Comparative Study on Environmental Benefits of Using low-Sulphur Oil and Shore Power Technology for Ship Berthing

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Abstract: In order to compare the environmental benefits of two emission reduction measures, i.e. using low-sulphur oil and shore power technology, this paper takes the ships arriving at Guangzhou port as an example, based on the ship data of entry and departure visa of Guangzhou port in 2015, and uses statistical analysis to determine the relationship between different ship types of diesel engines, ship berthing time and ship deadweight tonnage, and based on the use of low-sulphur oil and berthing using shore power air pollutants emission. On the basis of emission factors and diesel engine load, the environmental benefits of the two emission reduction measures are calculated by the calculation model established by the dynamic method. The results show that: (1) in 2015, when ships berthing in Guangzhou port used low-sulphur oil with sulphur content of 0.5%, PM₁₀, NO_x, SO_x and CO₂ decreased by 231.6t, 165.5t, 2039.3t and 0t respectively, when using low-sulphur oil with sulphur content of 0.1%, PM₁₀, NO_x, SO_x and CO₂ decreased by 244.1t, 517.1t, 2382.7t and 0t respectively. when ships berthing in Guangzhou port used shore power, PM, NO_x, SO_x and CO₂ decreased by 283.8t, 2975.6t, 2407.7t and - 3782.2t respectively. (2) compared with the use of low sulphur oil, the use of shore power by berthing ships has a significant advantage in NO_x emission reduction. In terms of particulate matter, SO_x and CO₂ emission reduction, there is no significant difference between the two measures.

1 Introduction

Maritime transport is the most important mode of transport in international trade, which has made a great contribution to global economy and trade, but also brought about air pollutants, especially the atmospheric environment in the port area [1-4]. In order to control the air pollution of the port and strictly control the emission requirements of berthing ships, the emission reduction measures that berthing ships can choose include the use of low-sulphur oil, the use of shore power and other measures [5]. In November 2018, the implementation plan for the emission control area of air pollutants from ships issued by the Ministry of Transport clearly proposed the requirements for berthing ships to enter the emission control area to use low-sulphur oil and shore power.

Berthing ships using low-sulphur oil and shore power technologies as the main emission reduction measures of ships, which have significant environmental benefits in the emission of particulate matter, NO_x and SO_x pollutants [6-8]. Ship type, berthing time, ship tonnage and other factors will affect the environmental benefits of the two emission reduction measures. In order to compare

the differences in environmental benefits between the two emission reduction measures, this paper takes the ships arriving at Guangzhou port as an example, and takes the five main ship types of container, dry bulk cargo ship, general cargo ship, liquid bulk cargo ship and ro-ro ship as the research object. According to ship data of entry and departure visa of Guangzhou port in 2015, Based on the statistical analysis to determine the relationship between the diesel engine for power generation of different types of ships, the length of ship's berthing time and the ship deadweight tonnage, and the emission factors of air pollutants from berthing ships using low-sulphur oil and shore power, and the load of generating diesel engine, the environmental benefits of the two emission reduction measures are calculated respectively by the calculation model established by the dynamic method, to provides a reference for the development of ship emission reduction measures guidelines.

2 Overview of Guangzhou Port

By the end of 2014, Guangzhou port had 533 berths, 69 berths above 10000 tons, with a total length of 46958

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meters, cargo throughput of 36.99 million tons and container throughput of 12.29 million TEU.

According to the statistics of the maritime department, in 2015, the number ships of entry and departure Guangzhou port reached 207968, and the main types of ships were 35874 container ships, 45588 dry bulk cargo ships, 59634 general cargo ships (including dry cargo ships, multi-purpose ships and general cargo ships), 14177 liquid bulk cargo ships (including oil tanker, chemical tanker), and 548 ro-ro ships. The number of above five types of ships reached 155821, which is 74.9% of the number of ships entry and departure Guangzhou port in 2015. This paper takes the above five types of ships as the research object and makes a comparative analysis.

3 Research methods

3.1 Pollutant emission calculation model

There are two methods to calculate the emission of pollutants from ships: dynamic method and fuel oil method [9]. With the development of ship management information, the dynamic method based on ship activity level is widely used to calculate ship pollutant emission

Table 1. The function relationship between the ship DWT and the rated power of generating diesel engine

Type of ship	Ship deadweight ton	Rated power of generating diesel engine (kW)
Container	DWT>120000t	P = 147854
	120000t≥DWT>50000t	P = 1277.9 + 0.11DWT
	50000t≥DWT	Y = 310.3 + 0.15DWT
Dry bulk cargo	DWT>400000t	P = 4398
	400000t≥DWT>350000t	P = 3600
	350000t≥DWT>300000t	P = 3150
	300000t≥DWT>100000t	P = 2219
	100000t≥DWT>30000t	P = 1746
	30000t≥DWT>10000t	P = 586.6 + 0.025DWT
	10000≥DWT	P = 49.8 + 0.057DWT
General cargo	DWT>10000t	P = -1208.3 + 0.18DWT
	10000t≥DWT	P = -6.6 + 0.089DWT
Liquid bulk cargo	DWT>10000t	P = 2395.7 + 0.0048DWT
	10000t≥DWT	P = 66.1 + 0.14DWT
Ro-ro ship	All	P = 965.1 + 0.16DWT

3.3 Load factor of generating diesel engine

During ship berthing, the power generated by the diesel engine mainly provides power for lighting equipment, domestic sewage treatment device, ventilation system, air conditioning system, onboard communication equipment, etc. According to the working experience of marine engineers, the load of diesel engine is about 60% of its rated power during berthing, and the load factor in this paper is 0.6.

inventory [10]. The dynamic method is to calculate the emission of air pollutants by parameters such as the power of generating diesel engine, the time of berthing, the load factor and the emission factor. In this paper, the dynamic method is used to calculate the emission of air pollutants from ships berthing.

$$E_k = \sum (P_i \times LF_i \times T_i) \times EF_k \quad (1)$$

Where, E_k is emissions of a pollutant(unit: g), P_i is rated power of generating diesel engine of the i ship, LF_i is the load factor of generating diesel engine of the i ship, T_i is the operation time of the generating diesel engine during berthing of the i ship(unit: h), EF_k is the pollutant emission factor(unit: g/kWh), i is the number of berthing ships, k is the pollutant number.

3.2 Rated power of generating diesel engine

It is very difficult to know the rated power of generating diesel engine of every ship. In this paper, through sampling survey, relying on the information of ship database, statistical analysis method is adopted to establish the functional relationship between different types of ship DWT and the rated power of generating diesel engine, as shown in Table 1.

3.4 Operation time of generating diesel engine

The berthing time of a ship is affected by such factors as the ship type, quantity, loading and unloading efficiency, weather conditions, water traffic control, etc. the berthing time of each ship is different. In theory, the ship data of entry and departure visa record the time of ship arrival and departure. According to the arrival time and departure time, the estimated berthing time is not accurate and cannot be accepted. Guangzhou Port Dispatching Centre is responsible for the inbound and outbound dispatching of vessels above 3000DWT, and records the inbound and outbound time of vessels in

detail. Based on this, for ships more than 3000DWT, this paper establishes the functional relationship between the ship's deadweight tonnage and berthing time according to the data of Guangzhou Port Dispatching Centre and the

ship type, for ships less than 3000DWT, according to the survey data statistics, the berthing time of most of ships is 10-14 hours, and the berthing time of ships less than 3000DWT is 12 hours.

Table 2. The function relationship between the ship DWT and the berthing time of the port

Ship deadweight tonnage	Type of ship	Length of berthing time(h)
$DWT \geq 3000t$	Container	$T = -0.00002DWT + 17.0$
	Dry bulk cargo	$T = 0.0002DWT + 51.5$
	General cargo	$T = 0.0004DWT + 20.8$
	Liquid bulk cargo	$T = 0.0006DWT + 31.0$
	Ro-ro ship	$T = 0.0001DWT + 16.7$
$DWT < 3000t$	All	$T = 12$

3.5 Pollutant emission factors

3.5.1 Emission factors of pollutants from ships using low-sulphur oil

Marine fuel oil includes residual fuel oil and distillate fuel oil. Through a questionnaire survey of ships arriving at Guangzhou port, most of the ships berthing at Guangzhou port use residual fuel oil, with an average sulphur content of 2.7%; ships less than 3000DWT

generally use marine distillate oil or ordinary diesel oil, with ordinary diesel oil as the main fuel oil.

When the ship enters the emission control area, the fuel oil with sulphur content no more than 0.5% shall be used from January 1, 2019, when the ship enters the inland river control area from January 1, 2020, the fuel oil with sulphur content no more than 0.1% shall be used. In this paper, the environmental benefits of two kinds of low-sulphur oil with sulphur content of 0.5% and 0.1% are analyzed. See Table 3 for the emission factors [8] of generating diesel engine with different sulphur content.

Table 3. Emission factors of generating diesel engine with different sulphur content

Fuel Type	sulphur content	PM ₁₀ (g/kWh)	NO _x (g/kWh)	SO _x (g/kWh)	CO ₂ (g/kWh)
Residual fuel oil	2.7%	1.44	14.7	11.98	683
Low-sulphur oil	0.5%	0.32	13.9	2.12	683
Low-sulphur oil	0.1%	0.26	12.2	0.46	683

3.5.2 Pollutant emission factors of shore power used by ships

In the calculation of the air pollutant emission of the ship using shore power, the emission in the power generation process should be considered [6]. In 2016, China coal-fired power generation accounted for 65.5% of the total power generation, and the emission factors of air

pollutants in the coal-fired power industry [11] are shown in Table 4. China power generation methods include thermal power, wind power, solar energy, nuclear power, etc. in addition to coal-fired power, the emission of clean energy power generation is zero. See Table 4 for the calculation of air pollutant emission factors of China power industry.

Table 4. Air pollutant emission factors of China Coal-fired power industry and power generation industry in 2016

	PM (g/kWh)	NO _x (g/kWh)	SO _x (g/kWh)	CO ₂ (g/kWh)
Coal-fired power industry	0.08	0.36	0.39	822
Power generation industry	0.052	0.24	0.26	538

4 Results and discussion

4.1 Calculation of environmental benefits of using low-sulphur oil for berthing ships

For ships using low-sulphur oil, the conversion of ships to low-sulphur oil has been completed before entering the port, and the berthing time of ships is the time of using low-sulphur oil for generating diesel engines.

The sulphur content of general diesel oil is 350ppm before June 30, 2017, and 50ppm after July 1, 2017. General diesel oil is mainly used for ships less than 3000DWT.all of which meet the requirements of low-sulphur oil. During the berthing of ships, it is not necessary to convert low-sulphur oil. In this paper, the environmental benefits of two kinds of low-sulphur oil with sulphur content of 0.5% and 0.1% are analyzed.

According to the ship data of entry and departure visa of Guangzhou port, formula (1) and table1 -3, the reduced air pollutant emissions of ships berthing in

Guangzhou port after switching to low-sulphur oil in 2015 are calculated as shown in Table 5. It can be seen that for ships berthing in Guangzhou port, the use of low-sulphur oil with sulphur content of 0.5% is reduced by

231.6t, 165.5t, 2039.3t and 0t for PM₁₀, NO_x, SO_x and CO₂ respectively, and 244.1t, 517.1t, 2382.7t and 0t for PM₁₀, NO_x, SO_x and CO₂ respectively.

Table 5. Reduction of air pollutants from berthing ships to use low-sulphur oil in Guangzhou Port

Emission reduction measures		PM ₁₀	NO _x	SO _x	CO ₂
Transfer to oil with sulphur content 0.5%	Reduction(t)	231.6	165.5	2039.3	0
	Reduction(%)	77.8	5.4	82.3	0
Transfer to oil with sulphur content 0.1%	Reduction(t)	244.1	517.1	2382.7	0
	Reduction(%)	81.9	17.0	96.2	0

4.2 Calculation of environmental benefits of berthing ships using shore power

For the use of shore power when the ship is berthing, all ships can use shore power during berthing. Due to the operation time of loading and unloading shore power, the time of berthing ship using shore power is shorter than that of berthing ship. The operation of shore power loading and unloading of small ships is convenient and short time-consuming, which can be ignored; the power consumption of large ships is long, which generally takes 1 hour according to the experience of terminal operators. In this paper, the time of using shore power during

berthing of ships less than 3000DWT is calculated as the time of berthing; the time of using shore power during berthing of ships more than 3000DWT is calculated as the time of berthing minus one hour.

According to the ship data of entry and departure visa of Guangzhou port and formula (1) and table 1, table 2 and table3 of ships entering and leaving Guangzhou port, the reduced air pollutant emissions of ships berthing Guangzhou port after using shore power in 2015 are calculated as shown in Table 6. It can be seen that PM, NO_x, SO_x and CO₂ are reduced by 283.8t, 2975.6t, 2407.7t and - 3782.2t respectively after berthing ships using shore power in Guangzhou port.

Table 6. Reduction of air pollutants after berthing ships using shore power in Guangzhou Port

Emission reduction measures		PM	NO _x	SO _x	CO ₂
Using shore power	Reduction(t)	283.8	2975.6	2407.7	-3782.2
	Reduction(%)	95.3	97.9	97.2	-2.7

4.3 Error analysis

There are five factors that affect the accuracy of the two emission reduction measures: (1) there is an error between the power of generating diesel engine obtained from the ship database and the actual power of the ship. (2) there is a certain error between the berthing time of the ship obtained from data of Guangzhou Port Dispatching Centre and the actual berthing time of the ship, and the berthing time of the ship's shore power operation also exists in a certain error. (3) the load of the diesel engine of the ship's power generation is the instantaneous value of the time change according to the factors such as the ship type and the power load at that time, which is replaced by a constant, it is bound to produce errors. (4) the different models and brands of the generating diesel engine, the emission factors are bound to be different, which will also have an error impact on the results. (5) When calculating the emission of particulate matter, the two emission reduction measures use different concepts of particulate matter, which also affects the accuracy of comparison.

5 Conclusion

(1) through statistical analysis, the relationship between the diesel engine of different ship types, the time of berthing and the ship's load is determined. According to the emission factors of air pollutants for using low-sulphur oil and for using shore power, the load of generating diesel engine, and the data of ship entering and leaving port visa, the calculation model can be used to calculate the environmental benefits of taking emission reduction measures for berthing ships.

(2) the use of low-sulphur oil and shore power by berthing ships has obvious emission reduction effect in terms of particulate matter, NO_x and SO_x. There is no change in CO₂ emission when using low-sulphur oil. CO₂ emission will slightly increase after using shore power of berthing ships.

(3) compared with using low-sulphur oil, the use of shore power by berthing ships has obvious advantages in NO_x emission reduction. In terms of emission reduction for particulate matter, SO_x and CO₂, the two measures have little difference in emission reduction effect.

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