Researches Regarding the Modification of Dissolved Oxygen Concentration in Water

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Abstract

The paper presents the influence of a liquid temperature (tap water) on the dissolved oxygen concentration. The equation that determines the variation speed of dissolved oxygen concentration in the water is integrated using implicit Runge-Kutta method. The study presents the theoretical and experimental results conducted on a laboratory installation equipped with modern measurement devices.

Keywords: *Water oxygenation, Fine bubble generator.*

1. Introduction

The water oxygenation consumes from 50% to 90% of the total energy of a secondary wastewater treatment plants [1]. Systems development of immersed fine bubble oxygenation has accelerated; it has a higher efficiency of oxygen transfer towards many other oxygenation systems [2].

Studies in the literature [3] showed that fine bubble oxygenation devices could save 50% of energy compared with coarser bubble diffusers.

The size of formed bubbles depends on the flow and pressure in the distribution pipe and on the orifice of their release [4][5].

The general problem of the equipment based on the dispersion of a gas in water is to produce small air bubbles, in economically way.

Introducing air into a volume of water can be achieved mechanical or pneumatically [6].

Fine bubble generators (FBG) must ensure a uniform dispersion of gas throughout the liquid mass in order to be mixed and at the same time to provide, the necessary oxygen for carrying out chemical or biological processes that takes place in the respective basin.

For achieving plates with orifices of FBG, recent studies [7] lead to the use of advanced nonconventional technologies, namely, spark erosion processing.

2. Solving the equation that determines the speed of dissolved oxygen concentration in water

The differential equation of first order, which defines the transfer speed of the O_2 from air in stationary water, is [8]:

$$\frac{dC}{d\tau} = ak_L\left(C_s - C\right)\left[\frac{kg}{m^3}\cdot\frac{1}{s}\right] \qquad (1)$$

where: $dC/d\tau$ – the transfer speed of dissolved oxygen in water; ak_L – volumetric mass transfer coefficient [s^{-1}]; C_s – mass concentration of oxygen in water at saturation [kg/m^3]; C – current mass concentration of oxygen in water [kg/m^3].

To solve this equation (1), the implicit scheme of Runge-Kutta numerical method is applied, that in xOy plan has the form [9]:

$$\begin{cases} y_{i+1} = y_i + \dfrac{\Delta x}{2}\left(\Delta y_1 + \Delta y_2\right) \\[2mm] \Delta y_1 = f\left(x_i + \left(\dfrac{1}{2}+\dfrac{\sqrt{3}}{6}\right)\Delta x,\, y_i + \dfrac{1}{4}\Delta y_1 + \left(\dfrac{1}{4}+\dfrac{\sqrt{3}}{6}\right)\Delta y_2\right) \\[2mm] \Delta y_2 = f\left(x_i + \left(\dfrac{1}{2}-\dfrac{\sqrt{3}}{6}\right)\Delta x,\, y_i + \left(\dfrac{1}{4}-\dfrac{\sqrt{3}}{6}\right)\Delta y_1 + \dfrac{1}{4}\Delta y_2\right) \end{cases} \qquad (2)$$

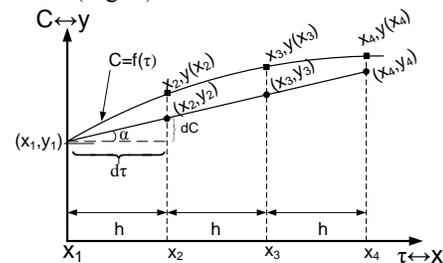In the case of equation (1), the mass concentration C is y and time τ is x (Fig. 1).

Fig. 1 Numerical integration of the ordinary differential equation (1)
Computing notations: ■ – points placed on the curve $C=f(\tau)$; ● – points placed on the integral curve. $(x_1,y_1)\rightarrow(0,C_1)$; $(x_2,y_2)\rightarrow(0,C_2)$

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If the variables are replaced, x with τ and y with C, from the equations system (2), is obtained:

$$C_{i+1} = C_i + \frac{\Delta\tau}{2}(\Delta C_1 + \Delta C_2) \tag{3}$$

$$\Delta C_1 = f\left(\tau_i + \left(\frac{1}{2} + \frac{\sqrt{3}}{6}\right)\Delta\tau, C_i + \frac{1}{4}\Delta C_1 + \left(\frac{1}{4} + \frac{\sqrt{3}}{6}\right)\Delta C_2\right) = \tag{4}$$

$$= ak_L\left(C_s - \left(C_i + \frac{1}{4}\Delta C_1 + \left(\frac{1}{4} + \frac{\sqrt{3}}{6}\right)\Delta C_2\right)\right)$$

$$\Delta C_2 = f\left(\tau_i + \left(\frac{1}{2} - \frac{\sqrt{3}}{6}\right)\Delta\tau, C_i + \left(\frac{1}{4} - \frac{\sqrt{3}}{6}\right)\Delta C_1 + \frac{1}{4}\Delta C_2\right) = \tag{5}$$

$$= ak_L\left(C_s - \left(C_i + \left(\frac{1}{4} - \frac{\sqrt{3}}{6}\right)\Delta C_1 + \frac{1}{4}\Delta C_2\right)\right)$$

Through successive solving of the equations (3 ... 5) the dissolved oxygen concentration C_{i+1} can be found at any point in the interval $[\tau_{max}\ \tau_0]$, where the $\tau_0 = 0$, the initial concentration of dissolved oxygen is C_0. After performing a computer program the function C = f (τ) graph is obtained.

3. Theoretical studies regarding the influence of tap water temperature on the dissolved oxygen concentration

The determination of the temperature influence was performed using tap water from the Laboratory of Thermodynamics, Engines, Thermal and Refrigeration Equipment Department. The water was heated from 24 ℃ to 30 ℃ with an electrical resistor of 1200 W power.
In order to achieve theoretical researches there were chosen two situations regarding the tap water:
1- t=24 ℃; C_0 =3,12 mg/ dm^3; C_s =8,3 mg/dm^3;
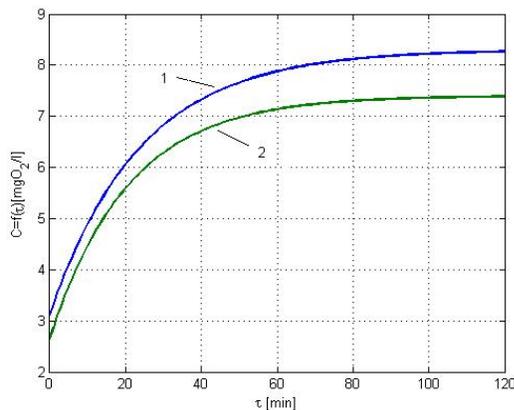2- t=30 ℃; C_0 = 2,65 mg/ dm^3; C_s = 7,4 mg/ dm^3.

Fig. 2 The variation of dissolved O$_2$ concentration in tap water function of time: C=f(τ)
1 - theoretical results for tap water at the temperature t= 24°C,
2 - theoretical results for tap water at the temperature t= 30°C

Figure 2 shows the variation curves of dissolved O$_2$ concentration in water function of time for tap water at the temperature of 24 °C (curve 1) and at the temperature of 30 °C (curve 2).

4. The description of the experimental stand

The research aim is to validate or not the theoretical results previously obtained.
The experimental stand is composed of [10]:
- Compressor, to produce compressed air with the following operating parameters: maximum discharge pressure p = 8 bar, aspirated flow rate = 200 dm^3/min, operating temperature t = -10^{0}C ÷ 100 ^{0}C, electric motor power P = 1.1 kW at rpm n = 2850 rpm/min, tank volume (V = 24 dm^3).
The compressor is equipped with a manometer 0-16 bar to show the pressure in the tank compressor and a pressure reducing valve for the establishment of the pressure in the piping system.
- Air pipes for the delivery of the compressed air, made of plastic, with the inner diameter of Ø15mm and a wall thickness of 2 mm; these supplies the fine bubble generator with air and ensures the evacuation of the excess air supplied by the compressor to the atmosphere.
- The aeration tank constructed of Plexiglas plates with thickness of 5 mm, having the dimension, 0.5×0.5×1.5(W × L × h).
- Fine bubble generator which consists of elements to connect to the compressed air pipe, the generator body and an element to dispersion of air into the water mass.
The sketch of the stand used for performance of experimental researches is presented in Figure 3.
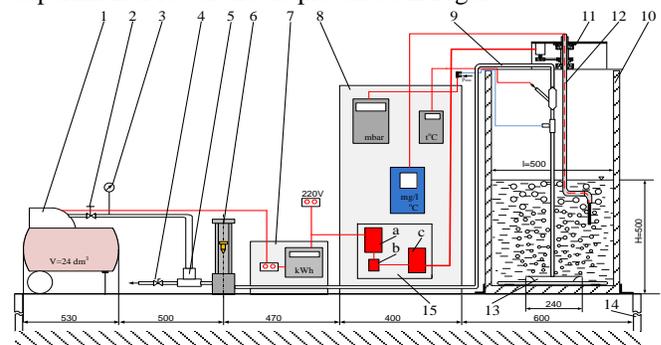

Fig. 3 Sketch of the experimental setup for researches regarding water oxygenation
1– electro compressor with air tank; 2– pressure reducer; 3–manometer; 4–union for air exhaustion in the atmosphere; 5– T-joint; 6– rotameter; 7– electrical board; 8– measurement device panel; 9– pipe for the transport of the compressed air to the FBG; 10– water tank; 11– mechanism for the actuation of the probe; 12– oxygen meter probe; 13– FBG; 14– plant holder; 15–control electronics: a– supply unit, b- switch, c- control element

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During the measurement, the pressure of the compressed air and the air flow were measured, these values were kept constant in time.

5. Experimental research regarding the influence of tap water temperature on the dissolved oxygen concentration

The experimental measurements for the determination of the influence of water temperature on the efficiency of oxygenation processes were performed in a rectangular plexiglass tank having a height of 1.6 m and a width of 0.5 m shown in Fig. 3. The tank was filled with water having a temperature of 24 °C for the first set of measurements at 30 °C for the second set of measurements. In the table, on columns, was noted: 1- the number of measurement, 2- oxygenation time [min], 3- dissolved oxygen concentration in water at FBG testing [mmH$_2$O], 4- air pressure entering the FBG [mbar], 5- intake air pressure in the FBG [mmH$_2$O], 6- supply air volumetric flow rate in the FBG [dm^3/h], 7-pressure drop on FBG [mmH$_2$O], 8- hydrostatic load [mmH$_2$O].

Table 1: The values of the measured variables for t_{H2O}= 24 °C

1	2	3	4	5	6	7	8
No	τ	C	p	p	$\dot{V}$	Δp	H
0	0	3,12	57,2	583,44	600	20,44	500
1	15	4,85	57,2	583,44	600	20,44	500
2	15	5,95	57,2	583,44	600	20,44	500
3	15	6,92	57,2	583,44	600	20,44	500
4	15	7,45	57,2	583,44	600	20,44	500
5	15	7,77	57,2	583,44	600	20,44	500
6	15	7,89	57,2	583,44	600	20,44	500
7	15	8,12	57,2	583,44	600	20,44	500
8	15	8,23	57,2	583,44	600	20,44	500

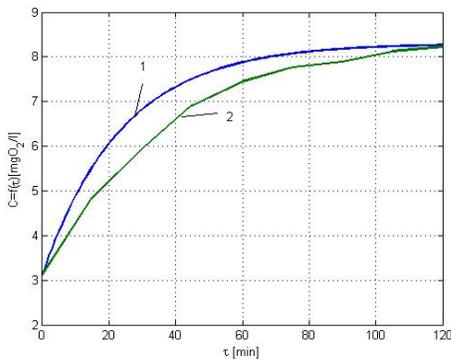Based on the data from Table 1, the curve (2) of Figure 4 is plotted.

Fig. 4 The variation of dissolved O$_2$ concentration in tap water: C=f(τ)
1 - theoretical results for tap water at t= 24°C,
2 - experimentally determined values for tap water at t=24°C

In Table 2 are listed the results of the experimental measurements made on the tap water at 30 °C.

Table 2: The values of the measured variables for t_{H2O}= 30 °C

1	2	3	4	5	6	7	8
No	τ	C	p	p	$\dot{V}$	Δp	H
0	0	2,65	57,2	583,44	600	20,44	500
1	15	4,25	57,2	583,44	600	20,44	500
2	15	5,55	57,2	583,44	600	20,44	500
3	15	6,16	57,2	583,44	600	20,44	500
4	15	6,72	57,2	583,44	600	20,44	500
5	15	7,15	57,2	583,44	600	20,44	500
6	15	7,25	57,2	583,44	600	20,44	500
7	15	7,30	57,2	583,44	600	20,44	500
8	15	7,35	57,2	583,44	600	20,44	500

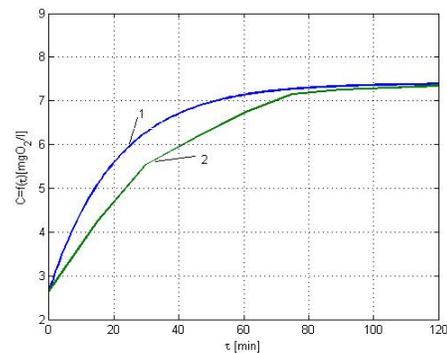Based on the data from Table 2, the curve (2) of Figure 5 is plotted.

Fig. 5 The variation of dissolved O$_2$ concentration in tap water: C=f(τ)
1 - theoretical results for tap water at the temperature t= 30°C,
2 - experimentally determined values for tap water at the temperature t=30°C

Theoretical and experimental curves are similar, which means a good coincidence between theory and practice. If the experimental research results are plotted on the same diagram (Fig. 6) is observed that the values of the dissolved O$_2$ concentration in water at 24 °C are higher.
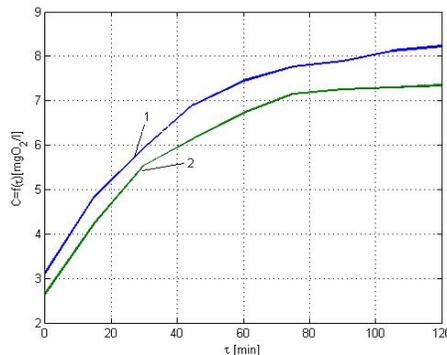

Fig. 6 Experimental research results
1- C=f(τ) for t$_1$=24 ℃; 2- C=f(τ) for t$_2$=30 ℃

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Oxygen transfer rate is higher in the first few minutes of the oxygenation of water with a temperature of 30 °C because the initial concentration is lower than in the case of water with a temperature of 24 °C.

5. Oxygenation process efficiency

The oxygenation process efficiency indicates the percentage of oxygen transferred to the water of the total amount of oxygen (about 21% of the amount of atmospheric air) introduced into the water mass.

Oxygenation efficiency is given by the equation [10]:

$$\eta_{ox} = \frac{V}{\dot{m}_{O_2}} \cdot \frac{dC}{d\tau} \cdot 100 \ [\%] \qquad (6)$$

where: $dC/d\tau = w$ – transfer speed of the dissolved oxygen $[kgO_2/m^3 s]$; V – water volume subjected to oxygenation $[m^3]$; $\dot{m}_{O_2}$ – flow rate of the oxygen introduced in water [kg/s];

$$\dot{m}_{O_2} = \rho_{O_2} \cdot \dot{V}_{O_2} \quad [kg/s] \qquad (7)$$

$\dot{V}_{O_2}$ – oxygen volumetric flow rate $[m^3/s]$; ρ_{O_2} – oxygen density $[kg/m^3]$.

Introducing the equation (1) and equation (7) into equation (6) results:

$$\eta_{OX} = ak_L(C_s - C)\frac{V}{\rho_{O_2} \cdot \dot{V}_{O_2}} \cdot 100 [\%] =$$
$$= ak_L(C_s - C)\frac{V}{\dot{V}_a \cdot \alpha_0 \cdot \rho_{O_2}} \cdot 100 \ [\%] \qquad (8)$$

where: α_0 - the percentage of O_2 of instilled air; $\dot{V}_a$ – air volumetric flow rate $[m^3/s]$.

In literature [10] there is a simple relation:

$$\eta_{ox} = \frac{8,4H(C_s - C)}{\alpha_0} \qquad (9)$$

where: H - is the water depth, H = 0.5 m.

Replacing in equation (9), successively, for the two cases, over the entire process, is obtained:

$$\eta_{OX,24°C} = \frac{8,4 \cdot 0.5(8.23 - 3.12)}{21} = 1.022 \ [\%] \qquad (10)$$

$$\eta_{OX,30°C} = \frac{8,4 \cdot 0.5(7.35 - 2.65)}{21} = 0.94 \ [\%] \qquad (11)$$

It is found that $\eta_{OX,24°C} > \eta_{OX,30°C}$.

6. Conclusions

- For the tap water at $t_1 = 24$ °C the value of C increases from $C_{0,24 °C} = 3.12$ mg/dm^3 to $C_{s, 24 °C} = 8.3$ mg/dm^3 in 120 minutes.

- For the tap water at $t_2 = 30$ °C the value of C increases from $C_{0,30 °C} = 2.65$ mg/dm^3 to $C_{s, 30 °C} = 7.4$ mg/dm^3 in 100 minutes, although $C_{0,30 °C} < C_{0,24 °C}$.

- So, with the increase of initial temperature of the liquid, the initial concentration of dissolved oxygen decreases and the value of C_s is reached in a shorter time.

- The oxygenation process efficiency is more favorable when the initial temperature of the water is lower.

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