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JFE Ballast Water Management System†

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Abstract:

JFE Engineering developed a proprietary ballast water management system (hereinafter abbreviated JFE-BWMS. JFE BallastAce® is a registered trademark for the system of JFE Engineering Corp.) utilizing filter(s), two chemical agents, and Venturi tubes as a ballast water treatment system for ships. For practical application of the JFE-BWMS, JFE Engineering determined the optimum conditions for high efficiency treatment of the object aquatic organisms in studies from basic experiments through practical tests[1,2]. This paper describes the results of verification of the treatment performance of the JFE-BWMS and an assessment of the environmental impact of the discharged ballast water in a series of experiments from land-based tests (treatment capacity: 350 m^3/h) to an onboard test in which an actual 1 000 m^3/h JFE-BWMS installed aboard a 47 000 DWT bulk carrier (DWT: Deadweight ton). These tests were conducted with the aim of commercializing the system, and conformed to the guidelines[3,4] established by the International Maritime Organization (IMO). In all cases, satisfactory treatment results which satisfied the relevant discharge standards[5] were obtained in these tests, and an assessment of the results showed that the system has no adverse impacts on the ship's crew and the shipboard environment or marine environment. These results demonstrated that the JFE-BWMS satisfies both treatment performance and safety requirements at a high level. The system received final approval from the IMO on March 23, 2010[10], and received type approval from the Japanese government on May 26, 2010.

1. Introduction

In recent years, the movement and spread of plankton, bacteria, and other aquatic organisms by ship ballast water has emerged as a global problem with adverse effects on the marine environment, fisheries and other industries, and human health[6].

In response to this problem, in February 2004, the International Maritime Organization (IMO) adopted the "International Convention for the Control and Management of Ships' Ballast Water and Sediments"[7] and established the D-2 standard[5] as a discharge standard for ballast water. Following this, "Guidelines for Approval of Ballast Water Management Systems (G8)"[3] and "Procedure for Approval of Ballast Water Systems that Make Use of Active Substances (G9)"[4] were established by the 53rd Session of the Marine Environment Protection Committee (MEPC53) in June 2005.

These guidelines require that ballast water management systems not only satisfy the D-2 standard, but also minimize impacts on the ship's crew and shipboard environment, and on the marine environment when ballast water is discharged. Concretely, for treatment systems using active substances (chemical substances such as chemical agents that may possibly affect the environment), which includes the JFE BallastAce® (registered trademark of JFE Engineering Corp.; hereinafter abbreviated JFE-BWMS), after receiving final approval[8–10] from the IMO in connection with environmental assessments on impacts by conducting land-based tests and onboard tests by the methods specified in the above-mentioned guidelines, "type approval" must be obtained from respective administration.

JFE-BWMS is a proprietary ballast water management system utilizing filter(s), two chemical agents, and Venturi tubes as a ballast water treatment system for ships developed by JFE Engineering.

This paper describes the results of the study of prac-

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tical application of the JFE-BWMS, focusing on the above-mentioned land-based and onboard tests.

2. Outline of JFE-BWMS

2.1 Principle of JFE-BWMS

The JFE-BWMS uses two chemical agents, a chlorine-based agent, TG Ballastcleaner® (registered trademark of Toagosei Co., Ltd.), for disinfectant treatment of microorganisms, and a reducing agent, TG Environmentalguard® (registered trademark of Toagosei Co., Ltd.) for neutralization of total residual oxidant (referred to as TRO, hereinafter) in the ballast water at the time of discharge.

Figure 1 shows the flow of the JFE-BWMS. After uptake of seawater from the sea chest by the ballast water pump, the water passes through a strainer, followed by a filter. This operation removes most of the plankton and particulate substances larger than 50 μm. These organisms, etc. are discharged back into their original marine habitat together with the backwash water. Because TG Ballastcleaner® is injected after the filtration process, the filter backwash water contains no TG Ballastcleaner®, and thus has no impact on the marine environment.

The TG Ballastcleaner® which is injected into the seawater after filtration process reacts mainly with soluble organic matter and inorganic matter, and acts on the plankton and bacteria which have passed through the filter. This seawater then passes through the venturi tube system, where the seawater containing TG Ballastcleaner® receives strong stirring/mixing action by the powerful vortices generated in the tubes, ensuring effective extinction of the plankton and bacteria by the TG Ballastcleaner®.

The treated water which has passed through the venturi tubes is charged into the ship's ballast water tanks. The concentration of total residual oxidants (TRO) including residual chlorine and others remaining in the treated water due to injection of the TG Ballastcleaner® decreases over time as a result of self-decomposition and reaction with organic matter, etc. However, this TRO prevents re-growth of organisms, hatch out of eggs of plankton, etc. in the ballast tank while the ship is sailing.

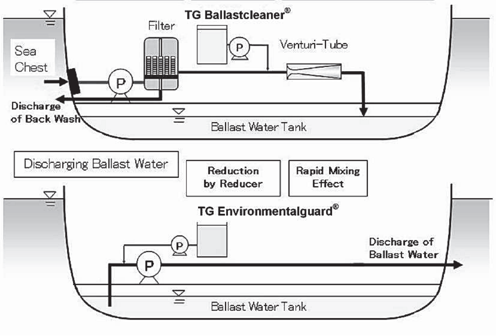

Fig. 1 Basic concept of JFE-BWMS

When the ballast water is discharged, TG Environmentalguard® is injected into the ballast water containing TRO, and completely neutralizes and detoxifies the ballast water, taking advantage of the powerful stirring effect of the ballast pump. The neutralized/detoxified water is then discharged safely from the ship.

2.2 Features of Actual System

In operation of the JFE-BWMS, the optimum system parameters are set so as to ensure effective action of the chemical agent and avoiding environmental impacts. Work performed by the operator is minimal, consisting mainly of pushing the start and stop buttons for ballast water uptake and discharge.

2.2.1 Operation of system during ballast water uptake

During ballast water uptake, the motor driven valves of filter inlet/outlet and in the backwash piping open when the ballast pump or booster pump is started, and simultaneously with this, rotation of the filter backwash arm begins. As a result of these operations, ballast water is introduced into the piping system of the JFE-BWMS. The condition of filter blockage is monitored by a pressure transmitter and differential pressure transmitter installed at the inlet/outlet of the filter. When the differential pressure exceeds a preset value, the backwash flow rate is increased automatically by opening another motor driven valve installed in the backwash piping, thereby increasing the backwash flow rate.

The filter mainly removes large aquatic organisms and solid matter larger than 50 μm. After the filter, TG Ballastcleaner® is injected into the filtered water by a multipoint dispersed injection method via injectors in order to realize rapid diffusion in the piping. The flow rate of the TG Ballastcleaner® injection pump is controlled by an inverter so that the concentration of TRO in the treated water conforms to the setting value.

A multi-tube parallel venturi system is installed downstream from the TG Ballastcleaner® injection point. When the water passes through these venturi tubes, it receives powerful stirring by the strong vortices generated as it passes from the throat to the expansion part, ensuring complete action of the TG Ballastcleaner® on the microorganisms. After these treatment processes, the treated water is transported to the ballast tanks as ballast water.

2.2.2 Operation of system during ballast water discharge

During ballast water discharge, the JFE-BWMS is switched from the treatment system used in ballast water uptake to the bypass system by operation of a motor driven valve. In the bypass system, first, the TRO concentration of the ballast water is measured, and an inverter-controlled pump injects a sufficient amount of TG Environmentalguard® to completely neutralize the measured TRO concentration. The TG Environmentalguard® injection point is upstream of the ballast pump. The neutralization reaction is accelerated by the stirring effect of a powerful turbulent flow generated by impeller blades of the pump, which rotate at high speed. As a result, TRO is completely eliminated in the piping before the ballast water is discharged from the ship. Downstream from the ballast pump, the ballast water is monitored by a high accuracy TRO meter which enables measurement of the condition of chemical reduction. Sure neutralization of the treated water is confirmed by continuous measurement of the reduction condition of the water. The discharging system is also designed to shut down automatically in the unlikely event that TRO is detected for a certain period of time.

The plankton and bacteria extinction operation during ballast water uptake is called primary treatment, and the above-mentioned neutralization treatment is called secondary treatment. In particular, the properties of the secondary treatment water which is to be discharged from the ship are important in assessing the performance and safety of the treatment system.

2.3 Control of Chemical Injection

2.3.1 Concept of control

The water quality of the seawater in ports and harbors is affected by a variety of factors, including the topography of the surrounding land, the presence or absence of rivers, the flow rate of any rivers, etc., and chlorine consumption differs depending on the sea area. Therefore, control of the injection ratio based on the TRO concentration after the completion of processes in which chlorine-consuming reactions occur is an effective approach for avoiding over-injection or under-injection of TG Ballastcleaner®, when taking on ballast waters of differing qualities.

Figure 2 shows an example of change over time in the TRO concentration when TG Ballastcleaner® is injected in seawater. From Fig. 2 (b), it was found that the TRO concentration decreases gradually over several tens of days. However, focusing on the period immediately after injection (Fig. 2 (a)), an initial rapid consumption reaction is completed in a very short period of time. Based on these experimental results, injection of TG Ballastcleaner® is controlled by feedback control using the TRO concentration at the point when this initial consumption reaction is substantially completed as the input signal.

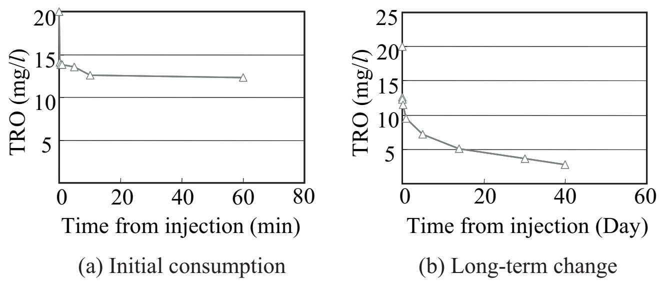

Fig. 2 Change of TRO after injection of TG Ballastcleaner®

TG Environmentalguard® is a reducing agent. Therefore, when injecting TG Environmentalguard® at the time of ballast water discharge, it is considered that this agent reacts not only with the TRO in the discharge water, but also with dissolved oxygen. Therefore, the relationship between the TG Environmentalguard® injection rate and the TRO concentration was obtained in a basic experiment using seawater, which has a dissolved oxygen content of approximately 7 mg/*l*. Based on this experiment, the TG Environmentalguard® injection rate is set with a certain allowance relative to the equivalent necessary concentration to neutralize the detected concentration of TRO, and the injection rate is controlled by feedforward control.

2.3.2 Treatment and control during ballast water uptake

Figure 3 shows the flow of TG Ballastcleaner® injection control during ballast water uptake.

The injection rate is controlled to a fixed value for a certain initial period of time at the start of injection, after which the TRO concentration in the ballast water is measured, and the result is fed back to the controller (PLC). The PLC controls the TG Ballastcleaner® injection pump by an inverter so as to adjust the average TRO concentration during a specified period of time

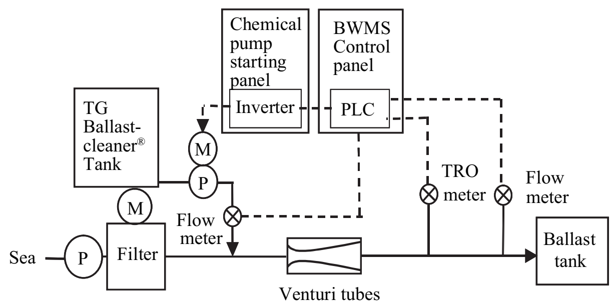

Fig. 3 Control flow diagram for uptaking of JFE-BWMS

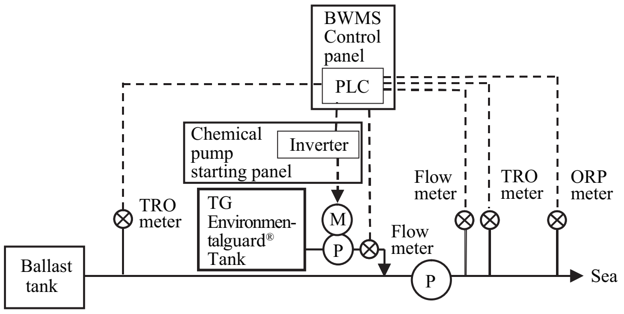

Fig. 4 Control flow diagram for discharge of JFE-BWMS

Photo 1 Preparation work for test water

within the control target range.

Injection rate control for the TG Ballastcleaner® injection pump also includes compensation for fluctuations of the treated water flow rate.

2.3.3 Treatment and control during ballast water discharge

Figure 4 shows the flow of injection control of TG Environmentalguard® during ballast water discharge. As during ballast water discharge, the injection rate is controlled to a fixed value for a certain initial period of time at the start of injection, after which the TRO concentration in the ballast water is measured, and the result is input to the PLC. The PLC then calculates the necessary amount of TG Environmentalguard® for the neutralization treatment from the average TRO concentration for a specified period, and controls the TG Environmentalguard® injection pump using an inverter. In this process, monitoring is performed with a high accuracy TRO meter to ensure that the ballast water is in a reduced condition. Injection rate control for the TG Environmentalguard® injection pump also includes compensation for fluctuations in the discharge water flow rate.

3. Performance Tests

3.1 Land-based Tests

The methods of the land-based tests are specified in G8[3)] and G9[4)] as established by the IMO. The necessary conditions are (1) treatment scale of 200 m^3/h or more, (2) stipulation of the water quality of the object water, (3) evaluation of the treated water after holding for 5 days in a tank simulating a ballast tank, and (4) a specified number of repetitions using two types of water selected from among fresh water, brackish water, and seawater.

In this test, an apparatus in which a JFE-BWMS test plant with a treatment scale of 350 m^3/h was installed in a 20-foot ISO container. The test was performed at BallastTech-NIVA AS, which is a testing organization located in Norway, and conformed to the method provided in G8[3)] and G9[4)].

Photo 1 shows the preparation of the test water for the land-based tests. Using the tank shown in the photo, 500 m^3 of test water was prepared, and at least 200 m^3 of treated water and control water were stored in tanks. The following presents an outline of the land-based tests and a summary of the results.

3.1.1 Results of chemical injection control

Figure 5 shows time series data during ballast water uptake operation. Simultaneously with the start of operation, TG Ballastcleaner® was injected at a constant rate, and the TRO value increased, temporarily reaching

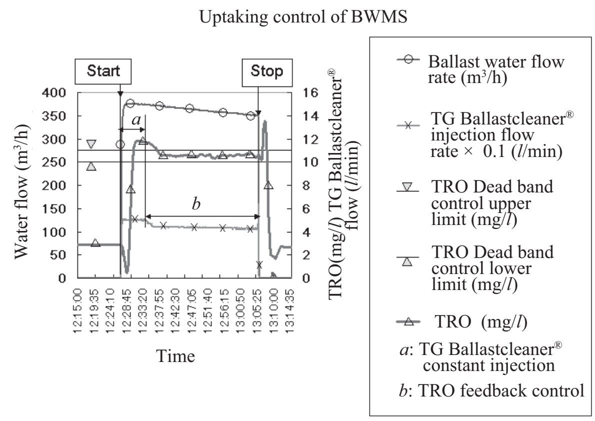

Fig. 5 Trend data at uptaking

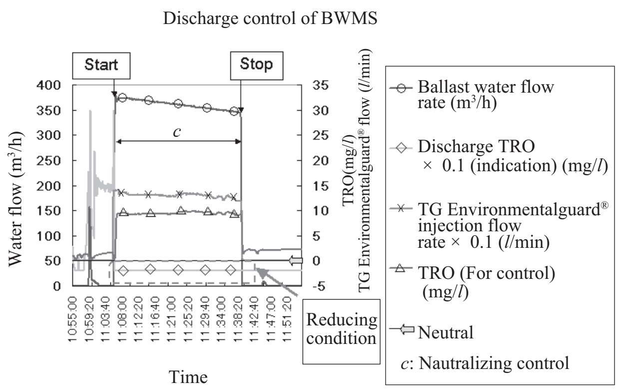

Fig. 6 Trend data at discharging

a slightly higher value than the target value. However, after several minutes, feedback control began and the TG Ballastcleaner® injection rate decreased. As a result, the concentration of TRO in the treated water was controlled to within the target range within a short time. Thereafter, the trend was stable, with values within the target range.

Figure 6 shows time series data for ballast water discharge operation. Simultaneously with the start of operation, TG Environmentalguard® was injected at a constant rate, and as a result, the TRO concentration of the treated water immediately decreased to 0 mg/*l* or less. After the transition to feedforward control of the TRO concentration, the TRO concentration of the treated water showed a trend of less than 0 mg/*l*. From this, it was judged that the treated water is maintained in a reducing condition by the JFE-BWMS.

3.1.2 Treatment performance

Table 1 shows the quality of the test water used in the land-based test specified by G8[5)], together with the threshold values.

It is normally necessary to add artificial substances and plankton in order to satisfy these conditions. Likewise, in this test, suspended solids (SS), particulate organic carbon (POC), and dissolved organic carbon (DOC) were added to the water, in order to satisfy the chemical water quality conditions, and large and small planktons and, when necessary, heterotrophic bacteria, were added to satisfy the biological conditions as shown in Photo 1. As test water salinity conditions, brackish water and seawater were selected.

In all tests, 200 m^3 or more of primary treatment water was prepared and stored in a light-shielded model ballast tank for 5 days, after which neutralization treatment was performed to obtain the secondary treatment water used as the object of the test. Treatment performance was assessed by analyzing the organism content of the water after secondary treatment.

In these land-based tests, the tests were performed for a total of 10 test cycles, comprising 5 cycles each with brackish water and seawater, as required by G8[3)]. **Table 2** shows the results of the treatment performance test for plankton. These results confirmed that the plankton content of the secondary treatment water satisfied the D2 standard[5)] in all of the test cycles. The results of the analysis of bacteria species also confirmed that the D2 standard[5)] was satisfied for all species, *Escherichia coli* (*E. coli*), *Enterococcus*, and *Vibrio cholerae*, specified in the D2 standard[5)].

Together with the toxicity tests for aquatic organisms and analysis of disinfection byproducts using the secondary treatment water obtained in these tests, an environmental assessment was also carried out using the data on disinfection byproduct data. The results are presented in the following sections.

Table 1 G8[3)] land-based test specifications for test water quality

Test water	Brackish water		Seawater	
Test cycle	2, 3, 4, 5, 6 (mg/*l*)	G8 Guideline (mg/*l*)	1, 7, 8, 9, 10 (mg/*l*)	G8 Guideline (mg/*l*)
Salinity (PSU)	20.6–21.5	3-32	32.1–33.6	>32
Dissolved organic carbon (DOC)	5.4–7.1	>5	1.5–1.8	>1
Particulate organic carbon (POC)	5.6–7.2	>5	1.5–2.0	>1
Total suspended solids (TSS)	75.7–81.5	>50	12.5–14.4	>1

Table 2 Treatment efficacy (Aquatic organisms)

Tast cycle	Organisms	Test water			Day 5 (Treated)		
		G8	Mean	Max.	G8	Mean	Max.
2, 3, 4, 5, 6 B.W.	≥50 μm (ind.m[3)])	>1×10[5]	165 103	208 956	<10	0.32	1.3
	10 μm-50 μm (ind./m*l*)	>1×10[3]	1 669	2 014	<10	0.0	0.0
1, 7, 8, 9, 10 S.W	≥50 μm (ind.m[3)])	>1×10[5]	143 717	173 787	<10	0.26	1.0
	10 μm-50 μm (ind./m*l*)	>1×10[3]	1 898	3 578	<10	0.0	0.0

B.W. : Brackish water S.W.: Seawater

3.1.3 Toxicity tests

As toxicity tests for aquatic organisms using the secondary treatment water, acute toxicity tests and chronic toxicity tests, including reproducibility tests, were performed with 5 types of organisms from among algae, fish, and crustaceans. As a result, no adverse effects were found, including not only mortality effects, but also negative effects on reproduction and growth. These tests verified the fact that discharged ballast water which has received neutralization treatment in the JFE-BWMS has no effects on aquatic life.

3.1.4 Environmental assessment of discharged ballast water

Screening and concentration analysis were performed simultaneously on the disinfection byproducts contained in the secondary treatment water. Assessments of the effects on aquatic organisms and assessments of the effects on the ship's crew and the general public, assuming the detected byproducts are discharged in environmental waters at the concentrations concerned, were carried out in accordance with the methods[8,9)] designated by the IMO.

The results confirmed that discharge of ballast water treated by the JFE-BWMS is safe, both for aquatic organisms, and for the ship's crew and the general public in ports and seashore areas.

3.2 Onboard Tests

3.2.1 Method of onboard tests

The onboard tests were performed by providing a bypass line in the ballast water piping on the port side of the SAGA Pioneer, which is a 47 000 DWT Box Shape Bulker owned by SAGA Ship Holdings AS, a member company of the Nippon Yusen Group, when that vessel was newly constructed, and installing a JFE-BWMS with a treatment scale of 1 000 m^3/h aboard the ship. **Photo 2** and **Photo 3** show the SAGA Pioneer and the component equipment installed aboard the ship, respectively. Operation of the system was performed remotely from the BWMS operation panel installed in the ballast control room.

In the onboard test, 3 ballast tanks on the port side were used to hold the treated water, and for comparison purposes, 3 ballast tanks on the starboard side were used with untreated control water. Sampling of the treated water and control water was performed using a sampling pipe with a valve installed in the ballast water piping on the downstream side of the ballast pump.

3.2.2 Operational data during onboard test

As in the land-based test, the results of the onboard test confirmed that the TRO concentration could be controlled to within a set value range during ballast water uptake.

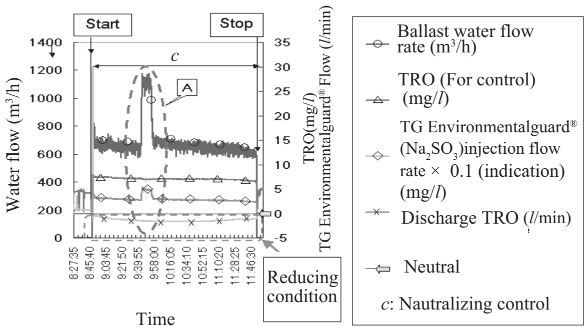

Fig. 7 Trend data of JFE-BWMS during Discharge

Figure 7 shows time series data for TRO neutralization/reduction of the discharged water during discharge of ballast water in the onboard test. In Fig. 7, "A" shows the time period when the ballast water flow rate was increased in order to confirm system performance at the maximum discharge flow rate. The results shown in this figure confirmed reliable neutralization/reduction of the TRO in the discharged water during ballast water discharge by the JFE-BWMS installed onboard an actual ship.

Photo 2 Test ship SAGA Pioneer

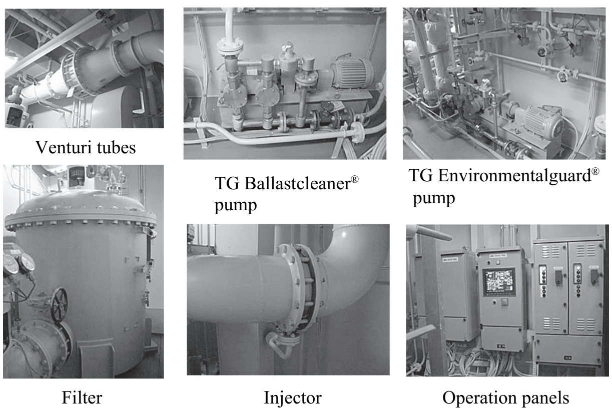

Photo 3 Onboard installation of JFE-BWMS

3.2.3 Treatment performance in onboard tests

Among the various treatment performance tests carried out as part of the onboard tests, **Table 3** shows the results for plankton count. The numbers shown in the table are the average values for 3 samples in the initial period, middle period, and final period during ballast water uptake and discharge. An analysis for bacteria was also performed with sample water taken at the same time, and confirmed that the system satisfies the D2 standard.

The results of these tests confirmed that the system completely satisfied the D2 standard, which is the IMO discharge standard for plankton and bacteria, in all cycles of the onboard tests.

Table 3 The treatment performance (Aquatic organisms)

Plankton	Test cycle	1	2	3	G8 (Guideline)
Large	Uptaken	19 741	64 814	27 285	≥100
≥50 μm	Treated	0	0	0	<10
(ind./m^3)	Control	177 304	65 712	52 038	≥10
Small	Uptaken	753	1 140	780	≥100
10–50 μm	Treated	0	0	0	<10
(ind./m*l*)	Control	627	743	117	≥10

3.3 Corrosion Resistance of Equipment Materials and Stability of TG Ballastcleaner® Concentration

3.3.1 Sodium hypochlorite corrosion resistance of materials

Because the main ingredient of TG Ballastcleaner® is sodium hypochlorite, which is a corrosive substance, it is necessary to use component materials with adequate corrosion resistance against sodium hypochlorite in sections from the chemical tank to injectors, which come into contact with the stock solution. Furthermore, the ballast piping and inner surfaces of the ballast tanks are exposed to seawater with a maximum chlorine concentration of 20 mg/*l*. Because no data were available for corrosiveness at this concentration, corrosion tests of the following items were carried out using primary treatment water containing 20 mg/*l* of TG Ballastcleaner®. From the results, it was concluded that there is no observable effect, in comparison with natural seawater, for any of the items except unpainted steel plate.

(1) Corrosion test of tar epoxy-coated, modified epoxy-coated, and Zn-coated steel plates with simulated defects.
(2) Condensation test of the above materials.
(3) Corrosion test and condensation test of unpainted steel plate.
(4) Test to confirm effect on the performance of Zn electrode for sacrificial corrosion protection.
(5) Test to confirm effect on piping packing.
(6) Test to confirm effect on component materials of valves in ballast piping system.

3.3.2 Stability of TG Ballastcleaner® concentration

The available chlorine concentration of sodium hypochlorite, which is the main ingredient of TG Ballastcleaner®, decreases gradually as a result of self-decomposition at high temperatures. Self-decomposition can be suppressed, and a suitable concentration for use can be maintained for an extended period of time, by providing a cooling function for the ship's TG Ballastcleaner® storage tank in order to hold the temperature to no more than 20°C. The effectiveness of this countermeasure was also confirmed in the onboard test.

4. Conclusion

Land-based tests and onboard tests of the JFE Ballast Water Management System (JFE-BWMS) were carried out to obtain certification for commercial use. The following results were obtained.

(1) In all test cycles in the land-based tests (350 m^3/h) and onboard test (1 000 m^3/h), the JFE-BWMS demonstrated high treatment performance, satisfying the D2 standard[5] established by the IMO.
(2) In the land-based tests, the results of acute toxicity and chronic toxicity tests of secondary treatment water (released seawater) after neutralization confirmed safety for aquatic life (algae, fish, crustaceans).
(3) An environmental assessment of the disinfection byproducts contained in the secondary treatment water after neutralization confirmed that the discharge from the system is safe for aquatic life, ship's crew members, and the general public in ports and seashore areas.
(4) The effect of TG Ballastcleaner®, which consists mainly of sodium hypochlorite, on corrosion of materials used in ballast piping and tanks was investigated. The results confirmed that this chemical agent has no effect on any of the relevant materials except unpainted steel plates.

A system which enables re-supply of TG Ballastcleaner® and TG Environmentalguard® to all ships without delay is now being constructed by implementation of an OEM supply system by local companies, including quality control, by the Toagosei Group and JFE Engineering Corp., which will supply the chemical agents.

5. Final Remarks

Based on the results of various land-based tests and an onboard test, as described in this paper, the JFE-BWMS satisfies the D2 discharge standard for aquatic organisms. The results of an environmental assessment also confirmed that the discharged ballast water is safe for the environment, ship's crews, and the general public.

These results demonstrate that the JFE-BWMS is a ballast water treatment system which can be installed and operated on ships with no problems.

The system received final approval from the IMO on March 23, 2010[10], and received Type approval from the Japanese government on May 26, 2010.

In conclusion, the authors wish to express their sincere thanks to all those concerned in the Maritime Bureau of Japan's Ministry of Land, Infrastructure, Transport and Tourism and the Ship Equipment Inspection Society of Japan for their wide-ranging guidance regarding the interpretation of IMO-related conventions and guidelines in connection with test methods, procedures for type approval, and related issues, and to those concerned at Monohakobi Technology Institute and SAGA Ship Holdings AS for their generous support in installation of the JFE-BWMS on shipboard and the

onboard tests.

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