Research of operation efficiency of side-stream membrane bioreactors

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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. A detailed study required to analyze how to implement reconstruction of WWTP by means of membrane equipment that can be located close to existing facilities of biological treatment in small containers without the installation of new capital containers is required. Following that goal there is a certain interest to investigate the operation of side-stream membrane bioreactors under various pressure conditions and to compare its corresponding efficiency and costs (capital and operation). The paper is focused on estimation of operation parameters (backwash frequency, power consumption and specific energy consumption) for three values (1.6 g/L, 2.5 g/L and 7 g/L) of mixed liquor suspended solids (MLSS) if the filtration goes under pressure of 0.5 bar.

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 [1-3], but also for single buildings or small objects connected to municipal water supply and sewage systems[4,5]. Compact dimensions of MBR facility allow their placing even in basements of the buildings [6]. 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. Materials and methods
The most common solution for a membrane bioreactor is a submersed membrane module, which often requires additional tanks [7, 8]. However, in case of reconstruction of small wastewater treatment plants (WWTP), it seems more convenient not to violate the existing technology and vertical lay-out of plant, especially in case on strict spatial limits [9-11]. A detailed study required to analyze how to implement reconstruction of WWTP by means of membrane equipment that can be located close to existing facilities of biological treatment in small containers without the installation of new capital containers is required [12-14].
Following that goal there is a certain interest to investigate the operation of side-stream membrane bioreactors under various pressure conditions and to compare its corresponding efficiency and costs (capital and operation). The objectives of our research are:

1. To study the process of detention of suspended particles (of active sludge) using membrane methods at different values of operating pressure.
2. To increase performance of membrane bioreactors, as well as to determine the optimal range of working pressure under which it is possible to prevent clogging of membranes and breakthrough of the contaminants in the filtrate.

In this paper, there is a focus at studying the performance of membranes at different concentrations of mixed liquor suspended solids (MLSS) in order to obtain data on the specific performance of membranes.

Membrane elements with capillary ultrafiltration membranes were used for the bench-scale research with pore size of 0.1 micron and total area of membranes surface of 1 m². The above-mentioned membrane module was of standard characteristics (pore size, material) for ultrafiltration membranes.

The bench scheme is shown at figure 1. The feed wastewater (mixed liquor after the stage of biological treatment) goes from the feed water tank 1 to the membrane apparatus 3 using the working pump 2. The working pressure is regulated by means of a hydroaccumulator tank 4, pressure switch 5, a bypass valve 10, and a pressure gauge 12. The filtrate after the membrane module was collected in the filtrate samplers 7.

A mandatory condition for the functioning of membrane modules is their backwash. Deionized water obtained at the reverse osmosis plant was used for backwashing. The initial wash water was placed in the wash water tank 8. Switching tanks was performed using valves 6. The working pump fed the wash water into the filtrate path; afterwards it was collected through the source water path to the wash water samplers 9. Switching of pipelines was carried out by means of valves 6. Pressure control was carried out using a pressure switch 5, a bypass valve 10 and a tank-accumulator of washing water 11.

Figure 1. Scheme of the bench-scale model: 1 – feed water tank; 2 – pump; 3 – membrane module; 4 – hydroaccumulating tank; 5 – pressure switch; 6 – valve; 7 – sampler tank; 8 – washing tank; 9 – washing water sampler; 10 – bypass valve; 11 – hydroaccumulating tank for washing; 12 – pressure gauge.
3. Results

There were three concentrations of MLSS investigated within the research. MLSS concentration of 1.6 and 2.5 g/L are similar to those in conventional activated sludge systems (if in case of reconstruction side-stream MBR is applied afterwards), MLSS of 7 g/L is in a range of optimum values for submerged MBR. Operation pressure was taken of 0.5 bar that is a pressure used for vacuum-driven membrane bioreactors [15]. Basing on experimental results, dependencies of product water volume obtained throughout test cycle to time and MLSS values are developed and shown at figure 2.

![Figure 2. Growth of permeate volume through time](image)

It is predictable, that higher efficiency (or higher filtered volume) was achieved at low MLSS value (1.6 g/L). In condition of 2.5 g/L and 7 g/L efficiency is 20% and 50% lower respectively. So we can see that the efficiency drops not as dramatic as it may be expected comparing to difference between max and min MLSS values. The most intensive growth of filtrate production is witnessed at the initial period of filtration – almost linear growth can be seen within first 3 minutes (for all three MLSS). Afterwards, the intensity is decreasing especially in case of high MLSS due to fouling resistance.

![Figure 3. Flux decrease within filtration cycle (pressure=0.5 bar)](image)
The same process can also be described through the dependence between flux and duration of filtration (figure 3). High MLSS value results in instant pore fouling and flux drops three times after 2 min of filtration. However, after initial clogging the process decelerate showing similar intensity with two other values of MLSS. To determine the volume penetrated through membrane during certain time, we can select time on abscissa axis and then draw straight line parallel to ordinate axis. Area of obtained figure corresponds to volume of filtered wastewater during selected time.

For our further investigation of operation conditions, we focused at three possible operation modes – filtration cycle duration of 3, 6 and 10 minutes or 20, 10 and 6 backwashes respectively (figure 4). It is obvious that the shorter filtration cycle is, the larger is product water volume. On the other hand, the more often backwashes are applied, the larger is the volume of water required to implement efficient backwash and the lower is “useful” product water amount defined as a difference between total product water amount and water used for backwashing. Backwash efficiency depends on product water pressure value and time period of backwash. In addition, backwash efficiency can be evaluated as percentage of foulant (suspended solids) removed from membrane surface. Therefore, it seems very important to define balanced duration of filtration that corresponds to minimal operational costs.

Figure 4. Filtered volume of wastewater in different operation conditions

Figure 5. Flux determination in case of different backwashes amount
Experimental data processing for experiments are presented on figures 5 and 6. Figure 5 shows dependencies of specific membrane flux (L h⁻¹) to MLSS concentration and frequency of backwashes. Total product flux of membrane module decreases with the increase of suspended foulant concentration. Figure 6 demonstrates dependencies of flow used for backwashing on washing frequency and suspended matter concentration in the feed water. As it can be seen, the increase in MLSS tends to increase in water consumption due to increase of frequency of backwashes and washing time.

**Figure 6.** Backwash flow intensity in case of different backwash frequency

Figures 7-9 shows examples of evaluation of “useful” product water flow as a function of MLSS during operation of the module at a pressure of 0.5 Bar for various backwash frequencies performed at 2 Bars. Figure 7 refers to frequency of 20 backwashes, figure 8 – to 10 backwashes, and figure 9 – to 6 backwashes. There are four graphs at each of these figures referring to following: a flow of single cycle of filtration (Q₁f); a flow used for backwash (Qₜ); a total flow (Qₜₜ) that is a sum of Q₁f and Qₜ; a useful flow (Qₜ), which is a difference Q₁f and Qₜ.

**Figure 7.** Dependencies of flows to MLSS in condition of 20 backwashes
Having an optimum operation mode determined the next step of the research was to define the entire energy consumed and the specific energy consumption per flow units. Within this we assumed that according to Q-H function of centrifugal pumps electric power required to pump up 1 m³/h at 1 m of height is 0.5 kW. Figure 10 shows values of specific energy consumption calculated for the useful flow values shown on figures 7-9. Afterwards we have determined real energy consumption (figure 11) to provide useful flow. That means that real energy consumption should sum up both power for filtration and power for backwash, so the specific energy consumption can be determined as the relation of real power consumption to useful flow.
4. Conclusions

1. The analysis of flow values showed that the flow increase intensity has maximum values within first three minutes of filtration. The intensity then drops due to fouling resistance especially at high MLSS values.

2. Shorter filtration cycles provide higher overall amount of filtered water, however it also means more frequent backwashes that increase water needs for that purpose.

3. The value of MLSS has a strong impact at plant's performance by affecting at specific energy costs as they significantly grow.

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