Aeration system to be used in wastewater treatment

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Abstract. The main purpose of the authors is to develop an improved aeration system to be used in wastewater treatment that will reduce the energy consumption by 20% for conventional activated sludge wastewater treatment plants (WWTPs) and by 40% for Moving Bed Biofilm Reactor (MBBR) WWTPs. A new type of aeration system based on fine-bubble diffusers with high endurance and reliability made from corrosion resistant metals is developed. The paper presents the innovative aeration systems with holes smaller than Ø 1 mm. An ultrasound system is used to clean the diffusers for clogging prevention. Ultrasound systems are used in WWTPs, but in the treatment process and not as an additional solution for anticlogging.

1. Introduction

Water aeration installations have evolved over time from mechanical surface aerators to fine bubble generators, aeration technologies apply to both resting liquids, as well as flowing liquids at very low speeds (w < 0.1 m/s). Aeration installations aim both to provide the oxygen necessary for the evolution of a biological process, if it exists, and to mix homogeneously the liquids containing different particles in suspension [1].

The oxygen required for the aeration process is taken from atmospheric air and introduced into water by three methods: pneumatic, mechanical and mixed. Figure 1 presents schematically the water oxygenation installations used in the wastewater treatment technique. Pneumatic systems consist of air compressor stations equipped with blowers or compressors, distribution network, air dispersing devices in water, and flowmeters [2]. Mechanical aerators operate on the principle of pumping the liquid to the free surface or to a certain amount of water in the depth of the basin. The flow of liquid drives the atmospheric air and spreads it into the mass of water in the form of bubbles. Mixed equipment operates on the principle of dispersion in water and the convection of mechanical equipment.

For efficient water aeration, it is necessary to ensure a uniform dispersion of air throughout the mass of water in a tank or basin; the air must be uniformly distributed to provide the oxygen demand required by the respectively process.

By the size of the air bubbles entering the mass of water in a tank, the air diffusers are divided as follows [3]:
- fine bubble generators with diameter, \( d_b < 1 \) mm;
- medium bubble generators with diameter, \( d_b = 1 \div 3 \) mm;
- big bubbles generators with diameter, \( d_b = 3 \div 120 \) mm.

The bubbles’ sizes depend on the diameter of the air outlet, the pressure and air flow in the distribution network.
Figure 1. a – pneumatic aeration; b – mechanical aeration; c – mixed aeration; 1 – compressed air; 2 – hydrodynamic current conduction wall in the tank; 3 – water tank; 4 – rotor; 5 – aeration brush; 6 – motor; 7 – air diffusers [4].

Figure 2 presents a modern aeration system where automation of equipment is used, but also real-time control of the functional parameters of the wastewater treatment plant (WWTP).

Figure 2. The general form of an aeration system: 1 - air pumping station; 2 - air transport ducts; 3 - air diffusers; 4 - mechanical mixer; 5 - control and measurement equipment [5].

The existing aeration process within the WWTPs is a great consumer of energy. For this reason, researchers are searching for new and improved methods/equipment to increase the aeration efficiency. To rise the efficiency of an aeration system, the quantity of dissolved oxygen transferred to the water has to be increased. This goal can be achieved in 3 ways, namely, to increase: the specific transfer area between air bubbles and wastewater; the gradient of the concentration; or the diffusivity of the medium [6]. Regarding the first method (to increase the specific transfer area between air bubbles and wastewater), it is known that the ratio between the volume of the air bubble (sphere) and area of the air bubble is $d/6$, where $d$ is the diameter of the sphere. To maximize the contact area between the air bubbles and wastewater it is desired a minimum value for the ration $d/6$, and so a smaller diameter of the air bubble is required. The air diffusers with micro-orifices are made especially from elastomer materials [7], but these types of materials are not recommended to be used in Mobile Bed Biofilm Reactors (MBBR). At the present, medium bubbles diffusers made from stainless steels are used in MBBR processes [8]. It is very difficult to obtain small orifices in stainless steel pipes.

In this context, the authors propose a new method to obtain small orifices in stainless steels air diffusers, based on unconventional technologies - electro-erosion process. Electro-erosion processing is a method of dimensional processing of metallic materials in which the removal of excess material is
based on the erosive effects of pulse electrical discharge, repeatedly primed between the workpiece and an electrode called a transfer object. This technology can be applied to high-strength metallic materials in order to obtain surfaces of a shape that cannot be easily and precisely achieved by classical cutting techniques. The processed metal is subject to erosion by means of electrical discharge made between metal and a copper electrode tool in a dielectric environment (e.g. lamp oil).

Some of the advantages of using electro-erosion are: realization of complex forms that would otherwise be difficult to be realized with other conventional cutting technologies and equipment; very hard metals are processed with small tolerances; very small parts can be molded where conventional cutting technologies may break the piece from excess cutting pressure; there is no direct contact between the cutting tool and the processed material; a good surface finish after the cutting process is obtained [9].

2. Material and methods

For the realization of the micro-orifices, it can be used the electro-erosion process, as well as classical CNC machining. At the base of the electro-erosion processing, the phenomenon of electro-erosive discharge by electric impulses between the two electrodes – the tool and the piece that are immersed in a dielectric fluid. The two electrodes are positioned reciprocal at a certain optimum distance, which must be maintained throughout the processing. For obtaining of small orifices for metal materials, a combined system can be used, the tool electrode wire is guided by a glass tube to avoid the buckling of the wire. For the calibration of the holes made by electro-erosion it is mandatory that in the last stage to perform a calibration of the orifices through the drilling operations [10]. The authors present the principle of the realization of the micro-orifices in Figures 3 to 6.
When electro-erosion is used one way to get maximum erosion at the piece electrode is to choose the appropriate pair of electrode-tool-workpiece material; Table 1 shows the specific consumption of electrodes for a certain volume of eroded material for various couples of material. It is usually used to make tool electrodes, electrolytic copper and its alloys (with chromium, tellurium etc.) or sintered and sometimes graphite.

Table 1. Types of materials [11] (and their characteristics) used in the electro-erosion process.

| Material          | Average current [A] | The flow of eroded material [mm³/min] | Specific consumption of electrodes [relative values] |
|-------------------|---------------------|---------------------------------------|-----------------------------------------------------|
| Tool-electrode    | Piece               |                                       |                                                     |
| Copper            | Steel               | 8                                     | 25,9                                                | 0,1                                                 |
|                  | Titanium            | 10                                    | 6,4                                                 | 0,3                                                 |
|                  | Copper              | 12                                    | 14,4                                                | 1,6                                                 |
| Aluminum          | Steel               | 8                                     | 8,7                                                 | 1,7                                                 |
|                  | Titanium            | 10                                    | 2,6                                                 | 8                                                   |
| Brass             | Steel               | 15                                    | 47,5                                                | 1                                                   |
|                  | Carbides            | 15                                    | 32,7                                                | 3                                                   |
| 90W – 10Ag        | Steel               | 15                                    | 55,7                                                | 0,05                                                |
|                  | Carbides            | 15                                    | 45,9                                                | 0,14                                                |
| 65WC – 10Ag       | Steel               | 15                                    | 36,1                                                | 0,08                                                |
|                  | Carbides            | 15                                    | 27,8                                                | 0,21                                                |
| 50Cu-50C          | Steel               | 15                                    | 63,8                                                | 0,34                                                |

The efficiency of electro-erosion processing is also influenced by the dielectric fluid, which must completely fill the gap between electrodes and meet the following conditions:
- have low thermal and electrical conductivity;
- be stable over time and not alter its characteristics under the influence of electric discharge;
- have a flash point above 40 °C;
- be chemically neutral.

Electro-erosion processing combined with CNC manufacturing processes has become a precise and reliable method of machining, which is now widely used among conventional chipping methods. It is especially popular for small volume productions such as prototypes [13-14]. Different processes with electric discharge machining, including turning, milling and drilling, are possible. In addition to mold making, electro-erosion is usually applied in the automotive and aerospace industries, for example, in the production of aircraft engines.

3. Results and discussions
The air diffusers were designed and realised. During the first step the diffusers were designed using specific CAD software. The air diffuser was conceived as being formed from 2 main parts: a perforated plate and a cassette (box/case). This method was used because during the experimental research, not all 10 diffusers will be tested at the same time, and the achievement of a small number of carcasses is sufficient. To ensure fund savings only few cassettes will be realized and, depending on the experiments only the perforated plates will be exchanged.

The three-dimensional CAD model of the plate with micro-orifices is represented in the Figure 7, while in Figure 8 is presented the 3D CAD model of the diffuser box.
The channels were processed by milling and the micro-orifices by CNC drilling, as presented in Figure 9. a) and Figure 9. b).

For the diffuser cassette execution, it can be used modern technologies by adding material – fused deposition modelling (FDM) [12]. Additive technologies can bring considerable advantages, with help of which it possible to realize functional parts in a relatively short time and with a low price. The material used was PLA (polylactic acid), which is ecological and biodegradable. The air diffusers with boxes made from PLA are presented in Figure 10.

Also, air diffusers made from 100% stainless steel were designed and realised. The authors designed the carcass and plates with AutoCAD in 2D and 3D. In Figure 11 the design results are presented.
In order to investigate the holes made, the microscopic method was used and the results are presented in Figures 12 to 15.

![Stainless steel case - lateral view](image1)
![Stainless steel housing - 3D assembly drawing](image2)
![Diffuser - 3D drawing](image3)

**Figure 11.** Diffusers designed within DFR Systems SRL.

For this purpose, the Olympus GX-51 microscope was used, which is an inverted metallurgical microscope with the possibility to perform researches in several modes and modes.

![Microscopic image of the hole Ø0.1 mm, magnification 1000x.](image4)
![Microscopic image of the hole Ø0.5 mm, magnification 200x.](image5)
![Microscopic image of the hole Ø0.7 mm, magnification 100x.](image6)
![Microscopic image of the hole Ø0.9 mm, magnification 100x.](image7)

**Figure 12.** Microscopic image of the hole Ø0.1 mm, magnification 1000x.

**Figure 13.** Microscopic image of the hole Ø0.5 mm, magnification 200x.

**Figure 14.** Microscopic image of the hole Ø0.7 mm, magnification 100x.

**Figure 15.** Microscopic image of the hole Ø0.9 mm, magnification 100x.

Using the microscope program, the mean diameters were measured and presented in Table 2, showing the difference between the theoretical and measured diameters.

**Table 2.** Comparison between theoretical nominal and measured diameters.

| Theoretical nominal diameter [mm] | Average measured diameter [mm] | Relative error [%] |
|----------------------------------|-------------------------------|-------------------|
| 0.1                              | 0.10462                       | 4.62              |
| 0.5                              | 0.485                         | 3                 |
| 0.7                              | 0.69094                       | 1.29              |
| 0.9                              | 0.89692                       | 0.34              |

The authors also propose a cleaning system for micro-orifices. During the last years, the ultrasound technique started to be implemented in wastewater treatment processes. The application of ultrasonic technology receives wide attention by the specialists in wastewater treatment field. The use of ultrasound technology had good results in the degradation of persistent organic compounds that are found in different types of wastewaters. Nevertheless, up to now, the ultrasound technology was not applied to prevent aeration diffusers clogging. The authors propose an ultrasonic mechatronic system for the micro-orifices’ cleaning. The cleaning system is coupled with a sensor and controlled by a computing unit to send clogging of the micro-holes through which oxygen (air) is introduced into the wastewater tank. The oxygen flow monitoring sensor will send the commands to the computing unit,
which will trigger the start command of the mechatronic ultrasonic system. In order to achieve good ultrasound transmission performance in the aeration plate with orifices of the diffuser, it is necessary to achieve a good rigid coupling between the ultrasonic concentrator and the plate with orifices to be ultrasonicated.

4. Conclusions
This new aeration system based on fine bubbles of air inserted into the wastewater tanks lead to an increased efficiency in both energy consumption and wastewater treatment. Due to the interaction between the aeration system and the biofilm carriers, the air diffusers have to be robust to resist to this repeated impact. That is why, currently, the mobile bed biofilm reactors are using aeration systems realised from anti-corrosive metallic components. Due to different mechanical Constrains holes with diameters larger than 1 mm are realised. The new solutions and products described in this paper represents a new stage in mobile bed biofilm reactors development. By using fine air bubbles, a smaller air quantity can be utilized, and a lower investment is needed with the blower system, meanwhile the energy demand is also reduced.

5. References
[1] Wagner M R and Pöpel H J 1998 Wat. Sci. and Techol. 38(3) 1-6
[2] Brewer T F, Shea P and Cheng RC 2018 Opflow. 44(9) 6-7
[3] Ámand I et al. 2013 Wat. Sci. and Tech. 67 11
[4] Moga I C 2013 Aspecte tehnico-economice referitoare la echipamentele și instalațiile de oxigenare din cadrul stațiilor de epurare monobloc (București: Certex)
[5] Patulea A 2012 Thesis (București: Politehnica Press)
[6] Rosso D, Larson L E and Stenstrom M K 2008 Wat. Sci. and Tech. 57(7) 973-978
[7] Mohseni E, Herrmann-Heber R, Reinecke S F and Hampel U 2019 Chemical Engineering and Processing-Process Intensification (Amsterdam: Elsevier)
[8] Collivignarelli M C, Abbà A and Bertanza G 2019 Env. Sci. and Poll. Res. 18(1) 1-7
[9] Leppert T 2018 Conf. Proc. 1. 020014
[10] Dontu O 2015 Masini si sisteme integrate de fabricatie (București: Printech)
[11] Unune D R and Mali H S 2015 Proc. of the Insti. of Mech. Eng., Part B: Jo. of Eng. Man. 229(10) 1681-1693
[12] Besnea D, Gheorghe I, O Dontu, Moraru E, Constantin V and Moga I C 2018 Int. J. of Mechat. and Appl. Mec. 4 61-65
[13] Daescu A I, Holban E, Boboc MG, Raischi MC, Matei M, Ilie M, Deak G and Daescu V 2017 Journal of Environmental Protection and Ecology 18 304
[14] Ilie M, Ghita G, Matei M, Deak G, Dumitră D F, Moncea A M, Marinescu F, Laslo L A, Fronescu D F and Daescu V 2018 Journal of Environmental Protection and Ecology 19 646

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