Origin of NOx emission from ships inside major bays in Japan

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ABSTRACT

The amount of NOx emission from ships inside the major bays in Japan, i.e., Tokyo Bay, Osaka Bay and Ise Bay, are analyzed and the strategies in the reduction of NOx emission are discussed. Normally each ship has three sources of NOx emission, i.e., main engine, auxiliary engine and auxiliary boiler. Since wide range of ships are in operation in these bays, each of the ships are categorized in 4 ranks by the size of each ships. The amounts of NOx emission from each source and each rank of ships are estimated separately and compared with each other to understand the origin of NOx emission inside these bays.

From the systematic calculations, it was explored that more than half of the amount of NOx was emitted from the auxiliary engines during the anchorage period. Especially the influence of the NOx emission from auxiliary engines of larger sized ships of rank 4, the largest category, is the largest. This should be mainly due to the longer anchorage and cargo work time necessary for handling the larger amount of cargo of larger sized ships. On the other hand the NOx emission from main engines is mainly emitted from the small sized ships of rank 1. Same tendencies are obtained through the NOx emission calculations of three major bays in Japan. From these results, it is suggested that the usage of land electricity in larger sized ships is effective in the reduction of NOx emission in major bays.

Key words: *Emission, NOx, Ship, Main engine, Auxiliary engine.*

1. INTRODUCTION

To maintain air quality and to preserve both of global and regional environment, the reduction of pollutant emissions from ships should be one of the key issues [1]. From this point of view, the stringent regulations for NOx and SOx emissions from ships were proposed in MEPC, Marine Environment Protection Comittee in IMO, and are in effective now. The final stage of NOx regulation of Tier 3, 80 % reduction in NECA, NOx Emission Control Area, will be in effective from January 1, 2016.

Before the discussions of pollutants regulations, to assess the influence of the pollutants from ships on environment, especially for the environment of coastal area, the committee of Marine Air Pollution, MAP, was organized in 1992 at Marine Engineering Society in Japan, MESJ, with the financial support from the Environment Agency, the government of Japan. To evaluate this influence, the committee gathered a number of data concerning the actual conditions of ship operation in major bays and evaluated the emission level of air pollutants and found that the influence of the emissions from ships are one of the dominant factors [2],[3].

Normally each ship has three sources of NOx emission, i.e., main engine, auxiliary engine and auxiliary boiler. Since wide range of ships are in operation in the major bays, each of the ships are categorized in 4 ranks by the size of each ships. The amounts of NOx emission from each source and each rank of ships are estimated separately and summed up to know the total amount of NOx emission. In the report of MAP, the total amount and the influence on the environment of coastal area are mainly discussed and the breakdown of the each emission sources and ship size was not discussed in detail. Therefore, to understand the origin of NOx emission inside the major bays in Japan, the authors recalculated the amount of NOx emissions from each sources and each ranks of ships and compared each other.

2. CALCULATION PROCEDURE OF THE AMOUNT OF NOx EMISSION

To calculate the amount of NOx emission from ships inside the major bays, i.e., Tokyo Bay, Osaka Bay and Ise Bay, the routes to and from the major ports in the bay has to be modelled and the emission factor has to be defined for each of the emission sources, i.e., the main engines, the auxiliary engines and the auxiliary boilers. The major part of the calculation procedure is summarized in this section, which is a same procedure proposed and developed in the activity of MAP [2].

2.1. Definition of the calculation area

2.1.1 Tokyo bay

The calculation area of the Tokyo Bay was defined as the northern part of the line connected between Kurihama of Kanagawa prefecture and Kanaya of Chiba prefecture. The area of about 70 km in the eastern and western direction and about 50 km in the northern and southern direction except the coastal and land areas was divided into a calculating mesh of about 1 km square. The volume of ships traffic and the number of ships in anchorage was estimated.

2.1.2 Osaka bay

The calculation area of the Osaka Bay was defined as the area surrounded by Osaka prefecture, Hyogo prefecture, Awaji island, the Tomogashima Channel and the Akashi Strait. The area of about 80 km in the eastern and western direction and about 70 km in the northern and southern direction except the coastal and land areas was divided into a calculating mesh of about 1 km square.

2.1.3 Ise bay

The calculation area of the Ise Bay was defined as the northern part of the Irako Channel. The area of about 100 km in the eastern and western direction and about 60 km in the northern and southern direction except the coastal and land areas was divided into a calculating mesh of about 1 km square.

2.1.4 Treatment of anchorage position and operating route

The major ports of each bay were selected and treated as the point emission sources of NOx. On the other hand, the major and typical route for each port was selected and analyzed as the line emission source. The outward and home ward routes were treated separately.

2.2. Calculation procedure of amount of Nox emission

2.2.1 Categorization of ship size

Since wide range of ships are in operation in these bays, each of the ships are categorized into 4 ranks by the size, i.e., by the gross tonnage of each ships. Each ranks are called as the rank 1, the smallest size ship category, to the rank 4, the largest size ship category, as indicated in Table 1.

Table 1. Category of ship size

Rank	1	2	3	4
Gross tonnage	under 500	500 - 5000	5000 - 10000	over 10000

2.2.2 Operation mode inside each bay

The operation mode of ships inside each bay is treated as 4 stages of Full (F), Standby Full (SF), Half (H), Slow (S) and Dead Slow (DS). The load factors of main engine for each operation mode and each ship size category are listed in table 2. Each ship enters into each bay with the operation mode of F and changed to SF, H, S and DS as closing to the port.

Table 3 shows the navigation speed of each ship size rank and each operation mode. From these data and the length of the route inside the calculation mesh, the duration of navigation in each mesh can be obtained.

Table 2. Load factor of main engine under each operation mode (the values are in %)

Mode	Rank 1	Rank 2	Rank 3	Rank 4
F	83	61	61	46
SF	68	42	30	19
H	46	32	20	14
SF	26	21	11	11
DS	17	15	8	9

Table 3. Average speed of ships under each operation mode (the values are in kt)

Mode	Rank 1	Rank 2	Rank 3	Rank 4
F	10	11	11	12
SF	8	8.5	8.5	9
H	6	6	7	7
SF	3	3	3.5	3.5
DS	2	2	2	2

2.2.3 Load Factor during Anchorage

Operations of the auxiliary diesel engines and the auxiliary boilers are considered during anchorage in the port. The load factors of auxiliary diesel engines and the auxiliary boilers are listed in the tables 4 and 5 respectively. The duration of anchorage in the port was separated for the duration for cargo handling work and the duration for non-cargo work, i.e., idling and/or waiting duration. Table 6 shows the duration of anchorage for each rank of ship size.

2.2.4 Calculation procedure

The NOx emission calculation was conducted as following procedures.

1) The average tonnage of each ship size category was calculated by using the data of the number of ships arriving in ports of each bay in one year (table 7).
2) The typical value of the rated output for each ship size category was calculated by following equations.

   Rated output of main engine:

   P = 67.45 X0.50

   Rated output of auxiliary engine:

   P = 7.18 X0.54 x 2 units

   Capacity of auxiliary boiler:

   B = 0.0267 X0.48 x 2 units

   Where X = average tonnage of each ship category (t), P = rated output (PS), B = capacity (t/h).
3) The NOx emission intensity was calculated from the following formulae of NOx emission factor with the load factor and the rated output.

   Main engine and auxiliary engine:

   N = 0.00149 P1.14

   Auxiliary boiler:

   N = 0.08 x 22.4/46 W

   Where W = 73.48 B0.41, N = amount of NOx emission (Nm3/h).
4) In the case of navigation, the amount of yearly NOx emission in the calculation cell was obtained from the average ship speed, the length of navigation route within the calculation cell, the NOx emission intensity and the number of ships passing through the navigation route.

5) On the other hand, the amount of yearly NOx emission during anchorage was calculated from the number of ships anchored in each ports, average duration of anchorage and the NOx emission intensity of the auxiliary diesel engines and the auxiliary boilers.

Table 4. Load factor of auxiliary engine (the values are in %)

	Rank 1	Rank 2	Rank 3	Rank 4
Non - Cargo work	42	47	48	52
Cargo work	54	62	56	63

Table 5. Load factor of auxiliary boiler (the values are in %)

	Rank 1	Rank 2	Rank 3	Rank 4
Non - Cargo work	50	55	50	52
Cargo work	70	61	55	60

Table 6. Duration of anchorage (hr)

	Rank 1	Rank 2	Rank 3	Rank 4
Anchorage	6.8	16.3	19.5	39.3
Cargo work	6.8	8.6	12.6	27.1

Table 7. The number of ships in each bay

Rank	Tokyo Bay	Osaka Bay	Ise Bay
1	230529	141835	68552
2	81806	69658	23113
3	7672	18738	3740
4	14038	11184	8117
Total	334045	241415	103522

3. RESULTS AND DISCUSSIONS

3.1. Amount of NOx emission in major bays

Figure 1 shows the calculated results of the amount of NOx emission in each bay. Total amount of NOx emissions in Tokyo Bay is around 37000 t/year which corresponds rather well with the results obtained by MAP. The breakdown of the total amount is around 43 % from main engine, 52 % from auxiliary engine and 5 % from auxiliary boiler, and found that the auxiliary engine is the largest emission source of NOx in Tokyo bay.

Total amount of NOx emission in Osaka bay is around 27500 t/year and the breakdown is around 38 % from main engine, 57 % from auxiliary engine and 5 % from auxiliary boiler. On the other hand, total amount of NOx emission in Ise bay is around 17000 t/year and the breakdown is around 42 % from main engine, 54 % from auxiliary engine and 4 % from auxiliary boiler. Total amounts of NOx emission in both bays are also well correspondent with the calculation results of MAP.

From these calculation results, it can be found that the characteristics of breakdown is equivalent among the major bays and the auxiliary engine emits more than half of the amount of NOx during the anchorage in the ports.

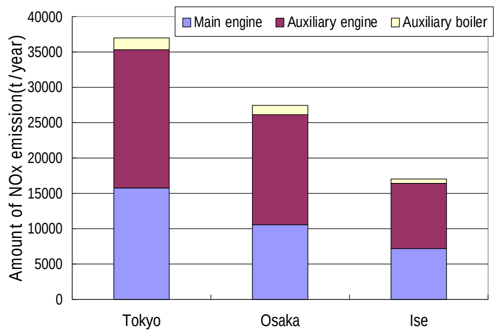

Figure 1. Amount of NOx emission in each bay

3.1.1 Amount of NOx emission in Tokyo bay

Figures 2 and 3 show the calculated results of the amount of NOx emission in Tokyo Bay. The same data are differently sorted out to see the effect of engine category in Fig.2 and to see the effect of the ship size in Fig.3. As discussed above, concerning the NOx emission from main engine, the emission from the ship size of rank 1 is the largest. This should be mainly due that the number of ships in the rank1 is extremely larger than that of larger sized ships. However, concerning the NOx emission from auxiliary engine, the emission from the larger sized ships, especially rank 4, is the largest. It is also found that the amount of emission from auxiliary boiler is very small compared with main engine and auxiliary engine.

Figure 3 shows that the amount of NOx emission from the ships of rank 4 is the largest and that from the ships of rank 1 is the 2nd largest. However the amount of NOx emission from the ships of rank 3 is extremely small mainly due to the small number of ships operating in Tokyo bay. In the case of ships of rank 1, the main engine is the dominant source of NOx emission. The reason of the small amount of NOx emission from auxiliary engine is the short anchorage duration for cargo handling. On the other hand, in the case of the ships of rank 4, the auxiliary engine is the dominant source of NOx emission.

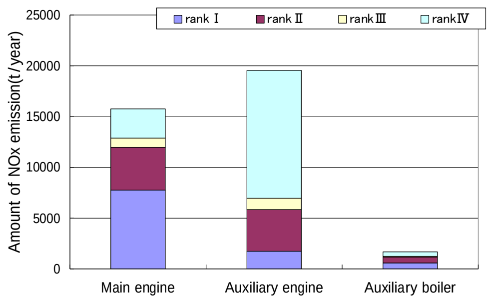

Figure 2. Amount of NOx emission of each engine category (Tokyo Bay)

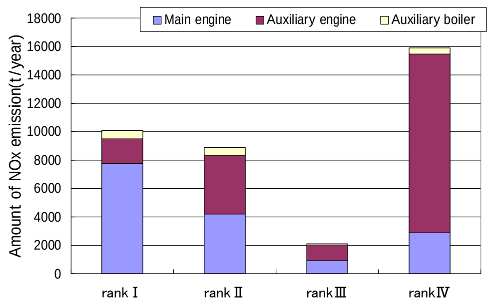

Figure 3. Amount of NOx emission of each ship size (Tokyo Bay)

This should be mainly due to the longer anchorage duration for the large amount of cargo handling.

Figure 4 indicates the effect of engine category and shows the very similar tendency with that in Tokyo Bay, i.e., NOx emission from auxiliary engine is the largest. From Fig. 5, it is found that the amount of NOx emission from the ships of rank 2 is the 2nd largest and is close to the value of rank 4. This should be mainly due to the large number of ships in rank 4 operating in Osaka bay. Similar to the case of Tokyo Bay, main engine is the dominant source of NOx emission in the rank 1 ships and auxiliary engine is the dominant source in the rank 4 ships. In the case of ships of rank 2, NOx emissions from main engine and auxiliary engine are equivalent level.

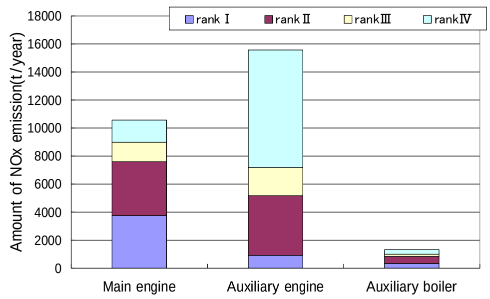

Figure 4. Amount of NOx emission of each engine category (Osaka Bay)

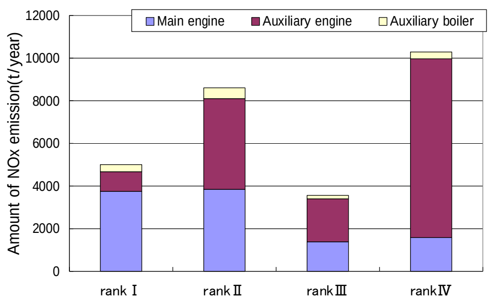

Figure 5. Amount of NOx emission of each ship size (Osaka Bay)

3.1.3 Amount of NOx emission in Ise bay

Figures 6 and 7 show the calculated results of the amount of NOx emission in Ise Bay and indicate the very similar tendency with that in Tokyo Bay and Osaka Bay. The very characteristic for Ise Bay case is the larger effect of the NOx emission from the ships of rank 4, the largest size of ships. Therefore the ships of rank 4 are the dominant source of NOx emission of auxiliary engines.

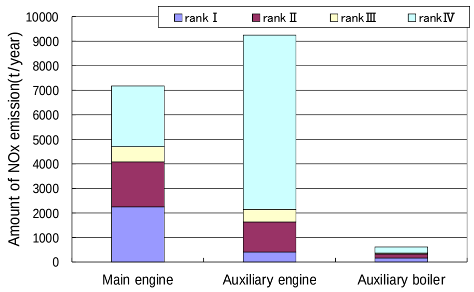

Figure 6. Amount of NOx emission of each engine category (Ise Bay)

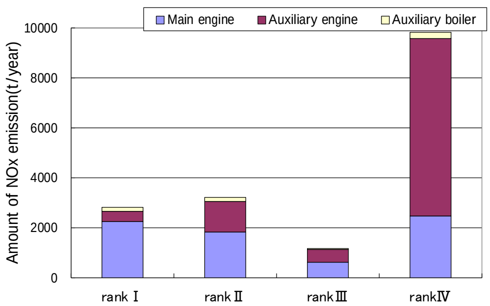

Figure 7. Amount of NOx emission of each ship size (Ise Bay)

3.2. Distributions of NOx emission intensity in major bays

The distributions of NOx emission from main engine during navigation in each bay are indicated in Figs. 8, 9 and 10 for Tokyo Bay, Osaka Bay and Ise Bay respectively. In the case of Tokyo Bay, Fig. 8, every ships passing through the Uraga channel with an operation mode of Full and the intensity of NOx emission distribution along this route is very high. Similar tendency can be found in the case of Ise Bay, Fig.10, which the NOx emission intensity around the Irako channel, the entrance of Ise Bay, is very high since all of the ships entering Ise Bay is passing through this route.

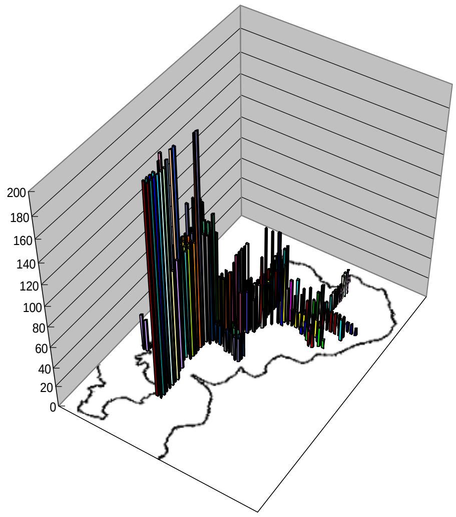

Figure 8. Distribution of NOx emission intensity in Tokyo Bay

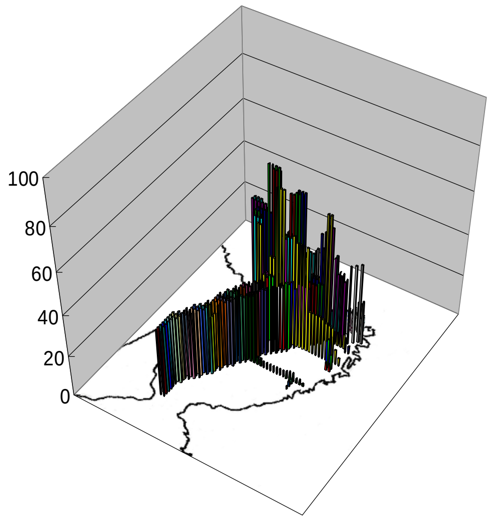

Figure 9. Distribution of NOx emission intensity in Osaka Bay

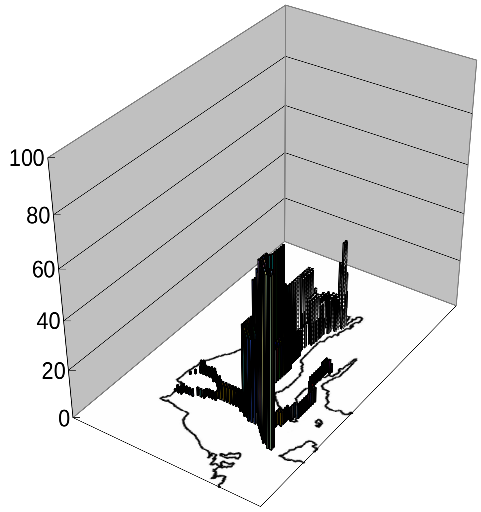

Figure 10. Distribution of NOx emission intensity in Ise Bay

On the contrary, in the case of Osaka Bay, Fig. 9, the intensity of NOx emission distribution becomes higher around the center of Osaka Bay. Since there are two routes in entering Osaka Bay, i.e., the route of Tomogashima channel and the route of Akashi strait, these two routes crossed each other around the center of Osaka Bay.

3.3. NOx reduction by the usage of land electricity

From the calculations and discussions of former sections, we found that more than half of the amount of NOx was emitted from the auxiliary engines during the anchorage period. In order to reduce the NOx emission during the anchorage period, the effectiveness of the usage of land electricity was examined in this study. Assuming that the NOx emission can be negligible during the usage of land electricity, the amount of NOx emission was calculated under following 3 conditions. 1) The ships of all ranks utilized the land electricity during the cargo-handling period and the amount of NOx emission from auxiliary engine during this period was calculated using a load factor for non-cargo handling. 2) Only the ships of rank 4 utilized the land electricity during the cargo-handling period. 3) Only the ships of rank 4 utilized land electricity all through the anchorage period and the auxiliary engines were not used.

Figure 11 shows the calculated results of the amount of NOx emission inside Tokyo Bay. In the case of condition 1, the reduction of the NOx emission from auxiliary engine is around 60%, which corresponds to the reduction of 34% in total emission. In the case of condition 2, i.e., the land electricity was used only in the ships of rank 4, it can be expected the reduction of 25% in total emission which still is an effective reduction with smaller modification. Furthermore, in the case of condition 3, i.e., the stopping of auxiliary engines of rank 4 ships and the using of land electricity, the reduction of 34% in total emission can be achieved.

The calculated results for Osaka Bay are indicated in Fig. 12. It can be found that the reductions to the total emission of around 36%, 22% and 30% can be achieved in the conditions of 1, 2 and 3 respectively. In the case of Ise Bay, Fig. 13 shows that the reductions of around 37%, 30% and 41% can be achieved. These results indicate the effectiveness of the utilization of land electricity, especially for larger ships like rank 4, to the reduction of NOx emission inside the major bays.

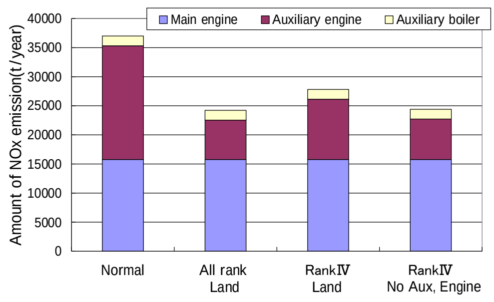

Figure 11. Reduction of NOx emission with each countermeasure (Tokyo Bay)

Land: Usage of land electricity

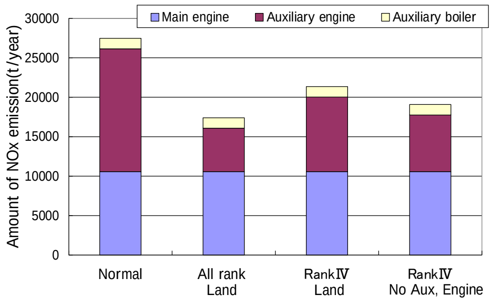

Figure 12. Reduction of NOx emission with each countermeasure (Osaka Bay)

Land: Usage of land electricity

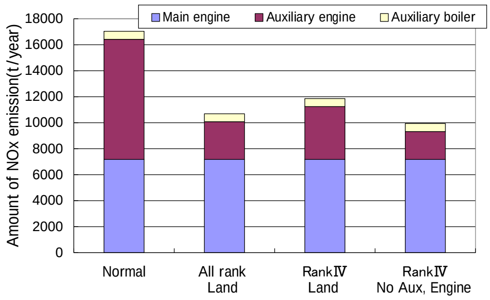

Figure 13. Reduction of NOx emission with each countermeasure (Ise Bay)

Land: Usage of land electricity

4. CONCLUSIONS

The amounts of NOx emission from ships inside three major bays in Japan are analyzed and the strategies in the reduction of NOx emission are discussed. It was explored that more than half of the amount of NOx was emitted from the auxiliary engines during the anchorage period. Especially the influence of the NOx emission from auxiliary engines of rank 4 ships, the largest category, is the largest. This should be mainly due to the longer anchorage and cargo work time necessary for handling the larger amount of cargo of larger sized ships. On the other hand, the NOx emission from main engines is mainly emitted from the small sized ships of rank 1. Same tendencies are obtained through the NOx emission calculations of three major bays in Japan. From these results, it is suggested that the usage of land electricity in larger sized ships is effective in the reduction of NOx emission in major bays.

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Nguồn gốc khí thải NO_x từ các tàu thuyền neo đậu ở các Vịnh chính của Nhật Bản

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TÓM TẮT

Lượng khí thải NOx từ các tàu neo đậu bên trong các vịnh chính tại Nhật Bản như Vịnh Tokyo, Vịnh Osaka và Vịnh Ise được phân tích và các giải pháp đề xuất giảm khí thải NOx được thảo luận. Thông thường, mỗi tàu có ba nguồn phát thải NOx bao gồm: động cơ chính, động cơ phụ và lò hơi phụ. Do có nhiều tàu hoạt động trong các vịnh này, các tàu được phân thành 4 loại chính dựa trên kích thước tàu. Lượng phát thải NOx của mỗi nguồn phát thải và mỗi loại tàu được đánh giá độc lập và so sánh với nhau để tìm hiểu nguồn gốc của khí NOx bên trong các vịnh trên.

Các tính toán phân tích cho thấy hơn 50% lượng phát thải NOx là từ các động cơ phụ trong thời gian neo đậu tại vịnh. Đặc biệt, mức phát thải NOx từ các động cơ phụ của loại tàu có kích thước lớn nhất (Rank 4) là cao nhất. Nguyên nhân chính của việc này là do thời gian neo đậu và thời gian chuyển hàng từ cản lên các tàu này lâu nhất. Nói cách khác, lượng phát thải NOx từ các động cơ chính là từ các tàu kích thước nhỏ (Rank 1). Xu hướng tương tự được tìm thấy ở các vịnh còn lại. Từ kết quả đạt được, tác giả đề xuất việc dùng nguồn điện từ cảng cho các tàu kích thước lớn nhất là giải pháp hiệu quả để giảm NOx trong các vịnh chính này.

Từ khóa: *Khí thải, NOx, Thuyền, Động cơ chính, Động cơ phụ.*

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