A New Solution for Water Aeration

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Abstract: *The paper presents a new solution of water aeration, namely: the introduction of compressed air into the water transport pipes. This eliminates those reservoirs, pumps, decanters, ponds, etc., which pursue the intervention in the case of the construction of a water treatment plant. To measure the dissolved oxygen concentration in water, a non-invasive method is displayed.*

Keywords: *Water aeration, fine bubble generator.*

1. Introduction

The issue of reducing water pollution is topical and requires minimum energy consumption.
Between mechanical and pneumatic aeration, the most favourable is pneumatic aeration, which can be achieved by:
•the use of porous diffusers built of ceramic, plastic or elastic materials;
• installation of pipes with orifices Ø 1-3 mm on the tank base;
• the construction of fine bubble generators with orifices of Ø <1mm.
By aerating the water, it is intended to increase the dissolved oxygen content in water, which favours a more acceptable existence of the living beings in the water. Aeration of polluted water can be carried out in tanks where water can be immobile or moving at a reduced speed. This paper proposes a solution for the aeration of waters, namely: the introduction of compressed air into the waste water pipes.
For vertical pipes, the solution has the following advantages:
- the investment expenses needed for the construction of aeration tanks are reduced;
- the expenses for the operation of the water aeration system are reduced;
- a rigorous control of the parameters that determine the quality of the water to be aerated is ensured.
The equipment used for water oxygenation is based on the phenomenon of dispersing a gas (air, pure oxygen, ozone) in the water. The purpose of this equipment is to produce gas bubbles as small as possible in accordance with the requirements of the process. According to the size of the gas bubbles that are dispersed in the water mass, they are classified into the following categories (Fig.1).

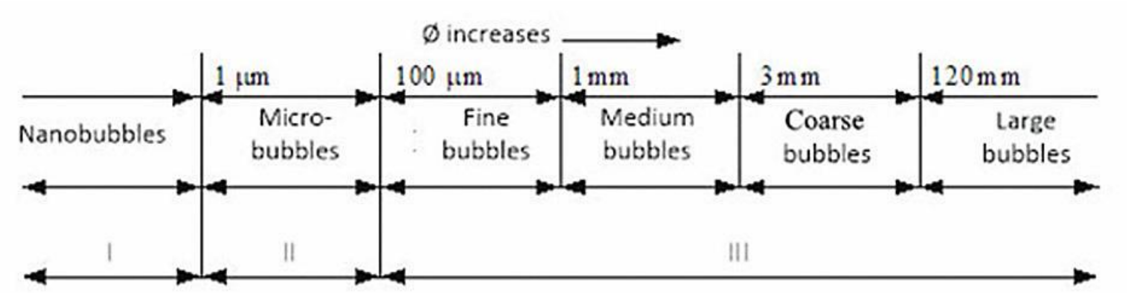

Fig. 1. Classification of gas bubbles according to their diameter (Ø)
I - the area where the gas bubbles can be observed under the microscope;
II - the area where the gas bubbles can be observed with difficulty;
III - the area where the gas bubbles can be observed with the naked eye.

The current trends, evaluated from the diversity of the economic agent’s offers and presented in the literature, consist of identifying the solutions of decreasing the diameter of the gas bubbles (oxygen, air) to increase the gas - liquid contact surface within the volume of water subjected to the oxygenation process. The various current technologies aim to reduce the energy consumption allocated to achieving the highest possible mass transfer of oxygen to the water [3] [4].

2. The equation of oxygen transfer speed to water

The equation which defines the transfer speed of the O_2 from air to water is [4][5]:

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

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].
The term ”ak_L” includes [4][5]:
a – interphase contact specific surface:

$$a = \frac{A}{V}\left[\frac{m^2}{m^3}\right] \tag{2}$$

A – gas bubbles area [m^2]
V – biphasic system volume (air plus water) [m^2]
k_L– the coefficient of mass transfer [kg/m^3]
Equation (1) indicates the modification of oxygen concentration over time, as a result of molecular diffusion of O_2 from the area with high concentration to the area with low O_2 concentration.
From equation (1) it is noted that to increase the transfer speed of the O_2 to water, the following are required:
I. the increase of k_L and C_s
II. the decrease of C_0
The conditions I and II are given in Table 1.

Table 1: Solutions for increasing $dC/d\tau$

No.	The purpose	Theoretical solution	Practical solution
1	The increase of a	The decrease of the gas bubble diameter	The decrease of the F.B.G. orifices diameter
2	The increase of k_L	The turbulence enhancement	- FBG rotation - Using mobile FBG
3	The increase of C_S	The increase of the O_2 concentration into the water	Introduction of air, oxygen, O_3 into water
4	The decrease of C_0	Minimum C_0 values depending on the nature of the microorganisms existing into water	- Decrease of the initial water temperature - Introducing substances into water that reduce the value of C_0

From the above, it is noted that the value of "a" increases if the diameter of the bubble (d_b) decreases; as a result, in practice, the aim is to obtain bubbles of the smallest diameter.

3. The analysis of the proposed solution

From Table 1, it is intended to achieve point 3 by introducing an air stream into the water transport pipe. This process increases the dissolved oxygen concentration in water which leads to a more favourable existence of the living beings in the water.
Water aeration is applied in water treatment plants, in ponds, pools, etc. These facilities require large space and investment, high maintenance and exploitation costs. A simpler and cheaper solution for water aeration is proposed, namely: the injection of compressed air into waste water transport pipes to the emissary. As a result, the oxygen concentration in the water will increase; there is an interphase mass transfer.
The proposed solution can be applied because modern methods for measuring the dissolved oxygen content in water have been invented and developed. Thus, a plastic or glass tube is mounted along the water pipe line and a sensor is used to facilitate the measurement of dissolved oxygen content in water.
The water flow rate $\dot{m}_{H_2O}\left[kg/s\right]$ flowing through a pipe and having a dissolved O_2 concentration in section 1-1 equal to C_0 is specified (Fig.2).

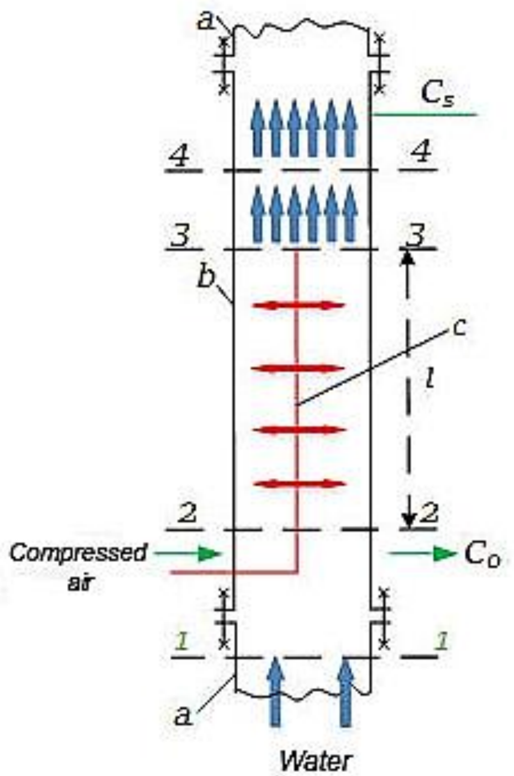

Fig. 2. Computing notes
a - water transport pipe; b - transparent glass or plexiglass tube; c - compressed air distribution system

Between sections 1-1 and 4-4, the water stream increases its mass with:

$$\Delta_{in} = \dot{V} \cdot \left(C_s - C_0\right)\ [kg/s] \tag{3}$$

Where: $\dot{V}$ - the volumetric water flow rate [m^3 / s].

In section 4-4, a mass flow rate is obtained:

$$\dot{m}_{4-4} = \dot{m}_{1-1} + \Delta\dot{m}\ [kg/s]$$

Prior to section 2-2, an air flow rate is injected to increase the dissolved oxygen concentration from C_0 to C_S. After a distance x (section 2-2 => 3-3), it is considered that all air has been injected so that the dissolved oxygen concentration in the water increases from C_0 to C_s [mg / dm^3]. In Section 4-4 downstream of 3 - 3 the value of C_s (function of t_{H_2O}) is measured.

From the previous researches [6] [7] [8] for a running time (τ) of the aeration system, C_0 = 5.45 mg/dm^3 to C_s = 9.2 mg/dm^3. The volume of the aerated water is V = 0.125 m^3_{H2O} and the amount of the injected air in water is $\dot{V}_{air}$ = 600 dm^3 / h = 0.6 m^3 / h.

If this process is simulated through a process flowing water and air, the following are obtained:

• For water:

$$\dot{V}_{H_2O} = \frac{V}{\tau} = \frac{0.125}{2 \cdot 3600} = 0.01736 \cdot 10^{-3} \quad m^3/s$$

The water speed w_{H_2O} = 0.8 m / s and the pipe diameter are selected [4] [6].

$$\dot{V}_{H_2O} = 0.785 \cdot d^2 \cdot 0.5 \left[m^3/s \right]$$

$$d = \sqrt{\frac{0.01736 \cdot 10^{-3}}{0.785 \cdot 0.8}} = 0.0525 \cdot 10^{-2} = 52.5 \ mm$$

• For air

The air flow rate:

$$\dot{V}_{air} = 600 \ dm^3/h = 0.6 \ m^3/h = \frac{0.6}{3600} \ m^3/s = 0.166 \cdot 10^{-3} \ m^3/s$$

So $\dot{V} = A \cdot w_{air} = 0,785 d^2 \cdot w_{air}$

w_{air} = 0.5 m / s is chosen and $\frac{0.6}{3600} = 0.785 d^2 \cdot 0.5$ results.

$$d = \sqrt{\frac{0.6}{3600 \cdot 0.785 \cdot 0.5}} = \sqrt{\frac{0.6}{1413}} = \sqrt{0.000424} = 0.0206 \, m$$

$$d_{air} = 2 \ cm = 20.6 \ mm$$

4. Presentation of the constructive solutions of the fine bubbles generators

Regarding the aeration of the water circulated through the pipes, different constructive solutions can be conceived (Fig.3). In figure (a), water penetrates into the tube (1) and through the pipes of height h, reaches the orifices (2); the compressed air enters a cylindrical chamber (4) and flows into the water through the orifices (3).

The water and air jets circulate upwardly over the distance "l" from C_0 to C_s. In figure b the air penetrates into the cylinder (2) and enters into the water through the orifices (3); water flows upwardly into the space between the tube (1) and the lateral area of the cylinder (2). After the distance "l", the dissolved oxygen concentration in water increases from C_0 to C_s.

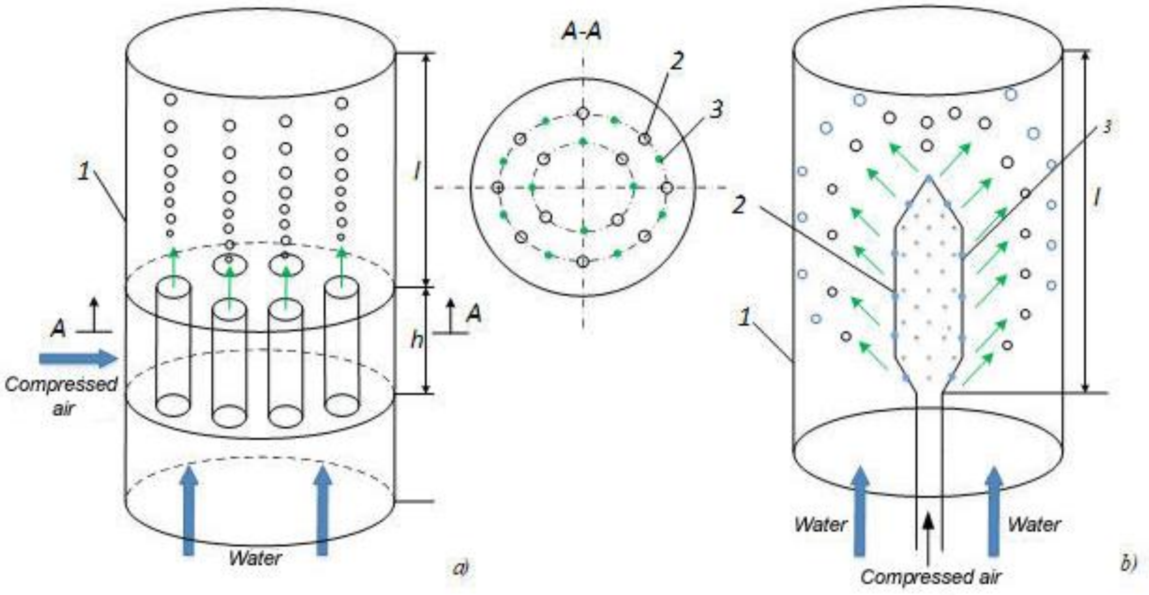

Fig. 3. Constructive solutions for the FBG
a) FBG with air dispersion through orifices placed on a circular plate; 1 - transparent plexiglass tube; 2 - orifices through which water passes; 3 - orifices through which compressed air passes.
b) FBG with air dispersion through orifices located on the side surface of a cylinder; 1 - transparent plexiglass tube; 2 - cylinder with orifices; 3 - orifices through which compressed air passes.

5. Non-invasive method of measuring the dissolved oxygen concentration in water

The current variety of applications, industrial or laboratory, requiring real-time monitoring of fluids variation in oxygen, has led to the development of several measurement methods.
Non-invasive measurement of dissolved oxygen concentration is the most recent method used in the food and beverage industry.
The determinations are accurate and can be done by means of a sensor applied to a transparent surface (glass or transparent plastic) (Fig.4).
The principle of the measuring devices is the one of oxo-luminescence [9], [10].

Fig. 4. Non-invasive device for measuring dissolved oxygen concentration

Figure 4 shows how to use a non-invasive device for measuring the concentration of dissolved oxygen in water passing through a pipe [11].
The main features of this device are: it uses a non-invasive, non-destructive method; applicability in gaseous or liquid media; long life of sensors without complicated calibration or maintenance operations; usable in industrial or laboratory environments; easy to use, portable and versatile; accurately determine the dissolved oxygen content in water.

6. Installations for the aeration of water transported through pipes

Water transport through pipes is carried out by horizontal or vertical pipes.

6.1. Aeration of water through horizontal pipes

In this case (Fig.5) there are two problems:
a) In the mixing chamber, air bubbles will rise to the top of the chamber, resulting in an inefficient mix between air and water.
b) Measurement of the dissolved oxygen concentration in water can only be carried out in the water tank (12) by means of the probe (13) of the oxygen meter.

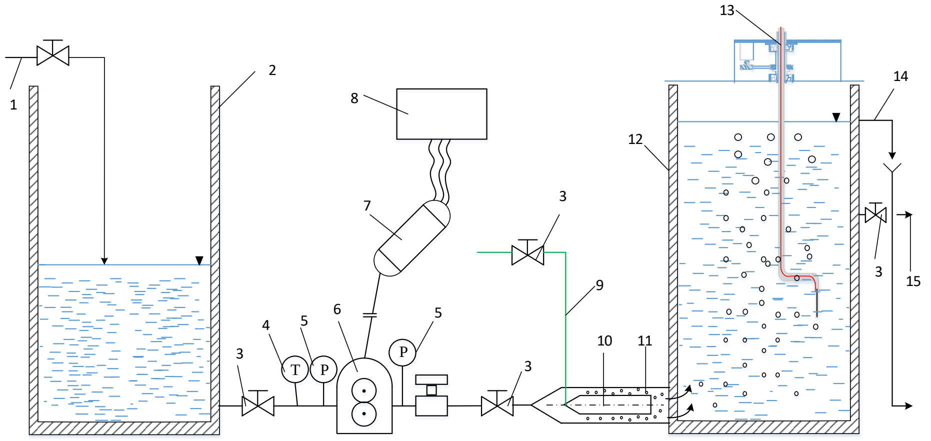

Fig. 5. Scheme of the water aeration system when the water is transport by horizontal pipes
1 - water supply connection; 2 - water tank, 3 - regulating valves; 4 - digital temperature measuring device; 5 - digital pressure manometer; 6 - rotating volumetric pump with two profiled rotors; 7 - three-phase electric motor; 8 - panel with electrical devices for regulating the pump speed; 9 - compressed air supply pipe; 10 - fine bubbles generator; 11 - air-water mixing chamber; 12 - tank with aerated water; 13 - oxygen concentration measurement probe; 14 - overflow; 15 - supply line for the consumer aerated water

6.2 Aeration of water through vertical pipes

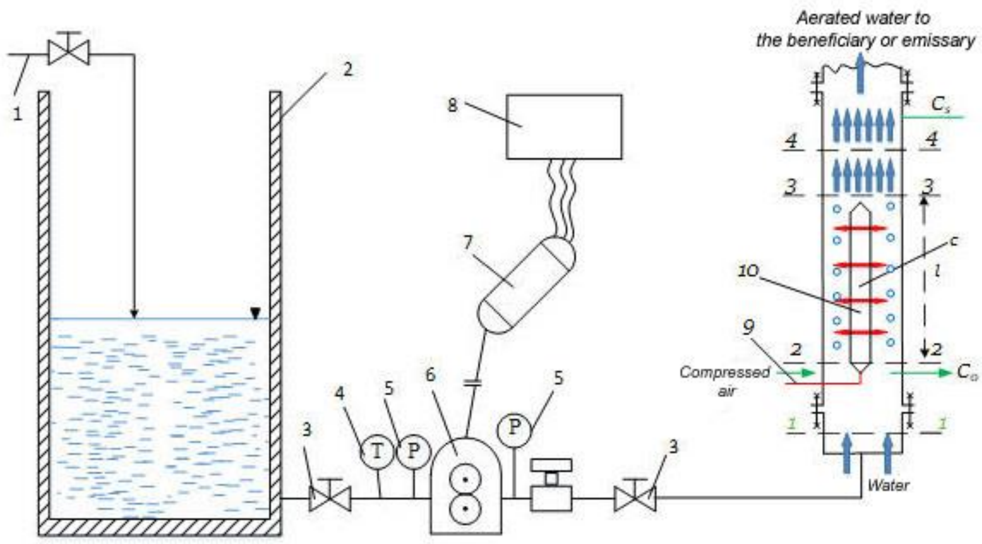

Fig. 6. Scheme of the water aeration system when the water is transport by vertical pipes
1 - water supply connection; 2 - water tank, 3 - regulating valves; 4 - digital temperature measuring devices; 5 - digital pressure manometer; 6 - rotating volumetric pump with two profiled rotors; 7 - three-phase electric motor; 8 - panel with electrical devices for regulating the pump speed; 9 - compressed air supply pipe; 10 - fine bubbles generator

Figure 6 shows that air bubbles emitted by FBG move vertically with the water stream; so, after a certain distance, concentration increases from C_0 to C_s.

7. Conclusions

1. It is intended to aerate the water by injecting compressed air into pipes carrying polluted water.
2. With this constructive solution, those aeration pools of hundreds of m^2 disappear, thus reducing the investment in the field of water pollution;
3. The operating costs of the water treatment plant are reduced in the sense that a single technician is required to supervise the two C_0 and C_s probes in Figure 2;
4. If the water has suspensions, its circulation will be from top to down in counter-pressure with the compressed air. This issue will be solved in future papers;
5. The solution presented in the paper eliminates many maintenance and operating costs that are nowadays in operation.

Acknowledgments

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