Application of MBR to an easily installed municipal wastewater treatment plant

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Abstract An easily installed wastewater treatment plant was developed using an MBR process. The plant consists of inlet pumps, automatic fine screen, a main reactor in which aerator-mixer and MF membrane separators are installed and a control board. The main reactor is a sheeted pond which is easily constructed on-site by an excavation. As a result, the installation of this plant is easy and inexpensive, operation is easy, yet the effluent quality is high. The 50 m^3/d pilot plant was constructed in our experimental facility in Ibaraki Pref., and operated from January 1997 to April 1998 to evaluate performance, stability and the ease of separation and installation of each unit. The results were satisfactory in all areas, except the durability of membrane permeability in the latter half of the experiment. For both hollow fibre type and plate type, membrane permeability immediately decreased due to the deposit of concentrated sludge cake on the surface, even though continuous bubble washing had been made. Hence, drastic improvement is needed in the way of sludge deposit control on the membrane surface. This is the key for the developed system to become a practical one.

Keywords MBR; municipal wastewater treatment; single reactor; advanced wastewater treatment; easy installation; small scale

Introduction

The popularization of sewerage in Japan has reached a prescribed level in large cities and the kernel cities of each province, although it is still low in small to medium size municipalities. Recently, the focus of sewerage construction has moved to these small to medium size municipalities and the suburbs of large cities, where the regional sewerage system is a normal sewerage system. Normally, a regional sewerage system needs much time for the construction of sewer mains, so the environmental improvement of rivers or other receiving waters tends to be delayed. In such cases, from a point of promoting environmental protection, it is desirable to begin the wastewater treatment earlier temporally, for the municipalities where sewerage pipe nets had already been constructed except for connection to the regional trunk sewer main. Some temporal wastewater treatment plants have already been operating under the system of tentative municipal wastewater treatment plants. The system promises to scrap the temporal plant after connection to the regional sewer mains. Thus, it is not economical if the temporal wastewater treatment plant has an insufficient operation term. The adequate operation term in the existing system is between ten to 15 years, longer than the time before the beginning of regional sewer services for many municipalities. If the temporal treatment plant is portable and can be used repeatedly, the adequate term will not be an important condition because the plant will be used in another place until the end of its mechanical life. Therefore, the development of a portable wastewater treatment plant has been planned.

We propose an MBR using a sheeted pond, as a modified portable wastewater treatment plant. The main reactor of the proposed system is newly constructed on-site whenever the plant moves, because the sheeted pond construction is easy and inexpensive. The pond is easily restored to the original land conditions, which reduces the psychological resistance of the landowners to rent their land for a wastewater treatment plant. The system has only

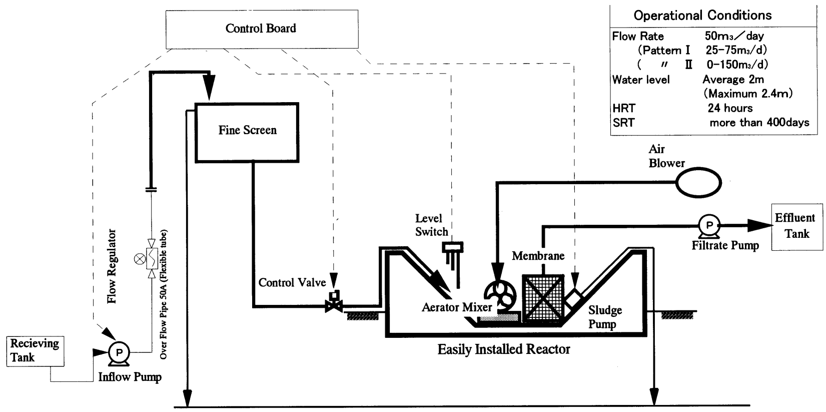

Figure 1 Outline of the pilot plant

one tank while the other system has two or more tanks, such as a sedimentation tank or an equalization tank (Figure 1). This is a key advantage of the system because the dismantling and setting up a large water tank requires much time and manpower.

We collected research cooperatives publicly on development of a practical aerator-mixer or practical membrane separator to be applied to our proposed treatment process. Four private companies subscribed to the research cooperatives. They were FLYGT Japan, Ltd.; Kobe Steel, Ltd.; Maezawa Industries, Inc.; and Hitachi Kiden Kohgyo Ltd. The research began in 1996 and lasted until the end of FY1997. FLYGT Japan and Hitachi Kiden Kohgyou joined the development of the aerator-mixer, Kobe Steel joined the development of the membrane separator and Maezawa Indsutries joined both.

Outline of the plant and operational conditions

Pilot plant

The pilot plant consisted of a variable flow inlet pump, a running filter cloth screen, a rubber coated pond as a reactor where aerator mixer and membrane separator were installed, a submerged pump to draw out mixed liquor, an air-blower and a filtrate pump. Figure 1 is the outline of the pilot plant.

The inflow varied hourly a day in two daily patterns by intermittent operation of the inlet pump. The filter cloth screen was used to remove both fine fibres and coarse suspended solids from the influent to protect the membrane. The reactor was rectangular shaped with four slanted planes at 45 degrees, 8.3 m×7.6 m opening, 2.55 m depth and 3.3 m×2.8 m flat bottom. The depth of the reactor was two metres with a standard capacity of 50 m^3, limited to 2.45 m by an overflow pipe and static level controller. The submerged sludge pump was installed to control SRT or the concentration of activated sludge in the reactor. The inflow pump and the submersible pump were operated by program controls.

Developed apparatuses

FLYGT Japan developed a submerged aerator mixer unit, which had a mixer and a series of tube air diffusers on the same steel basement. Air and electric power were supplied from an air blower and a control board on the ground. Hitachi Kiden Kohgyo developed a floating aerator mixer unit, which had a simple screw aerator mixer fixed on a pair of floats. Electric power was supplied from a control board on the ground. Maezawa Industries developed a submerged injector system which had a driving pump and four injector units. Air and electric power were supplied from an air blower and a control board. Also, Maezawa Industries developed a submerged hollow-fibre MF membrane separator unit. The entire unit was

Table 1 Specifications of membrane units

	Kobe steel	Maezawa industries
Unit type	submerged multi-plates	submerged hollow-fibers
Pore size	0.4 micro metre	0.1 micro metre
Material of membrane	Polyolefin	Polyethylene
Effective surface area	178–225 m^2	312 m^2
Unit size	2.5 m(L)–1.8 m(W)–2.6 m(H)	1 m(W)–2 m(L)–2.6 m(H)
Air blower	3.1 Nm^3/min. 3.7 kW	2.4 Nm^3/min. 2.2 kW
Filtrate pump	0.095 m^3/min. 1.5 kW	0.06 m^3/min. 0.4 kW

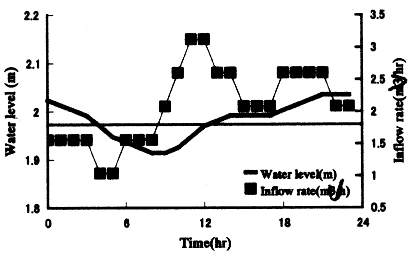

Figure 2 Flow rate pattern (I) and water level

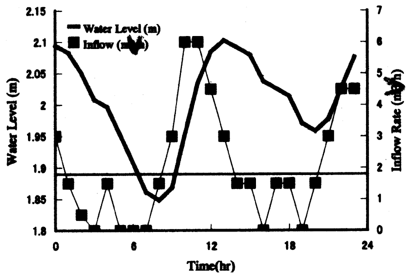

Figure 3 Flow rate pattern (II) and water level

enclosed by a stainless steel plate to reduce mixed liquor flow from inside to outside, because the inside was continuously aerated to wash the membrane surface and DO rich mixed liquor flow affects the anoxic conditions for denitrification. Cleansing air was supplied from an air blower and the filtration force was suction of the effluent pump. Kobe Steel developed a submerged multi plate MF membrane separator unit. The concept of this unit was similar to the former membrane unit, except for the type of membrane. The specifications of these membrane units are indicated in Table 1.

Operational conditions

The daily volume of inflow to the plant was 50 m^3 and average HRT was 24 hours. The inflow was raw sewage of the Kasumigaura Purification Center in Ibaraki Prefecture. The rate of inflow hourly changed from 25 m^3/day to 75 m^3/day in pattern No.1 and 0 to 150 m^3/day in pattern No.2. Pattern No.2 was a typical inflow pattern in a very small wastewater treatment plant in Japan. These flow patterns are shown in Figure 2 and Figure 3. The outflow (filtrate of membrane) rate was constant at 50 m^3/day under ordinary conditions. Hence, depth of the reactor changed as shown in Figure 2 or Figure 3. The mixed liquor was drawn out only two times throughout the experimental period, so the SRT was longer than 400 days. The first draw out occurred by accident in the transportation of the mixed liquor for the reconstruction work of the submerged unit. The second draw out was done to reduce MLSS to less than 10000 mg/l. The experimental periods were separated into six terms by the combination of aerator-mixer and membrane separator (Table 2). In the middle of the fourth term, the inflow rate pattern was switched from No.1 to No.2.

Aeration was intermittently cyclic for nitrogen removal and some aerators were DO or DO/ORP controlled. The basic aeration cycle was two hours in every term and aerated time in a cycle was changed manually with the oxygen demand of the reactor. Mixing was different to each aerator-mixer, but commonly it was strong in the aeration time.

Filtration was also intermittently cyclic. The basic cycle was 20 minutes (18-minute filtrate, 2-minute pause) for the hollow-fibre unit and ten minutes (8-minute filtrate, 2-minute pause) for the multi-plates unit. Continuous washing by aeration was common to these units.

Table 2 Experimental term of apparatu combination

No.	Term	Aerator mixer	Membrane unit
1	1997. 1.17–3.17	Tube diffuser and mixer	Multi-plates
2	1997. 3.18–6.3	Floating screw	Hollow-fibres
3	1997. 6.4–8.27	Injectors	Multi-plates
4	1997. 8.28–11.17	Tube diffuser and mixer	Hollow-fibres
5	1997. 11.18–1998. 2.12	Floating screw	Multi-plates
6	1998. 2.13–4.29	Injectors	Hollow-fibres

Results of experiment

Removal of organic matter

The removal of organic matter in this system was stable and at a high-level. The BOD removal rate was more than 95%, and residual BOD slightly increased when the MLDO had decreased in the latter half of the experiment (Figure 4). The COD_{Mn} removal rate was more than 80%, and residual COD_{Mn} were almost constant throughout the experimental period (Figure 5).

Nitrogen removal

The intermittent aeration time was 25 to 33% of a cycle time and the rest was anoxic mixing for denitrification except inside the enclosed membrane unit where it was aerated every time. Under these conditions, more than 90% of the nitrogen was removed, and the effluent total nitrogen concentration was less than 3 mg/l. In the beginning of the experiment, nitrogen removal was not stable because of a longer aeration time, and in some later periods it dropped due to the decrease of organic loading associated with the membrane clogging. These situations are shown in Figure 6. In the middle stable period, the major part of the remaining nitrogen was organic nitrogen in contrast to the unstable beginning or some later periods where nitrate was the major component of residual nitrogen.

Removal of T-coliform

The nominal pore size of the membrane used in this experiment was 0.2 to 0.4 micrometres so that it was impossible for any kind of coliform to pass the membrane. But some amount of T-coliform was detected in the filtrate of the plant. The level of T-coliform was less than 1000 CFU/100 ml, which met the criteria for discharge or for the reuse for human contact prohibited uses. As shown in Figure 7, the T-coliform number in the filtrate had shown an upward trend as time went by, which might mean those damaged parts of the membrane increased. It was observed that some large matter had come into the pond from outside and were in contact with the membrane unit sometime. This seemed to be the cause of membrane damage. Back washing of the hollow-fibre membrane was thought to be an effective way of washing to remove clogging materials. But it also removed clogs on damaged parts, and led to the leak of bacteria from those damaged parts.

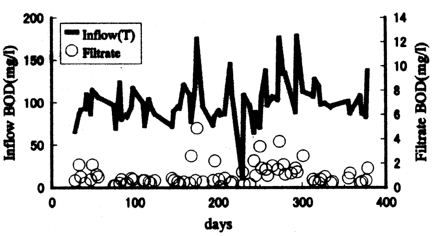

Figure 4 BOD removal

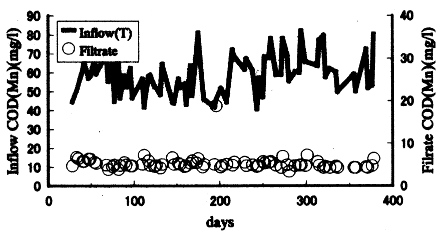

Figure 5 COD(Mn) removal

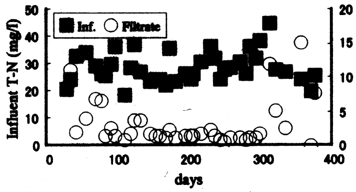

Figure 6 Nitrogen removal

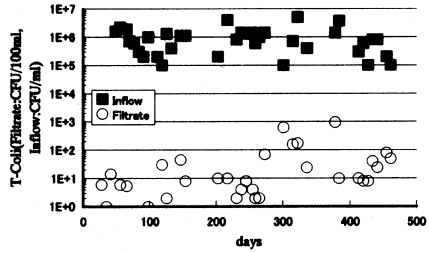

Figure 7 Removal of T-coliforms

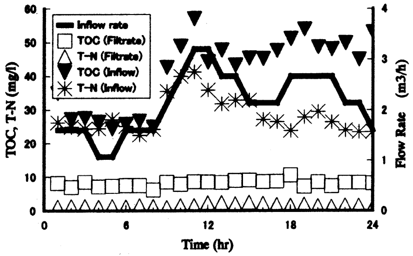

Figure 8 Response to hourly change

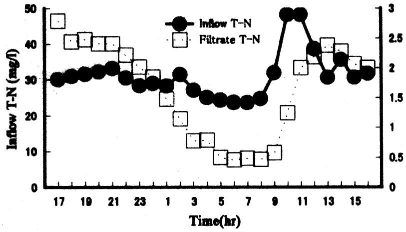

Figure 9 Houring change of T–N

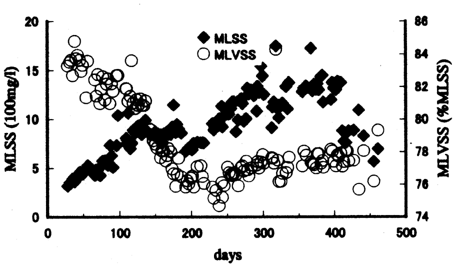

Figure 10 MLSS and MLVSS(%) in the reactor

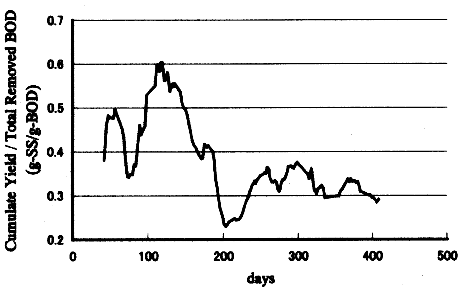

Figure 11 Sludge yield per removed BOD

Response to hourly change of load

The reactor worked as a perfect flow equalization tank as shown in Figure 2 and Figure 3. According to the 24-hour test in experimental term No.3, the variation of organic substances (TOC) in the filtrate was small compared to the variation of influent (Figure 8). So that the system worked as an equalization tank of organic loading to the environment. However the nitrogen was changed following the inflow fluctuation (Figure 9).

General sludge yielding

The MLSS gradually increased, conversely, MLVSS gradually decreased until the 130th day from the beginning of the experiment, as shown in Figure 10. Then the increase of MLSS stopped but the decrease of MLVSS continued until around the 230th day due to the procedure of decomposition under high water temperature. The decrease of MLVSS ceased around the 230th day, then turned into the slow increase phase. MLSS also turned into the increase phase again after accidental sludge leakage around the 180th day. The second draw out of the mixed liquor was made around the 390th day and MLSS concentrations dropped to 8,000 mg/l.

Figure 11 indicates the calculated sludge yield per BOD removal of the system. The rate in Figure 11 is the average of the previous 14 days. The sludge yielding rates fluctuated from 0.15 to 0.6. In the period between the 230th and 410th day, it was relatively stable and varied within 0.29 to 0.37.

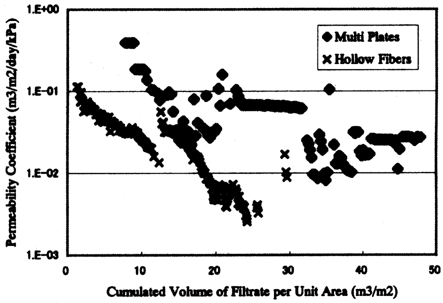

Figure 12 Change of membrane permeability

Flux of the membrane

The membrane permeability changed as shown in Figure 12.

The multi-plate membrane unit operated in terms No.1, 3 and 5. The average permeable coefficient was 0.17 m^3/m^2/day/kPa in term No.1, 0.07 m^3/m^2/day/kPa in term No.2 and 0.02 m^3/m^2/day/kPa in term No.5. It was difficult to recover the flux by water washing or chemical cleansing of the membrane module in term No.5.

The hollow-fibre membrane unit operated in terms No.2, 4 and 6. The average permeable coefficient was 0.07 m^3/m^2/day/kPa in the term No.2, 0.02 m^3/m^2/day/kPa in term No.4 and about 0.01 m^3/m^2/day/kPa in term No.6. It was also difficult to recover the flux by cleansing the membrane unit in term No.6.

The common clogging factor of these membrane units was the high concentration of the activated sludge in the reactor. So the adequate control of MLSS and effective deposit control to the surface of the membrane are needed to achieve higher performance of the system.

Discussion

Application of the system as an easily installed temporary wastewater treatment plant

All developed units had adequate abilities for the single aeration pond used in the experiment and for repeated dismantling and setup. And, totally, the system operated well throughout the experimental period. Thus, the proposed system is technically adequate as the easily installed temporary wastewater treatment plant. The cost is the most important factor for the temporary plant, so we have made rough cost estimations and compared them between this system and the biological aerobic filter (BAF) system as a conventional temporary wastewater treatment system. The construction cost, cost of moving, setting and dismantling, final disposing cost of the plant and operation and maintenance (O/M) cost were calculated. The calculations were made under the condition that the plant must be moved and reconstructed twice in 15 years. The results of estimations and comparisons are indicated in Figure 13 and Figure 14. In these figures, the construction cost includes construction costs, the cost of the moving, setting and dismantling and final disposing cost. According to Figure 13, the construction cost of the proposed system is lower than the BAF system but the O/M cost is higher than the BAF system in all aspects. The total cost of the system in 15 years of temporary use is lower than that of the BAF if the plant scale is less than 1000 m^3/day. Considering the subsidies to the construction, the proposed system seems inalterable to the conventional system except in the case of a very small plant such as 100 m^3/day or less. According to Figure 14, this high operation cost is the result of the high membrane operation cost which includes the replacement cost and periodical cleaning cost. So the key to the practical use of this system is the drastic procedure of a surface deposit control method to prolong the washing intervals and lower the price of the membrane module.

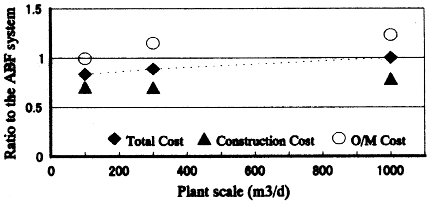

Figure 13 Result of cost comparison

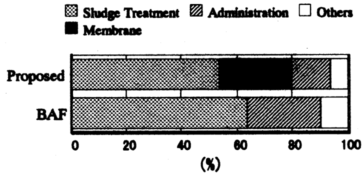

Figure 14 Details of O/M cost

Application of the system to other cases

The effluent quality from the system is so good and safe without disinfection that it will be better to use this in small communities located in a river head area. It might be useful to prevent the spread of infectious bacteria and protozoa like *Chryptosporidium*. In this case, the reactor may not be the coated earth pond, it may be a permanent construction like a RC ditch. Also, installation is easy and it can be operated without sludge draw out for at least six months. Thus, the system is suitable as an emergency plant in a natural disaster, or as a temporary treatment plant at a large event such as the Olympic games or Exposition. Also it is possible to use it as an on-site water reclamation facility, because the effluent quality matches the criteria for aesthetic water, sprinkling water and flushing water, without disinfection.

Conclusions

The MBR process was modified for use in an easily installed temporary wastewater treatment plant using a coated earth pond. The pilot plant experiment was made by the research cooperative of PWRI and four private companies. The results indicated many advantages of this system such as highly stable treatment, high nitrogen removal rate up to 90%, low COD_{Mn} residuals and high bacteria removal without disinfection. The system works well if MLSS is less than 10,000 mg/l and treatment is possible without draw out of excess sludge till the upper limit of MLSS. In such long SRT operation, the excess sludge generation is low. The system is more costly in terms of O/M than the conventional BAF system due to the high membrane module price and high washing timing.

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