Ballast Water Management System Using Solid Chemical†

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Abstract:

JFE Engineering has developed and commercialized the composite ballast water management system, which comprises filtration, liquid active substance, and venture tubes (“JFE BallastAce”). Though the system enables reliable treatment with low cost, it is difficult to provide this system for the ships that cannot make a port call at chemical supply base. In this paper, the practical application of solid active substances for this system which can provide the system for such ships is discussed. The system has been applied for the land based tests in accordance with the International Maritime Organaization (IMO) guidelines using the system with the capacity 250 m^3/h. The treatment performance of the system cleared the biological standard for discharged ballast water defined as D2 by IMO and the safety of the discharged ballast water treated by this system has also been confirmed.*

1. Introduction

In 2010, JFE Engineering introduced a ballast water management system called “JFE BallastAce*”[1] into the market. “JFE BallastAce*” is a composite ballast water management system comprising filtration, a liquid active substance (Trade name: “TG BallastCleaner**,” Main ingredient: Sodium hypochlorite; Hereinafter, “liquid chlorine agent”), and Venturi tubes. This system has been highly evaluated for its excellent treatment performance and economy. Chemical supply bases have been established in 26 cities in Japan and other countries, and as of February 2013, orders had been received for a cumulative total of 260 ships. A further increase in the number of ships using “JFE BallastAce*” is also expected.

However, since it would not be realistic to establish chemical supply bases at all ports in every country, the system could not be applied to ships which are not able to make calls at ports where bases are located, as it is difficult to transport the chemical to areas that are distant from supply bases for supply to ships because the effective chlorine concentration of the liquid chlorine agent gradually decreases due to self-degradation of its main ingredient, sodium hypochloride[2].

A system that uses a solid chemical with excellent storability and biocidal ability would provide an effective solution to this problem. That is, if the chemical can be loaded when the ship is in dock, it is possible to construct a ballast water management system that requires no resupply or only minimal resupply until the ship enters dock again. Therefore, JFE Engineering developed a new ballast water management system using a solid chemical agent.

This paper reports the results of a study of practical application of the new ballast water management system, from selection of the solid chemical to verification of its performance in land based tests.

2. Outline of System

2.1 Selection of Solid Chemical

In selection of the solid chemical, the biocidal ability and safety of sodium percarbonate, calcium hypochlorite, and sodium dichloroisocyanurate dihydrate (hereinafter, DICD), which are representative solid biocides,

† Originally published in *JFE GIHO* No. 32 (Aug. 2013), p. 74–78
* “JFE BallastAce” is a registered trademark of JFE Engineering Corporation in Japan.
** “TG BallastCleaner” is a registered trademark of Toagosei Co., Ltd.


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Table 1 Comparison of sodium dichroloiso-cyanurate dehydrate (DICD) and calcium hypochlorite

	Calcium hypochlorite	DICD
Chemical formula	$Ca(ClO)_2$	$C_3Cl_2N_3NaO_3 \cdot 2H_2O$
CAS* Registry Number	7778-54-3	51580-86-0
Active ingredient	Hypochlorite	Hypochlorite
Percentage of active ingredient	72%	55%
UN** Number	1748	3077
UN** Hazard Class	5.1	9
Packing Group	II	III

*CAS: Chemical Abstracts Service
**UN: United Nations

were evaluated.

Although sodium percarbonate has excellent safety, the concentration of its active ingredient, hydrogen peroxide, is low at 32%. Furthermore, due to the low biocidal ability of hydrogen peroxide, several times larger than that of sodium hypochlorite must be added in order to obtain the same effect[3]. Therefore, this chemical was excluded from the selection.

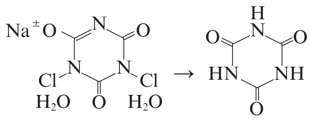
Calcium hypochlorite has a 72% available chlorine concentration and thus can be expected to have high biocidal ability, but safety was an issue, as a fire involving this substance occurred during container transportation in the past[4]. Therefore, as shown in **Table 1**, the United Nations classifies calcium hypochlorite in Hazard Class 5.1: Oxidizing Agents and in Packing Group II, substances presenting Medium Danger.

On the other hand, although DICD has an available chloride concentration of 55%, it falls under Hazard Class 9: Miscellaneous Dangerous Substances and Articles, Including Environmental Hazardous Substances and is designated as a Packing Group III substance, presenting Low Danger. Thus, the safety of DICD is higher than that of calcium hypochlorite.

For these reasons, DICD was adopted in this system. For systems using an active substance having biocidal ability, the manufacturer and product name must be designated in the application to the IMO. The DICD used in this system is "NEO-CHLOR MARINE***" manufactured by Shikoku Chemicals Corp.

2.2 Characteristics of DICD

As shown in Eq. (1), DICD dissociates into isocyanuric acid in pure water, which does not have biocidal ability, and sodium hypochlorite (NaOCl) and hypochlorous acid (HOCl), which have biocidal ability. For this reason, it is conceivable that the biocidal ability of DICD and its reactivity with seawater after injection into seawater do no differ greatly from those of the liquid chlorine agent.



$+ NaOCl + HOCl$ ··· (1)

Therefore, in order to determine whether the biocidal ability and reactivitity with seawater components are similar to those of the liquid chlorine agent or not, the changes over time in the concentration of total residual oxidant (TRO) of DICD and the liquid chlorine agent when dissolved in seawater were investigated. The results are shown in **Fig. 1**. From this figure, DICD displays an initial consumption behavior and attenuation trend similar to those of the liquid chlorine agent. Moreover, the concentrations of disinfection byproducts such as organochlorine compounds, etc. which were measured simultaneously with the TRO concentration also showed values that were substantially in agreement with those when the liquid chlorine agent was added. From these results, the biocidical ability and reactivity of DICD were considered to be similar as those of the liquid chlorine agent.

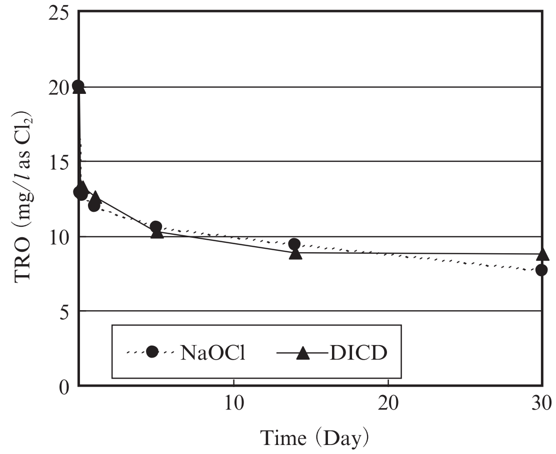


Fig. 1 Total residual oxidant (TRO) changes of sodium dichroloiso-cyanurate dehydrate (DICD) and NaOCl in seawater

In order to confirm the long-term storability of DICD, the available chlorine concentration of DICD when stored in a dark place at room temperature (20–25°C) for 3 years and 4 months was investigated. The decrease in the available chlorine concentration was limited to 3.7% of the initial value. Thus, if DICD is stored under appropriate conditions, it can be expected to maintain its biocidal ability for 3 years or longer.

2.3 Treatment Flow

Figure 2 shows the treatment flow during uptake of ballast water. First, large plankton in the uptake seawa-

*** "NEO-CHLOR MARINE" is a registered trademark of Shikoku Chemicals Corporation.

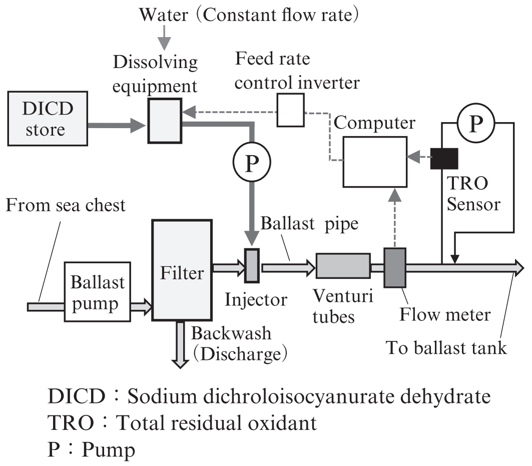


Fig. 2　Schematic diagram for uptake of ballast water

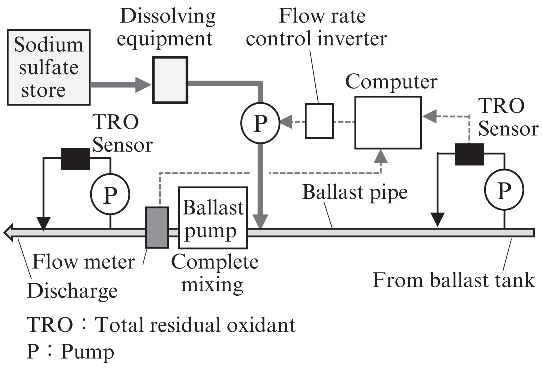


Fig. 3　Schematic diagram for discharge of ballast water

ter are removed by filtration. Remaining plankton and bacteria are treated by injection of the DICD liquid active substance and the final stage Venturi tubes, and the sterilized ballast water is then injected into the ballast tanks. In this process, feedback control of the DICD injection rate is performed by the feed rate of the DICD granules determined by the TRO concentration of the treated water.

Figure 3 shows the treatment flow during ballast water discharge. During ballast water discharge, first, the TRO concentration is measured. TRO is chemically neutralized by injecting a sodium sulfite solution by feed forward control based on the measured value of the TRO concentration. After the ballast water passes through the ballast pump, the TRO concentration is measured again, and after confirming that TRO is not detected, the ballast water is discharged into the ocean.

3. Performance Tests

3.1 Land Based Tests

The methods of the land based tests are specified in guidelines G8[5] and G9[6] established by the IMO. The necessary conditions are (1) the treatment scale is

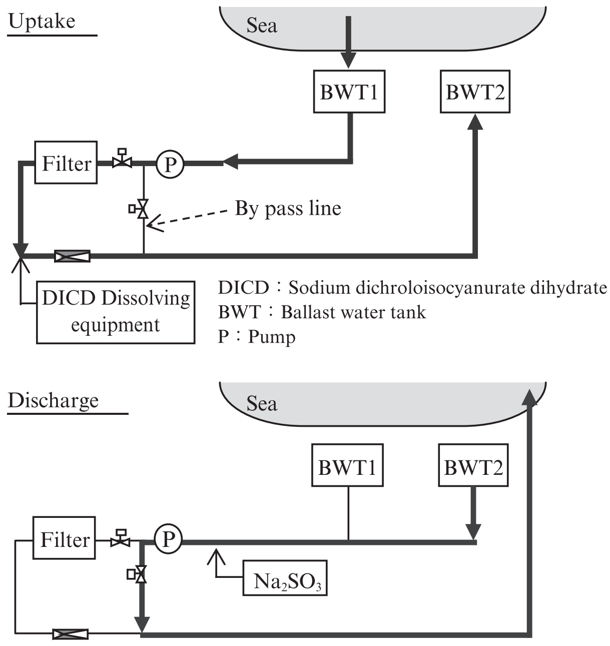


Fig. 4　Schematic flow diagram of Land based test

200 m^3/h or more, (2) water of the specified water quality is used in treatment, (3) the object of evaluation is treated water held for 5 days in a tank simulating a ballast tank, and (4) tests are performed with 2 types of water from among fresh water, brackish water, or seawater. The treatment results are evaluated by comparison with the organism count and bacterial count shown in the D2 Standard[7] established by the IMO.

For the land based test, a device with a treatment scale of 250 m^3/h was installed at a test site in Tongyeong City, Gyeongsangnam-do, Korea, and the test was performed by the Korea Marine Equipment Research Institute under commission from JFE Engineering, in accordance with the methods provided in G8[5] and G9[6].

Figure 4 shows the flow of the land based test. So that the water quality of the water being treated would conform to the provisions of G8[5], suspended solids, particulate organic carbon, dissolved organic carbon, cultivated plankton, and heterotrophic bacteria were added to uptake seawater taken up into simulated ballast water tank 1 (BWT1). For the test water used under the brackish water condition, the test water was adjusted to the specified salinity by diluting uptake seawater with tap water. The primary treatment water obtained by treating the test water by the flow for uptake of ballast water was stored in BWT2. After 5 days, the secondary treatment water obtained by the treatment in the flow for “discharge of ballast water” was used in toxicity tests for aquatic organisms and water quality analyses.

3.2 Treatment Performance

Table 2 shows the results of treatment of aquatic

Table 2 Treatment performance in land based test (Aquatic organisms)

Test water	Aquatic organisms	Test water			Secondary treated water		
		G8*	Mean	Max.	G8*	Mean	Max.
Sea water (N = 5)	≧ 50 μm (ind./m^3)	>1×10^5	3.59×10^5	5.44×10^5	<10	0.2	1.0
	10–50μm (ind./ml)	>1×10^3	1.36×10^3	2.28×10^3	<10	0.2	1.0
Brackish water (N = 5)	≧ 50 μm (ind./m^3)	>1×10^5	3.39×10^5	4.53×10^5	<10	0.2	1.0
	10–50 μm (ind./ml)	>1×10^3	1.56×10^3	2.22×10^3	<10	1.0	2.0

*G8: Test standard[5, 7]

organisms. Tests were performed 5 times using seawater and 5 times using brackish water, for a total of 10 tests. In all tests, it was confirmed that the aquatic organisms in the object water being treated and in the secondary treatment water satisfied the D2 standard[7]. Furthermore, the results of analysis of bacteria also satisfied the D2 standard[7] for *Escherichia coli* (*E. coli*), *Enterococcus*, and *Vibrio cholera* provided in the same standard.

3.3 Toxicity Tests

In order to determine the effect of the secondary treatment water on aquatic organisms, acute toxicity and chronic toxicity were investigated using algae (*Skeletonema costamtum*), a marine rotifer (*Brachionus plicatilis*), and a fish (*Paralichthys olivaceus*). In the results of these tests, no lethal effects or adverse effects on growth (viability) were found. This verified the fact that the secondary treatment water has no significant effect on aquatic organisms.

3.4 Environmental Effects of Discharged Ballast Water

The quantities of disinfection byproducts and isocyanuric acid contained in the secondary treatment water were determined, and the effect of treated ballast water discharged in the environment and the effects on the ship's crew and the general population were assessed in accordance with the methods[8, 9] designated by the IMO. Although the content of isocyanuric acid in the secondary treatment water was 8.5 mg/l at maximum, this was rapidly diluted by the seawater at the point of discharge. Based on the dilution rate calculated by the method[8] specified by the IMO, the predicted environmental concentration (PEC) was calculated as 128 μg/l. On the other hand, from the toxicity data in the literature[10], the predicted no effect concentration (PNEC) was calculated as 320 μg/l. Thus PEC was substantially lower than PNEC. According to the OECD, in case PEC/PNEC<1, the latent ecological risk is small, and a further environmental impact assessment is not necessary[10]. From this, it was judged that the environmental impact of ioscyanuric acid contained in ballast water after treatment by this system is substantially zero. Similar assessments were also carried out for other byproducts, and in all cases, a PEC/PNEC ratio of <1 was confirmed.

Thus, these results confirmed that ballast water treated by the ballast water management system using a solid chemical is safe for aquatic organisms, and is also safe for members of the ship's crew and the general population in ports and coastal areas.

4. Basic Approval and Final Approval

JFE Engineering submitted an application summarizing the study results presented in this paper and received basic approval of DICD at the 62nd Marine Environment Protection Committee (MEPC62) meeting held in July 2011. The system received final approval at MEPC64 in October 2012.

5. Conclusions

In order to realize practical application of a new ballast water management system using a solid chemical agent, an appropriate solid chemical was selected and land based tests were carried out. The following results were obtained.

(1) The safety and biocidal ability of candidate chemical substances were evaluated, and as a result, sodium dichloroisocyanurate dihydrate (DICD) was adopted.
(2) It was confirmed that DICD maintains its performance for 3 years or longer when stored under appropriate conditions.
(3) In a series of 10 land based tests (250 m^3/h), the water quality of the treated water satisfied the D2 standard established by the IMO, demonstrating the high treatment performance of the developed system.
(4) From the results of acute toxicity and chronic toxicity tests performed with secondary treatment water (simulating discharged ballast water), safety with respect to aquatic organisms was confirmed.
(5) Based on the results of analyses of the isocyanuric acid and other disinfection byproducts contained in the secondary treatment water, the safety of aquatic organisms, crew members, and the general population in ports and coastal areas was confirmed.
(6) The safety and required performance of the chemical agent were verified, and final approval of the IMO

was obtained.

Equipment which avoids direct exposure of crew members is used in loading NEO-CHLOR MARINE*** on ships and in resupplying the ballast water management system. By making it possible to use a solid chemical agent in the "JFE BallastAce*" ballast water management system, this newly-developed system will enable a larger number of customers to use "JFE BallastAce*."

6. Concluding Remarks

From the results described above, the ballast water management system using a solid chemical satisfied the IMO's D2 standard in all cases, in the same manner as the existing "JFE BallastAce*," which uses a liquid active substance and has already been commercialized. The results of an environmental impact assessment confirmed that discharged ballast water treated by the newly-developed system is safe for the environment, ship's crews, and the general population.

The authors which to express their heartfelt appreciation to all those concerned at the Maritime Bureau of Japan's Ministry of Land, Infrastructure, Transport and Tourism for their wide-ranging guidance in connection with obtaining the approval of the IMO and type approval, as well as related procedures, and Ballast Tech NIVA AS and the Korea Marine Equipment Research Institute for conducting the tests necessary for obtaining basic approval and final approval for the newly-developed ballast water management system.

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