IJISET - International Journal of Innovative Science, Engineering & Technology, Vol. 8 Issue 2, February 2021
ISSN (Online) 2348 – 7968 | Impact Factor (2020) – 6.72
www.ijiset.com

Design and Construction of an Air Microbubble Generator Used for Water Aeration

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Abstract

The paper presents an original constructive solution for a fine air bubble generator; the pressure loss of the air stream as it passes through the fine bubble generator and the air flow rate passing through the generator are determined. A series of modern measuring instruments used in experimental researches are also presented. The paper describes the experimental installation built in the laboratory, the researches methodology and the results obtained regarding the increase of the dissolved oxygen concentration in the water.

Keywords: *water oxygenation, fine air bubbles generator.*

1. Introduction

By aeration of water is meant the process of transferring a gas into a liquid, namely atmospheric air into water.
The term oxygenation is used when it is introduced into water:
- a mixture of air + oxygen from a cylinder;
- pure oxygen from a cylinder;
- low nitrogen air (95% O_2 and 5% N_2) delivered by oxygen concentrators.
- a mixture of atmospheric air and ozone (O_3).

Aeration and oxygenation aim to increase the content of dissolved oxygen in water.
Depending on the operation principle, aeration systems are classified into three classes [1] [2]:
A) Mechanical aeration installations;
B) Pneumatic aeration installations;
C) Mixed aeration installations.
All three classes aim to increase the oxygen content of the water (Figure 1).

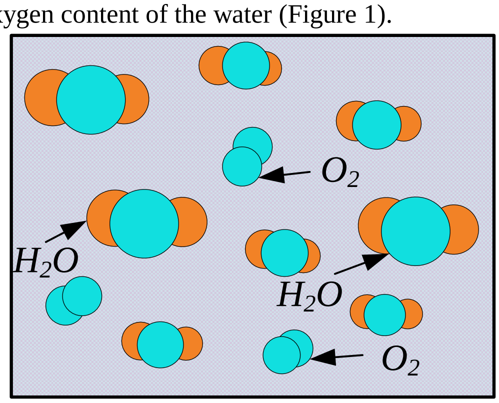

Fig. 1 Oxygen dissolved in water (blue spheres).

The figure shows that each water molecule consists of an oxygen atom coupled to two hydrogen atoms (orange spheres). Oxygen dissolved in water is found in the water molecules. The amount of oxygen dissolved in water depends on the following parameters [3] [4]:
a) Atmospheric pressure;
b) Water temperature;

c) Water salinity;
d) The degree of water turbulence.
The oxygen contained in the atmospheric air is 21% by volume; it is taken from the atmosphere and introduced into the water by means of dispersion elements which must ensure:
- a more uniform distribution of air bubbles, in a volume of water: tank, basin, etc.
- the orifices of the dispersion device must be as small as possible, thus ensuring the immersion in water of air bubbles with the smallest diameter.
- the dispersing device must ensure an increased reliability of the installation and at the same time have a loss of air pressure as small as possible.
Water oxygenation is a mass transfer process with wide applications in the technique of water treatment and purification. Oxygenation equipment is based on the dispersion of one phase in the other, for example gas in liquid, energy consuming process.
Dissolved oxygen is an important parameter in assessing water quality due to its influence on living organisms in a volume of water. In Limnology (study of lakes), dissolved oxygen is an essential factor [1]. Dissolved oxygen levels that are too high or too low can affect aquatic life and affect water quality.
Introduction of microbubbles in water has been shown to improve the efficiency of these aeration processes, due to the large specific interfacial area in relation to the small volume of gas bubbles [1] [2]. As a result, there is a need to create a network of air dispersion in water through bubbles with the smallest diameter.
Regarding the construction of fine bubble generators from the literature, it is revealed that the smaller the diameter of the air bubble introduced in water, the higher the speed of oxygen transfer to water.
Unconventional technologies were used in the construction of fine bubble generators.
Thus, the orifice plates of the fine bubble generators were made by EDM and micro-drilling. Through micro-drilling, orifices of Ø 0.1 mm were made, and by EDM holes were made with Ø 0.3 mm, Ø 0.5 mm. Aeration systems are effective when it generates fine gas bubbles and ensure a uniform distribution of air introduced into the water. By creating the most efficient aeration systems, the consumption of electricity from the compressed air stations is reduced.
According to the size of the diameter of the air bubbles, the bubbles can be classified as follows (figure 2):

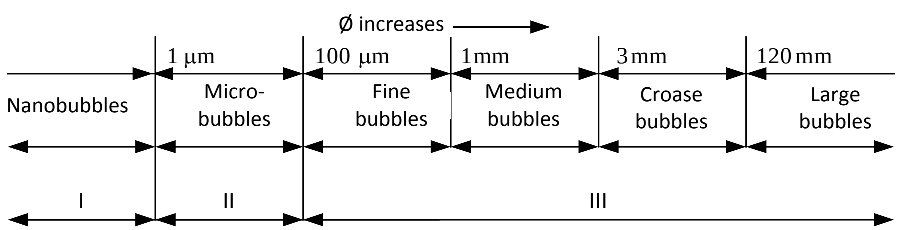

Fig. 2 Classification of gas bubbles according to their diameter [5].

According to the way the bubbles are obtained, the aeration installations are divided into three categories:
a) Aeration installations with drilled pipes;
b) Aeration installations provided with porous diffusers;
c) Aeration installations with fine bubble generators;

2. Presentation of the constructive solution of the fine bubble generator

According to specialized papers, the main functional parameters that highlight the performances of the oxygenation process are:
- Constructive characteristics of microbubble generators; the constructive characteristics refer both to the diameter of the orifice of the fine bubble generator through which the air is released into the water mass, the distance between two orifices and the distribution of the orifices (on the dispersion element of the microbubble generator) and to the chosen constructive solution of the bubble generator. This refers to the shape of the dispersion plate and its thickness, but also to the construction of the body of the microbubble generator.
- Mounting characteristics of microbubble generators in the aeration tank.

These characteristics refer both to the mounting distance from the tank radiator and to the distribution of the generators in the aeration tank, but also to the way of connecting the microbubble generators to the compressed air network and the shape of the aeration tank.

The most important element of microbubble generators is the element of air dispersion in water, i.e., the plate with orifices, which can be built in different shapes (circular, rectangular, tubular, spherical, etc.).

For the construction of high-performance microbubble generators, two conditions are imposed, relations (1) and (2) [3].

* The first condition refers to the correlation between the thickness of the plate in which the air emission orifices are made and the diameter of these orifices (figure 3):

$$\frac{s}{d_0} > 3 \qquad (1)$$

Where:
-s - the plate thickness in which the orifices are made;
-d_0 - orifice diameter.

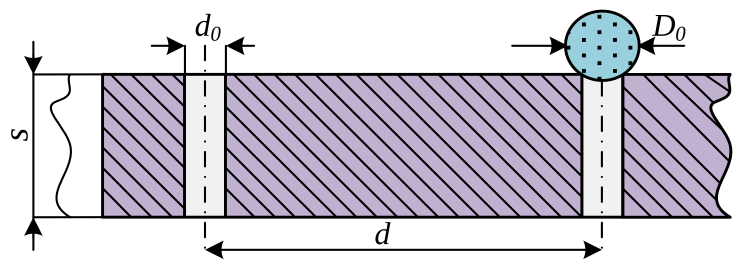

Fig. 3 Location of orifices in the microbubble generator
d_0 - orifice diameter, $d_0 = 2r_0$; d - the distance between the axes of two orifices. D_0 - diameter of the gas bubble at the outlet of the orifice (at the time of its detachment); s - plate thickness.

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

$$\frac{d}{d_0} > 8 \qquad (2)$$

where d represents the distance between two orifices.

Therefore, in order to obtain microbubbles, the diameter of the orifice must be as small as possible (d0 <1 mm) and the distribution of the orifices in the plate must be uniform.

These two conditions can be achieved with the help of unconventional technologies or modern micro - processing technologies:

• EDM processing;
• electrochemical processing;
• laser processing;
• electron beam processing;
• micro-drilling machines in coordinates with drills Ø <0.5 mm.

The microbubble generator has as a dispersion element a rectangular metal plate, it being called MBG in rectangular shape.

The plate of thickness s = 2 mm, has 152 orifices with a diameter of 0,1 mm, the distance between the holes is 2 mm, respecting the two previous conditions:

$$\frac{s}{d_0} > 3 \rightarrow \frac{2}{0.1} = 20 \qquad (3)$$

$$\frac{d}{d_0} > 8 \rightarrow \frac{2}{0.1} = 20 \qquad (4)$$

The bubble columns at the exit of the perforated plate creates a bubble curtain, similar to that of a flat jet that has a rectangular cross section.

From previous researches [1], [3], taking into account 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:

$$n = \frac{1{,}2\cdot 10^{-6}}{\frac{\pi\cdot\left(0.1\cdot 10^{-3}\right)^2}{4}} = 152\,orifices \quad (5)$$

Figure 4 shows a plan view of the rectangular microbubble generator.

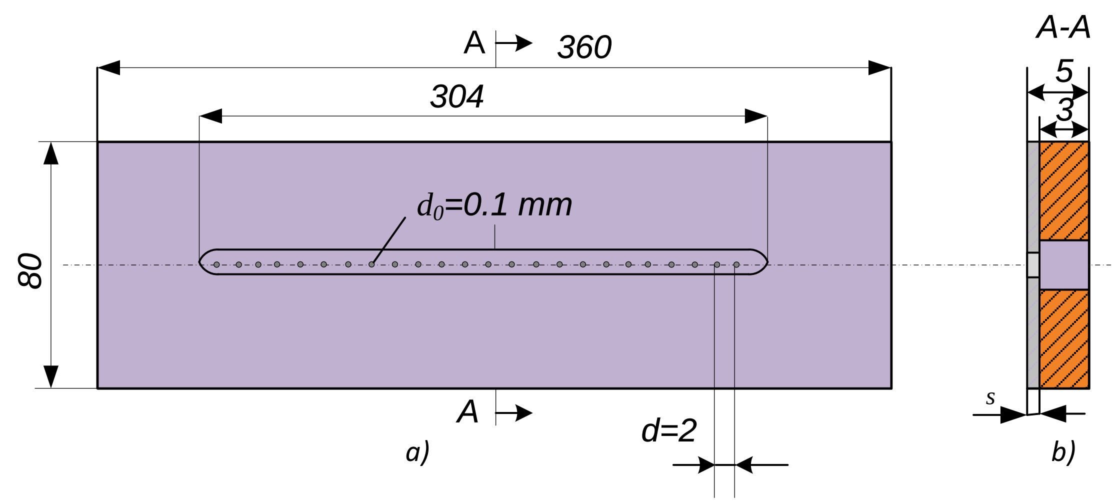

Fig. 4 Perforated plate of the microbubble generator
a - plan view; b - cross section.

Figure 5 shows the constructive solution of the microbubble generator (MBG) which is used in experimental researches.

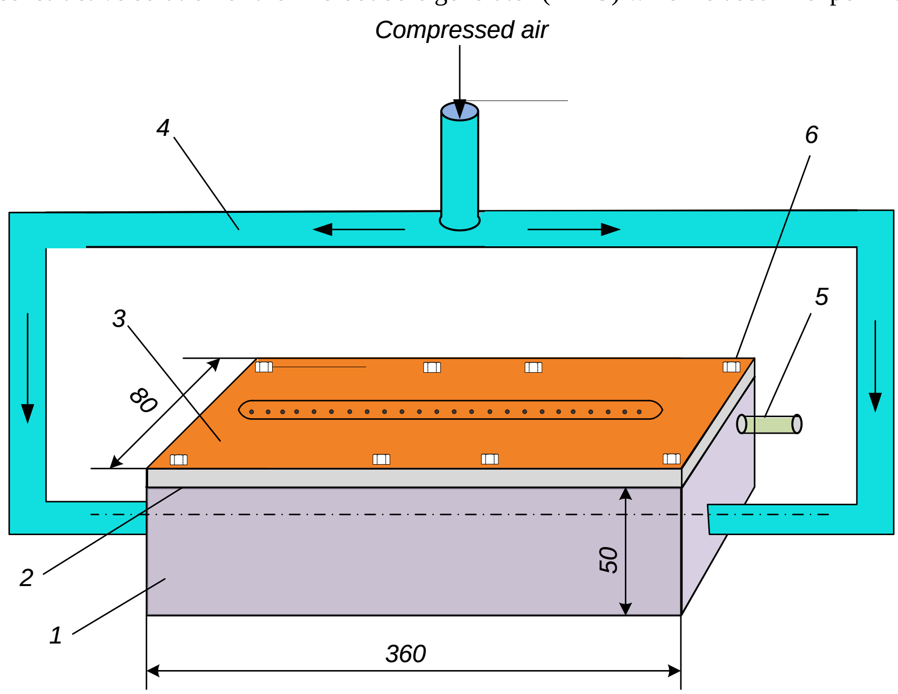

Fig. 5 Air microbubble generator
1 - compressed air tank; 2 - sealing gasket; 3 - plate with orifices; 4 - pipe Ø = 18 mm with compressed air; 5 - connection for measuring the air pressure in the tank; 6 - screws for fixing the perforated plate.

The orifices in the perforated plate were made by micro-drilling with the KERN Micro machine. This machine has an accuracy of ± 0.5 µm and can process parts with a height of 220 mm and a diameter of 350 mm.
To achieve this MBG which is an original constructive solution, a relevant theoretical and experimental basis was needed.

2.1 Establishing the operating regime of the microbubble generator

Depending on the volumetric air flow rate ($\dot{V}$) introduced into the MBG when forming air bubbles, there are three operating modes [8]:

- quasi-static regime ($\dot{V} < \dot{V}_{cr}$);
- dynamic regime ($\dot{V} \geq \dot{V}_{cr}$);
- turbulent regime ($\dot{V} >> \dot{V}_{cr}$).

The quasi-static regime is separated from the dynamic one by the critical flow rate ($\dot{V}_{cr}$).
The critical flow rate for water / air working fluids and orifices of the MBG of 0.1÷2 mm is calculated from the relation [3]:

$$\dot{V}_{cr} = \pi \cdot \left(\frac{16}{3 \cdot g^2}\right)^{\frac{1}{6}} \cdot \left(\frac{\sigma \cdot r_0}{\rho_{H_2O}}\right)^{\frac{5}{6}} \; [m^3/s] \qquad (6)$$

relation in which:
g -represents the gravitational acceleration, g = 9.81 [m / s^2];
σ - surface tension coefficient, for water $\sigma = 73 \cdot 10^{-3}$ [N / m];
ρ_{H2O} - water density, $\rho_{H2O} = 10^3$ [kg / m^3];
r_0 – orifice radius, $r_0 = 0.05 \cdot 10^{-3}$ [m].
For an orifice:

$$\dot{V}_{cr} = \pi \cdot \left(\frac{16}{3 \cdot 9.81^2}\right)^{\frac{1}{6}} \cdot \left(\frac{73 \cdot 10^{-3} \cdot 0.05 \cdot 10^{-3}}{1000}\right)^{\frac{5}{6}} \qquad (7)$$

$$\dot{V}_{cr} = 5.67 \cdot 10^{-7,47} \; m^3/s$$

$$\dot{V}_{cr} = 5.67 \cdot 10^{-7,47} \cdot 3600 \cdot 10^3 = 0.69 \; dm^3/h \; .$$

For the 152 orifices in the plate, the flow rate has the value

$$\dot{V}_{cr,plate} = 152 \cdot 0.69 = 105.11 \; dm^3/h \qquad (8)$$

Experimental researches are performed with an air flow rat $\dot{V} = 600 \;\; dm^3/h;$ e because $\dot{V} > \dot{V}_{cr}$ (600> 105.11) means that the operating regime of the MBG is "dynamic".

2.2 Analysis of pressure losses at the microbubble generator

The 152 orifices being distributed in parallel, the pressure loss on each will be equal. Figure 6 shows a diagram made for establishing pressure losses at the MBG [6].

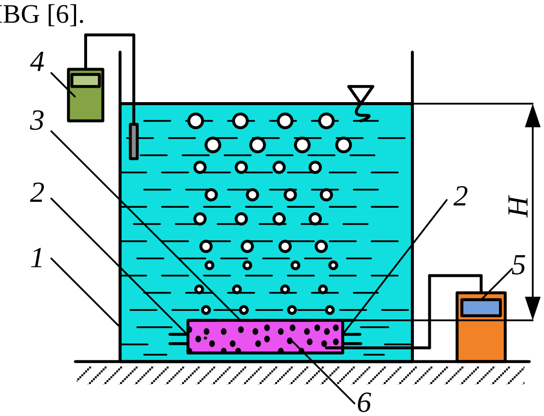

Fig. 6 Scheme for measurements
1 - water tank; 2 - compressed air inlet connections; 3 – orifices plate; 4 - thermometer with digital indication; 5 - manometer with digital indication; 6 - the body of the microbubble generator.

The pressure of the compressed air in the tank (6) is p_1 and it must cover:

$$p_1 = p_H + \Delta p_{ts} + \Delta p_p \qquad (9)$$

p_H - hydrostatic load, H = 500 mm H_2O;
Δp_{st} - pressure loss to overcome surface tension;
Δp_p - the pressure drop that occurs when air passes through the orifice to the dry plate.
The experimental measurements showed:
p_1 = 583 mm H_2O;
p_H = 500 mm H_2O.
The overpressure required to form the bubble is calculated with the relation:

$$\Delta p_{st} = \frac{2\sigma}{R_0} \qquad (10)$$

Where:
σ is the surface water / air tension at 20 °C; the value is: $\sigma = 73 \cdot 10^{-3}$ N / m;
R_0 - the bubble radius when it detaches from the plate with orifices.
Note: $d_0 = 2 \cdot r_0$ and $D_0 = 2 \cdot R_0$; $d_0 = 0.1 \cdot 10^{-3}$ m; $\rho_l = 10^3$ kg / m^3.
Air density is determined from the state equation [9]

$$\rho_g = \frac{p}{RT} \ kg/m^3 \qquad (11)$$

$$\rho_g = \frac{10325 + 583 \cdot 9.81}{287 \cdot (20 + 273.15)} = 1.26 \ kg/m^3$$

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

$$D_0 = \sqrt[3]{\frac{6 \cdot 73 \cdot 10^{-3} \cdot 0.1 \cdot 10^{-3}}{(10^3 - 1.26) \cdot 9.81}} = 0.00164 \ [m]$$

$$R_0 = \frac{D_0}{2} = \frac{0.00164}{2} = 0.00082 = 0.82 \cdot 10^{-3} m$$

From relation (10) it results:

$$\Delta p_{st} = \frac{2\sigma}{R_0} = \frac{2 \cdot 73 \cdot 10^{-3}}{0.82 \cdot 10^{-3}} = 178.04 \ N/m^2 \qquad (12)$$

$$\Delta p_{st} = \rho_{H_2O} \cdot g \cdot \Delta h_{st} \ N/m^2$$

or

$$\Delta h_{st} = \frac{p_{ts}}{\rho_{H_2O} \cdot g} = \frac{178.04}{10^3 \cdot 9.81} = 18.14 \cdot 10^{-3} \ m \qquad (13)$$

$$\Delta h_{st} \approx 18.14 \ mm \ H_2O$$

Relation (9) becomes:

$$583 = 500 + 18.14 + \Delta_{pp} \qquad (14)$$

Δp_p = 64.86 mm H_2O.

The first term to the right of equation (14) represents the overpressure required to overcome the hydrostatic load, the second to overcome the surface tension, and the third refers to the pressure required for an air bubble in the MBG compressed air tank to pass through the plate to the volume of water. In another aspect, the passage of air through the orifice plate can be studied as a local hydraulic resistance.

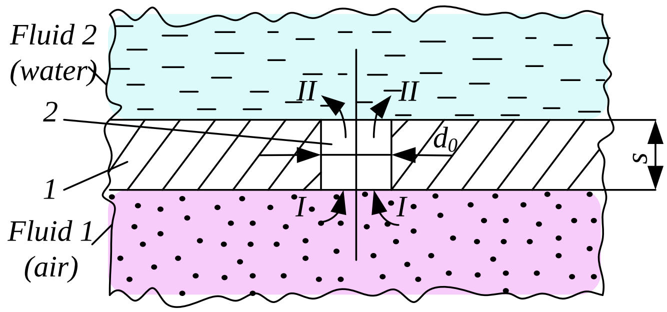

Fig. 7 Calculation notations
1 – orifices plate, thickness s = 1 mm; 2 - orifice with d_0 = 0.1 mm.

The passage of air through the orifice can be considered as a local resistance formed by (figure 7):
- reduction of the section of passage from the air in the box to the entrance to the orifice (I - I) characterized by the coefficient of the local load loss ζ_1;
- linear pressure loss on the Ø 0.1 mm channel, length s = 2 mm;
- increase of the section from the orifice outlet (II - II) to the water in the tank ζ_2;

$$\Delta p = \zeta_1 \cdot \rho_{air} \cdot \frac{w_{1r}^2}{2} + \lambda \cdot \frac{l}{d} \cdot \rho \cdot \frac{w^2}{2} + \zeta_2 \cdot \rho_{air} \cdot \frac{w_{1r}^2}{2} \quad (15)$$

The values of the local (ζ) and linear (λ) pressure loss coefficient are found in [7] [8].

2.3 Calculation of the air flow rate delivered to the microbubble generator

The air flow rate through the orifices is calculated with the relation:

$$w = \sqrt{\frac{2\Delta p}{\rho_{air}}} \; m/s = \sqrt{\frac{2\rho g \Delta h}{\rho_{air}}} \quad (16)$$

$$w = \sqrt{\frac{2 \cdot 9.81 \cdot 64.86}{1.26}} = 31.77 \; m/s$$

The actual air flow speed w_r is:

$$w_{I,r} = \varphi \cdot w_t \;\; m/s$$

where φ is the speed coefficient; φ = 0.71.

$$w_{I,r} = 0.71 \cdot w = 22.9 \; m/s;$$

Determining the air flow rate delivered to the microbubble generator
The air flow rate to the microbubble generator is:

$$\dot{V} = A \cdot w \;\; [m^3/s]$$

The area of the introduced air outlet section has the value:

$$A = n \cdot \frac{\pi \cdot d_0^2}{4} = 152 \cdot \pi \cdot \frac{(0.0001)^2}{4} = 1.19 \cdot 10^{-6} \;\; m^2 \quad (17)$$

For the real speed the flow rate is obtained:

$$\dot{V}_{I,r} = A \cdot w_{I,r} = 1.19 \cdot 10^{-6} \cdot 22.9 = 0.02732 \cdot 10^{-3} \;\; [m^3/s]$$

$$\dot{V}_{I,r} = 0.0273 \cdot 10^{-3} \cdot 3600 = 100 \cdot 10^{-3} \;\; m^3/h = 100 \;\; dm^3/h \quad (18)$$

Starting from this value, the experimental researches were carried out, resorting to higher air flow rates, but of the same order of magnitude. Experiments and measurements were performed to increase the dissolved oxygen concentration in the water.
MBG original design a number of advantages:
-ensures a uniform distribution of air in the water;
-knowing the section of air inlet to water $152 \cdot \frac{\pi}{4} \cdot (0.0001)^2 = 1.19 \cdot 10^{-6} \;\; m^2$, the exact air flow rate into water is known;
- the orifices of Ø 0,1 mm, ensure a working regime in the field of fine bubbles, the air bubbles in the water having Ø = 0.7 mm = 700 μm, are also called “microbubbles” [9] [10];

-the design and construction of this MBG with 0.1 mm orifices required collaboration with ICPE which has equipment's for unconventional technologies:

- EDM processing;
- micro drilling processing.

The pressure losses in the air flow rate calculated in the theoretical researches are much smaller than those of the porous diffusers [11].

3. Measuring equipment's and devices used in experimental installations

For the supply of compressed air the pressure and the temperature of the water and the air high precision devices were used, with digital indication presented below.

The air compression equipment consists of an electro compressor shown in Figure 8.

The Chicago Pneumatic CPRA 24 L20 Compressor is a single-stage reciprocating air compressor, designed and built for semi-professional and professional applications.

The air compressor is equipped with ON / OFF pressure switch, plug power cable, quick-coupling pressure regulator, cylinder pressure gauge and adjustable pressure gauge, safety valve, condensate drain valve, wheels and transport handle.

Chicago Pneumatic CPRA 24 L20 Compressor is an air compressor recommended for semi-professional and professional uses in blowing, inflating wheels, driving small pneumatic tools.

Fig. 8 CHICAGO PNEUMATIC – CPRA 24 L20 Compressor.

The features of this compressor are:
Drive: Electric motor;
Number of pistons: 1;
Number of compression stages: 1;
Suction air flow rate: 222 [dm^3 / min];
Free discharge air flow rate: 156 [dm^3 / min];
Maximum pressure: 8 bar;
Bottle capacity: 24 [dm^3];
Power: 1.5 [kW];

Supply voltage: 230 [V];
Noise level: 97 dB;
Dimensions : 570 x 255 x 590 [mm];
Weight: 25.0 [kg].
Devices for measuring temperature, pressure, air flow rate, dissolved oxygen concentration in water (electrical method) are successively presented.

Air temperature is measured using a digital thermometer (Figure 9), produced by HANNA Instruments, Canada, and consists of a microprocessor that analyzes and displays data received from a temperature sensor.

The device has a scale for measurements between - 50,0 and 150,0 ℃ with a resolution of 0,1 ℃ and an accuracy of ± 0,3 ℃ (between -20 and 90 ℃) / ± 0,5 ℃ (output). The sensor is made of stainless steel with a wire length of 1 m.

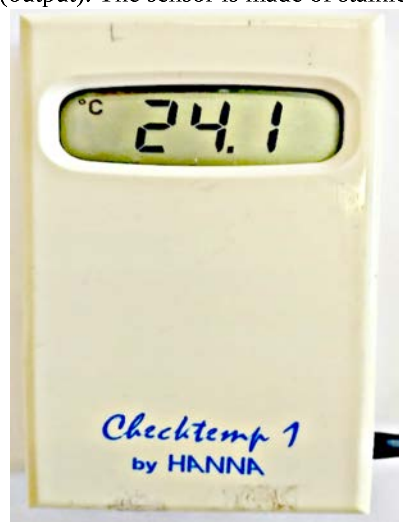

Fig. 9 Checktemp 1digital thermometer.

The pressure at the inlet to the fine bubble generator is measured using digital differential manometers: GDH 07 AN (figure 10.a) and Digitron PM 20 (figure 10.b). It consists of a piezoresistive transducer and an electronic microprocessor with digital display; the devices have a sensitive element of high fineness and precision, of piezoresistive type, which takes over the quantity to be measured and transforms it into electrical quantity. This quantity is passed on to the microprocessor which picks up, processes and displays the electrical signal on the display.

a b

Fig. 10 Digital differential manometers.

Using a rotameter (figure 10), ***the air flow rate*** introduced into the fine bubble generator is measured, the device is based on the movement of a float inside a graduated frustoconical tube, arranged vertically with variable section.
The rotameter is a flow meter with constant pressure difference and rotating float.

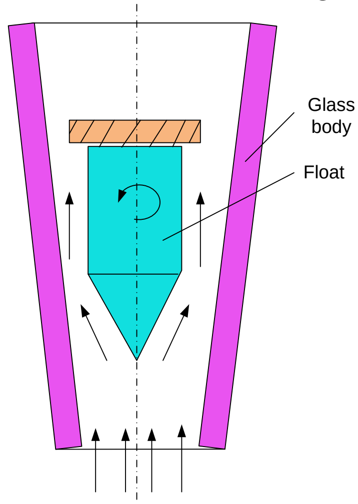

Fig. 11 Digital differential manometers.

Oxygen dissolved in water following the oxygenation process is measured using a polarometer probe oxygenometer. The oxygen meter is manufactured by HANNA Instruments, Canada, and consists of a microprocessor (Figure 12) that establishes the connection with the measuring probe that is inserted into the water through the connecting cable.

Fig. 12 Oxygenometer
1-microprocessor; 2-cable connection; 3-probe body; 4-small cylinder containing the electrolyte solution; Oxygen-permeable 5-Teflon membrane; 6-ampoule with electrolyte solution; 7- temperature sensor.

Figure 13 shows on the left the sketch of the oxygenometer with electronic display, and on the right are presented the construction data of the polarographic probe.

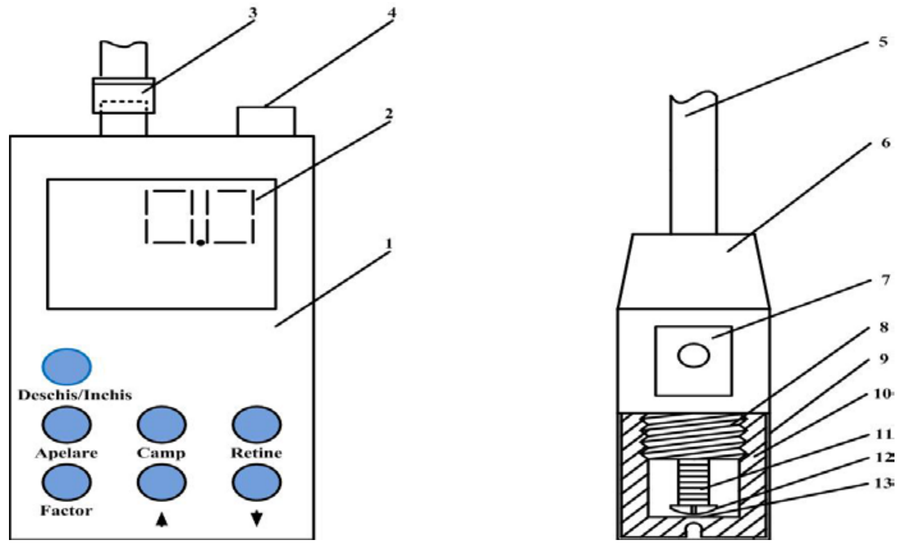

Fig. 13 Oxygenometer and polarographic probe sketch.
1-oxygenometer; 2-electronic display; 3-probe connector; 4-power supply connection; 5-cable probe; 6-probe; 7-temperature sensor; 8-rubber gasket; 9-protective cover; 10-membrane cover; 11- anode (around which there is electrolyte solution); 12-platinum cathode; 13-Teflon permeable membrane to gas

The polarographic probe contains a small contains a small cylinder in which there is an electrolyte solution, two electrodes and a temperature sensor. The base of the cylinder is constructed of a Teflon membrane that is permeable to oxygen.

4. Experimental researches

The scheme of the installation used to carry out the experimental researches is presented in figure 14.

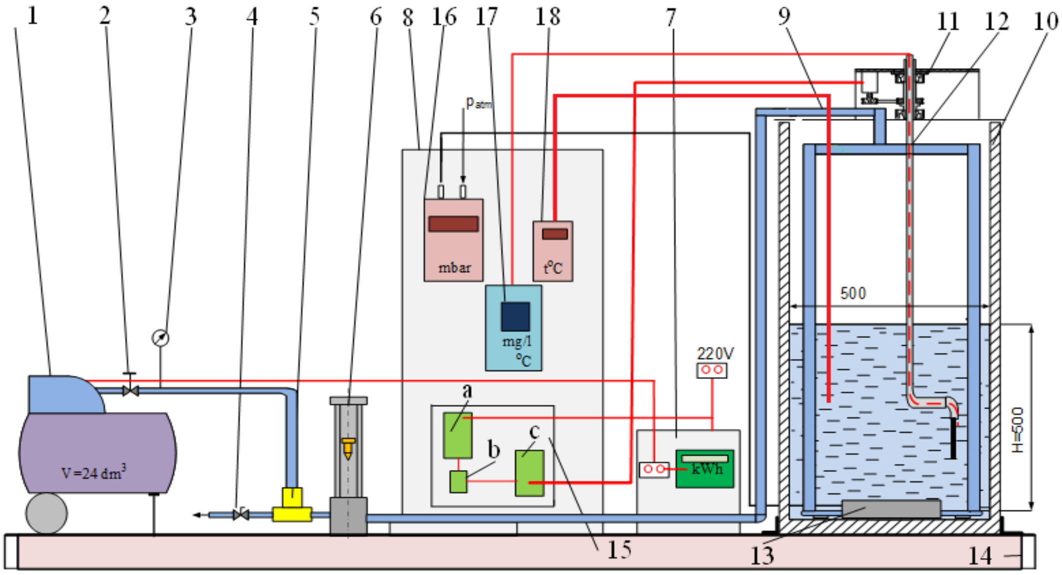

Fig. 14 Scheme of the experimental installation for researches on water oxygenation

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 bubble generator; 10 - water tank; 11 - mechanism of actuation of the probe; 12 - oxygenometer probe; 13 - bubble generator; 14 - support for installation; 15 - control electronics: a - power supply, b - switch, c - control element, 16 - digital manometer; 17 - oxygenometer; 18 - digital thermometer.

Figure 14 shows that, after compressing the air, the air temperature, pressure and flow rate are measured; subsequently it is introduced in MBG with the parameters: $\dot{V} = 600\ dm^3/h$; H = 573 mm H_2O.

The duration of the experiments is 2 hours, during which time the dissolved oxygen concentration in the water increases from C_0 to C_s.

Taking into account the gas volumetric flow rate, an air velocity results through the MBG supply line.

$$\dot{V}_{I,r} = A \cdot w \qquad (19)$$

$$w = \frac{\dot{V}}{A} = \frac{\dot{V}}{\frac{\pi \cdot d_i^2}{4}} = \frac{600 \cdot 10^{-3}}{3600} \cdot \frac{1}{0.785 \cdot (0.012)^2}$$

$$w = 1.474\ m/s$$

As a result, the Reynolds number is $Re = \frac{w \cdot d_i}{\upsilon} = \frac{1.474 \cdot 0{,}012}{16 \cdot 10^{-6}} = 1105.5$, so the theoretical flow regime is laminar.

During the experimental researches, the following values are kept constant: gas pressure at the entrance to the MBG, gas flow rate, hydrostatic load.

At an interval of 15 minutes the air supply to the MBG is interrupted and the oxygenometer probe (7) is inserted; the signal taken from the probe is processed in the microcomputer and digitally displayed on the microcomputer screen.

The operation of the MBG of rectangular shape with 152 orifices with a diameter of Ø 0.1 mm is shown in figure 15.

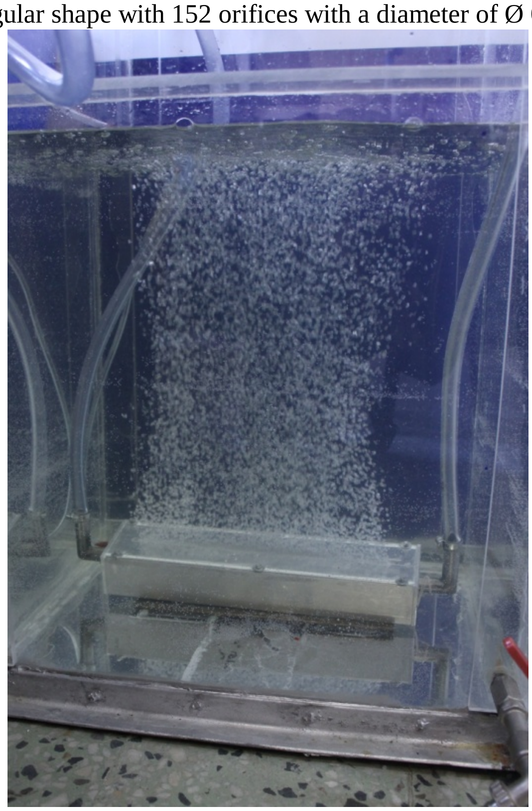

Fig. 15 Microbubble generator with 152 orifices Ø 0.1 mm in operation.

The microbubble generator is equipped with a perforated plate with orifices of Ø 0.1 mm made by micro-drilling [12] [13]. Figure 16 shows on the right side the transparent plastic tank in which the oxygenometer probe is inserted. In the central area of figure 15 there is a panel with devices: thermometer, manometer, oxygenometer.

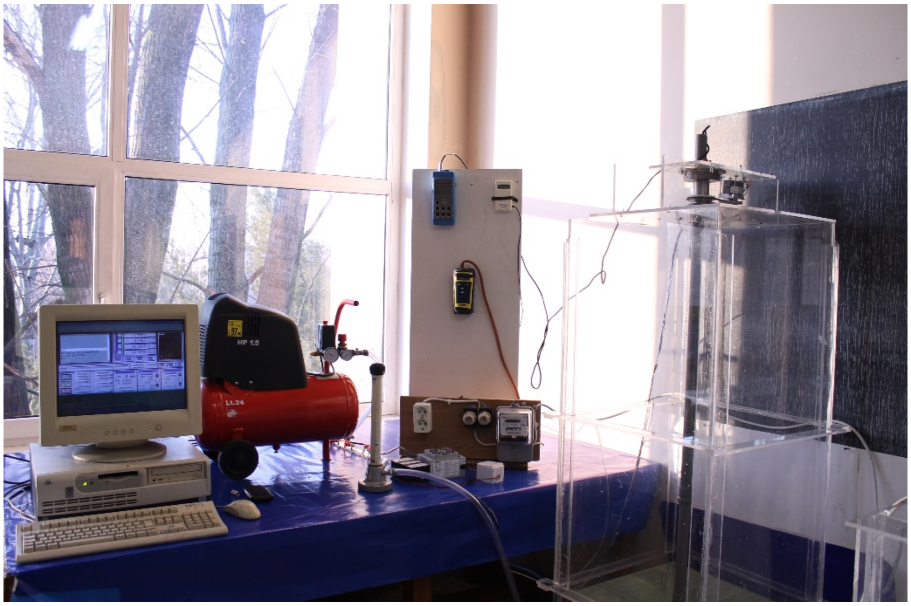

Fig. 16 Overview of the experimental installation for the introduction of atmospheric air.

To the left of Figure 15 is a computer, an electro compressor, a rotameter.
Carrying out the measurements involves the following steps:
1. Check that the 152 orifices are working, i.e., air is introduced into the microbubble generator (MBG);
2. Fill the tank with water up to H = 500 mm H_2O;
3. Measure C0, t_{H2O}, t_{air};
4. Insert the MBG and note the time (τ);
5. Every 15 minutes, remove the MBG microbubble generator. outside the tank and measure the dissolved oxygen concentration;
6. When a horizontal level of the function C = f (τ) is reached, the measurements stop with the condition: $C \approx C_s$;
7. From previous researches [14][15][16][17], the dissolved oxygen concentration in water tends to saturate after two hours. So, the measurement of the oxygen concentration will be performed at the times: 15 minutes; 30 minutes; 45 minutes; 60 minutes; 75 minutes; 90 minutes; 105 minutes; 120 minutes.
8. At the end of the measurements, clean the oxygenometer probe and drain the water from the tank.

5. Experimental obtained results

Following the measurements, the data in Table 1 were obtained.

Table 1. Concentration values as a function of time

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 data in table 1, the graph in figure 17 was drawn.

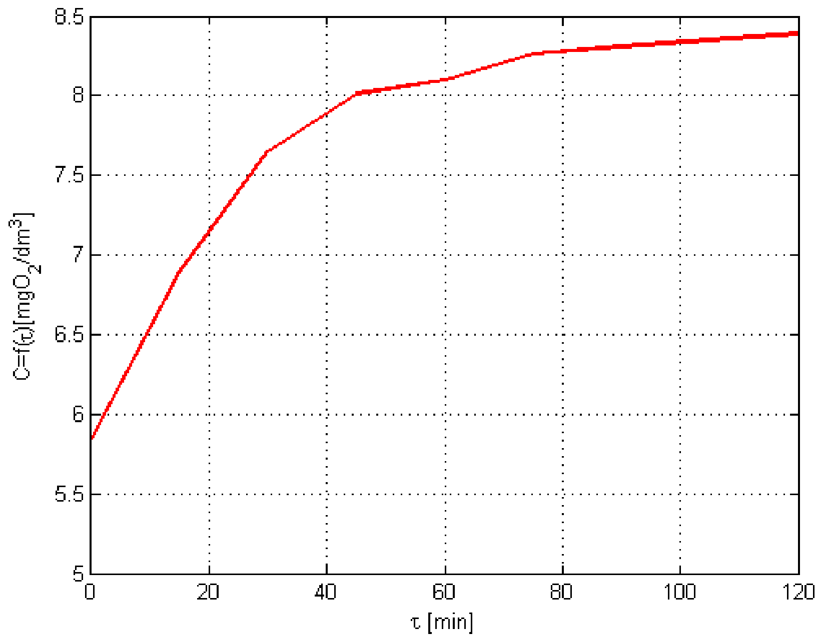

Fig. 17 Variation in the dissolved oxygen concentration in the water in time.

These results are in good agreement with those theoretically obtained.

6. Conclusions

- It is obvious that the specialized papers promote the idea of forming air bubbles with the smallest diameter; this leads to an increase in the dissolved oxygen concentration in the water.
- The constructive solution proposed in the paper for a bubble generator with a diameter of 0.1 mm generates a new possibility to attack the "nm" range, i.e., 10^{-9} m.
- Subsequent researches will focus on the development of fine air bubble generators with a diameter of the order of nanometers.

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