DETERMINATION OF NO_X EMISSION FACTOR FOR DIESEL ENGINES OF RECREATIONAL BOATS BY ON-BOARD MEASUREMENT

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SUMMARY

In this study, NO_x emissions from diesel engines of 75 recreational boats were measured on-board in accordance with the simplified method specified in the IMO's NO_x Technical Code. The study was carried out in boats with ranging between 14.42 m-37.50 m in length and engines power varying between 138 kW–2,040 kW. NO_x emissions were measured by using a portable exhaust gas analyser (Testo 350 Marine) in ppm in a dry basis. An in-house programme was to develop to calculate the final emission results in g/kWh. The main aim of the study is to develop NO_x emission factors for recreational boats, which are not specifically included in previous emission factor studies. The NO_x emission limits of the marine diesel engines of the recreational boats were found in range of 0.92 g/kWh – 10.69 g/kWh while the mean emission factor was found as 4.81 g/kWh. Since these values are obtained from real measurements, they are considered to set an example for future studies and will provide ease of calculation for the compliance of pleasure boats with the NO_x Technical Code. Besides, it is the first study to demonstrate a measurement flow diagram, which was developed as a combination of real-time measurement limitations and NO_x Technical Code requirements to standardise the measurement process.

NOMENCLATURE

$c_{gas,dry}$	NO_x concentration in the exhaust gas, dry (ppm)
$c_{gas,wet}$	NO_x concentration in the exhaust gas, wet (ppm)
D_{cyl}	Engine Cylinder Displacement (cm^3)
f_a	Test condition parameter
f_c	Carbon Factor
f_{fd}	Fuel specific factor for exhaust flow calculation on dry basis
H_a	Absolute humidity of the intake air (g/kg)
k_{hd}	Humidity correction factor
k_{wa}	Dry to wet correction factor for the intake air
L_{OA}	Length overall of the vessel (m)
L_R	Register Length of the vessel (m)
p_a	Saturation vapour pressure of the engine intake air (kPa)
p_b	Total barometric pressure (kPa)
p_c	Charge air pressure (kPa)
P_m	Maximum power at the test engine speed under test conditions (kW)
p_s	Dry atmospheric pressure (kPa)
p_{sc}	Saturation vapour pressure of the charge air (kPa)
q_{mad}	Intake air mass flow rate on dry basis (kg/h)
q_{maw}	Intake air mass flow rate on wet basis (kg/h)
q_{mew}	Exhaust gas mass flow rate on wet basis (kg/h)
q_{mf}	Fuel mass flow rate (kg/h)
q_{mgas}	Emission mass flow rate of individual gas (g/h)
R_a	Relative humidity of the intake air
r_h	Hydrocarbon response factor
T_a	Intake air temperature (K)
T_{Exh}	Exhaust gas temperature (K)
T_{Fuel}	Fuel oil temperature (K)
T_{SC}	Charge air temperature (K)
T_{SCRef}	Charge air reference temperature (K)
T_{Sea}	Seawater temperature (K)
w_{ALF}	% H content of fuel
w_{BET}	% C content of fuel
w_{DEL}	% N content of fuel
w_{EPS}	% O content of fuel
W_F	Weighting factor
w_{GAM}	% S content of fuel

1. INTRODUCTION

Although the share of the maritime sector in global energy demand is relatively low, it is predicted that the total fuel consumption of ships will increase by 43.5% in 2050, even in the best scenario (Eyring et al., 2005). The International Maritime Organization (IMO) aimed to monitor and keep all ship-related pollutants under control through the International Convention for the Prevention of Pollution from Ships (MARPOL 73/78). MARPOL 73/78 consists of six protocols and Annex VI aims to prevent pollution from ship flue gases and came into force in 2005. MARPOL Annex-VI (will be referred as Annex-VI in the following text) specifically focuses on flue gas emissions. Annex-VI consists of regulations on ozone depleted substances (ODSs), particulate matter (PM), volatile organic compounds (VOCs) and especially nitrogen oxides (NO_x) and sulphur oxides (SO_x). Among them, NO_x has been evaluated differently than others and subjected to more detailed regulations.

Nitrogen in the atmosphere is in the form of N_2 and behaves like a noble gas and does not react with other elements. On the other hand, the nitrogen element (N) shows reactive properties and combines with oxygen to form NO_x compounds. NO_x is mostly formed in the form of NO in internal combustion engines and can be produced in high amounts at temperatures above 1300°C, as the amount of oxygen in the supply air being the limit. On the other hand, at temperatures of 760°C and below, it is produced in very small amounts or not at all (EPA, 1999). NO_x gases are particularly play an important role in the formation of ground level ozone, which may cause heart and lung diseases in case of inhalation. Additionally, NO_x is known to be one of the major causes of acid rain (Andreoni et. al, 2008; IMO-MEPC, 2005).

Diesel vehicles have long been considered as major contributors to NO_x emissions. On-board measurement may be new to ship emissions, but it is a relatively mature technology for vehicle emissions. On-road measurement is one of the most reliable technique to determine real-world emissions of diesel vehicles. It can also be used as an effective tool to estimate the differences between engine certification cycles and real-world operating conditions. There are many studies that have been conducted to determine the actual NO_x emission values by performing on-board measurements of diesel engines with the characteristics we have discussed in our study (Liu et. al., 2011; Yang et. al., 2018; Papadopoulos et. al., 2020; Huo et. al., 2012; Pondicherry et. al., 2021).

Shipping activities are responsible for 12-13% of NO_x emissions generated worldwide (Smith et. al., 2014). Although this ratio seems low, the emissions are expected to cause remarkable deleterious impacts considering that 70% of the emissions are produced at a distance of 400 km from the shore (Eyring et. al., 2010). Therefore, IMO has aimed to keep ship-related NO_x emissions under control with Regulation 13 within the scope of Annex-VI. For this purpose, diesel engines with a power of 130 kW and above were classified according to their revolutions per minute (RPM) and NO_x limits were determined in accordance with these tiers. These limitations are shown in Table 1:

Ships navigating in all regions except Emission Control Areas (ECA) have to use engines manufactured according to Tier II standards. The situation is different for ECA regions. ECA regions are the USA and Canada coasts and the Caribbean waters of the USA. NO_x constraints in these regions are called as Tier III and are applied more stringently than in other regions. Measurement and certification of NO_x emissions from ship diesel engines (Engine International Air Pollution Prevention-EIAPP) is carried out in accordance with NO_x Technical Code 2008 principles.

To create emission restrictions, rules must be developed, and to develop rules, the problem must be defined at its source. Therefore, there is a need to create an emissions inventory first. The most reliable way to create an emission inventory is to make real measurements. Thus, the inventory to be obtained and the emission factors to be calculated accordingly will contribute to the development of international regulations for different ship types.

There are numerous studies on NO_x emissions formed by medium-speed diesel engines in the literature (Cooper & Ekström, 2005; Cooper & Andreasson, 1999; Winners & Fridell, 2010; Guardipola et. al., 2017; Rodriguez & Murcia, 2013; Khan et. al., 2013) and some of them focused on developing emission factor for NO_x (Beecken et. al., 2014; Bai et. al., 2020; Pirjola et. al., 2014; Moreno-Gutiérrez & Durán-Grados, 2021).

Studies on ship emissions generally utilize current emission factors, activity information of ships, and main and auxiliary engine loads during operation. It is seen that very few studies in the literature have performed on-board measurements. This is because such measurement studies are costly in terms of time/labour and money. Besides, it is quite difficult to measure while ships are continuing their routine activities. In each of these studies, on-board NO_x emission measurements were carried out on high-powered diesel engines of one or several large tonnage ships (Cooper & Ekström, 2005; Cooper & Andreasson, 1999; Moldanova et. al., 2009; Winners & Fridell, 2010). In a study investigating the effects of NO_x emissions from recreational boats, instead of on-board measurement, the effect of the emissions of these boats on air quality was examined by measuring the change in ambient air (Van der Zee et. al., 2012).

Besides these studies on large ships, there are also more specific studies focusing on small recreational boats. A study conducted in 1990 focused on the measurement of exhaust gas emissions from pleasure boats and small commercial ships. During the measurements, the engine was operated at 100%, 80%, 60%, 40% loads and idle. The

Table 1: NO_x emission limits (IMO, 2020).

Tier	**Ship Construction Date on or After**	**Total Weighted Cycle Emission Limit (g/kW-h)** ***n* = Engine's Rated Speed (RPM)**		
		$n < 130$	$n = 130 - 1999$	$N \geq 2000$
Tier I	1 January 2000	17.0	$45 \times n^{-0.2}$	9.8
Tier II	1 January 2011	14.4	$44 \times n^{-0.2}$	7.7
Tier III (ECA)	1 January 2016	3.4	$9 \times n^{-0.2}$	2.0

average NO_x formation rate was obtained as 31.3 g/h or 2.74 g/kWh (Coates & Lassanske, 1990). Another study concluded that emission amount is depend on shaft torque, shaft speed, supply air pressure and temperature, ambient air temperature, pressure and humidity, fuel shaft position, fuel consumption and exhaust gas temperature (Götze et. al., 1997). A recent study utilized a portable emission measurement system to calculate CO, HC, NO_x and PM emissions of seven different ships whose gross ton values are ranging between 360-6028. The measurements were realized during manoeuvring and cruising phases and the emission factor of NO_x has been calculated as 0.72-5.83 g/kg (Peng et. al., 2016). A study conducted in China utilized a portable sampling device to measure $PM_{2.5}$ and heavy metal emissions. One of the ships that have been focused within the scope of the study was a fishing boat and it was concluded that the ratios of S, Si, Al and Ca are much higher than the other heavy metals in the fishing boat (Wen et. al., 2018).

The engines we have measured in our study are high-speed diesel engines. By carrying out measurement studies on similar engines at similar powers, NO_x emission prediction models based on various engine parameters are developed (Provataris et. al., 2017; Liu et. al, 2016). Testo 350 Marine portable emission device, which we used during the measurement, was previously used and tested in another study conducted in 2011 as a test bench and on-board for measuring NO_x emissions on a medium-speed marine diesel engine (Uriondo et. al., 2011).

On-board emission factor studies in the literature are generally based on data obtained from ocean voyages of one or more large commercial ships equipped with heavy/medium speed high power diesel engines. Similarly, most of the studies in the literature used the test bed data provided by the manufacturing company and utilized statistical analysis. Some recent studies have focused on different types of ships in order to calculate emission factors for different types of emissions. On the other hand, since the machinery and operating conditions of these ships differ greatly, the obtained emission factors cannot be accepted precisely. Therefore, in this study, on-board measurements were carried out on vessels with similar characteristics (high speed engines and small-scale ships). Primary aim of this study is to fill the gap in emission factor determination methodologies, especially for low power high speed engines. The study can also be used to update existing emission factor inventories. We also aim to present the practical guideline for the on-board simplified measurement method and to share the results obtained for 75 boats. In addition, average emission factors for recreational small boats are presented together with the probability density function. Besides, a flow diagram, which will make an important contribution for standardisation of measurement process, was offered for the further studies, in which similar measurements will be realized.

2. MEASUREMENT METHOD, DATA COLLECTION AND COMPUTATIONAL METHODOLOGY

NO_x Technical Code determines the mandatory procedures for the testing, inspection and certification of all marine diesel engines, which are specified in Annex VI Regulation 13, for engine manufacturers, ship owners and flag states. The methods specified in NO_x Technical Code for emission measurement are divided into two methods: Test Bed Methods and On-Board Methods. While the former is the procedure applied in the first approval tests, regardless of the location of the test, the latter is used to verify that the pre-certified engine continues to comply with the relevant NO_x emission limit value.

On-board procedures are divided into three methods. These are engine parameter check method, simplified measurement method and direct measurement and display method. The engine parameter check method assumes that unless the critical components, which may change the NO_x emissions, don't change, the NO_x values will remain same during the life-time of the engine. In this case, it is checked whether a change has been made on the engine and no measurement is made. In the direct measurement and display methods, engine performance parameters are measured, calculated and recorded together with the absolute minimum value of NO_x emission.

The simplified measurement procedure used in this study was developed for on-board approval tests of the engines and, when necessary, is used for renewal and interim survey. The simplified measurement method is an on-board verification procedure. Although the name of this procedure is simplified, it has great difficulties in practice since it requires direct on-board measurement. Measurements in this method include all calculations required for test bed measurements. The permissible deviations in the measured values and the calibration periods of the measuring devices are slightly higher.

For boats below 400 GRT, the relevant flag state is authorized to take appropriate measures to ensure compliance with the provisions of Annex VI. In addition, the flag state can delegate its authority to a different organization and issue the required (EIAPP, IAPP) certificates based on these measurements. Annex VI regulations are applied to all marine diesel engines equipped after 1st of January, 2000 or undergoing major overhaul and with a power output of 130 kW or more. In this study, on-board measurements were made with the simplified measurement method for the engines of recreational boats (yachts and gullets) located in the region between Alanya and Bodrum and it was investigated whether they comply with the NO_x emission upper limit value to which the ship engines are subjected. The working area and the types of boats measured are shown in Figure 1, and the measurements were carried out in three years between 2018 and 2020.

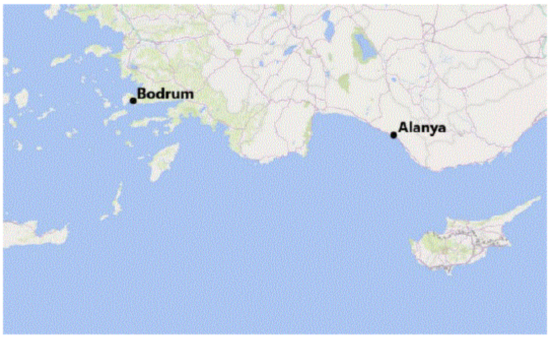

Figure 1. Study area

Descriptive statistics regarding the basic parameters of the boats are shown in Table 2. Of the 75 boats in total, 39 have single-engine and 36 have double-engine. All of the engines equipped on the boats are high speed four stroke water cooled marine diesel engines.

The sketch diagram of the measurement is presented in Figure 2 and the equipment and critical equipment used in the measurement are numbered and described in Table 3.

Testo 350 Marine emission measuring device (14) was used to determine the NO_x emission in ppm. The device takes the exhaust sample with the probe (15) through a hole drilled in the exhaust line. The sample taken is transferred to the measuring device with the cable and hose (17) connected to the part (16) located behind the probe and evaluated with the sensors on the device. The control of the device is carried out by a handheld computer (19) connected to the device by cable (18). It is worthy to note that the emission analyser is of chemiluminescent detector (CLD) type and only measures NO and NO_2 in accordance with NO_x Code.

The ambient temperature (°C) and relative humidity (%) of the environment were measured with the TESTO 610 electronic temperature and humidity meter. The speed of the engine was obtained from the boat's tachometer. The scavenge temperature of the engine was measured with a Fluke 62 Max infrared thermometer. The power, cylinder displacement and specific fuel consumption values of the engine were obtained from the engine manual and test bed. Weight factors and NO_x/exhaust density ratio were obtained from the NO_x code. Fuel's hydrogen, oxygen and nitrogen contents have been determined in accordance with the fuel spectrum specified in the seaworthiness certificate of the boat.

While the exhaust sample was taken from the engine, as stated in the NO_x code, a hole of 1/2" was opened at a distance of at least 10 times the exhaust line diameter after the turbocharger outlet of the engines and the plug was welded. In this way, the penetration of the measuring probe into the exhaust line is provided. After the measurement, the plug is closed. The exhaust lines of such engines are water cooled. However, protecting the measuring probe from getting wet is very important. Therefore, additional attention has been paid to opening the hole before the water intake. In each measurement mode, at least 10 minutes were waited for the engine exhaust parameters to stabilize and at least five values were recorded for each mode.

Since torque measurement is practically not possible in such boats, the power of the engine in each measurement mode is determined by means of the correlations provided for "propeller-law-operated main and propeller-law-operated auxiliary engine" in the NO_x code. This causes some uncertainty in the calculation of the engine power. It has been predicted that this uncertainty is limited within ± 5% as suggested by NO_x code.

The gas_x value, which measures the conformity of the engine to the tier limit value, was obtained in accordance with the calculation flow diagram given in Figure 3. The calculation algorithm is also presented in Table 4.

Uncertainty analysis was performed using the measured ambient temperature, scavenge temperature, engine speed, relative humidity, ambient pressure, engine power and NO_x (ppm) values in each mode. Maximum uncertainty values for temperature (± 2°C), pressure (± 0.05 hPa), relative humidity (± 2.5%) and NO_x, ppm (± 2.0%), obtained from the last calibration certificates of the relevant measuring device, uncertainty limits for engine speed and engine power. Uncertainty in gas_x was calculated in accordance with (Moffat, 1998). The NO_x code allows a total uncertainty of 10%, and the uncertainty value calculated in this study was calculated as 4.73%.

Table 2: Descriptive statistics of boats.

	N	Min.	Max.	Mean	Std. Dev.
L_{OA} (m)	75	14.42	37.50	24.58	5.65
Breadth (m)	75	4.00	8.32	6.49	0.94
Depth (m)	75	1.30	4.30	2.86	0.69
GRT	75	16.41	242.00	98.83	49.22
Rpm	75	1,150.00	3,300.00	2,156.00	326.53
Cylinder Displacement (cc)	75	5,184.00	48,700.00	11,983.60	6,125.05
Fuel consumption (kg/h)	75	16.80	431.51	70.28	64.31
Engine Power (kW)	75	138.00	2,040.00	354.70	300.58

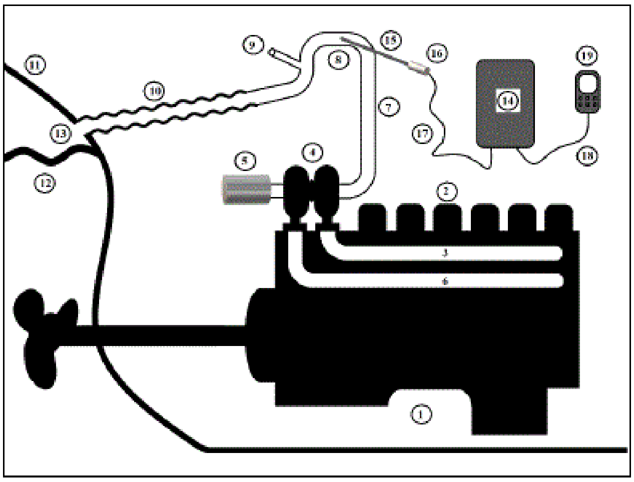

Figure 2. Sketch diagram of measurement

Table 3: Description of sketch diagram.

No.	Description	No.	Description
1	Diesel engine	**11**	Transom of the boat
2	Cylinder	**12**	Sea level
3	Turbocharger	**13**	Exhaust discharge
4	Exhaust manifold	**14**	Testo 350 measurement device
5	Intake air filter	**15**	Exhaust sampling probe
6	Scavenge manifold	**16**	Filter
7	Exhaust line	**17**	Cable and hose
8	Swan neck	**18**	Cable
9	Exhaust cooling water	**19**	Handheld computer
10	Flexible neoprene pipe		

Figure 3 is a flow diagram, which is a sum of how the various calculation formulas in the NO_x Technical Code should be used in a measurement system. Figure 3 summarizes the order in which these formulas within the Technical Code should be used in a measurement process. For this reason, Figure 3 creates a systematic that can be used in future studies.

3. RESULTS

Box plots for $C_{gas,wet}$ values obtained at four different engine loads are given in Figure 4. It can be said that the $C_{gas,wet}$ statistics at four different loads are close to each other. Few outliers were detected in the 75% and 100% measurement modes. Considering the third quartile values at four engine loads, the $C_{gas,wet}$ value of 75% of the boats is below about 1000 ppm. Considering the median values, it was observed that the highest median value occurred at 50% engine load with 770 ppm. According to the figure,

Table 4: NO_x emission computing algorithm.

No.	Calculation step
1	Read P, D_{cyl},T_{SCRef} and SFC from test bed results or engine specs.
2	Determine O_i, W_f and u_{gas} from NO_x technical code.
3	Determine w_{ALF},w_{DEL} and w_{EPS} based on the diesel oil type.
4	Measure R_a,T_a, T_{SC},p_b,n_d and c_{gasdry} for each mode.
5	Calculate H_a from R_a, T_a and p_b.
6	Calculate k_{hd} from T_a,T_{SC},T_{SCRef} and H_a.
7	Calculate q_{mf} from SFC and O_i.
8	Calculate q_{mew} from T_a, p_b,D_{cyl}, q_{mf} and n_d.
9	Calculate f_{fw} from w_{ALF},w_{DEL} and w_{EPS}.
10	Calculate k_{wr} from w_{ALF}, f_{fw}, H_a, q_{mf} and q_{mew}.
11	Calculate C_{gaswet} from k_{wr} and c_{gasdry}.
12	Calculate q_{mgas} from c_{gaswet}, O_i,W_f and P.
13	Calculate gas_x from q_{mgas},O_i,W_f and P.

$C_{gas,wet}$ values for two engines at 75% and 100% load are observed as outliers.

Other descriptive results calculated for the $C_{gas,wet}$ value are presented in Table 5. Although it is observed that the lowest $C_{gas,wet}$ value occurs at 25% load and the highest $C_{gas,wet}$ value at 75% load, the average values calculated for all loads are close to each other. The standard deviation values calculated for the $C_{gas,wet}$ value at 25%, 50% and 75% loads and expressing the variability show slight differences. When the variations observed at different loads are compared according to the coefficient of variation, it is seen that the $C_{gas,wet}$ variation of the machines is at maximum 25% load and at least 100% load. It is thought that the reason for this high variability obtained according to the measurement results of different engines is the complex structure of the formation of NO_x in the engine cylinders.

In Figure 5, $C_{gas,wet}$ values measured at four different engine loads for 15 different engine speeds ranging from 1150 RPM to 3300 RPM are summarized. The graph shows that $C_{gas,wet}$ values measured at high engine loads, shown in green and yellow, are often higher than at low engine loads. This situation is not surprising considering the formation mechanism of NO_x. In some measurements however, higher $C_{gas,wet}$ values were observed at low engine loads compared to high engine loads. The probable reason for this is that the turbocharger cannot provide enough filling air at low loads in engine.

It is seen that $C_{gas,wet}$ variability due to engine load is low in the range of 1500 RPM-2400 RPM, and that $C_{gas,wet}$ average has an increasing trend depending on the cycle in

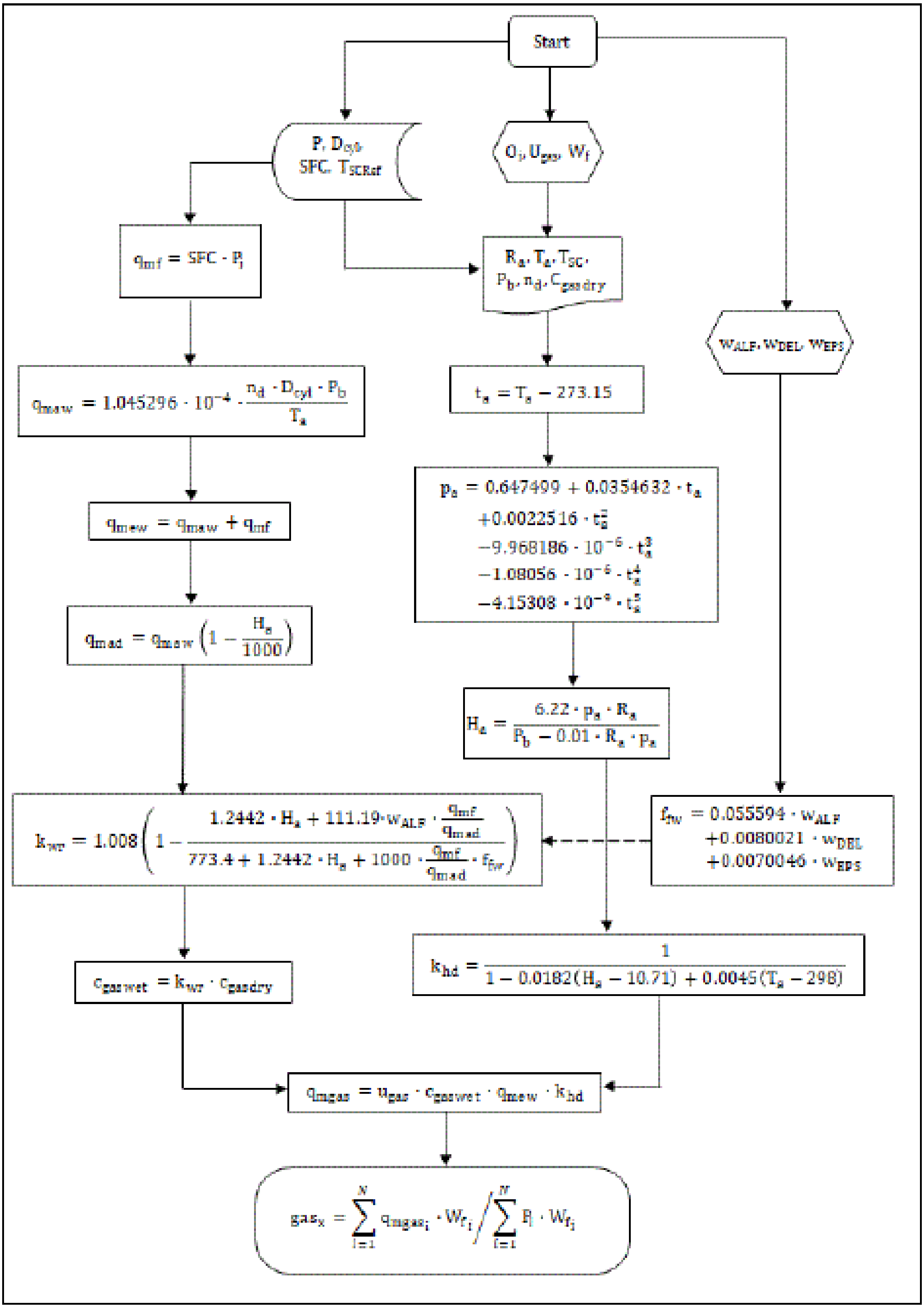

Figure 3: NO_x emission computation flow diagram

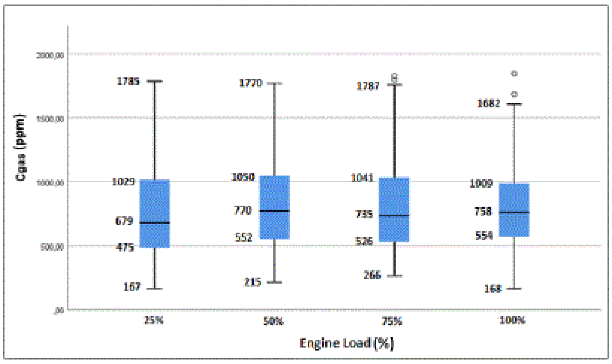

Figure 4. $C_{gas,wet}$ values at four different engine loads

Table 5: Descriptive findings for $C_{gas,wet}$, ppm.

Load	Mean (ppm)	Std. Dev. (ppm)	Coefficient of Variation (%)
25%	745	377	50.60
50%	822	376	45.74
75%	829	378	45.60
100%	823	339	41.19

this range. In the range of 2450 RPM-2850 RPM, $C_{gas,wet}$ variability depending on the engine load is high.

In Figure 6, the scattering plot of the tier limit levels (see Table 1) and the n_d and gas_x values of the measurement results are shown according to the year when the engine was equipped (or undergoing major revision). The upper limit level allowed (10% more than the tier limit value) in accordance with Annex VI is also added to the chart.

Since the area where the measurement is made is not the ECA region, there is no engine subject to Tier III. 48 of the engines are subject to Tier I and 27 of them to Tier II. It was observed that only one of the engines, which are subjected to Tier II, produces emissions above the limit value. Similarly, among the engines subjected to Tier I, three engines produce emissions above the limit value. However, the emission values of these engines do not

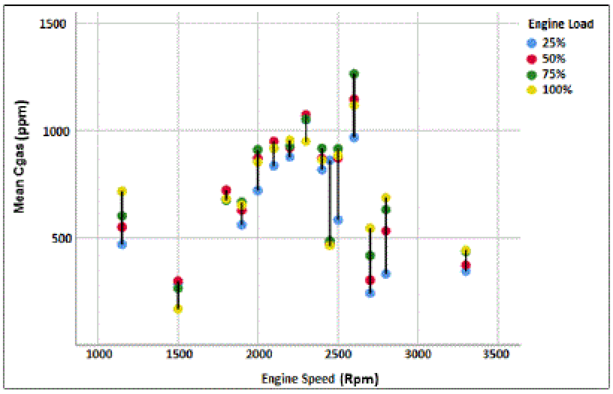

Figure 5. $C_{gas,wet}$ values at four different loads depending on the engine speed

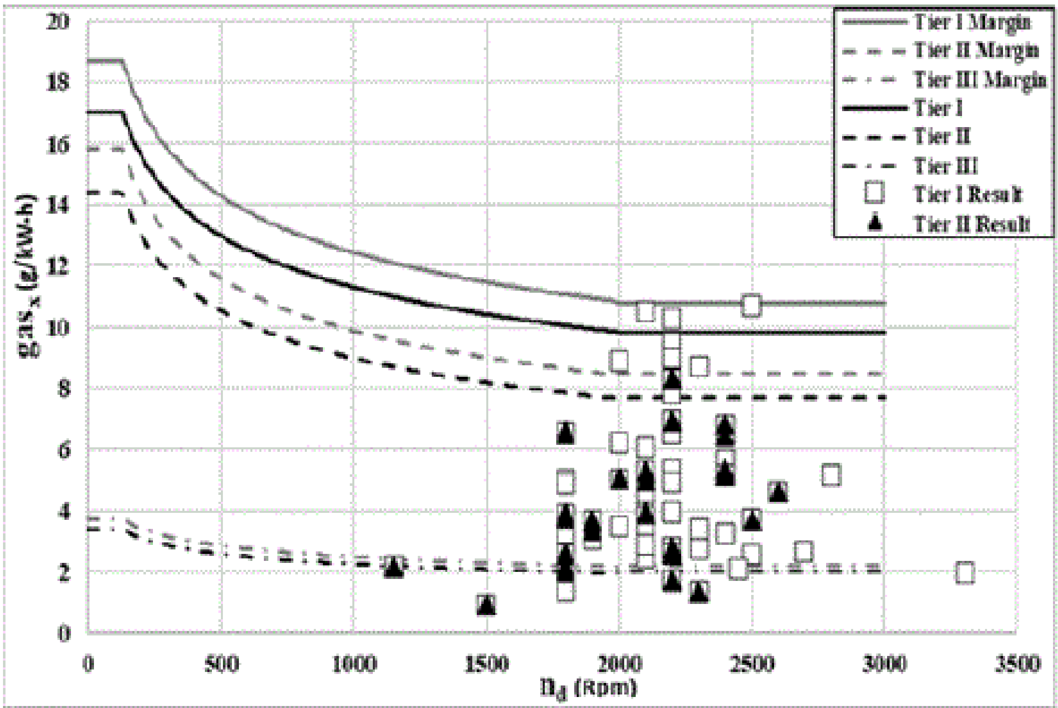

Figure 6. gas_x values in four different loads depending on the engine speed

exceed 10% of the tier limit level, which is the upper limit level allowed. In other words, the NO_x emission value of all the engines remains below the upper limit level allowed. Examining the graph show that no significant relationship is expected between gas_x and engine speed intuitively. As a matter of fact, the calculated correlation coefficient was not found to be significant ($p > 0.5$).

In Figure 7, the distribution of emission factors (g/kWh) obtained according to the measurement results of the boats is shown. When the probability density function is examined, a two-peaked distribution, which shows that the engines measured do not come from a homogeneous population, is observed. However, it can be said that the distribution is skewed to the right, that is, the NO_x values tend to aggregate around low emission values. The maximum value seen in the Boxplot (10.69 g/kWh) is below the maximum acceptable limit value, which is 10% higher than the maximum limit value presented in EU Directive 2003/44 and MARPOL Annex VI Regulation 13 Tier-I (10.78 g/kWh).

Descriptive statistics calculated for the emission factors of engines according to the measurement results are presented in Table 6. The average value of the emission factor calculated according to these statistics was determined as 4.81 g/kWh and the median value as 3.95 g/kWh.

The power and operating time of the engines are often multiplied by the emission factors in order to reach the emission amounts. Therefore, it is critical to determine the emission factor close to reality. In this study, a comprehensive emission factor determination study was carried out for the first time on 75 recreational boats with on-board measurement. The results in Table 6 can be used to give more realistic results in the emission inventory studies for recreational boats.

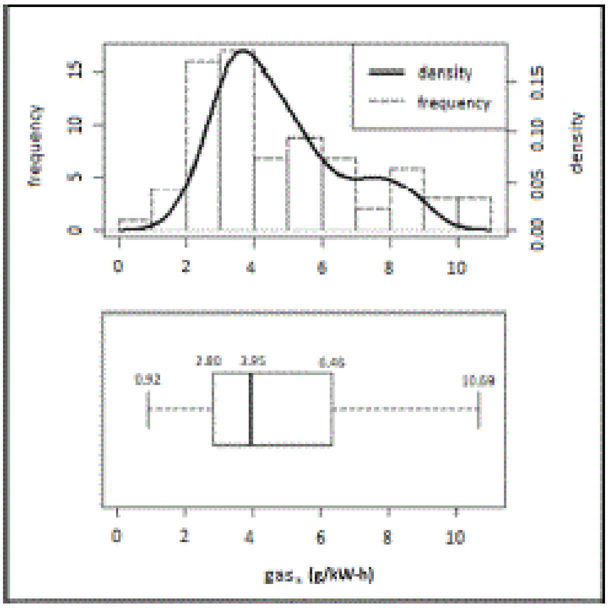

Figure 7. Distribution of emission factors (g/kW-h) obtained depending on the measurement results

Table 6: Descriptive findings for gas_x (g/kW-h) value.

Mean	4.81
Median	3.95
Std. Dev.	2.53
Std. Error	0.29
Skewness	−0.35
Kurtosis	0.78
Range	9.77
Minimum	0.92
Maximum	10.69

4. DISCUSSION

Although shipping emission is a well-known and well-studied subject, there are very few studies on emission factors of recreational boats. In addition, none of the studies have been conducted by on-board measurement method. For this reason, comparing the results obtained from this study with previous studies will not give accurate results. The comparisons made with the results of similar studies in the literature are given in the following paragraph.

The emission factor presented by Trozzi for high-speed diesel engines in recreational boats is around 9.8 g/kWh (Trozzi & De Lauteris, 2019). Trozzi states that he compiled the emission factors of such boats from Winther and Nielsen (2006), in which these factors were determined as limit values, which are based on EU Directive 2003/44, for NO_x for recreational boats. For these reasons, it is perhaps necessary to review the emission factor values for such engines, as this study is based on actual measurements performed on a large number of boats. As a matter of fact, NO values are found to be around 5.5 g/kWh in the measurement engine catalogues and in the test bed measurements made on motors of similar type and power (Cerne et. al., 2008)[. Since the emission factors obtained from previous studies are not directly derived from measurement data, they must be considered as partially correct.

On-board measurement studies on road vehicles are available in the literature regarding HDVs' engines. On the other hand, marine vehicles and engines operate under very different conditions than road vehicles. NO_x emission formation occurs as a result of complex reactions depending on the operating conditions of the engine. Therefore, comparing the results of the studies, which focused on on-board measurements of road vehicles, with the results of the present study is not considered appropriate.

5. CONCLUSIONS

NO_x emissions, like all other exhaust gases, are considered to be the source of major problems leading to various environmental and health problems. For this reason, international organizations such as IMO are developing various regulations to control and reduce these emissions and constantly update them. NO_x emissions are subject to MARPOL Annex VI Regulation-13, and NO_x measurements are made according to the information contained in the NO_x Technical Code. In this way, it is possible to make an emission inventory and the compliance of ships with Regulation-13 can be inspected.

These measurements are used to develop emission factors as well as to make an emission inventory. In this way, emission factors for certain types of ships and/or engines are calculated and these values are used to create an emission inventory. Since it is not possible to measure continuously for all types of ships, it is very important to use the correct emission factor to create the correct emission inventory. The only way to create the correct emission factor is to take measurements from real engines operating at various loads. There is a gap in the literature for relatively small ships, as emission factors are established specifically for large cargo ships. Although various factors are suggested for these vessels, none of them will give reliable results since they are not produced from real-time measurements.

This study, in which the emission factor of recreational boats is measured on-board, is the first in terms of the size and number of the boats considered. According to the measurement results made according to the NO_x Technical Code, the emission factor median value of 75 recreational boats was calculated as 3.95 g/kWh and the average value was 4.81 g/kWh. This value has been determined for ships with a length of 14.42-37.50 m and an engine power of 138-2040 kW, and it can be used for ships of sizes and power close to these values. Since this is the most comprehensive emission factor measurement study compared to other studies in the literature, we believe that it will fill an important gap and will pioneer future. In addition, especially the flow diagram described in Figure 3 constitutes a guiding measurement standard for future studies. Thus, a standard method has been developed that can be applied to all ship types within the scope of the NO_x Technical Code. Briefly, this is the first study to cover development an emission factor for NO_x, validation and confirmation of NO_x Technical Code, and contribution for standardisation of the implementation of the Code.

In further studies, it is aimed to make a calculation for other types of ships using this diagram and to obtain emission factors for all ship types based on real measurements. In this way, emission factors that exist in the literature but whose accuracy is questionable will be updated more realistically.

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