Research on Ship Carbon Emission Statistical Optimization Based on MRV Rules

Pu Chen, Hailin Zheng(✉), and Bin Wu

School of Naval Architecture and Maritime, Zhejiang Ocean University, Zhoushan 316022, China

hlzhzjou@126.com

Abstract. Transportation, which accounts for 20% of the world's energy consumption and greenhouse gas emissions, is still rising fast. How to reduce greenhouse gas emissions and reduce the energy consumption of ships has become a major issue. This paper compares and analyzes four monitoring methods: fuel supply tracking, fuel tank level monitoring, flow meter monitoring and carbon dioxide gas monitoring. Carbon emission sources such as main engine, auxiliary engine, boiler, gas turbine and inert gas generator are monitored. Then, the quantitative methods of ship carbon emissions are compared, and the influence of ship impact factors on the calculation results is analyzed, so as to give the optimization measures.

Keywords: Ship · Carbon emission source · Monitoring method · Statistical optimization

1 Introduction

On March 22, 2018, the international energy agency (IEA) released its 2017 global energy and carbon dioxide status report, in which it announced that global energy-related carbon dioxide (CO_2) emissions (the largest source of man-made greenhouse gas emissions) increased 1.4% year on year to 32.5 billion tons in 2017, a record high. In the global carbon emissions, the carbon emissions of ships account for the largest proportion. With the increase of the carbon emissions of ships, the pollution of ships to the environment has also been widely concerned by the society. The research on ship carbon emission monitoring methods mainly involves the specific interests of stakeholders such as ports, shipowners and other relevant shipping departments in economy, health and environmental protection. It is of positive significance in reducing the adverse impact of air pollution on human environment, and also relates to the realization of emission reduction targets of operating ships. Therefore, this paper studies the current monitoring methods and carbon emission sources of ship carbon emissions and proposes corresponding optimization measures [1].

F. Neri et al. (Eds.): CCCE 2022, CCIS 1630, pp. 139–147, 2022.
https://doi.org/10.1007/978-3-031-17422-3_13

2 Carbon Emission Monitoring Methods for Ships

Carbon emissions from ships sailing on the sea mainly come from main engines, auxiliaries, boilers, gas turbines and inert gas generators. The carbon emission sources use different types of fuel, so the carbon emission factors are not the same. Ship fuel oil is generally divided into two types, namely residue type (heavy oil) and distillate type (light oil). In addition, many ships will use cargo as fuel, such as LNG ships.

For long-haul cargo ships, the main engine type is generally a low-speed diesel engine (two-stroke), using heavy oil, corresponding to the carbon emission factor of 3.114 or 3.151, see Table 1 for details.

Table 1. Characteristics of each carbon source of the ship.

Source of carbon emission	Machine type	Fuel type	Emission factor
Main engine	Low speed diesel engine	Heavy fuel oil	3.114
		Light fuel oil	3.151
Auxiliary engine	Medium/high speed diesel engine	Light fuel oil	3.206
Boiler	Auxiliary boiler, or Medium/high speed diesel engine	Light fuel oil	3.206

2.1 Fuel Supply List (BDN) Tracking and Bunker Periodic Inventory

BDN is provided by the fuel supplier as follows: 1) receiving the name of the fuel supply vessel and its IMO number; 2) fuel supply port; 3) fuel supply start time; 4) fuel supplier name, address and telephone; 5) fuel Name; 6) quantity of fuel (metric tons); 7) density of fuel at 15 degrees Celsius (kg/m^3); 8) sulphur content of fuel (%m/m); 9) a statement signed and certified by the supplier's representative (Prove that the fuel supplied is in accordance with paragraphs 14.1 or 4(a) and 18 of Annex 6 of the MARPOL Convention).

The calculation method of fuel consumption per unit time is as follows:

Fuel consumption is equal to the amount of fuel at the beginning of the period plus the amount of BDN minus the amount of fuel at the end of the period and then minus the amount of fuel at the end of the period.

Due to its poor accuracy and limited application range, this method cannot analyze each carbon emission source of ships one by one, and can only roughly calculate the total fuel consumption of carbon emission source, and it must be used in combination with the fuel tank level monitoring method.

2.2 Fuel Tank Level Monitoring

This method is simple and relatively low in cost. It is also unable to monitor various carbon emission sources of ships. The monitoring frequency is generally 2 times a day, and 1 time every 15 min when refueling. The liquid level is monitored by sounding equipment to read the level height of the fuel tank, which is converted into fuel volume after measurement, and then converted into fuel weight according to the fuel density (which can be obtained through BDN).

The calculation method of the fuel consumption of a ship in unit time or fixed voyage is as follows:

(Navigation on the sea) Fuel consumption equals to level in the tank when leaving the current port of call plus level difference when refueling during the voyage minus level in the tank when arriving at the next adjacent port minus level when the fuel is rejected during the voyage difference (parking) fuel consumption equals to tank level at the current port of call plus level difference when refueling during port stop minus level in tank when leaving the current port of call minus level difference when pumping out fuel during port stop.

2.3 Flow Meter Monitoring for Fuel Combustion Process

The electronic flow meter mainly measures the volume of the accumulative flow to monitor the carbon emission source of the ship main engine. The volumetric flow meter is mainly used for carbon emission sources such as auxiliary engines and boilers driven by medium-high speed diesel engines. The accuracy is up to 0.1–0.2%.

The types and characteristics of the flow meter are shown in Table 2:

Table 2. Flow meter types and characteristics for fuel monitoring.

Category	Subcategory	Measurement parameter	Accuracy	Applicable object or place
Electronic flow meters	/	Cumulative flow (volume)	0.2%	Main engine
Velocity sensing flow meters	Turbine meter	Instantaneous flow rate (volume of liquid flowing per unit time)	N/A	Large ship
Inferential flow meters	Variable aperture meter	Hydraulic difference	3.0%	/
Optical flow meters	N/A	Instantaneous flow rate (volume of liquid flowing per unit time)	N/A	/
Positive displacement flow meters	Oval gear, rotary piston	Cumulative flow (volume)	0.1–0.2%	High speed fluid
Mass sensing flow meters	Coriolis meters	Instantaneous flow rate (quality of liquid flowing per unit time)	0.05–0.2%	High value fluid

Fuel consumption per unit time or fixed voyage is calculated as follows:

(Sea voyage) Fuel consumption is equal to the sum of the flow meters at each carbon emission source during the voyage.

(Docking port) Fuel consumption is equal to the sum of the flow meters at each carbon emission source during the port stay.

2.4 Direct Carbon Emission Measurement

There are four kinds of methods for ship carbon emission monitoring, seen in Table 3 for details. The use of waste gas flow meter, through the main engine, auxiliary machinery, boiler chimney and other places directly measure the ship's carbon emissions, high accuracy, high cost, and for all types of carbon emission sources are applicable.

Fuel consumption per unit time or fixed voyage is calculated as follows:

(Sea voyage) Fuel consumption is equal to the total exhaust gas during the voyage times the ratio of the co_2 concentration to the carbon emission factor.

(Docking port) Fuel consumption is equal to the total amount of exhaust gas during port stay times the ratio of co_2 concentration to carbon emission factor.

3 Carbon Emission Calculation Method of Ship

3.1 Carbon Emission Calculation Method Based on IMO Emission Factor

In 2008, IMO MEPC/57 conference put forward new shipbuilding aiming to reduce ship emissions of greenhouse gases "CO_2 design index" (EEDI) and operation of the ship operating efficiency index (EEOI), involving two index calculation of fuel CO_2 conversion coefficient of emission factors, namely the EEOI unit transport power is defined as the ship amount of CO_2 emissions, MEPC. 1/Circ. 684 circular the vessel operating efficiency index (EEOI) voluntary use guide recommended EEOI formula (1):

$$EEOI = \frac{\sum_{\mathrm{j}} FC_j \times CF_j}{m_{c\,\mathrm{arg}\,o} \times D} \tag{1}$$

where FC_j means the actual consumption of fuel of class j, CF_j means the carbon dioxide emission factor, $m_{c\ \mathrm{arg}\ o}$ means the cargo transportation volume and D means the cargo transportation distance [2–7].

3.2 Calculation Method for Monitoring Oil Consumption of Flow Meter

The fuel consumption of the ship mainly comes from the main engine and secondary engine oil consumption. The fuel consumption of ship is directly proportional to the cubic power of ship speed [8]. Fuel consumption times carbon emission factor is equal to carbon emissions, the carbon emissions of a single voyage can be calculated by formula (2).

$$E_{CX} = EF_{CX} \times \left[MF_K \times \left(\frac{S_{1k}}{S_{0k}} \right) + AF_K \right] \times \frac{d_{ij}}{24S_{1k}} \tag{2}$$

where E_{CX} means the total carbon emissions of a ship for a voyage, EF_{CX} means fuel consumption, i means the starting port, j means the arrival port, MF_K means the daily fuel consumption of the main engine, S_{1k} means the real-time speed, S_{0k} means the rated speed, AF_K means the daily fuel consumption of the auxiliary machine, d_{ij} means the distance between the ports.

Table 3. Comparative analysis of ship carbon emission monitoring methods

	Costs/burden for ship owner or operator	Accuracy	Verification cost	Monitoring emissions types	Voyage monitoring	Annual monitoring	Emissions from each carbon source	Feedback timeliness	Mandatory	Data Consistency	Applicable to carbon emission sources
BDN tracking	No equipping cost	1–5%	highest	CO_2, SOX	Not applicable	applicable	Not clear	Serious lag behind	yes	Difficult to ensure	Main engine, auxiliary engine and boiler (cannot be monitored separately)
Tank sounding	1000–3000 USD	2–5%	higher	CO_2, SOX	applicable	applicable	clear	lag behind	no	Difficult to ensure	Main engine, auxiliary engine and boiler (cannot be monitored separately)
Flow meter monitoring	15000–60000 USD	0.05–2%	low	CO_2, SOX	applicable	applicable	clear	Real-time	no	Easier to ensure	Electronic flowmeter (main engine), volumetric flowmeter (auxiliary boiler)
Direct emission monitoring	100000 USD	2%	low	CO_2, SOX, NOX, PM and so on	applicable	applicable	clear	Real-time	no	Easier to ensure	Main engine, auxiliary engine, boiler (can be monitored separately)

3.3 Direct Carbon Emission Measurement Calculation Method

In unit time or fixed voyage, the exhaust gas flow meter is used to measure the concentration of carbon dioxide, the temperature of flue gas, the volume percentage of water vapor in the flue gas, the static pressure of flue gas and the flow rate of flue gas. An enhanced flue gas analyzer and a temperature and humidity meter are needed. Firstly, the carbon dioxide emission rate is calculated according to the clapeyron equation [9], as follows:

$$M_{CO2} = \frac{P * V_{总} \times (1 - \varphi) \times 44}{R * T} \times (V_{CO2} + V_{CO}) \times 10^{-6} \quad (3)$$

where M_{CO2} indicates the instantaneous emission rate (t/s) of carbon dioxide, P means the absolute pressure (pa) at the flue measurement point, $V_{总}$means the total volume of the flue at the flue monitoring point (m3/s), and the monitoring of the flue gas. V_{CO2} and V_{CO} means the volume fraction (%) of carbon dioxide and carbon monoxide, R means the standard gas molar volume, T means the thermodynamic temperature (K).

1) The calculation method of carbon dioxide emissions during the monitoring period is as follows:

$$S_{CO2} = M_{CO2} * t \quad (4)$$

2) Calculate the carbon emissions by the mass ratio method, that is, calculate the carbon dioxide consumption for a period of time by the ratio of the fuel consumption to the measured time, as in Eq. (5):

$$S_m = \frac{S_{CO2} * N_m}{N} \quad (5)$$

where S_m indicates the amount of carbon emissions(t) in the measured time, N_m indicates the fuel consumption(t) during the recording period, N indicates the fuel consumption(t) during the monitoring period.

3) The time ratio method calculates the carbon dioxide emissions, that is, calculates the carbon emissions by the ratio of the sailing time to the time period, as shown in Eq. (6):

$$S_m = \frac{S_{CO2} \times t_m}{t} \quad (6)$$

4) The load ratio method calculates the carbon dioxide emissions, that is, the carbon emission rate and the ship load are used to calculate the carbon emissions, as in Eq. (7):

$$S_m = \frac{M_{CO2} \times G_m \times t_m}{F} \quad (7)$$

where F indicates that the equipment monitors the average load (t/h), G_m indicates that the equipment is normally negative (t/h).

4 Analysis of Existing Problems in Carbon Emission Statistics of Water Transport Ships

4.1 The Monitoring Method Has a Large Error to the Statistical Results

Fuel supply note (BDN) tracking and bunker periodic inventory of vessels not suitable for cargo fuel or not available to BDN and must be used in conjunction with bunker level monitoring methods. The calculated fuel consumption of ships is larger than the actual one because the fuel in fuel piping system is neglected. Fuel tank level monitoring can be carried out manually or electronically, but the accuracy varies with the ship structure and software changes, and the calculation results do not include the fuel remaining in the fuel relationship, so the calculation results are larger; The flow meter is used to monitor the fuel combustion process in the fuel equipment. The calculated result is closer to the actual fuel consumed by the ship, and it is easy to distinguish the carbon emission of the ship within and outside the EU region, which is convenient for the preparation of carbon emission report, but the monitoring equipment costs more. However, technical input, calibration and verification of data and professional information technology support are needed to ensure the accurate collection, storage and transmission of data. Due to the lack of experience in use by shipowners, the carbon dioxide emission monitoring system is still out of reach.

4.2 Applicability Analysis of Carbon Emission Calculation Method of Ship

4.2.1 The Calculated Values of IMO Factors are Different

According to the calculation formula of EEOI, the ship energy efficiency operation index is mainly affected by the actual consumption of fuel oil and the carbon dioxide emission factor, which is related to the fuel type, and the fuel consumption is mainly affected by the diesel engine type, ship speed, cargo capacity and other factors. Therefore, it is not a simple linear correlation between the EEOI value and the influence factors.

4.2.2 The Monitoring Calculation of Flow Meter Makes the Statistical Result Close to the Actual Value

While monitoring all kinds of carbon emission sources, the flow meter monitoring method can take into account the residual fuel in the fuel pipe system, so the calculated fuel consumption of ships is close to the actual value. However, in the practical application process, the influence of environmental factors such as wind, wave and flow should also be considered, as well as the ship's own factors such as ship's dirty bottom (which can be multiplied by a dirty bottom coefficient according to the ship's dock repair period), the aging degree of the machine, mechanical transmission efficiency and acceleration distribution map [10].

4.2.3 Monitoring of Field Exhaust Gas Flow Meter Makes the Statistical Results More Accurate

On-site monitoring of carbon emissions, accurate access to fuel combustion carbon emissions. Mass ratio method depends on the accuracy of fuel measurement data, and its practical application value is relatively small. The quantitative method of time ratio method is better than the mass method, provided that the boiler combustion condition is consistent with the monitoring period. The load method is reliable because it considers the influence of boiler.

5 Optimization Measures of Ship Carbon Emission Statistics

5.1 Optimize Monitoring Methods and Explore New Perspectives on Emission Reduction

In terms of improving the efficiency of ship operations and the potential to adapt to future policies, supply single tracking, liquid level measurement only provides total fuel consumption, and direct carbon emission measurement only provides total carbon emissions, while flow meter monitoring provides real-time feedback on the amount of all exhaust gases emitted by the ship in each range. In terms of promoting emission reduction, single-supply tracking and liquid level measurement monitoring have been widely used, which cannot provide a new perspective for emission reduction. However, flow meter monitoring and direct carbon emission measurement methods are not widely used, which have great potential for emission reduction. Therefore, we should give full play to the monitoring methods under digital mode.

5.2 The Correlation Degree of Impact Factors is Analyzed to Improve the Quantification Accuracy of Carbon Emissions

Different quantitative methods are affected by different factors. The paper analyzes the three main influencing factors of EEOI fuel consumption, cargo carrying capacity and voyage distance. Under the condition that two of the factors remain unchanged, the vessel energy efficiency operating index shows a linear positive correlation, linear negative correlation and nonlinear negative correlation with fuel consumption, cargo carrying capacity and voyage distance respectively. Therefore, it is necessary to improve the accuracy of carbon emission statistics by analyzing the correlation degree of each impact factor through real ship data.

6 Conclusions

Although the MRV rules allow applicable ships to use any of the four types of carbon emission monitoring methods described above, ship borne carbon dioxide gas monitoring equipment is not widely used. Future carbon emission calculation is mainly based on fuel consumption monitoring, namely fuel supply single tracking, fuel tank level monitoring and flow meter monitoring methods. According to the quantification method of ship carbon emission, it is found that there is a non-simple linear relationship in the statistical process of ship carbon emission which is affected by various factors.

Acknowledgement. Zhejiang University Students' Science and Technology Innovation Activity Plan and New Miao Talent Project (2021R411041); Zhejiang Ocean University's National innovation and entrepreneurship training program for College Students (202010340035).

References

1. Yihong, W., Fuqiang, L.: Exploring low-carbon operation and practicing green development. China Ports **08**, 25–28 (2018)
2. Hailin, Z., Shuaijun, W., Hu, L.: Carbon emission analysis of ships based on AIS data. China water Trans. (Second Half) **14**(03), 157–158 (2014)
3. Peng, W.: Research on economic speed in ship operation. Dalian Maritime University (2016)
4. Zhenyang, Z.: Research on monitoring means and limitation methods of ship carbon emission. Dalian Maritime University (2015)
5. Shanshan, Y., Chuanxu, W.: Ship speed optimization under different carbon emission control policies. J. Dalian Marit. Univ. **41**(03), 45–50 (2015)
6. Qingbin, C.H.E.N.: Discussion on EEDI technical emission reduction measures. J. Jimei Univ. (Nat. Sci.) **17**(6), 454–459 (2012)
7. Junkai, N.I.: Research on ship energy efficiency operational indicator. Shanghai Jiao Tong University, Shanghai (2010)
8. Bin, L.I.: Introduction and analysis of ship energy efficiency design index and energy efficiency operation index. World Shipping **35**(3), 23–26 (2012)
9. Qiang, W.A.N.G.: Effects and countermeasures of executing new ship energy efficiency design index (EEDI). Guangdongship Build. **4**, 21–23 (2015)
10. Qiang, W.A.N.G.: Ship calculation and analysis of ship energy efficiency operation index. Navig. Technol. **6**, 26–28 (2015)