Report by the expert board for the environmental impact assessment of discharge water from Scrubbers
(Japan)

July 2018

NOTE

This document is an English translation of the original Japanese version of the report issued in July 2018.

Contents

1. Introduction

1.1 Regulation of SOx emission from ships and the use of scrubbers

    1.1.1 Outlook of SOx regulations in accordance with Annex VI of MARPOL 73/78

        1.1.1.1 IMO 2020 Global Cap development

The International Maritime Organization (IMO) is a specialized agency of the United Nations which was founded in 1958 and which has been given the authority to set global standards for the safety and security of shipping and the prevention of marine pollution by ships. One of the two major committees established by the IMO is the Marine Environment Protection Committee (MEPC), which covers environmental issues and sets global standards for pollution prevention of the marine environment by ships. Under its remit, the MEPC has adopted international conventions such as the International Convention for the Prevention of Pollution from Ships (MARPOL 73/78) and the International Convention for the Control and Management of Ships' Ballast Water and Sediments, 2004.

Exhaust gas from ships is one of the significant anthropogenic sources of air pollution, and one of its representative pollutants is sulphur oxides (SOx), which is harmful to human health causing respiratory and circulatory diseases. Since the amount of SOx in exhaust gas from ships depends upon the sulphur content of the fuel oil used, a new regulation for MARPOL Annex VI (Regulation 14) was adopted to introduce a global standard applicable to all ships and limit the sulphur content in ship fuel oil. With regard to the extent of sulphur content deemed acceptable, a phased approach is applied and it is stated under the requirements of the current phase that sulphur content in fuel oils for all ships shall not exceed 3.50% m/m; the actual average of sulphur in HFO, however, is around 2.5 % m/m. For ships operating within present-day Emission Control Areas (ECAs) such as the Baltic Sea area, the North Sea area, the North American area or the United States Caribbean Sea area, the sulphur content in fuel oil is not to exceed 0.10% m/m (equivalent to its level of MDO).

In October 2008, a series of amendments to the Regulation 14 was adopted to strengthen the sulphur limit to 0.50% m/m for ships operating within non-ECA areas starting on 1 January 2020. This implementation date (1 January 2020) was, however, subject to a provision requiring the IMO to carry out a study on the global availability of low sulphur content fuel oil so that the MEPC could determine whether the 2020 Global Cap was to become

effective on 1 January 2020 or to be deferred until 1 January 2025. In accordance with the above provision, a report was submitted to MEPC70 held in October 2016 and its assessment concluded that the refinery industry had the capability to supply sufficient quantities of low sulphur content fuel oil to meet the demand anticipated in the year 2020. Based on this conclusion stated in the report, MEPC70 decided that the new global cap was to come into effect on 1 January 2020 as scheduled.
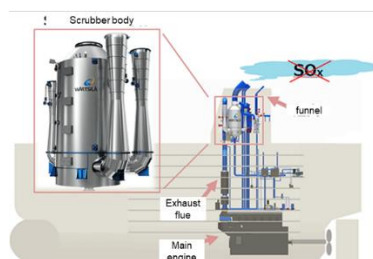
1.1.1.2 Principle methodologies to meet the 2020 Global Cap

In order to comply with the 2020 Global Cap, three methodologies as indicated in Fig. 1-1 below are the possible options.

- Option 1: Use of fuel oils with sulphur content of 0.50% m/m or lower (compliant fuel oils)
- Option 2: Use of High Sulphur HFO in combination with the installation onboard of a SOx Exhaust Gas Cleaning System (EGCS), known as a "scrubber" to reduce SOx from air emissions
- Option 3: Use of alternative fuels (LNG fuel, etc.); LNG fuel is, for example, not only free of SOx emissions, but its use can also reduce emissions of NOx and CO_2.

| Option 1: Use of fuel oils with a sulphur content of 0.5% m/m or lower | Option 2: Installation of a scrubber. Onboard removal of SOx from exhaust gas following combustion of High Sulphur HFO | Option 3: Use of LNG as a fuel [alternative fuels] LNG emits zero SOx. |

Figure 1-1 three options to comply with the 2020 Global Cap

Ship owners/operators, who are committed to compliance, will be obliged to decide on choosing one of the above three options. This report is, however, focused on Option 2 (the installation of a scrubber) and, therefore, is designed to evaluate the risks which discharge water from scrubbers may pose adverse effects to the marine aquatic organisms and the water quality of the Japanese

coastal areas. For this purpose, a general description of scrubbers and a forecast of their use onboard are provided in the following subparagraphs.

1.1.2 General description of scrubbers and associated washwater

1.1.2.1 General description of scrubbers

Different types of scrubbers are currently available to comply with the 2020 Global Cap which are categorized into the following three types depending upon the treatment principles used (see Fig. 1-2).

-1. Open-loop type scrubbers take seawater as a reagent media, and the washwater is then discharged back into the sea.

-2. Closed-loop type scrubbers use freshwater as a reagent media, and the washwater is then neutralized and recirculated.

-3. Hybrid type scrubbers enable switching between open and closed modes. The choice among the three options mentioned above depends upon shipowner preference, etc.
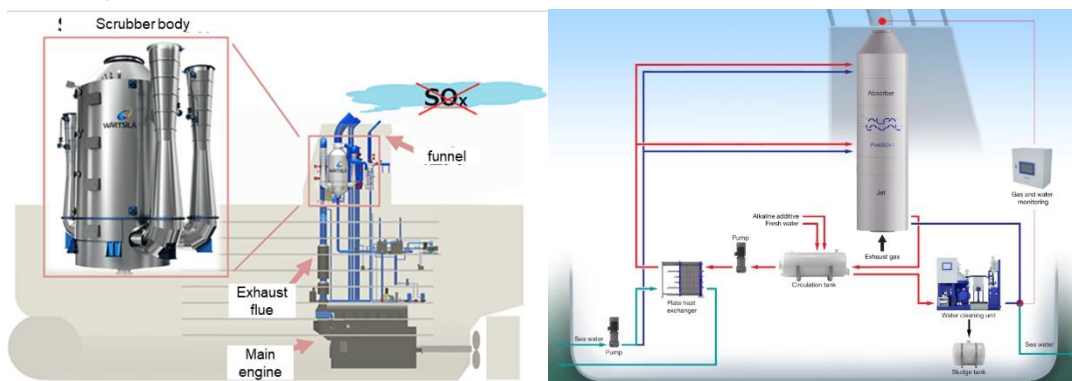
In the right figure, the blue arrows indicate the flow of operation of an open-loop scrubber (one-through seawater treatment), while the red arrows indicate that of a closed-loop scrubber (recirculated fresh-water treatment).
(*The figures are courtesy of Alfa Laval and Wartsila.*)

**Figure 1-2 Descriptions of treatment principles of three types of scrubbers**

1.1.2.2 Forecast use of the Scrubber onboard in Japan

Although the use of scrubbers is regarded as one of the compliant measures to meet the 2020 Global Cap, according to a forecast by the Japanese Ministry of Land, Infrastructure, Transport and Tourism (MLIT), the number of vessels fitted with scrubbers is limited.

Figure 1-3 shows a forecast submitted to a cross-industry board[1] established in Japan to aid in the smooth implementation of the 2020 Global Cap. Although the forecast suggests that the number of ships fitted with scrubbers is expected to increase slightly after the effective date, the total number of ships fitted with scrubbers will not have reached more than 5% of fleet by the year of 2030 that visited the ports in Japan. (See Fig. 1-3)

Even though the actual number of ships equipped with scrubbers may exceed the forecast due to the future market changes, the existing technical challenges and physical limitations related to the onboard installation of scrubbers as well as the significant initial investment (OPEX) are required for installation. It is probable that use of the compliant HFO or MDO will be the major methods used to comply with the 2020 Global Cap.

The above forecast, however, does not consider the balance of the three types of scrubbers; therefore, for the purpose of this Environmental Impacts Assessment (EIA), it is assumed that all scrubbers installed onboard are open-loop type to presume the worst case emission scenario, which leads the discharge flow amount is maximized.
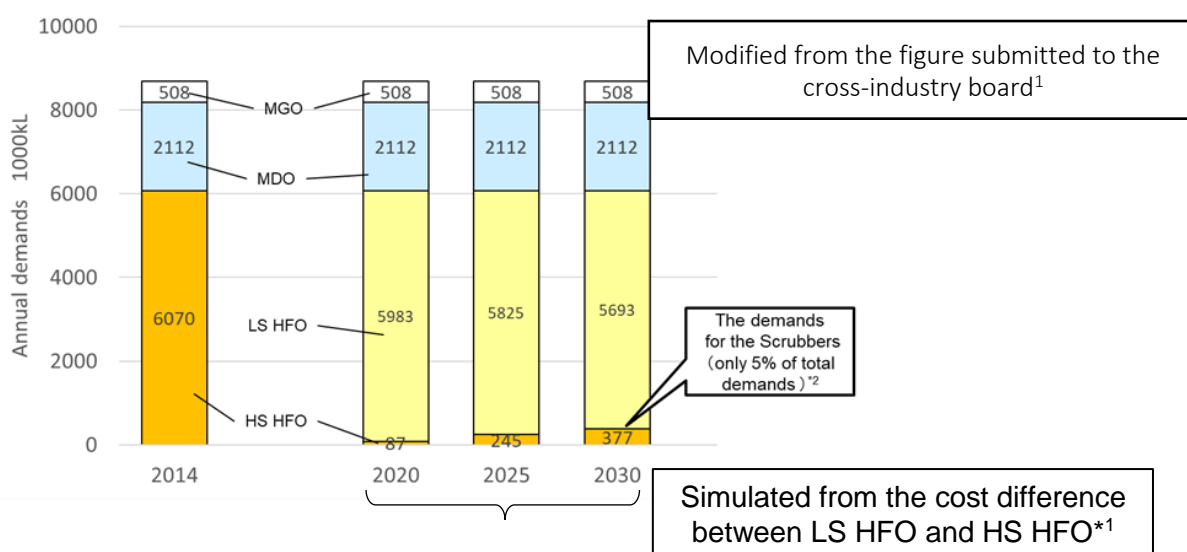
∗1   On the assumption that the price gap between high-sulphur HFO and low-sulphur HFO is JPY5,000, taking into account cost economy.

∗2   Suggests that the demand for high-sulphur HFO will increase as the supply of scrubbers also increase; however, the estimated demand will hit its peak in the year 2030 and will gradually decrease due to technical challenges and physical restrictions related to the onboard installation of scrubbers.

Figure 1-3 Demand forecast of scrubbers in Japan

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[1] The cross-industry board included shipowners, ship operators, fuel providers and representatives from relevant Administrations.

1.1.2.3 Global discharge criteria for scrubber discharge water

The IMO standard for discharge water from scrubbers is provided in the IMO's *2015 Guidelines for Exhaust Gas Cleaning Systems (Resolution MEPC.259 (68))* (hereinafter "IMO Guidelines"), which are shown in the following Table 1-1.

Table 1-1 Discharge water criteria as set out in the IMO Guidelines (Resolution MEPC.259 (68))

pH criteria	should comply with one of the following requirements – a pH of > 6.5 measured at the ship's overboard discharge with the exception that during maneuvering and transit, the maximum difference between inlet and outlet of 2 pH units is allowed. – The pH discharge limit is the value that will achieve as a minimum pH 6.5 at 4 m from the overboard discharge point with the ship stationary
PAHs (Polycyclic Aromatic Hydrocarbons)	<= 50 μg/L PAHphe (phenanthrene equivalence) above the inlet water PAH concentration (when Flow rate =45(t/MWh)).
Turbidity	The maximum continuous turbidity in washwater should not be greater than 25 FNU (formazin nephelometric units) or 25 NTU (nephelometric turbidity units)
Nitrates	Beyond that associated with a 12% removal of NOX from exhaust, or beyond 60 mg/l normalized for a washwater discharge rate of 45 tons/MWh, whichever is greater.

The criteria in the aforementioned IMO Guidelines have already been fully incoporated into the Japanese national regulation *'Act on Prevention of Marine Pollution and Maritime Disaster'*. This act also establishes criteria for other discharges from ships, taking into account of the other annexes of MARPOL 73/78.

The criteria are consistent with the purpose stated in the *Basic Environment Act*, which preserves human health, the ecosystem and fisheries stocks, and resources. By the orders of the *Basic Environment Act*, environmental water quality standards have been established in accordance with the classification of sea areas.

The objective of the *'Act on Prevention of Marine Pollution and Maritime Disaster'* is to contribute for attaining these environmental water quality standards, and it sets out criteria for discharge of wastewater[2] from ships. In addition to the national standards as mentioned above, discharge water from scrubbers shall

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[2] In accordance with the *Act on Prevention of Marine Pollution and Maritime Disaster*, the "wastewater" in this footnote source is included in "waste liquid substances loaded on a ship for the purpose of disposal by throwing and combustion for disposal in the sea area".

further meet the international criteria as shown in Table 1-1. On the other hands, the discharge criteria for wastewater from onshore facilities such as power plants and factories, etc. were established by another national law called the *'Water Pollution Prevention Act'*; these criteria, however, do not apply to the discharge water from ships according to Japanese legal framework. (See Fig. 1-4)
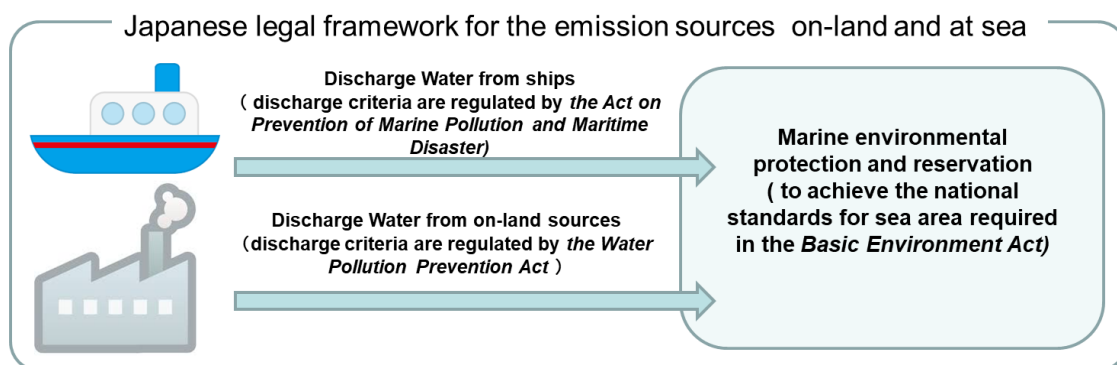
Japanese legal framework for the emission sources on-land and at sea

Discharge Water from ships
（ discharge criteria are regulated by *the Act on Prevention of Marine Pollution and Maritime Disaster)*

Discharge Water from on-land sources
（discharge criteria are regulated by *the Water Pollution Prevention Act* ）

Marine environmental protection and reservation
(to achieve the national standards for sea area required in the *Basic Environment Act)*

Figure 1-4 Applicable national laws and relevant discharge standards for conservation of sea area environment

1.2 Environmental Impacts Assessment (EIA) overview

As mentioned in 1.1.1 above, the main objects of installing a scrubber is to reduce SOx gas emitted into the atmosphere and to reduce the amount of secondary Particulate Matter 2.5 (hereafter PM2.5) contained in sulphate[3], which is formed from SOx gas through a photochemical reaction. The emission of SOx and secondary PM2.5 may cause respiratory and circulatory diseases such as lung cancer, etc. when emissions at sea accumulate in onshore residential areas by convective diffusion and when exposure-doses of these substances exceed a certain level of concentration (e.g. National standards or WHO standards).

Although abatement by scrubbers contributes to the reduction of airborne emissions of SOx and PM2.5, the risks which may be result from the behavior of these substances in discharge water still remains to be evaluated. SO_2 is, when in contact with the seawater, dissolved and oxidized to form sulphuric acid (H_2SO_3). As sulphuric acid is strongly acidic in nature, discharge water from scrubbers is ionized and a high concentration of hydrogen ions decreases the pH of the

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[3] SO_2 is the predominant form of SOx in exhaust gases. When emitted in the atmospheric area, the majority of SO_2 is oxidized through photochemical reaction to form H_2SO_4; however, a part reacts with the ammonium contained in the atmosphere to form ammonium sulphate. While SO_2 is a gas, H_2SO_4 and ammonium sulphate are formed as particulate matter in the atmospheric air. This particulate matter is called secondary particle and is the major composition of PM2.5.

washwater. This discharge water, nonetheless, is rapidly diluted by the seawater surrounding the hull right after overboard discharged, and the low pH thus immediately be recovered due to the natural buffering capacity (alkalinity) of natural seawater. Accordingly, it is less probable that the low pH of washwater from scrubbers may cause unacceptable risks to the marine environment surrounding the hull. Furthermore, as a long-term effect, any sulphite (SO_3^{2-}) in the receiving water could be oxidized to form sulphate (SO_4^{2-}) in the seawater which in fact is already present in natural seawater. Since sulphate is the representative composition of sea salt. It is, therefore, also less probable that the additional sulphate (SO_4^{2-}) in discharge water will pose unacceptable risks to marine aquatic organisms.

On the other hand, it is recognized that a separate evaluation is necessary for environmental risks which may be caused by remaining substances such as the small amount of heavy metals contained in fuels or in their unburnt combustible content, or NOx and Polycyclic Aromatic Hydrocarbons (PAHs), the discharge of which are also regulated by the IMO.

In order to evaluate the above, this EIA is designed to evaluate short- and long-term environmental risks to marine aquatic organisms as a result of discharge water from scrubbers as well as long-term environmental risks to the quality of the water in Japanese coastal areas.

1.2.1 Risks to marine aquatic organisms

First, in order to analyze a flow field of discharged washwater surrounding a hull, a computational fluid dynamics (CFD) simulation was conducted on a hull model. Next, based upon the simulation results, the dilution ratio changes between the discharge water and the receiving water were calculated (see Chapter 2).

Simultaneously with the above, toxicity testing using Whole Effluent Toxicity (WET) methodology [4] (an internationally recognized test method for wastewater discharge measured by a test organism's response upon exposure to effluent samples) was carried out using samples taken from actual washwater from scrubber and the dilution ratio needed for acceptable risks were delivered. Lastly, with this dilution ratio and the changes of dilution ratios as the result of the simulation, the probability that washwater

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[4] WET testing is a method to assess discharge water from an effluent upstream of a facility by evaluating its toxicity and required dilution ratio without the need to identify toxic substances in the discharge water. It is utilized by authorities in the United States to determine the adverse effects of discharge water. It is also an internationally recognized testing method and has been adopted as the recognized means to assess residual toxicity of ballast water after treatment by chemical active substances. Refer to "Chapter 3. Assessment of the risks to marine organisms and ecosystems" for details.

from scrubber may cause unacceptable risks to the marine aquatic organism was assessed.

Further to the above, the probability that lower pH and higher temperature of washwater from scrubbers may cause unacceptable risks to the marine aquatic organism was assessed, based on the above-mentioned dilution ratio in the receiving water (See Chapter 3).

1.2.2 Long-term risks to water quality of Japanese coastal areas

Long-term risks by the Scrubber discharge water to the water quality of Japanese coastal area was assessed, based on the national environmental standards as established in accordance with the *Basic Environment Act*. For this purpose, substances whose emission is regulated by the act was focused on, and the risks was evaluated that washwater from scrubbers may cause in following methodologies; First it was identified the substances regulated by the environmental standards which may be contained in exhaust gas from ship or washwater from scrubbers. Among these target substances, it was further identified the substances which may remain for a long-term in the marine ecosystem. Second, simulation of the accumulated concentration after ten years of these substances in following geographical conditions was conducted, and it was evaluated if washwater from scrubbers may introduce adverse effect on the current attainment of the environmental standard (See Chapter 4):

- coastal areas having higher density of sea traffic
- coastal areas which have not sufficiently attained the applicable environmental quality standards

(Total amount of annual emission of washwater from scrubbers correlate with the above conditions of coastal areas.)

2. Simulation on the Flow behind ships

    This chapter describes a calculation methods on how scrubber water discharged from stern could be diluted under the circumstances of turbulent flows behind a ship. The calculation method and result are as follows.

2.1 Calculation by numerical fluid simulation

2.1.1 Flow dilution ratio calculation

        Distribution of dilution ratios was estimated after scrubber discharge water (SDW) from the stern was spread over by turbulent flow (swirls) behind the ship's hull. First, the hydrogen ion concentration distribution was calculated using the analytical solution of the Diffusion-Convection Equation showing the distribution of hydrogen ion concentration due to diffusion during convection; next, the dilution ratio was calculated from the first result and the hydrogen ion concentration in the scrubber discharge. In this series of calculations, the physical dilution and diffusion due to turbulent flows with vortex behind the discharge were considered, but neutralization and the other chemical reaction with alkalinity of seawater were not taken into account.

2.1.2 Diffusion-Convection Equation

        Vessels in actual seas are sailing in flow fields with diffusion effects brought by waves, ocean and tide currents, etc. In this survey, without taking such effects into account, a simplified physical model was used as follows:

        1) A ship is sailing straight ahead in calm waters at a constant speed.

        2) This ship is releasing SDW from her astern outlets and below the waterline at a constant discharge rate (mol/s).

        With this model, a stationary concentration distribution of hydrogen ions can be calculated around the hull by solving a Diffusion-Convection Equation for the stationary flow field with a source corresponding to the SDW outlet in a uniform flow at the same speed as the ship.

        Therefore, the equation to be solved in the coordinate system for which the origin is the SDW outlet is shown in Fig. 2-1 and its analytical solution is as follows:

        Note that under the assumed condition that the SDW is sufficiently diffused by the turbulent flow in the receiving waters, the amount of SDW is not included in the diffusion term in the analytical solution; so, only flow speed and horizontal and vertical diffusion coefficients affect diffusion/convection effects.

Calculation target and its coordinate system:
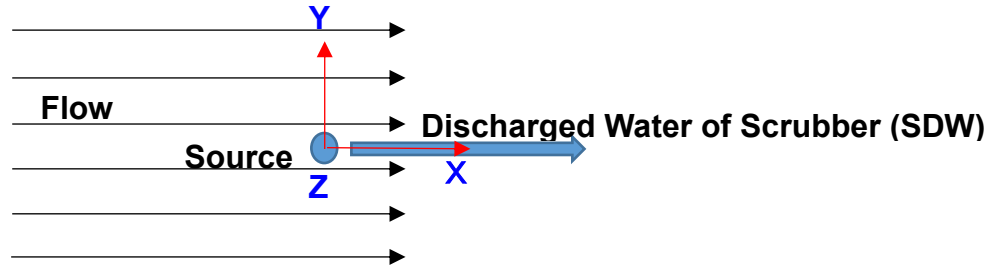
Figure 2-1 Coordinate system for numerical simulation

(View over the surface of the water)

Diffusion-Convection Equation:

$$u\frac{\partial C}{\partial x} = K_y\frac{\partial^2 C}{\partial y^2} + K_z\frac{\partial^2 C}{\partial z^2}$$

Analytical solution:

$$C = \frac{q}{4\pi x\sqrt{K_y K_z}}\exp\left(-\frac{u}{4x}\cdot\frac{y^2}{K_y}\right)\left\{\exp\left(-\frac{u}{4x}\cdot\frac{(z-d)^2}{K_z}\right) + \exp\left(-\frac{u}{4x}\cdot\frac{(z+d)^2}{K_z}\right)\right\}$$

Note:

u :   Flow speed (m/s)

C :   Hydrogen ion concentration of a mixture of SDW and water (mol/m^3)

Ky :   Horizontal diffusion coefficient (m^2/s)

Kz :   Vertical diffusion coefficient (m^2/s)

d :   Depth of the source from waterline (m)

q :   Discharge rate of hydrogen ions in SDW at the source (mol/s)

2.1.3 Diffusion coefficients Ky and Kz

In order to solve the convection-diffusion equation shown in Section 2.1.2, two diffusion coefficients, the horizontal diffusion coefficient Ky and the vertical

diffusion coefficient *Kz*, are required. Since the diffusion coefficients are expressed by the ratio of the turbulent flow Schmidt number Sc and the coefficient of virtual viscosity in this calculation, a distribution of the coefficient of virtual viscosity was estimated by numerical simulation in the field downstream of the stern of a general merchant vessel (a PANAMAX bulk carrier) used as a sample. The diffusion coefficient was obtained delivered based upon the result. Details of the calculation are as follows.

i) Sample ship outline

A PANAMAX bulk carrier is a major ship type for domestic voyage, which is relatively large in size and amount of exhaust gas emissions: (LBD of 222 m, 33 m and 12.2 m), design speed 14.2 knots, DWT 82,000 tons, MCR 9.5MW)

ii) Calculation method outline

Incompressible Reynolds Averaged Navier-Stokes (RANS) with Finite Volume Method for spatial discretization was used for flow analysis. A propeller was modelled by the Simplified Propeller Theory (SPT) as an Infinitely-Bladed Propeller model. A ladder was omitted in order to simplify the calculation. Spalart-Allmaras model (one equation model) was used for turbulent model.

(Reference)

The following documents provide detailed reference about the calculation method and the turbulent model:

"Numerical Calculation Method for Fluid Dynamics", University of Tokyo Press
"Incompressible Fluid Analysis", University of Tokyo Press
"Turbulence Modeling for CFD", David C. Wilcox, DCW Industries, Inc.

iii) Operational conditions for calculations

The vessel's speed was assumed to be constant speed at 12 knots, supposing that the ship is sailing at the maximum speed limit on designated congested routes, regulated by the Japanese Maritime Traffic Safety Act.

iv) A result of calculation of Coefficient of Virtual Viscosity

Distribution of coefficient of virtual viscosity is as shown in Fig. 2-2 when viewed in the center cross section of the hull. In addition, looking at a cross section of a depth of 1 m from the waterline is as shown as an example in Fig.

2-3. As a result, it is 0.2 m^2/s or more at 2 m behind the ship or 0.3 m^2/s or more at 10 m behind the ship, and the result is that the turbulence corresponding to a coefficient of 0.2 m^2/s is widely distributed near the both side surfaces of the hull. For reference, the 3-D contour of the coefficient of 0.2 m^2/s is shown in Fig. 2-4.
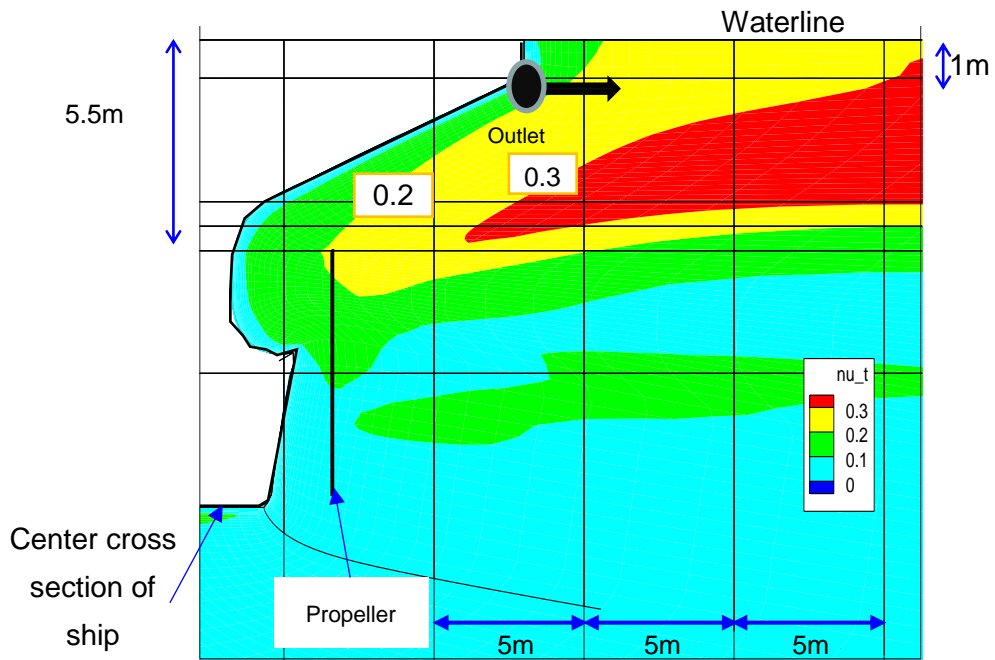
Figure 2-2 Distribution of the coefficient of virtual viscosity behind the ship (Center cross section of the ship)
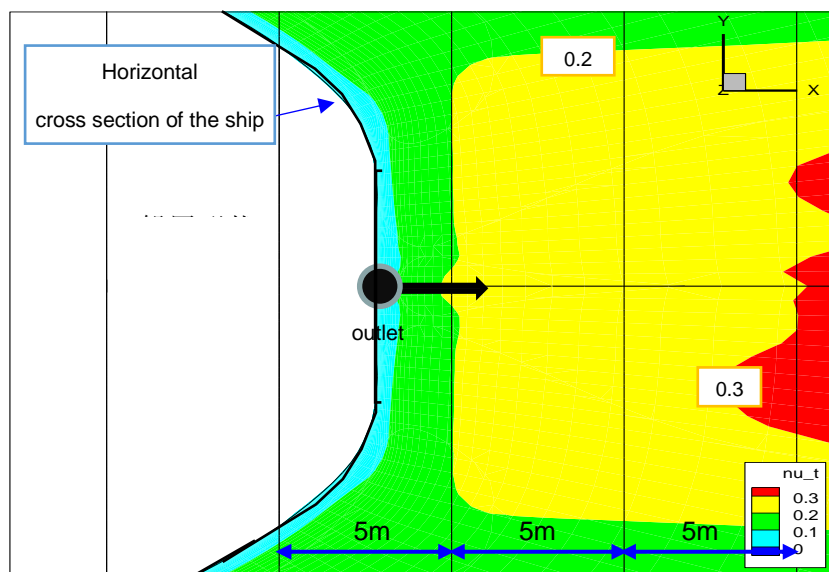
Figure 2-3 Distribution of the coefficient of virtual viscosity behind the ship

(Horizontal cross section at the depth of 1 m from the waterline)
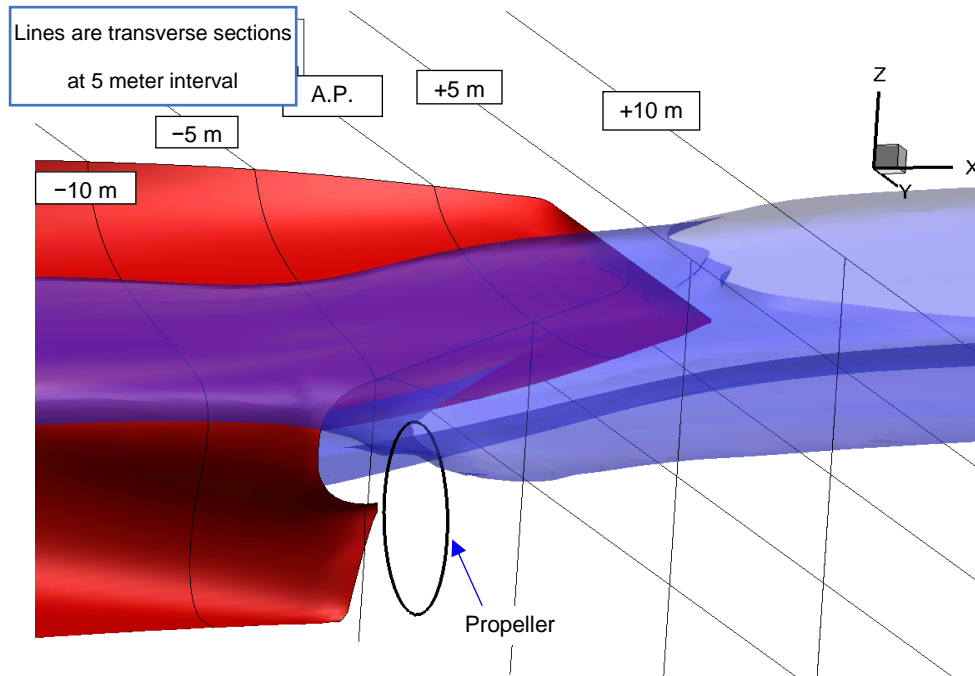
Figure 2-4 Distribution of coefficient of virtual viscosity around stern

(3D image of the distribution of 0.2 m²/s, looking up diagonally from below the ship)

2.1.4 Dilution ratio calculation

Based on the results of numerical simulation on the coefficient of virtual viscosity behind the general merchant ship used as the sample ship, the distribution of dilution ratios by physical mixing due to turbulence behind the stern was calculated. In this calculation, the following parameters were used:

i) Speed of a uniform flow u=6.17 m/s (=12 knots)

ii) Assumed that the outlet of SDW is located in the center cross section and at a 1 m depth below the waterline with the coefficient of virtual viscosity (vt) set at 0.2 m²/s conservatively taking into account the results in Section 2.1.3 above. The diffusion coefficients $ky = kz (= vt/Sc)$, therefore, can be set at 0.29. Here the Schmidt number Sc is defined as the ratio between the coefficient of virtual viscosity to the diffusion coefficient and is set to 0.7 (Reference should be made to "Numerical Calculation of Combustion" (The Japan Society of Mechanical Engineers).

iii) S: Hydrogen ion concentration in SDW (mol/l)

This is set to $1.0 \times 10^{-3.1}$ (mol/l) because its pH is 3.1 (See Table 3-7). Similar values are also observed in the running tests of the other types of scrubber test machines. Hydrogen ions in the ambient fluid around the ship are set to 1.0×10^{-7} (mol/l) because the effect of neutralization is neglected in the calculations and neutral water is assumed to be the ambient fluid. In order to use the actual figure of hydrogen ion concentration in the mixed water, analytical solution C is re-set and added to both figures of the original analytical solution C and that of ambient fluid.

iv) The main engine power of the sample ship is 7.4 MW at the ship speed of 14.2 knots. In cases where the speed drops down to 12 knots, main engine power becomes 4.5 MW as the required engine power is proportional to speed to the third power. Assuming that the ratio of the amount of exhaust gas emission to the SDW is not changed, the hydrogen ion concentration in SDW decreases nearly by 40%. In this calculation, however, the amount of SDW and hydrogen ion concentration at 4.5 MW is not used, and the amount 7.4 MW is used instead.

v) H: Discharge rate of SDW (ton/hour)

In order to calculate H, the equation referenced in 'Marine Pollution Bulletin 88 (2014), 292-301' was used.

Namely, H=45 (ton/(hour×MW)) * Main Engine Power (MW).

vi) H': Discharge rate of SDW (l/second)

H'=H*1000/3600

vii) q: Discharge rate of hydrogen ions in SDW (mol/s)

q=S×H'

Using the above formulas and parameters, the local dilution ratio X is calculated by using the hydrogen ion concentration W (pH) at an arbitrary point indicated by coordinates (x, y, z) obtained from the Diffusion-Convection Equation, The specific calculation method is as follows.

i. Define the pH of SDW before being mixed with water as z (z = 3.1 this time);

ii. Define the pH of SDW after dilution as W;

iii. Define the hydrogen ion concentration derived from ionization of neutral water as D (mol/l);

iv. Define the degree of dilution ratio as 10 to the X_{th} power. (e.g., when diluting 100 times, X=2.);

v. The relationship of z, W, D and X is formulated as follows:

$$10^{(-(z+X))} = -D + 10^{-W} \qquad (1)$$
$$D^2 + 10^{(-(z+X))} \times D - 10^{-14} = 0 \qquad (2)$$

(Note) Formula (1) is derived from the hydrogen ion concentration after dilution by diffusion $[H^+] = 10^{-W} = [H^+]_{H2O} + [H^+]_{H2SO4} = D + 10^{-(z+X)}$

Formula (2) is derived from Ionic product of water
$[H^+][OH] = (D + 10^{-(z+X)}) \cdot D = 1.0 \times 10^{-14}$

vi. Determination of pH (W) after dilution by diffusion

First, using the formula (2) above, the concentration D (mol/l) of hydrogen ion generated by ionization of water corresponding to an arbitrary dilution ratio X with z being known is determined. Then, W is calculated by substituting D, X and z into formula (1). With this, the pH (W) corresponding to the arbitrary dilution ratio X can be calculated; therefore, the local dilution ratio was inversely calculated from the solution C (hydrogen ion concentration) of the Diffusion-Convection Equation by using the correspondence between W and X as an indicator.

2.2 Numerical fluid simulation results

Based on the above, the results of a trial calculation of dilution ratio distribution are as follows:

2.2.1 Calculation of physical dilution ratio behind the ship

Assuming the discharge point of SDW at the vertical-center cross section of the ship and a depth of 1 m (Fig. 2-5), assuming the virtual viscosity coefficient to be 0.2 m²/s as lower averaged figure, using the Diffusion- Convection Equation representing the diffusion state of the SDW of the sailing vessel, a physical dilution ratio distribution due to a turbulent flow with vortex behind the discharge point was

calculated. The time to reach each point was also calculated by dividing the distance from the discharge point by ship speed.

2.2.2 Dilution simulation results

The physical dilution ratio per time elapsed after the discharge is shown in Fig. 2-5 and Table 2-1.
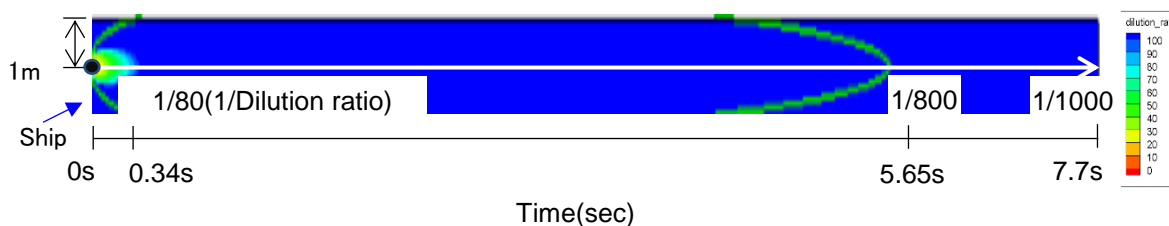
Figure 2-5 Physical dilution ratio per time elapsed after discharge (depth: 1 m)

Table 2-1 Physical dilution ratio per time elapsed after discharge

Time(sec)	0.17	0.25	0.34	2.87	5.65	7.7	60.3	114.4	129
Dilution ratio	40	60	80	500	800	1,000	5,000	8,500	9,416

(Note 1) The dilution ratio of the SDW takes a minimum value at a downstream position (18 times the ship-length) when it is 20 meters in the lateral direction, which is approximately 70,000 times. In the case of parallel sailing, it takes the half value by superposition.

(Note 2) The degree of dilution would become 5,539[*2] times in cases where the scrubber-installed ships are overlapped at a 129-second interval[*1] on the same route and successively the SDW is overlapped.

* 1 Based on the sailing of up to 28 vessels per hour in the Nakanose Passage (11 km in length) in Tokyo Bay where the frequency of navigation is high.

* 2 Although it is unrealistic for a couple of ships to navigate on the same track, strict conditions are assumed.

3. Assessment of the risks to marine organisms and ecosystems

3.1 Assessment of the risks to marine organisms and ecosystems

3.1.1 Overview

The adverse effect and risks of discharge water on marine organisms and ecosystem are unlikely to reach to the acceptable level, as long as it complies with the discharge standards in the scrubber guidelines[5] established by MEPC. On the other hand, regarding the effects of trace hazard substances other than sulphurous acid, such as heavy metals, NOx or polycyclic aromatic hydrocarbons

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[5] RESOLUTION MEPC.259(68), 2015 GUIDELINES FOR EXHAUST GAS CLEANING SYSTEMS

(PAHs), which are slightly contained in unburnt fuel or fuel itself, may cause potential but unacceptable risks.

Therefore, ecotoxicity tests were conducted to evaluate the quantitatively aggregated adverse effect, without specifying the individual harmful substances contained in the discharge water. Furthermore, the dilution rate to reach a safe level (i.e. the scientifically acceptable level) was delivered for two diffusion fields, assumed for local diffusion fields for short term effects, such as the hull surroundings considered in Chapter 2, and closed enclosed waters for long-term effects considered in Chapter 4. The safety factor (i.e. assessment factor) for universalizing the results of the ecotoxicity tests was set, based on internationally recognized risk analysis methodology.

Finally, considering the time necessary to reach the dilution rate that can be regarded as safe in the two diffusion fields, it was comprehensively evaluated the toxic effects on marine organisms and the ecosystem.

In this study, the toxicity test using scrubber discharge water and its assessment was conducted by ClassNK.

3.1.2 Ecotoxicological test overview

3.1.2.1 WET method concept for evaluating toxicity of discharge water

Generally, as measures against environmental pollution, emission control has been carried out based on thresholds that can be regarded as safe for individual target substances. However, even if each chemical substance is below the reference value, the possibility of the risk being harmful to the environment due to the aggregated effect with other substances cannot be ruled out. From such a background, in order to investigate whether the discharge water is toxic or NOT, a WET method has been drawing attention. In this testing, test organisms, such as micro algae, daphnia, zebra fish, are exposed with the discharge water, and then evaluates the toxicity of the discharge water based on the endpoints (e.g. mortality , growth rate and health condition) of the organisms

For example, the Clean Water Act has regulated individual substances in the United States; however, WET testing was adopted in 1987 as wastewater monitoring tool, and 56 industries and public sewage treatment plants have adopted to use this testing since then. In the United States, if it is judged to be toxic in the WET testing, evaluation procedures, such as improvement procedures and manuals are standardized, and the subsequent countermeasures are required. Generally, about 10 fold dilution is expected as

an initial dilution after release into the environment. And, therefore, if it is calculated as a harmless in the short term viewpoint after the 10 fold dilution by the results of WET, then the discharge water without additional mitigation measures could be accepted.

In addition, WET testing has already been adopted in the regulatory framework also in Canada and Germany, and is being studied for introduction in Europe (WFD, Water Framework Directive)[6], Asian countries such as Korea, China, Singapore and others.

Also in Japan, the Ministry of the Environment launched a study meeting from 2009 (FY2009) and is examining the way to utilize the new wastewater management method, etc. as a method to complement the existing wastewater regulation for on-land sources.

3.1.2.2 Toxicity test using biological response (Whole Effluent Toxicity: WET testing)

The WET testing was conducted according to standardized test method using three kinds of organisms at different trophic levels, namely fish (3rd nutrient stage), crustacean (2nd nutrient stage), and algae (1st trophic stage). Tests using freshwater species or brackish water species have been already standardized by the US Environment Agency (US EPA), while WET testing using 'marine' organisms are not standardized yet. In principle, it is not permitted during WET testing to adjust the salinity of the wastewater to be evaluated; therefore, it is not possible to apply the above standard method using the test species living in fresh water.

Therefore, for WET testing on discharge water using seawater, an international standard test method using marine organisms for evaluating toxicity of a single chemical substance is utilized accordingly. For example, in "Methodology on Ecological Impact Assessment Method for Approval of Ballast Water Treatment Equipment" created by the Ballast Water Working Group of the Expert Meeting on the Scientific Field of Marine Pollution in the United Nations (GESAMP BWWG), international standard test methods based on a single chemical substance prepared by OECD, ISO, US EPA or ASTM International (formerly American Society for Testing and Materials) and the like

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[6] Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for the Community action in the field of water policy

for the WET testing It is recommended to use methods that are deemed appropriate after selecting adequate tests for a single chemical substance.

In this survey, a WET acute toxicity tests were conducted using the three marine test organisms with the test method shown in Table 3-1.

The main change from the original test method for a single chemical substance is a method for preparing dilution series from raw water.

In addition, in the case of a substance targeted for a single substance, it is required or recommended that the environmental conditions such as dissolved oxygen (DO), pH, water temperature should be maintained as constant in all of the control and dilution series. On the contrary, the actual pH of the discharge water of Scrubber is about 3.1, the dissolved oxygen concentration is about 3.2 mg/L, and the recommended pH and the dissolved oxygen concentration value are far apart from each other. However, to aggregate the adverse effect of the pH and the dissolved oxygen concentration, in this experiment both the dissolved oxygen concentration and the pH were not adjusted at pretreatment with the dilution by a natural seawater, both will be recovered.

All WET testing was conducted at the test facility Environment Creation Laboratory of IDEA Co., ltd.

Table 3-1 Whole Effluent Toxicity testing using marine organisms, and the base test for usual toxicological tests using a designated substance

Test organism	International standard
Growth inhibition test using micro-algae (Ddiatom:Skeletonema costatum) using growth rate after 72 hours as the endpoint	ISO 10253: Water quality - Marine algal growth inhibition test with Skeletonema costatum and Phaeodactylum tricornutum, Third edition (2016) was used for in principle. (The validity criteria taken into account are those required in TG OECD201, OECD GUIDELINES FOR THE TESTING OF CHEMICALS Freshwater Alga and Cyanobacteria, Growth Inhibition Test (2011))
acute toxicity testing using crustacean (Ptilohyale: *Hyale barbicornis*) using mortality after 96 hours as the endpoint	USEPA Ecological Effects Test Guidelines OPPTS 850.1020: Gammarid Acute Toxicity Test (2016) was used in principle.
acute toxicity testing using fish living in brackish water (Adrianichthyidae: *Oryzias javanicus*)	OECD GUIDELINES FOR THE TESTING OF CHEMICALS No. 203: Fish, Acute Toxicity Test (1992) was used in principle. (The validity criteria taken into account are those required in US EPA Methods for Measuring the Acute Toxicity of Effluents

using mortality after 96 hours as the endpoint	and Receiving Waters to Freshwater and Marine Organisms, Fifth Edition (2002))

3.1.2.3 Methodology
i) Growth inhibition test using micro-algae

For the algae growth inhibition test, nine exposure areas and control areas were set for scrubber drainage, and test organisms were exposed under the conditions shown in Table 3-8. The nine exposure area included 100% (raw discharge water from scrubber without any dilution) and the dilution ratio of exposure area was set to 2. That is, from the original water, 100%, 50%, 25%, 12.5%, 6.3%, 3.2%, 1.6%, 0.8%, 0.4% and 0.2% (v/v) of diluted samples were prepared.

Based on the cell densities of each test container measured every 24 hours from the start of exposure, the average growth rate at each exposure period throughout the exposure period and the average growth inhibition rate at each exposure time was calculated for the control group and each exposure group. Based on the growth inhibition rate at each exposure concentration, the 50% growth inhibition concentration (ErC50) for the test organism was calculated by the least squares method. In addition, for the average growth rate throughout the exposure period, a statistically significant difference between the control group and each exposure group was tested. Whether there was a difference in the growth rate of each dilution area relative to the control plot was examined by one-way analysis of variance (ANOVA) and Dunnett's test. The significance level (p) in the test was set to 0.05. Based on the test results, the minimum effect concentration (LOEC) at 72 hours exposure, the dilution ratio in the lowest exposed area where the statistically significant difference was observed at the average growth rate compared with the control group. The dilution ratio in the lower exposure area was taken as the maximum no effect concentration (NOEC). These were used to evaluate the acute toxicity of test samples to test organisms at 72 hours exposure. Information on the test organisms is shown in Table 3-2.

Table 3-2 Marine test organisms used for growth inhibition test of micro-algae

Species name	Diatom *Skeletonema costatum*
strain and its history	the original strains is the NIES-16, which was provided from the NIES in Japan
inoculum culture (preculture)	Several series of inoculum culture in the test medium were prepared 3 days before start of the exposure test. Incubate the inoculum culture under the same conditions as the test cultures. After the preculture, the healthy and the algae are in the

exponential growth phase were selected for the exposure.

ii) Crustacean acute toxicity test

For the crustacean acute toxicity test, ten exposure areas and control areas were set for scrubber drainage, and test organisms were exposed under the method and conditions shown in Table 3-8. The nine exposure area included 100% (raw discharge water from scrubber without any dilution) and the dilution ratio of exposure area was set to 2. That is, from the original water, 100%, 50%, 25%, 12.5%, 6.3%, 3.2%, 1.6%, 0.8%, 0.4% and 0.2% (v/v) of diluted samples were prepared.

For the control group and each exposure group, the number of dead organisms was measured every 24 hours from the start of the exposure and the behavior and appearance abnormality in the surviving organisms were observed, with the cumulative mortality rate during the exposure period being calculated. Based on the cumulative mortality rate at each exposure concentration, the 50% lethal concentration (LC50) for the test organism was calculated by the Binomial method. It is also determined the lowest exposed area (100% dead minimum) at which all test organisms died during the exposure period and the highest exposed area (0% dead highest concentration) that did not show death during the exposure period. Furthermore, for the number of cumulative deaths during the exposure period and the number of abnormalities observed in behaviors and appearance, the significant difference between the control group and each exposure section was tested by the chi-square test applying the significance probability correction by the Bonferroni-Holm method. The significance level (*p*) in the test was set to 0.05. Based on the test results, the dilution ratio in the lowest exposed area where significant death or abnormal individual increase was observed was calculated as the minimum effect concentration (LOEC) at 96 hours exposure, the dilution ratio in the next lower exposure area was set to the maximum no-effect concentration (NOEC). These were used to evaluate the acute toxicity (lethal or sublethal effects) to the test organisms at 96 hours exposure of the test sample.

In the guideline (USEPA Ecological Effects Test Guidelines OPPTS 850.1020) that was referred to in this test method, the pH of the test water is to be in the range of 6.0 to 8.5, while the saturation degree for the dissolved oxygen concentration is to be in the range of 60 to 100% as a required test

establishment condition to carry out the test. Scrubber discharge water as a test sample decreases pH and dissolved oxygen concentration due to its characteristics. In this study, exposure tests were carried out with no adjustment either of pH and dissolved oxygen concentration, considering the drop in pH and dissolved oxygen concentration as an influence on the test organism. Information on the test organisms is shown in Table 3-3.

Table 3-3 Marine test organisms used for acute toxicity test of crustacean

Species name	Ptilohyale *Hyale barbicornis*
strain and its history	For this test, a strain established in Asian Water Environment Laboratory, National Institute for Environmental Studies, National Institute for Environmental Studies was obtained from the Kagoshima University Faculty of Marine Resources and Environment Education Research Center in September 2005, Followed by subcultured of *Hyale barbicorni* in the test facility.
preculture	For the test, juvenile of healthy female adults were harvested and used in a 2 liter glass water tank containing breeding water (about 1.5 L) until the test was used for testing under the following conditions: . The mortality rate in this acclimatized rearing group for 7 days before the test was 5% or less. preculture water: Natural seawater filtered with a pore size 10 μm filter (sea water of the same quality as dilution water) Breeding system: semi-static type (once a week with water change) Water temperature: 24 ± 2 ° C Illumination: White fluorescent lamp light, 16 hours light period / 8 hours dark period Feeding: Tetra-Marine® mixed feed for marine fish and Ana aosa Ulva sp. Once a day On the day before the exposure test, externally healthy individuals were selected from the acclimatized group and placed in a test container and allowed to stand in a thermostat set at 24 ° C until the start of exposure.

iii) Fish acute toxicity test

In the fish acute toxicity test, ten exposure areas and control areas were set for scrubber drainage, and test organisms were exposed under the method and conditions shown in Table 3-8. The nine exposed areas included 100% (raw water of scrubber drainage) where the dilution ratio of exposed section was set to 3.2. That is, samples diluted from raw water were selected for nine exposure areas: the 100% group, 32% group, 10% group, 3.2% group, 1% group, 0.32% group, 0.1% group, 0.032% group and 0.01% group (v / v).

For the control group and each exposure group, the number of dead organisms was measured every 24 hours from the start of the exposure and the behavior and appearance abnormality in the surviving organisms were

observed, with the cumulative mortality rate during the exposure period being calculated. Based on the cumulative mortality rate at each exposure concentration, the 50% lethal concentration (LC50) for the test organism was calculated using the binomial method. Moreover, the lowest exposure concentration (100% minimum death level) was calculated, at which all test organisms died during the exposure period and the highest exposure concentration (0% death maximum concentration) that did not show death during the exposure period. Furthermore, the dilution ratio in the lowest exposed area where significant death or abnormal individual increase was observed was calculated as the minimum influence concentration (LOEC) at 96 hours exposure, the dilution ratio in the next lower exposure area as the maximum no-effect concentration (NOEC). These were used to evaluate the acute toxicity (lethal or sublethal effects) to the test organisms at 96 hours exposure of the test sample.

In the guideline (OECD Guidelines for the Testing of Chemicals No. 203) that was referred to in this test method, the pH of the test water is to be in the range of 6.0 to 8.5, while the dissolved oxygen concentration is to be in the range of 60 to 100% as a required test establishment condition to carry out the test. Scrubber discharge water as a test sample decreases pH and dissolved oxygen concentration due to its characteristics. In this test, the reduction of pH and dissolved oxygen concentration was regarded as an influence on the test organisms, and the exposure test was conducted without adjusting the pH and dissolved oxygen concentration. Information on the test organisms is shown in Table 3-4.

Table 3-4 Marine test organisms used for acute toxicity test of fish

Species name	Adrianichthyidae *Oryzias javanicus*
strain and its history	A strain established on October 2005 from Kagoshima University Faculty of Marine Resources and Environment Education Research Center, and subsequently provided *Oryzias javanicus* kept rearranged within the test facility.
preculture	For the test, juvenile of healthy female adults were harvested and used in a 10 liter glass water tank until the test was used for testing under the following conditions: . The mortality rate in this acclimatized rearing group for 7 days before the test was 5% or less. Preculture water: Natural seawater filtered with a pore size 10 μm filter (sea water of the same quality as dilution water) Breeding system: flow system (once a week with water change) Water temperature: 26 ± 2 ° C

	Illumination: White fluorescent lamp light, 16 hours light period / 8 hours dark period
	Feeding: Brine shrimp twice a day
	On the day before the exposure test, externally healthy individuals were selected from the acclimatized group and placed in a test container and allowed to stand in a thermostat set at 26 ° C until the start of exposure.

3.1.2.4 Discharge water test samples and preparation

The test sample for this test was washwater discharged from an actual scrubber installed on board. Experiments were conducted under the open-loop mode using natural seawater as an experimental scrubber model and mimicked the scrubber discharge water to be tested

i) Natural seawater

The seawater used for the preparation and dilution of simulated discharge water was withdrawn from Oigawa Port (Yaizu City, Shizuoka Prefecture). After sand filtration, the collected natural seawater was further filtered with a 10-μm pore-sized filter to obtain raw water for experiment. Raw water for preparing simulated discharge water was collected in a 500-liter polyethylene container and about 3 tons was used for scrubber experiments. Also, the seawater (dilution water) used to prepare the dilution area was sampled in a polyethylene container for 10 L at the same time when the raw water for preparing the simulated discharge water is collected and stored in a cool and dark place (set at 4 degrees). Immediately before preparing the test solution, it was returned to room temperature and used. For the raw water used for diluting the test sample, water temperature, dissolved oxygen concentration, pH, salinity and turbidity were measured before running the experimental scrubber.

ii) Experimental scrubber model operation

In this test, an experimental 4-stroke 257 kW medium speed diesel engine was used. The main eyes and appearance are shown in Table 3-5 and Fig. 3-1, and the system configuration of the scrubber used in the test is shown in Fig. 3-2. This scrubber is a hybrid wet scrubber (exhaust tower height 8.17 m, tower diameter 76.2 cm) made by Alfa Laval Co., the exhaust gas is cooled by a primary spray before the exhaust smoke tower, and is further desulphurized in the secondary spray part (filled with a filler to increase the

gas-liquid contact ratio). In this test, seawater passed through the inside of the equipment once (single pass) as a sample, so it was necessary to switch from the closed-loop operation mode with fresh water during normal operation of this scrubber to the open-loop (one pass) operation mode with seawater was carried out. At this time, salt concentration in the discharge water was monitored to confirm switching to seawater. In the closed-loop operation mode, the fresh water in the circulation tank immediately under the smoke evacuation tower was repeatedly used, but in the closed-loop operation mode, water was supplied from the make-up water tank side and the drainage route of the washing water was switched to the drain tank.

Table 3-5 Representative engine parameters

manufactures	Matsui Iron Works Co., Ltd.
Engine type	MU323DGSC
injection system	mechanical
cylinders #	3
cylinders bore	230mm
stroke	380mm
Power output (MCR)	257kW
Rated speed	420rpm
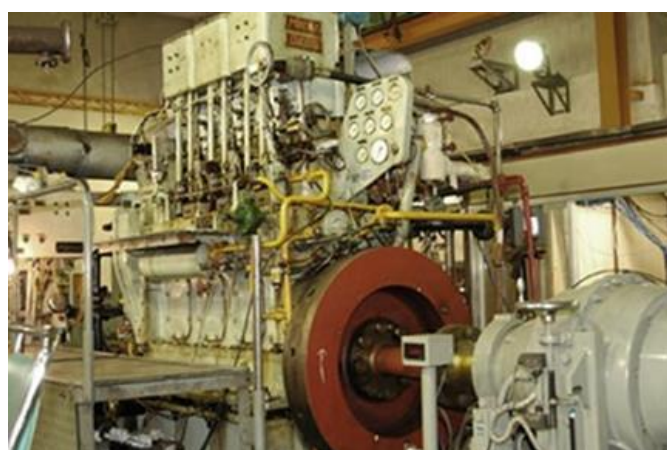
Figure 3-1 Engine overview
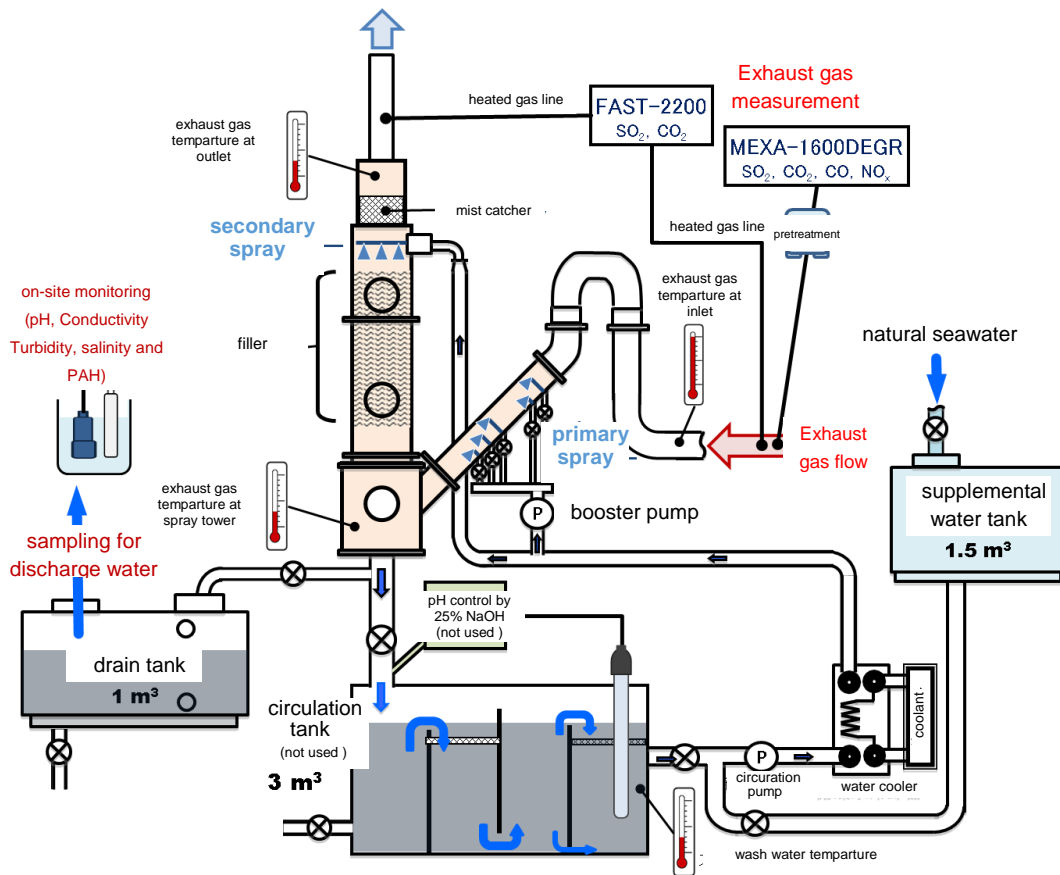
Figure 3-2 Scrubber system scheme for mimicking discharge water

The fuel properties of Type C heavy oil used in this experiment are shown in Table 3-6. This Type C heavy oil is the typical Type C heavy oil used in domestic shipping vessels and ocean shipping vessels.

Table 3-6 Fuel properties

	unit	
Density(15℃)	g/cm^3	0.9783
Viscosity 50℃)	mm^2/s	198.6
Poor point	℃	≦15
Flashpoint (PM method)	℃	177
Water	%(m/m)	0.03
Residual carbons	%(m/m)	12.7
Ash	%(m/m)	<0.01
Sulphur	%(m/m)	2.24
Carbon	%(m/m)	86.8
Hydrogen	%(m/m)	10.6
Nitrogen	%(m/m)	0.19
Oxygen	%(m/m)	0.2
Asphaltene	%(m/m)	6.06
Dry sludge (TSE)	%(m/m)	0.0065
Total specific energy (measured)	J/g	42850

Operation of the engine started with MDO, then started switching to High sulphur heavy oil, after switching to heavy oil, set to 50% load, and started the one-pass operation mode at the instant when the engine became stable. Figure 3-3 shows engine operation data in the vicinity of the sampling time of discharge water. Regarding the operation conditions of the scrubber in the one-pass operation mode, reference was made to the scrubber operation conditions at the actual ship provided by the manufacturer in the same mode, and adjusted so that the water quality is as bad as possible based on the maker's attendance. As the final test condition, manual adjustment was made so that the set value of the washing water flow rate was set to 6 m^3/h with respect to the exhaust gas flow rate at 50% load of about 600 m^3/h (estimated from the theoretical value). In this setting, the scrubber washwater flow rate/exhaust gas flow rate ratio is about 1/100, which is close to the minimum limit ratio at which the SOx removal rate can be maintained as the operation condition in the one pass operation mode, so that the pollutant in the

discharge water is maximized it is expected to be. The actual flow rate is also shown in the figure. After introducing the exhaust gas into the scrubber, it was operated for a while with a closed loop, switched the water supply to the make-up water tank side in a stable place, and then switched the drainage route to the drain tank side after about 1 minute. The arrows in Fig. 3-3 indicate the time zone during which one pass was performed. The total washing water flow rate during one pass operation was 6.15 m^3/h on average, which agreed with the set target.

Considering operating conditions such as the exhaust gas/seawater flow ratio, the use of low quality fuel, the size of the engine used, etc., the simulated discharge water produced this time is close to the setting that brings the worst discharge water concentration. Excluding aromatic hydrocarbons (PAH), the pH, turbidity and discharge water are close to the upper limit of the IMO standard for nitrates (see Table 3-7).

Table 3-7 Water properties measured at the site

Parameters	Untreated seawater in supply tank	Washwater	
		Upper part of scrubbing tower	Lower part of scrubbing tower
pH	8.09	3.65	3.17
Conductivity [ms/cm]	47.5	47.4	37.3
Salinity [PSU]	30.9	30.5	23.6
Turbidity [NTU]	0.96	16.5	19.4
PAH(Phe)[μg/l]	1.12	3.55	1.31
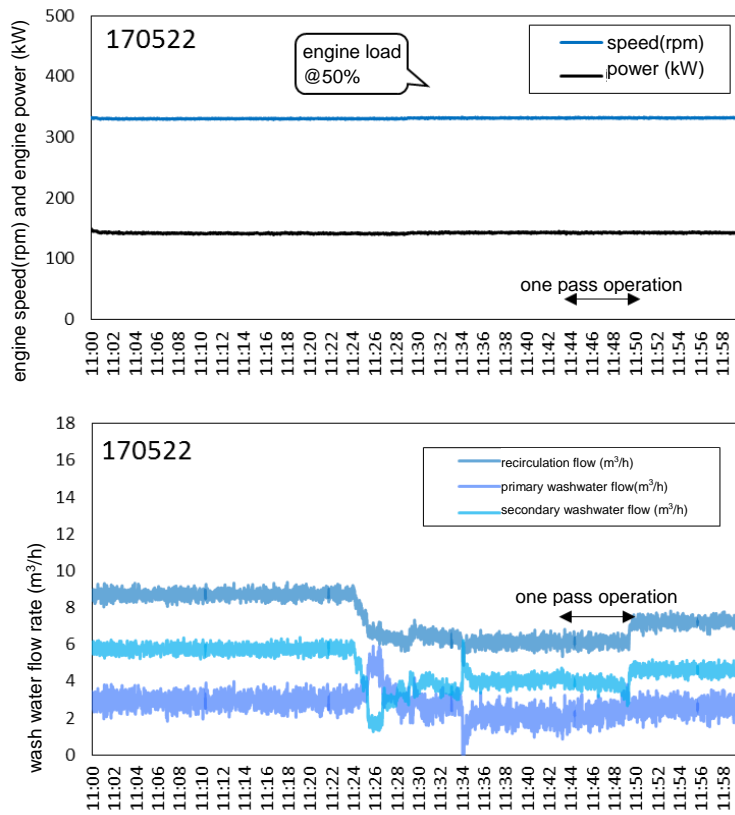
Figure 3-3 Flow rates (primary washwater flow, secondary washwater flow and recirculation flow) of scrubbers during tests

Table 3-8 Summary of WET testing conditions

test conditions	Fish acute toxicity	Crustacean acute toxicity	micro algae growth inhibition
guidelines for methodology	OECD TG203 (1992) Fish, Acute Toxicity Test .	US EPA Ecological Effects Test Guidelines OCSPP 850.1020 (2016) Gammarid acute toxicity test.	ISO 10253 (2016) Water quality－Marine algae growth inhibition test with Skeletonema costatum and Phaeodactylum tricornutum.
the species of test organism	Adrianichthyidae *Oryzias javanicus*	Ptilohyale *Hyale barbicornis*	Diatom *Skeletonema costatum*
test duration	96 hours	96 hours	72 hours
seawater for dilution	natural seawater salinity was adjusted to that of the discharge water within 1 psu	natural seawater salinity was adjusted to that of the discharge water within 1 psu	ISO medium (After adding the ISO Nutrients to natural seawater 0.45um filtration was applied to remove particulate material, bacteria and algae.) salinity was adjusted to that of the discharge water within 1 psu
Volume of the cell	3 L	500 mL	100 mL
Concentrations of test substance	10 individuals/ vessel	5 individuals/ vessel	initial cell density: 2,000 cells/mL
Replicates	1	4	6(control) 3(dilution series)
total number of the test vessels	10 cells in the dilution series + Control(seawater for dilution)+ Travel Blank sample (to check the contamination during the transportation between the test cite and the test facility)		
dilution ratio	2		2
endpoint	mortality rate (96hr-LC50)	mortality rate (96hr-LC50)	growth inhibition rate

test conditions	Fish acute toxicity	Crustacean acute toxicity	micro algae growth inhibition (72hr-ECr50、72hr-NOEC)
water exchange	every 24 hours	every 24 hours	none
water temperature	26 ± 1˚C	24 ± 1˚C	20 ± 2˚C
Feeding	none	none	none
aeration	none	none	none
light	16 hours cool white light 8 hours dark cycle	16 hours cool white light 8 hours dark cycle	The photon fluence rate at the average level 60-120 µmol/m^2/s under continuous white light
validity criteria	1.mortality in the control: <10% 2.DO in the control:>60% 3.pH in the control: 6.0～8.5 (Dissolved oxygen and pH are not adjusted for the dilution cells. For this reason, DO and pH validity criteria are not applied to dilution areas.)	1.mortality in the control: <10% 2.DO in the control:>60% 3.pH in the control: 6.0～8.5 (Dissolved oxygen and pH are not adjusted for the dilution cells. For this reason, DO and pH validity criteria are not applied to dilution areas.)	1. The control cell density: >16 in 72 h. 2. The variation coefficient of the control specific growth rates: < 7 %. 3. The control pH: < 1.0 during the test 4. The mean coefficient of variation for section-by-section specific growth rates (days 0-1, 1-2 and 2-3, for 72-hour tests) in the control cultures: <35% 4th criterion is added in accordance with OECD TG201

3.1.3 Test condition data and results

The characteristics of scrubber simulated discharge water brought back to the laboratory and subjected to toxicity tests are as shown in Table 3-9. The pH in the simulated discharge water fell from 8.1 to 3.5 which is the normal value of natural seawater since it incorporates SOx and others. Along with this, a decrease in dissolved oxygen concentration was observed. The turbidity (NTU) also increased, and black particulate matter could be seen.

Table 3-9 Water quality of test water and scrubber discharge water

Parameter	Original sea water		EGCS wash water
	21 May 2017[1]	22 May 2017[2]	May 22, 2017
Temperature (°C)	19.1	15.9	29.0
pH value	8.1	8.2	3.5
Dissolved oxygen concentration (mg/L)	7.4	7.6	2.2
Salinity (psu)	32.6	32.7	32.7
Electric conductivity (mS/m)	49.7	49.5	50.0
Turbidity (NTU)	0.68	0.62	13.6
Color	clear	clear	light black

1) Water quality immediately after sampling
2) Water quality after transportation

3.1.3.1 Algae growth inhibition test results

In the control group, cell density after 72 hours increased from 155 to 180 times (initial 164 times) the initial cell density. The coefficient of variation between containers of the average growth rate (1.70 day-1) throughout the exposure period was 1.0%, the variation coefficient of the daily growth rate was 9.7%, and the change in the pH of the test solution was 0.8. In addition, the test environment (water temperature, light intensity, etc.) was maintained in the appropriate range throughout the exposure period, and there were no factors that affected the reliability of the test results. Since the pH of the test sample was about 3.1, the lower the dilution ratio of the test sample; that is, the more the test sample was contained, the lower the pH was confirmed as compared to the diluted seawater.

The average growth rate throughout the exposure period for each exposed area was in the range of -0.60 (indicating a decrease from the initial cell density) to 1.73 day-1, which was statistically significant. In the 100% group significant differences were observed, but no significant difference was observed between 0.010% and 32% (See Fig. 3-4). The growth inhibition rate (the ratio of the growth rate difference between the control group and the exposed group) to the control group was −1.8 (which indicates that the growth rate is larger than that of the control group) to 0.4% in the 0.010% to 32% groups. The growth inhibition rate in the 100% group, where a significant difference in average growth rate was observed, was 135.3% in comparison to the control group (See Fig. 3-5). In addition, no significant abnormality was observed in the morphology and appearance of the exposed algae cells as compared with the control group.
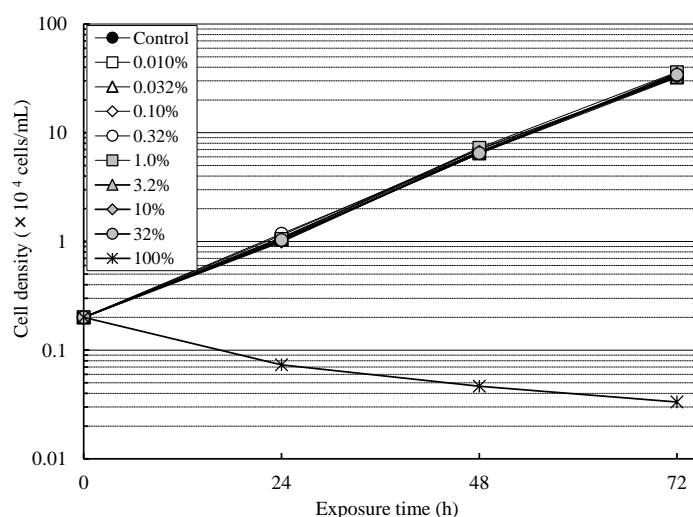
Figure 3-1 Cell density of control and dilution cells during acute WET tests using micro-algae (*Skeletonema costatum*)

(Average cell density among the replicates is indicated both for the control and dilution series)
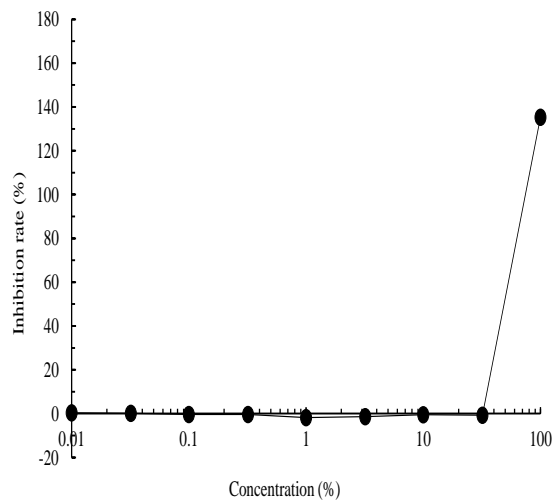
Figure 3-6 Relationship of dilution ratio and strength of toxicity during acute WET tests using micro-algae (Skeletonema costatum)
(X values indicate dilution rate of the discharge water,

Higher Y values indicate a lower growth inhibition rate in comparison to the control group)

3.1.3.2 Crustacean acute toxicity test results

The cumulative mortality rate after 96 hours of exposure in the control group was 0%, satisfying the efficacy criteria of the test. In addition, the water temperature and salt content of the test solution were maintained in the appropriate range throughout the exposure period, and there were no factors that affected the reliability of the test results. Since the pH of the test sample is about 3.1, the diluted dissolved oxygen saturation of the test sample is increased through the exposure period in the 50% and 100% groups, and in the 25% group in the tests newly started at the beginning of the test and every 24 hours Dissolved oxygen saturation immediately after preparation of the solution is less than 60%, there is a possibility of influence due to low dissolved oxygen concentration (actually a phenomenon of staying on the water surface for some test organisms was seen).

The cumulative mortality rate after 96 hours of exposure was 80% in the 25% group, 100% in the 50% group and 100% group (See Fig. 3-6 and Table 3-11), and in the 25% exposed group a statistically significant difference was observed compared with the control group. No abnormalities were observed in the behavior and appearance of surviving individuals during the exposure period in all exposed plots. The exposure time was set at 96 hours, but because the

acute effects were expressed immediately, the calculated LC50 was calculated to be 20% throughout the exposure period as shown in Table 3-10.

Table 3-10   LC50 of the acute toxicity test of each section of exposure duration, using Crustacean (*Hyale barbicornis*)

Exposure time (h)	LC$_{50}$ (%)	95 percent confidence limits (%)	Statistical method
24	20	12.5 - 25	Binomial method
48	20	12.5 - 25	Binomial method
72	20	12.5 - 25	Binomial method
96	20	12.5 - 25	Binomial method

LC$_{50}$ values express in percent-concentration of the EGCS washwater.
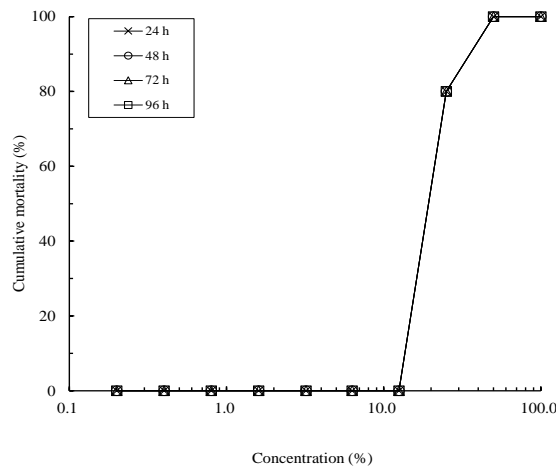

Figure 3-7 Relationship of dilution ratio and strength of toxicity during the acute WET tests using crustaceans (*Hyale barbicornis*)
(X values indicate dilution rate of the discharge water,

Higher Y values indicate a higher mortality in comparison to the control group)

Table 3-11 cumulative death number of the acute toxicity test of each section of exposure duration, using Crustacean (*Hyale barbicornis*)

（Cumulative death number after 24, 48, 72 and 96 hours' exposure）

Exposure group	Cumulative number of dead animals (Percent of cumulative mortality)									
	24 h					48 h				
	Vessel-1	Vessel-2	Vessel-3	Vessel-4	Total	Vessel-1	Vessel-2	Vessel-3	Vessel-4	Total
Control	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
0.2%	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
0.4%	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
0.8%	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
1.6%	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
3.2%	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
6.3%	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
12.5%	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
25%	3 (60)	3 (60)	5 (100)	5 (100)	16 (80)	3 (60)	3 (60)	5 (100)	5 (100)	16 (80)
50%	5 (100)	5 (100)	5 (100)	5 (100)	20 (100)	5 (100)	5 (100)	5 (100)	5 (100)	20 (100)
100%	5 (100)	5 (100)	5 (100)	5 (100)	20 (100)	5 (100)	5 (100)	5 (100)	5 (100)	20 (100)
Exposure group	72 h					96 h				
	Vessel-1	Vessel-2	Vessel-3	Vessel-4	Total	Vessel-1	Vessel-2	Vessel-3	Vessel-4	Total
Control	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
0.2%	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
0.4%	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
0.8%	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
1.6%	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
3.2%	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
6.3%	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
12.5%	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
25%	3 (60)	3 (60)	5 (100)	5 (100)	16 (80)	3 (60)	3 (60)	5 (100)	5 (100)	16 (80)
50%	5 (100)	5 (100)	5 (100)	5 (100)	20 (100)	5 (100)	5 (100)	5 (100)	5 (100)	20 (100)
100%	5 (100)	5 (100)	5 (100)	5 (100)	20 (100)	5 (100)	5 (100)	5 (100)	5 (100)	20 (100)

3.1.3.3 Fish acute toxicity test results

The cumulative mortality rate after 96 hours of exposure in the control group was 0%, satisfying the efficacy criteria of the test. In addition, the water temperature and salt content of the test solution were maintained in the appropriate range throughout the exposure period, and there were no factors that affected the reliability of the test results. For pH, a concentration-dependent decrease in the test sample was confirmed. Dissolved oxygen concentration was below 60% as dissolved oxygen saturation over the exposure period in the 100% group, while dissolved oxygen saturation immediately after preparation of a test solution newly prepared at the start of the test and every 24 hours in the 25% group and 50% group, and in the 12.5% group, was used at the beginning of the test, at 48 hours and at 72 hours. Since the dissolved oxygen saturation immediately after preparation of liquid was less than 60%, there is a possibility of influence by low dissolved oxygen (nose raising was actually observed in some test organisms).

The cumulative mortality rate 96 hours after the exposure was 100% in the 50% group and the 100% group as shown in Table 3-12 and Fig. 3-8, and no dead organisms were observed in the exposed sections below the 25% group. No abnormalities were observed in behaviour and appearance of surviving organisms in the old test solution after 24 hours in all exposed groups. Therefore, as shown in Table 3-13, the calculated LC50 was calculated to be 35% through the exposure period.

In addition, abnormal swimming (surface swimming) was observed in 12.5% group and 25% group immediately after transferring the test organisms to the newly tested test solution.

Table 3-12   cumulative death number of the acute toxicity test of each section of exposure duration, using Fish (*Oryzias javanicus*)
（Cumulative death number after 24, 48, 72 and 96 hours' exposure）

Exposure group	Cumulative number of dead organisms (Percent of cumulative mortality)			
	24 h	48 h	72 h	96 h
Control	0 （0）	0 （0）	0 （0）	0 （0）
0.2%	0 （0）	0 （0）	0 （0）	0 （0）
0.4%	0 （0）	0 （0）	0 （0）	0 （0）
0.8%	0 （0）	0 （0）	0 （0）	0 （0）
1.6%	0 （0）	0 （0）	0 （0）	0 （0）
3.2%	0 （0）	0 （0）	0 （0）	0 （0）
6.3%	0 （0）	0 （0）	0 （0）	0 （0）
12.5%	0 （0）	0 （0）	0 （0）	0 （0）
25%	0 （0）	0 （0）	0 （0）	0 （0）
50%	10 （100）	10 （100）	10 （100）	10 （100）
100%	10 （100）	10 （100）	10 （100）	10 （100）

Table 3-13 LC50 of the acute toxicity test of each section of exposure duration, using Fish (*Oryzias javanicus*)

Exposure time (h)	LC_{50} (%)	95 percent-confidence limits (%)		Statistical method
24	35	25	- 50	Binomial method
48	35	25	- 50	Binomial method
72	35	25	- 50	Binomial method
96	35	25	- 50	Binomial method

LC_{50} values express in percent-concentration of the EGCS washwater.
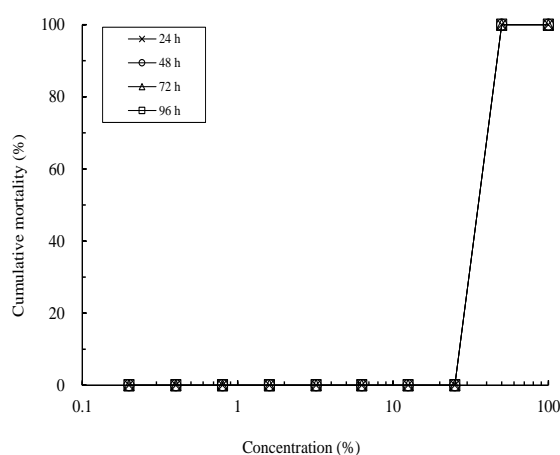

Figure 3-8 Relationship of dilution ratio and strength of toxicity during the acute WET tests using Fish (*Oryzias javanicus*)

(X values indicate dilution rate of the discharge water,

Higher Y values indicate a higher mortality in comparison to the control group)

3.1.3.4 Identification of NOEC and LC50 based on short-term testing
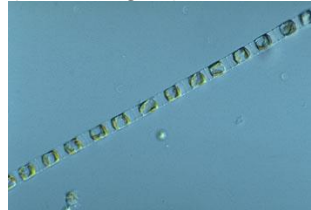
Based on the above test results, the dilution rate at which the lowest mortality rate is 50% and the dilution rate at which the mortality rate becomes 0% in the three marine organisms are 1/5 (LC50) and 1/8 (NOEC). In other words, among the three comprehensive toxicity tests, the dilution rate that is not affected is 12.5% in the invertebrate that developed the highest toxicity; that is, by diluting the EGCS discharge water to about 1/8, it is considered that there is no short-term obvious influence on one indicator organism.

In the test results of invertebrates, since the pH before dilution rises to 12.5% and falls to 7.5% after dilution, it is prescribed that the residual toxicity because low pH and low dissolved oxygen concentration resulting therefrom are predominant. It is presumed that the toxicity in other factors can be neglected.

As a conclusion, if the physical dilution ratio is 10 to 20 times for ordinary seawater, it is possible to sufficiently clear the emission regulation value (5.0 or more) of the water turbidity law at the same time as the IMO guidelines value of 6.5 regarding the pH, and it is considered that no negative influence appears on the test organism.

However, the calculation of this no-effect concentration is the dilution ratio when seawater having sufficient alkalinity is also used in the toxicity test for the experimental constraint condition; there is also a possibility that it may be necessary in the case of using brackish water and this point is examined in the latter part of this chapter.

Table 3-14 summary of the WET testing results

		EC50 or LC50	NOEC	LOEC
Algae (micro-algae)	Diatom (*Skeletonema costatum*)	49% (48 ~ 50%)	32%	100%
Invertebrates (crustacean)	Ptilohyale (*Hyale barbicornis*)	20% 12.5 ~ 25%	12.5%	25%
Vertebrate (fish)	Adrianichthyidae (*Oryzias javanicus*)	35% 25 ~ 50%	25%	50%

ErC50   Concentration: dilution area (calculated) estimated that the test species is at lethal 50% during the test period

NOEC   Maximum dilution ratio not affected for the test species during the test period (selected from actual dilution cell)

LOEC   Minimum dilution ratio dilution affected for the test species during the test period (selected from actual dilution cell)

3.1.4 Establishment of a safety dilution ratio using assessment factors (general dilution ratio)

Here, the universal PNEC (predicted no-effect concentration) is estimated from the dilution rate using the acute lethality as the end point, which is the experiment result, and using a safety factor called an assessment factor.

The endpoint of the toxicity study conducted this time is an acute effect (growth inhibition after 72 hours, death after 96 hours). For other end points other than acute lethality for other more vulnerable marine organisms, such as chronic if the influence is assumed, the calculated 1/8 dilution rate may not be sufficient. The idea of estimating the safety dilution ratio PNEC in consideration of the effect on marine organisms that are more vulnerable than such test organisms is frequently used in ecotoxicity. The method of calculating PNEC is organized by a combination of selection method from multiple toxicity values and setting method of assessment factor, and it is summarized in OECD guidelines and guidelines of ECHA, etc. In Japan, it has been adopted as the initial risk assessment method based on the Chemical Substitution Law.

The result was compared from multiple toxicity values in the "Methodology on the Ecological Impact Assessment Method for Approval of Ballast Water Treatment Equipment" prepared by the BWWG at the Expert Meeting on the Scientific Field of UN Marine Pollution (GESAMP) which adopts a setting method showing a combination of selection method and assessment coefficient. The method is as shown in Table 3-15. This methodology has been approved by MEPC of IMO.

Because the acute toxicity was conducted on three species of marine organisms, Table 3-15 of PNEC general was applied as the assessment factor to calculate the PNEC set by GESAMP BWWG. Here, PNEC general refers to a general PNEC assuming a case in which a long-term exposure to residue is continued in a closed sea area or the like.

As the usual PNEC applied in closed seas, etc., the minimum LC50 = 1/5 of the three types of toxicity test results (96 hours half-lethal concentration of Fusagemoku shown in Table 3-15) was assigned an assessment factor of 1/1,000 (coefficient of the second row from the top shown in Table 3-15) and is calculated as 1/5000. In conclusion, if the dilution ratio = 1/5,000 (5,000 hold dilution) is expected in the area, then even when exposed to that concentration continuously for a long period of time, it can be assessed that there is no effect on all marine organisms.

3.1.5 Establishment of assessment factor for local safety dilution ratio setting around hull (near ship dilution ratio)

The assessment factor (1/1,000) used in the calculation of the dilution ratio of 1/5000 mentioned in the previous section is based on the assumption that the marine organisms will be exposed continuously for a long time. However, in the vicinity of the sea route and the harbour, there may be a situation in which the dilution diffusion is intermittently exposed to a higher concentration before proceeding sufficiently.

It is stated in the same methodology that it is effective to use PNEC near ship assuming such a situation, and different assessment coefficients are applied. In this case, the safety dilution ratio is calculated to be $1/5 \times 1/100 = 1/500$.

It can be concluded that it can be compared with the dilution ratio of 1/500 as a short term evaluation around the hull as shown in Chapter 2. If the discharge water is expected to be diluted by 500 folds' around the hull, then it can be assessed that there is no effect on all marine organisms.

Table 3-15 Assessment factor to deliver PNEC, established by GESAMP BWWG

Data-set	Assessment Factor	
	PNEC general	PNEC near ship
Lowest short-term LC50 from freshwater or marine species representing one or two trophic levels	10,000	1,000
Lowest short-term LC50 from three freshwater or marine species representing three trophic levels	1,000	100
Lowest short-term LC50 from three freshwater or marine species representing three trophic levels + at least two short term LC50 from additional marine taxonomic groups	100	10
Lowest chronic NOEC from one freshwater or marine species representing one trophic level, but not including micro-algae	100	
Lowest chronic NOEC from two freshwater or marine species representing two trophic levels, which may include micro-algae	50	
Lowest chronic NOEC from three freshwater or marine species representing one trophic level, but not including micro-algae	10	

3.1.6 Conclusions

From the results of the acute toxicity tests (WET), the safety dilution ratio, corresponding to PNEC general, was estimated at 5,000 folds' dilution, using the assessment factor by GESAMP BWWG. After discharge, the time to reach the dilution rate of 1/5,000 is estimated about 1 minute (See Chapter 2), and the dilution and diffusion continues; therefore, it is considered that further dilution rate can be sufficiently assured even in an enclosed sea area. For this reason, it is considered that there is less possibility that of marine organisms may be exposed with the raw scrubber discharge water without the dilution even in the enclosed sea area.

Secondly, the safety dilution ratio corresponding to the evaluation on the local (PNEC near ship) was 500 folds' dilution, from the results of the acute toxicity test (WET). The time to reach the same dilution rate is 2.87 seconds, and it is considered it is not possible that any short-term adverse effects may be occurred on marine organisms around Ship hull.

3.2 pH changes in the receiving water

3.2.1 Overview

As measurement of pH from the test in paragraph 3.1, the actual pH of the scrubber discharge water is around 3. In the IMO guidelines, it is required to recover to 6.5 by 4 m even under the worst case (i.e. anchoring but full discharge). However, there is no mention about the behavior up to the point 4 m apart during navigation. For this reason, in this section, the pH change in discharge flow around a ship hull during navigation was assessed.

In this survey, the calculation of pH in seawater was carried out by ClassNK

3.2.2 Required dilution rate from titration curve

The pH of natural seawater is on the weak alkaline side of 8.0 - 8.2 and also has a buffering function that does not directly affect the pH by stoichiometric calculation, the buffering function is caused from the balances among carbonates concentration which is originally comes from the dissolution of atmospheric CO_2. The strength of this buffer capacity is expressed in terms of alkalinity, and it is around 2,200 μg/ml for seawater with high salinity not diluted with river fresh water. Therefore, when scrubber discharge water is discharged into the seawater environment, the scrubber discharge water further reach to pH of around 8.0 than the pH estimated from the physical dilution rate. For example, when discharge showing acidity of pH 3.0 is diluted tenfold with pure fresh water with zero alkalinity, then the pH rises only about 1.0, but when it is diluted with natural seawater it increases further by the alkalinity function. In this way, the pH change when diluting the scrubber drainage is referred to as titration curve.

Some marine organisms, such as *Coccosphaerales* (micro-algae who has small plates of $CaCO_3$ on its cell), are known to be vulnerable to pH changes. On the other hand, the actual ocean pH changes due to various environmental factors, especially in the sea areas affected by summer and river water, even in natural seawater or short-term pH 8.0 is observed. Here, when localized to pH less than 8.0, evaluation was carried out assuming that some adverse effect was given to fragile organisms.

Regarding the quantitative influence on the pH of SOx in exhaust gas in natural seawater, a theoretical formula with alkalinity and pH in seawater as an initial condition is known. Here, the theoretical formula published in the manual by the Exhaust Gas Cleaning System Association (EGCSA), an industrial association that manufactures scrubber (EGCS), was used (see Fig. 3-9).

Using this formula, the SO_2 concentration in discharge water to achieve pH 3.1 in the scrubber discharge water is 0.056 mmol/kg at pH 8.0, compared to 3.23 mmol/kg, requiring dilution 1/58 will be calculated with these two numbers. In actual seawater, dilution will proceed in a short time as described in Chapter 2, so gradual dilution is not considered here.
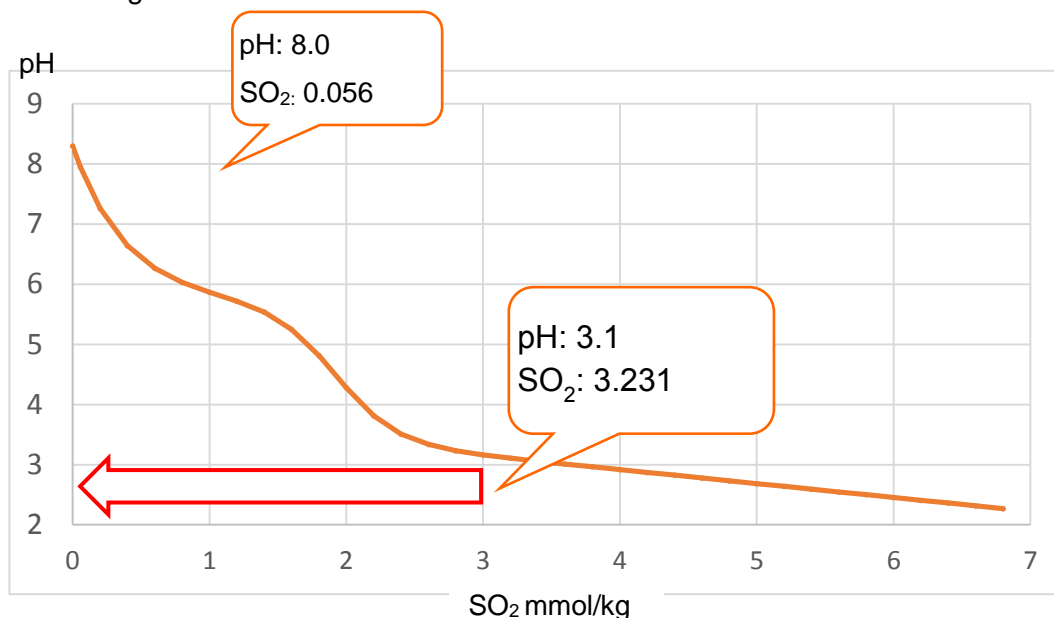
Figure 3-9 Theoretical pH titration curve of SO2 solution in natural seawater (With 2,200 μg/ml of alkalinity)

3.2.3 Assessment results

From the theoretical titration curve, the lower pH in the scrubber discharge water can be expected to recover to pH 8.0 or higher with diluted of more than 1/88 by the normal seawater. According to the dilution simulation (See Table 2-1), the required dilution ratio can be expected to reach in 0.25 seconds after discharge by strong swirl around the ship hull. Even if the alkalinity of the surrounding seawater becomes is less than the above set conditions, it is unlikely that a water mass with a pH less than 8.0 will occur around the hull.

Taking into account that ships are basically moving, and the discharge water would be immediately caught in a turbulence and swirl generated around the hull, it is considered that it is not unlikely that the lower pH in the scrubber discharge water poses any unacceptable risks to the surrounding ecosystem.

Dissolved oxygen concentration in the discharge water is considered to be almost 0 mg/L due to the lower pH, however, as same as the logic seen in Chapter 2, with rapid dilution of more than 1/58 in a short second, the dissolved oxygen concentration in the surrounding seawater is fully recovered.

3.3 Temperature change of seawater in surrounding area

3.3.1 Overview

Discharge water from Scrubbers may cause risks by the harmful substances in exhaust gases, but also by the thermal energy against marine environment. The risk is understood as an increase in seawater temperature in the surrounding water. It is already reported and recognized that in the high water temperature season such as summer, there is an influence on marine organisms, which is fragile against a temperature rise, such as eggs and larva; for example, the US state of Hawaii limits temperature rises in discharge water to within 1 degree.

In this section, whether the thermal effects of the discharge water makes any thermal effects on the marine environment was evaluated, referring to voluntary mitigation target at domestic land facilities in Japan. In this survey, the calculation of seawater temperature in the environment was carried out by ClassNK.

3.3.2 Basic thoughts

Regarding the thermal effect on the marine environment, voluntary mitigation measures in power plants are known in Japan. Each domestic power plant is working to reduce the temperature rise (temperature increase range) in the area surrounding where their seawater coolant is discharged.

In this case, a unified manner is applied to all power plants that the maximum temperature rise at the surrounding is limited to 1 degree. The Interim Report on Warm Water Plume Problem by the Water Quality Subcommittee under the Central Water Pollution Control Council of Ministry of Environment Japan stated that although the adverse effects varied among the biota, however, the most fragile organisms such as algae indicate detectable adverse effects at the condition of constant exposure with the raised temperature by 2 to 3 degrees. The report also stated any adverse effects may not be expected if the temperature rise of less than 1 degree. Based on this conclusion by the expert group, the power plant and some facilities on land maintained their temperature rise by less than 1 degree using the mitigation measures, such as increasing initial diffusion by a devise and discharge from the deeper point.

It is considered that the scrubber disparage has less flow rate per one vessel than the hot discharge water from a power plant, and since the former is moving, it is difficult to assume that the scrubber discharge is fixed in one local point. Considering the safety side, it was assessed using a simple simulation whether

the temperature rising region of more than 1 degree can disappear in short time after discharge, assuming that some adverse effect above 1 degree.

3.3.3 Calculation using simulation results of flow behind ship

As mentioned above, the temperature of washwater will be increase by the thermal energy transfer during the physical contact with the exhaust gas in a high temperature, same as that used in the power plants. The increased change can be calculated from the flow ratio of washwater/air, temperature changes in exhaust gas (inlet/outlet) and the temperature of washwater. In cases where the flow ratio of washwater/air is assumed to be 45 t/kWh, as referenced in the guidelines, the temperature increased by 15 degrees Celsius.

In this case, it is assumed that the temperature of discharge water set as 40 degrees from the maximum value measured, the temperature of the surrounding water set as 0 degrees from the average temperature in the winter at Hokkaido Island (the North Island of Japan), which may be considered as the worst case. Then, the simulation results of flow behind a ship (see Chapter 2) were applied. Moreover, the time required to reach to each temperature was calculated. The results are shown in Table 3-16: for supplemental information, the results under the condition of delta 20 degrees (20 degrees in surrounding seawater and 40 degrees in exhaust gas). In both cases, the water with a higher temperature can be diluted in 1 second and the delta can be estimated to be less than 1 degree.

In addition, the possibility of a thermal layer being caused by a plume of 40 degrees was assessed. Maintaining thermal potential in the plume is necessary to establish a steady thermal layer even after the plume reaches the seawater surface. However, according to the results mentioned above, it is estimated that the thermal potential will be relieved by a rapid and aggressive dilution caused by the swirl around the hull. Therefore, it is unlikely that the thermal plume could reach the seawater surface and make a steady thermal layer.

Table 3-16 Temperature and time duration of thermal plume discharged from ship

dilution rate	40	60	80	500	800	1,000	5,000	8,500	9,416
time duration after discharge (sec)	0.17	0.25	0.34	2.87	5.65	7.7	60.3	114.4	129
ΔT in surrounding temperature of 0 degrees	1.00	0.67	0.5	0.08	0.05	0.04	0.01	0.00	0.00
ΔT in surrounding temperature of 20 degrees	0.50	0.33	0.25	0.04	0.03	0.02	0.00	0.00	0.00

3.3.4 Assessment results

It is concluded that the discharge water with 40 degrees Celsius can be diluted in 1 second, and the delta can be estimated to less than 1 degree. Therefore, under the conditions that the ship is moving and the swirl can mitigate the hot plume, the hot plume itself could be steady, and it is quite unlikely that the thermal energy added in the discharge water may cause any risks on the surrounded ecosystem.

For the long term thermal accumulation in the local area, the total annual thermal energy from total ships operating in Tokyo Bay is estimated as the order of 1/10,000 compared with that from one single LNG burnt power plants placed in the bay; the additional energy, therefore, may be negligible.

4. Evaluation of long-term risks to water quality

   4.1 Assessment abstract

   In the previous chapter, the risks that washwater from scrubbers may cause to seawater was assessed. During the assessment, specific substances in washwater yet anaylzed WET and physicochemical properties (pH and discharge-temperature) were not identified.

   In this chapter, individual substances which may be contained in washwater was focused on, and whether these substances may pose unaaceptable risks to Japanese enclosed coastal sea areas was assessed. For this purpose, the accumulated concentrations (after ten years) were calculated and compared with the standard criteria set out by the *Basic Environment Act* or the current concentrations of the selected areas in the following methodology:

   First, screening of substances, which may be contained in washwater taking into account the actual measurement results of the washwater, was conducted. In addition, three representative sea areas was seleced, taking into account of density of sea traffic as well as geographical view points.

   Second, the daily and annual discharge amount of the identified substances in the selected areas was calculated under the worst case scenario. Based on the result, annual concentration for ten years was simulated, and whether discharge water from scrubbers may cause unaaceptable risks from the view point of the environmental protection and the conservation of Japanese coastal waters was assessed.

   In the above assessment, actual measurement of the washwater (e.g. polycyclic aromatic hydrocarbons (PAHs)) and simulation of environmental concentration of the identified substances was conducted by *ClassNK*.

   4.2 Screening for target substance identification

   4.2.1 Representative substances in washwater from scrubbers

   This subparagraph outlines the substances to be assessed which may be contained in washwater from scrubbers. As shown in Fig. 4-1, in its abatement process, scrubbers takes in seawater onboard, washes out nearly all amount of aquous soluable gases (NO_2 and SO_2) and PM in exhaust gas and be chemically stable in the washwater as acid solution. Some proportion of CO_2 gas may also be washed out and be soluable as carbonate acid. However, the contribution of carbonate acid is smaller than that of NO_2 and SO_2, because of its Henry coefficient. Also, the formed hydrogencarbonate (weak acid) from CO_2 could be unstable because of its dissociation constant of bicarbonate.

PM mainly consists of particular carbons, however it may also contain toxic subtances including Polycyclic Aromatic Hydrocarbons (PAHs) and havy metals. As mentioned in Chapter 1, the IMO Guidelines sets out discharge water criteria for PAHs and it requires that PAH should be continuously monitored on phenanthrene mainly. Table 4-1 shows the result of actual measurement of the amount of PAHs other than phenanthrene. During the discussion for original draft of the IMO Guidelines, the MEPC considered that the 16 PAHs as regulated by US EPA would be representative PAHs in washwater from scrubbers.

Moreover, other 6 PAHs than the 16 PAHs mentioned above were added, taking into account of the ecotoxicity and availability of quantitative analysis. For example: 1-methylnaphthalene and 2-methylnaphthalene as shown in Table 4-1 are methylated naphthalene, which is one of the 16 PAHs. Prior to operation of the scrubber, it was confirmed that the measured concentration of all the targeted PAHs in both seawater and ground water for use were below detection limits. In the washwater from the scrubber, even though 9 out of 22 PAHs were detected, the amount of the detected PAHs respectively was slightly above their detection limits (5 ppt (0.005µg/L or 10 ppt (0.01µg/L)). Accordingly, it is less probable that the identified 22 PAHs may cause unacceptable risks.

Table 4-2 shows the measurements of the amount of heavy metals (zinc, lead, copper, cadmium). The result suggests that the amounts of these metals were less than their detection limits (excluding iron, vanadium and nickel) and the amount of the same in the actual discharge water from the scrubber would be expected to be 1/100 of the discharge criteria as set out by the *Water Pollution Prevention Act* or the *Act on Prevention of Marine Pollution and Maritime Disaster*, therefore, these heavy metals are excluded from the scope of the screening as described hereafter.

In theory, the concentration of iron and zinc as provided in Table 4-3 is higher than the concentration of the same in the exhaust gas emitted following combustion of the heavy fuel oil in Table 4-1 or in the washwater from the scrubber[7] following abatement of the above-mentioned exhaust gas. It is assumed that the higher concentration derives from iron and zinc is leached out from the steel pipes in the discharge lines under low pH of the washwater. When a scrubber is installed on an

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[7] For instance, whereas the maximum concentration of iron and zinc in washwater from scrubbers are 997 µg/L and 48.25 µg/L respectively, the concentration of the same in the washwater after abatement by a scrubber of the exhaust gas emitted upon combustion of the HFO as sampled for Table 4.1 is no more than 50 µg/L and 4 µg/L respectively.

actual ship, non-metallic surfaces are used for piping of discharge lines; thus, such leaching of iron and zinc is estimated to be negligible.

Substances contained in exhaust gas emissions from ships				Substances contained in washwater from scrubbers	
	Weight basis (%)	Volume basis (%)	Note		Penetration
Nitrogen	76.90	80.86	From the original contents in atmospheric air[*1], assuming residual O_2 content would be 13%	Nitrogen	Insoluble
Oxygen	14.63	13.47	From the original content in atmospheric air[*1], assuming residual O_2 content would be 13%	Oxygen	Insoluble
Argon	1.31	0.97	No change from atmospheric content[*1] because of its less reactivity by combustion	Argon	Insoluble
Carbon dioxide	6.88	4.56	Theoretical volume, assuming residual O_2 content would be 13%	Carbon dioxide	Partially dissolved into washwater (ocean acidification may be assessed only on SO_2 and NO_2)[*3]
Sulphur dioxide	0.11	0.05	Theoretical volume, assuming sulphur content of 2.5%	Sulphur dioxide	All volume dissolved in to washwater
Nitrogen dioxide	0.26	0.17	Theoretical volume, from NOx Tier 1 regulation	Nitrogen dioxide	12% volume dissolved into washwater[*2]
Other gases	0.06	0.03	Original content in atmospheric air	Other gases	Insoluble
PM	0.01	—	Using IMO default EF	PM	OM include in PM trapped in washwater[*3], then assessed as COD[*4]

Figure 4-1 Diagram of the transition of substances from exhaust gas to washwater from scrubbers

*1　Composition of atmospheric area by volume: N_2 78.1%, O_2 20.9%, Ar 0.934%, CO_2 0.039%, others (Ne,He,CH_4) 0.027%

*2　It is assumed that the residual oxygen concentration was 13% taking account of permissible oxygen concentration for diesel engines as set out by the Air Pollution Control Act, and that the dissolved amount of NO_2 in the washwater is 12%.

*3　Due to CO_2, NO_2 and SO_2 in the washwater, effect of CO_2 to pH is small, taking into account of its Henry coefficient and dissociation constant.

*4　OM: Organic Matter; COD: Chemical Oxygen Demand

Table 4-1 Actual measurement of the concentration of Polycyclic Aromatic Hydrocarbons (PAHs) contained in washwater from a scrubber

Substances analyzed			Unit	Seawater (immediately after sampling)[2]	Seawater (after transportation) [3]	Discharge water 1 (50% Load)	Discharge water 2 (25% Load)	Fresh water (for pre-heating)[4]
P A H	Naphthalene	91-20-3	µg/L	< 0.005	< 0.005	< 0.005	0.006	< 0.005
	2-methylnaphthalene	91-57-6	µg/L	< 0.005	< 0.005	< 0.005	0.006	< 0.005
	1-methylnaphthalene	90-12-0	µg/L	< 0.01	< 0.01	< 0.01	<0.01	< 0.01
	Biphenyl	92-52-4	µg/L	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
	Acenaphthylene	208-96-8	µg/L	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
	Acenaphthene	83-82-9	µg/L	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
	Fluorene	86-73-7	µg/L	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
	Dibenzothiophene	132-65-0	µg/L	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
	Phenanthrene	85-01-8	µg/L	< 0.005	< 0.005	< 0.005	0.006	< 0.005
	Anthracene	120-12-7	µg/L	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
	Fluoranthene	206-44-0	µg/L	< 0.005	< 0.005	< 0.005	< 0.005	<0.005
	Pyrene	129-00-0	µg/L	< 0.005	< 0.005	< 0.005	0.007	< 0.005
	Benz[a]anthracene	56-55-3	µg/L	< 0.005	< 0.005	< 0.005	0.006	< 0.005
	Chrysene	218-01-9	µg/L	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
	Benzo[b]fluoranthene Benzo[j]fluoranthene[1]	205-99-2 205-82-3	µg/L	< 0.01	< 0.01	<0.01	0.012	< 0.01
	Benzo[k]fluoranthene	207-08-9	µg/L	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
	Benzo[a]pyrene	50-32-8	µg/L	< 0.005	< 0.005	< 0.005	0.014	< 0.005
	Perylene	198-55-0	µg/L	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
	Indeno[1,2,3-cd]pyrene	193-39-5	µg/L	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
	Dibenzo[a,h]anthracene	53-70-3	µg/L	< 0.005	< 0.005	< 0.005	0.006	< 0.005
	Benzo[g,h,i]perylene	191-24-2	µg/L	< 0.005	< 0.005	< 0.005	0.014	< 0.005

∗1 For Benzo[b]fluoranthene and Benzo[j]fluoranthene, the sum of these two substances were indicated.

∗2 Clean seawater sampled from Fujieda, Japan, after sand-filtration and 10 um filtration.

∗3 the seawater was sampled at the site before the use, to check the contamination during its transportation and piping at the test cite.

∗4 Freshwater used to heat-up the test scrubber (to save the consumption of the clean seawater).

Table 4-2 Measurement of the amounts of heavy metals contained in heavy fuel oil for ships

		Unit	HS HFO ①	HS HFO ②	HS HFO (10samples)
Basic Properties	Viscosity	cSt@50°C	278	299	87 ~ 276
	Carbon	% m/m	88.1	85.7	86.6 ~ 87.3
	Hydrogen	% m/m	11.3	11.3	10.3 ~ 12.4
	Nitrogen	% m/m	0.4	0.4	0.09 ~ 0.22
	Sulphur	% m/m	2.6	2.9	0.28 ~ 2.49
Heavy metals	Vanadium	mg/kg	122	121	44 ~ 63
	Nickel	mg/kg	23	22	16 ~ 23
	Iron	mg/kg	16	16	3 ~ 17
	Zink	mg/kg	1	< 1	0 ~ 3
	Lead	mg/kg	< 1	< 1	0
	Cupper	mg/kg	< 1	< 1	—
	Cadmium	mg/kg	< 1	< 1	—
	Chrome	mg/kg	< 1	< 1	—
	Arsenic	mg/kg	< 0.5	1	—

Sources：For fuel oils refined outside of Japan (heavy fuel oil (1) and (2)), actual measurements conducted by *ClassNK*. For fuel oils refined within Japan (domestic heavy fuel oils), data analyzed by *NMRI*.

Table 4-3 Actual measurement of the amounts of heavy metals contained in washwater from a scrubber

Substance	unit	Actual concentration of heavy metal			Discharge criteria for onshore sources
		30% engine load	50% engine load	80% engine load	
Vanadium	µg/L	39	9.9	58	NA
Nickel	µg/L	18.0	10.6	17.9	NA
Iron	µg/L	528	326	997	10000
Zink	µg/L	17.3	31.7	48.3	2000
Lead	µg/L	1.39	0.584	1.755	100
Cupper	µg/L	3.00	9.37	8.12	3000
Cadmium	µg/L	0.03	0.042	0.035	30
Chrome	µg/L	11.6	14.8	22.8	2000
Arsenic	µg/L	0.030	0.018	1.02	100

Effluent load in the column of the Table describes the effluent load by the washwater after abatement of combusted heavy fuel oils refined outside of Japan.

4.2.2 Identification of target substances based on the *Water Pollution Prevention Act*

Screening of the substances whose effluent load is regulated by the *Water Pollution Prevention Act* was performed. Among those substances regulated, Table 4-4 and Table 4-5 provide the result of the screening of the substances regulated for living environment by the act. In the process of screening, investigation, whether each substances with discharge standards set in the *Water Pollution Prevention Act* are included in the fuel or newly generated in the combustion atmosphere, was conducted. The existence of Heavy metals were assumed from representative fuel analysis results or actual measurement values in discharge water from the test scrubber using typical fuel. Since some harmful organic carbon has no actual measurement value, it is excluded when it is not theoretically included in fuel and lubricant. Based on the results of the screening, since many of the substances designated as the wastewater standards specified by the law are used for solvents, etc., it is not possible that they exist in the wastewater from the exhaust gas well-burned. The measured concentration of metals including heavy metals is smaller than the discharge water standard values for on-land sources. Accordingly, among the substances shown in Table 4-4 and Table 4-5, detailed quantitative substances to be studied include pH and nitrogen content lowered by sulphuric acid or the like contained in the waste water (NO x in the exhaust gas is dissolved, It is present as nitrate nitrogen and nitrite nitrogen, phosphorus content (which

may be contained in a trace amount in the fuel) and COD (a part of the unburnt fuel is present as organic carbon).

The *Act on Prevention of Marine Pollution and Maritime Disaster* also specified substances for discharge water from ships, however, it is not possible that the discharge concentration of Scrubber may exceed the standards of materials for dumping to the sea, and the actually measured Concentration of heavy metals are is also lower than emission limit in the Act. Therefore, it can be concluded that there is no need for a detailed quantitative study on designated substances under the same law.

Table 4-4 Screening of the substances to which permissible limits for living environment are set out by the *Water Pollution Prevention Act*

("-" means the relevant substance is contained in neither of fuel oils, lubricant oils or exhaust gas. "+" means the relevant substance should be subject to assessment.)

Harmful substance		Discharge criteria[8]	whether contained in washwater from scrubbers	whether to be assessed
Cadmium and its compounds		0.03mg Cd/L	Refer to table3-4	
Cyanogen compound		1 mg CN/L	-	
organophosphorus (Parathion, Methyl parathion, Methyldemeton, EP and N only)		1mg/L	-	
Lead and its compounds		0.1 mg Pb/L	Refer to table3-4	
Hexavalent chromium compound		0.5 mg Cr(VI)/L	Refer to table3-4	
Aresevic and its compounds		0.1 mg As/L	Refer to table3-4	
Mercury, alkyl mercury and other mercury conpounds		0.005 mg Hg/L	-	
Polychlorinated biphenyl		0.003 mg/L	-	
Trichloroethylene		0.1 mg/L	-	
Tetrachloroethylene		0.1 mg/L	-	
Dichloromethane		0.2 mg/L	-	
Carbon tetrachloride		0.02 mg/L	-	
1,2-Dichloroethane		0.04 mg/L	-	
1,1-Dichloroethylene		1 mg/L	-	
Cis-1,2-Dichloroethylene		0.4 mg/L	-	
1,1,1-Trichloroethane		3 mg/L	-	
1,1,2-Trichloroethane		0.06 mg/L	-	
1,3-Dichloropropene		0.02 mg/L	-	
Thiuram		0.06 mg/L	-	
Simazine		0.03 mg/L	-	
Thiobencarb		0.2 mg/L	-	
Benzene		0.1 mg/L	-	
Selenium and its compounds		0.1 mg Se/L	-	
Boron and its compounds	Discharged to sea area:	230 mg B/L	-	
Fluorine and its compounds	Discharged to sea area:	15 mg F/L	-	
Ammonia, Amonium	Ammoniac nitrogen by 0.4	100 mg/L	Below IMO standards	

[8] Discharge criteria are defied as "allowable limit" under the *Water Pollution Prevention Act*

Harmful substance		Discharge criteria[8]	whether contained in washwater from scrubbers	whether to be assessed
compound, Nitrous acid compound and Nitric acid compound	Sum of Nitrous acid compound and Nitric acid compound:			
1,4-Dioane		0.5 mg/L	-	

Table 4-5 Screening of the substances to which permissible limits for living environment are set out by the *Water Pollution Prevention Act*

(- means the relevant substance is contained in neither of fuel oils, lubricant oils or exhaust gas. + means the relevant substance should be subject to assessment.)

Harmful substance		Discharge criteria[9]	whether contained in washwater from scrubbers	whether to be assessed
Concentration of hydrogen ions (Hydrogen index)(pH)	Discharged to sea area:	Between 5.0 and 9.0	Above IMO standards	+
Biochemical oxygen demand (BOD)		160 mg/L (Daily average 120 mg/L)	Found traces of unburnt combustible content	+ Evaluated as COD
Chemical Oxygen Demand (COD)		160 mg/L (Daily average 120 mg/L)	Found traces of unburnt combustible content	+
Suspended Solids (SS)		200 mg/L (Daily average 150 mg/L)	-	
N-hexane extractives content (Mineral oils content)		5 mg/L	-	
N-hexane extractives content (Animal and plant oils and fats content)		30 mg/L	-	
Phenols content		5 mg/L	-	
Copper content		3 mg/L	Refer to table3-4	
Zinc content		2 mg/L	Refer to table3-4	
Soluble iron content		10 mg/L	Refer to table3-4	
Soluble manganese content		10 mg/L	-	
Chrome content		2 mg/L	Refer to table3-4	
Coliform bacteria count		Daily average 3000 counts /cm^3	-	
Nitrogen content		120 mg/L (Daily average 60 mg/L)	Below IMO standards	+
Phosphorus content		16 mg/L (Daily average 8 mg/L	Below IMO standards	+

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[9] Discharge criteria are defied as "allowable limit" under the *Water Pollution Prevention Act*

4.2.3 Identification of target substances based on the *Basic Environment Act*

Screening of the substances whose effluent load is regulated by the *Basic Environment Act* was performed. Among those substances screened, from Table 4-6 to Table 4-10 provides the result of the screening of the substances regulated for protection of human health by the act. With respect to heavy metals and hydrocarbons, the values were obtained by a representative fuel analysis or by an actual analysis of washwater by use of the analyzed fuel. Hydrocarbons other than PAHs were excluded, as no actual analysis was available, unless they were theoretically contained the fuel oils or lubricant oils.

Upon screening, it was clear that following target substances in washwater which may pose risks to the marine aquatic organism; total phosphorus (occurs in minute amounts in fuel oils), total nitrogen (dissolved NOx in exhaust gases) and COD (constitutes a part of unburnt fuel as an organic carbon). Further, a quantitative analysis of pH was conducted by simulation to assess the impact of sulphates ion and nitrates ion in washwater. For substances other than those mentioned above, it was concluded that no further quantitative analysis was needed as these substances are not in fuel oils or lubricant oils.

Table 4-6 Screening of the substances whose total effluent loads are regulated by the *Basic Environment Act* for protection of human health

("-" means the relevant substance is contained in neither fuel oils, lubricant oils nor exhaust gas. "+" means the relevant substance should be subject to assessment.)

Substance	National Standard	Whether contained in washwater from scrubbers	whether the substance to be assessed
Cadmium	0.003 mg/L	Refer to Table 4-3	-
Total cyanide	Not detected	not contain	-
Lead	Below 0.01 mg/L	Refer to Table 4-3	-
Hexavalent chromium	Below 0.05 mg/L	Refer to Table 4-3	-
Arsenic	Below 0.01 mg/L	Refer to Table 4-3	-
Total mercury	Below 0.0005 mg/L	not contain	-
Alkyl mercury	Not detected	not contain	-
PCB	Not detected	not contain	-
Dichloromethane	Below 0.02 mg/L	not contain	-
Carbon tetrachloride	Below 0.002 mg/L	not contain	-
1,2-Dichloroethane	Below 0.004 mg/L	not contain	-
1,1-Dichloroethylene	Below 0.1 mg/L	not contain	-
Cis-1,2-Dichloroethylene	Below 0.04 mg/L	not contain	-
1,1,1-Trichloroethane	Below 1 mg/L	not contain	-
1,1,2-Trichloroethane	Below 0.006 mg/L	not contain	-
Trichloroethylene	Below 0.01 mg/L	not contain	-

Tetrachloroethylene	Below 0.01 mg/L	not contain	-
1,3-Dichloropropene	Below 0.002 mg/L	not contain	-
Thiuram	Below 0.006 mg/L	not contain	-
Simazine	Below 0.003 mg/L	not contain	-
Thiobencarb	Below 0.02 mg/L	not contain	-
Benzene	Below 0.01 mg/L	not contain	-
Selenium	Below 0.01 mg/L	not contain	-
Nitrate nitrogen and Nitrate nitrogen [10]	Below 10 mg/L	Below IMO standard	+
Fluorine	Below 0.8 mg/L	not contain	-
Boron	Below 1 mg/L	not contain	-
1,4−Dioxane	Below 0.05 mg/L	not contain	-

Table 4-7 Screening of the substances whose total effluent loads are regulated by the *Basic Environment Act* for conservation of Living environment

("-" means the relevant substance is contained in neither fuel oils, lubricant oils nor exhaust gas. "+"

means the relevant substance should be subject to assessment.)

parameters	National Standard for marine pollution			Whether contained in washwater from scrubbers	whether the substance to be assessed
	A	**B**	**C**		
	Fisheries class1 Water bath Natural Environment Conservation And B or less	Fisheries class 2 Industrial water And C	Environmental protection		
pH	>=7.8 =<8.3	>=7.8 =<8.3	>=7.0 =<8.3	Below IMO standard	+
COD	=<2mg/L	=<3mg/L	=<8mg/L	Below IMO standard	○
DO	>7.5mg/L	>5mg/L	>2mg/L	DO value is small however, the effect on water quality is not assumed	-
***E. coli* group number**	1,000MPN/100mL	—	—	—	-
n-hexane extracts	ND	ND	—	—	-

1. Natural Environment Conservation: Environmental Conservation such as Nature Search
2. Fisheries Level 1 grade: for fishery organisms such as red sea bream, yellowtail seaweed and seaweed seawater, and for marine products of aquatic grade 2 grade, aquatic grade 2: for aquatic organisms such as bora,
Environmental conservation: To the extent that discomfort does not occur in the daily life of the people (including coastal walks etc.)

Table 4-8 Screening of the substances whose total effluent loads are regulated by the *Basic Environment Act* for conservation of Living environment

("-" means the relevant substance is contained in neither fuel oils, lubricant oils nor exhaust gas. "+"

means the relevant substance should be subject to assessment.)

Item	National Standard for eutrophication				Whether contained in washwater from scrubbers	whether the substance to be assessed
	I	II	III	IV		
	Natural environment conservation and II Listed in the following column (Excluding Fisheries type 2 and 3)	Fisheries type 1 and column III (Excluding Fisheries types 2 and 3)	Fisheries type 3 and column IV (Excluding Fisheries type 3)	Fisheries type 3 Industrial water Biological habitat preservation		
total nitrogen	<0.2mg/L	<0.3mg/L	<0.6mg/L	<1mg/L	Below IMO standard	○
total phosphorus	<0.02mg/L	0.03mg/L	0.05mg/L	<0.09mg/L	—	○

The National standard should be verified as daily average.

2. Conservation of natural environment: Environmental preservation such as natural exploration
Fisheries type 1 species: Various fishery organisms including benthic fishes and shellfishes are well-balanced and stably harvested
Fisheries type 2: Fisheries organisms, mainly fish, are excluded, except for some benthic fishes and shellfishes,
Fisheries type 3: certain fishery organisms that are resistant to pollution are mainly caught,
Biological habitat preservation: the limit to inhabit the bent life throughout the year

Table 4-9 Screening of the substances whose total effluent loads are regulated by the *Basic Environment Act* for conservation of Living environment

("-" means the relevant substance is contained in neither fuel oils, lubricant oils nor exhaust gas. "+" means the relevant substance should be subject to assessment.)

substance	National Standard		Whether contained in washwater from scrubbers	whether the substance to be assessed
	area for organism A	area for organism extra A		
	Sea area where aquatic life lives	In the sea area for organisms, sea area that requires conservation as a spawning ground (breeding ground) of aquatic life or a breeding ground for kindergarten		
total zinc	<0.02mg/L	<0.01mg/L	not contain	-
Nonylphenol	<0.001mg/L	<0.0007mg/L	not contain	-
Linear Alkylbenzene Sulfonate	<0.01mg/L	<0.006mg/L	not contain	-

Table 4-10 Screening of the substances whose total effluent loads are regulated by the *Basic Environment Act* for conservation of Living environment

("-" means the relevant substance is contained in neither fuel oils, lubricant oils nor exhaust gas. "+" means the relevant substance should be subject to assessment.)

parameters	National Standard			Whether contained in washwater from scrubbers	whether the substance to be assessed
	area for oranism1	area for oranism2	area for oranism3		
	Maintain and regenerate places where preservation and regeneration of a place where aquatic organisms with low oxygen tolerance can live in the inhabitation stage or places where low oxygen-	Maintain a place where aquatic organisms can be reprocessed except in aquatic organisms that preserve and regenerate places where aquatic organisms can live, or aquatic organisms with low oxygen	Maintain and regenerate places where aquatic organisms that are highly tolerant to hypoxia can live in the inhabitation stage, water bodies that preserve and regenerate places where highly		

	tolerance-resistant aquatic organisms can be reproduced at the reproduction stage	tolerance at the reproduction stage, except for aquatic organisms with low oxygen tolerance at the inhabitation stage Waters to be regenerated	oxygen-tolerant aquatic organisms can be reproduced at the reproduction stage, and waters that eliminate inanimate areas		
Dissolved Oxygen at lower layer	> 4.0mg/L	> 3.0mg/L	> 2.0mg/L	not contain	-

The National standard should be verified as daily average.

4.2.2 Target coastal area selection

With respect to coastal areas, those with a higher enclosure and a greater volume of sulphur oxide emissions (density of sea traffic was higher) were selected.

The *Water Pollution Prevention Act* has identified 88 enclosed coastal areas out of Japanese waters on the basis that their enclosure indexes are more than 1. Furthermore, the *Water Pollution Prevention Act* and the *Act on Special Measures concerning Conservation of the Environment of the Seto Inland Sea* introduce measures for control of effluent loads to mitigate water pollution caused by density of population and industry. Currently total permissible loads for total nitrogen, total phosphorus and CODs are established for Tokyo Bay, Ise Bay and the Seto Inland Sea respectively. Therefore, these three coastal areas were selected as target coastal areas. Table 4-7 shows the comparison of the three areas based on several geographical parameters and sulphur oxides emission, etc., and Fig. 4-11 shows the geographical maps of the three areas.

Table 4-11 Comparison of parameters of the 3 target coastal areas

	Tokyo Bay	Ise Bay	Seto Inland Sea
Size of area (km^2)	1380	2130	21827
Enclosure index	1.78	1.52	1.13
Pattern (Nitrogen)	II,III and IV (Outside bay entrance and central area: III and IV)	II, III and IV	II, III and IV (Outside Mizushima and Osaka Bay: II)
SOx in emission gas (tons/year)	14,918	7,991	57,989
Sulphur content in scrubber (tons/year)	7,459	3,996	28,995
Sulphur content in scrubber per area	5.41	1.88	1.33

Data sourse for the size of the coastal areas and the enclosure index: Environmental Guidebook on the Japanese Enclosed Coastall Seas (88 Coasstal Sea Areas), published by the Ministry of the Environment (Japan).

Total volume of SOx emission, total volume of discharge water from scrubbers and sulphur rate were calculated in this EIA.
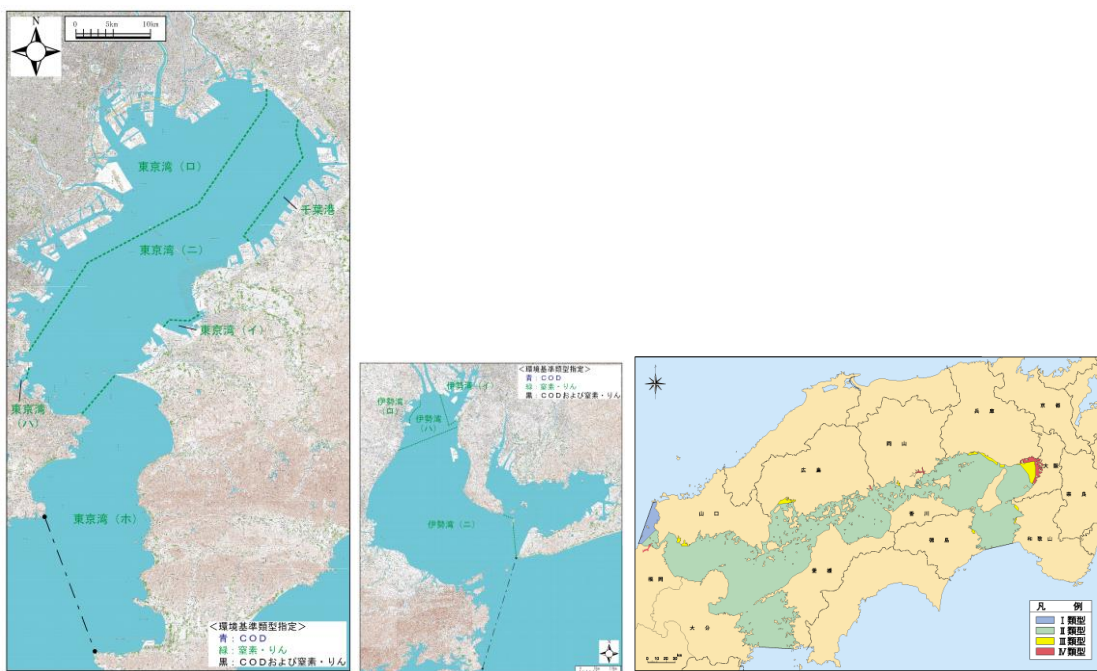

Figure 4-2 Geographical map of the 3 target coastal areas (Tokyo Bay, Ise Bay and the Seto Inland Sea)

4.2.3 Estimate of volume of discharge of the target substances and effluent loads to the target areas

In this sub-paragraph, the volume of discharge of the target substances identified in 4.2.1 within Japanese waters collectively and within the target three coastal waters selected in 4.2.2 (Tokyo Bay, Ise Bay and the Seto Inland Sea) was estimated.

With respect to the number of ships and the volume of emission of exhaust gas, the data was applied, which was obtained from the database based on the AIS data received at coastal stations. The database was established at the time when the Japanese Government considered the introduction of the Emission Control Areas (ECA). Fishing boats were excluded from the data as fishing boats already use compliant fuels.

For the purpose of the calculation, it is assumed that, when all number of the ships are installed with scrubbers, therefore, all amount of the sulphur content in fuel oil (2.46%[11] in HFO and 0.61% in MDO) is dissolved into the washwater and discharged to the target coastal areas.

The other assumptions made are as follows:

- 12% of NOx will be removed from the NOx in the exhaust in accordance with the IMO Guidelines, in which discharge of nitrates should not beyond 12% removal of NOx from the exhaust regardless of the actual amount of discharge of washwater, or beyond 60 mg/L normalized for washwater discharge.
- All the amount of organic carbon compounds contained in PM is classified as COD (chemical oxygen demand).

Table 4-12 provides the calculation results under the above assumptions.

Table 4-12 Daily emission rate of air pollutant in Japan (total) and in the 3 target coastal areas and daily rate of air pollutant contained in discharge water from scrubbers from all ships operating in Japan

Units: tons/day

	Tokyo Bay	Ise Bay	Osaka Bay	Seto Inland Sea (including Osaka Bay)	total Japan (for reference)
Fuel consumption per day	1,048	561	672	4,610	21,022
Total NOx emissions (NO$_2$)	64	36	41	313	1,766
Total SOx emissions (SO$_2$)	42	22	25	159	840
Total PM emissions (Total PM)	7	1	4	28	150
Total nitrogen load (NO$_3$-N)	2.42	1.38	1.6	11.9	67.4
Sulphur load (SO$_4$-S)	20.4	10.9	12.6	79.4	420.6
Total phosphorus load (PO$_4$-P)	0.034	0.020	0.022	0.171	0.970
COD load(O$_2$)	0.51	0.10	0.3	2.2	11.4

The emission rates of Japan (total) are summed up for all domestic and international ships operating within coastal areas of 50 NM.

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[11] Sulphur contents in the MDO for internal navigation was set as the results from the monitoring by National Internal Navigation Union, for that of all HFO was set as the global average from IMO Sulphur Monitoring in 2005

4.3 Summary of the long-term simulation

To assess the effect of washwater from scrubbers to the target coastal areas, a long-term simulation is needed to compare the predicted environmental concentration (PEC) with the environmental standards and/or the actual concentration.

provides the description of the adopted model for the long-term PEC simulation; MAMPEC-BW (special version of the Ballast Water of Marine Antifoulant Model to Predict Environmental Concentrations). This long-term PEC simulation program was developed and recommended for conducting EIA of chemical substances contained in ballast water discharged.

Table 4-13 General description of long-term simulation

Item	Summary
Scope of time axis (Average time of output concentration for time axis)	From each seasonal and annual average When considering accumulation, 1 year to 10 years against yearly average
Scope of space (Space averaging)	Fixed grid: 10 km grids (grid of depth is changeable)
Comparison	Environmental criteria
Impact of geographical conditions	Affected by geographical conditions (same emission amount may result in different outcomes depends on bays) Sea tide is identified in the horizontal and vertical
Impact of hydrographic conditions	Reproduces flow fields by flow density from sea tide and river. Therefore, outcome may be different depending on size and width of river affect areas.
Impact assessment of multiple sources	Possible (Identified as line or surface sources)
Geographical shape of discharge area	Identified as initial diffusion width
Chemical reaction	Long-term response can be taken into account (photolysis and bio-accumulations)
Model of this project	MAM-PEC 3.1
Developer	CEPE
Area in the model	Simplified as 10×10×20
Output	Annual average concentration on each grid points

4.4．Long-term simulation results

In accordance with the description of the simulation model as above, the accumulated concentration of the target substances as identified in 4.2.1 was calculated, in the target areas as selected in 4.2.2, with the assumption that all existing ships are fitted with scrubbers and the scrubbers are in operational use for ten years. Table 4-14 provides the result of the simulation. The same result was examined against the current actual values.

The additional accumulated concentration for NO3-N, PO4-P and COD is negligible, being less than 1/100 fold to 1/1000 fold than the current concentration. In addition, together with the additional accumulated concentration of sulphates ion and nitrates ion, the pH changes are calculated to be no less than ΔpH = −0.0035.

In accordance with the above, the additional accumulated concentration caused by washwater discharge from scrubbers would not introduce adverse effect on the current attainment of the environmental standard of pH, total nitrogen, total phosphorus and COD.

Table 4-14 Calculation results of the annual concentration for 10 years conducted by MAMPEC and comparison with the actual annual concentration as of 2015

Item	Additional Accumulated concentration after 10 years		
	Tokyo Bay	Ise Bay	Seto Inland Sea
pH	NO changes [*1] (current rage pH 8.3)[*3]	NO changes [*1] (current rage pH 8.2)[*3]	NO changes [*1] (current rage pH 8.1)[*3]
Nitrate nitrogen (mg/L)	7.34×10^{-4} (current rage 0.27-0.74)[*2]	5.30×10^{-5} (current rage 0.29-0.54)[*2]	2.01×10^{-3} (current rage 0.14-0.71)[*2]
Phosphate-phosphorus (mg/L)	8.73×10^{-6} (current rage 0.025-0.065) [*2]	6.19×10^{-7} (current rage 0.029-0.065) [*2]	2.09×10^{-5} (current rage 0.012-0.050) [*2]
COD(mg/L)	3.85×10^{-4} (current rage 2.2-2.9)[*2]	8.11×10^{-7} (current rage 2.4-3.5)[*2]	9.62×10^{-4} (current rage 1.8-2.7)[*2]

∗1 The pH changes caused by the additional accumulated concentration of sulphate ions and nitrate ions is not less than 0.0035 with the assumption that all SO_2 and NO_2 in the exhaust gas are penetrated into the washwater from scrubbers.

∗2 Source: "Measurement results of water quality in public waters in 2016", published by the Environmental Management Bureau of the Ministry of the Environment,

∗3 The actual rate is from the data contained in Wise-area comprehensive Water Quality Study in 2015 as published on the Ministry of Environment's website (in Japanese).

4.5 Evaluation of the calculation results

4.5.1 Evaluation of the identified substances

Upon evaluation of the simulation, it is assumed the worst cased scenario where all existing ships are fitted with scrubbers and the scrubbers are used in open

mode for ten years. As a result, the additional accumulated concentration by the target substances is less than 100 folds' dilution of the current concentration in the respective target areas(in case only 5% of the ships are installed with scrubbers, the additional accumulated concentration would be estimated as less than 2000 folds' dilution).

Furthermore, the additional accumulated concentration of the target substances will be saturated due to the exchange with open water sea, and thus, it is not expected that the accumulated concentration will further increase after ten years.

4.5.2 Evaluation based on permissible effluent loads for nutrient salts

Article 3 of Chapter 3 of the *Water Pollution Prevention Act* (hereinafter referred to as the "WPPA") allows establishing more stringent emission standards based upon the maximum permissible effluent loads. Based on said article, the maximum permissible effluent loads and associated effluent standards for individual onshore sources are enforced in Tokyo Bay, Ise Bay and the Seto Inland Sea respectively. The following paragraph focuses on the effluent standard regulation enforced in the Seto Inland Sea, which is the most stringent among these three coastal areas and compare and evaluate the actual effluent load from the onshore facilities and from ships.

Table 4-6 provides emission loads of the identified substances (total nitrogen, total phosphorus and COD) from ships and from onshore facilities into the Seto Inland Sea. This calculation in Table 4-12 was conducted with the assumption that all ships that use HFO are fitted with scrubbers. As specified in Table 4-6, emission load from ships contributes less than 1% for the COD load and less than 3% for the total nitrogen load compared with that actual effluent load from onshore facilities.

In addition, the act also sets out the maximum targets for the total effluent loads. According to the annual reports, the margins from the actual loads towards the target loads are more than 12 tons. Therefore, even when the emission from ships would be regulated under the scope of the act, the actual effluent loads could not exceed the target loads.

Finally, it should be noted that the above calculation considers the worst case of scenario (the volume of discharge of washwater is calculated as being theoretically maximum); where all existing domestic and international ships are installed with open-loop scrubbers.

In accordance with the above, additional emission loads that washwater from scrubbers cause to the permissible effluent loads applied to the coastal areas is limited, taking into account of the ratio of such additional emission loads to the total effluent loads and of the margin from the actual emission loads to the target loads. In conclusion, the effect that washwater from scrubbers causes to the permissible effluent standards upon the target coastal areas is signigficantly limited.

5．Conclusions

This EIA was performed to evaluate both short- and long-term environmental risks caused by discharge water from scrubbers (EGCSs) to the marine environment and the marine aquatic organisms through following methodologies:

Methodology applied to evaluate short-term environmental risks:
- Fate (dilution ratio) on washwater from scrubber after overboard discharge (See Chapter 2)
- WET testing of the discharge water and the environmental short-term risks on the marine aquatic organism (See paragraph 3.1)
- changes in pH of discharge water from scrubbers following dilution with seawater (See paragraph 3.2)
- changes in seawater temperature following discharge of washwater from scrubbers (See paragraph 3.3)

Methodology applied to evaluate long-term environmental risks on the assumption that all ships will be equipped with scrubbers:
- WET testing and the environmental long-term risks to the marine aquatic organism (See paragraph 3.1)
- additional accumulated concerntration of the target substances which may pose unacceptable risks to the quality of water of Japanese coastal areas (See Chapter 4)

As a result of the above-mentioned EIA, it was concluded that the risks either to the marine environment and the marine aquatic organisms are in the acceptable range.

It should be noted that doing the assessment of long-term environmental risks, it was assumed that all existing domestic and international ships are installed with open-loop scrubbers, while actual the number of ships to be equipped with scrubbers would be limited. Among limited ships with all types of scrubbers, the number of ships which requires overboard discharge of washwater (i.e. open-loop scrubbers) is further limited. For the reasons stated above, it was further concluded that risks of discharge water from scrubbers to the marine environment and the marine aquatic organism are negligible from short- and long-term perspectives.

Appendix

The members of the expert board
for the environmental impact assessment
of discharge water from Scrubbers.

Chairman   Prof. Jirou Koyama, Kagoshima University

Members   Prof. Takashi Ishimaru, Marine Ecology Research Institute

Prof. Koji Takasaki, Kyusyu University

Dr. Chiori Takahashi, National Maritime Research Institute

Mr. Toshiyuki Matsumoto, ClassNK

Prof. Yutaka Michio, Tokyo University

Dr. Kazuyo Yamaji, Kobe University

Affiliated Ministries[12]

Ministry of Land, Infrastructure, Transport and Tourism

Ministry of Environment

Ministry of Agriculture, Forestry and Fisheries / Fisheries Agency

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[12] List of participants from the Ministries indicated in the Japanese version is omitted.