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Researches on Water Aeration Flowing through Pipes

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Abstract: *The paper proposes that the water aeration to be carried out by introducing compressed air into the wastewater transport pipelines. For this purpose, a system for dispersing the air in the water flowing through the pipes was designed and built; the air coming out through a series of orifices drilled in a spiral mounted inside the pipe moves equidistantly with the water. An experimental installation for the study of the biphasic air + water flow is presented, an installation that also serves to measure the concentration of dissolved oxygen in water.*

Keywords: *Water aeration, dissolved oxygen, oxygenometer, oxygen transfer.*

1. Introduction

Water aeration is a process of increasing the amount of dissolved oxygen in water, to ensure proper water quality.
Oxygen in water comes in two forms:
• O_2 bound to H_2.
• Free O_2, called dissolved oxygen in water.
Free oxygen is represented by oxygen that is not bound to any other element. Dissolved oxygen is represented by these free oxygen molecules in the water. The water-bound oxygen molecule (H_2O) is a compound and is not considered in determining the level of dissolved oxygen.
Dissolved oxygen is an important parameter in the evaluation of water quality due to its influence on living organisms in a water volume, a level of dissolved oxygen too high or too low can affect aquatic life and water quality.
An optimal level of dissolved oxygen must be maintained in the water.
The amount of dissolved oxygen in water differs from one life form to another; crabs and oysters need minimal amounts of oxygen ($1 \div 6$ mg / dm^3), while shallow water fish need a higher level ($4 \div 15$ mg / dm^3) [1] [2].
Water aeration is used in the following areas [3] [4]:
- in water treatment processes by removing dissolved inorganic substances, or chemical elements such as: arsenic, cadmium, cobalt, chromium, iron, manganese, nickel, zinc, lead.
- biological treatment of wastewater.
- in water disinfection processes by ozonation.
-in the separation and collection of existing fats in wastewater.
It is known from the literature [5] [6] that the process of aeration of water can be achieved by:
a. mechanical aeration.
b. pneumatic aeration.
c. mixed aeration.
Pneumatic aeration is clearly superior to mechanical aeration systems [7] and is achieved by introducing compressed air into the water, below the free surface of the liquid.
The aerating equipment consists of:
I. drilled pipes located on the water tank base.
II. porous diffusers of ceramic, glass, perforated membranes.
III. fine bubble generators (FBG) at which ø <1 mm.
In the case of stationary water, any of the three variants may be used: I, II, III.

For water flowing through pipes, the placement inside the pipe, in a flow section, of one of the constructive solutions I, II, III, would reduce the area of the flow section, which would lead to large pressure losses.
As a result of the researches, the authors found an original solution for dispersing air into water flowing through pipes, a solution presented in paragraph 3.

2. Analysis of the biphasic fluid (water + air) flow through pipes.

In the study of biphasic fluid flow, there may be different types of flows, of which three cases may occur:
a) Bubble flow (figure 1)
- in this case, the air is dispersed in the water in the form of bubbles.

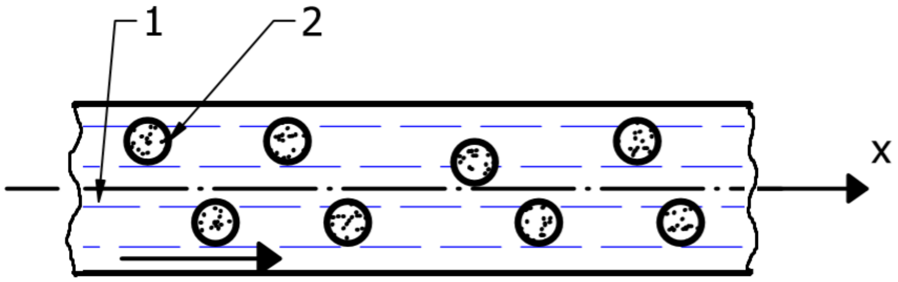

Fig. 1. Bubble flow
1- water; 2- air bubbles

b) Flow with gas plugs (figure 2)

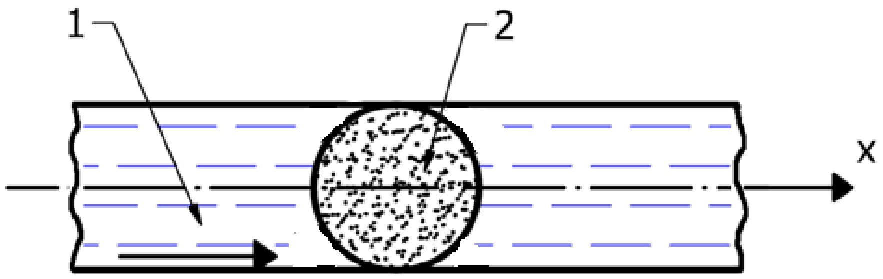

Fig. 2. Flow with gas plugs
1- water; 2- air bubble

The air bubbles form a plug that will move at a speed equal to the speed of the water.
c) Layered flow (figure 3)

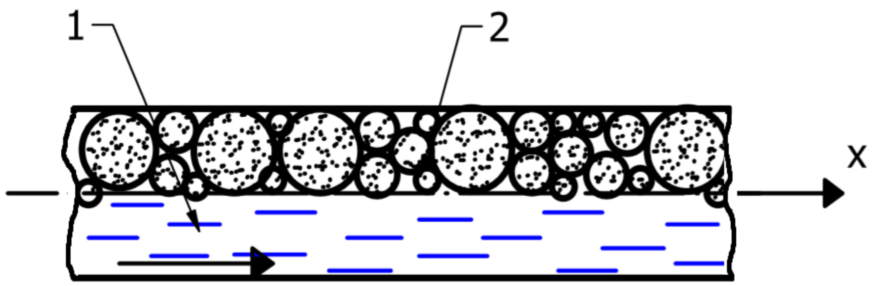

Fig. 3. Layered flow
1- water; 2- air bubbles

Since the density of the air is lower than the water density, the air bubbles rise in the upper part of the pipe, thus appearing the separation surface between liquid and gas.

To determine the flow regime, it is considered that the water volume to be aerated in time (τ) of 2 hours, is V = 0.125 m³.
This volume will flow through a pipe with an inner diameter of 44 mm, as a result the flow rate and water speed will be [8]:

$$\dot{V} = \frac{V}{\tau} = \frac{0.125}{2 \cdot 3600} = 0.01736 \cdot 10^{-3}\ m^3/s \tag{1}$$

$$w = \frac{\dot{V}}{\frac{\pi}{4} d^2} = \frac{0.01736 \cdot 10^{-3}}{0.786 \cdot (0.044)^2} = 0.0115\, m/s \tag{2}$$

For water at 20 °C, the kinematic viscosity is [8]:
$\nu = 1 \cdot 10^{-6}\ m^2/s$
so, Reynolds number will be:

$$\mathrm{Re} = \frac{w \cdot d}{\nu} = \frac{0.0115 \cdot 0.044}{1 \cdot 10^{-6}} = 506 \tag{3}$$

Since Re <2320, the water flow regime is laminar.
The air flow rate in water:

$$\dot{V} = \frac{0.6}{3600} = 0.0001666\ m^3/s \tag{4}$$

The area of the air outlet section in the water, considering previous researches [9] [10] [11] is chosen $A = 1{,}2 \cdot 10^{-6}\ m^2$; the number of air orifices in the water is:

$$n = \frac{A}{\frac{\pi d^2}{4}} = \frac{1.2 \cdot 10^{-6}}{\frac{\pi}{4} \cdot (0.3 \cdot 10^{-3})} = 17 \tag{5}$$

3. Presentation of the constructive solution for the air dispersion in the water flowing through a pipe

For the controlled and uniform introduction of compressed air into the water, a flat spiral was constructed; the spiral is made of a copper capillary tube with an outer diameter of 3 mm and an inner diameter of 1 mm.
In the spiral, 17 orifices were made with ø = 0.3 mm.
The spiral contains three circles (figure 4) with diameters of 16 mm, 26 mm, 36 mm and lengths of 50.24 mm, 81.64 mm, 113.24 mm.
The total length (L) of the spiral is 244.92 mm.

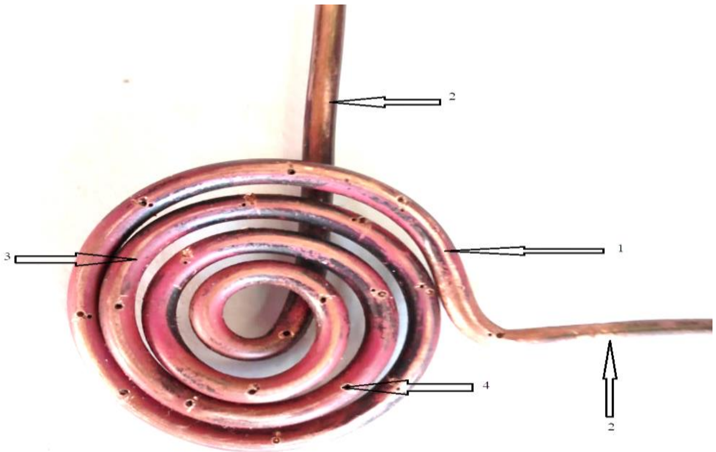

Fig. 4. Spiral with 17 orifices with ø = 0.3 mm
1– pipe Ø - 50 x 3 mm; 2 - compressed air inlet connections;
3 - spiral; 4 - orifices

The distance between two orifices will be:

$$l = \frac{L}{n} = \frac{244.92}{17} = 14.4\ mm \quad (6)$$

Several orifices will be made in each circle:

$$n_1 = \frac{L_1}{l} = \frac{50.24}{14.4} = 3 \quad (7)$$

$$n_2 = \frac{L_2}{l} = \frac{81,64}{14.4} = 6 \quad (8)$$

$$n_3 = \frac{L_3}{l} = \frac{113.24}{14.4} = 8 \quad (9)$$

There are a total of 17 orifices with ø = 0.3 mm (figure 5).

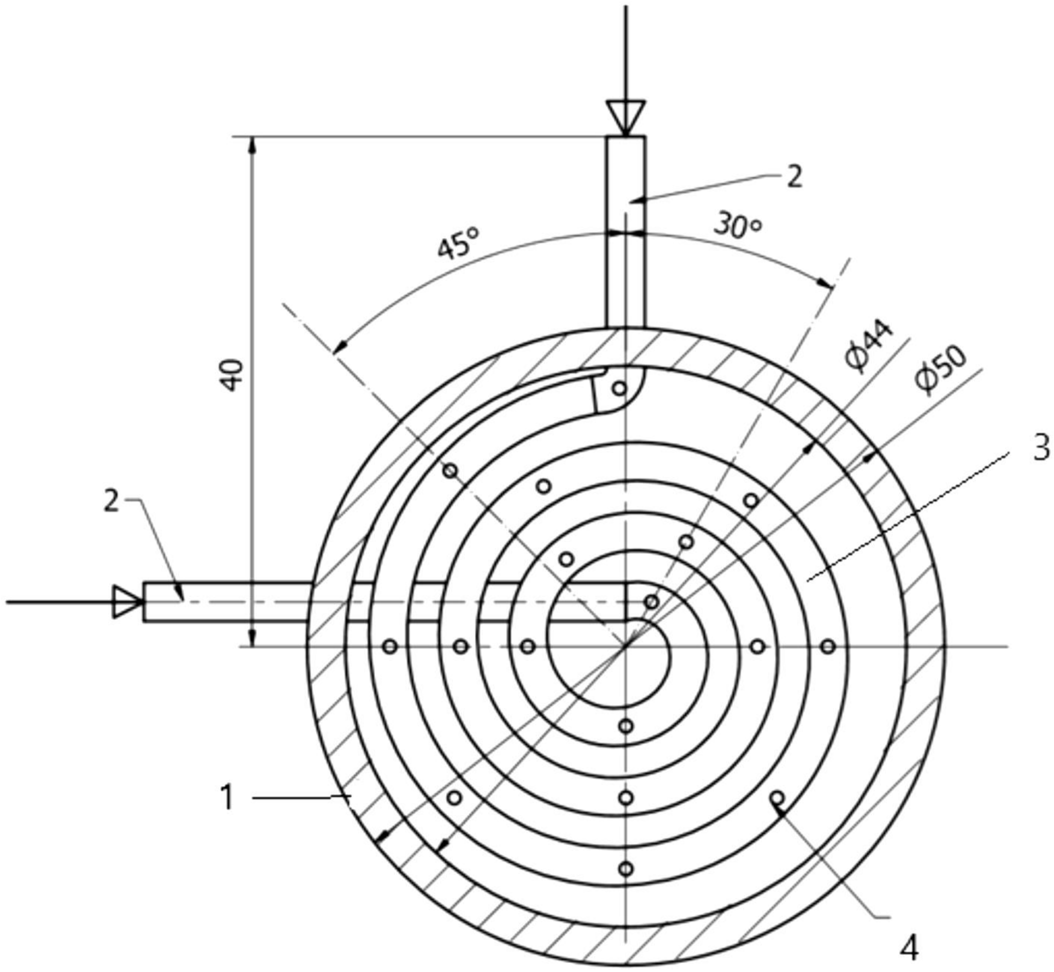

Fig. 5. Cross section through the pipe where the spiral is located.
1-pipe Ø 50x3 mm; 2- compressed air inlet connections; 3- spiral; 4- orifices Ø 0.3 mm

Compressed air enters the spiral through the two connections (2).

4. Presentation of the experimental installation for water aeration flowing through pipes

Pipes that carry water can be placed in a horizontal or vertical position. Only the case of horizontal pipes will be analyzed (figure 6).

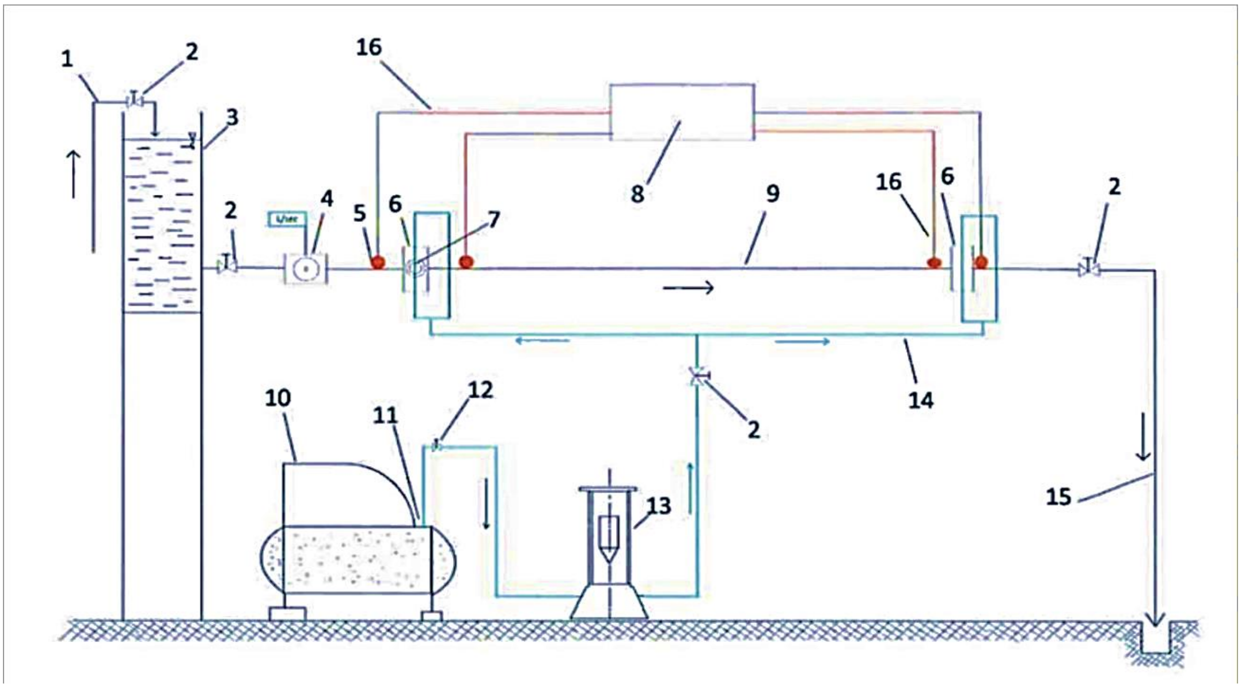

Fig. 6. Scheme of the experimental installation
1– water supply pipe; 2 - tap; 3 - water tank; 4 - flow meter; 5 - light insulating spot; 6- flanges; 7 - spiral; 8 - oxygenometer; 9 - transparent plexiglass pipe; 10 - electrocompressor; 11 - compressed air tank; 12 - pressure reducer; 13 - rotameter; 14 - compressed air pipes; 15 - water drainage pipe to the sewer network; 16 - optical fiber.

Figure 7 shows that a spiral (1) is mounted inside the transparent plexiglass pipe. Through the two connections (2), the compressed air enters the spiral and then, through the 17 orifices, exits and moves concurrently with the water.

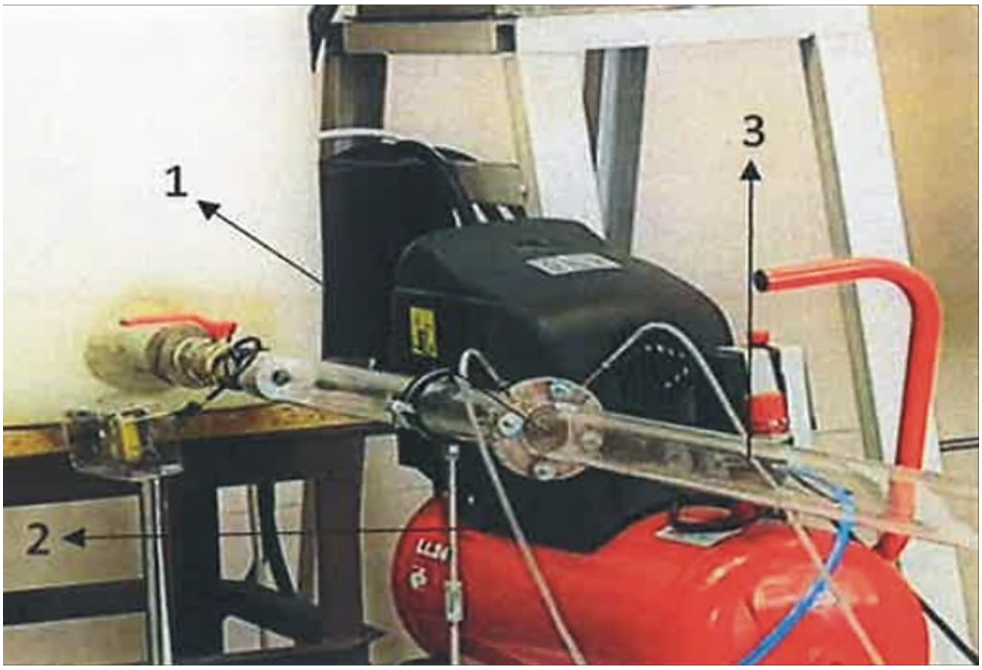

Fig. 7. The spiral placed between the flanges
1– spiral; 2 - compressed air connections; 3 - transparent plexiglass pipe.

The dissolved oxygen concentration in water can be measured by one of three methods: chemical, electrical, optical [12] [13].

The transparent plexiglass pipe (3) allows the measurement of the dissolved oxygen concentration in water by the optical method, namely by a non-invasive process.
The signal from the sensor (5) is transmitted to the oxygenometer via the optical fiber (16).
In Figure (8), an overview of the experimental installation can be seen.

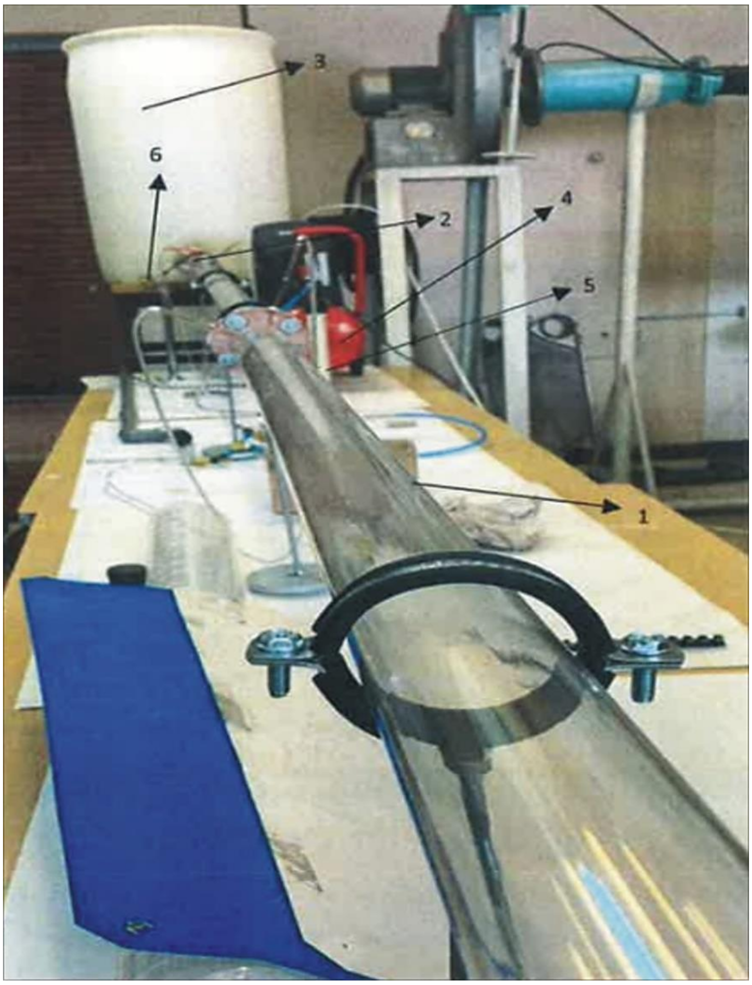

Fig. 8. Overview of the experimental installation
1-pipe ø 50 x 2; 2- spiral; 3- water tank; 4- compressor; 5- rotameter; 6 - electronic flow meter.

The experimental installation designed and built in the laboratory of the Faculty of Mechanical and Mechatronics Engineering is useful for the study of increasing the dissolved oxygen concentration in water flowing through horizontal pipes.

5. Conclusions

1. An air dispersion system in cross-section of the pipe carrying the aerated fluid is an efficient and original solution.
2. The shape and number of orifices in the spiral depend on the air flow rate to be introduced into the water at one or two successive points.
3. By introducing air into the horizontal pipes at several successive points, until the dissolved oxygen concentration at saturation is reached, those enormous basins can be removed from the water treatment plants, thus reducing the value of the investments.
4. If the pipe carrying the aerated fluid is metallic, a short tube of transparent plexiglass shall be fitted along its path so that it is possible to measure the dissolved oxygen concentration in the water by a non-invasive method.
5. The aeration of the water flowing through vertical pipes will be studied later and will be compared with the solution proposed in this paper.

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