Third Report on the Technical Evaluation of Membrane Bioreactors (MBRs): Energy Efficiency and Response to Inflow Variations (Draft)

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Technical Evaluation Committee
Japan Sewage Works Agency

Technical Evaluation Committee

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Background of the Technical Evaluation

Membrane Bioreactor (MBR) is an activated sludge process that carries out solid-liquid separation by membrane. It features excellent capabilities, such as generating high-quality treated wastewater at compact facilities. As of March 2022, 25 wastewater treatment plants (WWTPs) in Japan have MBRs in operation. While many of them are newly constructed small-scale facilities, MBR is expected to be an optimized solution for medium- to large-scale facilities with land limitations when upgrading to nutrient removal or significant retrofitting.

The Japan Sewage Works Agency (JS) has consistently pursued MBR's research and development since initiating its demonstration project for application in WWTPs in 1999. In November 2003, JS conducted the first technical evaluation for MBR to clarify its applicability to the wastewater treatment process and to review its design and operational management notes. JS also established its internal design procedures for small-scale and newly constructed facilities, contributing to the introduction of the first MBR in Japan and its popularization and development. After the initial evaluation, as MBR progressed in its technical development and increased adoption, JS implemented a second technical evaluation in April 2013 to expand the MBR application to retrofit opportunities in medium to large-scale facilities. The second evaluation aimed to systematize and clarify the detailed technical features of MBR diversity, proposing versatile planning, design, and operational management schemes applicable to medium- to large-scale facilities.

The second technical evaluation presented two key points: ①MBR's energy and cost savings, and ②the expansion of application targets, including combined sewerage, as the next R&D direction to enhance functional improvement further and encourage adoption. JS has implemented the technology development of a new MBR system focusing on these two points. These endeavors have clarified the current standards for MBRs' energy-saving performance and operational capabilities in response to inflow variations, including rainfall. In addition, the standard performance evaluation scheme of MBR has been considered, and information was collected regarding membrane replacement at WWTPs. Evaluating and publishing MBR's current technical performance based on the latest knowledge significantly contributes to the further expansion, promotion, introduction, and technical development of its applications. Based on the above background, the Third Technical Evaluation was implemented in November 2021.

Objectives of the Technical Evaluation

The Second Technical Evaluation addressed two issues of MBR: ① Energy-saving performance and ② the flow variation response range.
The Third Technical Evaluation will clarify MBR's current performance standards based on the demonstration results of the Second Technical Evaluation.

Additionally, regarding ③Performance evaluation methods of MBR and ④Membrane replacement status, the Third Technical Evaluation will compile the knowledge gained after the second evaluation to promote the application and implementation of MBR.

Evaluation Target Technology

The Third Technical Evaluation targets the MBR, which is used for the second treatment and nutrient removal. To evaluate the energy-saving performance and the response range of inflow variation, the study results of four types of MBR systems, as demonstrated by joint research with private companies, are utilized; however, this does not evaluate the performance of each MBR system individually. These four MBR systems, which are either immersed or combined types, are modified Ludzack-Ettinger processes that incorporate recycled nitrification/denitrification processes as a biological treatment method.

Scope of Evaluation

The Third Technical Evaluation will only cover the newly identified matters of the four items mentioned after the second evaluation. Based on the results of the Second Technical Evaluation, other issues related to MBR will be excluded from the Third Technical Evaluation.

The Third Technical Evaluation shall scope reaction tank facilities, membrane separation facilities, and pre-treatment facilities, which include primary sedimentation tanks and fine screens.

Energy-Saving Performance of MBR

1. Energy consumption mechanism of MBR

① An MBR system consumes energy for various equipment. The primary equipment of immersed MBR is a sludge scraper and a raw sludge pump of the primary sedimentation tank, if it was used, a mixer and internal circulation device of the reaction tank, a blower for aeration cleaning or biological auxiliary diffuser, membrane separation devices, such as membrane filtration pumps and chemical cleaning devices, and excess sludge pumps.

② The blower is the highest energy consumer of the above, accounting for 70-80% of the total energy consumption in the MBR system.

2. An approach to saving energy in MBR systems

① Reducing the power of blowers is the most effective way to reduce the MBR system's power. However, since the power of the other facilities cannot be ignored, the fundamental approach to saving energy for MBR involves reducing the driving powers of multiple facilities.

② Many case examples try to reduce the Specific Air Demand per permeate (SAD_p) by decreasing the Specific Air Demand based on membrane area (SAD_m). This initiative enhances membrane elements or units, including extended membranes, higher-integration multi-stage units, and enhanced diffusers. On the other hand, there is an example of making membranes have higher flux. This approach aims to reduce SADp by reducing the size of membrane areas. Besides, there are other initiatives to reduce SAD_m and SAD_p, including improving aeration methods for membrane cleaning, such as intermittent or automatic control, enhancing the filtration performance of activated sludge, such as lowering activated sludge concentration and chemical addition, and inhibiting various forms of fouling, such as improving or optimizing chemical cleaning methods. While the reduction effect of the blower's power by reducing the aeration airflow rate is offset by increasing the aeration airflow rate of the auxiliary diffusers, the latter rate never exceeds the former rate

③ There are approaches to reducing the power of the auxiliary diffuser, such as making diffusers highly efficient, improving dissolved oxygen efficiency by reducing activated sludge concentration, and automatic control of the aeration rate, such as DO control or ammonia control.

④ Adopting gravity filtration for membrane filtration, siphon filtration, airlift pumps for internal circulation, and low-power agitators for anoxic tanks are examples of reducing the power of facilities other than blowers.

3. Energy consumption of MBR

① The four MBR systems, which the Third Technical Evaluation deals with, focus on making membranes longer, high integration, higher flux, and reducing cleaning aeration rate by improving chemical cleaning methods as energy-saving approaches. Specific MBR systems can conserve more energy by integrating siphoned filtrations with low air flow rate diffusers. Consequently, these MBR systems have demonstrated the capability to maintain stable membrane filtration under reduced cleaning aeration conditions, with SAD_m of 0.15-0.20 $Nm^3/(m^2 \cdot hr)$ and SADp of 4.6-8.0 Nm^3/m^3.

② For these four kinds of MBR systems, the estimated unit energy consumption per treated wastewater scoping a treatment capacity of 50,000 m^3/day was 0.25 - 0.38 kWh/m^3 when the facility is designed to treat daily average wastewater. This means that energy-saving MBRs with a unit energy consumption of 0.3 kWh/m^3 or below are becoming a reality, and this figure is equivalent to the average unit energy consumption of conventional advanced treatment/nutrient removal processes.

③ Energy-saving MBR can reduce energy consumption within the range of the above-mentioned estimation for the four MBR systems; it can also reduce construction costs by reducing the blower's volume and the membrane unit's price.

Inflow Variation Response of MBR

1. Operation of flux variation and peak flux

① The MBR system can adapt to short-term inflow variation by time changes and rain weather through "Operation of flux variation," which can change the membrane treatment flow rate by linking the flux. Since the response range is determined by "peak flux," which is the upper value of temporarily increased flux, clarifying its level is essential.

② The four MBR systems that this Third Technical Evaluation deals with have demonstrated that the systems enable stable long-term operation within 0.7-1.2m/d peak flux against the standard time variation of inflow rate. This figure is equivalent to 1.4-1.5 times the daily average flux of each MBR system.

③ Conversely, these MBRs have demonstrated that peak flux enables continuous 24-operation ranges of 1.1-1.2m/d against inflow increasing in rainy weather. This value is equivalent to 1.4-2.0 times the daily average flux at fine weather of each MBR system.

2. Notes on the flux variation operation

① The above-mentioned peak flux levels are ranges within the stable operation. In the individual MBR facility, clarifying the acceptable conditions for flux fluctuation operation during actual operation is essential.

② When performing flux fluctuation operations against temporary inflow variations, some MBR systems require increasing the aeration airflow rate for membrane cleaning to prevent membrane pressure.

③ Some MBR systems require changing chemical cleaning requirements or increasing aeration air volume when performing flux fluctuation operations against increased inflow in rainy weather.

Other Items

1. Performance evaluation methods of MBR

① There has been no standard evaluation method for MBR performance in Japan. Based on a specific evaluation scheme, evaluating and clarifying the performance of membrane units and the entire system operations used in individual MBR systems are essential for improving MBR technical reliability and promoting its implementation.

② There are four kinds of performance evaluation methods for membranes: the "Bore diameter measurement test," the "Pure water permeability test," and the "Bacteria inhibition capability test," which characterize membranes and verify their performance, and the "Assembly integrity test," which aims to confirm that membrane elements have no leaks.

③ There are two evaluation methods for MBR systems. The first is "Operation performance evaluation," which verifies the performance of biological or membrane treatments at actual facilities or experimental plants. Another is "Energy consumption evaluation," which verifies the energy-saving performance of the entire MBR system at actual facilities or experimental plants.

④ Aside from standardizing and operating these performance evaluation methods, standardizing reports and indications of membranes or MBR systems specifications based on the evaluation results are essential.

2. Membrane replacement status for MBR

① In MBR systems, membrane treatment performance may decrease due to fouling progress, which is not recovered by usual chemical cleaning, or treated water quality may decrease due to damaged membrane elements or units. In these cases, MBR systems require replacement of the membrane with a component or unit. Clarifying membrane replacement costs is crucial for accurately evaluating the costs of MBRs. Hence, organized information on membrane replacement at actual facilities is required.

② Information obtained from fifteen domestic WWTPs with MBRs in operation for 10 years or more showed that seven WWTPs have not replaced their MBR membranes. Four WWTPs have had below 10% accumulated replaced membrane areas, representing 73% of all WWTPs.

③ Besides the above facilities, four WWTPs, partly including aeration tank lines, have more than 20% of accumulated replaced membrane areas after 10 years of operation. While two of the four WWTPs have replaced the membrane units of all aeration tanks, it is assumed that one experienced an unexpected, unique inflow, and another had continuous insufficient membrane cleaning due to an unstable aeration airflow rate. The other two WWTPs have replaced several membrane elements due to damage, which may be caused by heavy accumulation of fouling inside the aeration tanks.

④ Five WWTPs out of fifteen have started replacing membrane units after 11-16 years of operation based on the manufacturers' suggestions or the membrane unit's standard service life.

Future Development Direction

The social landscape has undergone significant changes due to population decline, decarbonization, and the acceleration toward achieving a circular economy. Wastewater projects require decarbonization initiatives, efficient and effective city planning, and expanded collaboration with other business fields to contribute to the community's revitalization and strengthening while maintaining their original mission: conserving the water environment and promoting water circulation. MBR is a promising technology due to its substantial benefits, including the creation of compact facilities suitable for renovation and wide-area or collaborative management with a limited footprint in urban areas, the improvement of water environments, the promotion of reuse, and the reduction of risk from pathogenic microbes.

MBR requires an urgent reduction in GHG emissions throughout the lifecycle of construction, renovation, retrofit, and disposal, as well as R&D to achieve low-cost projects that promote and expand utilization for various demands. These initiatives are essential keys to MBR's future development direction.