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INNOVATIVE TECHNOLOGICAL SOLUTIONS FOR EFFICIENT BIOLOGICAL WASTEWATER TREATMENT

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Abstract: The aeration process for a biological wastewater treatment plant is the main electrical energy consumer. The paper presents an innovative aeration system to be used in Mobile Bed Biofilm Reactors. It is known that this technology uses metallic air diffusers with medium bubbles, so an increased air quantity is required. The authors propose an innovative aeration system based on metallic diffusers with micro-orifices equipped with an ultrasound anti-clogging system. In this way smaller quantities of air will be introduced inside the bioreactors.
Keywords: additive technologies, aeration system, air diffuser, dissolved oxygen, micro-orifices

1. INTRODUCTION

The aerobic biological treatment stage needs important quantity of electrical energy. The aeration efficiency is higher in the case of the smaller air bubbles (Alex et al, 2016; Alkhalidi and Amano, 2015). Depending on the size of the air bubbles entering the water tank, the bubble generators are divided as follows: fine bubble diffusers with diameter smaller than 1 mm; medium bubble diffusers with diameter, situated between 1 and 3 mm; large bubble generators with diameter bigger than 3 mm (Metcalf and Eddy, 2003). The dimensions of the bubbles depend on the diameter of the air outlet, the pressure and the air flow in the distribution network. Due to the presence of the biofilm carries inside the Mobile Bed Biofilm Reactor, the aeration system has to be very robust, which is why are used the metallic diffusers, especially perforated pipes are preferred (Boltz at al, 2019). More than this, small orifices are difficult to be realized in metallic pipes.

The technical solutions for the construction of the air diffusers made up to now are not unitary, the porosities and material characteristics of the diffusers used in biological wastewater treatment are different. The most used fine bubble air diffusers are:

≡ Fine bubble diffusers with ceramic plates. Ceramic materials are the oldest materials used for the realization of the fine bubble generators. The ceramic plates are made of alumina, aluminium, silicate or silicon. The generators of fine bubbles with ceramic materials are in operation for a long period of time and are very well known both the advantages and the problems in operation.

Figure 1 - Ceramic diffuser plate (Patulea A, 2012)

≡ Fine bubble diffusers with porous plastic plates. Recent discoveries among the realization of fine bubble generators lead to the use of plastics in their construction because they have much better technical-economic properties than ceramic materials. Due to the properties of the plastic materials, the size of the gas outlet holes can be controlled.

Figure 2 - Porous plastic diffusers (Patulea A, 2012)

Figure 3 - Fine bubble diffusers with perforated membranes (Patulea A, 2012)

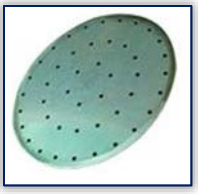


Figure 4 - Perforated plate for fine bubble generators (Patulea A, 2012)

≡ Fine bubble generators with perforated membranes. They differ from those previously presented as they do not have a network of interconnected ports through which the air must flow. The speakers are materials with very high elastic properties such as rubber, latex, silicone materials.

≡ Fine bubble generators with perforated plates. These diffusers have the same mode of operation as perforated membranes, but this time the materials from which they are executed are rigid metal or plastic materials in which individual holes are executed that cross the material from one face to another and allow air to be dispersed in the water.

2. MATERIAL AND METHOD

The micro-orifices are realised using CNC machining centres. The diffusers will have a different shape, like a box instead of a perforated pipe. Parts of the air differs can be realised by additive manufacturing. Additive manufacturing, also known as 3D printing, realize different components into layers directly from a digital file (Ngo et al, 2018). 3D printing is a rapidly growing field having an important impact on different industries by simplifying the several processes to go from designing to a finished product (Tofail et al, 2018). Additive manufacturing can advantageously fabricate complex geometries with no part-specific tooling and much less waste material, filling a gap left by the other manufacturing processes (Camacho et al, 2018).

The numerical simulations were obtained with the help of FlexPDE software. FlexPDE is a scripted finite element model builder and numerical solver (Liu, 2018). The script is entirely written by the user and FlexPDE performs the operations necessary to turn a description of a partial differential equations system into a finite element model, solve the system, and present graphical and tabular output of the results (Liu, 2018). To write the script, the user will use: an editor for preparing scripts, a mesh generator for building finite element meshes, a finite element solver to find solutions, and a graphics system to plot results.

FlexPDE has no pre-defined problem domain or equation list, so the authors made the mathematical modeling of the aeration process. The general dispersion equation was simplified and adapted.

3. RESULTS

Were realized some air diffusers for the biological wastewater treatment consisting from plates with micro-orifices with diameters between 0.1 and 1.1 mm. For the execution of the plate holes on the CNC machining centres it is necessary to generate the program in machine language. This technological process was chosen due to the superior execution accuracy compared to the electro-erosion processing process, the short execution time, the reduced costs and the existence in the laboratory equipment of a CNC machining centre. The Romanian researchers have made the following plates (Figure 5), to be tested in laboratory conditions: 1 plate with 0.3 mm holes - 50 holes; 1 plate with holes of 0.3 mm - 18 holes; 1 plate with holes of 0.4 mm - 18 holes; 1 plate with holes of 0.4 mm - 34 holes; 1 plate with 0.4 mm holes - 50 holes; 1 plate with holes 0.5 mm - 18 holes; 1 plate with 0.5 mm holes - 50 holes; 1 plate with holes of 0.7 mm - 9 holes; 1 plate with holes 0.9 mm - 6 holes; 1 plate with 1.1 mm holes - 4 holes. The technology used was subtractive one, and namely CNC drilling and milling, because it has significant advantages over unconventional EDM process that are extremely expensive.

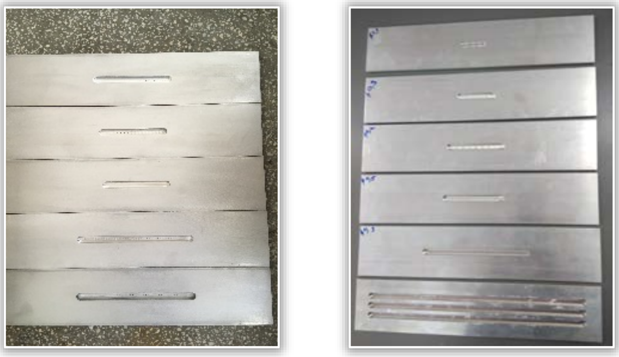


Figure 5 - Plates with holes obtained

The micro-orifices and the microstructure obtained were investigated microscopically by several specialized optical devices at University “Politehnica” of Bucharest labs (Figure 6) and the results being satisfactory. The accuracy of the resulted micro-holes and the surface condition are acceptable. The next step in the diffusers realization was to obtain the cassettes that will integrate the plates.

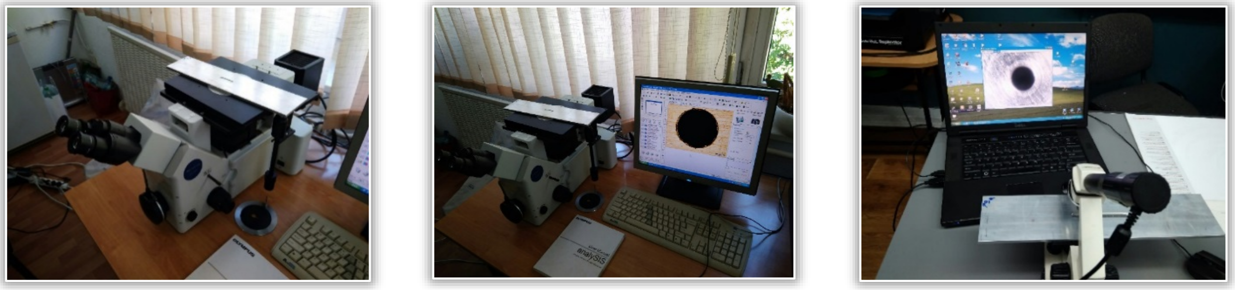


Figure 6 - Optical investigations of the plates (Besnea et al, 2018)

On the cassettes, practically, will be fitted the plates with micro-holes through which the air will be blown to oxygenate the wastewater. A new and viable method for this purpose has been proven to be the use of additive technologies. The cassettes were realized by additive technologies and namely the thermoplastic extrusion technology (Fused Deposition Modeling). Some steps of the realization of these cassettes are presented in the figure 7. As materials, the polylactic acid and acrylonitrile butadiene styrene was used. Apart from the relatively low costs, these materials have quite good mechanical properties.

Figure 7 - 3D printing of the cassettes

Manufacturing time is also relatively low. Among the main manufacturing stages of the cassettes are: design of the cassette in specialized software, converting to .stl format, generating a special code for the 3D printer, which will follow the trajectories described by the program to materialize layer by layer the entire volume, the proper printing – and the post-processing stages, which consist in the elimination of the sacrificial layers and the cleaning of the resulting piece. Special materials were used for the realization of different cassettes, namely, Polylactic acid and Acrylonitrile butadiene styrene (Figure 8).

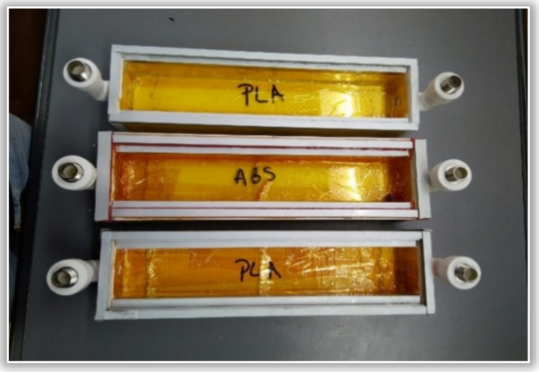


Figure 8 - Resulted 3D printed cassettes from PLA and ABS

Figure 9 - The assembly of the plates with cassettes (Besnea et al, 2018)

Finally, the assembly was made between the perforated plates and the cassettes (Figure 9). The developed aeration system was tested (Figure 10) in a water basin, demonstrating the efficiency of these combinations of methods used.

Figure 10 - The testing of the developed system (Moraru et al, 2019)

For the production of the designed boxes, the additive manufacturing was used. Additive technologies allow the manufacturing of products of any geometry in layers based on a designed 3D model. If in case of conventional processing technologies, the piece is made by removing material, in the case of Rapid Prototyping manufacturing technologies the piece is made by adding material, as much as necessary and where necessary.

Apart from the advantage of material savings, these technologies also have the following benefits: the possibility of obtaining complex geometries, which cannot be achieved by other technologies; improved properties of the finished pieces; relatively low cost.

Also, metallic cassettes for the perforated plates were realized by the Romanian authors of the present paper. Pictures taken during the production of the diffusers are shown in figure 11. It can be seen how an air diffuser is connected to the rest of the aeration system. The flexible hose is used to be easy to insert and remove from the experimental basin. To check the air pressure inside the diffuser, a socket is provided of which a manometer is connected via a hose.

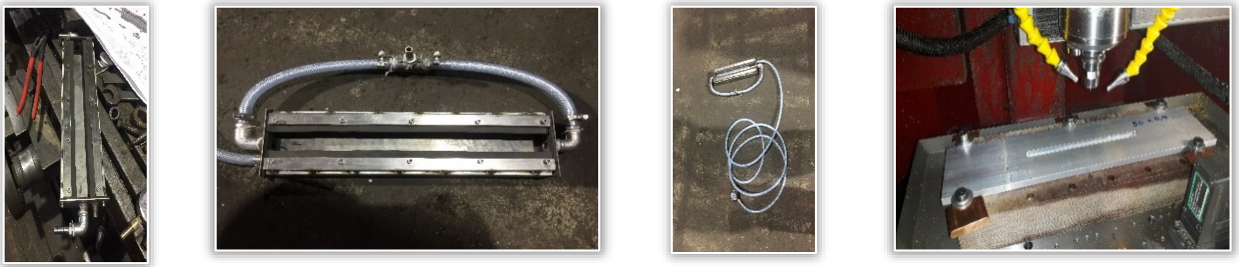


Figure 11 – Metallic diffusers

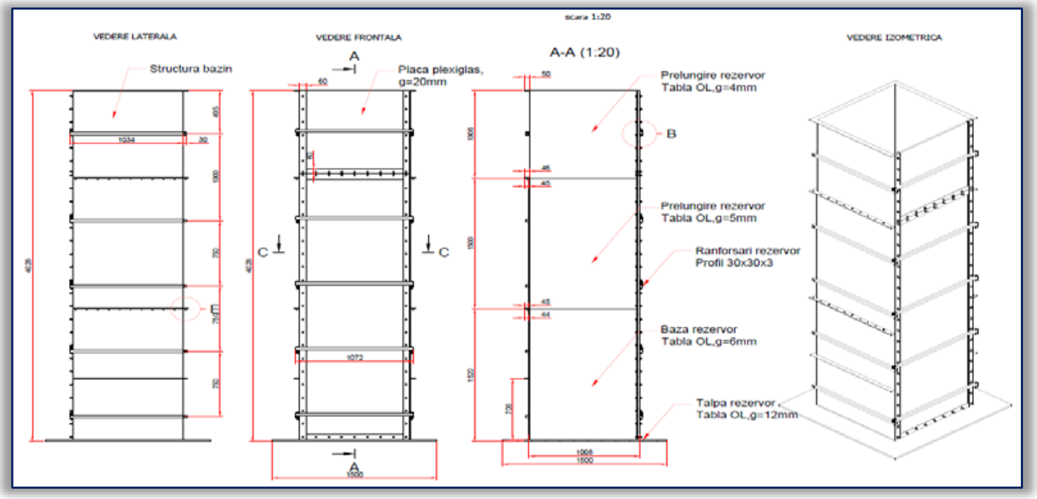
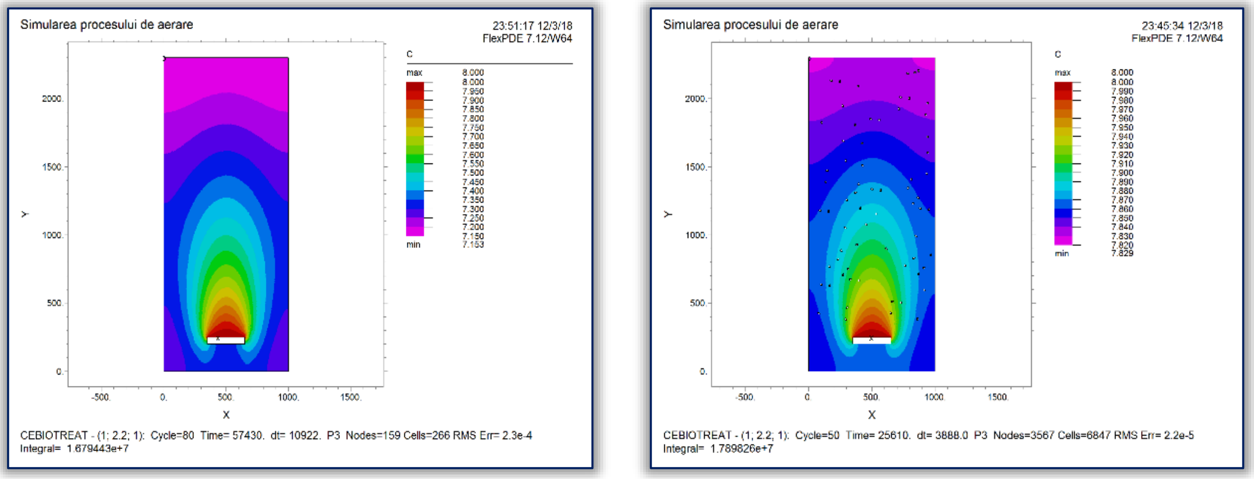


Figure 12 – Experimental installation

The efficiency of each one of the 10-air diffuser realised will be established. The principle method is to measure the modification of the dissolved oxygen (DO) concentration in time, from 0 mg/l to the saturation concentration. Zero oxygen concentration will be achieved by adding excess of chemicals. In this way, the initial DO in the water will be consumed. Sodium sulfide can be used for water deoxygenating. The moment when DO reach 0 mg/l is considered the measurements' baseline. A constant air flow will be introduced by the aeration during one set of measurements. Tap water will be introduced inside the bioreactor. A system of data collection and distance transmission will be provided for the laboratory set-up. The data measured by the DO sensor and water temperature values are recorded and sent with the help of a special modem. Following a certain modem configuration, the recorded data can be seen live on the internet by accessing a specific web address. The results are stored in the format ".csv", which are easily converted in Excel format. So, the oxygenation curves can be easily plotted and the aeration efficiency will be determined. It is desirable that the experiments take place in tanks with the height close to the real one found in the wastewater treatment plants. An example of an experimental tank is presented in Figure 12.

The experiments will be realised in 2 conditions without and with biofilm carriers. It was demonstrated, with the help of the numerical simulation (figure 13) that the presence of the biofilm carries increase the aeration efficiency.



a. Aerobic tank without biofilm carriers – DO profiles

b. Aerobic tank with biofilm carriers – DO profiles

Figure 13 - Numerical simulations of the aeration process in biological treatment tanks

Numerical simulations of the aeration process were performed considering a basin with the following dimensions: 1,000 x 1,000 x 2,500 mm. It is observed that when using the biofilm carriers, the dissolved oxygen concentration in the basin is higher than the case the biofilm carriers are not used. This fact is explained by the increase of the retention time of the air bubbles inside the basin, which on their way to the surface are slowed by the biofilm carriers.

4. CONCLUSIONS

The authors propose a new aeration system mainly used for MBBR technology, where currently medium bubble diffusers are uses. The technologies for making the new metal diffusers is an innovative one, the devices are made in two major parts: the cassette and the perforated plate with holes smaller than 1 mm. In order to prevent the clogging of these air diffusers, the authors from the Polytechnic University of Bucharest have developed an ultrasonic system that will be tested with the aeration system.

The new aeration system can be made with reduced costs, with the possibility that the cassettes can be made of different materials, including anticorrosive metals or plastics. Also, 3D printing technologies can be used to create the boxes of the air diffusers.

The authors will continue the researches by testing the efficiency of the 10 types diffusers, by establishing the optimum amount of air to be introduced into the aerobic treatment tanks and by testing the ultrasound system to prevent clogging.

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