Onboard Water Quality Monitoring System EG-100 for Ships

Kiichiro TOMIOKA
Yuta HASHIMA

Environmental regulations are getting stricter every year, and the exhaust gas emission from ships is no exception, although until recently maritime regulations have lagged behind those for automobiles due to their multi-jurisdictional “borderless” nature. Meanwhile the IMO (International Maritime Organization) has decided to enforce NOx and SOx regulations globally, including environmental measures in which the sulfur content of fuel oil shall be limited to 0.5% or less starting in the year 2020 as part of the SO_x regulations. Although compliance to this regulation is possible using a low-sulfur fuel, an alternative method for compliance while continuing to use current high-sulfur fuel is to install a scrubber device on the ship that cleans the exhaust gas. The washwater from the scrubber is also subject to this regulation as it is discharged outside the ship into the open sea after being processed. We developed a device to monitor the water quality of this process and have begun selling it. This article introduces the product features as well as our business model.

Keywords NO_x regulation, SO_x regulation, Scrubber, Washwater monitoring, pH, PAH, Turbidity

Introduction

Various international conventions are applied to ships that sail on the high seas. Major international conventions include SOLAS (International Convention for the Safety of Life at Sea), the International Convention on Load Lines (1966), and MARPOL 73/78 (International Convention for the Prevention of Pollution from Ships, 1973 as modified by the Protocol of 1978). These international conventions have been discussed and negotiated by the IMO (International Maritime Organization, a specialized agency of the United Nations).

There are five committees under the IMO, of which the MEPC (Marine Environment Protection Committee) is responsible for the technical standards related to the marine environment. Maximum limits for the nitrogen oxide (NOx) in exhaust, and the sulfur content of fuel oil, have been phased in over the years, under Annex VI, Regulations 13 and 14 of the MARPOL Convention. The permitted maximum limits are shown in **Figure 1**.

NOx Emission Control Areas (NECA) and SOx Emission Control Areas (SECA) were established and regulations are being gradually strengthened. As regards to SOx regulations, it was decided that the sulfur content of fuel oil shall be limited to 0.5% or less in open sea areas from 2020 onward. Right now ship owners, shipbuilders, and environmental equipment engineering companies are considering what measures to take. Current measures to meet NOx regulations include EGR (Exhaust Gas Recirculation) and SCR (Selective Catalytic Reduction). The implementation of these measures is affected by the price difference between compliant fuels and Heavy Fuel Oil C, which is why more and more ship owners are looking towards installing scrubbers as a way to comply with SOx regulations.

NOx Reduction Technology

NOx abatement devices can be roughly divided into two categories.

1. EGR Systems: Exhaust Gas Recirculation (EGR) reduces NOx generation by lowering the combustion temperature through recirculation of exhaust gases into the charge air.
2. SCR Systems: A system in which an aqueous urea solution is sprayed into the hot exhaust gas converting NO_2 into nitrogen gas (N_2) and water (H_2O) by catalytic reaction to reduce the amount of NOx emissions.

SOx Reduction Technology

This technology uses a wet scrubber that injects fresh water or seawater into the exhaust gas to absorb the SOx. With this method, it is possible to remove about 98% of the SOx present in the exhaust gas, achieving a reduction that is equivalent to using a low-sulfur fuel. The scrubber’s washwater circulation method can be classified into the following three methods; which is adopted depends on the regulations imposed at the harbors or along the route that the ship sails.

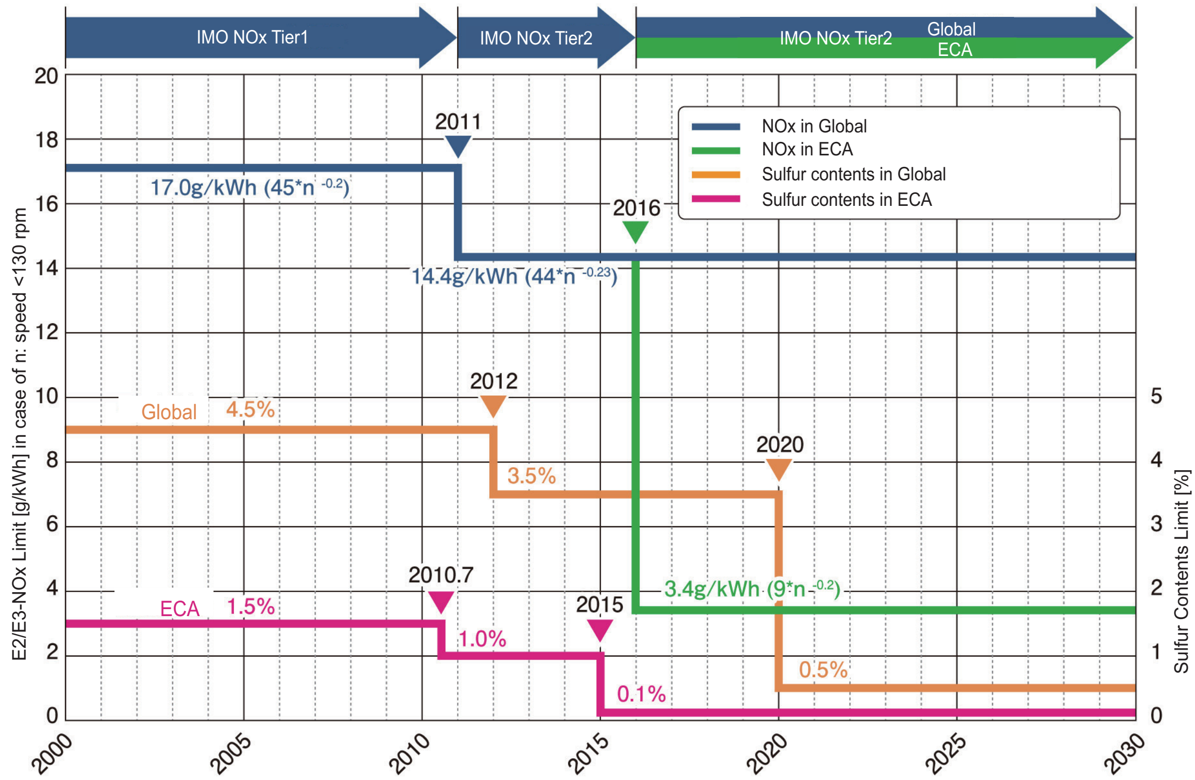


Figure 1 Emission regulations of IMO

Open loop system

The flow is depicted on **Figure 2**. This is the most common type of scrubber for ships. It cleans the exhaust gas using seawater, and discharges the washwater back into the sea. When the natural alkalinity of the seawater is low, sufficient desulfurization performance may not be obtained. This system is only effective if the seawater is alkaline. This system is only effective if the seawater is alkaline. Also, due to washwater discharge limitations set by local or regional regulations, discharge is not allowed in prohibited areas. In either case, it would be necessary to switch to a low-sulfur fuel when sailing through those areas. Water quality monitoring devices need to be installed on the intake side and the discharge side of the scrubber.

Closed loop system

The flow is depicted on **Figure 3**. Fresh water or seawater inside the ship is used as the washwater, which is then circulated. In circulation, the water needs to be neutralized by sodium hydroxide (NaOH). Water treatment system is necessary for the washwater to be discharged into the environment. Water quality monitoring devices need to be installed on the scrubber's intake side as well as the discharge side.

Hybrid system

This type of scrubber allows switching from an open loop to a closed loop system, and vice versa. It is usually operated as an open loop, and switched to a closed system when sailing through areas where washwater discharge is prohibited. Use of the hybrid

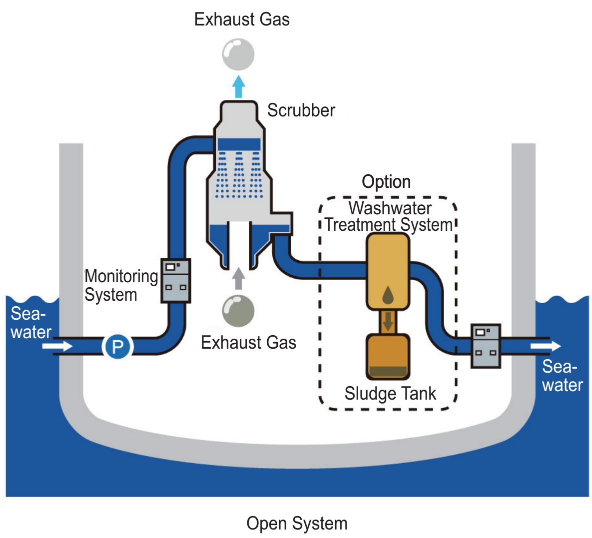


Figure 2 Open loop scrubber system

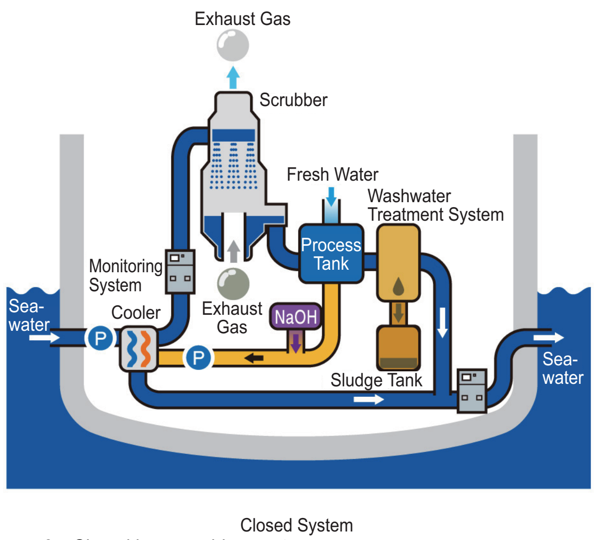


Figure 3 Closed loop scrubber system

Figure 4 Scrubber appearance

Figure 5 Installation on board

type scrubber system has been increasing over recent years due to the expansion of areas where washwater discharge is prohibited. Scrubber installation examples are shown on **Figure 4**. The scrubber is installed on the left side of the main chimney marked with a white circle.

The regulatory parameters are shown on **Table 1** [1] The pH, PAH (Polycyclic Aromatic Hydrocarbons), turbidity and temperature need to be measured and recorded continuously when discharging washwater. The strict emission control values are defined for pH, PAH and turbidity.

Table 1 Scrubber overview

Parameters	Regulation requirement	Notes
pH	pH (Discharge) ≥ 6.5 (pH of discharge water not less than 6.5) or pH (Intake)-pH (Discharge) ≤ 2 (Maximum difference between inlet and outlet of 2pH) or pH (Discharge) ≥ 6.5 (4 m from a discharge point)	Maneuvering or in transit
PAH	Depending on washwater flow rate Examples, 45t/MWh: 50μg/L 90t/MWh: 25μg/L	Total volume control
Turbidity	not be greater than 25 FNU (Formazin Nephlometric Units) or 25 NTU (Nephlometric Turbidity Units) or equivalent units, above the inlet water turbidity	Moving average for 15min.

Overview of Water Quality Monitoring System

The water quality monitoring system is part of the scrubber system, where it monitors treated water and determines whether it satisfies washwater discharge regulations or not. It therefore plays a crucial role in the operation of a ship. The requirements for water quality monitoring system as specified in the Guidelines for Exhaust Gas Cleaning Systems are as follows (**Table 2**).

Table 2 Requirements for parameters by guideline [1]

Parameters	Requirements
pH	• The pH electrode and pH meter are to have a resolution of 0.1 pH units and temperature compensation • The electrode has to meet requirements in BS 2586 or equivalent • The meter has to meet the requirements in BS EN ISO 60746-2:2003 or equivalent
Turbidity	Turbidity monitoring equipment has to meet requirements in ISO 7027:1999 (Water quality – Determination of turbidity) or USEPA 180.1 (Determination of Turbidity by Nephelometry)
PAH	• PAH measurement has to use ultraviolet light technology for washwater flow rates not greater than 2.5 t/MWh • For washwater flow rates greater than 2.5 t/MWh, fluorescence technology is to be used

Table 3 Interfering factors to measurement

Affector	Parameters	Symptoms
Bubble	pH	Abrupt change
	PAH	Unstable reading
	Turbidity	Error increasing
		Unstable reading
Dirt	pH	Slow response
		Drift
	PAH	Slow response
		Drift
		Error increasing
	Turbidity	Drift
Seawater	pH, PAH, Turbidity	Increasing of organic fouling on sensors

In order to obtain the type approval certificate, it is necessary to pass the required environmental, vibration and EMC tests for each classification, as well as satisfy IMO guidelines. EG-100 is certified by Class NK, planning to apply for other classes.

The onboard installation status is shown in **Figure 5**.

Business Characteristics

Unlike ordinary businesses, the maritime industry involves many different stakeholders—ship owners, shipbuilders, engineering companies, ship operating companies, the classification society in each country, and the flag country that a ship belongs to. Ships are subject to regional and local regulations. Once a monitoring system is installed onboard, it moves between Asia, Europe, South America, and North America, borderlessly. Products therefore must always offer stable performance, easy daily maintenance, and reliability in a range of tough environments. There are rules specific to shipbuilding, such as the necessity for commissioning at dock and sea trials, which are special tests to prove the seaworthiness of the vessel. Added to that, there are cases where years can elapse between the ordering of construction and the delivery of a ship.

Challenges of Continuous Measurement

System data is monitored to proof compliance with environmental regulations and is therefore critical for ship operation and environmental protection. However, there are many interfering factors in the sample, which may affect each sensor in many ways. They are listed in **Table 3**.

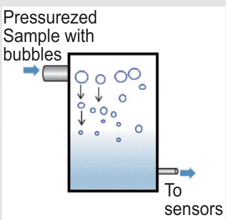
De-bubbler

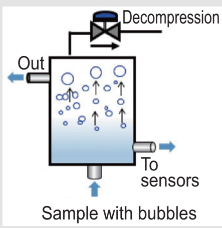
Seawater pumped up by a high pressure pump on the intake side in an open loop system, as well as washwater sprayed in the scrubber, contain a large amount of fine bubbles that need to be dealt with. Different de-bubbling countermeasures were tested, and the results are compared on **Table 4**.

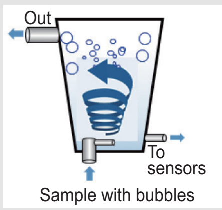
For the water quality monitoring device we adopted pressurized de-bubbler and ultrasonic de-bubbler (patent pending) technologies. Ultrasonic de-bubbling is a gas-liquid separation method whereby ultrasonic waves generated from an ultrasonic transducer create high-pressure and low-pressure areas in a liquid; in the low-pressure areas dissolved gasses and fine bubbles expand to become large bubbles which then rise to the surface and are eradicated. The de-bubbling chamber equipped with ultrasonic transducer is optimized for scrubber intake by taking into consideration various physical factors such as the position of the intake, drainage of the de-bubbled water, the

Table 4 Comparison of de-bubblers

Characteristics \ Methods	Pressurized	Decompression	Cyclone	Ultrasonic
Continuous Measurement Availability	YES	N/A	YES	YES
Flow Rate Affection	YES	N/A	YES	NO
Residual Bubble Affection	YES	YES	YES	NO
Downsizing Of De-bubbler Chamber	YES	NO	NO	YES







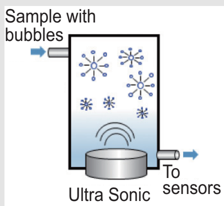


Figure 6 pH sensor

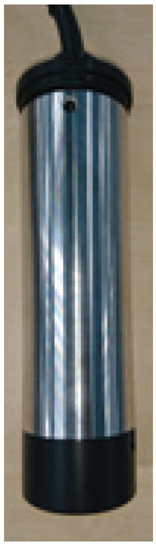


Figure 7 Turbidity sensor

location of the transducer, as well as the diameter and length of the chamber itself. The de-bubbling time is much shorter than with other methods, and it is suitable for continuous measurement as fluctuations in flow rate affect it only minimally.

Anti-fouling countermeasures

In an open loop system the water being measured will essentially be seawater, therefore requiring measures to prevent the accumulation of organic matter inherently present in the water. By contrast, closed loop systems require countermeasures against soot and oil contamination. The sampling line within the device employs a line cleaning function to clean the line at any time, thereby preventing the accumulation of organic matter inside the sampling line or on the sensor. The pH/PAH sensor adopts know-how gained over the years in developing ultrasonic cleaning devices for land-based facilities, and the turbidity sensor adopts wiper cleaning whose effectiveness has also been proven in plants on dry land.

Challenges of Each Sensor

pH sensor

Seawater is a liquid with a high ion concentration.

The pH electrode leaks a small amount of internal solution during use. When the KCl concentration of the internal solution is thinned due to prolonged use, its concentration becomes lower than seawater. This may lead to contamination of the internal solution through the liquid junction. In order to measure seawater over the long term with high stability, a gel capable of supersaturating the internal solution for a KCI concentration of 4mol/L or higher was used. This eliminated the need for daily replenishment of KCI, therefore greatly improving maintainability. pH senor is shown in **Figure 6**.

Principle : Glass electrode method
Measuring range : 1-11pH
Internal liquid : Hydrophobic polymer gel supersaturated potassium chloride
Wetted part material : Glass, PVDF, PE
Cleaning system : Ultrasonic cleaning system (Option)

Turbidity sensor

In a closed loop system, the sample turns black, which severely influences the turbidity meter and narrows the measurable range. We therefore developed a sensor that is less susceptible to black sample influence.

The turbidity sensor is shown in **Figure 7**.

Principle : 90 degree scattering method
Measurement range : 0-500 FNU
Measuring wavelength: 850nm
Wetted part material : PVC, POM, EPDM, NBR, Ti, FKM
Cleaning system : Wiper cleaning system

PAH sensor

PAH (Polycyclic Aromatic Hydrocarbons) constitute the oil components contained in heavy oil, and is the generic term for 16 components defined by the EPA (Environmental Protection Agency). The PAH sensor measures one component, phenanthrene, among them as a surrogate. Phenanthrene emits fluorescence at 360nm with an excitation wavelength of 254nm. By measuring this fluorescence intensity, the total PAH concentration is determined.

Solubility of Phenanthrene is too poor as to allow preparation of PAH calibration solutions with water only. We therefore prepared a pure water-based standard solution by dissolving the phenanthrene with an organic solvent. As a result, the standard solution is highly volatile and therefore extremely difficult to prepare and use in the high-temperature high-humidity

Figure 8　PAH Probe

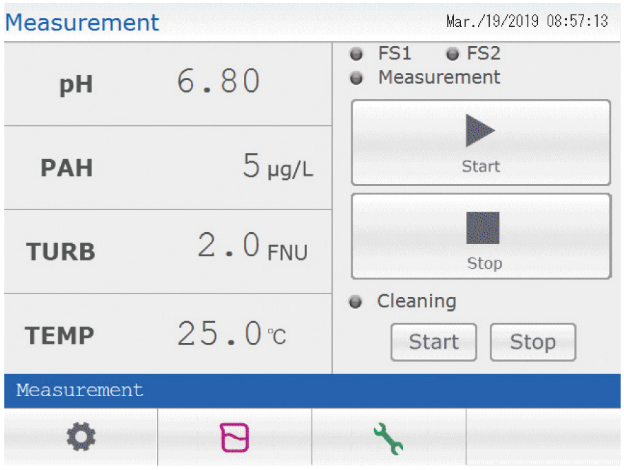


Figure 9　Operation panel

environment of a ship. A system that allows easy calibration and checking even onboard a ship is what is most needed, and such a system that will allow a ship's crew to easily calibrate and check is currently being developed (patent pending).

To facilitate calibration onboard of ships, a fluorescent glass is used which shows fluorescence at the same wavelengths as phenanthrene. Beforehand, the fluorescent glass is calibrated against a phenanthrene standard in a landbased laboratory, enabling calibration onboard ships without the need for phenanthrene standard solutions. Due to photo bleaching and thermal decomposition, organic fluorescent materials are not generally good choices for reference materials for PAH sensors. However, fluorescent glass (inorganic material) is not affected by these factors and is therefore very suitable for use onboard ships. A traceable photo sensor is embedded in the reference sensor. The assigned value of the fluorescent glass with the standard solution by this reference sensor is also traceable. Therefore, when calibrating the sensor, it is possible to use fluorescent glass as well as the standard solution. The PAH sensor is shown in **Figure 8**.

Principle : Fluorescence spectroscopy
Measurement range : 0-50µg/l, 0-500µg/l, 0-5000µg/l
Measuring wavelength : 254nm (excitation),
360nm (fluorescence)
Wetted part material : POM, Ti
Cleaning system : Ultrasonic cleaning system (Option)

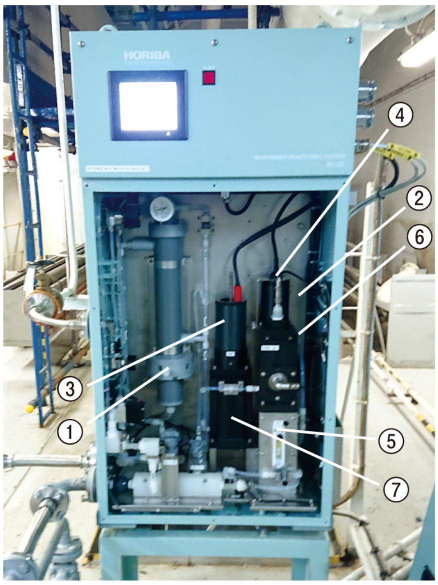


Figure 10 Internal structure

Table 5　The functions of icons

Icon	Function	Description
	Settings	Display setting screen
	Calibration	Display calibration menu screen for each sensor
	Maintenance	Display maintenance screen
Start	Measurement Start	Start measurement sequence
Stop	Measurement Stop	Halt measurement, wait for next measurement start
	Alarm	Displayed when alarm activated

Table 6 Product Specifications EG-100

General description	Name of unit	EG-100-SI (Inlet line)
		EG-100-SO (Outlet line)
	External dimension	600 (W) × 400 (D) × 1700 (H) mm except for protruding object
Measurement condition for EG-100-SI	Sample condition	0.1 MPa – 0.4 MPa 3 L/min for supply
	Fresh water line*1	0.1 MPa – 0.7 MPa 3 L/min for supply
Measurement condition for EG-100-SO	Sample condition	0 – 0.1 MPa 3 L/min for supply
	Fresh water line*1	0.1 MPa – 0.7 MPa 3 L/min for supply
Connection	Sample in line	JIS10K25A
	Sample out line	JIS5K25A
	Fresh water line	JIS5K15A
Measurement item	pH specification	1 – 11 pH (with temperature compensation)
	PAH specification	select a range from 0 – 50/500/5000 μg/L
	Turbidity specification	0 – 500 FNU
	Temperature specification	0°C – 100°C (sample temperature 0 – 40°C)

*1 Before connecting fresh water supply to the cabinet, confirm flushing the pipe line for removing rust and piping scale in advance.

Operation panel

Figure 9 shows the default screen of the operation panel.
Icons are used to depict functions, enabling intuitive operation even by crew who are not accustomed to using measuring system.
A list of icons is shown in **Table 5**.

Product specifications

The **Table 6** shows the product specifications.

Internal structure

The internal structure is shown in **Figure 10**.

① De-bubbler (Ultrasonic transducer on lower end)
② pH sensor
③ PAH sensor
④ Turbidity sensor
⑤ Flow meter
⑥ Holder (Turbidity & pH)
⑦ Holder (PAH)

Implementation assessment data

It is currently difficult to evaluate the continuous operation of the monitoring device since, until 2020, the scrubbers onboard ships will not be fully running unless they enter a designated area. With the cooperation of the Port and Airport Research Institute as well as Tokyowan Ferry, we have been able to carry out continuous measurements using seawater by installing monitoring devices on their ferry that operate between Kurihama in Kanagawa Prefecture, and the port of Kanaya in Chiba Prefecture.

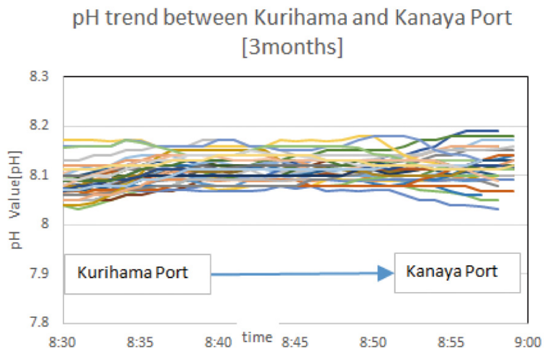


Figure 11 Trend chart on pH

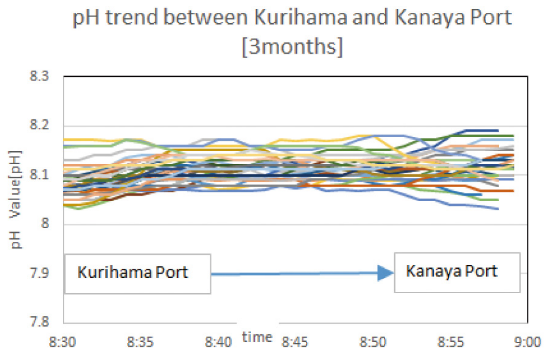


Figure 12 Trend chart on PAH

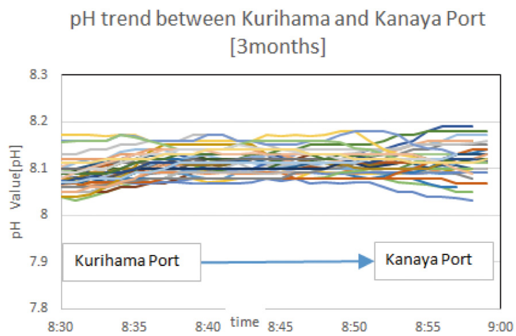


Figure 13 Trend chart on Turbidity

The data for recent three months period is shown in **Figures 11-13** below.

The pH meter shows what is commonly considered to be the pH of the sea water, and is measured at a stable level. Slight changes are seen when the ship docks or sets sail (**Figure 11**), compared to normal navigation, as the turbidity meter picks up changes as the ocean floor becomes shallower and the ship's propellers agitate sludge from the seabed at the time of docking and departure (**Figure 12**). The PAH sensors show stable readings around 5 ppb (**Figure 13**).
Performance checks were performed periodically, but by virtue of the cleaning mechanism, no adhesion of organic matter on the sensor nor deterioration in sensitivity occurred, thereby yielding stable readings.

Conclusions

Water Quality Monitoring System, EG-100 is a product aiming at long-term stable operation, enhancement of functions (de-bubbler, cleaning system) and improvements of usability and maintainability (intuitive understanding of control pane, gel type inner solution and calibration system by fluorescent glass) under conditions where stable measurements are difficult. These functions are believed to contribute to the stable operation of the scrubber and to allow meeting compliance with ship regulations.

HORIBA will strive to increase the value of its brand in the ship business by rising to the challenge in new industries and boosting added value in ways that no other company can.

Acknowledgements

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[1] Class NK Guidelines for Exhaust Gas Cleaning Systems (Ver.3) October 2018

Kiichiro TOMIOKA
Water Business Promotion Office
HORIBA Advanced Techno, Co., Ltd.

Yuta HASHIMA
Global Development
HORIBA Advanced Techno, Co., Ltd.

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