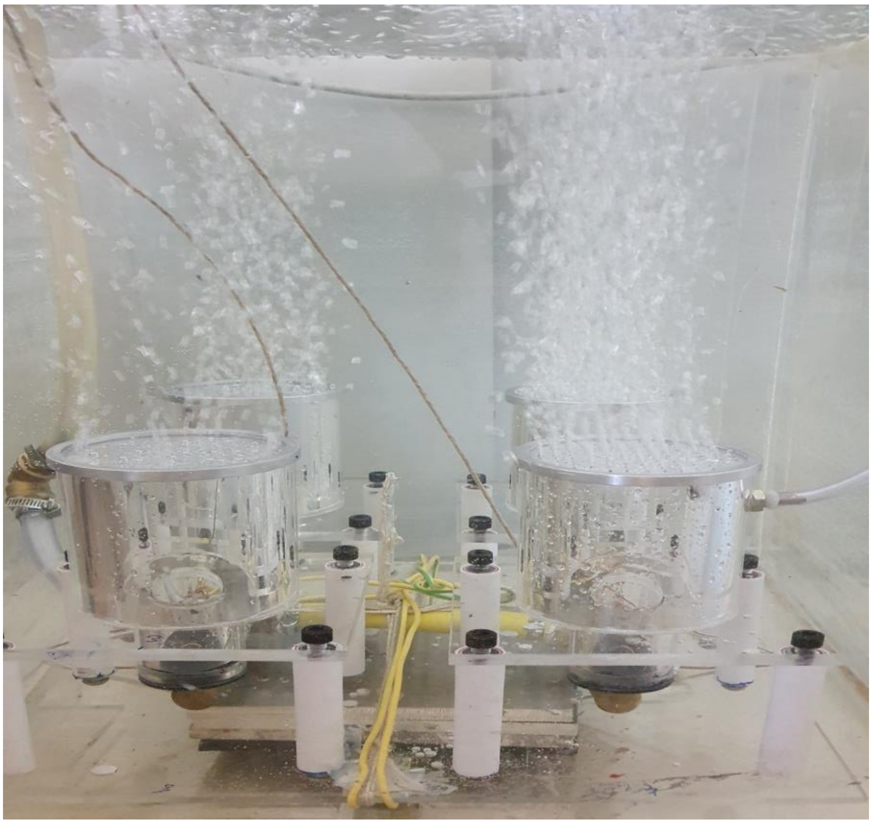


Fig. 23. Bubble curtain emitted by the set of four four cylindrical bodies with orifices of Ø 0.05 mm forming the F.B.G.

The results of the measurements carried out in the case of **version II** were systematized in table 6.

Table 6. Experimental values of the concentration of oxygen dissolved in water as a function of time, $C_{O_2} = f(\tau)$, in the case of **variant II.**

Nr. Crt.	τ [min]	0	15	30	45	60	75	90	105	120
1	C [mg/dm^3]	5,84	7,45	7,80	8,10	8,20	8,28	8,32	8,35	8,39
2	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 obtained experimental data, the graph of the function $C_{O_2} = f(\tau)$ was drawn for **version II** as shown in figure 24.

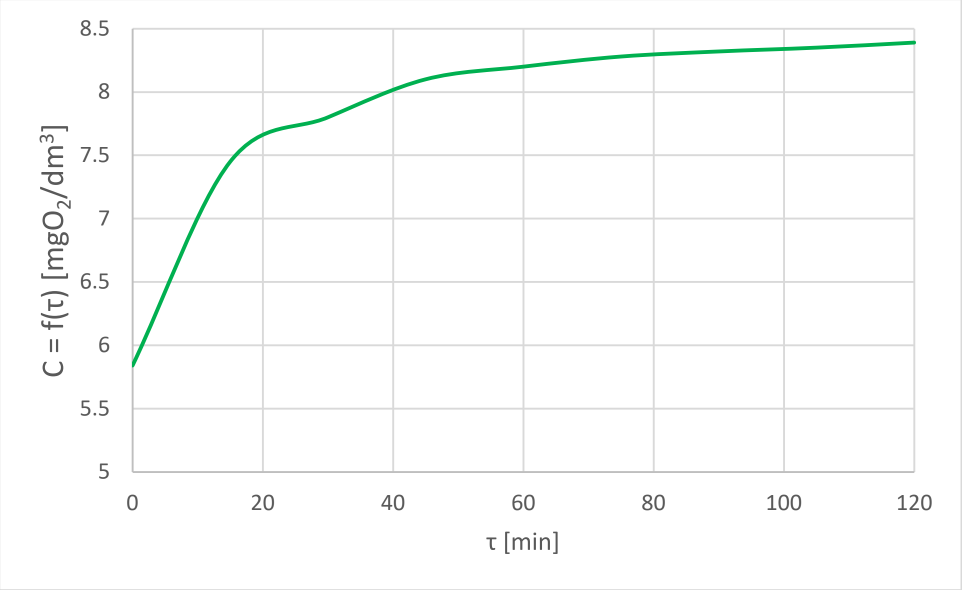


Fig. 24. The graphic representation of the function $C = f(\tau)$ for version II

1 – $C = f(\tau)$ - experimental – for F.B.G. with Ø 0,05 mm;

Also in this variant, in order to make a comparison between the theoretical and experimental results, the obtained results are highlighted in table 7, and their comparative situation is presented graphically in figure 25.

Table 7. Theoretical and experimental values of the concentration of oxigen dissolved in water as a function of time in the case of version II

Nr. Crt.	τ [min]	0	15	30	45	60	75	90	105	120
1	C theoretical Var.II [mg/dm^3]	5,84	7,47	7,84	8,18	8,22	8,30	8,36	8,39	8,42
2	C experimental Var.II [mg/dm^3]	5,84	7,45	7,80	8,10	8,20	8,28	8,32	8,35	8,39
3	C_S [mg/dm^3]	8,4	8,4	8,4	8,4	8,4	8,4	8,4	8,4	8,4

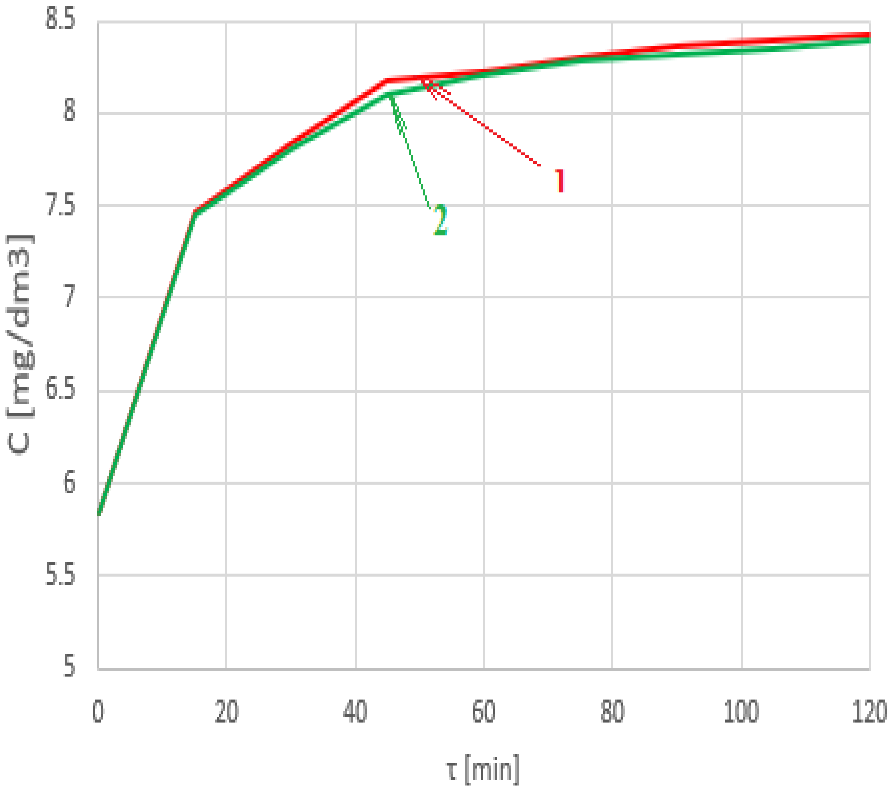


Fig. 25. Comparative graphic representation of the function C = f(τ) for **version II**,

1 – C = f(τ) – theoretical, for F.B.G. with Ø 0,05 mm;

2 – C = f(τ) – experimental, for F.B.G. with Ø 0,05 mm;

To demonstrate the efficiency of the water aeration process in the case of the two variants of F.B.G. a comparison is made of the theoretical and experimental results obtained for them, during the research as follows**:**

-in table 8, the theoretical values obtained for the two variants studied are systematized;

Table 8. Theoretical values of the concentration of oxygen dissolved in water as a function of time in the case of the two versions

Nr. Crt.	τ [min]	0	15	30	45	60	75	90	105	120
1	C theoretical Var.I [mg/dm^3]	5,84	6,92	7,68	8,05	8,18	8,28	8,33	8,36	8,40
2	C theoretical Var.II [mg/dm^3]	5,84	7,47	7,84	8,18	8,22	8,30	8,36	8,39	8,42
3	C_S [mg/dm^3]	8,4	8,4	8,4	8,4	8,4	8,4	8,4	8,4	8,4

The comparative graphic representation of the theoretical variation of the dissolved oxygen concentration in wateras a function of time, in the case of the two variants, is presented in figure 26.

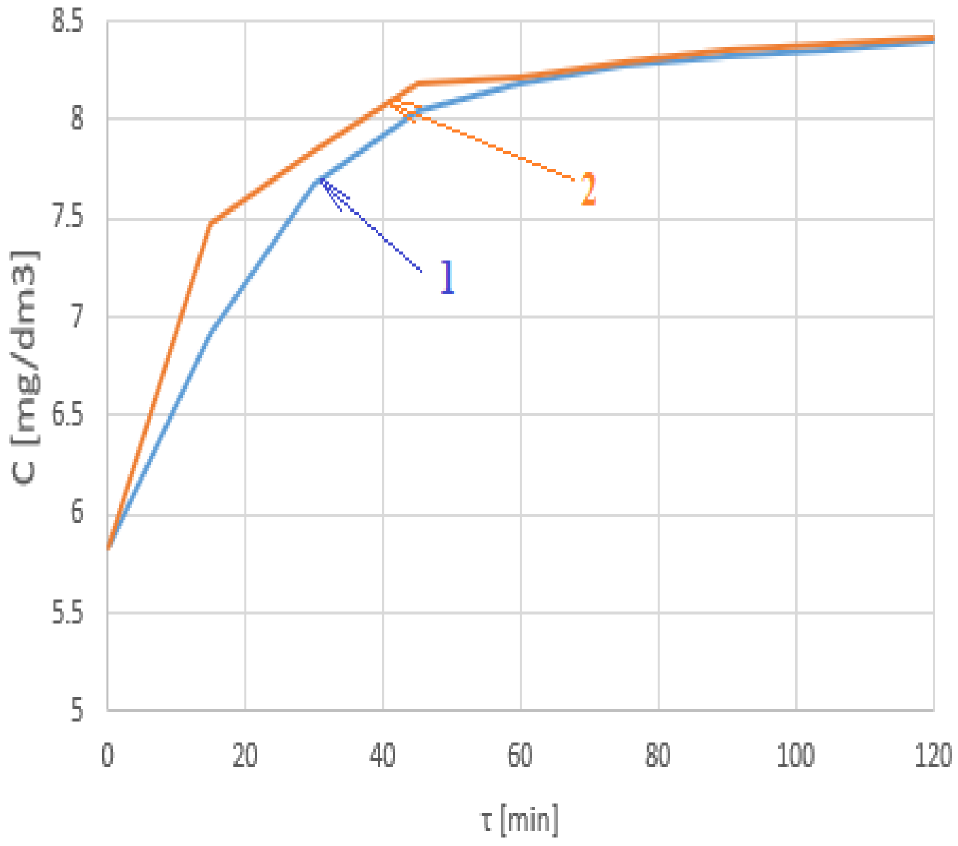


Fig. 26. The comparative graphic representation of the theoretical values of the function C = f(τ) for the two versions:

1 – *C* = f(τ) – theoretical, for F.B.G. with Ø 0,1 mm;

2 – *C* = f(τ) – theoretical, for F.B.G. with Ø 0,05 mm;

Also, in table 9, the experimental values obtained for the two versions studied are highlighted.

Table 9. Experimental values of the concentration of oxygen dissolved in water as a function of time in the case of the two versions

Nr. Crt.	τ [min]	0	15	30	45	60	75	90	105	120
1	C experimental Var.I [mg/dm^3]	5.84	6,89	7,65	8,01	8,10	8,26	8,31	8,35	8,39
2	*C* experimental Var.II [mg/dm^3]	5,84	7,45	7,80	8,10	8,20	8,28	8,32	8,35	8,39
3	C_S [mg/dm^3]	8,4	8,4	8,4	8,4	8,4	8,4	8,4	8,4	8,4

In this case, the comparative graphic representation of the experimental variation of the dissolved oxygen concentration in water as a function of time, in the case of the two variants, is presented in figure 27.

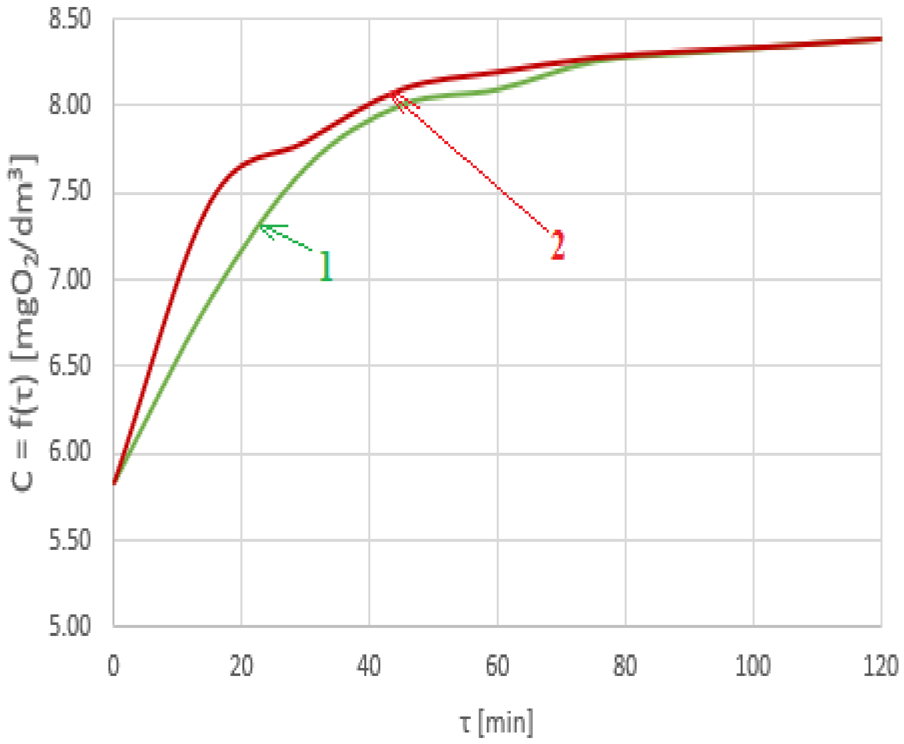


Fig. 27. The comparative graphic representation of the experimental values of the function C = f(τ) for the two versions:
1 – *C* = f(τ) – experimental, for F.B.G. with Ø 0,1 mm;
2 – *C* = f(τ) – experimental, for F.B.G. with Ø 0,05 mm;

From figure 27, it can be seen that on the time interval 0 – 75 minutes there is a significant difference between the two curves. As a result, it is noted that the second version, respectively the version with G.B.F. with holes of Ø 0.05 mm is more favorable in terms of increasing the concentration of dissolved oxygen in the water.

Conclusions

Following the experimental researches carried out for the two verions, the following were found:

1.) From tables 4 and 6, respectively, one can observe that the values of the dissolved oxygen concentration in water experimentally measured at appropriate time points are higher in **version II**, so, **version II** ensures a more efficient aeration;

2.) In tables 1 and 2, respectively, one can observe that the increase in the dissolved oxygen concentration in water from C_0 to C_s is faster in the case of using the fine bubble generator with orifices with a diameter Ø 0.05 mm.

3.) From the graphical representation figure 27 of the variation of the dissolved oxygen concentration in water as a function of time $C_{O_2} = f(\tau)$ one can observe that the values of the function, $C_{O_2,II} = f(\tau)$ are superior to those of version I, so water aeration is more efficient.

Original contributions

a) The construction of the fine bubble generator in **version II** required an original idea by dividing the 452 orifices into four circular plates each with 113 orifices of Ø - 0.05 mm; the arrangement of the 452 orifices in a straight line led to very large tank dimensions and high pressure losses for the air to be immersed in the water.

b) The technology of execution of the orifices of Ø - 0.05 mm required the elaboration of an original technological conception [21] [22].

C. CONCLUSIONS

C1. General conclusions

1. The author has developed a study on water aeration, which leads to an efficient aeration system.

2. The construction of a fine bubble generator in which the perforated plate has orifices of Ø - 0.05 mm is a performance. The technology of execution of these orifices required a series of tests and collaborations between POLITEHNICA University of Bucharest and other specialized institutions in the country.

C2. Original contributions

In accordance with the objectives of the doctoral thesis and analyzing the theoretical and experimental results obtained by the elaboration of this doctoral thesis, the following contributions can be highlighted:

❖ **Theoretical contributions:**

1. Elaboration of a rich biographical study on water aeration with applications in the country;

2. Development of a technology for the production of fine bubble generators in which the perforated plate has orifices with a diameter of 0.1 mm and 0.05 mm, respectively.

3. Establish a mathematical relation that shows the relationship between the dissolved oxygen concentration in water and the diameter of the air inlet.

4. Elaboration of a theoretical study regarding the comparison of two types of fine bubble generators, rectangular and circular with holes made by micro-drilling; the variation curves of the concentration of oxygen dissolved in water as a function of time were obtained, by numerical integration of the differential equation of the transfer rate of oxygen in water, for the two types of fine bubble generators, establishing that the bubble generator fine **Variant II** in which the perforated plate has holes with a diameter of 0.05 mm is more advantageous.

5. Carrying out a comparative study between the two versions and choosing the most efficient version, namely **version II**.

- **Numerical contributions:**

6. Detailed exposition of the Euler numerical method, the separate step method and the explicit algorithm, by integrating the ordinary differential equation of the transfer rate of oxygen to water, with the presentation of the logical calculation scheme.

7. Development of a calculation program to determine the dissolved oxygen concentration in water over time in two cases:

- a fine bubble generator with orifices Ø 0.1 mm is inserted in the water.
- a fine bubble generator with orifices Ø 0.05 mm is inserted in the water.

8. Elaboration of a calculation program for establishing the mathematical relation: $C = \mathrm{f}\,(d_b)$ for the two studied versions $d_0 = 0.1$ mm, respectively $d_0 = 0.05$ mm.

- **Experimental contributions:**

9. The realization, with appropriate developed technologies, of the two variants of G.B.F., respectively **Variant I** and **Variant II**; the holes were executed by micro-drilling with modern machines for micro-processing, equipped with special drills.

10. The design and development of the laboratory facility for the experimental study of the two variants of fine bubble generators, equipped with high-performance measurement and control equipment and an electronic data recording and processing system).

11. Specifying and detailing the purpose and methodology of experimental research, indicating the sequence of measurement stages.

12. Development of a methodology for conducting experimental research in order to validate the theoretical results obtained in chapters 4, 5 and 6.

13. The conception, design and practical implementation of the experimental installation for the study of aeration of water flowing through pipes, with an original system of dispersion of air in water, consisting of a spiral of a thin copper tube perforated with holes of 0, 1 mm.

14. Provision of a non-invasive method for measuring the concentration of oxygen dissolved in water in the experimental installation for the study of aeration of water flowing through pipes.

15. The results of theoretical and experimental researches have been translated into publications in the country and abroad, as follows:

- 2 ISI indexed papers;
- 8 BDI indexed papers.

C3. Prospects for further researches

Further researches is considered in the following directions:

- Finding constructive solutions of F.B.G. by using microtechnologies;
- The use of nanotechnologies in water aeration processes.

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ANEXA

Lista de lucrări publicate

Articole publicate în reviste cotate ISI

1. **Marilena Monica BOLTINESCU (ROZA),** Nicolae Vlad SIMA, Dorina Nicoleta ALBU, Mihaela PETROȘEL (BĂNICĂ) and Mihaela CONSTANTIN, Researches on increasing the dissolved oxygen concentration in stationary waters,E3S Web of Conferences **286**, 01001 (2021) https://doi.org/10.1051/e3sconf/202128601001 ,***TE-RE-RD*** 2021

2. **Marilena Monica BOLTINESCU (ROZA),** Nicolae BĂRAN, Albertino Giovani ROZA, Mihaela CONSTANTIN ,*The use of microtechnology's in the construction of water aeration installations,* ***COFRET 2021*** *IOP Conf. Series: Earth and Enviromental Science* ***960*** *(2022)012019*

Articole publicate în reviste cotate BDI

1. **M. M. BOLTINESCU (ROZA)**, N. BĂRAN, N.V. SIMA, R. VOICU,M. CONSTANTIN, The Use of Microtechnology's for the Construction of Some Devices Necessary for Water Aeration, **Asian Journal of Applied Science and Technology (AJAST**) (Peer Reviewed Quarterly International Journal) Volume 2, Issue 4, Pages 70-78, Oct - Dec 2018

2. M. F. ŞTEFĂNESCU, N.V. SIMA, **M. M. BOLTINESCU (ROZA),** M. PETROȘEL, M. CONSTANTIN, Design and Construction of an Installation for Testing Bubble Generators Used for Water Aeration, **Asian Journal of Applied Science and Technology** Volume 4, Issue 4, Pages 73-81, October - December 2020.

3. **Marilena Monica BOLTINESCU (ROZA)**, Nicolae BĂRAN, Mihaela CONSTANTIN, Researches on the Development of a Nanobubbles Generator Used to Waters Aeration , ISSN 1453 – 7303 **“HIDRAULICA”** (No. 3/2020) Magazine *of Hydraulics, Pneumatics, Tribology, Ecology, Sensorics, Mechatronics*

4. **Marilena Monica BOLTINESCU (ROZA)**, Nicolae BĂRAN, Nicolae Vlad SIMA, Mihaela CONSTANTIN Theoretical and Experimental Researches on the Determination of Pressure Losses on Bubble Generators Used for Water Aeration, ISSN 1453 – 7303 **“HIDRAULICA”** (No. 4/2020) Magazine *of Hydraulics, Pneumatics, Tribology, Ecology, Sensorics, Mechatronics*

5. **Marilena Monica BOLTINESCU (ROZA)**, Nicolae BĂRAN, Mihaela CONSTANTIN, Cătălina DOBRE, Researches on water aeration using fine bubbles generators, ISSN 1453 – 7303, pag. 53 – 60, **“HIDRAULICA”** (No. 1/2022) Magazine *of Hydraulics, Pneumatics, Tribology, Ecology, Sensorics, Mechatronics.*

6. **Marilena Monica BOLTINESCU (ROZA)**, Nicolae BĂRAN, Mihaela CONSTANTIN, Determining the Relation between the Size of the Air Bubble Immersed in Water and the Dissolved Oxygen Concentration, ISSN 1453 – 7303, pag. 95 – 105, **“HIDRAULICA”** (No. 1/2022) Magazine *of Hydraulics, Pneumatics, Tribology, Ecology, Sensorics, Mechatronics.*

7. **Marilena Monica BOLTINESCU (ROZA)**, Nicolae BĂRAN, Alexandru GRIGORE, Remus VOICU, Mihaela CONSTANTIN, Researches on Water Aeration Flowing through Pipes, ISSN 1453 – 7303, **“HIDRAULICA”** (No. 2/2022) Magazine *of Hydraulics, Pneumatics, Tribology, Ecology, Sensorics, Mechatronics.*

8. **Marilena Monica BOLTINESCU (ROZA)**, Nicolae BĂRAN, Mihaela PETROȘEL, Albertino Giovani ROZA, Mihaela CONSTANTIN, Increasing the oxygen transfer rate to stationary water, ISSN 1453 – 7303, **“HIDRAULICA”** (No. 2/2022) Magazine *of Hydraulics, Pneumatics, Tribology, Ecology, Sensorics, Mechatronics.*