A Filtering device for improving the quality of cooling water in turbine generator of Sihwa Tidal Power Plant

T. K. Kim, H. J. Kwak, J. H. Bang, M. S. Kim, B. S. Kim

Abstract—**The turbine generator cooling water system of Sihwa Tidal Power Plant is an economical system in which the cooling water cools the turbine generator through a circulation pump and the rising temperature recirculates heat exchange with seawater through a surface cooler. However, as the cooling water facility continues to operate and a long period of time passes, the cooling water quality in the piping deteriorates. In particular, the increasing the concentration of Fe ions in the coolant may promote corrosion of circulating pipes, which may reduce the stability of the water turbine generator operation. Even if the coolant whose water quality has deteriorated is replaced, additional cleaning agents must be treated, but chemical treatment was difficult due to concerns over pipe damage. To overcome this, a filtering device for improving the water quality of cooling water was applied. Through the application of filtering devices for about a month, the water quality was improved by reducing the concentration of cooling water Fe ions by about 70%, and the facility maintenance cost was reduced by about $110,000 per year. We can greatly contribute to maintaining the economical cooling water system and securing the operational stability of water turbine generators by applying the cooling water filter.**

Keywords*—*Filtering device, Cooling water, Coolant, Fe ion, Anticorrosive, Corrosion,

I. INTRODUCTION

THE Sihwa Tidal Power Plant is the largest tidal power plant in the world. The capacity of this power plant is 254MW in total, consisting of 10 generators of 25.4MW, and generates 552GWh of electricity annually, which can be used by 500,000 people for one year. This Power Plant generates twice a day when rising tide and controls the water level of Sihwa Lake by opening eight floodgates during low tide.

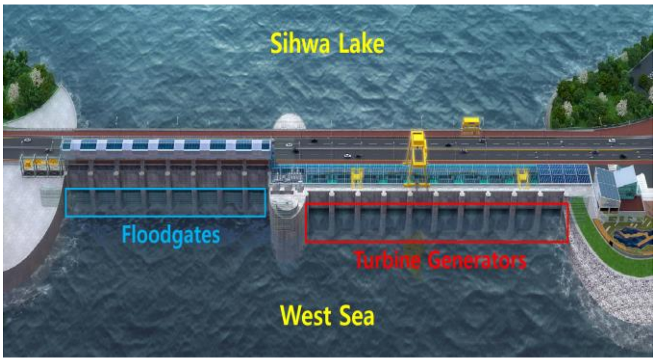

Fig. 1. The Sihwa Tidal Power Plant is the largest tidal power plant in the world. This Power Plant has 10 turbine generators and 8 floodgates.

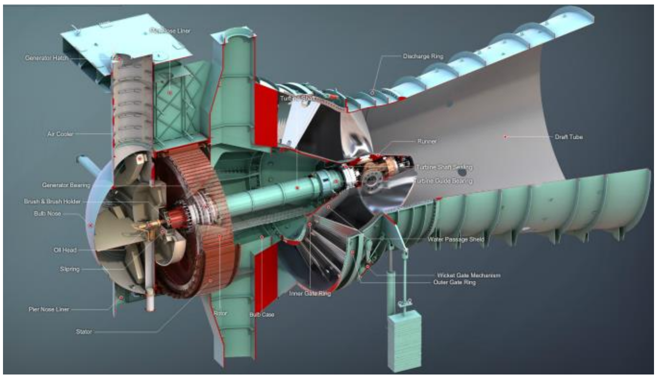

Fig. 2. The Sihwa Tidal Power Plant's turbine generator schematic diagram. At rising tide, the wicket gates open and the runner rotates to generate electricity.

The Sihwa Tidal Power Plant's coolant system is a system in which cooling water cooled by the surface cooler is supplied to major parts such as the air-water cooler, bearing lubricant, and governor operating oil in a closed circulation method to exchange heat. This cooling water circulation system is an economical structure, but it is a facility that requires periodic maintenance and inspection as it is impossible to check internal conditions.

This work collaborated with "Prime-Tech International" to improve the water quality of Sihwa Tidal Power Plant."

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Prime Tech International is manufacturer of 'Filtering device' and gives advice of coolant and anti-corrosive liquid.

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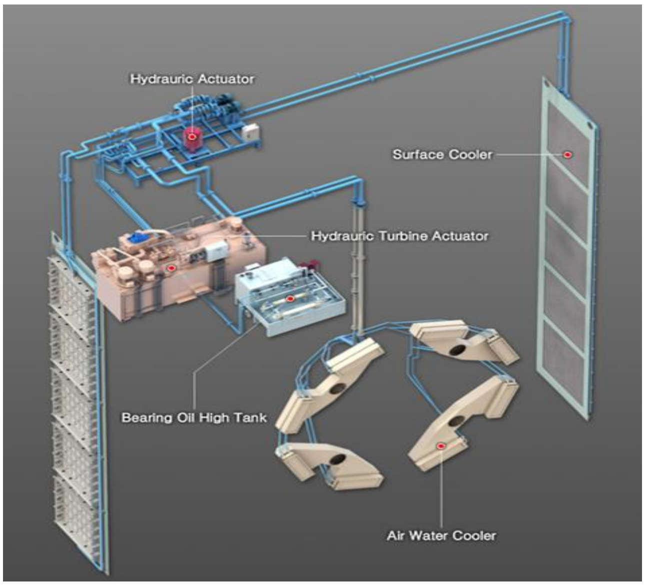

Fig. 3. The Sihwa Tidal Power Plant Coolant system is water circulation system in which the coolant filled in the pipe circulates to cool each part of the turbine generator.

TABLE I
COMPOSITION OF THE SIHWA TIDAL POWER PLANT COOLANT SYSTEM

Category	Value
Coolant	1,590L, 70% tap-water, 30% addictive
Circulation pump	80 m^3/hr, 30mH, 2EA
Piping	Carbon Steel(A106 GR-B)

The 30% Addictive consisted of a mixture of anticorrosion and propylene glycol-based antifreeze.

In addition, the heat-exchanged cooling water returns to the surface cooler, which is buried in the water turbine structure, and the cooling water pipe cannot be replaced or repaired.

Due to the above field conditions and concerns over facility problems caused by invisible coolant water quality, we requested a specialized institution to analyze the coolant water quality in December 2015. The water quality analysis items and normal operation range were mainly analyzed based on the water quality standards of cooling water according to Korean industrial standards.

TABLE II
RESULTS OF COOLANT QUALITY IN DECEMBER 2015

Category	pH	Electric conductivity	Turbidity (NTU)	Fe ion (ppm)
Range	6.5~8.0	Under 800	Under 20	Under 1.0
Unit 1	8.4	1040	129	117
Unit 2	8.5	902	32	35.2
Unit 3	7.9	813	97.1	44
Unit 4	8.3	813	116	88.1
Unit 5	8.1	808	232	138
Unit 6	7.9	847	179	91.1
Unit 7	7.6	870	76.1	40.4
Unit 8	7.3	832	94	54.1
Unit 9	7.9	724	15.4	16.2
Unit 10	7.2	857	89.5	69.7

In this table, pH and turbidity that promote corrosion of pipes exceeded the standard value, and the measured value of 'Fe' ions was confirmed to be very serious.

Based on the results of cooling water quality analysis, we established maintenance standards for cooling water facilities from February 2016. The main contents were the inspection items and inspection cycles of cooling water facilities, and the main items of water quality management were eight items, including pH, electrical conductivity, turbidity, and 'Fe' ions.

If the pH exceeds 8.0, scale components may be deposited and attached to pipes, causing performance degradation. High electrical conductivity means that there are many substances that cause corrosion or pipe scale generation in cooling water. In the case of turbidity, corrosion increases and 'Fe' ions increase due to the stagnant characteristics in the pipe, resulting in a complex effect.

Accordingly, we decided to replace the cooling water during the major inspection period every three years when the main inspection and management of the turbine generator are conducted, and the replacement history is as shown in the table below.

TABLE III
REPLACEMENT OF COOLANT AS OF 2020

Category	2016	2017	2018	2019
Unit 1	Done			Done
Unit 2			Done	
Unit 3			Done	
Unit 4				
Unit 5	Done			Done
Unit 6	Done			Done
Unit 7		Done		
Unit 8				
Unit 9				
Unit 10				

In 2017, the waste storage space after replacement was not secured and could not be replaced.

II. MAJOR PROBLEMS IN COOLANT SYSTEM

A. *Method of replacement coolant*

In Sihwa tidal power plant, the method of coolant replacement is flushing. In general, in order to replace the cooling water, it is necessary to drain the entire water and clean the pipe.

However, if you look at the cooling water system in Figure 3 again, there is no valve or pipe that can drain the water at the bottom of the cooling water system of Sihwa Tidal Power Plant. In addition, Surface Cooler is buried in a concrete structure, making it difficult to install drain valves and pipes.

As a result of checking the cooling water quality analysis data, it was found that there is a limit to simply replacing the cooling water. The turbine unit 7, which replaced the cooling water in 2017, has a very different 'Fe' ion concentration compared to the unit 9, which has not replaced the cooling water for nine years. Based on this result, it seems that we will need to replace the coolant considering the condition of the internal pipe, not the simple coolant replacement.

TABLE IV
RESULTS OF COOLANT QUALITY IN MAY 2020

Category	pH	Electric conductivity	Turbidity (NTU)	Fe ion (ppm)	Using years
Range	6.5~8.0	Under 800	Under 20	Under 1.0	-
Unit 1	10.1	384	72.8	4	1
Unit 2	10.1	1188	261	194.2	2
Unit 3	10.0	865	167	143.8	2
Unit 4	7.7	868	155	134.4	9
Unit 5	10.0	342	157	17.9	1
Unit 6	11.2	574	50.8	6.8	1
Unit 7	9.8	388	247.2	**491**	3
Unit 8	6.2	1141	492	**212.8**	9
Unit 9	7.7	770	10.3	**17.1**	9
Unit 10	6.2	1261	457	**321.5**	9

These results were self-analysis in Sihwa Tidal Power Plant by using simplified water quality analyzer.

B. *Types of anti-corrosion liquid*

In the meantime, tap water and additives were added when replacing cooling water, and antifreeze and anti-corrosion liquid were used together as these additives. At this time, a nitrite-based material was used as an anti-corrosion liquid.

The performance of this nitrite-based material is different from depending on the corrosion state inside the pipe. When the piping condition is good, it shows excellent effects, but in situations where corrosion occurs, it has no effect at all. We decided to change the type of anti-corrosion liquid to Molybdate-based silicate system with the advice of "Prime Tech International," which has technology in the field of cooling water and water treatment.

Accordingly, in August 2020, cooling water was replaced for turbine generators Unit 7, 8, and 10 using a new anti-corrosion liquid. After replacing three turbine generators' coolant, the results of the water quality analysis in January 2021 are shown in the table below.

TABLE V
RESULTS OF CHANGING COOLANT IN JANUARY 2021

Category		pH	Electric conductivity	Fe ion (ppm)
Range		6.5~8.0	Under 800	Under 1.0
Unit 7	Before	9.8	388	491
	After	10.3	325	**11**
Unit 8	Before	6.2	1141	212
	After	8.1	436	**104**
Unit 10	Before	6.2	1261	321
	After	8.0	441	**7**

When comparing before and after cooling water replacement, a slight improvement was confirmed.

The 'Fe' ion value has improved compared to the previous one, but it is still higher than the standard range value. In the case of Unit 8, it can be seen that the reduction rate of the 'Fe' ion concentration is low.

Due to the structural conditions of the Sihwa tidal power plant, it is impossible to clean pipes and replace all of them, which are essential for improving the water quality of cooling water, so we have to consider other measures.

III. INSTALLING A FILTERING DEVICE

In order to improve the function of the anti-corrosion liquid and prevent pipe corrosion, we decided to introduce and test the 'fe' ion filter targeting the 'Fe' concentration, a major corrosion factor in the coolant.

TABLE VI
COMPOSITION OF 'FE' ION FILTERING DEVICE

Category	Value
Device size	800mmW, 800mmL, 1700mmH
Pressurizing pump	1 m^3/hr, 30mH, 1EA
Micro Filter	5 ㎛ 1EA, 1 ㎛ 1EA
Main Filter Material	Katalox light, 4EA

A filtering device for removing 'Fe' ion consists of two solid filters for each type and four Katalox light 'Fe' ion filters.

The composition of the filtering device for the removal of 'Fe' ions that we introduced this time is not too difficult. The 'Fe' ion filter is a facility that removes 'Fe' ions in water using a total of three types of filters. The main composition is a pressurizing pump, two types of microfilters, a set of 'Fe' filtration filters (composed of four), and a control panel that monitors data.

First, a 5 ㎛ microfilter was used to remove primary solids in the cooling water. After that, 'Fe' ions are removed using a dedicated filter called 'Katalox light' that can be adsorbed after transforming 'Fe' ions in the coolant into insoluble. After the 'Fe' ion filter, a 1㎛ microfilter was used to remove residual solid substances in the cooling water and prevent the leakage of the filtrate.

The coolant 'Fe' ions can be removed sequentially through three types of filters, and the real-time 'Fe' concentration value can be checked through the monitoring control panel.

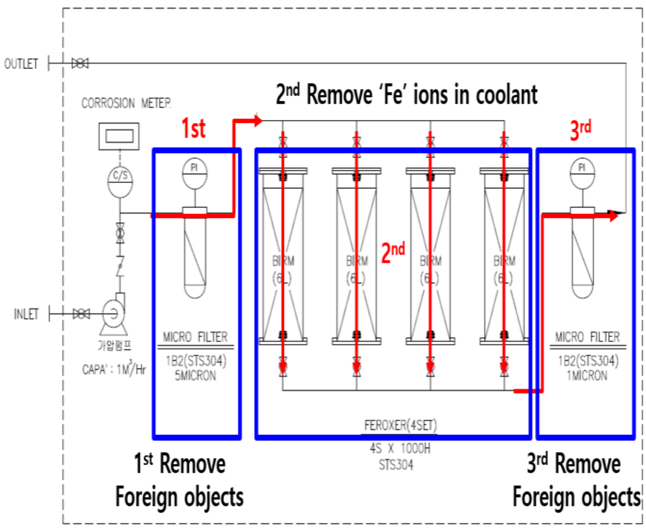

Fig. 4. A schematic diagram of a filtering device.

Fig. 5. Fe ions Filtering Device is now operating in Sihwa Tidal Power Plant. This device can be installed in a portable manner.

In addition, filters can be replaced in a timely manner through checking the pressure value before and after the filter and visual inspection of the filter housing. This 'Fe' filtering device is movable so that it can be flexibly installed and operated. This filter is an equipment manufactured by "Prime Tech International," and the performance of the filter was checked in advance at the manufacturer's factory before on-site installation.

TABLE VII
'FE' ION VALUE ACCORDING TO THE NUMBER OF FILTER TIMES

Filter Times	0	1	3	5	10	15
'Fe' ion (ppm)	9.81	9.53	8.15	7.6	4.79	3.41

Before the filter was operated (0 filtration times), the Fe ion concentration was 9.81. After operating the filter (15 filtration times), it was confirmed that it decreased by 65% to 3.41.

Based on the results of the table above, we confirmed that the performance of the filtering device and the number of filters are excellent. Filters of filtering device need to replace regularly, depending on consumption products. Although it varies depending on the conditions of use, a digital flow meter for measuring the passage flow rate is installed, so the replacement cycle can be checked due to the occurrence of an alarm due to a change in flow rate.

In the case of microfilters, visual inspection is performed through a transparent filter housing and replaced when discolored. Alternatively, the replacement period can be checked in advance by the differential pressure of the pressure gauge at the front and rear of the filter.

IV. RESULTS

A. *Turbine Unit 7 'Fe' ion value*

First, on January 4, 2022, a coolant filtering device was installed and operated in Unit 7. The following is a graph of the 'Fe' ion value for about a month after installing the cooling water filtering device.

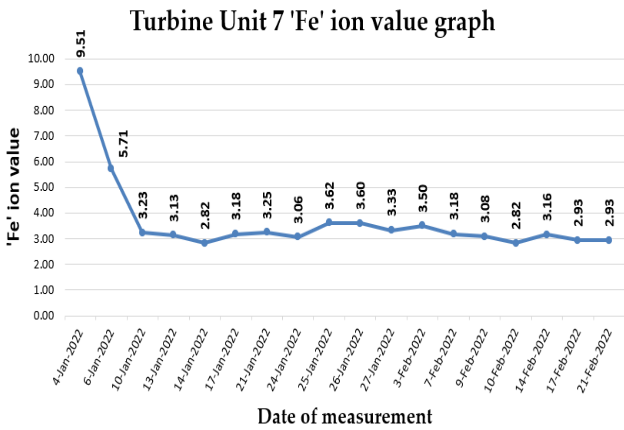

Fig. 6. Turbine Unit 7 'Fe' ion value graph about a month.

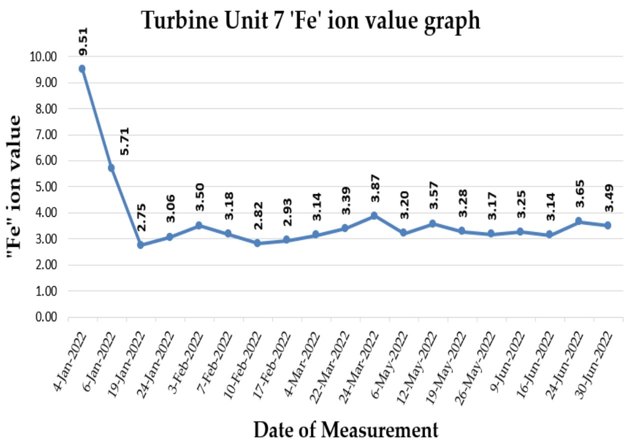

Fig. 7. Turbine Unit 7 'Fe' ion value graph the first half of 2022

On January 4, when the filter was installed, the 'Fe' ion value was 9.51, but on February 21, when the filtering device was stopped, it was 2.93, and the 'Fe' ion value was reduced by 69% for about a month.

After the uninstalling of the filtering device, the 'Fe' ion measurement value of the Turbine generator Unit 7 during the first half of 2022 has stabilized to between 3 and 4.

B. *Turbine Unit 8 'Fe' ion value*

On March 4, a filtering device was installed in the Turbine generator Unit 8, and Figure 6 shows the change in the 'Fe' ion value during the first month. On March 4, the 'Fe' ion value was 75.3, but the 'Fe' ion decreased incredibly rapidly and decreased to 0.5 on March 31.

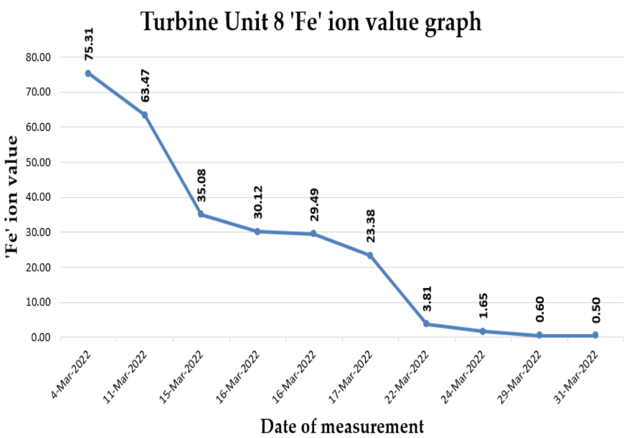

Fig. 8. Turbine Unit 8 'Fe' ion value graph about a month.

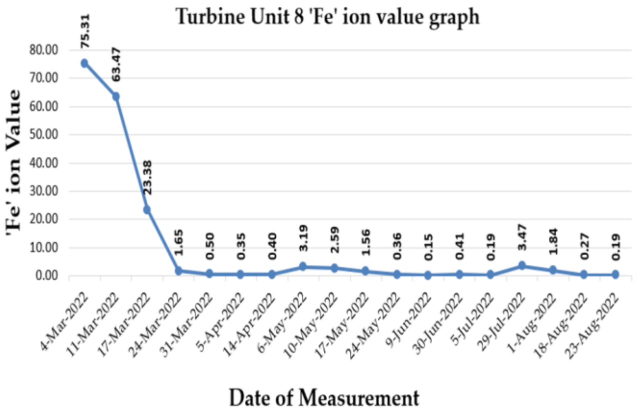

Fig. 9. Turbine Unit 8 'Fe' ion value graph half of a year.

Repeatedly running and stopping the filtering device until August 23, 2022, we found that it would eventually fall to 0.19. As a result of experiments with turbine generator Unit 7 and 8, we confirmed that the filtering device surprisingly reduces the 'Fe' ion value.

C. *Turbine Unit 2,3,4 'Fe' ion value*

To further maximize and spread these effects, We conducted cooling water quality analysis in August 2022. As a result of checking the results of the cooling water quality analysis in August, it was decided to replace the cooling water sequentially for the turbine generator Unit 2, 3, and 4. (Table VIII). After replacement, we decided to examine the change in 'Fe' ions through the operation of the filtering device.

TABLE VIII
RESULTS OF COOLANT QUALITY IN AUGUST 2022

Category	pH	Electric conductivity	Turbidity (NTU)	Fe ion (ppm)
Range	6.5~8.0	Under 800	Under 20	Under 1.0
Unit 1	10.6	393	232	27.8
Unit 2	10.1	1209	329	**227.4**
Unit 3	10.51	874	200	**178.3**
Unit 4	7.59	889	229	**139.8**
Unit 5	9.71	355	100	4.36
Unit 6	11.0	537	193	15.15
Unit 7	11.1	639	3.4	3.41
Unit 8	10.8	762	0.9	0.18
Unit 9	7.8	769	39.2	17.21
Unit 10	8.3	434	29.8	6.07

After Filtering device's effect, we decided to conduct cooling water quality analysis every quarter, and conducted in Aug 2022.

The replacement of the coolant in the turbine generator Unit 2, 3, and 4 was carried out in October, November, and December, respectively, and the filtering device was immediately operated. In December 2022, we finally confirmed the cooling water quality analysis of the turbine generator as follows.

It can be seen that the 'Fe' ion value of the cooling water in the turbine generator Unit 2, 3, and 4 has also improved remarkably through the replacement of cooling water and filtering devices. A picture of the turbine generator cooling water to show a visual effect is as follows.

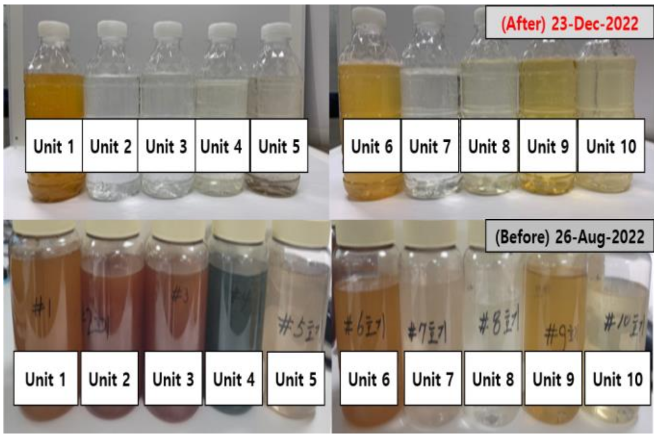

Fig. 10. Coolant Sampling for quality analysis(Aug and Dec 2022)

TABLE IX
RESULTS OF COOLANT QUALITY IN DECEMBER 2022

Category	pH	Electric conductivity	Turbidity (NTU)	Fe ion (ppm)
Range	6.5~8.0	Under 800	Under 20	Under 1.0
Unit 1	10.7	368	241	32.9
Unit 2	11.3	750	1	**0.7**
Unit 3	11.2	688	1	**1.1**
Unit 4	10.9	613	16	**1.3**
Unit 5	10.1	342	49	2.0
Unit 6	11.3	504	165	16.5
Unit 7	11.3	534	2	5.4
Unit 8	11.2	853	9	2.3
Unit 9	7.8	760	8	18.3
Unit 10	8.4	404	30	6.5

This shows the results of the fourth quarterly water quality analysis in 2022

When comparing the photos above and below of the turbine generator Unit 2, 3, and 4, it can be seen that the use of the filtering device after replacing the cooling water has a very good improvement effect on the cooling water.

V. CONCLUSION

We have been paying attention and making efforts for about 10 years to improve the water quality in the cooling water system of the Sihwa Tidal Power Plant. In particular, through many years of analysis, it was realized that the cooling water quality needs to be improved due to internal corrosion of cooling water pipes, especially corrosion caused by 'Fe' ions.

We also reduced the 'Fe' ion concentration through the filter, and additionally improved the turbidity of the cooling water. By checking the real-time 'Fe' ion concentration data attached to the device, it became possible to respond immediately to the quality of the cooling water. In particular, turbine Unit 7 and 8, which applied the filtering device for the first time, surprisingly reduced the 'Fe' concentration.

Through the introduction of this 'Fe' ion filter, it is possible to obtain a cost reduction effect of approximately $95,000 in loss costs for 3 days of power generation shutdown when replacing cooling water, $7,000 in cooling water replacement costs, and $8,000 in waste treatment costs, in total $110,000. (The cost is based on the exchange rate of won to dollar as of March 2023.)

If there is something to be additionally reviewed in the future, it is judged that it is necessary to study the material of the filter currently used in the filtering device. In particular, if a filter that is more efficient and can be expected to have a longer lifespan than "Katalox Light", which can adsorb 'Fe' ions after transforming them into insoluble ones, is devised and confirmed, this filtering device will be able to show even more amazing performance.

If other power plants equipped with cooling water systems for stable operation of generators, such as Sihwa Tidal Power Plant, are experiencing difficulties with internal corrosion of pipes, it is thought that effective results can be obtained if a filtering device is introduced like ours. Also, if you are planning to build a tidal power plant in the future, this idea will be very useful and we will be able to give you better advice.

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