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Reaserch Article

Modelling of Ship Originated Exhaust Gas Emissions in the Strait of Istanbul (Bosphorus)

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Abstract

In addition to being one of the largest metropolises in the world, Istanbul is also one of the busiest routes of international maritime transport through the Strait of Istanbul (SoI). Currently, the average number of ships which passes through SoI is approximately 45,000. This number does not increase much due to the natural structure of SoI. So, larger ships with larger tonnages pass through SoI. In addition to the existing transit ship traffic in SoI, ship-based exhaust pollution caused by local maritime traffic adversely affects human health, comfort and the environment.

In this study, the exhaust emissions generated by the ships of the local companies transporting in SoI were investigated. In addition, exhaust emissions from ships, one of the most important air pollutant emission sources such as motor vehicles, industrial processes and heating of residences in Istanbul, were calculated and presented. Ship exhaust gas emissions in SoI were calculated based on actual ship movements and ship machinery information using the bottom up method.

Keywords: SoI, Emission, Air pollution, Vessel traffic

Introduction

The increase in anthropogenic greenhouse gas accumulations in the atmosphere has been observed since the industrial revolution. If human-induced increases in carbon dioxide (CO2) emissions are sustained at the current rate, it is predicted that CO2 accumulation, which was around 280 ppm in the pre-industrial period and 368 ppm in 1998, would reach 500 ppm by the end of the 21st century (IPCC, 1996; Talapatra, 2019). It is aimed to reduce anthropogenic CO_2 emissions by 45% in 2030 compared to 2010 and to achieve net zero emissions by 2050. In this regard, it is expected that steps will be taken to achieve rapid and comprehensive transformations in land, energy, industry, buildings, transportation and cities (IPCC, 2007; Gazioğlu, et al., 2015-2016; Ülker, et al., 2018; Gazioğlu, 2018; Gorji, et al., 2019 Mersin et al., 2019).

Exhaust gas emissions progressively become a more strict topic of public interest in the context of merchant shipping industry. Exhaust emissions from marine diesel engines comprise nitrogen, oxygen, CO2, carbon monoxide (CO), oxides of Sulphur (SOX), nitrogen oxides (NOX), hydrocarbons, water vapour and smoke. Oxides of nitrogen and sulphur are of special concern as threats to vegetation, the environment and human health. Ship emissions easily spread over long distances across the atmosphere between land and continents over the sea, causing global, regional and local adverse impacts on sea and land air quality (Qinbin et al., 2002; Burak et al., 2009). Ship-related emissions that have a direct impact on human health are nitrogen oxide (NO_X), sulfur oxide (SO_X) and particulate matter (PM). Approximately 80% of the World Trade fleet is either anchored in the port or navigates close to a shore for 55% of the time and emissions are concentrated through specific channels / regions (ICCT, 2007). The impacts of ship emissions are more common in inland seas, narrow canals, straits, gulfs and port areas. The effects of these effects on human health are asthma, respiratory diseases, cardiovascular disease, lung cancer and early death (NRDC, 2004).

The most important sources of air pollution in Istanbul are industrial emissions, heating of houses and workplaces, emissions from motor vehicles and emissions from ships (Ünal et al., 2011; Kural et al., 2018). The increasing population, traffic and industry and the resulting uncontrolled emissions result in deterioration of air quality in the mega-city. The field dust transport from the Algerian, Libyan and Tunisian deserts to Istanbul in spring is another source of air pollution. The greatest harm to this dust transport contributes to the increase in particulate concentration (PM_{10}, $PM_{2.5}$) in the city (Karaca et al., 2009; Günay et al., 2018; Aslan & Akyürek, 2018).

The emissions generated by the existing local and transit vessel traffic in SoI, where approximately 15 million people live, account for about 10% of the current emissions. These emissions from ships adversely affect human health, comfort and environment. It is very important to calculate the inventory of ship-based exhaust emissions and to examine the effects of these emissions and to monitor these emissions through other academic studies.

Baseline Literature Review

There are studies on ship-based air pollution on a regional and global scale. All of these studies show that the exhaust emissions generated by ships increase every year within the total global emissions and that the upward trend continues. Eyring et al. (2008) examined the effects of gas and particulate emissions from ocean transport on anthropogenic emissions and air quality. The harmful effects of these emissions on human health and climate change were also included. It has been shown that approximately 70% of ship emissions occur within 400 km of the coastline, causing these emissions to cause air pollution at ground level, especially the effects of sulphuroxide emissions and particulate matter emissions are felt in these areas and threaten human health.

Corbett et al. (2010) examined exhaust emissions generated by ships on commercial routes in the polar region, greenhouse gases in the region, black carbon and other air pollutants present. The pollution caused by the ship in the Arctic region has been investigated in scenarios for years. Within the scenarios, it has been determined that the emissions generated in the polar region will increase global warming considerably and especially CO_2 emissions will increase from 17% to 78%. Measures that can be taken to reduce emissions within the scope of the study are also mentioned.

Jalkanen et al. (2014) conducted a comprehensive inventory of ship-based exhaust emissions in the European Seas (Baltic and North Sea) of 2011. The obtained emissions were analyzed in terms of seasonal, geographical area and ship type and flag state. Total ship exhaust emissions in the European Seas are 121 million tons of CO_2, 3 million tons of NO_X, 1.2 million tons of SO_X, 0.2 million tons of CO_2 and 0.2 million tons of $PM_{2.5}$. CO_2 emissions in the Baltic Sea are 55% higher than in the North Sea. At the same time, the total exhaust emissions in this region (Baltic Sea and North Sea), 88% higher than the ship emissions in the Mediterranean was revealed by the study.

Vianna et al. (2014) examined the effects of maritime emissions on air quality in the coastal zone in Europe. In this study, an in-depth literature review focusing on particulate matter and gas pollutants has been carried out to measure the effects of international maritime emissions on urban air quality in coastal areas of European seas. The distribution of emissions generated by the maritime trade according to the particle size of the particles, the effects of exposure to emissions of the population living in the coastal zone and the atmospheric deposition of the emissions were also evaluated within the scope of the study. According to the results of the study, it is calculated that particulate matter emissions caused by ship emissions in European seas coastal areas are composed of 1-7% PM_{10}, 1-14% $PM_{1.5}$ and at least 11% PM_1 of particulate matter pollution in air.

Jalkanen et al. (2012) established a comprehensive emission inventory of exhaust emissions (CO_2, NO_X, SO_X, CO, and $PM_{2.5}$) generated by ship traffic in the Baltic Sea between 2006 and 2009. Ship emissions before and after the Baltic Sea was declared SECA (May 2006) were compared. Ship emissions were calculated from the Automatic Identification System (AIS) published by the ships and it was observed that NO_X emissions in 2009 increased by 7% more than 2006 and SO_X emissions in 2009 decreased by 14% compared to 2006. The reason for this is stated as the beneficial effects of the declaration of SECA in the region's sea. The distribution of emissions by seasons and the distribution of emissions by ship types, flag states and weights were also examined.

Eyring et al. (2004) examined the emissions of the maritime sector by 2050 in scenarios and with the introduction of new technologies in this area. According to the scenarios, NO_2 emissions will be between 8.8 and 25.0 billion tons in 2020, NO_2 emissions will be between 3.1 and 38.8 billion tons in 2050, and SO_2 emissions will be 25.9 billion tons in 2050.

Kesgin and Vardar (2001) examined the emissions of transit ships passing through the Turkish straits and passenger ferries, sea buses and passenger engines that make up the local traffic. Strait of Istanbul emission results for local traffic are 2,720 tons of NO_X, 383 tons of CO, 170,491 tons of CO_2, 129 tons of VOC, 80 tons of PM, and transit vessels of 4,344 tons of NO_X, 403 tons of CO, 173,362 tons of CO_2, 131 tons of VOC, 65 tons PM was found. In the analysis, transit ships accounted for 51% of the total ship emissions, total NO_X ship emissions were 10% of the NO_X emissions generated by motor vehicles in Istanbul, and cargo ships from transit vessels were the most emissions-generating vessels. It is revealed that transit ships will increase by 5% every year and emissions of ships will increase by 5% every year.

Deniz and Durmuşoğlu (2008) conducted emission analyzes of the current ship traffic in the Marmara Sea in 2003. According to the calculation, total ship emissions were 5.451.224 tons of CO_2, 111.039 tons of NO_X, 87.168 tons of SO_2, 20.281 tons of CO, 5.801 tons of VOC, 4,762 tons of PM. 11% of these emissions Turkey NO_X emissions in general, have been found to constitute 0.12% to 0.1% CO and PM emissions. It has been determined that the amount of emissions emitted by the ships in the Turkish Straits constitutes 20% of the emissions in the Marmara Sea. Which is more than the existing railway and airway induced emissions of ships in the Sea of Marmara in Turkey emissions and emissions from the road is estimated to be less. It was found that NO_X, SO_2 and CO_2 emissions from ships in Marmara Sea accounted for 1% of global ship emissions. It was revealed that the emissions for the coming years will vary according to the type and size of the vessels and that the amount of emissions from the ships in the Marmara Sea will increase by 30% until 2010.

Borat et al. (1990) examined the heating, industrial and motor vehicles constituting urban emissions. It is determined that motor vehicles make up 10% of the emissions in the province in winter. Ship emissions were also investigated.

Meteorological factors play an important role in influencing air quality due to seasonal changes. These factors have a close relationship with the emissions of air pollution (NO_X, SO_X, CO, CO_2, PM, VOC). There are studies in the literature on this subject. Çuhadaroğlu and Demirci (1997) found that "moderate" and "weak relationships between pollutant sulfur dioxide (SO_2) and meterological factors in Trabzon city by using multiple linear regression analysis.

Turalıoğlu et al. (2005) developed a model by using stepwise multiple linear regression analysis which revealed the relationship between TSP and SO_2 concentrations and meterological factors. According to the results of the model, there is a "strong" relationship between TSP and SO_2 concentrations and cold air, relative humidity, high pressure, a "weak" relationship between wind strength and precipitation.

Guttikunda and Gurjar (2010) examined the relationship between air pollution in New Delhi, India and seasonal changes. Within the scope of the study, PM levels in New Delhi city were analyzed and it was found that PM levels increased every day. When seasonal changes are examined, it is observed that the effects of PM pollution are mostly 40-80% more in winter, especially in November, December and January compared to other months, and in summer, especially in May, June and July (10% - 60% compared to other months). A "strong" relationship was found between air pollution and seasonal changes and factors.

Study Area

SoI is a natural waterway that separates the European and Asian continents and connects the Black Sea and the Marmara Sea. The geographical boundaries of SoI have been determined as the line connecting the Anatolian Lighthouse to Rumeli Lighthouse in the north and the line connecting Ahırkapı Lighthouse to Kadıköy İnciburnu Lighthouse in the south according to the Istanbul Harbor Regulations. Within these limits, SoI is 17 nautical miles (31 km) from the midline.

Strait of Istanbul Vessel Traffic

Nearly 150 ships pass through SoI every day, and 2 million people are transported across 2,500 passenger boats daily. In SoI, the existing sea traffic, transit vessels, passenger traffic that makes up the local traffic city lines, sea buses, private passenger engines, cruise boats (yachts, sailboats), fishing vessels, agency boats, patrol boats, tugboats and military vessels.

The high density of maritime traffic in SoI also increases the number of marine accidents, and consequently indirect marine and air pollution that adversely affects human health.

- Transit vessels
- City lines vessels
- Sea buses
- Passenger motors for traveling and carrying passengers
- Military ships

Ship Originated Exhaust Pollution

Types of air pollution caused by ships;

- Nitrogen Oxide (NOx),
- Sulfur Oxide (SOx),
- Carbon dioxide (CO_2),
- Carbon monoxide (CO),
- Particulate Matter or Powder (PM),
- Volatile Organic Compounds (VOC),
- Hydrocarbons (HC).

Among these emissions, nitrogen oxides (NO_X), sulfur oxides (SO_X) and particulate matter (PM) have an environmental impact on the coastal areas where people live, while carbon dioxide (CO_2) and carbon monoxide (CO) have harmful effects on the global environment.

Models of Ship Originated Exhaust Pollution

There are many formulas for measuring air pollution from ships. According to our data, two methods are used. The first one is called BOTTOM UP, the formula/ model established according to the type of fuel and the amount of fuel burned by the ship, and the second is called UP DOWN, which includes the type of the ship, the tonnage of the ship, the cruising time, the main and auxiliary machinery type and the machine running time. BOTTOM UP model was used in the calculations based on the available data.

The following mathematical formula was used to determine the emission values from the vessels of four local marine companies. This formula is used for the total working hours and different emission values calculated for marine vessels operating in each company (Kılıç, 2010):

$$E = t * P * EF * ML \tag{1}$$

E: total value of emissions.
t: time value of the vessel.
P: The powers of the machines used by the vessel.
EF: Emission multiplier by ship type and emission type.
ML: Machine Load

Results

Due to the increasing energy demand, the needs of the countries are increasing and sea transportation is preferred by the countries in order to meet these needs. One of the busiest international routes of maritime transport is SoI. Currently, the average number of ships passing through SoI is approximately 45,000. This number does not increase much due to the natural structure of SoI. In this context, the exhaust emissions generated by merchant ships also increase in parallel.

In this study, the current ship traffic in SoI was examined through local traffic (city lines, sea buses, passenger engines).

According to these examinations made with the help of BOTTOM UP method, the following tables were created. Total daily cruising emission values (kg) in these tables are shown in Table 1, total daily maneuvering emission values (kg) are shown in Table 2, total daily free running emission values (kg) are shown in Table 3 and total daily non-cruising emission values are (kg) Table 4.

Table 1. Total daily cruising emissions (kg) (Demir, 2018).

Local Shipping Companies	NO_x	NMVOC	TSP	Fuel Consumpt.
İDO	1381.36	52.47	82.95	22793.35
İSH	135.95	5.22	8.06	2229.87
TURYOL	284.96	10.77	17.24	4669.84
DENTUR	60.66	2.27	3.60	994.64
Daily Total Value	1862.93	70.73	111.85	30687.7

Table 2. Total daily maneuvering emissions (kg) (Demir, 2018).

Local Shipping Companies	NO_x	NMVOC	TSP	Fuel Consumpt.
İDO	122.02	14.16	21.81	2565.05
İSH	9.85	0.87	1.51	201.66
TURYOL	15.9	3.25	2.58	305.04
DENTUR	9.63	1.07	1.68	202.58
Daily Total Value	157.4	19.35	27.58	3274.33

Table 3. Total daily free working emissions (kg) (Demir, 2018).

Local Shipping Companies	NO_x	NMVOC	TSP	Fuel Consumpt.
İDO	61.53	3.01	3.36	1083.37
İSH	6.46	0.28	0.35	111.59
TURYOL	4.58	0.02	0.08	81.11
DENTUR	4.72	0.12	0.23	83.04
Daily Total Value	77.29	3.43	4.02	1359.11

Table 4. Total daily off-road free-run emissions (kg) (Demir, 2018).

Local Shipping Companies	NO_x	NMVOC	TSP	Fuel Consumpt.
İDO	312.05	9.60	7.20	5208.87
İSH	71.90	2.21	1.66	1200.18
TURYOL	201.25	6.19	4.64	3359.32
DENTUR	164.52	5.06	3.80	2746.21
Daily Total Value	749.72	23.06	17.30	12514.58

Total non-navigational free working emissions of local maritime transport companies in kg (NOx, NMVOC and TSP). According to this, daily total emissions of free working emissions were determined as 749.72 (kg) in terms of NOx, 23.06 (kg) in terms of NMVOC and 17.30 (kg) in terms of TSP. Non-cruising free working emissions are the values obtained as a result of the operation of the auxiliary machinery during the waiting period of the berths after the work of the sea vehicles within the scheduled voyage. For example, a vessel should operate for 8 hours in 24 hours according to the schedule. The rest of the pier is on standby for the remaining 16 hours. However, the watercraft also operates auxiliary machines in this standby position, thus releasing emissions to the atmosphere. At this point, non-cruising free working emission values include the emission values released into the atmosphere during this time period. The absolute consideration in the calculations is the fact that the sea vessels emit emissions to the atmosphere not only when they are moving but also when they are connected in the standby position at the port. Because the marine vehicles need electricity when they are in the waiting position at the port and unless they are connected to the shore, they provide their electrical energy from diesel driven electric generators. In this case, the emission value is released to the atmosphere as they consume fuel. Therefore, an increase (s) is observed in the emission values accumulated in the atmosphere. Total daily emission values (kg) are given in Table 5.

Table 5. Total daily emissions (kg) (Demir, 2018).

Local Shipping Companies	NO_x	NMVOC	TSP	Fuel Consumpt.
İDO	1569.91	69.64	106.96	26442.66
İSH	152.26	6.37	83.76	22336.71
TURYOL	303.93	12.43	19.90	5055.99
DENTUR	75.01	3.46	5.41	1280.258
Daily Total Value	2101.11	91.90	216.03	55115.618

As can be seen from the table, total daily emissions of local maritime transport companies are calculated in kg and NOx, NMVOC and TSP values. Accordingly, daily total values of total emissions were determined as 2101.11 (kg) in terms of NOx, 91.90 (kg) in terms of NMVOC and 216.03 (kg) in terms of TSP. If it is necessary to evaluate the above total daily emissions over the annual value, it is sufficient to multiply the data obtained daily by the number of working days. The resulting emissions can be listed as follows (Demir, 2018):

NOx: 766905 kg = 767 Ton
NMVOC: 33544 kg = 34 Ton (2)
TSP: 78851 kg = 79 Ton
Fuel Consumption: 20117201 kg = 20117 Ton

It is important that the results which are obtained from the calculations can be compared with the values of large tonnage cargo ships. In this way, it will be possible to compare the values of small tonnage boats, ferries, high speed sea buses, ferryboats and fast ferries that carry passengers in Istanbul Local Sea Area. Relevant values can be listed as follows.

First, it is important to list the fuel consumption factors in terms of tons per day according to ship types. According to this; Container Ship (65,9); Liquid Bulk Ship (41.1);

Solid Bulk Ship (33,8); General Cargo Ship (21,3). Similarly, emission factors over tonnes can be listed as follows: NOx (57, 0); CO (7.4); NMVOC (2, 4); PM (1, 1); SO_2 (20) (Tuna and Elbir, 2013). If we need to expand the data, 2011 values can be taken as a basis. According to this; In 2011, the total annual emissions from the large tonnage vessel traffic passing through SoI were calculated as 3553 ty^{-1} for NO_X, 623 ty^{-1} for SO_2, 461 ty^{-1} for CO, and 69 ty^{-1} for PM_{10}. Accordingly, if it is necessary to act on the emission values of the sample ship types, it is determined that NO_X emission from cargo ships are 46% compared to the total emission rate and the tankers are 17%. In other words, 46% of the total emission value belongs to cargo ships and 17% belongs to tankers (Tuna and Elbir, 2013).

Discussion and Conclusion

In this study, the data of 2017 calculated the flue gas emission values of the sea vehicles which are owned by four local maritime transport companies operating in SoI. The results obtained were compared with the realistic fuel consumption values of the transportation companies and the results were compared.

This study was conducted for local maritime traffic elements of SoI, an important international waterway. There are a total of 151 marine vessels evaluated within the scope of the study. The main and auxiliary machine powers of these vessels vary from one another. When considered in this context, the emission values emitted from the chimneys of marine vessels operating in the local area produce an important result. Due to the increase in the length and tonnage of the vessels and the increase in the main and auxiliary machinery dimensions, the emission values reach the amounts to be considered as stated in the previous section.

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