INVESTIGATION THE EFFECT OF SO_x EMISSION REDUCTION ON TRANSIT SHIPS EMISSIONS AS OF JANUARY 1, 2020

by

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The Istanbul Strait is one of the choke points in the international maritime trade. 44868 ships have passed through the Istanbul Strait in the last two years. These merchant ships are emitting exhaust gas emissions such as CO_2, NO_x, SO_x intensively. These pollutants also affect human health and the environment. There is a consensus among scientists that ambient concentrations of particulate matter and SO_x have negative health impacts, including asthma, heart attacks, hospital admissions, and premature mortality. In this study, the exhaust gas emissions from ships are estimated based on real ship movements, and analyses are made according to the reduction from 3.5-0.5% of the allowed sulphur content of the fuel was implemented on January 1, 2020. Firstly, Annex four which is containing the regulations imposed by the International Maritime Organization was examined, and also SO_x emission which is caused by ships passing through the Istanbul Strait was investigated. Also, a new approach to Trozzi and Vaccaro methodology was built. After, emission projections for 2030 and 2040 were made and the rate of SO_x and particulate matter were analysed.

Key words: *MARPOL, International Maritime Organization regulations, maritime traffic, emission, the Istanbul Strait, SECA*

Introduction

The International Maritime Organization (IMO) has introduced regulations to prevent air pollution from ships and implemented Annex VI to the MARPOL 73/78 Convention. The directive covers all international vessels with a tonnage of 400 GRT and larger. There are several new measures taken by IMO under Annex VI. Mainly these measures can be stated:

– Emission control areas (ECA) and sulphur emission control areas (SECA) have been declared and emissions to be generated by vessels navigating in these areas have been taken under the standard limit.
– The NO_x emitted from the ships are regulated and achieved NO_x emissions reduction through three tiers [1].
– The reduction of sulphur content in ship fuels to years is regulated by rule 14. The sulfur content in the fuel shall not exceed 0.1%. Vessels must oscillate in this sulphur emission control areas (SECA) according to these limits [2].

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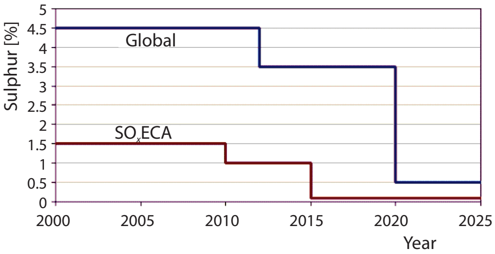

Figure 1. Marpol Annex VI SO_x limits [1]

For this reason, IMO recommends the use of marine diesel oil (MDO) within SECA. The MARPOL Annex VI SO_x limits are shown in fig. 1 [1]. Limits of SO_x in fuels requiring a maximum of 3.50% content since January 1, 2012 and 0.50% by January 1, 2020 will be implemented globally [2]. In SECA areas, ships will use the sulphur content in their fuel to zero by 2015, and for this purpose, they have to turn to zero-sulphur alternative fuels. This regulation has been implemented smoothly so far.

With all these regulations, IMO tried to take under control of the exhaust gas emission from ships which harms health and environment. A large and growing body of literature has investigated ship emissions. There is a consensus among scientists that ambient concentrations of particulate matter (PM) and SO_x have negative health impacts, including asthma, heart attacks, hospital admissions, and premature mortality [3-12].

Surveys such as that conducted by Corbett *et al*. [10] have shown that shipping-related PM emissions are responsible for approximately 60000 cardiopulmonary and lung cancer deaths annually, with most deaths occurring near coastlines in Europe, East Asia, and South Asia. Under current regulation and with the expected growth in shipping activity, annual mortalities could increase by 40% by 2012.

Eyring *et al.* [11] found that nearly 70% of ship emissions occur within 400 km of coastlines, causing air quality problems through the formation of ground-level ozone, sulphur emissions, and PM in coastal areas and harbours with heavy traffic. Furthermore, ozone and aerosol precursor emissions, as well as their derivative species from ships, may be transported in the atmosphere over several hundreds of kilometres, and thus contribute to air quality problems further inland, even though they are emitted at sea.

A study was conducted by Ozcan *et al.* [13] to find the relationship between asthma cases in Izmir and SO_x and PM. Regression analysis found a *strong* relationship between asthma cases and SO_x and PM.

Jalkanen *et al.* [14] estimated the exhaust emissions of CO_2, NO_x, SO_x, CO, and $PM_{2.5}$ originated from Baltic Sea shipping in 2006-2009. They found that the SO_x emissions in 2009 were approximately 14% lower, when compared to those in 2006, mainly caused by the fuel requirements of the SECA which became effective in May 2006, but affected also by changes in ship activity. The detrimental health effects caused by shipping exhausts are closely connected to the emissions of PM.

In this study, the exhaust gas emissions from ships are estimated based on real ship movements, and analyses are made according to the reduction from 3.5-1.0 % of the allowed sulphur content of the fuel was implemented on January 1, 2020.

Materials and methods

Maritime traffic in the Istanbul Strait

Current maritime traffic in the Istanbul Strait consists of transit ships, non-transit ships, city lines, passenger boats, sea buses, luxury boats, tugs, fishing vessels, and military vessels. Approximately 43000 transit ships are passing through the Istanbul strait every year. Figure 2 summarizes the number of transit ships passing through the Istanbul Strait for years [15, 16]. While the numbers of ships are decreasing, size and tonnage of them are increasing day by day. With the increase in size and tonnage, air pollution caused by these ships has increased in parallel. Large tonnage ships have to have larger engines to move, and these engines consume more fuel and cause more air pollution.

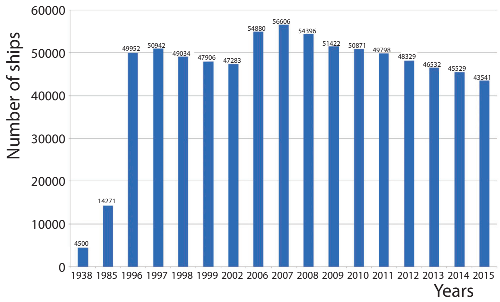

Figure 2. The number of transit ships passing through the Istanbul Strait for years [15, 16]

Trozzi and Vaccaro methodology

There are many approaches used to estimate exhaust gas emissions from ships. We used the bottom-up approaches of Trozzi *et al.* [17] methodology to calculate the transit ship traffic emissions in Istanbul Strait which is commonly used in literature.

Trozzi and Vaccaro [17-19] developed a methodology for estimating air pollutant emission from ships in a framework of a MEET project funded by the European Commission. Tables 1 and 2 list load factors of engines and the emission factors according to the modes of exhaust gas emissions. The ship emissions in the Istanbul Strait are estimated using the formulas of Trozzi and Vaccaro methodology:

$$\begin{gathered} E_i = \sum jklm \times E_{ijklm} \\ E_{ijklm} = S_{jkm}(GT) \times tjklm \times F_{ijlm} \\ S_{jkm}(GT) = C_{jkm}(GT) \times Pm \end{gathered} \tag{1}$$

Table 1. Load factors of main and auxiliary engines [19]

Ship types	Load factor of main engines [kW]	Load factor of auxiliary engines [kW]
Solid bulk	4.397	5.880
Liquid bulk	6.543	5.880
General cargo	2.555	2.120
Container	14.871	5.880
Passenger/Ro-Ro/Cargo	4.194	5.880
Passenger	10.196	5.880
High speed ferry	2.440	2.120
Tugs	2.033	2.120
Fishing	734	5.880
Other ships (military, service boats, *etc.*)	2.469	2.120

Table 2. Emission factors according to the modes of exhaust gas emissions [17]

Mode	Cruising			Manoevering			Hotelling		
Pollutant/Engine type	HSDE	MSDE	SSDE	HSDE	MSDE	SSDE	HSDE	MSDE	SSDE
NO_x	60	57	87	54	51	78	28	23	35
CO	2.8	7.4	7.4	10.6	28	28	120	99	99
CO_2	3200	3200	3200	3200	3200	3200	3200	3200	3200
VOC	1.0	2.4	2.4	1.5	3.6	3.6	28.9	23.1	23.1
PM	0.52	1.2	7.6	0.52	1.2	7.6	1.5	1.2	1.2
SO_x	10	10	54	10	10	54	10	10	54

HSDE: hıgh speed dıesel engınes, MSDE: medium speed diesel engines, SSDE: slow speed diesel engines

We needed the information of the class of ship, the type of engine, and tonnage of the ship, power of the main and auxiliary engine for calculation. With all this information's we can calculate the ship emissions (NO_x, SO_x, CO, CO_2, VOC, PM) according to the operation mode (cruising, manoeuvring, hoteling) by using the eq. (1) which is as for SO_x:

[[[[daily fuel consumption × ship tonnage] × 0.8 × the distance that ship navigated] / ship speed] / 1000] × SO_x emission factors of operation modes (cruising, manoeuvring, hoteling).

This equation gives us the real SO_x emission results for three operation modes and total emission. We calculate all types of emissions (NO_x, SO_x, CO, CO_2, VOC, PM) one by one with eq. (1).

Results and discussion

Calculating emissions from transit ships

The world fleet includes approximately 66% slow speed diesel engines, 32% medium-speed Diesel engines, and 2% other engine types [20-22]. The same distribution is used in the Istanbul Strait for transit ship emission calculations. Emissions from transit ships in the Istanbul Strait are calculated by using the eq. (1) and the results are 937017 tones per year for CO_2, 18324 tones per year for NO_x, 5,294 tones per year for SO_x, 2,138 tones per year for CO, 693 tones per year for VOC, 692 tones per year for PM. The highest levels of ship emissions were generated from solid bulk, liquid bulk, general cargo, and container, respectively. Solid bulk ships emit half of the total exhaust gas emissions in the Istanbul Strait.

A new approach to Trozzi and Vaccaro methodology

According to Trozzi and Vaccaro methodology, the average fuel consumption is calculated. When we analysed Trozzi and Vaccaro methodology, we realized that the fuel consumption part is not clear. Fuel consumption is depended on time. So, we can assume that it is a decreasing function:

$$C(t) > C(t+\varepsilon);\ \varepsilon > 0 \tag{2}$$

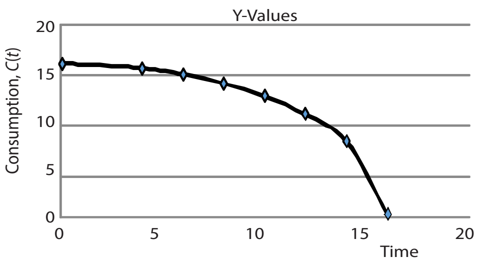

Figure 3. The representative graph of consumption function

Trozzi and Vaccaro methodology neglects this change. So, if we do not neglect this, we can build a new model. Let $C(t)$ be the consumption function. The representative graph of this function is given in fig. 3. There is a discontinuity $t = 0$. So, this is the second type of improper integral. The area under this graph gives us the result $C(t)t$. According to Trozzi and Vaccaro methodology emission is calculated by $C(t)tpF$ the formula. So, we can arrange this formula by using integral:

$$E = p_{\varepsilon\to O^+} F \lim \int_{\varepsilon}^{t} C(x)\mathrm{d}x \tag{3}$$

Future emissions

The year-on-year ratio of transit vessels crossing the Istanbul Strait is shown in fig. 2. The number of ships passing through the Istanbul Strait is having a decreasing trend starting from 2007, it will continue in the future as well. It was observed that small size and tonnage vessels were replaced by larger tonnage vessels [15]. With the increase in ship tonnage, emissions from ships also increase at the same rate. Large tonnage ships have big volume engines to navigate easily, and these engines consume more fuel and cause more air pollution. For the years of 2030-2040 projection, the function of FORECAST in Microsoft Office Excel was used which gives a future value along with a linear trend by using the transit ship data for the years between 2010 and 2015. It was predicted that 39636 ships will be crossing the Istanbul Strait for the 2030 years and 33590 ships for the 2040 years [16]. The projection of the transit vessel for 2030-2040 years is shown in fig. 4.

In the projection, the number of ships with a tonnage of 25000 tons and above and the number of ships with a length of 151-200 m will continue to increase. While the slight upward trend continues in bulk carriers, container ships and other ships (military, service, tugboats, luxury yachts), the downward trend in dry cargo ships will continue. The number of tanker ships will continue to increase until 2040. Figure 5 presents the projection of ship type expected to pass through the Istanbul Strait between 2030-2040.

Transit ship engines, length, and tonnage characteristics were used to make emission analyses which were derived from the projection of the years of 2030 and 2040. Projected future emissions of the Istanbul Strait are presented in fig. 6.

All emissions (NO_x, CO, VOC) are declining relative to 2015 values, while PM, and SO_x emissions are increasing. The reason for this result can be that large tonnage ships are crossing the Istanbul Strait even if the numbers of the transit ships are reduced. These two emissions, which have a close and harmful effect on human health, will continue to pose a danger without losing any impact in the Istanbul Strait region.

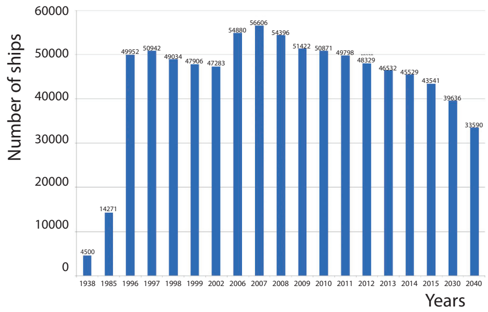

Figure 4. The projection of the transit vessel for 2030-2040 years

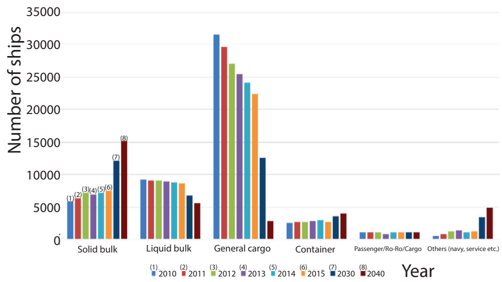

Figure 5. The projection of ship type expected to pass through the Istanbul Strait between 2030-2040

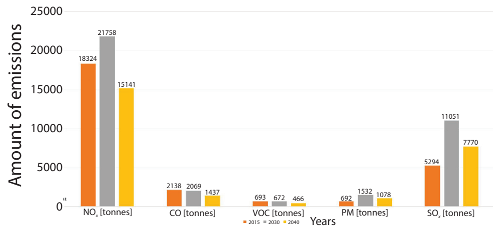

Figure 6. Projected future emissions for the years of 2030-2040

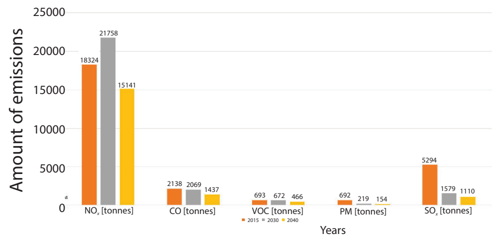

Figure 7. Exhaust gas emission results according to the reduction of the sulfur ratio

As of January 1 2020, ships operating international voyages with the tonnage of 400 GRT and greater will use fuels whose sulphur ratio has been reduced from 3.5%-0.5%. In our projection for the years 2030 and 2040, we obtained different results when we perform the emission analysis again according to the reduced sulphur content of the fuel vessels of the transit ships which are expected to pass through the Bosporus from 3.5-0.5%. Exhaust gas emission results according to the reduction of the sulphur ratio are shown in fig. 7. The PM and SO_x emissions, which have a direct detrimental effect on human health, are declining as they should, falling to acceptable levels, according to new emissions analysis. There is no change in other emissions (NO_x, CO, CO_2, and VOC) results.

Conclusions

It is very important to declare the Bosphorus region as an emission control area/sulfur emission control area to reduce ship-based air pollution around Istanbul. In this study, the regulations imposed by IMO and SO_x emission caused by ships passing through Istanbul Strait are examined. A new approach to the Trozzi and Vaccaro methodology was introduced and emission projections were made for 2030 and 2040, and SO_x and NO_x ratios were analyzed. If the emission control area/sulfur emission control area is declared, the sulfur ratio, which has already been reduced from 3.5-0.5% in the fuel, will be reduced to 0.0% by ships sailing in this region and the use of fuels that produce zero sulfur emissions will be ensured.

This important measure should be taken to ensure that the people living in this region grow as healthy individuals and to reduce air pollution in the long term. The extent to which air pollution is reduced in the areas declared as emission control area/sulfur emission control area has been demonstrated by scientific studies. In this regard, it is very important to make the necessary arrangements in our legal legislation and to implement the control mechanism.

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