Comparative Analysis of Ship Carbon Emission Monitoring Methods Based on MRV Rules

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Keywords: MRV, Ship Emission, Monitoring Methods

Abstract: Transportation industry accounts for 20% of the world's energy consumption and greenhouse gas methods, and research on ship carbon emission monitoring methods can help achieve the goal of operating ship emission reduction. By analyzing the MRV rules, the four monitoring methods of BDN tracking, tank level measurement, flow meter monitoring and direct carbon emission measurement were compared and analyzed in terms of equipment cost, data collection and verification cost, monitoring accuracy and feedback real-time.Results indicate that future carbon emission calculations are mainly based on fuel consumption monitoring, such as BDN tracking, fuel Tank sounding monitoring and flow meter monitoring.

1. Introduction

In June 2013, the European Commission applied to the European Parliament and the Council for approval of the regulations on the monitoring, reporting and verification of carbon dioxide emissions from maritime transport, the MRV rules. Effective on July 1, 2015. At the same time, the International Maritime Organization (IMO) has adopted a guide on the establishment of a ship's data collection system (DCS) at its 71st meeting of the Marine Environment Protection Committee (MEPC), which was adopted on March 1, 2018. Effective. In addition, on March 15, 2017, China Classification Society promulgated the Technical Specification for Carbon Emissions Verification of Ships in Water Transportation Enterprises, which has entered into force.

Regardless of whether it is domestic or international, the ship supervision department has formulated corresponding regulations for ship carbon emissions, and the ship's carbon emission monitoring has shifted from voluntary to mandatory. Therefore, it is necessary to describe in detail the methods, equipment and errors of carbon emission monitoring, and to develop a corresponding carbon emission monitoring plan.

2. Definition of MRV Rules

The rules require that from January 1, 2018, the applicable ship should report to the European Commission the information on the ship's fuel consumption, carbon emissions, port of call, distance traveled, sea time, cargo capacity, cargo turnover and average energy efficiency, including voyages. Both reports and annual reports.

2.1. Applicable Ship

For ships of 5000 gross tonnage and above, for the purpose of transportation of goods and passengers, ships that are connected to the ports of EU member states after January 1, 2018 have nothing to do with the nationality of the ship and the port of registry! These rules are not applicable to the following ships: warships, naval auxiliary ships, fishing vessels, wooden vessels, non-motorized vessels and government vessels for non-commercial purposes.

2.2. Related Definition of Monitoring Plan

1) Ship carbon emissions

Ship carbon emissions refer to the amount of carbon dioxide emitted to the atmosphere by ships.

2) Port of call
The port of call refers to the port where the ship is docked for loading and unloading or for the upper and lower passengers, except for ports where the ship is only for refueling, replenishment, crew handover or maintenance. In addition, the ship docked at the port to avoid risks, the port outside the port, shelter from the wind or participate in maritime search and rescue are not in line with the port of call as defined in these rules.
3) Voyage
A voyage is a voyage of a ship that carries out commercial activities such as loading and unloading or upper and lower passengers between two consecutive ports of call.
4) Voyage distance
The voyage distance refers to the straight-line distance or measured distance from the last berth of the current port of call to the first berth of the next adjacent port of call, and only refers to the voyage to the ground, calculated in nautical miles.
5) Sailing time
The maritime sailing time refers to the sailing time of the ship from the last berth of the current port of call or the end of the ship-to-ship transfer operation to the first berth of the next adjacent port or the end of the ship-to-ship transfer operation in the port. , calculated in hours.
6) Ship average energy efficiency
The average energy efficiency of a ship refers to the amount of fuel consumption or carbon emissions generated by the unit's navigation distance, or the amount of fuel consumption or carbon emissions generated by the completion of the unit cargo turnover.
7) Reporting cycle
The reporting cycle is a calendar year in which the ship's carbon emissions are monitored and reported. For voyages spanning two consecutive calendar years, the monitoring and reporting data should be calculated in the first calendar year.

2.3. Monitoring Data

2.3.1. Voyage Monitoring

For ships applying these rules, the shipping company must monitor the ship voyage data as follows, see Table 1 for details:

1) Name of departure and arrival port (including the time when the last berth of the port and the first berth of the port are reached, using World Time); 2) The total amount of fuel consumed by the ship and its corresponding carbon emission factor 3) carbon emissions; 4) sailing distance; 5) sea navigation time; 6) cargo capacity; 7) cargo turnover.

Table 1. List of voyage monitoring data

Parameters	Voyage duration	Duration when calling port of EU member states
Fuel consumption	included	included
Carbon emission	included	included
Distance travelled	included	excluded
Time spent at sea	included	excluded
Cargo transportation volume	included	excluded
Cargo turnover	included	excluded

According to Table 1, the voyage monitoring data of the ship does not include the sailing distance, sea navigation time and cargo load during the port call; the fuel consumption generated during the port call must be monitored, but not as the voyage report data; Within the jurisdiction of EU member states, carbon emissions generated during the period should be used as voyage report data.

The following vessels may be exempted from voyage monitoring: during the reporting period, the port of call for all voyages of the ship is within the jurisdiction of the EU member states; or during the reporting period, the ship is expected to be connected to the port of the EU member state for more than 300 flights.

2.3.2. Annual monitoring

For ships applying these rules, the shipping company must monitor its ship's annual data as follows, as detailed in Table 2:

1) The total amount of fuel consumed by the ship and its corresponding carbon emission factors; 2) the total amount of carbon emissions; 3) the total amount of voyage carbon emissions to and from the ports under EU jurisdiction; 4) the voyage carbon leaving the ports under EU jurisdiction Total emissions; 5) total carbon emissions from voyages arriving at EU-administered ports; 6) carbon emissions during the period of jurisdiction of EU member states; 7) total navigation distance, total maritime navigation time, total cargo turnover and average energy efficiency of ships .

According to Table 2, the annual monitoring data of the ship does not include the sailing distance, sea navigation time and cargo load during the port call; the fuel consumption generated during the port call must be monitored and used as the annual report data; the port of call is in the EU Within the jurisdiction of a Member State, the carbon emissions generated during the period shall be calculated as carbon emissions within the port; if the port of call is outside the jurisdiction of the EU member states, the carbon emissions generated during the period shall be calculated as voyage carbon emissions.

Table 2. List of annual monitoring data

Parameters	Voyage duration	Duration when calling port of EU member states
Fuel consumption	included	included
Carbon emission	included	included
Distance travelled	included	excluded
Time spent at sea	included	excluded
Cargo turnover	included	excluded

3. Ship Carbon Emission Monitoring Methods

Ships sail on the sea, and their carbon emissions are mainly from main engines, auxiliary engines, boilers, gas turbines and inert gas generators. The carbon emission factors vary depending on the type of fuel used by each carbon source. Ship fuels are generally divided into two categories, namely residue type (heavy oil) and fraction type (light oil). The former is used for normal navigation at sea and the latter is used for motorized navigation. In addition, many ships use cargo as fuel, such as LNG ships.

For long-haul freighters, the main engine type is generally low-speed diesel engine (two-stroke), using heavy oil, corresponding to carbon emission factor 3.114 or 3.151, refer to Table 3.

Table 3. 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

There are two methods for monitoring ship carbon emissions, direct monitoring and indirect monitoring. The direct monitoring method is to use carbon emission-related hardware equipment to measure the emission rate of carbon-containing gas to obtain carbon emissions; indirect measurement is mostly obtained by calculating the fuel consumption multiplied by the carbon emission factor, or by proportional The method is compared to the average carbon emissions in known cases.

3.1. BDN Tracking

According to the requirements of the International Pollution Prevention Convention (MARPOL), ships of 400 gross tonnage and above must retain BDN for each refueling and keep the ship for 3 years, effective from July 2010. In addition, the fuel sample to be supplied must be kept on board for 12 months or stored until the batch of fuel is exhausted, whichever is later.

This type of method adds little to the cost of any monitoring equipment, but has poor accuracy and limited range of use. It is not suitable for ships that are fueled by cargo or ships that are not available to BDN, and must be used in conjunction with fuel tank level monitoring methods.

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/m3); 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).

3.2. Tank Sounding

The liquid level monitoring reads the fuel tank liquid level height through the sounding equipment, converts it into fuel volume through the sounding depth meter, and converts it into fuel weight according to the fuel density (obtained by BDN). The liquid level monitoring methods include three types, electrical sounding, mechanical sounding and manual sounding. The corresponding monitoring equipment include oil dipstick, oil tank scale and liquid level detection tube.

This type of method is simple and relatively inexpensive, and can be monitored manually or electronically, but the accuracy varies with ship construction and software changes. The monitoring frequency is generally 2 times a day, and once every 15 minutes when fuel is added.

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

Wherein, the liquid level difference when adding fuel refers to the difference between the fuel tank level after the fuel is added and the fuel tank before the fuel is added. When the fuel is rejected, the liquid level difference refers to the difference between the fuel tank level before fuel rejected and after fuel rejected.

3.3. Flow Meter Monitoring

The above two methods ignore the fuel remaining in the fuel piping system, and the calculated fuel consumption of the ship is larger than the actual one. The flow meter is used to monitor the fuel combustion process in the fuel equipment. The calculation result is closer to the fuel actually consumed by the ship, which can achieve higher accuracy and easy to distinguish the carbon emissions of the ship in and outside the EU region, facilitating the preparation of carbon emission reports. However, the cost of monitoring equipment is higher. Flow meter types and characteristics are shown in Table 4:

The fuel consumption of the ship is mainly from the main engine and auxiliary machine of the ship, and the oil consumption. The fuel consumption of the ship is proportional to the cube of the ship speed. The fuel consumption multiplied by the carbon emission factor is equal to the carbon emission, and the carbon emission of a single voyage can be calculated by the formula (1).

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

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 4. 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

In the actual application process, it is also necessary to consider the influence of environmental factors such as wind, wave and flow; at the same time, the sewage bottom of the ship (which can be multiplied by a fouling factor according to the docking period of the ship), the aging degree of the machine, and the mechanical transmission. The ship's own factors such as efficiency and acceleration profile. Multiplying each factor by the above equation yields fuel consumption. When berthing at a port or anchorage, it can be connected to the shore or the auxiliary machine to generate electricity. The shore power does not need to calculate the fuel consumption.

3.4. Direct Carbon Emission Monitoring

The exhaust gas flow meter is used to directly measure the ship's carbon emissions through the chimney and other places, with high precision and high cost, and the shipowner's experience is lacking. The calculation method of the fuel consumption of a ship in unit time or fixed voyage is as follows:

First measure the carbon dioxide concentration, the flue gas temperature, the volume percentage of water vapor in the flue gas, the static pressure of the flue gas, and the flow rate of the flue gas. A reinforced flue gas analyzer and a temperature and humidity meter are required. First, calculate the carbon dioxide emission rate according to the Crabone equation, as follows:

$$M_{CO2} = \frac{P * V_{总} \times (1-\varphi) \times 44}{R * T} \times (V_{CO2} + V_{CO}) \times 10^{-6} \tag{2}$$

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).

Table 5. 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
BDN tracking	No equipping cost	1-5%	highest	CO2, SOX	Not applicable	applicable	Not clear	Serious lag behind	yes	Difficult to ensure
Tank sounding	1000-3000 USD	2-5%	higher	CO2, SOX	applicable	applicable	clear	lag behind	no	Difficult to ensure
Flow meter monitoring	15000-60000 USD	0.05-2%	low	CO2, SOX	applicable	applicable	clear	Real-time	no	Easier to ensure
Direct emission monitoring	100000 USD	2%	low	CO2, SOX, NOX, PM and so on	applicable	applicable	clear	Real-time	no	Easier to ensure

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

$$S_{CO2} = M_{CO2} * t \tag{3}$$

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 equation (4):

$$S_m = \frac{S_{CO2} * N_m}{N} \tag{4}$$

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 equation (5):

$$S_m = \frac{S_{CO2} \times t_m}{t} \tag{5}$$

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 equation (6):

$$S_m = \frac{M_{CO2} \times G_m \times t_m}{F} \tag{6}$$

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

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

In Table 5, in terms of improving the energy efficiency of the ship's operation and adapting to the potential of future policies, supply order tracking and liquid level measurement only provide total fuel consumption, direct carbon emission measurement only provides total carbon emissions, and flow meter monitoring can provide real-time feedback to the ship. The quantity of all exhaust gas emissions in each navigation section; in terms of emission reduction promotion, supply order tracking and liquid level measurement monitoring have been widely used, and new emission reduction perspectives cannot be provided. Flow meter monitoring and direct carbon emission measurement methods are not widely used. The potential for emission reduction is large.

4. Conclusions

Although the MRV rules allow applicable ships to use any of the above four types of carbon emission monitoring methods, current on board carbon dioxide gas monitoring equipment is not widely used, and future carbon emission calculations are mainly based on fuel consumption monitoring, fuel supply order tracking, fuel Tank level monitoring and flow meter monitoring methods.

In terms of monitoring equipment costs, the fuel supply bill tracking and liquid level measurement methods in the four types of carbon emission monitoring methods are relatively low cost, especially the fuel supply bill tracking method, and no monitoring equipment needs to be installed; in terms of monitoring accuracy, the flow meter monitoring and Direct carbon emission measurement accuracy is high, especially for flow meter monitoring, which is one order of magnitude higher than other methods; in terms of data collection and verification costs, fuel supply single tracking and liquid level measurement methods are costly due to the lack of automatic monitoring equipment. In particular, the fuel supply bill tracking method relies entirely on paper records.

Acknowledgement

Fund Project: Zhejiang University Students' Science and Technology Innovation Activity Plan and

New Miao Talent Project(2017R411056).

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