

# Researches on increasing the dissolved oxygen concentration in stationary waters

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**Abstract.** This paper presents a way to solve the transfer rate equation of oxygen in water. After running a calculation program, the graph of the function that indicates the increase of the dissolved oxygen concentration in the water as a function of time is plotted. Constructed in an original manner, the experimental installation allows the measurement of the increase of the dissolved oxygen concentration in water. The experimental obtained results are compared with the theoretically obtained data.

## 1 Introduction

The oxygen quantity that is dissolved in water is a function depending on salinity, the temperature and the pressure [1].

Hot water has less O<sub>2</sub> than cold water, salt water contains less O<sub>2</sub> than fresh water, and lower-pressure water has less oxygen than high-pressure water. Recommended dissolved O<sub>2</sub> degree for fishes is from 5.0 mg / dm<sup>3</sup> to 9.0 mg / dm<sup>3</sup>. In the case that the dissolved O<sub>2</sub> degree is under 3.0 mg / dm<sup>3</sup>, due to lack of oxygen, the fishes can die. If the dissolved oxygen level is over 9.0 mg/dm<sup>3</sup>, it can also be deadly to fishes.

Figure 1 shows that O<sub>2</sub> can be:

- O<sub>2</sub> bound to H<sub>2</sub>O
- free oxygen, namely: oxygen dissolved in water.

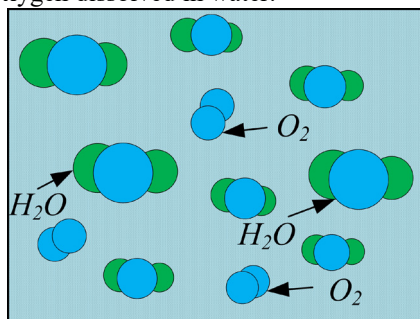


Fig. 1. The O<sub>2</sub> molecules dissolved in water.

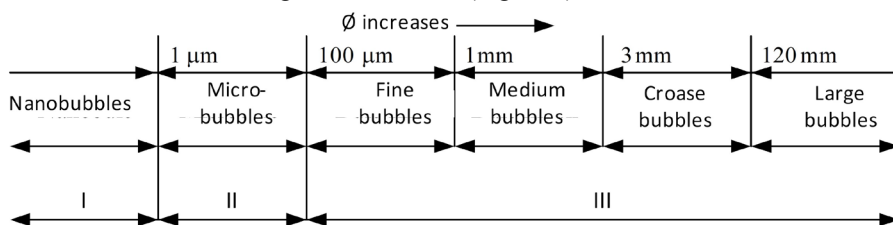
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The oxygen solubility in water is a function depending on the atmospheric pressure, the temperature, water turbulence and the magnitude of the air-water area.

Each water type source has its own biological and physicochemical specific features and differ from one area to another according to the composition of the minerals in the covered region, the contact duration, the temperature and the climatic regime.

The method of oxygenation of water is made on the basis of the transfer between air and water; from the air, oxygen is transferred through various methods. The air bubbles emitted by a system that forms it are placed in a water tank. Water oxygenation systems that generate very fine air bubbles are the most effective. From the literature [2] [3], it is known that the rate of O<sub>2</sub> transfer to water is higher as the diameter of the air bubbles decreases; the diameter of the air bubble depends on the diameter of the orifice in the perforated plate of a FBG.

The air bubbles can be arranged in as follows (Figure 2):



**Fig. 2.** Gas bubbles classification in function of Ø:

- I - the region where the air bubbles can be seen under a microscope;
- II - the region where the air bubbles are difficult to see;
- III - the region where the air bubbles can be seen with the naked eye.

The performance of a water oxygenation system is specified by the following two parameters [4][5]:

- the water oxygenation efficiency;
- the water oxygenation efficiency.

The method of aeration (oxygenation) of water is a fundamental field of Technical Thermodynamics, a discipline materialized by teaching the following courses: Mass and heat transfer, Gas Dynamics, Technical Thermodynamics.

## 2 Solving the oxygen transfer rate equation

In water oxygenation method, the temperature influences both the oxygen conditions, the dissolved O<sub>2</sub> saturation concentration and the mass transfer coefficient. The saturation concentration values are directly influenced by the water temperature [6].

The dissolved O<sub>2</sub> transfer rate in water depending on the temperature is given by the relation [7]:

$$\frac{dC}{d\tau} = (a \cdot k_L)_{20^{\circ}} \cdot (C_s - C) \quad [kg / m^3 s] \quad (1)$$

where:

- $a \cdot k_L$  – the transfer coefficient of the oxygen [s<sup>-1</sup>];
- $C_s$  – the mass oxygen concentration at saturation [kg / m<sup>3</sup>];
- $C$  – the current mass concentration of the O<sub>2</sub> [kg / m<sup>3</sup>].

After integrating relation 1 applying the limit condition  $C = C_0$  for  $\tau = 0$ , it results [6], [7]:

$$\frac{dC}{C_s - C} = a \cdot k_L \cdot d\tau \quad (2)$$

In the hypothesis that  $C < C_s$ , after performing the integration, it results:

$$-\ln(C_s - C) = a \cdot k_L \cdot \tau + ct \quad (3)$$

From the limit condition, the constant C is obtained:

$$C = C_0 \text{ when } \tau = 0 \quad (4)$$

resulting:

$$ct = -\ln(C_s - C_0) \quad (5)$$

Introducing 5 in 3 one can obtain:

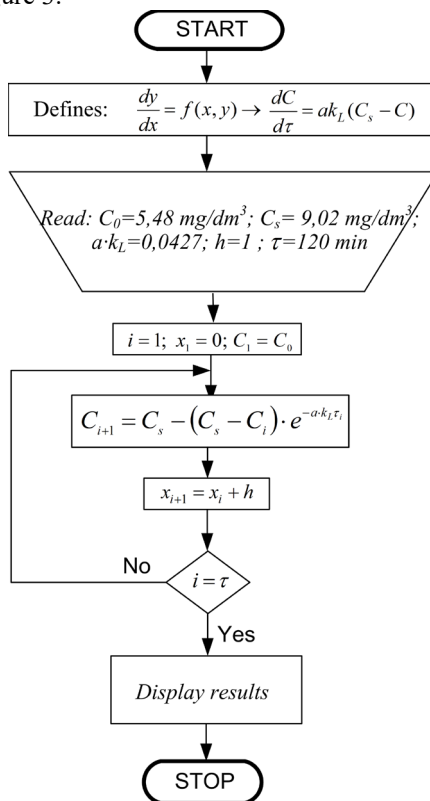
$$-\ln(C_s - C) = a \cdot k_L \cdot \tau - \ln(C_s - C_0) \quad (6)$$

From relation (6) one can obtain:

$$C = C_s - (C_s - C_0) \cdot e^{-a \cdot k_L \cdot \tau} \quad (7)$$

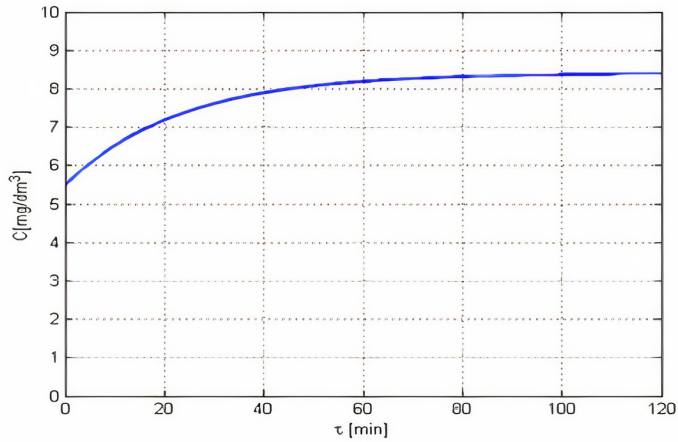
In equation (7), the following must be known:  $C_0, C_s, a, k_L$ .

For the determination of the values of  $C = f(\tau)$ , a computation program [8], [9] was elaborated, presented in figure 3.



**Fig. 3.** Logical computation scheme for determining the change of the dissolved  $O_2$  concentration.

After executing a calculation program (fig. 3), numerical values were obtained based on which, the curve in figure 4 was drawn.



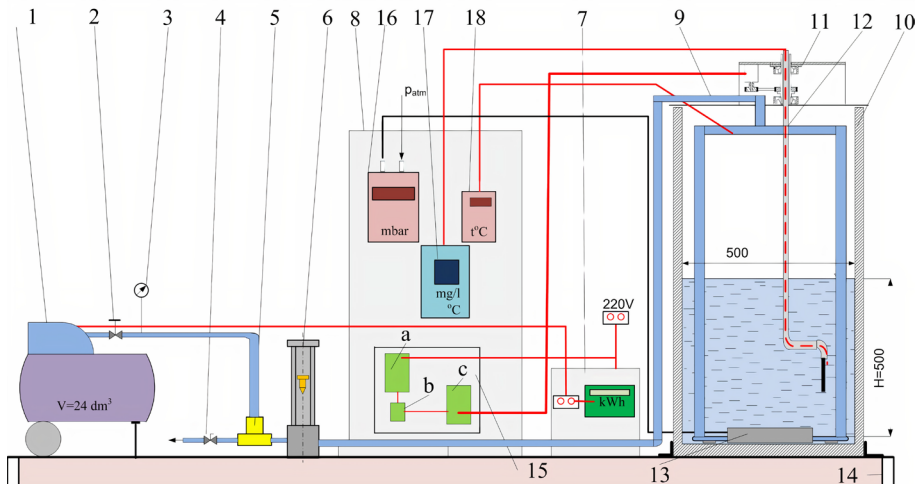
**Fig. 4.** The variation of the dissolved  $O_2$  concentration.

The main data that are maintained in the case of experimental researches are:

- the air flowrate:  $\dot{V} = 600 \text{ dm}^3/\text{h}$ ; the inlet air pressure in the fine bubble generator:  $p = 573 \text{ mmH}_2\text{O}$ ; hydrostatic load:  $H = 500 \text{ mmH}_2\text{O}$ ; duration of the experience:  $\tau = 120 \text{ min}$ ;  $C_0 = 5.84 \text{ mg} / \text{dm}^3$ ;  $t_{\text{H}_2\text{O}} = 23.7^\circ\text{C} \rightarrow C_s = 9.02 \text{ mg} / \text{dm}^3$ .

### 3 The presentation of the experimental installation

In figure 5 one can see the sketch of the experimental installation for measuring the concentration of the dissolved  $O_2$  in water, in time.



**Fig. 5.** Scheme of the experimental stand for researches related to water oxygenation

- 1 - electrocompressor with air reservoir; 2 - pressure reducer; 3 - pressure gauge; 4 - connection for evacuating air outside; 5 - T-bend; 6 - flowmeter; 7 - electrical instrument panel; 8 - gauge board; 9 - piping for transporting compressed air to the fine bubble generator; 10 - water tank; 11 - machinery of actuation of the probe; 12 - oxygenometer probe; 13 - fine bubble generator with orifices  $\varnothing 0.1 \text{ mm}$ ; 14 - installation support; 15 - indicator; a - main inlet, b - interruptor, c - pilot cell; 16 - digital pressure gauge; 17 - oxygenometer; 18 - digital thermometer.

The air compressed by the electrocompressor (1), traverseth the flowmeter (6) and subsequently goes into the FBG (13).

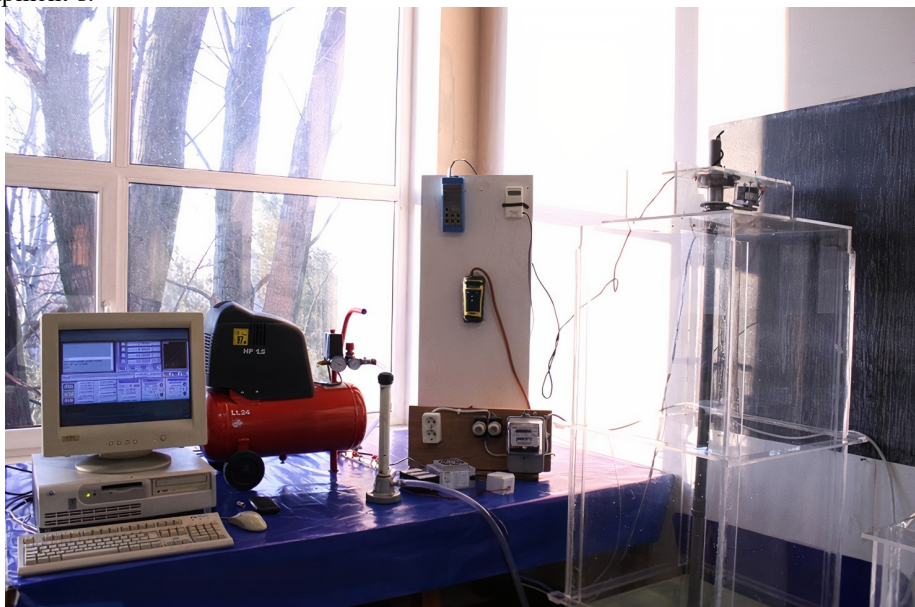
During the experiment, the following were measured: air flow rate, air pressure and the concentration of the dissolved oxygen in water.

The experimental installation (figure 5) comprises a series of devices mounted on the panel (8):

- digital thermometer with high accuracy, with thermistor sensor;
- differential pressure gauge, supplied with a piezoresistive transducer;
- oxygenometer with polarographic probe and microprocessor with digital board.

The electromechanical machinery for actuating the oxygenometer probe (11), (12), is supplied with a pecker motor; this machinery admits the cycle of the oxygenometer probe in the water mass, with a speed of 0.38 m/s [10][11].

Figure 6 shows an overview of the experimental stand, designed and constructed in the Laboratory of the Department of Thermotechnics, Engines, Thermal and Refrigeration Equipment's.



**Fig.6.** Overview of the experimental stand for studying the increase of the dissolved O<sub>2</sub> concentration.

One can observe that on the leftwards of the image (figure 6), there is a computer that controls the actuation machinery of the oxygenometer probe; next to the computer is an electro-compressor with a compressed air tank and the devices panel. To the right of the image, is the water tank, made of clear plexiglass.

## 4 Experimental researches, obtained results

The steps to be followed in experimental researches are the following:

1. Introduce compressed air into the fine bubble generator and observe if the 152 orifices with  $\varnothing 0.1\text{mm}$  are not blocked;
2. The tank is filled with water ( $H = 500\text{ mmH}_2\text{O}$ ) and measure  $t_{\text{H}_2\text{O}}$ ,  $C_0$ ,  $t_{\text{air}}$ ;
3. The FBG (fine bubble generator) is introduced in water and the time at which the experience is measured;

4. Introduce compressed air into the FBG and after 15 minutes pull out the FBG from the tank and insert the oxygenometer probe. This operation is performed every 15 minutes, until  $\tau = 120$  minutes is reached;

5. From previous researches [12][13][14], it was found that after a time of  $\tau = 120$  minutes, the value of  $C_0$  tends to  $C_s$ ;

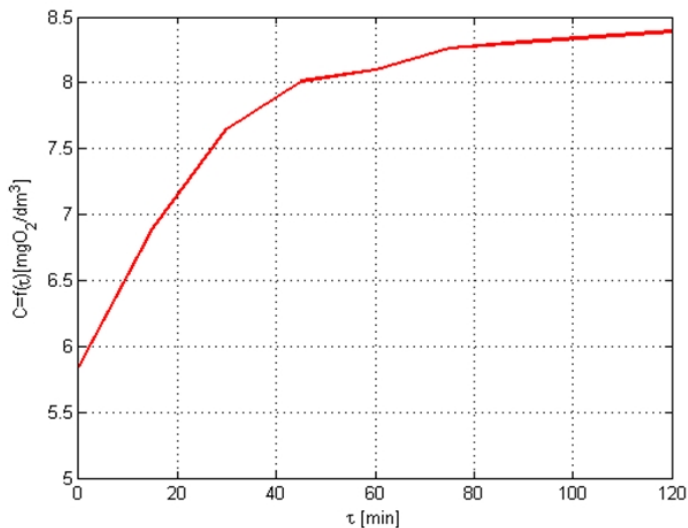
6. Finally, clean the oxygenometer probe and drain the water.

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

**Table 1.** The values of dissolved  $O_2$  concentration in water, in time.

|                                     |      |      |      |      |      |      |      |      |      |
|-------------------------------------|------|------|------|------|------|------|------|------|------|
| $\tau$ [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  |
| $\dot{V}_{IO_2} = 126$ [ $dm^3/h$ ] | 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    |
| $t_{H_2O}$ [ $^{\circ}C$ ]          | 23.7 | 23.7 | 23.7 | 23.7 | 23.7 | 23.7 | 23.7 | 23.7 | 23.7 |
| $t_{air}$ [ $^{\circ}C$ ]           | 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 |

In conformity with the data in table 1, the curve from figure 7 was drawn.

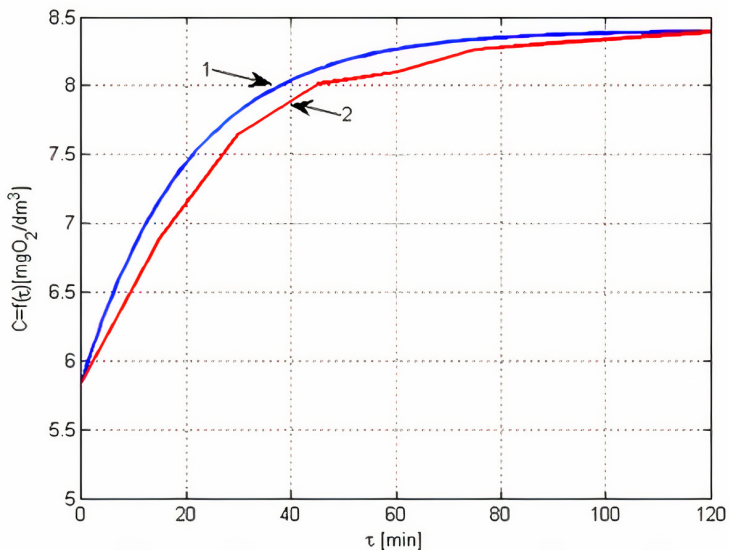


**Fig. 7.** The  $C = f(\tau)$  function.

From figure 7, one can observe that, with the passage of time the value of  $C_0$  tends to  $C_s$ .

Figure 8 compares the modification of the dissolved  $O_2$  concentration in water in the two cases:

- 1- graph plotted according to the theoretical data;
- 2- graph plotted according to the experimental data.



**Fig. 8.** The modification of the dissolved O<sub>2</sub> concentration.

Figure 8 shows a good coincidence of the two graphs, which demonstrates the accuracy and rigor of theoretical and experimental researches.

## 5 Conclusions

1. In the paper, the differential equation of the oxygen transfer rate in water was solved, by numerical integration.
2. A computation program was performed and the curve  $C = f(\tau)$  was drawn; the theoretical results are similar to those obtained in other papers on the field of study.
3. The paper presents an original installation, designed and built into see the change in the dissolved O<sub>2</sub> concentration in water.
4. Experimental researches has demonstrated the accuracy of theoretical calculations; for the graphs  $C = f(\tau)$ , the difference between theoretical and experimental values is small.

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