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THE COMPUTING METHODS FOR CO_2 EMISSIONS IN MARITIME TRANSPORTS

Doru COŞOFREŢ*, Marian BUNEA*, Cătălin POPA**

***Military Technical Academy. Bucharest, Romania**
****"Mircea cel Bătrân" Naval Academy. Constanța, Romania**
dorucosofret@yahoo.com

Abstract: *Nowadays the global climate changes have determined the international bodies to take measures in order to reduce emissions that contribute to the greenhouse effect. The main component of the exhausting gases produced by diesel engines is the CO_2 emissions, considered responsible for the greenhouse effect appearance. The CO_2 occurrence is largely dependent on the fuel carbon content as used in the diesel engines and further on the fuel consumption. In this context, it is worthwhile considering the maritime transportation activities taking place since 2011 when IMO took steps to reduce the emissions of CO_2 from the exhaust gases of marine diesel engines on ships, enforcing their energy efficiency standards. This paper presents a summary of the main methods for determining the CO_2 masses from the exhaust gases of marine diesel engines. These computation methods highlight usage opportunities from the sustainable management principles point of view, promoting the concept of energy efficiency onboard the ships. The undertaken researches open new perspectives in regulation framework, offering new tools for GHG ship emissions' monitoring and evidence.*

Keywords: **maritime transports, CO_2 emissions, gas emissions, sustainable development.**

1. Introduction

The climate changes occurring throughout the recent decades have drawn the attention of humanity to the importance of greenhouse gas emissions (GHG) curtailment as a global priority. Since 1997, based on Kyoto Protocol, the UN member states enforced in case of the industrialized countries the curtail of emissions of greenhouse gases by 5.2% within 2008-2012 as compared to 1990. In 2012 this Protocol was extended until 2020 by the Doha Amendment [13]. The last UN conference on climate issues was held in Paris in 2015, where an agreement was reached to maintain the average global temperature increment bellow 2° C, further restricting it to 1.5° C [13]. This agreement will fundamentally change the manner in which unsustainable economies will act with regard to fossil fuels consumption throughout the next decades In this context, the CO_2 will become the priority strategic target, considering the main exhaust emissions from diesel engines that significantly contribute to the greenhouse effect [2].

The transport services sector is one of the leading producers of greenhouse gases emissions that come from exhausting gases of propulsion engines and diesel generators (in the case of maritime means of transportation). Following the CO_2 emissions evidence of 2012, it was estimated that maritime shipping is responsible for 3.1% of total emissions of CO_2 worldwide [10], [13]. Furthermore, scenarios of future maritime ships show that by 2050 the level of CO_2 emissions could rise by 50% up to 250% due to the

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economic growth and global energy market evolutions [13].

In order to reduce the greenhouse gas emissions from ships, the International Maritime Organization (IMO), as the responsible body for the international maritime transports regulation, imposed certain standards of energy efficiency by Resolution MEPC.203 (62) of 2011 [8]. Thus, the energy efficiency standard imposed by the IMO is the *Energy Efficiency Design Index* (EEDI), which is determined for each category of vessel depending on its type and tonnage [7]. EEDI is expressed in grams of carbon dioxide (gCO2) per ship capacity (dwt) and haul distance (miles) [6].

Based on a set of input data processed in the framework of calculus algorithms, the study presented below was carried out by means of an inventory of computing methodologies for determining the CO_2 masses exhausted by the marine diesel engines. These methods are useful either for management to determine the on board energy efficiency of the ships, or for national and international port authorities to determine the GHG emissions from ships.

2. Computing Methods

Currently there are several methods to calculate the CO_2 emissions from the power supplying sources on board the maritime ships: the *analytical calculation methods* and the *statistical methods of calculation*.

2.1. Analytical methods

2.1.1. Stoichiometric method

This method of determining the mass emissions of CO_2 from the exhausting gases of marine diesel engines can be applied if the carbon content of the used fuel and the fuel consumption per hour are known. To determine the mass of CO_2, the chemical equation will be used, namely the stoichiometric oxidation of the carbon in the burnt fuel composition [3]. [11]. The issuance mechanism of CO_2 emissions from burning one kilogram of fuel is:

$$C + O_2 \rightarrow CO_2 + Q_C \quad (1)$$

where C = carbon mass in the fuel [kg C/ kg comb]; O_2 = the oxygen content of the air supply [kg O_2/kg air]; Qc = the resulting heat energy from the chemical reaction [Mj/Kmol].

The above stoichiometric equation for oxidation is usually expressed in kilo moles:

$$1\ kmol\ C + 1 kmol O_2 \rightarrow 1 kmol\ CO_2 + Q_C \quad (2)$$

The reaction of carbon dioxide formation can be converted from kilo moles to kg by taking into account the molecular weight of carbon and oxygen, as follows:

$$12\ [kg\ C] + 32 [kg] O_2 \rightarrow [44\ kg] CO_2 \quad (3)$$

or

$$1[kgC] + \frac{32}{12}[kg\ O2] \rightarrow \frac{44}{12}[Kg\ CO_2] \quad (4)$$

For an amount of carbon burned “c” [kg C / kg comb] from fuel, the combustion equation will be:

$$c\ [Kg\ C] + \frac{32C}{12}[Kg\ O2] \rightarrow \frac{44}{12} c\ [Kg\ CO_2] \quad (5)$$

Therefore, the mass of carbon dioxide resulting from the combustion of the *c* mass of carbon in the fuel quantity is:

$$m_{CO2} = \frac{44}{12} * c. \text{ for 1 kg of fuel } [KgCO_2] \quad (6)$$

where, for a given quantity of fuel consumed in a given period of time, the above equation can be written as:

$$m_{CO2} = \frac{44}{12} * c * C_h \quad [(Kg\ CO_2)/h] \quad (7)$$

where C_h = hourly fuel consumption [kg comb/h]; c = carbon contents in fuel.

2.1.2. Carbon balance method for determining the exhaust mass

This method may be used if the concentration of CO_2 can be determined in the exhaust gases of engines. To use this method CO_2 emission should be measured using a gas analyzer. We should also measure the hourly fuel consumption and the supplying air parameters (pressure and temperature) and find out the percentage of chemical components of the used fuel.

To compute the masses of the specific emissions of CO_2, the calculation algorithm of the Technical Code on controlling emissions of nitrogen oxides (NO_x) for marine diesel engines should be used. This algorithm uses the carbon balance method to determine the mass flow rate of the exhaust gas [6]. This method should value the concentrations of components in the exhaust gases which have been determined on the basis of carried out experimental measurements. Therefore. the formula for calculating the mass flow rate of the exhaust emissions is:

$$q_{me\_w} = C_h \cdot \left\{ \left[\frac{\frac{1.4\cdot(C\cdot C)}{\left(\frac{1.4\cdot C}{f_c} + H\cdot 0.08936 - 1\right)\cdot\frac{1}{1.293} + f_{fd}}}{f_c \cdot f_c} + C \cdot 0.08936 - 1 \right] \cdot \left(1 + \frac{H_a}{1000}\right) + 1 \right\} \quad (8)$$

where: C_h – hourly fuel consumption of the engine [kg comb/h]; C – carbon in fuel [%]; H – the hydrogen content of the fuel [%]; H_a – the absolute humidity of the supply air [g water/kg air]; N – nitrogen content of fuel [%]; O – the oxygen content in the fuel [%]; f_{fd} – fuel specific constant; f_c – carbon factor.

The flow rate mass of the specific CO_2 emissions of exhaust gases has been determined by applying the next formula:

$$q_{CO2} = u_{CO2} * c_{CO2\_w} * q_{me\_w} \text{[kgCO}_2\text{/h]} \quad (9)$$

where: u_{CO2} – CO_2 ratio of component density and density of exhaust gas; c_{CO2_w} – wet concentration of CO_2 in the exhaust gas component [ppm]; q_{me_w} – wet exhaust gas mass flow rate [kg/h]. [6]

2.2. Statistic method

This computing method of CO_2 emissions from ships is rough estimated and based on ships' emission evidence for different fuels in case of different types of ships and diesel engines by applying various operating modes. Applying this method, the mass of CO_2 emission can be determined using the next formula:

$$M_{CO2} = \frac{C_h * FE_{CO2}}{1000} \text{ [toneCO}_2\text{/h]} \quad (10)$$

where C_h = hourly fuel consumption of the engine [kg comb/h]; FE_{CO2} = conversion factor for emissions [kg CO_2 emissions / per comb tone]. [1]

Therefore, in order to estimate the mass of CO_2 emissions of a ship during a voyage, the hourly fuel consumption of each onboard engine must be determined, as well as the operating modes of the voyage and the type of the fuel used to supply the onboard engines in order to identify the emissions' conversion factors.

2.2.1. The emissions' conversion factors

Counting the CO_2 emissions recorded were calculated several sets of emission conversion factors (FE CO_2). in relation with the fuel type used in marine engines.

The carbon content of each type of fuel is constant and is not affected by the type of engine or by other parameters when the mass of CO_2 emissions in kg/tone of fuel consumed is determined. The CO_2 emission fuel factors for the main and auxiliary engines on board. computed based on emission inventories are [1]. [7]:

- for the HFO type of naval fuel:
  FE_{CO2} = 3500 kg CO_2 /tone of fuel;
- for the MDO type of naval fuel:
  FE_{CO2} = 3200 kg CO_2/tone of fuel;
- for the LNG type of naval fuel:
  FE_{CO2} = 2750 kg CO_2 /tone of fuel;
- for biodiesel type of naval fuel:
  FE_{CO2} = 1900 kg CO_2/tone of fuel;
- pentru mixture of biodiesel and MDO:
  FE_{CO2} = 2700 kg CO_2 /tone of fuel.

2.2.2. Fuel consumption calculation

If the fuel consumption is not known, then it can be approximated using two methods: the *engine type method* and the *type of ship method*.

a. The fuel consumption calculation using the engine type

The specific basic fuel consumption for marine engines is determined statistically depending on the engine type and the year of manufacturing. In Table no. 1, the specific fuel consumption values in g/kWh are revealed [9].

Age of engine	Slow speed engine	Medium speed engine	Fast speed engine
Before of 1983	205	215	225
1984–2000	185	195	205
After 2001	175	185	195

Table 1

Since the naval engines operate in different regimes during a voyage, the fuel consumption depends on the operating mode of the engine, which can be determined.

In the case of *propulsion engines,* the functional capacity depends on the speed of the ship. In order to determine the functional capacity of a vessel at a certain speed, the engine power must be initially determined in relation with the speed. For this purpose, the statistically determined formulas based on the type of vessel should be used, as follows [4]:

- for the cargo, bulk carrier and tanker types of ship:

$$P_{p\ max} = c * V_{max}{}^{3} \qquad (11)$$

- for the container ships:

$$P_{p\ max} = c * V_{max}{}^{4.3} \qquad (12)$$

where $P_{p\ max}$ = propelling power of the ship at the maximum speed; P_{max} = maximum engine power at flange; V_{max} = the maximum speed of the sheep; c = specific constructive coefficient of the ship.

The propelling power of the ship at maximum speed will be determined with the next formula [4]:

$$P_{p\ max} = 75\% * P_{max} \qquad (13)$$

Therefore. the propulsion power for a ship at a specific speed should be calculated using the next formulas [4]:

- for the cargo. bulk carrier and tanker types of ship:

$$P_1 = \frac{V_1{}^3}{V_{max}{}^3} * 75\% * P_{max} \qquad (14)$$

- for the containerships:

$$P_1 = \frac{V_1{}^{4.3}}{V_{max}{}^{4.3}} * 75\% * P_{max} \qquad (15)$$

Therefore, the hourly fuel consumption of the propelling engines according to the applied trip speed will be computed based on the next formulas:

- for cargo, bulk carrier and tanker ships:

$$C_h = C_{Specific} * \frac{V_1{}^3}{V_{max}{}^3} * P_{max} \qquad (16)$$

- for the container ships:

$$C_h = C_{Specific} * \frac{V_1{}^{4.3}}{V_{max}{}^{4.3}} * 75\% * P_{max} \qquad (17)$$

In the case of onboard *auxiliary engines,* in order to determine the specific fuel consumption, the different situations of charging generators should be considered and the following formula can be used [9]:

$$SFOC(Load\%) = SFOC_{base} * [0.455 * (Load\%)^2 - 0.71 * (Load\%) + 1.28] \qquad (18)$$

where $SFOC_{base}$ values are specified above in Table no.1.

The calculation of fuel consumption for auxiliary engines depends on the operating conditions of the vessel (e.g. voyage conditions, handling regimes, stationary/trip regimes) and will take into account the loading factor and the number of the auxiliary engines used.

b. The fuel consumption calculation using the type of ship

The fuel consumption computation method for the sailing ship on voyage trip should use the formulas presented in table no. 2 [10].

Table 2

Type of ship	Maximum power consumption (t/ day) depending on the gross tonnage (GT)
Bulk solids	$C_{day} = 20.189 + 0.00049 * GT$
Liquid bulk	$C_{day} = 14.685 + 0.00079 * GT$
Cargo	$C_{day} = 9.8197 + 0.00143 * GT$
Containership	$C_{day} = 8.0552 + 0.00235 * GT$
Ro-Ro/gen.	$C_{day} = 12.834 + 0.00156 * GT$
Passenger	$C_{day} = 16.904 + 0.00198 * GT$
High-speed Ferries	$C_{day} = 39.483 + 0.00972 * GT$
Tug	$C_{day} = 5.6511 + 0.01048 * GT$
Pescador	$C_{day} = 1.9387 + 0.00448 * GT$
Cargo inland waters	$C_{day} = 9.8197 + 0.00143 * GT$
Other ships	$C_{day} = 9.7126 + 0.00091 * GT$

Valuing the maximum consumptions as computed in table no. 2. for different functional regimes of the ship next fractions will be used [10]:

Table 3

Operating regime	Fraction
Voyage	0.80
Maneuver	0.40
Stationary:	
- implicity	0.20
- passenger	0.32
- oil ship	0.20
- others	0.12
Tug - support ships	0.20
- the moderate activity	0.50
- in towage	0.80

3. Conclusions

The mass of CO_2 emissions in case of onboard aggregates in maritime shipping can be determined both by using precise calculation algorithms and by using statistical methods based on the available data about the ship's engine. on board aggregates and the type of fuel used by them.

The calculation of CO_2 emissions from the ships is further required in order to determine the level of energy efficiency by computing the EEDI coefficient. The ship management will have to take the necessary measures in order to bring it within the IMO imposed range. It is also useful and necessary for the port authorities to be able to establish the level of these emissions in order to monitor the exhaust emissions in the harbor and adjacent area and enforce and levy environmental taxes for ship pollution. The sustainable development becomes a fundamental goal of our society in the future; the naval industry must align its strategies to this new framework. Therefore, the ship management will have to consider all these issues in the forthcoming years.

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