Performance of Hybrid MF Membrane Systems Using Polytetrafluoroethylene (PTFE) and Ceramic Membrane

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Abstract
This study seeks to examine the applicability of Hybrid MF Membrane Systems to surface water of the Yodo river, which has high pollution level and has its source in Lake Biwa, in place of the treatment method featuring chemical oxidation that generates by-products. Hybrid MF Membrane Systems (submerged type with PTFE membranes and casing type with ceramic membranes) are new water treatment systems that combine adsorption using activated carbon and biological oxidation with membrane separation. The testing units for these systems started operation in September 2009. Conditions for stable operation were examined for both systems, using trans-membrane pressure (TMP) as an index. Performance of each system was also studied. In the case of the Submerged Type MF Membrane System, certain findings were obtained concerning the relationship of the coagulant and powdered activated carbon (PAC) feeding rate with TMP. Favorable performance was also obtained through biological oxidation over nine detention hours during the low temperature period, with ammonia nitrogen and manganese ions respectively at below 0.02 mg/L and below 0.001 mg/L. On the other hand, a problem remained with the total organic carbon (TOC), which stood higher than the existing advanced water treatment system (AWTS) at 1.1 mg/L. In the case of the Casing Type MF Membrane System, conditions concerning stable operation were set following related researches. Under these conditions, performance of the system during the low temperature period was evaluated. The results indicated favorable removing rates, with turbidity at below 0.1 and TOC at 0.8 mg/L. On the other hand, ammonia nitrogen and manganese ions stood respectively at 0.09 mg/L and 0.025 mg/L following biological oxidation, which are levels scarcely better than the source water, suggesting the lowered bioactivity during the low temperature period as a problem yet to be solved.

Keywords
adsorption, advanced water treatment, biological oxidation, ceramic membrane, hybrid system, PTFE membrane

INTRODUCTION
The Osaka Municipal Waterworks Bureau (OMWB) has introduced an AWTS, which combines the conventional coagulation-sedimentation and rapid sand filtration system with ozonation and granular activated carbon treatment. The AWTS has enabled the degradation of trace organic substances, such as substances with musty odor, precursor substances of disinfection by-products, agricultural chemicals etc., while inactivating Cryptosporidium and other pathogenic microorganisms, thus dramatically improving the safety and reliability of tap water.

However, circumstances surrounding tap water quality are changing rapidly these days, considering the problem of bromate ions, which are by-products of ozonation that were incorporated into the drinking water quality standard in 2004; response to hazardous chemical substances that are yet to be regulated; rising health awareness among citizens; increasing customer needs for tasty water and distaste for bleach odor, and so on. In order to address such requirements, the OMWB constructed the Advanced Technology for Optimum Treatment Experimental Station (“testing plant”) , and has promoted the optimization and upgrading of existing treatment methods, and the development of next-generation water treatment technologies.

As a part of these efforts, the OMWB and the Hanshin Water Supply Authority (HWSA) are jointly developing new treatment technologies, which are intended to fully replace the existing methods. In place of a method featuring chemical oxidation that generates by-products, the joint study is focused on Hybrid MF Membrane Systems that combine adsorption using activated carbon and biological oxidation with membrane separation, and is in progress using the testing units (two lines respectively using PTFE
membranes (submerged type) and ceramic membranes (casing type)), which are installed inside the testing plant. These systems are expected to secure performance equivalent to the AWTS, reduce the generation of by-products, save space required, facilitate operation and maintenance control, cut down on chemicals cost, and make other contributions, through the biological oxidation-based treatment of various soluble substances free from by-products, and appropriate solid-liquid separation using membranes. This study examined conditions for the stable operation of the Hybrid MF Membrane Systems, using TMP as an index, clarified the relationship between parameters and TMP, conducted a performance study, and obtained findings on basic water quality items, including TOC, ammonia nitrogen and manganese ions. The results are reported below.

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MATERIALS AND METHODS

Overview of the Testing Units

Submerged Type MF Membrane System

Figure 1 indicates the test flow, and Table 1 shows the equipment specifications. In this test flow, surface water of the Yodo river is used as source water. After adding acid agent (sulfuric acid), PAC and coagulant (aluminum sulfate), source water is flowed into the biological oxidizing and PAC adsorption tank (“BOPA tank”), and filtered with PTFE membranes that are submerged in the BOPA tank. For physical cleaning, a combination of scrubbing and counter pressure cleaning using chlorine-added filtered water is used. Scrubbing is also conducted at a set interval during filtration. Wastewater from counter pressure cleaning, during which filtration is stopped, is returned to the BOPA tank. Desludging is conducted at a set interval from the bottom of the BOPA tank, in accordance with the set recovery rate.

Casing Type MF Membrane System

Figure 2 indicates the test flow, and Table 2 shows the equipment specifications. In this test flow, surface water of the Yodo river is used as source water. After adding acid agent (sulfuric acid), PAC and coagulant (aluminum sulfate), source water is flowed into the BOPA tank, and aerated in the BOPA tank, before flowed through the upward flow setting plate and filtered with casing type ceramic membranes that are attached outside the BOPA tank. Cross-flow filtration is adopted as a filtration method. The concentrated water is returned to the BOPA tank. Physical cleaning is conducted at a set interval on the membrane secondary side at an air pressure (approx. 0.5 MPa), stopping the filtration. Wastewater generated from cleaning is returned to the BOPA tank. Desludging is conducted at a set interval from the bottom of the BOPA tank, in accordance with the set recovery rate.

Method of Study

Submerged Type MF Membrane System

<Details of Study>

1) Examination on Conditions for Stable Operation

Conditions concerning stable operation for the Submerged Type MF Membrane System were examined as follows, using TMP as an index.
• Relationship between pH conditions in the BOPA tank and TMP
• Relationship between water quality items with seasonal change (WQISC) (algae of water source and manganese ions) and TMP
• Relationship between the interval of physical cleaning and TMP
• Relationship between chemical (PAC and coagulant) feeding rate and TMP

2) Study on Performance
Basic water quality items, such as TOC, ammonia nitrogen and manganese ions, were examined as follows, using chemical feeding rate as a parameter.
• Relationship between chlorine level in back wash water and performance
• Relationship between PAC feeding rate and performance

<Operating Conditions>
Operating conditions for the Submerged Type MF Membrane System are indicated in Table 3.

### Table 3. Operating Conditions for the Submerged Type MF Membrane System

<table>
<thead>
<tr>
<th>No.</th>
<th>Study period</th>
<th>Flux (m/d)</th>
<th>Detention*1</th>
<th>Coagulant feeding rate (mg/L)</th>
<th>PAC feeding rate (mg/L)</th>
<th>BOPA tank pH</th>
<th>Recovery (%)</th>
<th>Conditions for physical cleaning (combined with scrubbing)</th>
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</thead>
<tbody>
<tr>
<td>RUN1</td>
<td></td>
<td>95 - 100</td>
<td>Approx. 7.5 (non-adjusted)</td>
<td>99.5</td>
<td></td>
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<td>Once per 20 min.</td>
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<td></td>
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<td>5.7 m/d x 30 sec.</td>
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<tr>
<td>RUN2</td>
<td></td>
<td></td>
<td>3</td>
<td>25</td>
<td>6.8 - 7.0</td>
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<td>Chlorine-containing water: 5.7 m/d x 15 sec.</td>
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<td>RUN3</td>
<td></td>
<td></td>
<td></td>
<td>15</td>
<td></td>
<td></td>
<td></td>
<td>Filtered water: 5.7 m/d x 15 sec. (During 8/4 - 8/19, RUN3, reverse jet flux increased due to the failure of the flowmeter.)</td>
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<tr>
<td>RUN4</td>
<td></td>
<td></td>
<td>3</td>
<td>9</td>
<td></td>
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<td>Chlorine-containing water: 8.6 m/d x 15 sec.</td>
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<tr>
<td>RUN5</td>
<td></td>
<td></td>
<td>3</td>
<td>25</td>
<td>Approx. 7.5 (non-adjusted)</td>
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<td></td>
<td>Filtered water: 8.6 m/d x 5 sec.</td>
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<td></td>
<td>99.9</td>
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</tbody>
</table>

<Details of Study>

1) Examination on Conditions for Stable Operation
Conditions concerning stable operation for the Casing Type MF Membrane System were examined as follows, using TMP as an index.
• Relationship between recovery and TMP
• Relationship between circulating water and TMP
• Relationship between coagulation control (feeding point and coagulation pH control) and TMP
• Relationship between the interval of physical cleaning and TMP

2) Study on Performance
The test unit was operated under the conditions set based on the study as described in 1). The resulting performance was evaluated, and problems to be solved were identified considering the drinking water quality standard, target value for complementary items, and the performance of the AWTS.

<Operating Conditions>
Operating conditions for the Casing Type MF Membrane System are indicated in Table 4.
was changed respectively to 25 mg/L for RUN5-4 to RUN5-5, and to 5 mg/L for RUN6. In RUN5-4 to RUN5-5 and RUN6, the coagulant feeding rate did not affect the rising trend of TMP. However, the changed PAC feeding rate was reduced from 15 mg/L to 1.5 mg/L, and the rising trends of TMP before and after this reduction were compared (in doing so, the recovery rate was raised from 99.0 to 99.9%, in order to adjust the PAC level in the BOPA tank with conditions before the reduction). Consequently, the rising trend of TMP was slowed down, which is considered to suggest that a shorter interval of physical cleaning has an effect on conditions for stable operation with a focus on the relationship between WQISC and TMP.

Figure 3 indicates changes in TMP of the Submerged Type MF Membrane System. There was a large difference in changes of TMP between RUN1 and RUN2. As major causes for this difference, pH conditions in the BOPA tank (“pH conditions”) and seasonal differing source water quality were suspected. In order to verify difference due to pH conditions, operation was undertaken in RUN3 under two differing sets of pH conditions. This did not cause clear difference in the rising trends of TMP. With regards to seasonal differing source water quality, a focus was placed on the relationship between TMP and source water quality items with large seasonal changes (i.e. algae of water source and manganese ions; hereafter collectively referred to as “water quality items with seasonal change (WQISC)”)). The results showed that, in RUN2, in which the values of WQISC were relatively high, the rising trend of TMP was larger than that in other RUNs. Therefore, it is possible that WQISC have negative influence on the stable operation of membranes (see Figure 3 and Table 5). It will be required to promote examination on conditions for stable operation with a focus on the relationship between WQISC and TMP.

Figure 4 indicates changes in TMP from RUN5-1 through RUN5-3. From RUN5-1 to RUN5-2, the cleaning interval was shortened from 20 to 10 minutes, and the rising trends of TMP before and after this shortening were compared (in doing so, the cleaning flux was lowered from 8.6 m/d to 4.3 m/d, in order to adjust the water volume used for cleaning). Consequently, the rising trend of TMP was slowed down, which is considered to suggest that a shorter interval of physical cleaning has an effect to control the rise of TMP. From RUN5-2 to RUN5-3, the PAC feeding rate was reduced from 15 mg/L to 1.5 mg/L, and the rising trends of TMP before and after this reduction were compared (in doing so, the recovery rate was raised from 99.0 to 99.9%, in order to adjust the PAC level in the BOPA tank with conditions before the reduction). However, the changed PAC feeding rate did not affect the rising trend of TMP.

In RUN5-4 to RUN5-5 and RUN6, the coagulant feeding rate was changed respectively to 25 mg/L for RUN5-4 to RUN5-5, and to 5 mg/L for RUN6. Figure 5

### RESULTS AND DISCUSSION

#### Submerged Type MF Membrane System

**Examination on Conditions for Stable Operation**

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In RUN5-4 to RUN5-5 and RUN6, the coagulant feeding rate was changed respectively to 25 mg/L for RUN5-4 to RUN5-5, and to 5 mg/L for RUN6. Figure 5
indicates the resulting changes in TMP. Immediately following the reduction of coagulant feeding rate from 25 mg/L to 5 mg/L, the rising rate of TMP became larger as had been expected. However, the rising rate subsequently returned to the same level as before the reduction. Continued research is considered necessary.

**Study on Performance**

1) Relationship between Performance and Chlorine Level in Back Wash Water

Figure 6 indicates changes in the level of manganese ions in treated water in RUN5-4 through RUN7-2. Performance of manganese ions improved around the increase of chlorine level in back wash water. However, the performance was retained after the stop of chlorine addition. Continued research is considered necessary.

2) Relationship between Performance and PAC Feeding Rate

Figure 7 indicates changes in the level of TOC in treated water in RUN4 to RUN5. The PAC feeding rate was reduced from 15 mg/L to 1.5 mg/L (in doing so, the recovery rate was raised from 99.0 to 99.9%, in order to retain the PAC level in the tank). This resulted in a lowered TOC removal trend. This suggests that the PAC feeding rate affects the TOC performance substantially.

3) Summary

Table 6 shows the average values of TOC, ammonia nitrogen and manganese ions in treated water in 2010. Table 7 lists the average values in treated water for RUN7-2 only, in which the stop of chlorine addition and reduction of PAC feeding rate were undertaken. Partly because retention time in the BOPA tank was nine hours, which was longer than in the previous RUNs, the performances of ammonia nitrogen and manganese ions were improved in RUN7-2. On the other hand, the TOC performance was lowered. An action is considered necessary to improve the TOC performance.

**Casing Type MF Membrane System**

**Examination on Conditions for Stable Operation**

Figure 8 indicates changes in corrected TMP (at 25°C) from RUN1 through RUN3. The recovery rate was lowered from 99.5 to 99.0% from RUN1 to RUN2, thereby reducing the SS level in the BOPA tank from approx. 3,000 mg/L to 1,500 mg/L, and relieving the turbidity load on membranes. However, the rising trend of TMP did not change. Therefore, the turbidity-removing effect of the flow setting plate, which was attached to the BOPA tank, was verified. In the meantime, pressure rise in the first half was reduced in RUN3, compared to RUN1 and 2. Figure 9 shows changes in corrected TMP in RUN3 and their relationship with pH values.

During Period 1 in this figure, coagulant was fed 12.5 mg/L respectively into the point before and after the BOPA tank. During Period 2, coagulant was fed 25 mg/L only into the point after the tank, immediately before the filtration. Except during Period 3, TMP did not rise substantially. This is
considered to suggest that coagulation immediately before filtration has an effect to control the rise of TMP. While the circulation water ratio was set at 1:0 during Period 2, TMP did not rise substantially except during Period 3. Thus it was verified that circulation water ratio was not a governing factor for the rise of TMP. Therefore, the shearing force due to parallel flow on the membrane surface is not considered to contribute substantially to the control of rise in TMP.

In the early stage, the coagulation pH was controlled by adjusting pH in the BOPA tank at around 6.8. Because the BOPA tank pH rose during Period 3, additional acid was fed into the tank. This lowered the pH of treated water to below 6.5, causing a considerable deviation of coagulation pH from the appropriate pH zone. This is considered to be the cause of the rapid rise in TMP during Period 3.² ³

Based on the above results, conditions for stable operation were arranged as follows. The feeding point for coagulant is limited to the point after the tank. Acid is adjusted in order to control coagulation pH at approx. 6.5 - 6.8. Circulation water ratio is set at 1:0.3, and the small flow is secured, in order to prevent the clogging of flow channels of membrane elements ( φ 2.5 mm) due to turbidity, even though the effect of cross-flow to control TMP is minimal. The interval of physical cleaning is set at 120 minutes, based on the general cleaning interval for ceramic membranes, and considering the viewpoint of utility cost reduction.

**Study on Performance**

Under the conditions set as described above, RUN4 was operated. Its performance results are indicated in Table 8. For reference, this table also shows quality before adding chlorine to water treated by the AWTS. With regards to turbidity, stable removal was achieved by the membrane separation. Bromic acids also stood below the detection limit, because there is no process that generates them. On the other hand, ammonia nitrogen and manganese ions were not removed favorably, even though their removal was expected through biological oxidation in the BOPA tank. This is considered to be because the bioactivity was lowered during the low temperature period. Among items related to organic substances, TOC not only satisfied the drinking water quality standard ( ≤ 3 mg/L), but also showed performance equivalent to water treated by the AWTS. This was enabled by the combination of coagulation and membrane separation, coupled with the adsorption effect of PAC. On the other hand, the UV absorbance (260 nm) and fluorescence intensity values lagged slightly behind those of water treated by the AWTS.

It was considered that increased organisms would be effective to improve the performances of ammonia nitrogen and manganese ions during the low temperature period. Therefore, RUN3 was adjusted to a high recovery rate of 99.9%. The performances are shown in Figures 10 and 11. Both the figures use average values. The performance of manganese ions in treated water is not considered favorable, because they were not controlled below the target value (0.01 mg/L) not only below 10°C, but also at or above 10°C.

With regards to ammonia nitrogen, there was hardly any difference in the removal rate from that in the
RUN with the recovery of 99.5% (58% at or above 10°C, and 21% below 10°C), even though the organism level in the BOPA tank was theoretically five times as high. This suggests that, during a short detention time as in this testing unit (approx. three hours), improvement in biological oxidation performance cannot be expected through increasing organisms (SS level) in the BOPA tank.

Table 9 indicates the relationship of PAC feeding rate and recovery rate with TOC. It can be suggested from this table that the performance of organic substances can be improved through changing PAC feeding rate and recovery rate. According to the table, PAC feeding rate had been fixed at 15 mg/L up to RUN3, while the recovery was changed. The resulting performance was high above that of water treated by the AWTS in each cycle. By changing recovery rate from 99.0 to 99.9%, SS level in the BOPA tank differs by approx. 1,000%. Change in the TOC reduction rate is small compared to this percentage. Based on these, it is suggested that the excellence of TOC performance over that of the AWTS depends largely on PAC feeding rate, rather than on recovery rate. Therefore, the required removal performance is likely to be achieved for organic substances other than TOC, through using PAC feeding rate as a key parameter (it has been verified that the reduction rates of UV absorbance (260 nm) and fluorescence intensity vary by changes in PAC feeding rate). In RUN4, however, the PAC feeding rate and recovery rate were set respectively at 3 mg/L and 98.0%, aiming at achieving reduced chemicals cost and TOC performance equivalent to that of the AWTS treatment. It is considered necessary to examine how to set an appropriate feeding rate and recovery, considering the cost of PAC feeding.

### CONCLUSIONS

#### Submerged Type MF Membrane System

**Summary**

1) Examination on Conditions for Stable Operation
   - Research on the influence of pH adjustment on TMP indicated that there was no clear difference in the rising trend of TMP at pH 6.8 - 7.5.
   - Research on the relationship between source water WQISC (algae of water source and manganese ions) and TMP suggested a possibility that these items affect TMP.
   - Research on the behavior of TMP following the shortening of physical cleaning interval from 20 to 10 minutes indicated a slower rising trend of TMP, suggesting that a shorter interval of physical cleaning has an effect to control the rise of TMP.
   - The influence of reduction in PAC feeding rate and coagulant feeding rate on TMP is not clear at this point. Continued research is considered necessary.

2) Study on Performance
   - Research on the influence of chlorine level in back wash water on performance indicated that the performance of manganese ions improved around the increase of chlorine level. However, the performance was retained after the stop of chlorine addition. Continued research is considered necessary.
   - When the PAC feeding rate was reduced from 15 mg/L to 1.5 mg/L, a lowered TOC removal trend resulted. Because other conditions were also changed in this process, continued research is considered necessary.
   - Following the above actions (i.e. stop of chlorine addition to cleaning water, and reduction in PAC feeding rate), improved performances of ammonia nitrogen and manganese ions have been retained, though the TOC performance has declined. Therefore, actions should be examined to improve the TOC performance.

**Future Requirement**

- First, in the Submerged Type MF Membrane System only, verification should be continued on conditions for stable operation and on performance, using TMP as an index, under the conditions that the PAC and coagulant feeding rates are reduced and chlorine is not added to back wash water.
Casing Type MF Membrane System

Summary

1) Examination on Conditions for Stable Operation

- From the viewpoint of controlling TMP, conditions for the stable operation of this system were examined with filtration flux of 1.7 m/d. Based on this examination, the feeding of coagulant is limited to the point after the tank at the feeding rate of 25 mg/L. Acid is adjusted in order to control coagulation pH at approx. 6.5 - 6.8. Circulation water ratio is set at 1:0.3. The interval of physical cleaning should be set at 120 minutes. The PAC feeding rate and recovery rate will be set as appropriate based on future study, as parameters mainly concerning performance.

2) Study on Performance

- Research was conducted on performance of this system during the low temperature period, under the operating conditions set as described in 1). The results showed favorable turbidity performance below 0.1, owing to removal by membrane separation. At the same time, the TOC performance was equivalent to that of the AWTS at 0.8 mg/L on the average. This was enabled by the combination of coagulation and membrane separation, coupled with the adsorption effect of PAC. On the other hand, ammonia nitrogen and manganese ions stood respectively at 0.09 mg/L and 0.025 mg/L, which are levels scarcely better than the source water, despite the expectations for removal by biological oxidation in the BOPA tank. While the TOC performance was found favorable, the UV absorbance (260 nm) and fluorescence intensity values stood respectively at 0.010 and 54 on the average, which managed to reach certain performance levels but lagged slightly behind those of the AWTS.

- As an action to improve the performances of ammonia nitrogen and manganese ions, it was examined the possibility of upgrading the recovery rate and concentrating the organism level. Unfortunately, fundamental improvement turned out to be difficult with a short detention time (approx. three hours) in the BOPA tank.

Future Requirement

- The performance data of this system that are reported herein only cover a short term of approximately one month. It will be required to identify performance on a year-round basis, and examine how to achieve the targeted water quality.

- During a low temperature period, in which bioactivity slows down, the performance of manganese ions declines particularly remarkably. Because treatment with only the Casing Type MF Membrane System seems difficult, it should be examined how to combine it with other pre-treatment methods, such as Biological Roughing Filter (BRF), ozonation or feeding of chlorine or other oxidizing agents using a method that would not increase by-products (e.g. bromic acids), and so on.

REFERENCES


3) Y. Watanabe(2006), Water Metabolic System and Membrane Technology, MEMBRANE, 31(4), P.180-187

