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Water Aeration in Tanks or Flowing Through Pipes

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ABSTRACT

The paper presents theoretical and experimental researches on two installations that serve to aerate the water in order to increase the oxygen content dissolved in water. The first installation contains a fine bubble generator powered by compressed air; the air is blown into a tank with stagnant water. For some initial data, the equation of oxygen transfer rate to water is numerically integrated, and the obtained results are compared with experimental data. In the case of the second installation, the water flows at a low speed through a pipe in which a certain air flow is introduced: the experimental installation built in the laboratory of University Politechnica of Bucharest is presented.

Keywords: Water Aeration, Oxygen Dissolved in Water.

1. INTRODUCTION

Water is the most abundant and widely distributed chemical compound. More than 71% of the Earth's surface is the oceans, which contain 97% of the existing water quantity. More than 2% are in the form of glaciers at the two poles and make up over 75% of the world's clean water. Of the remaining 1%, some of the water is at very deep depths, so that only 0.6% of the total water of the planet is available to humans.

The industry is the first major consumer of water, following irrigation and municipalities.

To perform the dispersion of air in water, it is used: porous diffusers made of ceramic materials, sintered glass, rigid, porous plastics, metal plates or other materials in which very fine orifices are created, elastomeric membranes. The use of fine bubble generators built using unconventional technologies is currently being investigated: laser processing, spark-erosion, micro-drilling [1] [2].

Of the energy consumption of a water treatment plant, some, about 50%, is used for water aeration. Aeration is currently performed with porous diffusers made of ceramic or glass; it does not emit bubbles of equal size and emit non-uniformly on the surface of the diffusers. In the laboratories of University Politechnica of Bucharest, fine bubble generators (FBG) were designed and built, in which the plate with orifices is made by spark -erosion (Ø <0.5 mm). In this case, the orifices are equal and evenly distributed in the x0y plane.

The size of the air bubble produced by the device with fine pores is influenced by the air flow, the porosity of the diffuser, the viscosity of the fluid in which it is emitted. Fine bubbles are obtained when an air stream passes through porous plates immersed in water. Fine bubble aeration is able to maximize the total surface area of the bubbles and thus transfer more oxygen to the water. In addition, for small bubbles the time spent by each bubble in water is higher, allowing for a better transfer of oxygen to the water. As a general rule, smaller bubbles generate a higher rate of oxygen transfer.

In the literature [3] [4] [5] the diameter of air bubbles in water reaches values between 400 and 700 μm; these bubbles are called microbubbles. In this paper, a fine bubble generator (FBG) with orifices of 0.1 mm is presented, which generates fine air bubbles with Ø <0.7 mm.

2. AERATION SYSTEMS, THEIR CLASSIFICATION

As a fundamental process of thermodynamics, water aeration is a process of mass transfer between air and water. The process is based on the transfer of oxygen from the air or, directly, the transfer of pure oxygen into a mass of water. Water aeration (oxygenation) is the process of mass transfer of oxygen into the water mass. The mass flow of oxygen transferred from air to water is the oxygen required for the process. The aeration process can be performed [6] [7]:

a. by mechanical aeration;

b. by pneumatic aeration.

In the case of mechanical aeration, oxygen from the air is introduced into the water by actuating the rotors, performing surface aeration; in the case of pneumatic aeration, air or oxygen is released into the diffusers, which are placed below the water level, with bubble aeration being performed. Aeration is normally performed by using mechanical aeration, which uses surface aerators, with vertical or horizontal shaft, or by pneumatic aeration, that is, by air diffusion.

The aeration equipment is classified according to several criteria [8] [9] [10]:

❖ ***By the way of obtaining the interfacial contact surface:***

- equipment's that sprays water in the air and equipment in cascade;
- equipment's that disperses the gas in the water (deep mechanical aerators, etc.);
- mixed equipment's - spray the water in the form of drops and entrain the air through the jet effect upon mass re-entry of the water from the basin (surface mechanical aerators).

❖ ***By the movement of the active body of the aeration equipment:***

- static equipment's (static aerators, ejectors, etc.);
- dynamic equipment's (surface or depth mechanical aerators).

❖ ***Depending on the type of gas used for aeration:***

- equipment's that disperses air into water (deep mechanical aerators, pneumatic aerators, ejectors, etc.);
- equipment's that disperses pure oxygen in water (pneumatic type);
- equipment's with ozone or ozone enriched air in water (such as fluid jet pumps).

❖ ***By the constructive solution:***

- pneumatic equipment's with porous diffusers, static aerators, etc.;
- surface mechanical equipment's, medium or high depth with rotor, brush, etc. ;
- mixed equipment's.

❖ ***By the immersion mode of the dispersion device:***

- surface equipment's (mechanical surface aerators with rotor or brush);
- medium depth equipment's - the dispersion device is located at a depth of 1 ÷ 2 m (INKA type pneumatic devices, medium depth mechanical aerators, etc.);

- deep water equipment's - the dispersion device is located at about 3 ÷ 120 m (pneumatic, injector, mechanical deep water equipment's, etc.).

❖***Depending on the type of input system:***

- static aerators and mixers with spraying, bubbling with high or low pressure, blowing with large, medium or fine bubbles, splashing, spraying on a contact mass;
- mechanical aerators and mixers with brushes, injectors, slow or fast rotor, etc.;
- pressure aerators;
- equipment's based on the combination of the above mentioned procedures.

3. AIR DISPERSION IN WATER

The introduction of air into the water in order to increase the oxygen content dissolved in water can be achieved in two ways:

1. Introducing compressed air in the water tank, using fine bubble generator (FBG);
2. Air dispersion directly in the waste water transport pipe.

3.1. Water Aeration in Tanks

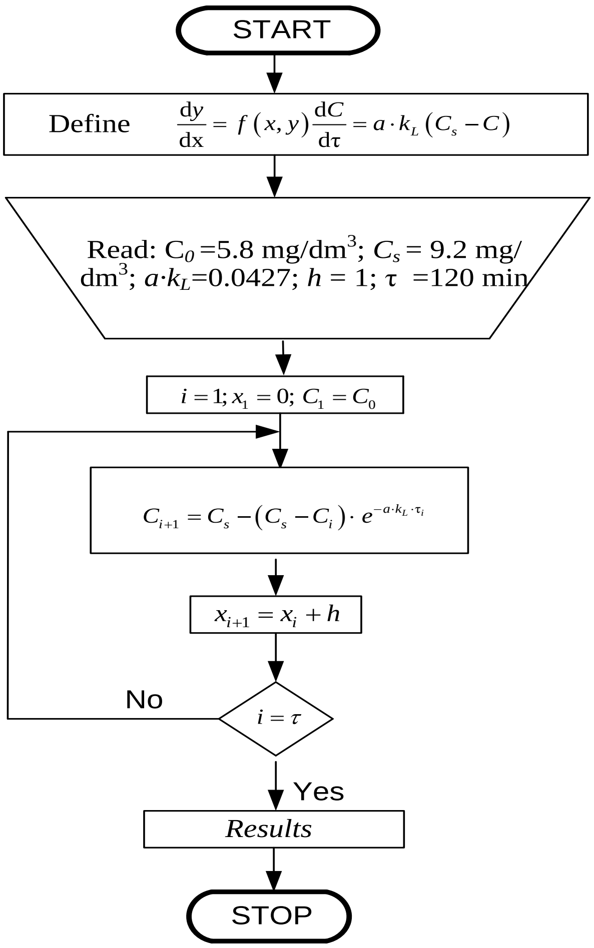

FIG 1: LOGICAL CALCULATION SCHEME FOR THE FUNCTION: C = f (x, τ) IN THE CASE OF AIR ENTERING THE WATER TANK IN FIGURE 2

The equation of the rate of oxygen transfer in water is [11][12]:

$$\frac{dC}{d\tau} = a \cdot k_L \left(C_s - C \right) \quad (1)$$

Where:

- $dC / d\tau$ is the rate of change of dissolved oxygen concentration in water (oxygen transfer rate);
- ak_L - the volumetric mass transfer coefficient [s^{-1}];
- C_s - oxygen concentration in water, at saturation
- C - current concentration of dissolved oxygen in liquid phase [kg / m^3].

For the numerical integration of equation (1), a calculation program was developed (figure 1).

The calculation results were used in the graphical representation of the function C = f (τ) in figure 4, (curve 1).

The sketch of the experimental installation for introducing air from the atmosphere into water is shown in figure 2.

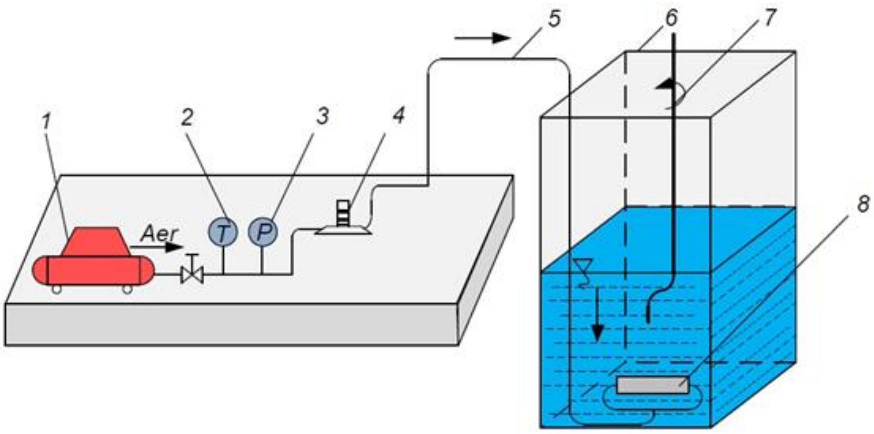

FIG 2: SKETCH OF THE EXPERIMENTAL INSTALLATION FOR BLOWING AIR FROM THE ATMOSPHERE INTO WATER

1 - AIR COMPRESSOR; 2 - THERMOMETER; 3 - MANOMETER; 4 - ROTAMETER; 5 - COMPRESSED AIR SUPPLY PIPE OF THE MICROBULE GENERATOR; 6 - PARALLELEPIPEDIC WATER TANK; 7 - OXYGEN METER PROBE; 8 - THE MICROBUBBLE GENERATOR WITH 152 ORIFICES Ø 0.1 mm

During the experimental investigations the following values will be kept constant: the gas pressure at the FBG entrance, the gas flow rate, the hydrostatic load.

For measuring the dissolved oxygen concentration in water, the electrical method was used [13] [14].

At an interval of 15 minutes, the FBG air supply is interrupted and the oxygen meter 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 rectangular-shaped FBG with 152 orifices Ø 0.1 mm in diameter is shown in Figure 3.

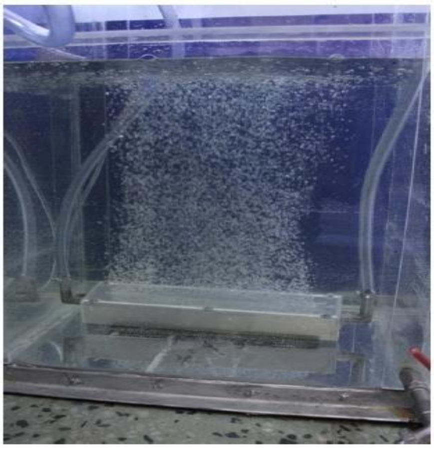

FIG 3: FBG WITH 152 ORIFICES Ø 0.1 MM IN OPERATION

FBG is provided with a perforated plate with Ø 0.1 mm orifices achieved by micro-drilling.

3.2. Comparison of Theoretical Results with Experimental Data

Following the running of the calculation program in figure 1, a series of data resulted on which the curve (1) of figure 4 was drawn. Following the experimental investigations, data were obtained that allowed to draw the curve (2) in figure 4.

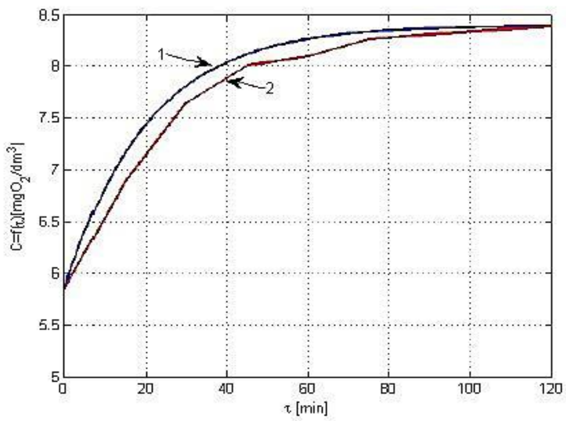

FIG 4: $C_{O2} = f(\tau)$ FOR ATMOSPHERIC AIR

1 - CURVE DRAWN ON THE BASIS OF THEORETICAL DATA; 2 - CURVE DRAWN ON THE BASIS OF EXPERIMENTAL DATA

From figure 4 one can see a good agreement of the data theoretically obtained with those experimentally obtained.

3.3. Water Aeration Flowing Through Pipes

In order to replace the water aeration in large tanks, in which the compressed air is introduced, a method of introducing the air directly into the water transport pipes is proposed; thus, in a section of the pipe, a spiral provided with orifices (Ø 0.3 mm) is fixed, through which the air comes out and circulates in an equilibrating manner with the water (figure 5). The diameter of the spiral (Ø 40 mm) is smaller than the inner diameter of the pipe Ø 46 mm; the spiral is supplied with compressed air at both ends (Figure 5).

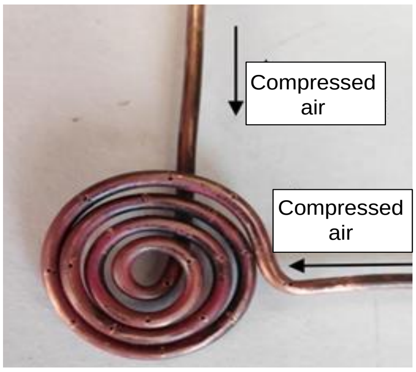

FIG 5: PLAN VIEW OF THE SPIRAL

The spiral is made of copper capillary tube Ø 3 x 1. The spiral is fixed between the flanges of the pipe (Figure 6).

The pipe is made of transparent plexiglass Ø 50 x 2 from Germany; the pipeline allows the measurement of the dissolved oxygen concentration in the water by the non-invasive optical method; optical sensors and the oxygen meter are to be purchased [15].

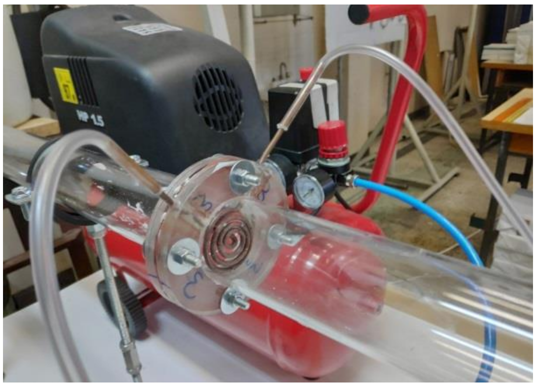

FIG 6: VIEW OF THE SPIRAL, FIXED BETWEEN THE FLANGES OF THE PIPE

Figure 7 shows an overview of the experimental installation.

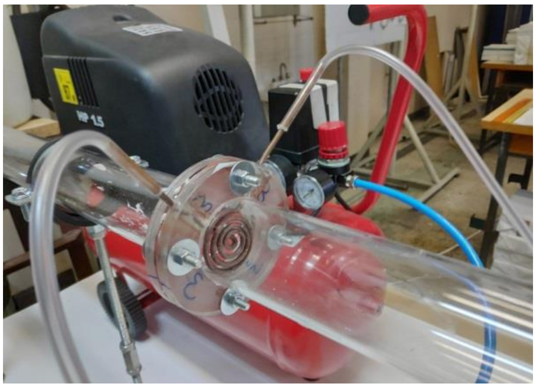

FIG 7: OVERVIEW OF THE EXPERIMENTAL INSTALLATION

1 - PIPE Ø 50 X 2; 2 - SPIRAL; 3 - WATER TANK; 4 - ELECTROCOMPRESSOR; 5 - ROTAMETER; 6 - ELECTRONIC FLOW METER

The presented experimental installation (figure 7) is used only for pipes located upright.

4. CONCLUSION

1) The creation of a microbubbles generator, at which the perforated plate has orifices Ø 100 µm, is a first in the field of water aeration;

2) The smaller the diameter of the air bubble immersion orifices in the water, the faster the oxygen transfer rate to the water will increase;

3) The advantages of using FBG are:

- There is a uniform dispersion of air bubbles in the water mass;
- The size of the air bubbles dispersed in the water mass is the same.

4) The pressure loss at a porous diffuser is 1.2 mH_2O [16] [17], and at a FBG is 0.02 mH_2O; as a result, the energy consumed for air compression is much lower in the case of FBG.

5) The theoretical and experimental researches, presented above, lead to a very good coincidence, a fact that reveals the correctness of these researches.

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