

Materials and Technologies Used in Wastewater Treatment

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Abstract. The biological wastewater treatment is based on biofilms activity. The biofilms can be fixed on biofilm carriers, that are made from varied materials, but most of them are made from high density polyethylene. The authors propose other mixtures of varied materials to obtain an increased load of microorganisms on biofilm carriers. During the experiments the load of microorganisms was increased up to 250% compared to the load on polyethylene biofilm carriers. Also, for the aerated biological tanks an innovative aeration system made from stainless steel pipes with fine pores (<1 mm) realized by electro-erosion, is proposed.

1. Introduction

The power consumption in both municipal and industrial wastewater treatment plants (WWTPs) has considerably increased during last decades, mainly because of the increased quantity of treated wastewater. Energy consumption is the largest budget item of an European WWTP. The energy demand in this sector will probably increase soon because of population growth and because of the need to comply with stricter European regulations in the field of water treatment, generating more energy intensive processes. Furthermore, the generation of greenhouse gasses (GHG) has become important for wastewater treatment. This paper is addressed to the general problem of power consumption in WWTPs and proposes different solutions (materials and technology) to minimize the negative effects on the environment.

In WWTPs, the oxygenation process is mainly necessary for the removal of carbon and nitrogen compounds and can represent up to 80% of the WWTP's total energy consumption [1]. An oxygen process optimization is therefore imposed with the purpose to reduce the operation costs, to guarantee an efficient and reliable treatment in such installations. During the last years, the fine bubbles aeration systems were often used to improve the oxygenation process performances [2]. Smaller bubbles have a greater surface area than the medium bubbles and therefore the quantity of dissolved oxygen that is transferred from air to wastewater mass is increased. That is why most retrofits WWTPs from coarse bubble to fine bubble will produce aeration energy savings of (20 - 40)% [3].

To increase the energy consumption in WWTPs, the authors proposes an improved mobile bed biofilm reactor (MBBR) system, including a new type al biofilm carrier and an advanced air diffuser.



In MBBRs the microorganisms grow protected within small biofilm carriers, which are carefully designed with high internal surface area. These biofilm carriers are suspended and mixed throughout the water phase. In most cases the material from which the biofilm carriers are realized is based on high-density polyethylene. This material is chosen because it has a close-to-water density. The biofilm carriers are maintained in the reactor using a perforated plate at the tank outlet. Air agitation or mixers are applied in a manner to continuously circulate the packing. The packing may fill 25% to 50% of the tank volume [4]. A final clarifier is used to settle suspended solids. The presence of biofilm carriers inside the wastewater tanks discourages the use of more efficient fine bubble aeration system, which would require periodic drainage of the aeration. Currently, for MBBR medium bubble aeration system are preferred.

2. Materials used for the fabrication of the biofilm carriers

2.1. Current MBBR systems and biofilm carriers used for wastewater treatment

Most of WWTPs use a biological treatment approach, where the activated sludge process is implemented. Activated sludge is a process in which air is introduced into wastewater tanks in order to sustain the growth and multiplication of different aerobic microorganisms capable to remove certain pollutants [5]. In the wastewater treatment process, massive quantities of air are bubbled inside tanks. Air is introduced inside the wastewater mass using air blowers and this system is the largest energy consumer in WWTP, accounting (50 - 80)% of all WWTP energy consumption. The energy consumption varies depending on aeration technology used and WWTP's geographical location [6]. An oxygen process optimization is therefore imposed with the purpose to reduce the operation costs, to guarantee an efficient and reliable treatment in such installations. During the last years, the fine bubbles aeration systems were often used to improve the oxygenation process performances.

In general, to increase the efficiency of an aeration system, the oxygen quantity transferred to the wastewater needs to be increased, and this can be done by increasing the transfer area (to have smaller air bubbles) or by increasing the air quantity introduced in the WWTP [6]. The second method is an intensive power consumption process and has to be avoided if smaller operational costs are desired.

MBBR technology utilizes free-moving biofilm carriers and represents a future evolution of the activated sludge process that allows a greater pollutant removal degree in smaller systems (i.e., bioreactors) [7]. The wastewater treatment with biomedica consists in adding biofilm carriers in aerated or anaerobic basins to support biofilm growth (Figure 1).

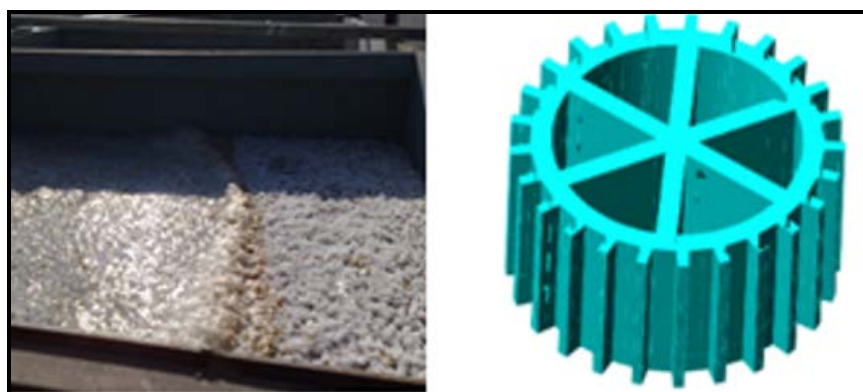


Figure 1. MBBR tank and example of a biofilm carrier.

The most common biofilm carrier has small cylindrical shape and is realized from plastic materials with a specific density close to 0.95 g/cm^3 . Regarding the biofilm carriers used in MBBR systems, several shapes and sizes are known. The majority of the biofilm carriers are realized from high density polyethylene [8, 9]. Polyethylene has hydrophobic properties and the biofilm slowly attaches. In this

context, a new material with more hydrophilic properties are proposed and tested for the biofilm carriers' realization.

2.2. New materials, based on high density polyethylene, proposed for biomedica realization - biofilm adhesion on the new materials

The authors proposed four new materials for biofilm carriers that have been tested to determine the microbial load formed on the new materials. It has been desired to obtain a material with hydrophilic properties to facilitate biofilm fixation and development. These four new materials were compared to the biofilm carrier realized from 100% high density polyethylene. So, in total five types of biofilm carriers were analysed by the authors.

The five types of biofilm carriers were incubated in the presence of activated sludge and aerated by orbital shaking (200 revolutions per minute) for 6 weeks at 20°C. The biofilm carriers were collected and treated with crystal violet (0.1%) for 15 minutes, then washed in sterile physiological saline solution (0.9% NaCl) for 4-5 times (or more) until the solution remained colourless, indicating that the excess of dye (not bound to the microorganisms) was removed. Subsequent, the biofilm carriers were treated with 30% aqueous acetic acid solution and the optical density of the solution was read at 570 nm [10].

The obtained value is proportional to the amount of microorganisms present in the microbial biofilm attached to biofilm carriers. Taking as a blank the version 1 of biofilm carriers (considered 100%), the following experimental biofilm carriers variants, developed and realized by the authors, have the following microbial loads, proportional to the intensity of the crystal violet solution absorption: 2 (120%), 3 (160%), 4 (130%) and 5 (253%). The biofilm carriers variants from 2 – 5 are made from different mixtures of (75 - 95)% high density polyethylene and (25 - 5)% other materials.

Another type of experiment (Table 1), made with only one type of biofilm carrier (namely variant no. 4), aimed at quantifying the dynamics of microbial biofilm formation, as measured by the crystal violet based method (on 5 biofilm carrier samples), but also at measuring the intensity of total dehydrogenase activity (on 5 another biofilm carrier samples) by monitoring the resazurin reduction by quantitating the fluorescence emission signal at 590 nm.

Table 1. Evolution over time of microbial biofilm formation on biofilm carrier no. 4 and its dehydrogenase activity. Optical density was determined by diluting the crystal violet solutions 10 times.

Time (days)	OD 570 nm	Resazurin reduction pg/min/ 5 biofilm carrier samples	Resazurin reduction pg/min/ DO 570
0	0.000	0	0
7	0.0947	0.5	0.528
14	0.2713	1.829	0.674
21	0.9701	386	39.79

The results show that for functional characterization of biofilm carriers it is necessary to quantify the formation of biofilm and its activity. The determination of the resazurine reduction rate is only one step, the second step of this type of determination will be the determination of the activity of biofilm formed on a certain type of biofilm carrier.

One of the ideas that emerged during the first step is precisely the possibility of immobilizing on the biofilm carrier either the complex/ native Endogenous microbiota or populations enriched in a particular physiological group (e.g. the denitrifying or ammonium oxidation bacteria) and their use in cleaning first at laboratory level and then, depending on the concrete results, at pilot level.

Additional characterization of the formed biofilm can also be done by using Sybr green staining and ethidium bromide homodimer, which enable the labell of dead cells (red fluorescence) as compared with total cells (both alive and dead - green fluorescence) (Figure 2).

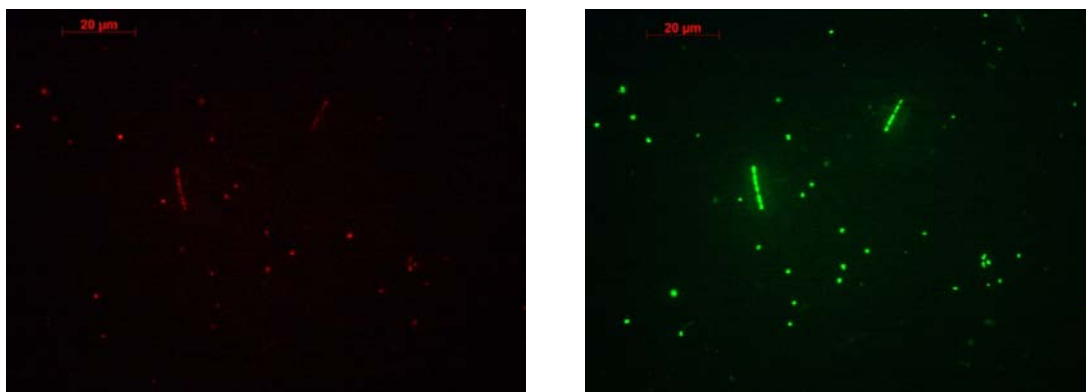


Figure 2. Live/dead cell assay on biofilm artificially cleaved from biofilm carrier no. 4. All cells are labelled with Sybr green (green fluorescence) and the dead ones are labelled with ethidium bromide homodimer (red fluorescence).

3. Aeration systems

3.1. Current aeration systems used in MBBR systems.

Currently, several types of diffusers are used in all types of WWTPs:

a. Porous diffusers (small bubbles diffusers). Numerous materials are used for the realization of porous diffusers. The most common materials that are used for porous diffusers are based on rigid ceramic and plastic materials and flexible rubber or plastic [11].

b. Nonporous diffusers. Nonporous diffusers produce larger-sized bubbles compared to the porous diffusers and consequently have lower aeration efficiency, but the advantages of lower cost and less maintenance costs may lead to a lower dissolved oxygen transfer efficiency and to increase the electrical energy costs [12]. This type of non-porous diffusers is made from perforated stainless-steel pipes.

c. Other diffusion devices. Jet aeration combines liquid pumping with air diffusion. The pumping system recirculates liquid in the biological tanks, ejecting it with compressed air through a nozzle assembly. This aeration system is particularly designed for deep (> 8 m) wastewater tanks.

MBBRs use an engineered aeration system consisting of stainless-steel pipe diffusers, manifold (or submerged air header), down pipes, and air-flow control valves. The so-called medium-bubble diffusers (nonporous diffusers) have relatively large circular orifices (i.e., when compared to membrane diffusers) situated along the underside which are less susceptible to scaling and fouling. These diffusers have slightly more efficient oxygen transfer efficiency than coarse-bubble diffusers, which is further enhanced by the presence of free moving plastic biofilm carriers. Operational experience has proven that medium-bubble diffusers require less maintenance than fine-bubble diffusers. The medium-bubble diffusers are characterized by lower oxygen transfer efficiency than fine bubble diffusers because the larger expelled bubbles travel through the water column rapidly and have a lower surface-to-volume ratio [13]. Unfortunately, the impact of biofilm carriers upon the oxygen transfer inside wastewater tanks has not been sufficient investigated; therefore, the impact of biofilm carriers on oxygen transfer efficiency in MBBR is poorly known. In MBBR aeration systems the air is introduced with the help of pipes connect to a blower. The bubbles are generated by the small orifices drilled in the pipes situated at the bottom of the biological basins. Diffusers typically used in MBBRs are 25 mm diameter stainless-steel pipes with (1 - 4) mm diameter orifices spaced (38 - 102) mm along the underside of the diffuser pipe.

Smaller bubbles have a greater surface area and therefore will transfer more oxygen. That is why most retrofits WWTPs from coarse bubble to fine bubble will produce aeration energy savings of (20 - 40). Porous diffusers made from porous ceramic materials, special glass, other porous materials are used in order to obtain air bubbles with very small diameters. Smaller pores have the disadvantage that they are more likely to clog.

Small bubbles can be also obtained by using membrane diffusers. The membrane lifetime for diffusers is 6 - 10 years in WWTP, depending on wastewater influent and operation conditions.

3.2. Modern technology for water aeration in biological water treatment plants.

The authors propose an improved aeration system that combined the advantages of stainless steel aeration systems (nonporous diffusers) with the porous diffusers. The authors conceived a metallic diffuser with very fine holes made by electro-erosion. In this way will be obtained a porous diffuser from a resistant anticorrosive material.

Some of the advantages of using an electro-erosion are specified in literature [14]: realization of complex shapes that would otherwise be difficult to produce with conventional cutting tools; extremely hard material are processed with very close tolerances; very small pieces can be shaped where conventional cutting tools may damage the part from excess cutting tool pressure; there is no direct contact between tool and work piece; delicate sections and weak materials can be machined without any distortion; a good surface finish after the drilling.

In this way the authors will obtain an innovative fine bubbles diffuser made of stainless steel (or of different metals and/or alloys). Very small holes are difficult to obtain by conventional machining processes. Holes in metal are obtained using an electric machine with a metal drill. Depending on the diameter of the drill different hole diameters are obtained. Due to material resistance reasons the drills cannot be very small in diameter, so that small holes cannot be obtained in metal materials by using conventional technologies. Small holes (<1 mm) will be realized by electro-erosion drilling.

The new aeration system made of stainless steel proposed by the authors has the following advantages: is sturdy and also resists to the interaction with the mobile biofilm carriers; there are no problems with the storage of diffusers until commissioning of the treatment plant; less maintenance than classical fine bubble diffusers; the pressure loss for the ceramic porous diffusers, which are currently being used, is 110 mm CA, while the pressure loss for the new fine bubbles diffusers is close to 24 mm CA for the same mode of operation. Thus, the pressure loss reduces with 1076 mm CA. This approximation is made for a single diffuser; the annual energy consumption for 1 ceramic porous diffuser is 16.47 kWh/year, while the annual energy consumption for the new diffuser is estimated at 0.356 kWh/year for the same mode of operation. Thus, the energy consumption can be reduced with 16.114 kWh/year/diffuser.

4. Conclusions

The wastewater treatment market is a mature industry that has been subject to decades of continuous tightening of water quality regulations. In addition, the entry into force of more stringent regulations at EU level will boost investments in new technologies so as to upgrade and optimize existing WWTPs probably reaching 350,000 € millions in 2025.

For these reasons the research team focused the attention to develop new and efficient equipment for wastewater treatment. It is proved that the new materials and manufacturing procedures (for both biofilm carriers and air diffusers) can lead to significant improvements in WWTP; increased treatment efficiency and decreased operational costs can be obtained by using the new material proposed by the authors. During the following experiments, *in situ* determination will be realized.

5. References

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