Rotational Cleaning Filter for Ballast Water Treatment System

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Our ballast water treatment system, ECOMARINE, has a unique rotational cleaning (RC) filter for pretreatment followed by treatment with ultra-violet or electrolysis chlorine. The RC filter can remove above 99.999% of large plankton from sea water and make constant flow-rate filtration over 100 hours without differential pressure rises. This paper explains the RC mechanism and the effect of cost-cutting for the system.

Keywords: Ballast Water and Sediments (BWS) Convention, International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWS), ballast water treatment, filter, plankton removal, rotational cleaning

1. Introduction

The International Convention for the Control and Management of Ships' Ballast Water and Sediments,[1] which regulates the discharge of ballast water containing foreign organisms from ships, was adopted by the IMO in February 2004, and is expected to take effect during 2016. This International Convention, which is intended to prevent the transboundary movement of aquatic organisms that affects the marine environment, imposes on all ships navigating in more than one ocean area the duty to remove or eliminate organisms in the sea water acquired when discharging ballast water in other ocean areas.

Our Ballast Water Treatment System (BWTS), ECOMARINE is onboard equipment that efficiently removes organisms from ballast water by passing the water through a filter unit, irradiating with ultraviolet rays, and generating chlorine through electrolysis.

This paper describes the features of ECOMARINE, or the development of its technologically advanced filter with a rotational cleaning system that has superior plankton removal performance.

2. Plankton Sizes and UV Efficiency

To discharge ballast water according to the Convention, plankton amounting to several tens of thousands to several million per 1 m^3 of seawater must be removed or eliminated to 10 or less as shown in **Table 1**.

Plankton are classified for convenience into L and S-sizes with a boundary of 50 µm. A typical BWTS removes most L-sized plankton with a filter unit in the primary stage and eliminate the remaining organisms in the secondary stage.

Figure 1 is a chart that indicates the survival rates of L and S-sized plankton before and after UV irradiation. The UV rays are generated with medium-pressure UV lamps. The test seawater was collected at Imari Bay. Measurement of the number of plankton the followed rule.[3]-[5]

Table 1. Regulation D-2 Ballast Water Performance Standard[2]

Organisms and Microbes	Performance standard
L-sized plankton Greater than or equal to 50 µm in minimum dimension	Less than 10 viable organisms /m^3
S-sized plankton Less than 50 µm greater than or equal to 10µm in minimum dimension	Less than 10 viable organisms /ml
E. coli Scientific name: Eschericha coli	Less than 250 cfu/100 ml
Enterococcus Scientific name: Interstinal Enterococci	Less than 100 cfu/100 ml
Vibrio cholerae (O-1 and O-139)	Less than 1 cfu/100 ml

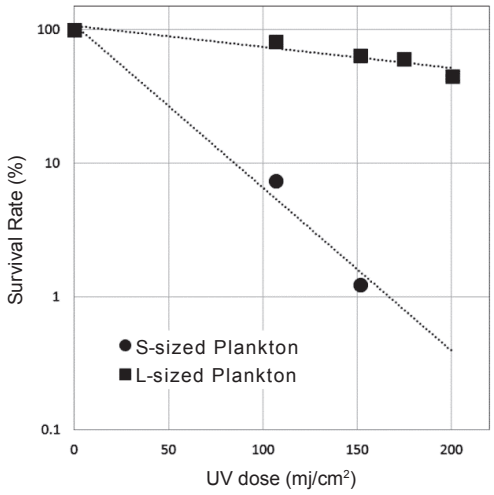

Fig. 1. Plankton Survival Rate Before and After UV Irradiation

In contrast to S-sized plankton that are efficiently eliminated according to the level of UV irradiation,

L-sized plankton are not easily eliminated by increasing the level of irradiation.

The reason for removing L-sized plankton with filter unit in the primary stage is that eliminating L-sized plankton by UV irradiation in the secondary stage requires very large amounts of energy, which is not efficient.

3. ECOMARINE — Our BWTS

Our Ballast Water Treatment System (BWTS), ECOMARINE product line consists of two models: ECOMARINE EC with an electrolytic chlorine generator and ECOMARINE UV with an UV irradiator.[6]-[8] As both models enables elimination at low levels of chlorine concentration and UV irradiation, they feature low power consumption and low environmental impact.

The above merits are achieved with our proprietary rotational cleaning filter (hereafter, "RC filter").

The RC filter removes 99.999% or more L-sized plankton, which achieves both a significant reduction in the load on the treatment unit in the secondary stage, and continuous filtration treatment without clogging causing a rise in the differential pressure or backwashing giving rise to a reduction in the flow of treated seawater.

4. Rotational Cleaning (RC) Filter

4-1 Plankton removal performance

The RC filter uses polyester nonwoven fabric. **Figure 2** shows the changes in the particle size distribution in water before and after filtration.

Since the filter has a degree of separation that reduces the most frequent particle size of 25 μm in the test seawater to 10 μm or smaller, not only can it remove L-sized (50 μm or larger) plankton almost completely, it can also remove 50% to 90% of the relatively small S-sized (10 to 30 μm) plankton.

In the simulated filtration test (**Photo 1**) using 0.1%-cornstarch dispersed seawater, the filtrate from a general stainless steel net filter was whitish. On the other hand, the nonwoven fabric used in the RC filter removed the cornstarch so that the filtrate was transparent.

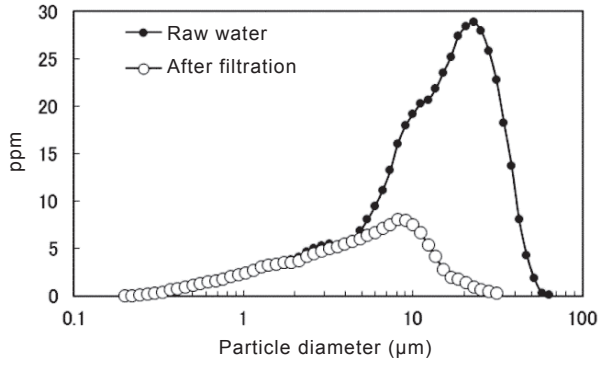

Fig. 2. Separation Performance of the RC Filter

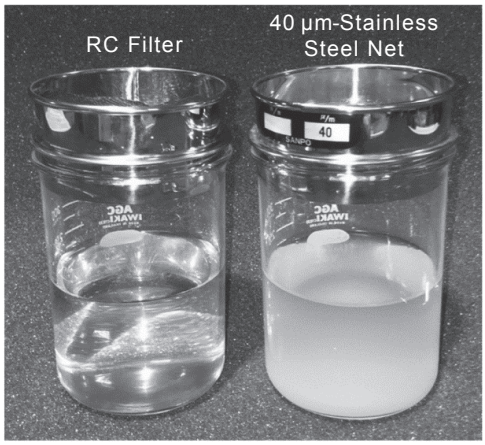

Photo 1. Separation Performance of the Stainless Steel Net Filter and the RC Filter

Figure 3 is a schematic diagram illustrating the structure of the ECOMARINE filter unit. The unit consists of 3 filtration layers of RC filters assembled in resin cartridge that can be easily replaced. Each unit has a filtration capacity of 100 m^3/h to 500 m^3/h depending on the size of the cartridge.

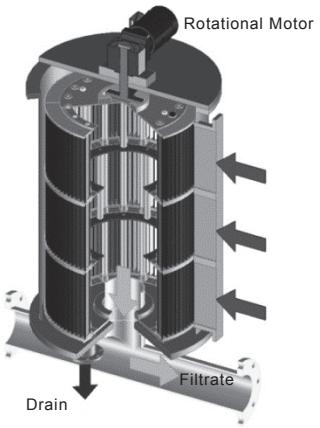

Fig. 3. Sample Configuration of the RC Filter

Table 2 lists the results of a filtration performance test on this unit using seawater. The experiment was conducted under the following conditions:

Site: Imari, Saga; Date: April to May, 2015
Filter: Rotational cleaning filter (Large Unit 1)
Flow: 250 m^3/h (filtration), 50 m^3/h (drain)
Plankton Inspection: Counting the number of L-sized plankton in 1 m^3 of filtrate concentrated with a plankton net under a microscope at a magnification of 200 times

The removal rate for several hundred thousand L-sized plankton per 1 m^3 of raw water was 99.999% or higher (**Table 2**). For the removal of L-sized plankton, the RC filter alone sufficiently satisfies the D-2 Standard indicated in **Table 1**.

Table 2. Filtration Performance Test Using Seawater*

Cumulative Operating Time (hr)	Number of L-sized Plankton (/m^3)		Removal Rate (%)
	Raw Seawater	Filtrate	
58	135,500	0	> 99.9993
94	209,000	0	> 99,9995
137	347,500	0	> 99.9997
273	225,500	0	> 99.9996

* Collected at Imari Bay.

4-2 Operating principle of rotational cleaning (RC)

The RC filter is based on the operating principle of rotational cleaning (RC), in which seawater is continuously injected into a rotating nonwoven pleated filter as illustrated in **Figure 4**. As the seawater is injected, cleaning and filtration are performed simultaneously and continuously.

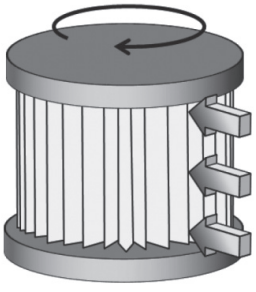

Fig. 4. Operating Principle of Rotational Cleaning

Only the pleat immediately before the seawater inlet (indicated by arrows in **Fig. 4**) through which seawater is being injected is washed. Sediment accumulates on the filter surface of most other pleats. As the cartridge rotates, the pleat to be washed is switched on and the sediment accumulated after each rotation is washed off by injection when the pleat passes the seawater inlet. Rotational cleaning enables continuous operation without interrupting filtration when the cartridge is rotated.

To examine the cleaning effect of rotational cleaning, we investigated changes in the differential pressure of the filter when the cartridge was rotated (at 50 r.p.m.) and when it was not rotated using the same filter and under the same filtering conditions as **Table 2**. (**Figure 5**)

When the cartridge is not rotated (**'a' in Fig. 5**), the differential pressure of the filter rises monotonically because the filtrate continues to accumulate on the filter surface.

Fig. 5 also shows the filtration curve for a general backwashing mesh filter of a similar size. Similar to 'a,' as no washing is performed during normal filtration, the differential pressure rises (**'c' in Fig. 5**).

In the case of the backwashing filter, when the differential pressure reaches a certain level (50 kPa in the example), backwashing is conducted. This is repeated during filtration. As **'c' in Fig. 5** indicates, the differential pressure is restored immediately after backwashing, but in general, the time interval between backwashings is gradually shortened.

On the other hand, rotational cleaning (**'b' in Fig. 5**) maintains the differential pressure in the whole unit at around 20 kPa. The sediment on the filter surface, which was found in the experiment where the cartridge was not rotated, is continuously washed and removed by rotational cleaning, which suppresses the rise in the differential pressure and enables constant and stable filtration.

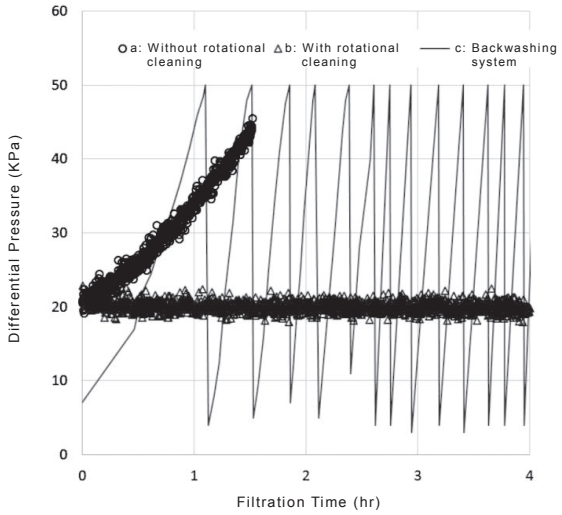

Fig. 5. Rotational Cleaning Suppresses the Rise in the Differential Pressure

4-3 Continuous filtration capacity

To measure continuous filtration capacity of the RC filter, we conducted an experiment that repeats filtra-

tion for 8 to 10 hours per day. **Figure 6** shows the changes in the filtration rate and the differential pressure. The experiment was conducted under the following conditions:

Site: Imari, Saga; Date: August, 2014
Filter: Rotational cleaning filter (Middle Test Unit)
Flow: 100 m^3/h (filtration), 20 m^3/h (drain)
Plankton Inspection: Counting the number of L-sized plankton in 1 m^3 of filtrate concentrated with a plankton net under a microscope with a magnification of 200 times

The RC filter exhibited almost no change in flow or no rise in differential pressure during 10 days of continuous operation (cumulative 100 hours). During operation, no L-sized plankton was detected in the sampling plankton inspection. The unit maintained a filtration performance of 99.999% or higher.

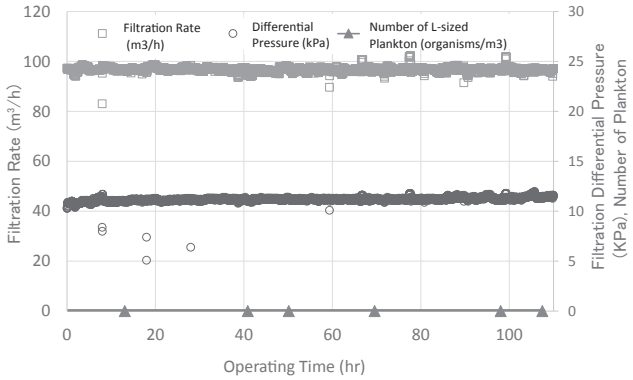

Fig. 6. Continuous Operation of the RC Filter

5. Power Consumption of ECOMARINE UV

As stated above, the RC filter in the primary stage of the ballast water treatment system is superior in removing plankton from seawater and it is a means of filtration that can reduce the load on treatment unit in the secondary stage.

Figure 7 shows a sample comparison of the UV power consumption for ECOMARINE. The power consumption for UV irradiation for ECOMARINE UV is very low, approximately half the average of products from other companies.

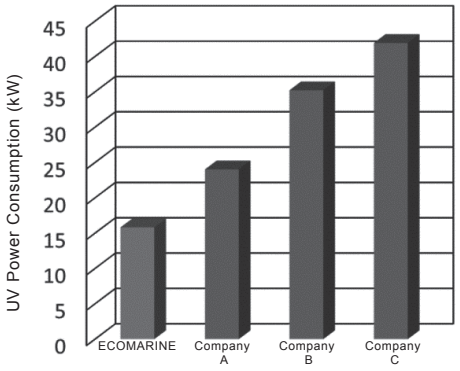

Fig. 7. Comparison of the UV Power Consumption for ECOMARINE

6. Discussion

To eliminate the organisms in seawater sufficiently with an UV irradiator or electrolytic chlorine (EC) generator, it is necessary to increase the level of UV irradiation or chlorine concentration per fixed amount of seawater above a threshold as shown in **Fig. 1**. Therefore, if the supply of filtrate to the UV or EC unit substantially changes because of a rise in the differential pressure or backwashing, the level of irradiation or concentration needs to be adjusted according to the level of supply, as shown in **Figure 8 (a)**.

However, due to the delay in UV output or chlorine generation in response to the input, it is difficult to control the amount of UV irradiation or chlorine generation in real time according to the flow of filtrate without a delay. If a constant amount of UV or chlorine is provided to match the concentration of organisms in the target seawater, the quantity of filtrate needed to eliminate the number of organisms in the seawater passing through the secondary unit during t1 to t3 will not be not sufficiently eliminated.

On the contrary, if excess UV or chlorine to match the maximum flow indicated with a dotted line in **Fig. 8 (c)** is provided to eliminate all organisms in the discharged ballast water, extra energy ΔE will be required.

In the case of the RC filter, the filtration rate is almost constant as shown in **Fig. 6**. Thus, the UV or EC unit can treat water if there is sufficient eliminating strength. In addition to the performance when removing L-sized plankton, the RC filter can reduce the load on the elimination unit in the secondary stage by providing a stable filtration rate. It is thought to have excellent performance as a BWTS filter.

As stated above, ECOMARINE can completely remove large organisms of size L or larger and eliminate small organisms of size S or smaller. In terms of treatment efficiency, the system as a whole reacts to changes in the amount of organisms in the target seawater with great flexibility.

This system is thought to have sufficient performance to comply with the Ballast Water Control Regulations[9] of the USCG, which are severer than the

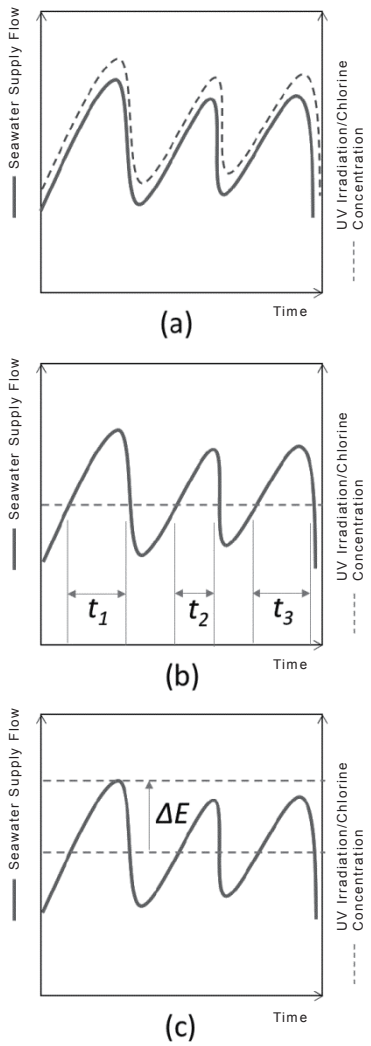

Fig. 8. Relationship between Filtrate Supply and Sterilizing Strength

BSW Convention, and its use is expected to spread in the years ahead.

7. Conclusion

We have developed a rotational cleaning (RC) filter for a ballast water treatment system called ECOMARINE that efficiently treats ballast water as specified by the Ballast Water and Sediments Convention. The RC filter can produce filtrate with 99.999% of large organisms removed from seawater without a reduction in the filtration rate or a rise in the differential pressure. It is a high-performance filter that has optimum characteristics as a filter for ballast water treatment systems.

For the current status of ECOMARINE, ECOMARINE UV, which is suitable for medium to small-sized vessels, has obtained a Test Certificate Prior to Enforcement by the Japanese Ministry of Land, Infrastructure, Transport and Tourism, and a product line with treating amounts from 100 to 1000 m^3/h is on the market. The electrolytic chlorine system, ECOMARINE EC will obtain Type Approval by the end of this year.

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