Development of Water Purification Equipment with RO Membrane for Mini-scale Water Supply Facilities

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INTRODUCTION

In Japan, decrease in water tariff revenue owing to the declining population, and increase in renewal demand on water supply facilities, etc., have given rise to many problems. As a countermeasure, although advances towards the progressive amalgamation of the waterworks operations are being made, the mini-scale water supply facilities in small islands/mountainous regions have problems such as water quality management, facility operation, and renewal. Most facilities due for restructuring were built during the high-growth period, and have since deteriorated. Further, although they should ideally be downsized due to depopulation, in many cases, investment recovery might prove difficult. An additional problem faced by water supply facilities is the lack of skilled engineers.

In order to address these problems related to mini-scale water supply facilities, we have developed portable water purification equipment. This developed equipment has advantages in that it is portable, can accommodate itself to the various kinds of raw water, can be compactly installed, and places little burden on the administrator. We installed this developed equipment at the mini-scale water supply facility in a small island and verified whether these problems can be solved.

In this paper, we report on the practical operating situation of field tests for eighteen months.

METHODS

1 Features of the Developed Equipment

1)High water purification performance by RO membrane filtration with pretreatment of MF membrane filtration
Individual operation by MF membrane filtration is available.
A block diagram of the developed equipment is shown in Fig. 1.

2)Fully-automatic operation system with back washing function
An operation system with a back washing function is equivalent to the water purification plant.
An alarm contact output is available in case of emergency regarding the treatment water quantity and transmembrane pressure difference, etc.

3)Provided with remote monitoring device
The operation data of the equipment can be obtained without going to the site, an alarm can be received by Email in real time when an emergency occurs, and therefore, manpower can be saved.

4)Light-weight, compact, and portable
Can be carried in through a typical single swing door (Width: 700 mm)

5)Unitization and prefabricated compact structure with caster
Easy transportation and assembly on site
The prefabricated structure of the developed equipment is shown in Fig. 2.

6)AC100V/200V power supply can be used
The power source can be easily supplied from plug sockets at home.
Can be operated by a commercial generator at places without power supplies.

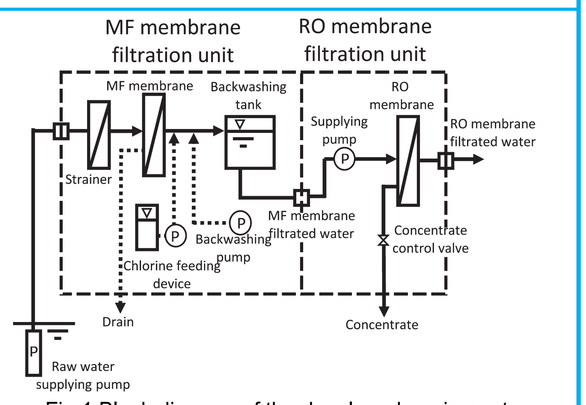
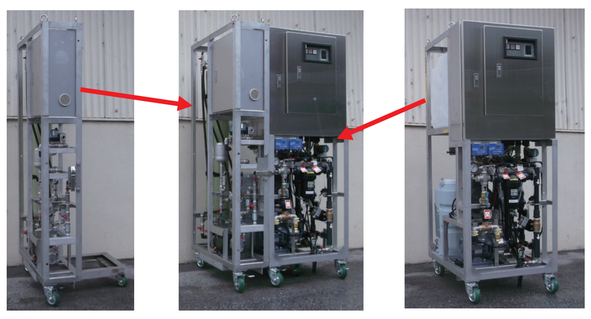


Fig.1 Block diagram of the developed equipment



RO membrane filtration Unit | Combined external appearance | MF membrane filtration Unit

Fig. 2 Prefabricated structure of the developed equipment

2 Field Tests

The installation scenario is shown in Fig. 3.
The water treatment flow chart in field tests is shown in Fig. 4.
The circumstance of the water resource are shown in Fig. 5.
An enlarged view of Fig. 5 is shown in Fig. 6.
The method of the field tests is shown in Table 1.

Fig. 3 Installation scenario

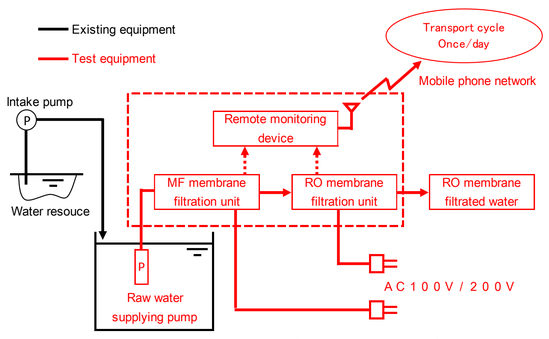


Fig. 4 Water treatment flow chart in field tests

Fig. 5 Circumstance of water resource

Fig. 6 Enlarged view of Fig. 5

Table. 1. Methods of the field tests

Items	Contents
Period of the field test	1/9/2016 - 31/3/2018 Duration 18 months
Workability of the carrying in and installation	Transport: By fishing boat and pickup truck Carrying in: Using manpower; Non-use heavy machinary Installation: Outdoor; Under the severe condition
Water purification flow chart	Shown in Fig. 4
Type of raw water	Water in reservoir
Quantity of raw water intake	10.24㎥/8h/day
Quantity of treatment water	5 ― 6㎥/8h/day
Operating hours	22:00 ― 6：00(8hours); Because of the restrictions on water intake
Remote monitoring method	The periodical data collections made by the remote monitoring system
Communication system	Mobile phone network
Contents of measured data	Flow rate of the water filtrated by the MF membrane MF transmembrane pressure difference Flow rate of the water filtraed by the RO membrane Supplying water pressure of the RO membrane ･･･a Consentration pressure of the RO membrane ･･･b *1 RO transmembrane pressure difference ･･･c Conductivity of water filtrated by the MF membrane Conductivity of water filtrated by the RO membrane Water temperature
Sampling cycle	Once/minute
Transport cycle	Once/day
Report means at the emergency alarm	E-mail 13 major incidents 4 minor incidents
Water purification performance	Analyze the following items by the standard methods for the examination of water (JWWA). iron manganese chloride ion hardness total residue total organic carbon(TOC) odor color turbidity totaly 9 items

*1 RO transmembrane pressure difference; c = a - b

Table. 2 Criteria for the chemical cleaning time of the MF membrane and replacement time of the RO membrane

Kind of Membrane	Measured data	Criteria
MF Membrane	MF transmembrane pressure difference	0.2 MPa or more
RO Membrane	Conductivity of RO membrane filtrated water	10 μS/cm or more *2
	Flow rate of RO membrane filtrated	90% or fewer of the initial flow rate *2
	RO transmembrane puressure difference	1.5 times the inicial pressure difference or more *2

*2 In case of detection of any of these conditions, the RO membrane must be replaced.

3 Evaluation Items

1)Workability of the carrying in and the installation
2)Water purification performance
3)Remote monitoring performance
Judgement for the chemical cleaning time of the MF membrane and replacement time of the RO membrane.
Criteria for the chemical cleaning time of the MF membrane and replacement time of the RO membrane are shown in Table 2.

RESULTS

1 Workability of the carrying in and the installation

The situation of transporting the divided equipment units by the fishing boat is shown in Fig. 7.
The results of the carrying in and the installation are shown in Table 3.
The time taken from carrying in the fishing boat to the installation was 7.5 hours, and the workability of the carrying in and installation was good.

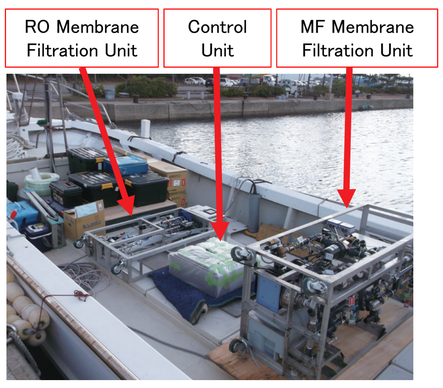


Fig. 7 Situation of transporting the divided equipment units by the fishing boat

Table. 3 Results of the carrying in and installation

Operation in first day	Situations	Time spent on	Evaluation
Carrying the equipment into the fishing boat at a harbor in the main island	Without using heavy machinary; only using manpower. (4 persons)	0.5 h	good
Transportation by the fising boat (main - small island)		0.5 h	good
Carrying the equipment out from the boat at a harbor in the small island	Without using heavy machinary; only using manpower.(4 persons)	0.5 h	good
Lifting the equipment onto a pickup truck	Without using heavy machinary; only using manpower.(4 persons)	0.2 h	good
Transportation by the pickup truck(harbor - installation site)		0.4 h	good
Carrying the equipment out from the truck	Without using heavy machinary; only using manpower.(4 persons)	0.4 h	good
Assembly and installation of the equipment	Because of the prefabricated structure, it was easy to assemble and install.	2 h	good
Piping, wiring and temporary water supply *3	Because of the hose piping, it takes a short time to complet.	3 h	good
	Total	7.5 h	

*3 Not including the adjustment for full operation

2 Water purification performance

As shown in Table 4, the raw water was especially high in metals, TOC, and color, Furthermore, odor was also detected, and high water purification performance was required to treat it. In MF membrane filtrated water iron, manganese, and turbidity were removed to the standard value of water quality or lower, and color could be reduced to approximately one sixth.
Therefore, we have recognized that MF membrane filtration has high water purification performance as a pretreatment device. Furthermore, since the RO membrane filtrated water was filtrated to a numerical value that fully satisfies Japan's water quality standards, we confirmed its high water purification performance.

Table. 4 Water analysis results at the beginning of operation

Items of inspection	Unit	Water quality standards	Raw water	→ MF membrane	→ RO membrane
iron	mg/l	0.3 or less	3.7	0.08	0.01 or less
manganese	mg/l	0.05 or less	0.06	0.005 or less	0.005 or ress
chloride ion	mg/l	200 or less	96	110	1.5
hardness	mg/l	300 or less	55	72	3
total residue	mg/l	500 or less	270	270	20 or less
TOC	mg/l	3 or less	8.2	6.7	1.2
odor		smell free	smelled	smelled	smell free
color	degree	2 or less	90	14	0.5 or less
turbidity	degree	2 or less	4.7	0.1 or less	0.1 or less

* The red letters are the over the standards

3 Remote monitoring performance

The data collected by the remote monitoring device is shown in Graph. 1.
The contents of symbols on Graph. 1 are shown in Table. 5.
The contents of alarm incidents from the remote monitoring device received by Email are shown in Table. 6.

1) As shown in Graph. 1, we could obtain the detailed data from the remote monitoring device, without going on the site.
2) The first date that was confirmed as the replacement date of the RO membrane, was April 22nd 2017 on symbol D. The next confirmed date was May 22nd 2017 on symbol F. The last confirmed date was May 25th 2017 on symbol G.
3) After confirming the replacement date of the RO membrane, we continued the experimentation for about 7 months (up to November 13th 2017, the period of J); then, we got several kinds of data after the replacement time of the RO membrane.
4) As shown in Table. 6, we detected one major incident and three minor incidents. Every incident could be received in real time with the data from remote monitoring device, without visiting to the site, and we could confirm the conditions of the equipment.
5) As shown in Graph. 1 and Table. 6, the chemical cleaning time of the MF membrane and the replacement date of the RO membrane could be ascertained precisely.
6) Under the severe conditions during outdoor installation, the developed equipment did experience any severe problems, and could continue operations; therefore, we could confirm the reliability of the remote monitoring system.

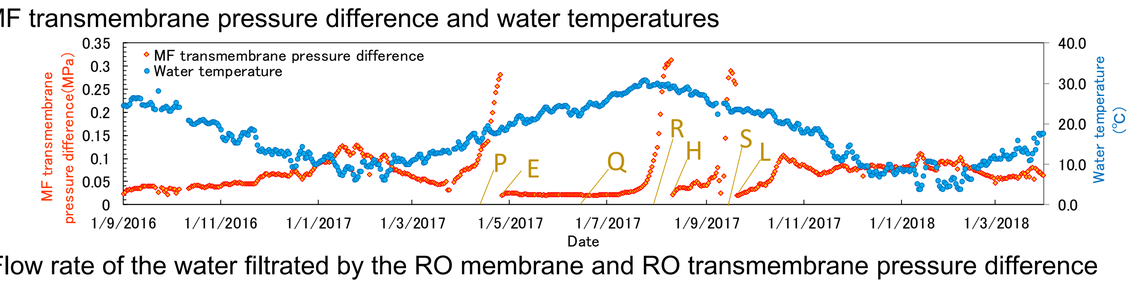
Table.5 Symbols and Contents on Graph. 1

Symbols of Graph	DATE	Contents
A	1/9/2016 - 22/4/2017	The period where the conductivity of water filtrated by the RO membrane was normal.
B	1/9/2016 - 22/5/2017	The period where the RO transmembrane pressure difference and flow rate of the water filtrated by the RO membrane were normal.
C	14/3/2017	RO transmembane pressure difference droped becaose of adjusting the flow rate of the concentrate through the RO membrane.
D	22/4/2017	The replacement date of RO memblane, that was detemined by the conductivity of water filtrated by the RO membrane.
E	25/4/2017	Replaced with the preparatory MF membrane; the removed membrane was sent to the factory for chemical cleaning.
F	22/5/2017	The replacemet date of the RO membrane, which was determined by the flow rate of water filtrated by the RO membrane.
G	25/5/2017	The replacemet date of the RO membrane, which was determined by the difference in RO transmembrane puressure.
H	10/8/2017	Replaced with the preparatory MF membrane; the removed membrane was sent to the factory for chemical cleaning.
I		The situation which the RO transmembrane pressure diffarence increased sharply. Use is continued after the time for replacement of the RO membrane.
J	22/4/2017 - 13/11/2017	The period during which the operation continued after the time for replacement of the RO membrane.
K	-	The situation where the conductivity of the water filtrated through the RO membrane was disturbed. Use is continued after the time for replacement of the RO membrane.
L	19/9/2017	Replaced with the preparatory MF membrane the removed membrane was sent to the factory for chemical cleaning.
M	13/11/2017	Actual the replacement date of RO membrane.
N	13/11/2017 - 31/3/2018	The period where operation was stable after replacing the Ro membrane.
O	21/3/2018 - 31/3/2018	The situation in which both the conductivity of the water filtrated through the MF membrane and the conductivity of the water filtrated by the RO membrane were increasing.

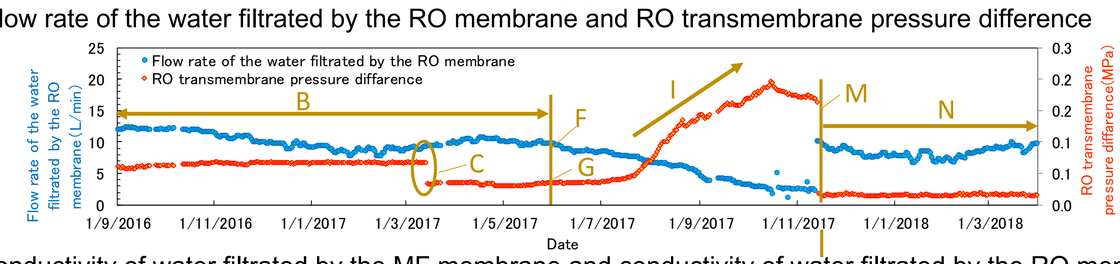
Table. 6 Contents of alarm incidents from the remote monitoring device received by Email

Simbols of Graph	DATE	Contents
P	20/4/2017	Minor incident was detected. MF membrane module clogging.
Q	21/6/2017	Major incident was detected. Incident of the flow rate of MF membrane filtrated. (Failure of the raw water supplying pump)
R	4/8/2017	Minor incident was detected. MF membrane module clogging.
S	19/9/2017	Minor incident was detected. MF membrane module clogging.

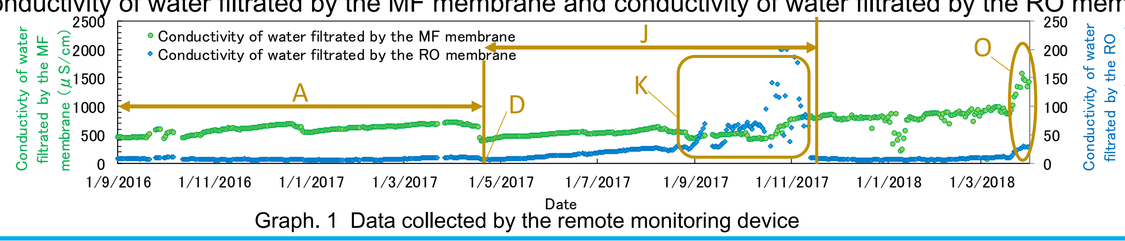
MF transmembrane pressure difference and water temperatures



Flow rate of the water filtrated by the RO membrane and RO transmembrane pressure difference



Conductivity of water filtrated by the MF membrane and conductivity of water filtrated by the RO membrane



Graph. 1 Data collected by the remote monitoring device

DISCUSSION

1)The result that we were able to carry and install the prefabricated devices with manpower without using heavy machineries was achieved by prefabricating the required devices into units so that they are easy to assemble and install on site. Therefore, we could verify that the developed equipment has high portability. Furthermore, the developed equipment could be installed compactly in an outdoor open space without constructing small building for its housing. We have been observed that many mini-scale water supply facilities have been constructed in the mountainous regions. Many of these facilities are located far away from towns and are inconvenient for maintenance of the facilities. In some cases, such facilities are located at places that are inaccessible by car. Further, there are many cases where there is not sufficient space for constructing a new facility. We consider that the developed equipment can be carried and installed at such as places easily.

2)The period during which the operation continued after the time for replacement of the RO membrane, shown by symbol J on Graph 1, was not the stabilized situation of the water purification performance as shown by symbols I and K. The operating period, denoted by symbol N, after the actual replacement date of the RO membrane, satisfied the criteria of RO transmembrane pressure differences, conductivity of water filtrated through the RO membrane, and the flow rate of the water filtrated through the RO membrane. Thus, we could confirm that the operation of the developed equipment was stable. For this reason, it is proper that we should replace the RO membrane on the date denoted by symbol D on Graph. 1. If the quality of raw water is better than that of the water we have used in this test, it can be expected that the replacement time of the RO membrane and the chemical cleaning time of the MF membrane would be extended. In the future, we would like to confirm how the replacement time of the RO membrane and the chemical cleaning time of the MF membrane vary depending on the difference in raw water quality and, obtain data on estimating the replacement time of the RO membrane and the chemical cleaning time of the MF membrane.

3)At symbol C on Graph 1, as the flow rate of the concentrate through the RO membrane was more than that when the operation started, we throttled the adjustment valve, shown in Fig. 1, so that the RO transmembrane pressure difference decreased. We learned that to control the RO membrane filtration unit, it is important that we obtain data on the flow rate of the concentrate through the RO membrane. Therefore, it makes sense to monitor the flow rate of the concentrate through the RO membrane.

4)As listed in Table. 6, email notification of incidents increased by four times on installing the remote monitoring device. For the major incident reported on June 21, 2017, we received an alarm that indicated a remarkable decrease in the flow rate of the water filtrated by the MF membrane. We checked the developed equipment at the site, and concluded that the cause behind this was that the raw water supplying pump failed and stopped. Therefore, the flow rate of the water filtrated through the MF membrane could not be secured. Thus, we immediately switched to an alternative pump and resumed operation. Another minor incident involved clogging of the MF membrane module. As we had information on the increase in MF transmembrane pressure difference from several days before with the help of the data collected from the remote monitoring device, we could compensate this with leeway. We received emergency alarms from the facility in real time and could deal with it immediately without being at the site. Thus, we could reduce manpower and the burden on the administrator.

5)Because the operation of the developed equipment is fully automatic and has both superior water purification performance and portability, it can be used in disasters. Because the developed equipment can be used as a permanent facility under normal circumstances, and as an emergency facility in times of disasters, we consider that it will be a mini-scale water supply facility that is conducive to disaster countermeasures for administrators.

CONCLUSIONS

1)Although the field test area was a small island that was difficult to access, we could carry the developed equipment and install it in the island easily.

2)From the results of the water analysis, we could confirm the superior water purification performance. With the help of the operation data obtained by the remote monitoring device, we could precisely obtain the operation status of the equipment and the replacement time of the RO membrane.

3)From the results of these field tests, we believe that the developed water purification equipment can solve the various problems faced by mini-scale water supply facilities. Furthermore, because this equipment can be used in case of emergencies, we believe this can contribute to "Safety waterworks "and "Critical Control countermeasure for natural disaster" on "New Waterworks Vision". We would like to continuously offer products that can provide solutions to various types of problems in the local community.

Fujita Yukio(2011)"Development of Water Purification Equipment for Mini-scale Water Supply Facility" The 4th IWA-ASPIRE