Wastewater treatment in membrane bioreactors. Features and application

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Abstract. Membrane bioreactors nowadays are intensively applied in wastewater treatment worldwide. Such type of treatment systems have a large scope of implementation at facilities of different capacity. Small space demand allows placing them in conditions of limited area available. Treatment using of MBR is a combination of sludge treatment and membrane filtration. Although the idea of replacing the conventional sedimentation tank activated sludge was attractive, it was difficult to adjust complex process operation of wastewater treatment due to three factors: high cost of membranes, low economic value of grey wastewater, as well as the rapid loss of membrane performance due to the pollution of her pores. Membrane module is used for the separation of sludge liquor that is an alternative to common sedimentation in secondary clarifiers. The article reveals the main features of membrane bioreactors application, concerning its advantages and disadvantages.

1. Introduction

Today, implementation of membrane technologies and equipment based on them goes in a very intensive way in many countries. Membrane bioreactors (MBR) for wastewater treatment is one of the most prospective and rapidly developing technologies that can be applied not only for large-scale projects, but also for single buildings or small objects connected to municipal water supply and sewage systems. Compact dimensions of MBR facility allow their placing even in basements of the buildings. The amount of produced wastewater in small objects is sufficient for MBR operation, which may save drinking water consumption and reduce the load at municipal water supply and sewage systems.

2. Features of the MBR technology

A membrane bioreactor combines biological treatment with active sludge with membrane mechanical filtration. The membrane module (figure 1) used for the separation of sludge liquor and is an alternative for a widely used method of activated sludge sedimentation in the secondary clarifiers, used in conventional systems of biological treatment in the aeration reactors (figure 2) [1,2].

The idea of membrane bioreactors has been implemented in the late 1960s, as soon as membrane ultrafiltration (UF) and microfiltration (MF) have become available not only for scientific but also for commercial use. The original process was introduced by the Corporation Dorr-Olivier – they used a combination of activated sludge and membrane filtration. Flat sheets membranes used in this process were made of polymers with pore size from 0.003 to 0.01 μm [1,3].

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cost of membranes, low economic value of grey wastewater, as well as the rapid loss of membrane performance due to the pollution of her pores. Because of the low payback all membrane bioreactors of first generation have been used only at few sewage treatment plants with special needs, e.g. at ski resorts [4-6].

Figure 1. Membrane bioreactor scheme: 1 – reactor; 2 – aerator; 3 – hollow fiber membranes; 4 – air; 5 – treated water; 6,9 - pumps; 7 – manometer; 8 – filtrate

Figure 2. Conventional scheme of treatment and treatment with MBR

Thus, one of the economic parameters for the first MBR facilities was their high cost and short lifetime of the membranes. There was a breakthrough in the development of membrane bioreactors happened in 1989, when the Corporation "Yamamoto" decided to put the membrane directly into the
bioreactor. Until then, all membrane bioreactors were installed in separate facilities and their principle of operation was based on high transmembrane pressure to maintain filtration, and this required maintaining a large flow of wastewater [2, 4, 7].

Treatment systems with membrane submerged in the bioreactor operate at a lower flow of sewage and use significantly less energy (power consumption can be two orders of magnitude lower than that of separate systems). In the configuration with the submerged membrane aeration is an important parameter that affects the process of water treatment. Aeration keeps solids suspended, cleans membrane surface and provides oxygen to the biomass for better biodegradability and cell synthesis.

Another economic factor is the power consumption, considering which provides the improvement of the bioreactors. Another key step in the recent development of membrane bioreactors the idea was to use a two-phase fluid for contamination control. This led to automation of cleaning processes. Low operating costs achieved within the application of submerged membrane bioreactor, along with a steady reduction in the cost of membranes has led to a significant increase of implementation of facilities since the mid 1990-ies. Since that time permanent research how to modify the design, to create improved types of membranes, to select of optimal flow rates of wastewater and the aerated air in order to increase the lifetime of the membrane are under way. The result of this research is smoothly operated process with implemented back-flushing, which allows stable operating of membrane bioreactors and consuming less energy for the process.

3. Construction of membranes

In the technology of MBR membrane modules (figure 3) are used the following basic designs: hollow fiber, flat, tubular. Table 1 shows comparison of different designs of membrane modules. The main type of membrane that is used now both for pressurized and submersible MBR is hollow fiber membrane modules which have the highest packing density, low material consumption and minimum cost [8, 9].

![Figure 3. Construction of membrane module](image)

### Table 1. Comparison of membrane features

| Parameter                  | Hollow fiber | Flat          | tubular          |
|----------------------------|--------------|---------------|------------------|
| Material                   | Polymer      | Polymer       | Polymer / ceramics |
| Placement density, m²/m³   | 300 – 600    | 50 – 150      | < 300            |
| Material demand            | Minimum      | Maximum       | Average          |
| Unit capacity              | Average      | High          | Low              |
| Mechanical properties      | Minimum      | Average       | Maximum          |
| Clogging ability           | Average      | Maximum       | Minimum          |
| Reverse washing resistance | Average      | Low           | Maximum          |
| Replacement ability        | No           | No            | Yes              |
| Cost                       | Minimum      | Average       | Maximum          |
Membrane for MBR are manufactured from the following materials: polyvinylidene fluoride, polyethersulfone, polypropylene, polyethylene, less chlorinated polyethylene, polysulfone, polyacrylonitrile, etc., In some cases, in membrane bioreactors used ceramic membranes of aluminum oxide, titanium, zirconium.

4. Features of MBR application
The advantageous features on membrane technologies comparing to conventional treatment can be as follows [5-7]:

– full detention of all suspended solids and microorganisms;
– maximum removal of suspended solids;
– enhanced removal of COD and BOD5;
– disinfection of treated water;
– low sensitivity to flow fluctuations and the quality of the source water;
– minimum HRT in the zone of separation of the solid phase;
– full retention of microorganisms in the reactor, which significantly changes the conditions of autoselective microorganisms of activated sludge;
– less area required for facility placement.

Within the application of membrane bioreactors operating parameters can be adjusted. Thus, if the load is high it is possible to increase the age of active sludge and accumulate slow-growing species of microorganisms (nitrifying microorganisms, oxidizing bioresistance connection). Moreover, the HRT of suspended solids can be extended until their complete biological degradation. One more feature to be considered is a growing resistance to parameters of the flow and pollutants concentration. As a result, the oxidation and hydraulic capacity may be significantly increased [3, 10].

There are also disadvantages to be meant that may reduce possible area of membranes implementation:

– high capital costs (cost of the membrane units is almost independent of performance);
– contamination of the membranes (and corresponding costs);
– high operation costs (electricity and membrane replacement);
– complicated management and control system;
– ensuring a sufficient level of aeration at high concentrations of activated sludge.

5. Description of factors affecting membrane operation
In this section factors to be considered if treatment with membrane technologies is meant will be overviewed.

Material of membranes. The choice of material is depended to the resistance to contamination substances contained in the treated wastewater (in particular, the intercellular organic substances, polysaccharides and proteins) and chemical resistance to washing procedures of the membrane modules. Most of the membranes have hydrophobic properties. The charge of the membrane also affects the degree of its pollution (e.g. membranes with a neutral charge is more resistant to sediment E. Coli bacteria group, that have positively and negatively charged groups on the surface). Manufacturers of membrane normally modify their surface by inputing various additives to the chemical composition of their material to improve the performance. Therefore, membranes from different manufacturers, made of the same material such as polyvinylidene fluoride, can have differences in characteristics [11].

Size of pores of the membranes is not critical: MF membranes with a pore size of 0.1 – 1 microns and UF membranes with a pore size of 0.01 – 0.1 µm shows almost the same efficiency in removing suspended solids and microorganisms, equalized by the accumulation of sediment on the surface of the membrane in the filtration process. Reduction of pore size improves the stability of the membrane to contamination, and their hydraulic flushing can help to remove sediment from the surface. Membranes with larger pores have a greater permeability, but have more significant decline in their performance.
Moreover, if the detention of viruses is needed, it is preferable to use a membrane with a pore size of less than 0.1 microns [5, 9].

**Membrane permeability (permeate flux).** The flow through the membrane is the main factor influencing the rate of formation of precipitate on its surface. There is the concept of "critical flux", above which the growth of the precipitate becomes invalid for the normal functioning of the membrane module. Many MBR facilities work with a constant performance, which is achieved by adjusting the transmembrane pressure. The pressure increase on the membrane in the process causing compression of the sediment and increase its resistance. During operation of membrane units should be avoided achieve a significant drop in the permeability and in a timely manner to conduct hydraulic and chemical wash. A number of researchers noted the phenomenon of the sharp decrease in the permeability of the membrane after a period of filtration (about 500 – 1000 hours). Up to now there is no clear explanation of this phenomenon [12].

**Aeration of the membranes.** The main way to control the process of membrane pollution is blowing their bubbles that remove deposits from the membrane surface and mix the surrounding fluid, improving the mass transfer. The cost of aeration / venting of the air is one of the main components of operational costs in MBR. Air flow to the membrane module is 0.2 to 1.3 m³/h per 1 m² of membrane in it. This value depends on the amount of fluid around the membranes, the specific area of membranes, intensity of air flow.

**The speed of movement of the filtered liquid near the surface:** as for submerged membrane modules increase the speed of the surrounding fluid has no significant positive impact on the removal of dirt from the surface of the membranes, on the contrary, there may be a violation of the flows of air bubbles and reduce the effectiveness of the air purge. For pressure tubular modules increase the speed of movement of the liquid within the tubular membranes allows reducing sedimentation and improving performance, but energetically it is more advantageous to combine this method with air purge (for example, the technology of "AirLift" Pentair).

**Hydraulic flushing.** Flushing with a reverse flow of the filtrate is an efficient tool to avoid sedimentation taken form ultrafiltration systems for water purification. As a rule, modules with flat membranes (except roller designs) do not allow reverse flushing. The intervals between back flushing and their duration are in the range 10 – 60 minutes and 15 – 300 seconds, respectively. MBR facilities also used pulsed flushing – frequent (1 every few seconds) pulses of the reverse current of the filtrate with less than 1 second. Operating experience of membrane bioreactors has shown that there is a simple way to reduce clogging of the membranes is a periodic suspension of filtration. At this point, the flow of air and fluid around the membranes to carry away with it the surface of the particles of impurities, and convective / diffusive flow of dissolved and colloidal impurities. The duration of the "downtime" of the membrane units is approximately 5 – 15% of the total time of their work.

**The nature and composition of the incoming wastewater.** The presence in waste water of a large amount of easily biodegradable organic matter contributes to the formation of a larger amount of extracellular polymeric substances (polysaccharides, proteins) that can clog the ultrafiltration membrane. Since membrane detain suspended matter, and partly polysaccharides and proteins, the concentration of these substances in the bioreactor increases, which causes an increase in resistance of the produced sludge. The increase in sludge age helps to reduce contamination of the membranes by reducing the content of polysaccharides in the sludge. It is also noted that in conditions of malnutrition adhesion of cells of activated sludge on the membrane surface becomes lower. The phenomenon of bacterial adhesion on the membrane surface and their subsequent growth helps to reduce irreversible membrane pollution other components and additional tertiary treatment of wastewater.

It was also established that, as a rule, the size of floccula of activated sludge in MBR is lower than in conventional facilities – aeration tanks, and the number of smaller particles increases with the sludge age.

Because of the membrane, especially the fibrous, are, in fact, the trap of floating impurities and a major suspension, the presence in water of such impurities is unacceptable. Given that the MDBs operate without primary sedimentation, the requirements for grids – it is recommended to install lattice
(grid) with prozorni not more than 1 mm, better 0.5 mm. Usually at stations set two types of grids: the first step - conventional screens of 4 – 6 mm in width, and the second step (after sand traps) recommended to protect the membranes screens of 0.5 – 1 mm in width.

6. Conclusions
Membrane bioreactors now have growing implementation world-wide, that is confirmed by the advantageous features over conventional treatment. A certain attention should be paid to type of membrane modules according to their characteristic features and operation peculiarities. High cost and integrated control and management systems remain as limiting factors for wider MBR application.

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