Choosing an Economical Solution for Water Aeration

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Abstract: *The paper presents four versions for increasing the concentration of dissolved oxygen in water:*
I - Introduction of atmospheric air,
II - Introduction of atmospheric air and oxygen from a cylinder in certain proportions,
III - Introduction of a low nitrogen gas (95% O_2 *+ 5%* N_2*),*
IV - Introduction of atmospheric air and ozone produced by an ozone generator.
Following some calculations, the most economical version was chosen, namely version III.

Keywords: *Water aeration, water oxygenation, energy consumption, dissolved oxygen concentration.*

1. Introduction

Aeration of water can be achieved by agitation at the surface (generally performed by mechanical aerators) by introducing air at the base of the tank, lake, etc. (aeration by pneumatic installations) or by spraying air with a device to allow the exchange of oxygen at the surface and the release of harmful gases. Thus, the aeration process can be performed, depending on the dispersion mode, with the help of [1] [2]:
a) Mechanical aeration installations;
b) Pneumatic aeration installations;
c) Mixed aeration installations
Initially, the aeration of the waters was ensured by mechanical aeration installations. Atmospheric air was introduced into the liquid mass by agitation at the surface of the water. In recent years, emphasis has been placed on the development of new methods of water aeration [3] [4].
Mechanical aeration systems are mechanical aggregates that provide hydrodynamic movements to disperse water in drops or films, in order to obtain a contact surface, as large as possible, between water and atmospheric air, and which homogenizes dissolved oxygen in the water mass [5] [6].
According to the location of the active organ, mechanical aeration systems are classified in [5]:
a) mechanical surface aeration installations (mechanical aerators with slow or fast rotor and vertical axis, aeration brushes);
b) medium depth mechanical aeration installations at which the active organ is located at a depth of 1 ... 2 m from the static water level in the tank;
c) mechanical deep aeration installations with the rotor located at about 4 ... 6 m from the static water level.

2. Installations for the introduction of gas mixtures into water

2.1 Version I: Installation for the introduction of atmospheric air into water

The installation for blowing atmospheric air into water is shown in Figure 1.

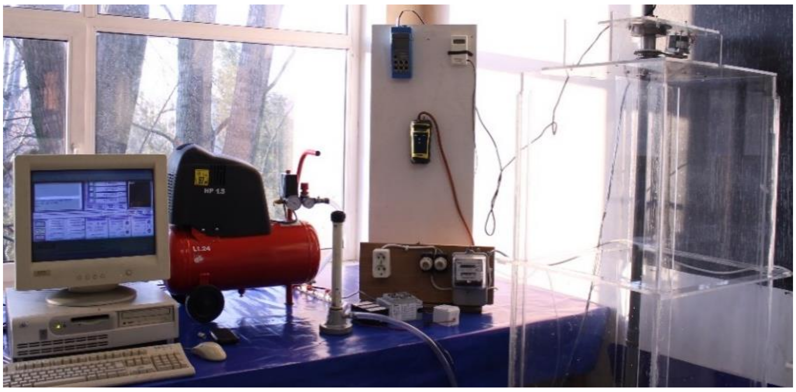

Fig. 1. Overview of the experimental installation for the introduction of atmospheric air

On the left side of figure 1, there is a computer, an electro compressor and a rotameter.

2.2 Version II: Installation for the introduction of a mixture of atmospheric air and oxygen from a cylinder

In figure 2 are distinguished:
- On the left is a computer and the electric compressor with the air tank;
- In the centre one can see the oxygen cylinder provided with pressure reducer and manometer;
- On the right is the transparent plexiglass parallelepiped tank.

Fig. 2. Overview of the experimental installation for the introduction of a mixture of gases (atmospheric air and oxygen)

Two hoses are inserted into the tank through which the microbubble generator (MBG) with a mixture of air and oxygen. The air flow rate and oxygen flow rate are measured separately with a rotameter; the air and oxygen are mixed in a mixing chamber and then the mixture reaches the MBG through two hoses connected at the two ends of the MBG.

2.3 Version III: Installation for the introduction of a low nitrogen gas

In figure 3 two oxygen concentrators are observed on the left side. The gas passes through a rotameter embedded in each oxygen concentrator and then the gas pressure and temperature at the inlet to the MBG.

Fig. 3. Overview of the experimental installation for the introduction of a low nitrogen gas

The atmospheric air aspirated from the atmosphere passes through a filter, is compressed and sent to the zeolite filters; here nitrogen is retained so that at the exit of the device a gas containing 95% oxygen is obtained. Each oxygen concentrator delivers 300 dm^3 / h.

2.4 Version IV: Installation for the introduction of a gas mixture made of atmospheric air and ozone

The TCB-300O3 ozone generator is a complex and controllable automatic device for decontamination of indoor air. The ozone generator TCB - 300O3 has a hard plastic body with degree of protection IP-56, which allows the use of this device in different conditions and spaces - residential, industrial, etc.
In figure 4 the ozone generator connected to the pipes of the water oxygenation installation is presented, and in figure 5, the electronic part of the ozone generator is observed.

Fig. 4. Plan view of the ozone generator connected to the pipelines

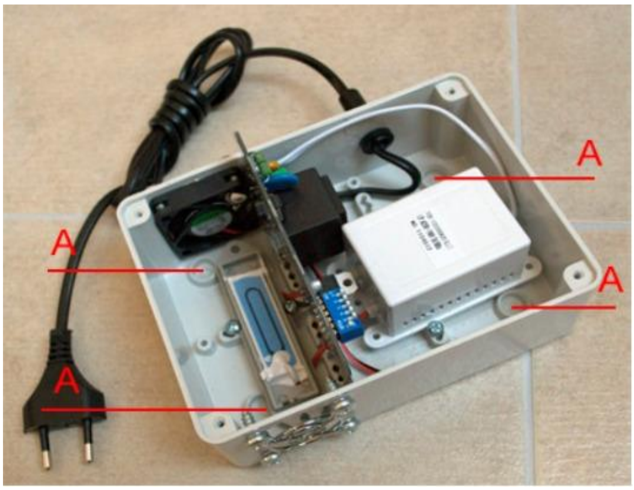

Fig. 5. Ozone generator components

The above installations are equipped with devices for measuring the flow rate and temperature of the conveyed fluids, devices with digital indication.

3. Theoretical determination of energy consumption, for the four studied versions

Problem formulation: what are the energy consumptions and the costs to reach from an initial concentration (C_0) to a saturation concentration (C_s) of dissolved oxygen in water in the case of the four studied versions?

3.1 Version I: Introduction of atmospheric air into water

For version I, 0.6 m^3/h of atmospheric air is introduced into the water. Energy E is the product of the consumed power P_I [kW] and the operating time of the installation τ [h].
For version I one can obtain:

$$E_I = P_I \cdot \tau_I \ \ [kWh] \tag{1}$$

$$P_t = \frac{n}{n-1} \cdot p_1 \cdot \dot{V}_a \cdot \left(\varepsilon^{\frac{n-1}{n}} - 1 \right) \cdot \frac{1}{10^3} \ \ [kW] \tag{2}$$

where:
n is the polytropic exponent n = 1.3;
p_1 - suction pressure of the compressor: p_1 = 1 bar;
$\dot{V}_a$ - volumetric flow rate of air sucked by the compressor: $\dot{V}_a = \frac{0.6}{3600} \ [m^3/s]$;

ε - compression ratio ε = 1.5.

$$P_t = \frac{1.3}{1.3-1} \cdot 1 \cdot 10^5 \cdot \frac{0.6}{3600} \cdot \left(1.5^{\frac{1.3-1}{1.3}} - 1 \right) \cdot \frac{1}{10^3} \ \ [kW]$$

$$P_t = 0.00705 = 7 \cdot 10^{-3} \ \ [kW]$$

Admitting an efficiency of the η_{agr} unit, compressor + electric drive motor, of 0.5, results in the real drive power:

$$P_I = \frac{P_t}{\eta_{agr}} = \frac{7 \cdot 10^{-3}}{0.5} = 14 \cdot 10^{-3} \ \ [kW] \tag{3}$$

The operation time of the installation is two hours, so the mechanical consumed energy to reach from C_0 to C_s will be:

$$E_I = P_I \cdot \tau_I = 14 \cdot 10^{-3} \cdot 2 = 28 \cdot 10^{-3} [kWh] \tag{4}$$

It is known that the average efficiency of a coal-fired power plant is about 30%, as a result of the electricity absorbed from the electricity network in the case of the first version will be:

$$E_{I,el} = \frac{E_I}{\eta_{CTE}} = \frac{0.028}{0.3} = 0.0933 [kWh] \tag{5}$$

3.2 Version II: Introduction of a mixture of atmospheric air and oxygen from a cylinder

For the four cases from version II the volume of gas aspirated by the compressor will be: $\dot{V}_a$ = 0.6/3600 m^3/s, and the compression ratio is ε = 1.5, the same as in version I.
As a result, the electricity absorbed from the grid will be the same:

$$E_{II,el} = \frac{E_I}{\eta_{CTE}} = \frac{0.028}{0.3} = 0.0933 [kWh] \tag{6}$$

3.3 Version III: Introduction of a low nitrogen gas

The oxygen concentrator type PLATINUM (2 pieces) used in the installation provides 300 dm^3/h of O_2, so both work with 600 $dm^3/h = 0.6\ m^3/h$.
From the technical data of the oxygen concentrator, it results that the maximum pressure at the outlet of the compressed gas is 0.35 bar, so the compression ratio compared to version I will be:

$$\varepsilon^{\frac{n-1}{n}} \rightarrow \varepsilon = 1.35^{\frac{1.3-1}{1.3}} < 1.5^{\frac{1.3-1}{1.3}} \Leftrightarrow 1.35^{0.23} < 1.5^{0.23} \Leftrightarrow 1.071 < 1.007$$

As a result, the electricity consumed from the network will be lower:

$$E_{III} = \frac{1.071}{1.007} = 0.09756$$

$$E_{III} = 0.0933 \cdot 0.09756 = 0.0900\left[kWh\right] \tag{7}$$

$$E_{III} < E_I$$

3.4 Version IV: Introduction of a gas mixture made of atmospheric air and ozone

Air + ozone is introduced into the installation; the air flow rate and the air pressure are the same as in version I; here appears an electricity consumption of the ozone generator.
To the $E_{I,el}$ = 0.0933 [kWh] value the electricity consumption of the ozone generator is added; from the package leaflet E_{ozon} = 0.04 [kWh].

$$E_{IV} = E_{I,el} + E_{ozon} = 0.0933 + 0.04 = 0.1333\left[kWh\right] \tag{8}$$

The theoretically calculated values are presented in table 1.

Table 1: Theoretically calculated values

No.	Introduced gas	Operating time $C_0 \rightarrow C_s$ [τ]	Value C_s [mg O_2/dm^3]	Time to reach C_s	Consumed electricity [kWh]
I	Atmospheric air	2 h	8.40	2h	0.0933
II	Case I-Air + 25 % O_2	2 h	10.73	15’	0.0933
	Case II-Air + 50 % O_2	2 h	21.46	5’	0.0933
	Case III-Air + 75 % O_2	2 h	32.21	3’	0.0933
	Case IV-Air + 100 % O_2	2 h	43.00	2’	0.0933
III	Atmospheric air with low nitrogen content (95 %)	2 h	34.80	2.5’	0.0900
IV	Air + ozone	2 h	8.98	87’	0.133

From table 1 it is observed that following the theoretical calculations the most advantageous method would be version III.

4. Conclusions

The originality of the paper is reflected in the development of a methodology for performing experimental measurements.
To make a comparison between the four studied versions, the initial data such as: gas flow rate in water, compressed air pressure, initial concentration of dissolved oxygen in water, water temperature and duration of experience are the same; differing in the composition of the gaseous mixture blown from the water.
Following the evaluation of energy consumption, the most favourable version is version III.
In this case there is a short time at which the oxygen concentration from $C_0 \rightarrow C_s$ is reached.

References

[1] Robescu, D. L., S. Lanyi, A. Verestoy, and D. Robescu. *Modeling and simulation of treatment processes*/*Modelarea şi simularea proceselor de epurare*. Bucharest, Technical Publishing House, 2004.

[2] Stenstrom, M. K., and D. Rosso. *Aeration*. Los Angeles, University of California, 2010.

[3] Nistreanu, V. *Unitary processes for water treatment/Procese unitare pentru tratarea apelor*. Bucharest, AGIR Publishing House, 2000.

[4] Oprina, G. *Contributions to the hydro-gas-dynamics of porous diffusers/Contribuţii la hidro-gazo-dinamica difuzoarelor poroase*. Doctoral thesis. University Politehnica of Bucharest, Faculty of Power Engineering, 2007.

[5] Călușaru, I. *The influence of the physical properties of the liquid on the efficiency of the oxygenation processes/Influenţa proprietăţilor fizice ale lichidului asupra eficienţei proceselor de oxigenare*. Doctoral thesis. University Politehnica of Bucharest, Faculty of Mechanical and Mechatronics Engineering, 2014.

[6] Pătulea, Al. S. *The influence of the functional parameters and the architecture of fine bubble generators on the efficiency of aeration installations/Influenţa parametrilor funcţionali şi a arhitecturii generatoarelor de bule fine asupra eficienţei instalaţiilor de aerare*. Doctoral thesis. University Politehnica of Bucharest, 2012.