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The study of environmentally friendly pretreatment system

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ABSTRACT

The Mitsubishi Heavy industries, Ltd. has been challenging the development of a chemical-free pretreatment. In this paper, we will present our experience of the field tests. The test results turned out to be very successful and proved that the chemical-free pretreatment is applicable for reverse osmosis seawater desalination. Chemical-free rapid sand filtration especially is the most promising process, which has been applied as a pretreatment system of salt manufacturing works in Japan and worked in condition for more than 40 years. Although the exact mechanism has not been identified, the performance of this system seems to be related to the microbial activity. It is hoped that this pretreatment system will solve the environmental problem that is caused by a seawater desalination plant.

Keywords: Pretreatment; Environmental friendly; Media filter

1. Introduction

Today, one of the largest global concerns is the deficiency of freshwater. This problem is getting even worse as the cities and populations are gradually growing due to the increasing need for water in the fields of agriculture, industry, and households. Due to this situation, the desalination technology has slowly started receiving global attention, as it could serve as a means for increasing the supply of available freshwater in those regions of the world where water is scarce. Especially, the demand for seawater desalination is slowly increasing, as the seawater is a practically unlimited resource of water. Among the few seawater desalination technologies known, the reverse osmosis (RO) technology is prevalent due to a host of merits such as lower energy that it offers than any other technology. In fact, several large-scale seawater reverse osmosis (SWRO) desalination plants have been built in recent years, and the construction of newer plants is expected to increase in the near future.

Although the RO seawater desalination technology has shown some progress, there are still few concerns voiced about the potential environmental impacts posed by such large-scale seawater desalination plants. One of the concerns put forth is the environmental impact caused by the chemicals that are used in any SWRO desalination plant. Especially the pretreatment system, which is needed to remove silts,

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Table 1
Chemicals for the pretreatment of an RO seawater desalination plant

Chemicals	Objectives
Chlorine	Disinfection of the intake facility for biological matter so as not to clog the inlet or pipe
SBS	Dechlorination to prevent the RO membrane from chlorine attack
Coagulant	Coagulation to make the removal of silts, suspended solids, and organic materials easy in pretreatment system.
Sulfuric acid	Optimization of the coagulation effect and prevention of scaling on the RO membrane

suspended solids, and organic materials before of the RO membrane and attain the requirement of RO elements, generally requires many chemicals. The chemicals that are used for pretreatment are summarized in Table 1.

Since the constituents of these chemicals are not normally necessary to be present in product water, they are finally discharged into the seawater. For example, Fig. 1 shows the picture of the discharge of a coagulant ($FeCl_3$) for the pretreatment of granular media filter. The dirty brown water is doomed to mix in seawater or dispose it of as the industrial waste after sludge treatment. The impact of these chemicals on the environment is becoming one of not to be ignored and there is an urgent need to minimize the impact to ensure the sustainability of the RO seawater desalination technology.

The Mitsubishi Heavy Industries, Ltd. has been challenging to reduce the chemicals for pretreatment.

Fig. 1. Picture of the discharge of coagulant ($FeCl_3$).

In the present paper, our experience of the field tests will be presented.

2. Merits of a chemical-free pretreatment

A chemical-free pretreatment has several merits to its credit other than just reducing the environmental impact. Such merits are summarized as follows:

Environment
- Elimination of the industrial waste
- No impact on the biological activity in the sea

Safety
- Elimination of the use of dangerous chemicals such as strong acid

Operation
- Easy operation without handling chemicals

Construction cost
- Unnecessity of chemical storage buildings and injection facilities of chemicals
- Elimination of sludge treatment facilities

Operation cost
- Reduction of the chemical cost
- Reduction of the cost of water analysis
- Elimination of the cost of sludge treatment
- Reduction of power consumption without injection and mixing power for chemicals

Additionally, the injection of the chemicals for pretreatment has an adverse effect on the RO desalination process. They are summarized in Table 2. The reduction of chemicals not only provides a lot of merit but also prevents these adverse effects. It means that a chemical-free pretreatment is a highly attractive approach both economically and environmentally.

3. The experience of a chemical-free pretreatment

The Mitsubishi Heavy industries, Ltd. has been challenging the development of the chemical-free pretreatment. Currently, two kinds of field tests were conducted to ensure the applicability of a chemical-

Table 2
Adverse effects of the chemicals on an RO desalination process

Chemicals	Adverse effects
Chlorine	It requires the dechlorination process to prevent the RO membrane from the chlorine attack
SBS	It causes the possibility of the deterioration of an RO membrane if it is overdosed [1]. In addition, it may cause biofouling [2]
Coagulant	It causes fouling by passing through the pretreatment system. In addition, it requires a sludge treatment process
Sulfuric acid	It reduces the boron rejection of an RO membrane

free pretreatment: one is in Qatar where no coagulant process was applied by the membrane pretreatment and the other is in Japan where a chemical-free process was applied by the rapid sand filtration. The details of the tests will be presented here.

3.1. No coagulant process applied by the membrane pretreatment in Qatar

3.1.1. Test field

A seawater desalination test plant was built to demonstrate the applicability of RO process for seawater desalination at Dukhan, Qatar. The production capacity of this demonstration plant is 200 m^3/d. It was set up in 2003 and started production in the end of 2005. The details of this plant can be shown in previous papers [3,4].

3.1.2. Pretreatment process

The schematic process diagram of this plant is shown in Fig. 2. The seawater of around 700 m^3/d was taken from a seawater intake line that was used for the existing plant. Since chlorine was injected at the intake of the existing plant, SBS was injected in front of the RO process for the dechlorination to prevent the deterioration of the RO membrane. The pretreatment system was composed of the media filter and membrane filtration. The specifications are shown in Table 3. The membrane type was changed in August, 2008 from the MF of Asahi Kasei Chemicals to UF the of Toray. No coagulant was used for the pretreatment, the reason being that there was no sludge treatment process.

3.1.3. Performance of pretreatment and RO process

SDI data after membrane filtration from 2005 to 2006 are shown in Fig. 3. The SDI was stable around 3 during the period when the MF modules were installed for the membrane pretreatment. The SDI of pretreated water was also stable after exchanging the membrane modules from the MF to the UF and the values constantly met the requirements of RO process that the SDI of the RO feed seawater should be less than 4.0.

The data of SWRO performance from 2008 to 2009 are shown in Fig. 4. The RO system, where 8 inch RO modules of Toray were installed, was operated by around 30% of recovery. The upper figure shows the temperature and the salinity of pretreated feed seawater, while the lower figure shows the data of the permeate flow rate and the salt rejection, which were normalized. In spite of different salinities and temperatures, the membrane performance was stable. These data proved that the performance of the no coagulant pretreatment system applied at Dukhan was excellent and demonstrated that this process was applicable for an RO seawater desalination plant as the RO pretreatment.

3.2. Chemical-free process by rapid sand filtration in Japan

3.2.1. Test field

In Japan, the salt manufacturing industry mainly applies the electrodialysis method. The pretreatment process is also needed at the upstream of the concentration by electrodialysis as well as the desalination by RO. Sand filtration was mainly applied as for pretreatment in the salt manufacturing factories in Japan. The Naikai Salt Industry Co. Ltd., which is one of the Japanese leading companies, has also been producing salt for around 40 years by the electrodialysis method. In the Naikai Salt Industry factory, which is located at the Tamano city in the Okayama prefecture along the Seto Inland Sea coast, the chemical-free pretreatment system by the sand filtration was applied [5]. That is, no chemical, such as chlorine, SBS, acid, and coagu-

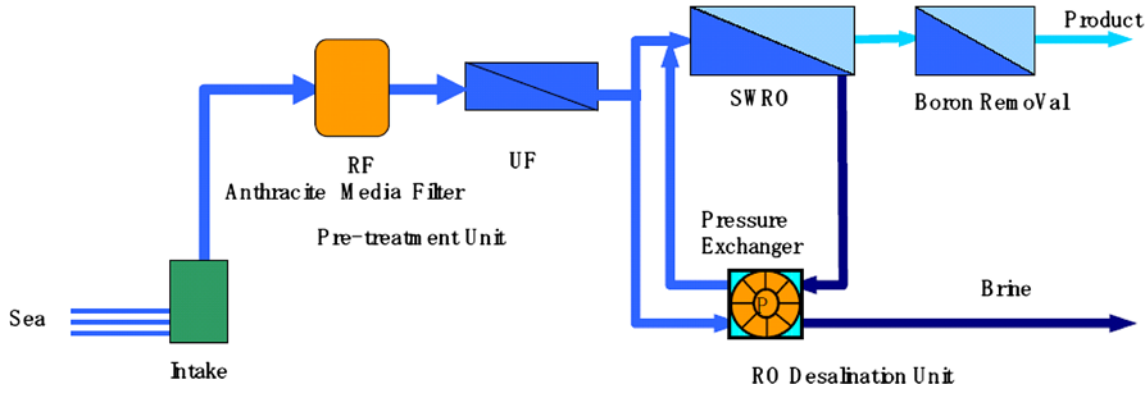

Fig. 2. A schematic process diagram of the demonstration plant at Dukhan.

Table 3
Specifications of the pretreatment system

Items	Specifications
Media	1-stage single-media filtration
Filter	Media: Anthracite
Membrane	(From operation start-up to August 2008) Asahi Kasei Chemicals, USV-6,203 (MF), 10 modules (From September in 2008) Toray, HFU-2020 (UF), 8 modules

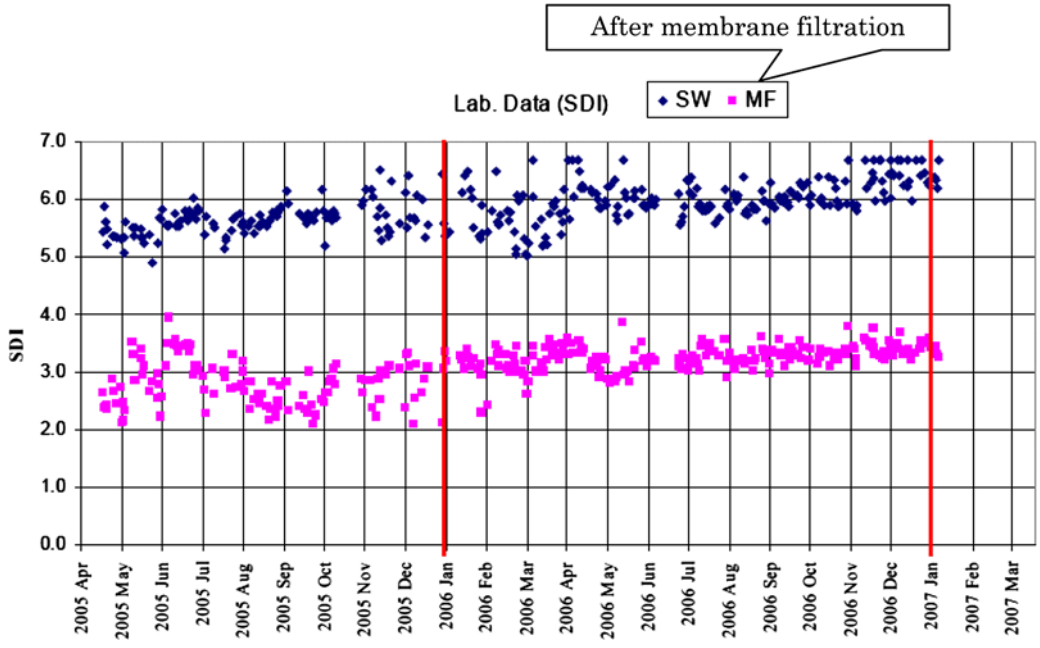

Fig. 3. SDI data of pretreatment system.

lant, was used. Despite being a challenging process, it still continues the stable supply of salt for 40 years. Mitsubishi Heavy Industries, Ltd. focused on this fact and started the investigation of the applicability of this attractive pretreatment system to the RO seawater desalination plant. So far, we did the investigation of the pretreatment system of the actual facilities and the demonstration of the SWRO module by using pretreated seawater by the chemical-free process of the Naikai Salt Industry.

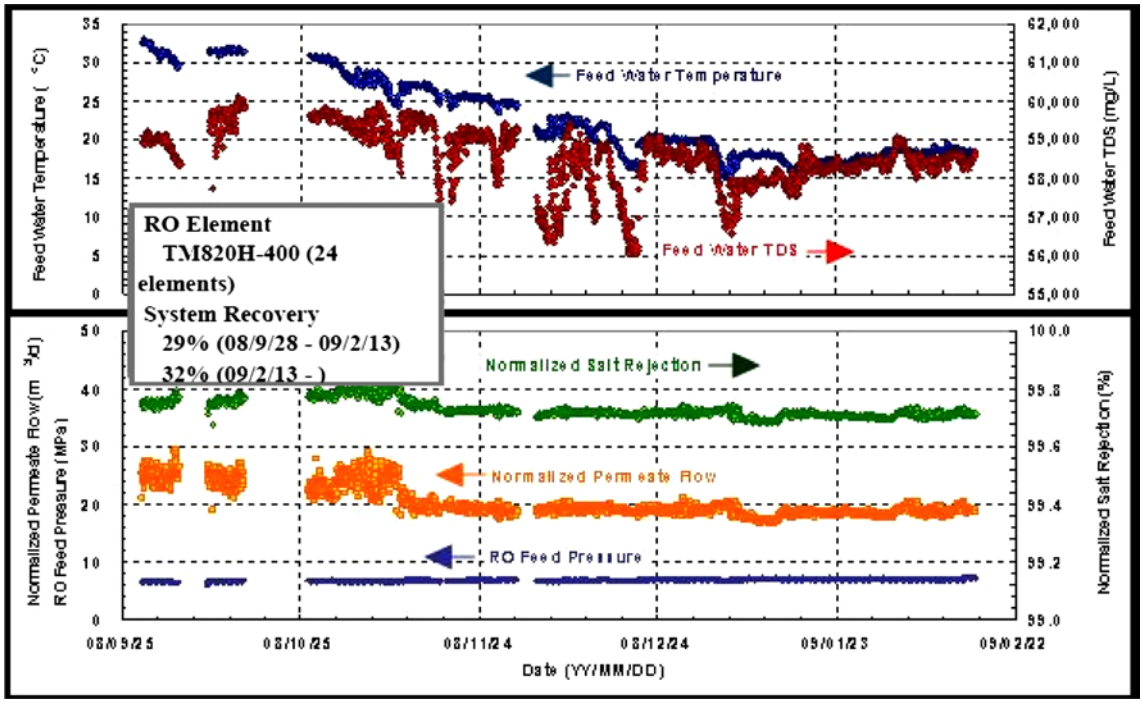

Fig. 4. Performance data of an RO system.

3.2.2. Pretreatment system

The pretreatment system of the Naikai Salt Industry is composed of a two-stage single-media filtration. Sand media are applied in both stages and the filtration velocity is 7–15 m/h, which means a rapid filtration was used in each stage. As mentioned above, no chemicals were injected at the upstream of pretreatment. Furthermore, chemical cleaning, which is inevitable for membrane filtration, is not needed. This means that this pretreatment is completely chemical-free.

3.2.3. Performance of pretreatment and RO process

The annual SDI data in 2008 on pretreatment are given in Fig. 5. The average value of SDI at the outlet of the second-stage filtration was around 3.3. This is also the allowable value for an RO seawater desalination.

One of the characteristic phenomena of this treatment is the elevation of SDI just after re-starting, which can be confirmed at the beginning of January, June, and September in Fig. 5. Sand was observed under the microscope at first to identify the root cause of this phenomenon. The observation result is seen in Fig. 6. The existence of adherent substances on the sand can be confirmed. This phenomenon seemed to have been caused by the microbial activity. We have investigated this phenomenon in detail.

To get more information on the behavior of bacteria in the SWRO system, an analysis of the microbial composition was carried out by the denaturing gradient gel electrophoresis (DGGE) method. The details of this analysis were confirmed in the previous paper [2]. For the investigation, we took a few sand samples just before the shutdown of the system and just after it re-started in August, 2009. The adherent substances on each sample were analyzed by the DGGE method. Fig. 7 shows the SDI data during the investigation period. The shutdown period was for a duration of around 5 days and the elevation of SDI and the data in 2008 were observed. The arrows in Fig. 7 mean the timing of sand media sampling. Fig. 8 shows that the DGGE profiles correspond to the 16S rRNA fragments that differ in the nucleotide sequence. Hence, the appearance and disappearance of fragments in the DGGE profiles approximate shifts in the microbial composition. This profile showed that the several species were distinguished only in the sample of August 16 that is just after re-starting. This result suggests microbiota was changed during the shutdown. The SDI was recovered when the microbiota also recovered. This correlation suggests that the filtration performance should be related to the microbial activity. The detailed mechanism of the biological filtration

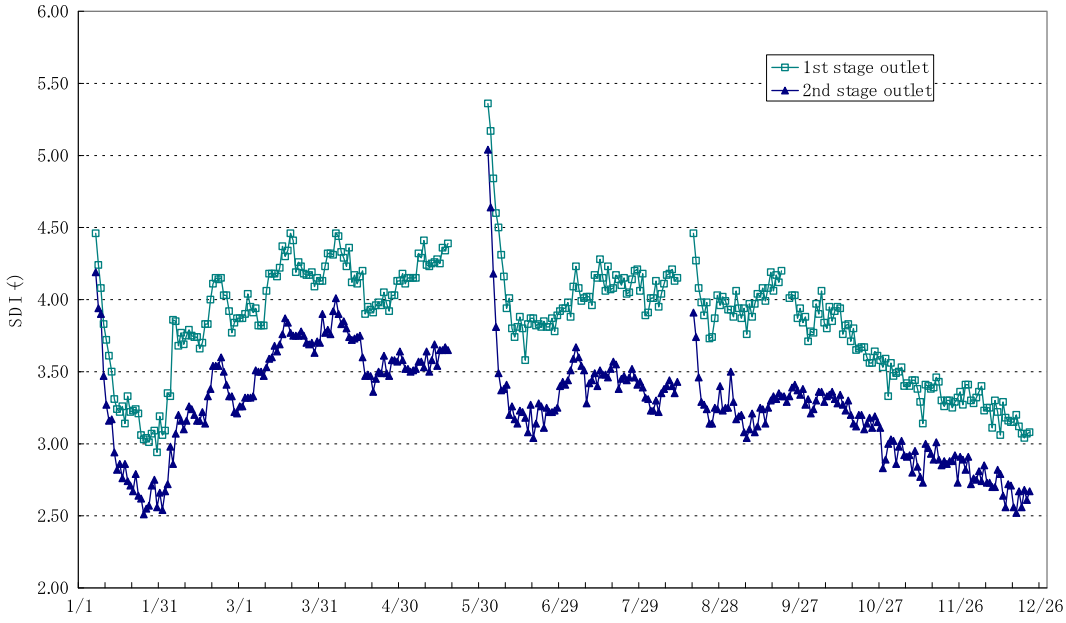

Fig. 5. SDI annual data in 2008.

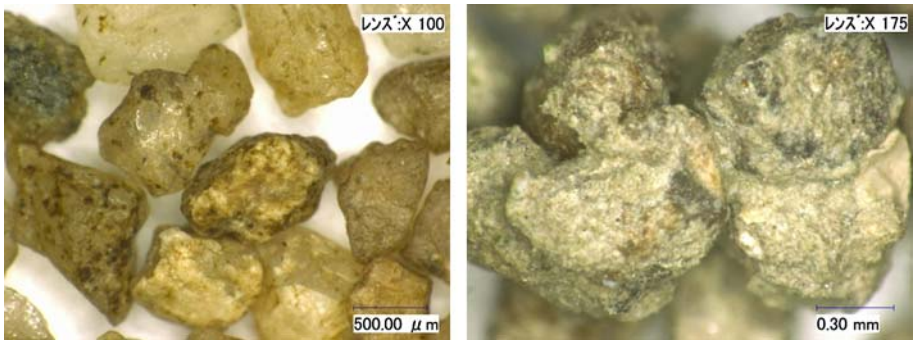

Fig. 6. Results of the microscopic observation of sands.

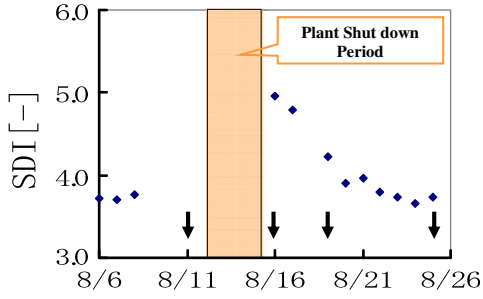

Fig. 7. SDI data during investigation period in 2009.

effect has not been elucidated. We need further investigation on this mechanism.

In addition, we performed the demonstration of an SWRO module by using the pretreated seawater adopting the chemical-free process of the Naikai Salt

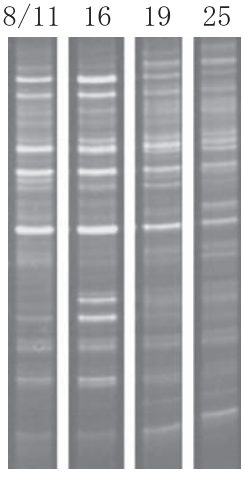

Fig. 8. DGGE profile of sand samples.

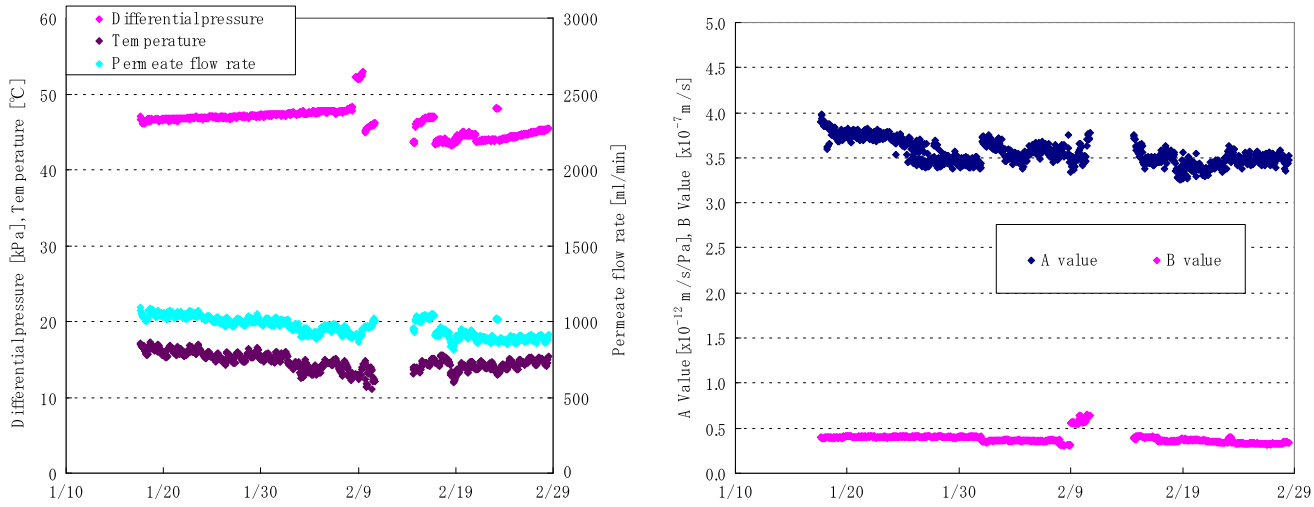

Fig. 9. Performance data of RO system.

Industry. The data on the SWRO performance are shown in Fig. 9. RO test unit, where one 2.5 inch SWRO module of Dow chemical was installed, was operated with around 15% of recovery. A value (water permeability), B value (salt permeability), and differential pressure are very stable respectively. These data proved that the chemical-free pretreatment system applied in the factory of the Naikai Salt Industry worked as the pretreatment system for the RO membrane and demonstrated that this process was applicable for an RO seawater desalination plant.

4. Conclusion

The chemical-free pretreatment system is very attractive from both economical and environmental points of view. The Mitsubishi Heavy Industries, Ltd has been challenging the development of this innovative pretreatment by demonstrating the applicability of the two kinds of field tests both in Qatar and Japan. In Qatar, the test results proved that the pretreatment without the coagulants is applicable for the pretreatment of RO seawater desalination. In Japan, the chemical-free pretreatment process by rapid sand filtration was applied for the pretreatment of RO seawater desalination and the result turned to be successful.

Especially chemical-free rapid sand filtration is the most promising process as it does not require any cleaning agent, which signifies a complete chemical-free process. The performance of this system seemed to be related to microbial activity as other researchers have also pointed out [6], but details pertaining to this point have not been identified. Further investigation for this mechanism will be needed.

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