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Comparative Economic Analysis on SOx Scrubber Operation for ECA Sailing Vessel

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Abstract : *The IMO (International Maritime Organization) has mandated the restriction of SOx emissions to 0.5 % for all international sailing vessels since January 2020. And, a number of countries have designated emission control areas for stricter environmental regulations. Three representative methods have been suggested to cope with these regulations; using low-sulphur oil, installing a scrubber, or using LNG (Liquefied Natural Gas) as fuel. In this paper, economic analysis was performed by comparing the method of installing a scrubber with the method of using low-sulphur oil without installing additional equipment. We suggested plausible layouts and compared the pros and cons of different scrubber types for retrofitting. We selected an international sailing ship as the target vessel and estimated payback time and benefits based on navigation route, fuel consumption, and installation and operation costs. Two case of oil prices were analyzed considering the uncertainty of fuel oil price fluctuation. We found that the expected payback time of investment varies from 1 year to 3.5 years depending on the operation ratio of emission control areas and the fuel oil price change.*

Key Words : *SOx, Scrubber, Retrofit, Economic Analysis, OPEX, CAPEX*

1. Introduction

Various types of air pollutants are being emitted due to combustion of fuel oils used in ships. Representative air pollutants emitted form vessels are NOx, SOx and CO_2 (IMO, 2015; Shi, 2016; Nunes et al., 2017). These substances are serious environmental destruction materials that can pollute the air environment and consequently cause harm to animals and plants on earth (Viana et al., 2014). A lot of efforts are being made internationally to solve these problems. Recognizing the seriousness, IMO has made a great effort to minimize emissions of air pollutions from ship through international committees. In accordance with MARPOL (International Convention for the Prevention of Pollution from Ships) Annex VI/Reg.14.1.3, fuel oil exceeding sulphur content of 0.5 % m/m shall be prevented from being used on all vessels engaged in international voyage since 1st January 2020 (IMO, 2016). In addition, vessels navigating the ECA (Emission Control Area) under Reg.14.4.3 of same convention have been prohibited from using fuel oil in excess 0f 0.1 % m/m of sulphur content since 1st January 2015.

Accordingly, several alternatives have been proposed to satisfy the enhanced SOx regulations (Schinas and Stefanokos, 2014; Seddiek and Elgohary, 2014; Lindstad et al., 2017). The first is use of low sulphur fuel oil with a sulphur content of less than 0.5 % m/m (Brynolf et al., 2014), the second is use of LNG fuel with no sulphur content (Acciaro 2014; Seo et al., 2016), and the third is installation of an additional SOx abatement device (Yang et al., 2012; Ulpre and Eames, 2014). For currently operated vessels, changes in the fuel propulsion system are expected to be difficult due to huge initial cost in constructing an LNG fuel service system and uncertainty about LNG fuel price fluctuations.

In fact, for the time being, the way to meet the SOx regulation in existing ships will be continuingly to use of low sulphur oil or to install SOx abatement equipment.

It is very important for ship owners to decide how to respond to SOx regulations with various methods that have been suggested (Kim and Seo, 2019). There has been a number of economic analysis of SOx scrubber installation (Gu and Wallace, 2017; Panasiuk and Turkina, 2015). However, it is difficult to find a study on retrofitting SOx scrubber for an existing vessel considering the navigation route.

In this study, we compared the efficiency of using low sulphur fuel oil versus the installation and operation of SOx scrubber to comply with global SOx regulations for an existing car carrier in international voyages. The following section 2 introduces technical information of three representative methods to cope with the SOx regulation. We also suggested plausible layouts and compared

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advantages and disadvantage of different scrubber types for retrofitting. Section 3 presents an economic analysis of SOx scrubber installation. Section 4 presents results and discussion, followed by conclusion in section 5.

2. Methods of SOx regulation response for ships

2.1 Use of low-sulphur oil

There are three types of low-sulphur oils that can be used as main fuel for ships. The first one is distillated MGO (Marine Gas Oil). The second is LSHFO (Low Sulphur Heavy Fuel Oil), which removes the sulphur component in high-sulphur oil through desulphurization facility. The third is blended oil that reduces fuel sulphur content to 0.5 % by mixing high sulphur heavy oil with high quality low sulphur oil. In order to use low-sulphur oils, appropriate measures should be taken so that the temperature of storage tank does not rise above the flash point, taking into consideration the characteristics of navigation area. However, if the temperature of distillate oil and mixed oil is too low, the wax component in fuel oil may be solidified in the fuel oil filter (CIMAC, 2015; MAN Diesel & Turbo, 2014).

2.2 Installation of a SOx scrubber

The SOx scrubber is a device that reduces total SOx component from exhaust gas through multi-layer chemical reaction after combustion of fuel oil in the engine. It is developed in two major types. One is dry type and other is wet type.

The dry type does not use any liquid, including water, during the exhaust gas cleaning process. Calcium hydroxide ($Ca(OH)_2$) is used as a reducing agent for removing SOx, and it is supplied into the SOx scrubber in the form of granules having a diameter of about 3 to 8 mm. SOx in the exhaust gas reacts with $Ca(OH)_2$ to finally produce $CaSO_4 \cdot 2H_2O$ in gypsum form, and the resulting gypsum grains are eventually discharged in land.

The wet type removes SOx by dissolving it through a chemical reaction by injecting cleaning liquid into the exhaust gas. Commonly used liquids are seawater or fresh water, and sometimes neutralizing agent is added. The SOx is dissolved and removed while spraying cleaning liquid in the passage through which the exhaust gas passes.

There are three methods for the wet type, the first is an open loop scrubber, the second is a closed loop scrubber, and the third is a hybrid loop scrubber. The open loop scrubber uses seawater as cleaning liquid to remove SOx in the exhaust gas. Seawater is discharged outboard directly after the reaction. Basically, even if SOx is absorbed, seawater is naturally neutralized by its alkalinity and satisfies the pH criterion for outboard discharge of washing water.

Although seawater is neutralized before discharge by its own alkalinity, separate diluting pumps and reductants can be used for vessels operating in waters lacking alkalinity, such as freshwater areas. Fig. 1 shows a schematic diagram of an open loop scrubber.

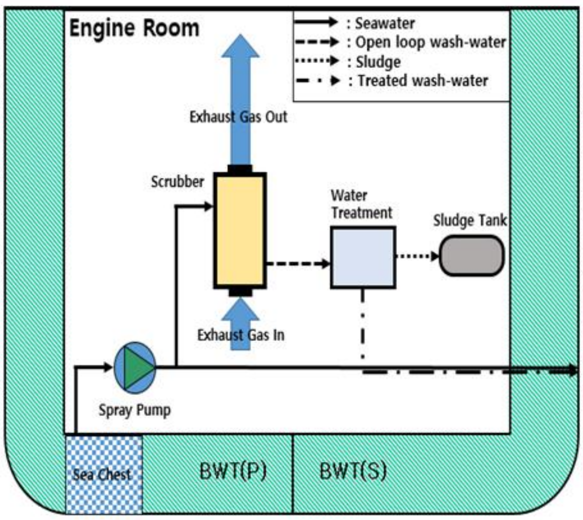

Fig. 1. Schematic diagram of an open loop scrubber.

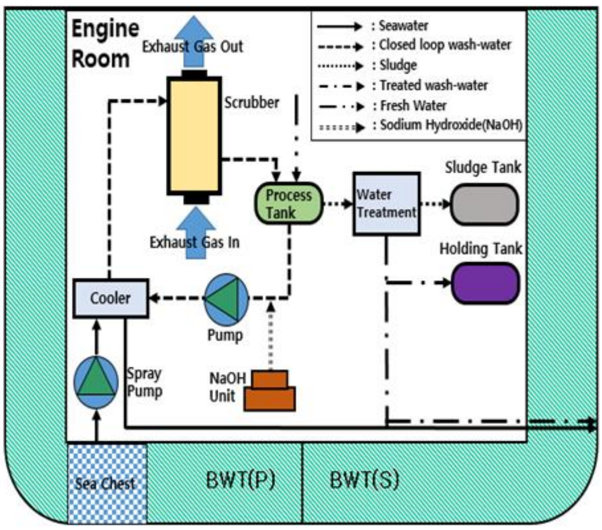

Fig. 2. Schematic diagram of a closed loop scrubber.

The closed loop scrubber uses clean water stored in the vessel as a wash solution for SOx removal. In this type, seawater is used for the purpose of cooling fresh water. Since there is no influence of pH concentration of seawater, it can be used in all waters.

The fresh water used for SOx removal is advantageous in that it can be used without being discharged overboard as it is neutralized with NaOH. However, since the neutralizing agent must be purchased and stored on the vessel, there is a fixed cost in terms of OPEX (Operating Expenditure). Fig. 2 shows a schematic diagram of a closed loop scrubber.

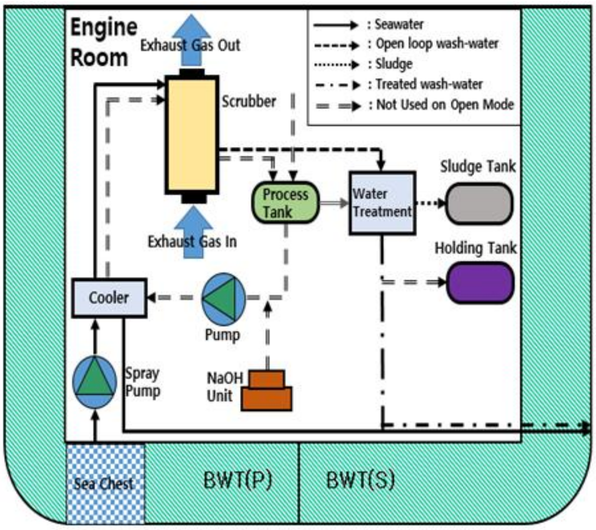

Fig. 3. Hybrid type scrubber in open loop operation.

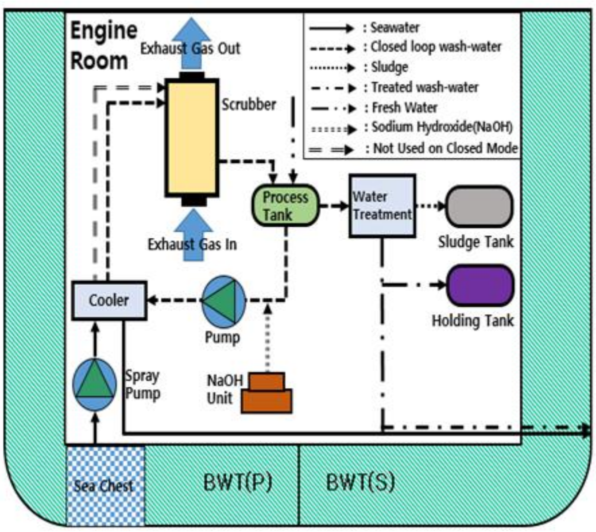

Fig. 4. Hybrid type scrubber in closed loop operation.

Hybrid scrubber can be used both open loop and closed loop as required, and can get all the advantages of each type. If the alkalinity of seawater is insufficient, or if the discharge water is regulated in some areas, the closed loop system can be used to remove SOx from the exhaust gas and satisfy the discharge requirements. If the alkalinity of seawater is sufficient and the pH regulation of discharge water is satisfied, the use of NaOH and fresh water stored on board can be reduced to minimize the operation and maintenance cost by using the open loop system.

Fig. 3 and 4 show the system configuration according to the usage of open loop and closed loop of hybrid type scrubber. To analyze the efficiency regardless of navigation route characteristics, installation of hybrid type scrubber was considered in cost analysis.

2.3 Installation of LNG fuel supply system

LNG is an environmentally friendly fuel that can reduce NOx, SOx and CO_2 emissions by 85 ~ 90 %, more than 90 %, and 20 ~ 25 %, respectively, compared to conventional marine fuel oils (Lee et al., 2015). LNG has more than 20 % higher calorific value than Bunker C, so it has a merit in reduction of the operating cost of the vessel by consuming less fuel. However, in order to supply LNG to the engine safely, it is necessary to install LNG fuel storage tank, fuel gas supply system and double wall pipes. This requires an additional investment cost up to about 20 ~ 30 % of the vessel price.

In addition, when the LNG storage tank is installed in a cargo hold, it causes a cargo loss, and additional power is required to operate the LNG propulsion system. Besides, in order to use LNG as a main fuel for ships, LNG should be safely and easily bunkered. However, since not enough LNG bunkering facilities have been build up to date, it is difficult to supply LNG cheaply and stably.

3. Economic analysis of SOx scrubber

3.1 Target Ship

In order to analyse the economy of the installation of a hybrid SOx scrubber, it is necessary to select a ship containing the ECA in its navigation route as the target ship. Therefore, we selected an international ship that travels between Korea and the United States as the target vessel. The main specifications of the ship are shown in Table 1.

Table 1. Specifications of the target ship

Item	Value
LOA (Length Overall) (m)	223
Breadth (m)	32
Depth (m)	35
Gross Tonnage (ton)	72,100

3.2 Voyage route

The main route was selected as a go and return route from Busan, Korea to New York, U.S.A. via L.A. as shown in Fig. 5 and 6. The route includes the US coast, which is ECA. In this area, low sulphur fuel should be used or SOx scrubber should be operated. Table 2 shows the operating distance in non-ECA and the ECA and the ratio of ECA in the overall route. The ship can voyage with high-sulphur fuel oil of sulfur content 3.5 % in non-ECA with scrubber operated. In the ECA, fuel oil should be converted and low sulphur fuel with a sulphur content of 0.1 % should be used, or, if a scrubber is installed, exhaust gas must be discharged through the scrubber while using high-sulphur fuel oil used in non-ECA.

Fig. 5. Voyage route from Busan to L.A.

Fig. 6. Voyage route from to L.A. to New-York.

Table 2. Information of navigation route

Navigation Route	Busan ↔ L.A.	L.A. ↔ New York	Total
Distance (NM)	5,274	4,981	10,225
ECA distance (NM)	561.5	591.2	1,152.7
ECA ration (%)	10.6	11.9	11.2

3.3 Calculation of target vessel fuel oil consumption

There are one propulsion engine and three generator engines on the target ship. The ship's operating rate is assumed to be 315days in normal voyage with NCR (Normal Continuous Rating) and 50days at anchorage in the port, and the annual fuel consumption is calculated accordingly. Table 3 shows the characteristics and SFOC (Specific fuel Oil Consumption) of main propulsion engine and generator engine. Table 4 shows the daily fuel consumption and the number of days of operation per year, reflecting the SFOC of each engine, taking into account the operating rate and fuel oil consumption.

Table 3. Engine particular

Engine	Item	Value
Main Engine	MCR (Maximum Continuous Rating, kW)	15,200
	NCR (kW)	12,920
	SFOC (g/kWh)	160.8
Auxiliary Engine	Power (kW)	1,400
	SFOC (g/kWh)	183

Table 4. Daily fuel consumption and operation schedule

Factor	Fuel oil consumption (ton/day)	Days/year
At sea	58.3	315
Harbor idling	5.82	50

3.4 Fuel oil according to area and time

In accordance with the global SOx regulations, after January 1st 2020, ships equipped with a scrubber can use high-sulphur fuel oil (sulphur content more than 3.5 % and non-equipped vessels should use only low sulphur fuel oil (sulphur content less than 0.5 %.

Furthermore, vessels navigating within the ECA should use fuel oil with a sulphur content of less than 0.1 %. Since the type of fuel oil may vary depending on the time of application, fuel oils used in the ship are classified as in Table 5.

Table 5. Types of fuel use

Factor	(Before) 31st. Dec. 2019		(After) 1st. Jan. 2020.	
	Non-ECA	ECA	Non-ECA	ECA
Without scrubber	HFO	MGO (0.1 % S)	LSHFO (0.5 % S)	MGO (0.1 % S)
with scrubber	HFO	HFO	HFO	HFO

3.5 CAPEX (Capital Expenditure) for SOx scrubber installation

It is assumed that a hybrid type scrubber is installed on the ship. The retrofitting cost includes cost of the scrubber, cost by the repair shipyard for the installation of the scrubber (structure modification, piping and accessories), and cost of design and off-hire incidents. Details of costs are shown in Table 6 (GSF, 2012). If LSHFO or MGO is used for the case where no scrubber is installed, initial cost may be incurred due to the modification of some piping and piping system, but it is not considered because it is an extremely small amount compared to installing a scrubber.

Table 6. CAPEX for hybrid SOx scrubber installation

Item	Cost (USD)
Machinery and equipment	2,600,000
Retrofitting and modification	2,400,000
Design and classification	500,000
Off-hire (20days)	17,000 (per day)
Total	5,480,000

3.6 OPEX (Operating Expenditure) for SOx scrubber

Hybrid type scrubber installed on the target ship is equipped with both open and closed loop. Additional fuel consumption for driving the cleaning water and the fuel oil consumption due to the back pressure of the exhaust gas discharged form the engine slightly increase due to SOx scrubber operation. In particular, in case of closed type, the cost of periodic consumption of NaOH for neutralization and sludge treatment is needed. In this paper, we consider all of these operating costs for analysis, since a hybrid type scrubber is selected. Table 7 shows the additional costs for operation of the hybrid type scrubber (Aminoff, 2014).

Here, the formula for sludge formation are as follows.

(1) $SO_2 + 2NaOH \rightarrow Na_2SO_3 + H_2O$

(2) $SO_2 + NaOH \rightarrow NaHSO_3$

Since SFOC is 160.8g/kWh as in Table 3, the sulphur content is 5.6 g/kWh (3.5 %). Then, the amounts of sludge production are 22 kg/MWh Na_2SO_3 for formula (1) and 18 kg/MWh $NaHSO_3$ for formular (2). We used averagely 20 kg/MWh for sludge production rate in this study.

Table 7. OPEX for hybrid SOx scrubber

Considerable Item		Value
Aux. engine additional fuel oil consumption	Sea (ton/day)	0.8
	Harbor idling (ton/day)	0.2
NaOH for neutralization	Consumption (ℓ/MWh)	17
	Cost (USD/m^3)	400
Sludge handling	Production (kg/MWh)	20
	Handling cost (USD/ton)	290

3.7 Fuel oil price

Fuel oil prices are one of the most influential factors in economic analysis, and are also the most difficult to forecast. Considering the difficulty in predicting fuel oil price fluctuations and their impact on the results, the analysis is done by applying two cases of fuel oil prices as shown in Table 8 (Clarksons research, 2017; Ship & Bunker; 2017; Bunkerworld, 2017).

Table 8. Cases of fuel oil prices

Factor	Case I (USD/ton)	Case II (USD/ton)
HFO (more than 3.5 % S)	250	450
LSHFO (0.5 % S)	420	650
MGO (0.1 % S)	450	700

4. Results and discussion

Basic data on the economic analysis are provided in section 3 based on the use of SOx scrubber and the use of low sulphur fuel oil. Based on this information, we estimated payback time of the SOx scrubber device through economic analysis. To compare payback time, NPV (net present value) was estimated by applying the following equation.

$$NPV = \left\{ \sum \frac{(B_{ECA} + B_{nECA} - OPEX)}{(1 + \frac{i}{100})^{year}} \right\} - CAPEX \quad (1)$$

Where, B_{ECA} is Benefit form using HFO instead of MGO in ECA. B_{nECA} is Benefit from using HFO instead of LSHFO in non-ECA. i is interest rate (5 %).

In addition, the following conditions were assumed to carry out the study.

1) Percentage of the target vessel operation in ECA : 11, 50 and 100 %

2) Beginning of global SOx regulation : 1st. Jan. 2020

3) Time of installation of the scrubber : 1st. Jan. 2020

The payback time for SOx scrubber installation was estimated for case I and II considering uncertainty about the fluctuation of fuel oil price based on information on the navigation route, fuel consumption, installation cost, operating expenses. Fig. 7 shows the payback time and benefits according to the operating rate of ECA based on the oil price of case I. If the ship operates only in ECA, payback time is less than one year. For ECA voyage rates of 50 % and 11 %, payback times are about 2 and 3.5years, respectively. For case I, return on the initial investment cost and the benefits that can be rained over a 10year period are more than 7, 10 and 15 million USD for ECA voyage rate of 11, 50 and 100 %, respectively. The results of case II is presented in Fig. 8. As the prices of fuel oils increase, it can be seen that the payback times are faster and the expected benefits are greater for all ECA operating ratios.

In this study, the age of ships, failure and maintenance cost of various devices during operation of SOx scrubber are not taken into consideration. And, there still remains the uncertainty on fuel oil price fluctuation according to global SOx regulations.

However, it can be seen that the higher the operating rate of ECA, the faster the payback time of installing a SOx scrubber. It is found that the installation of a SOx scrubber is advantageous and can lead to faster payback time and greater benefits as the fuel oil price rises.

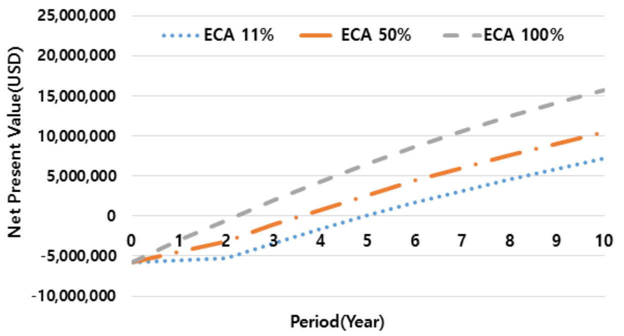

Fig. 7. Payback time and benefit based on the oil price case I.

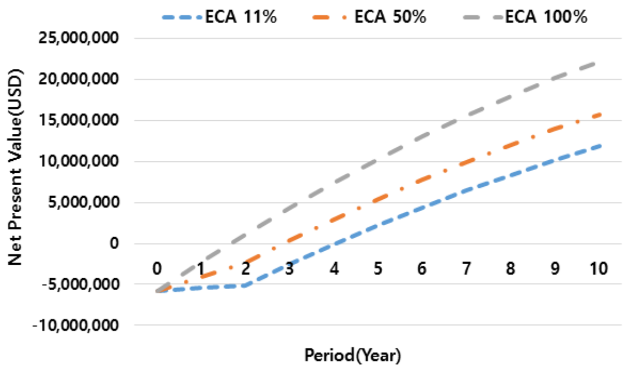

Fig. 8. Payback time and benefit based on the oil price case II.

5. Conclusion

In this paper, we presented various methods proposed to cope with SOx regulations for international sailing vessels, and provided information on their advantages and disadvantages. In particular, the technology for installation and operation of three types of the scrubber has been described and compared in detail. Among these various methods, economic analysis was performed by comparing the installation of a hybrid type scrubber with using the low-sulphur oil without installing the other devices. We estimated payback time and benefits considering the route, fuel consumption, CAPEX, OPEX, fuel oil price for an international voyage ship. As results of the analysis, it was confirmed that the expected payback time of the investment varies from 1 year to 3.5 years depending on the operation ratio of emission control areas and the fuel oil price fluctuations. As the target vessel modification, variations of many factors such as ship type, age, route should be considered.

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