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Research on location selection of the key monitored areas of black carbon emission from the ships along the coast of Liaoning Province

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Research on location selection of the key monitored areas of black carbon emission from the ships along the coast of Liaoning province

By

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DECLARATION

I certify that all the material in this research paper that is not my own work has been identified, and that no material is included for which a degree has previously been conferred on me.

The contents of this research paper reflect my own personal views, and are not necessarily endorsed by the University.

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ABSTRACT

Title of Research Paper: **Research on location selection of the key monitored areas of BC emission from the ships along the coast of LIAO NING province**

Degree: **MSc**

Next to Carbon Dioxide, the emission of Black Carbon (BC) is the second major factor which causes greenhouse effect and the declines in the Arctic sea ice. Therefore, BC gradually becomes a pollutant which catches the whole world's attention. The IMO begins to set a series of requirements and regulations on the limitation of BC emission by ships which should be echoed by shipping industry. This research goes as the following process: Firstly, the definition and recent researches on BC were introduced, elucidating that the pollutant emissions from ships, including BC, can do harm to the air, ecological environment, as well as human health. Secondly, we elaborated the measurement of BC, its influence factor and its applicability, and we revealed the impact that ship engine load, fuel quality and filters have on the emission of BC. This research paper also introduced the forming of pollutant emission list and its significance to the research on ship pollutant emission. In addition to this, we also learned about AIS (AIS), it was used to collect the information of ships in accordance with our survey and calculation and formed the track chart about coastal ship route around LIAO NING province. We finally chose the LAO TIE SHAN waterway as the key monitoring area of BC emission from ships because of its' large flow rate and highly convergence showed on track chart of ships. Besides, a series of formulae, such as the general formulae of ships' pollutant emission, improvement formulae and emission list model formula, were comprehensively used in this research paper, combined with the number of ships in the LAO TIE SHAN waterway in accordance with our survey and calculation and the fuel consumption factor as the research data. In this way, we worked out the total amount of fuel consumption by the various ships in the key monitoring area this quarter. At last, based on different kinds of ships, engine load and BC emission factor according to fuel quality, we got 18.52t as the estimated result of the total BC emission from ships in the area of the LAO TIE SHAN Waterway in accordance with our survey and calculation. This research paper draw lessons from the relative articles at home and abroad, and according to these we could finally work out the answer we need successfully.

KEY WORDS: BC pollution; AIS; Estimation formula; Emission factor

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LIST OF ABBREVIATIONS

AE	Auxiliary Engine
AIS	Automatic Identification System
BC	Black Carbon
BC-FSN	Black Carbon Filter Smoke Number
BC-PAS	Black Carbon Photoacoustic Spectroscopy
BLG	Bulk Liquid and Gas Sub-Committee
EC-TOA	Element Carbon Thermal Optical Analysis
GPS	Global Position System
HFO	Heavy Fuel Oil
ICOADS	International Comprehensive Ocean Atmospheric Data Set
IMO	International Maritime organization
LFO	Low Fuel Oil
LRIT	Long Range Identification and Tracking (System)
MARPOL	International Convention for the Prevention of Pollution From Ships
MDO	Marine diesel oil
ME	Main Engine
MEPC	Marine Environment Maritime Protection Committee
MGO	Marine gas oil
MSD	Medium Speed Diesel
PM	Particulate Matter

SOLAS	International Convention for the Safety of Life at Sea
SSD	Slow Speed Diesel
AE	Auxiliary Engine

CHAPTER 1

INTRODUCTION

1.1 The Background and Significance of the Project Research

As the environmental pollution has gradually become a global hot issue, Black Carbon (BC) has drawn great attention to the public. Through the researches of BC by the scholars all over the world in recent years, the definition of BC is set and its character is understood. What's important, the research has shown that the BC has a significantly promotional effect to the melt of the Arctic sea ice, thus IMO has gradually put into agenda series of schemes to decrease the emission of BC from ships, which deserves attention of the global maritime organizations and shipping entities.

Black Carbon, shortly called as BC, is the production of material contained with carbon (mainly petroleum, coal, carbon, trees, firewood, plastic garbage and animals' excrement) formed after the incomplete combustion, and is the major component of aerosol in the air (Xu.,2015). The BC aerosol is able to strongly absorb the solar radiation ranged from visible light and Infrared Wavelength, therefore it is assumed as the second major factor, next to carbon dioxide, which causes the global warming and is a great threat to global climate (AMAP, 2015). Besides, the BC aerosol is a kind of inhalable air pollutant, so it is also a hazardous factor to human health and ecological environment. In consequence, the emission of BC has drawn more and more attention from research fields about global climate changes and environment in the world.

Since the Industrial Revolution, along with the process of industrialization and the rapid development of science and technology, a large number of industrial raw materials, especially burning fossil fuels used to produce energy, making BC aerosol emissions substantially grow in the whole world.

In particular, when the BC sinks to the surface of the ice, it reduces its surface emissivity and absorbs the sun's radiation so that the temperature rises and the ice melts. For this unique characteristic of BC, the Arctic sea ice melting problem push the problem of BC to the forefront of environmental research. And with the development of ocean transportation, ship's increasing BC emissions will speed up the melting of the polar ice and thus has gained much attention from IMO. At present, according to a study, the measures of IMO to slow down the BC emissions are mainly enforced in the arctic as key navigational area. However, along with the strong recommendation and pressure from Europe and the United States for BC emissions control, restrictions on BC emissions will be most likely imposed on the navigational area all over the world rather than merely the North Pole.

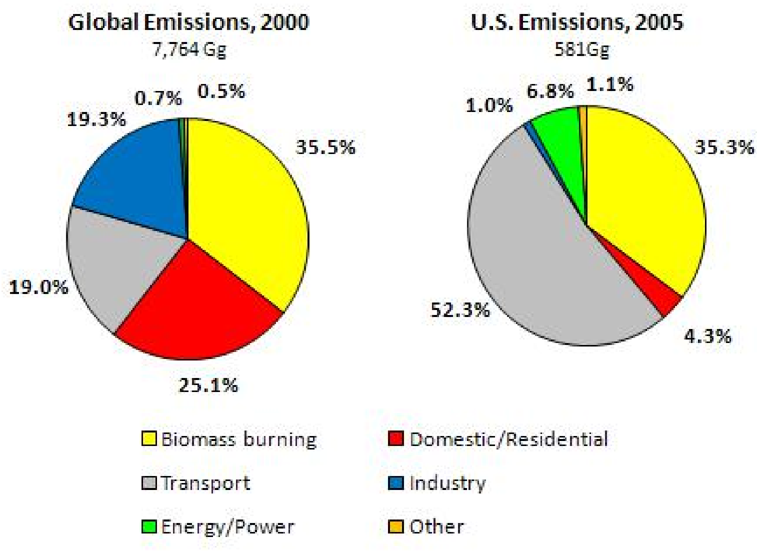


Figure 1.1 View of BC emissions in each area

Source: U.S. EPA. Report to Congress on Black Carbon (2012);

http:// www. epa. gov/ blackcarbon/

Therefore, the study on the BC emission of ships in the key navigational areas is of advanced significance to the development of the shipping industry as well as the health of human's living environment.

As we can see from Figure 1.1, the BC emission in the transportation industry accounts for a lot of the total emissions. The study of BC emissions is representative of the shipping industry, which is the largest transportation carrier.

1.2 Research Process of BC emission from shipping

The latest research shows that BC is the second leading cause of global warming, behind carbon dioxide (Wang, 2016). BC can exist in the atmosphere for about five to twelve days. The melting Arctic sea ice has become one of the hot issues of major international organizations; therefore, a lot of meetings among different countries and international organizations are held to discuss how to control the BC emissions from ships in order to slow down the declines of sea ice.

The pollution emissions from shipping have become a concern of the international community for a long time. In October 2008, on the 58th meeting of MEPC (Marine Environment Protection Committee), an important document mainly analyzed and summarized the pollution emissions from transportation industry and the reduction methods, which includes important information about the environment impact of BC. This was the first time for the international organizations to focus on the issue of BC.

The real progress in the issue of BC emissions was at the 15th meeting of the Bulk

Liquid and Gas sub-committee (BLG) in February 2011. In the meeting, CSC delivered files included a list of pollutants of shipping in the arctic area (including BC, organic carbon and sulfur oxide), and an assessment report provided by committee of experts (focusing on BC emissions). In this context, the secretariat has submitted a summary files in review of various methods and possible control measures on BC emission reduction. In the meeting, the Bulk Liquid and Gas sub-committee (BLG) asked the MEPC to give clear guidance on BC. Bulk liquid and gas (BLG) hopes the relevant units to the MEPC submit proposals in details, contributing to further determining the definition of BC. On the 62th Session of the MEPC of IMO, held in London from July 11, 2011 to July 15th 2011, pass through the international convention on the prevention of Marine pollution, thus the amendment of MARPOL Convention. The MARPOL Convention amendment is to use newly created areas and special maritime areas to enhance the control power over the pollutants emitted by ships. In addition, the MEPC has passed a resolution, which points out that the arctic polar ice melting is in relationship with emissions of shipping BC aerosol in the arctic area, and make instructions to require a clear definition of international ships emissions of BC material and study its measuring method, thus to reduce BC emissions by international voyage and to relieve the pressure on the melting of arctic sea ice (Bai &Li, 2016).

The issue of BC emissions in the Arctic was highlighted in the air pollution subject at the 65th meeting of the MEPC in May 2013. However, there was no agreement on the definition of BC.

The 2nd meeting of pollution prevention and response sub-committee (PPR2) of IMO was held from January 19th to 23th, 2015 in headquarter of IMO, London. Because there was no real agreement on the definition of BC, the meeting went on to study the issue of BC and reached a landmark agreement. In this meeting, the BC has finally been defined by "Bond et al.," and the concept was approved as a definition of BC in the shipping, which is a neutral material definition and is promoted by the general scientific institutions. According to the definition of a neutral substance, BC is defined as "a unique type of carbon element that is formed only in the flame of carbon-based fuel combustion". Its physical properties differ it from other carbon and carbon compounds in the composition of atmospheric aerosols (1) It can strongly absorb visible light; (2) It has the characteristics of maintaining its basic form at very high temperature, and it is difficult to melt; (3) It is difficult to dissolve in water and organic solvents, as well as in other components of atmospheric aerosols, and it exists as a polymer of small carbon spheres (Bond et al., 2013). The confirmation and unanimous approval of the definition of BC is an important outcome of the PPR2 meeting. Before that, the sub-committee also proposed the need for research on the measurement of BC. The sub-committee finally decided to put the focus of the current work on the agreed BC definition and collecting data, and then select the measurement method based on the BC emission. That is to say, there in only a consensus on the definition of BC and its characteristics currently, and then the collected data on BC will be evaluated, and the measurement will be determined based on the evaluation. Only when the measurement of BC is determined can we continue to seek for effective measures to control emissions.

1.3 Summary of the Chapter

This chapter introduces the definition and physical properties of BC, which can be seen that, as a pollutant emission, the threat to the environment of BC cannot be underestimated. Recent years, from the meetings of the Marine environment and Marine pollutants in IMO, we understand how the BC is being brought up and intensively studied step by step. It should be noted that, for navigational area in the Polar Regions, the Arctic sea ice melting will have devastating influence on the earth, so the control of the ship BC emissions is urgently needed.

In recent years, the international community has greatly focused on the ship pollutants emissions; we can see that the control of BC emissions has become a key topic pertinent to the international environmental protection strategy. Modern industrial pollution damage to the human's living environment, the threat of global warming and melting sea ice has quietly come. IMO has discussed on the topic of shipping BC emissions for several years and gradually formed a scheme to reduce emissions. So the research of shipping BC emissions in key areas is imperative.

CHAPTER 2

Introduction of Ship Pollution Emissions of Black Carbon

2.1 Data Collection of Ship pollution

Black carbon is one of the pollution emissions from ships. Before the research on black carbon emissions, it is necessary to understand the situation of ship pollution emissions to lay the foundation of the further research of black carbon. In addition to oily waste water, the great amount of smoke and organics formed after the combustion of fossil fuel is also the significant source of ship pollution.

Research on ship pollution emissions begins with data collection. As a means of transport, ships' sailing areas spread all over the world. Monitoring of ship pollution emissions sets the typical navigational area as the foundation, collects navigation information of various types of ships, including fuel types, fuel consumption and engine operating load. From different point of view, collecting the reliable data between ship's fuel consumption and air pollution emissions is very important: as the ship owner, they should firstly know the information of ship's fuel consumption, because it accounts for a great part in the costs of operating ship; Secondly, in order to understand the impact of ship pollution emissions on ecological environment in the near future, types of ship pollution emissions, emission areas and data of greenhouse gases needs to be quantified; Thirdly, to make and implement policies and regulatory approaches to environmental protection needs data on pollution emissions (such as the list of pollution emissions) as a reference.

There are a number of different monitoring methods used to build ship dynamics and fuel consumption information repositories. Some of the most important ways include Ship AIS (AIS), Automatic Mutual Marine Rescue System, fuel sales statistics, International Comprehensive Ocean Atmospheric Data Set (ICOADS), Long Range Identification and Tracking (LRIT) and port statistical data. The use of these electronic technology and statistics facilitates the regulation of ships, ensures the safety of sailing and also provides the ship information for the research on ship emissions.

2.2 Multiple effects of ship pollution emissions

According to the statistics, nearly 70 percent of the pollution emissions from ships occur in the water areas within 400 kilometers of land (VLIZ IMIS, 2013), and the potential of ships to cause air pollution in coastal areas is very high. For example, in the waters of the European Union, a lot of pollution comes from coastal ship routes and ships in ports. The air pollution caused by a large number of commercial ships is not merely harmful to the major ports, but also the small and medium-sized ports. Besides, the regional characteristics of the pollution emission will also affect the environment of the port city and endanger human health.

2.2.1 Effect of ship pollution emissions on human health

The concentration of PM in the air has been proved to have connections with human health. It remains unknown if the increase of PM concentration is due to ship pollution emissions, but the pollutants contained with vanadium, nickel and black carbon and polycyclic aromatic hydrocarbon usually generate in the process of sailing, which have been confirmed to have bad influence on human health. According to the statistics, about 60,000 people die each year from lung cancer and most of them are in coastal areas of East Asia, South Asia and Europe, which is related to the PM emissions of the shipping industry. In view of the annual increase in shipping activity, some scholars estimate that the number of people dying from lung cancer in 2012 has increased by 40% since 2002. What's more, according to the study of the previous data, the 3%~8% people who died from the disease correlative to PM2.5 is related to the pollution emission of the shipping industry(Liu, et al.,2018). Therefore, reducing the emission of pollutants generated by the burning of fuel from industrial, energy and transportation industries is of great significance to the improvement of human health.

2.2.2 Effect of ship pollution emissions on environment and air quality

Recent research has shown that compounds of sulfur and nitrogen, produced by pollution gas and particulate matter from ships, contribute to the acidification of soils and the eutrophication of water in coastal areas. In particular, the significant damage to the natural ecology and the economy will be done by the shipwreck and large-scale fuel leakage.

As mentioned earlier, nearly 70% of ship pollution emissions take place in waters within 400-kilometer distance from land. In the busy ports, the pollution emissions form ships can form ground-level ozone, multiplying sulfide and air PM levels, thus greatly affecting the air quality. What's more, the formation of ship emissions O3 and aerosol pollutants and its derivatives can be spread over hundreds of kilometers in the atmosphere, resulting in air pollution proceeding toward inland on a large scale. These emissions are not just the result of agglomeration of ship emissions near the port, but also in relation with the ship loading and unloading of goods, cargo truck and rail traffic, the emission information in details of which is scarcer.

2.3 Summary of the Chapter

In this new period of high-speed development of international economy and trade, as the greatest cargo transportation, the shipping industry promotes the economic development while brings a great number of pollution. In order to study the pollution emission from ships, including black carbon, the collection of ship information is an indispensable and a long-term work. Due to the widespread and dispersed sailing areas of ships, the data of ship pollution emissions is mainly collected through all kinds of science and technology devices such as AIS and ICOADS, combined with fuel sales statistics and the files of ship port registration. What's more, this chapter also introduces the effect of ship pollution emissions on human health, natural environment and air quality, reveals the damage that can't be ignored, manifests the importance of measures to reduce the ship pollution emissions, and lays the knowledge foundation for the further research on black carbon of ship pollution emissions in This research paper.

CHAPTER 3

Research on the building of ship BC emissions list

3.1 The Measurement of Black Carbon and Influence Factor

Based on the characteristics of black carbon, this chapter introduces the measurement methods of black carbon, the information of ship and the effect of ship's navigational state on black carbon emission. In order to study the black carbon emissions along the coastal routes of key monitored areas in LIAO NING province, the AIS technology was used to collect data of the number of ships and the ships navigation information in target area, preparing for further calculation of the ship black carbon emissions in the target area.

3.1.1 Measurement methods of Black Carbon

Currently, the major solutions to measure concentration of black carbon particle are optical measurement, thermal decomposition and photo thermal measurement (Wang, 2016).

1. Optical Measurement

Optical measurement method is widely used. This method takes the quartz fiber membrane which is pervious to light generally to collect the atmospheric aerosol samples, and measure the optical attenuation of different wavelengths permeated the filter membrane, in order to check the content. This method is easy to operate and has high resolution, which can realize real-time observation. The drawback is that other carbon-containing aerosols also affect the black carbon meter reading, so this method is of low accuracy.

2. Thermal Decomposition Measurement

The concentration of black carbon aerosols was measured by heating and oxidizing the aerosols collected from the quartz fiber membrane and collecting the released carbon. The disadvantage of this method is that some of the organic carbon is carbonized under the inert gas, so the result of the thermal decomposition method contains the carbon of black carbon and organic carbon. Therefore, the results of this method are not accurate.

Then through study some scholars point out to control temperature, time and gas atmosphere to solve the problem of organic carbon being carbonized in inert gas. Interference eliminated, thermal decomposition method can more accurately determine the concentration of black carbon particles.

3. Photo thermal measurement

Photo thermal measurement is a method combining optical measurement with thermal measurement. It is currently a relatively accurate method for measuring the concentration of black carbon ions, but it is not widely available in the light of the high cost of professional instruments.

3.1.2 The Measurement of ship black carbon emissions

There are two methods of measuring ship black carbon emissions: upside to downside & downside to upside

1. Onboard measurement, downside to upside

By onboard measurement, the BC emissions can be measured directly through the fuel consumption and flue gas, which can accurately measure the real-time results of each ship's pollution discharge. The total amount of black carbon emission in the region is measured by the superposition of each ship's emissions. But due to the high cost, difficulty in implementing, long time consumption of this method, it is unfavorable to practically operate.

2. Fuel Consumption, from upside to downside

Black carbon emission estimates are carried out through the fuel consumption and pollutant emission factors of various vessels in the region. However, in respect to the actual situation, there are many types of vessels in the region, and the quality of fuel is different, resulting in the difficulty in collecting the total fuel consumption and pollutant emission factors. This method is applicable to the estimation of pollution discharge of ships in small scale.

3.1.3The Affective Relationship between Ship Black Carbon Emissions and Ship Information and Navigation Condition

Since the black carbon emissions of ships is closely related to the basic information of ships and the sailing status of ships, it is necessary to consider many factors to calculate the black carbon emission of ships in a certain region.

There are many types of ships, including oil tankers, dangerous goods ships, bulk carriers, passenger ships, salvage vessels, fishing boats, etc. For ships of all sizes and tonnage, their pollutant emissions cannot be generalized. What’s more, BC emission has also been affected by the engine load, fuel quality and scrubbing equipment, which can result in the deviation of emissions (Lack et al., 2012)..

1. The Relationship between Engine Load and Ship Black Carbon Emissions

The Marine diesel engine can achieve the maximum fuel consumption and the maximum energy output under normal load conditions, which is the maximum fuel efficiency(ABS,1984). Maximization of fuel utilization ratio occurs at a certain operating load between the maximum engine operation and the average operation. Diesel engines under the engine's load consume the least amount of fuel, which means they produce the least amount of black carbon. When the engine is beyond the ideal load, the fuel utilization rate will normally be reduced and the black carbon emission will increase according to the deviation from the ideal load. For example, when the ship's engine load is reduced from 100% to 25% without restarting, the black carbon emission factor will rise to 3. When the engine load continues to drop to less than 25%, the black carbon emission factor will even soar to about 6.5 times.

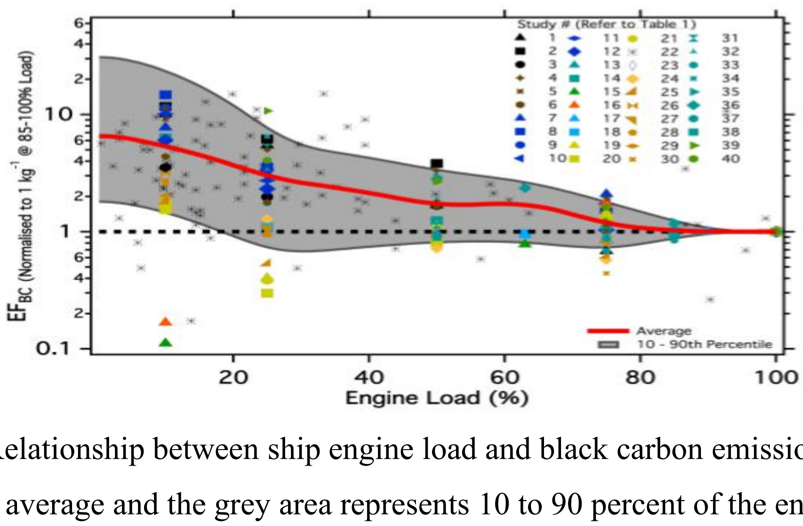


Figure 3.1 Relationship between ship engine load and black carbon emissions. (The red line is the average and the grey area represents 10 to 90 percent of the engine type)

Source: Lack, D. A., & Corbett, J. J. (2012)

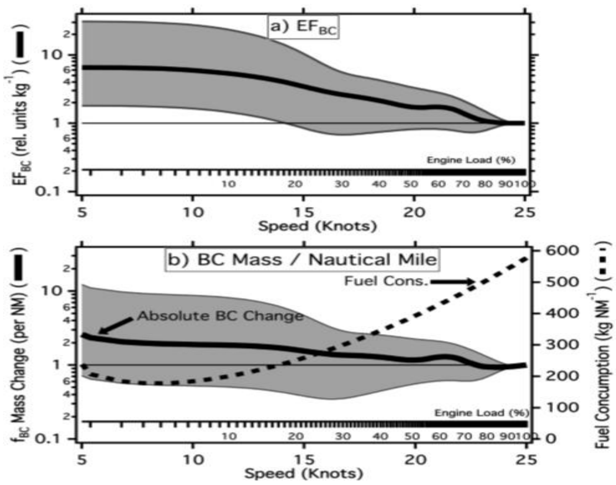


Figure 3.2 (a) The average value of black carbon emissions varies with ship speed and engine load (between 10% and 90%). (b) Potential absolute black carbon emissions caused by changes in ship speed and engine load. The black carbon emission data in (a) combined with the fuel consumption data in (b) generates new data in (b). In addition to fuel consumption, they are normalized to 100% engine load.

Source: Lack, D. A., & Corbett, J. J. (2012)

Table 3.1 Effect of Engine Load on Black Carbon Emissions

Study(#)	Engine Type	Fuel Type	Measurement
1-6	MSD	HFO,LFO	EC-TOA,BC-FSN
7-12,22-27	MSD	HFO,MGO,Biodiesels	BC-Filter,EC-TOA
13	MSD	HFO	EC-TOA
14	MSD	HFO	EC-TOA,BC-Filter
15	MSD	MDO	BC-PAS
16	SSD	HFO,MDO	EC-TOA
17	SSD	HFO	EC-TOA
18	SSD	HFO	EC-TOA
19-21	MSD	Biodiesel	EC-TOA
22	SSD,MSD	HFO,MDO,MGO	BC-PAS
23,24	MSD	HFO,MGO	EC-TOA
31-38	MSD	HFO	BC-FSN
39,40	MSD	MDO	BC-FSN

Source: Lack, D. A., & Corbett, J. J. (2012)

Some advanced ship engines can automatically detect and regulate engine load through electronic technology (Brown, 2009). This type of engine is in the process of technical research. It is planned to install on the newly registered ship and can detect the engine load of the ship in real time and automatically adjust to ensure the effective reduction of black carbon emission. Fuel efficiency can also be best achieved by properly reducing engine loads at full load. For the state of ship engines, the speed of the ship can accurately reflect the value of its load. The relationship between the black carbon emission and engine load of ships is shown in Figure 3.1. The relationship between the ship speed, engine load and black carbon emission is shown in Figure 3.2 .

The Table 3.1 reflects the corresponding relationship between the black carbon emission research data and the engine model and fuel quality:

2. The Relationship between Fuel Quality and Ship Black Carbon emissions

Table 3.2 The relationship between fuel quality and emissions in the literature

Study (#)	Low Quality Fuel Type,F_S(%),Ash(%)			High Quality Fuel Type,F_S(%),Ash(%)		
1	HFO	2.2	0.03	MGO	<0.01	<0.01
2	HFO	0.9	0.02	LFO	<0.05	<0.01
3	HFO	0.9	0.07	LFO	<0.05	<0.01
4	HFO	2.4	0.07	LFO	<0.05	<0.01
5	HFO	2.4	0.02	LFO	<0.05	<0.01
6	HFO	2.2	0.02	MDO	0.1	0.001
7	HFO	2.2	0.02	Biodiesel-Palm Oil	<0.01	0.002
8	HFO	2.2	0.02	Biodiesel-Animal Fat	<0.01	0.002
9	HFO	2.2	0.02	Biodiesel-Soya Bean	0.1	<0.001
10	HFO	2.2	0.02	Biodiesel-Sunflower Oil	<0.01	<0.001
11	HFO	2.2	0.02	MDO	0.1	0.001
12	HFO	2.2	0.02	Biodiesel-Palm Oil	<0.01	0.002
13	HFO	2.2	0.02	Biodiesel-Animal Fat	<0.01	0.002
14	HFO	2.2	0.02	Biodiesel-Soya Bean	0.1	<0.001
15	HFO	2.2	0.02	Biodiesel-Sunflower Oil	0.1	<0.001
16,17[a]	HFO	3.15	0.07	MDO	0.07	<0.01
18,19	HFO	0.83	0.04	MGO	0.1	<0.01

Source: Lack, D. A., & Corbett, J. J. (2012)

The relationship between fuel quality or ship speed and black carbon emissions is more complex than other Marine emissions. The relationship between sulfur emission and fuel quality has been clearly determined(Williams, 2009). Sulfur dioxide emissions are directly related to fuel sulfur content and ship engine load (Lack, 2009). However, the study on the effect of fuel quality on the other emissions of ships is rarely even known. Recent studies have shown that better quality fuel produces less sulfur particles and other organic particles in the process of incomplete combustion (Lack, 2011). Some balancing studies proved that it can be achieved by using low sulfur, low ash fuel instead of high sulfur content, high combustion ashes of fuel to reduce black carbon emissions, what's more, high quality fuel can reduce as much as 80% of black carbon emission factor. In addition, current studies have shown that, under 100% operating load, the black carbon emissions factor of the Marine engine can be reduced by 30% as shown in Table 3.2. This is very similar to the fuel consumption factor and engine load. Because of the improvement of fuel quality can also reduce black carbon emissions, the European parliament of IMO request to forbid the use of HFO heavy fuel oil in the arctic region, which can effectively reduce the polar area ship black carbon emissions, to control the source of melting glaciers.

The organic particles produced by fuel combustion contain large molecular weight aromatics and can seriously affect human health(Marin,2009). The relationship between the composition of residual fuel and the formation of black carbon remains unknown, but the black carbon is the product of incomplete combustion of the engine fuel. In fossil fuels or biofuels, the lower the concentration of sulfur, dust and large molecules of aromatic hydrocarbons, the greater the combustion efficiency. Heavy metal residual fuel oxidation ability in reducing black carbon is a relative factor in the generation, however, effective balancing information shows that the distillate fuel (i.e., low sulfur, low fuel combustion ashes) can effectively reduce black carbon emissions.

3. The Relationship between Filtration Equipment on Ship and Black Carbon Emissions

Ship scrubbing devices can effectively reduce the emission capacity of SO2, which equals to the ability to reduce sulfur dioxide by using low sulphur fuel. Recent studies have shown that ship emissions filters can effectively reduce most PM emissions anywhere, with a reduction of 25% to 98%. Although it can remove a lot of potential emission particles, but effective reduction of black carbon particles is uncertain for these three reasons (Petzold, 2011):

(I) Particle black carbon particles account for around 4% of ship emissions;

(II) The black carbon particles in the ship's exhaust gas are related to particles with a median diameter of less than 0.2 m;

(III) The wet scrubber filter is not qualitative to reduce the emission of black carbon particles, because the black carbon particles produced by the exhaust of the Marine engine can be hydrophilic and hydrophobic.

3.2 The list of ship pollution emissions

3.2.1 The construction of list of ship pollution emissions

The list of ship pollution emissions provides various parameters (including serial Numbers, names, coordinates, characteristic parameters, emissions, etc.) of the emission sources in a simplified manner (Liu, 2011). It is mainly used for determining the relationship between ship pollution emission and ship information, studying the various factors associated with pollution, and thus the measurement methods and effective supervision can be better made according to the data. List of vessel pollution emissions is usually established by a bottom-up approach (i.e., through integration of the ships pollution emission information to establish the macroscopic regional database) to obtain the source of the input data of the ship which can meet the regional air quality model.

3.2.1.1 The Construction of Featured Information

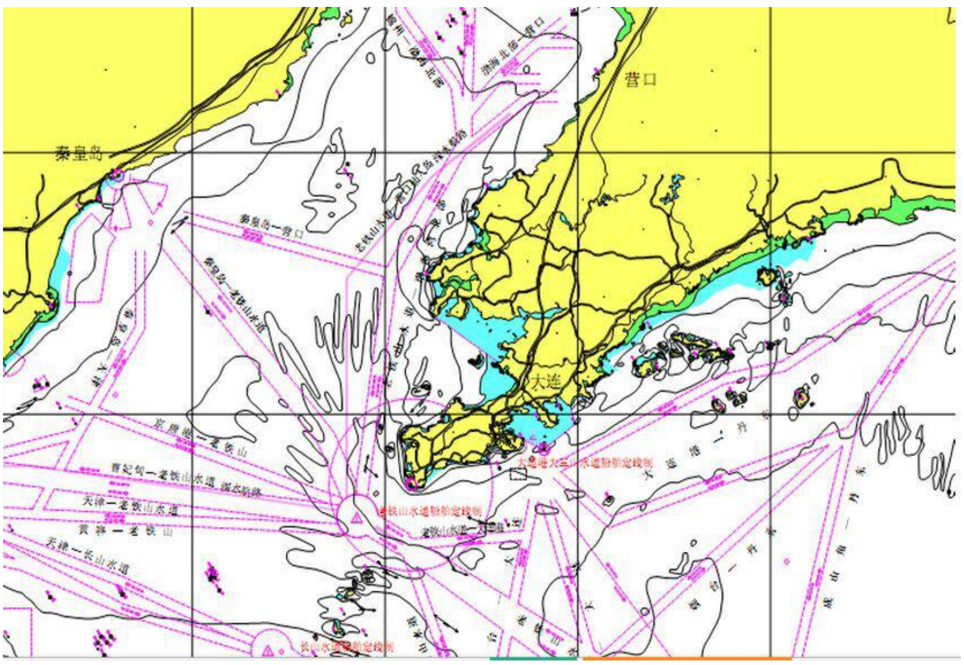


Figure 3.3 Figure of Coast Route of LIAO NING Province

Source: Ministry of transport of the People's Republic of China (2011). *The overall plan for the national coastal ship routing system.*

The coastal route of LIAO NING province is shown in Figure 3.3.Marine atmospheric pollution emissions inventory is based on port as the key point of monitoring unit, and according to the five states of the ship: on the sea, into port, out of port, motor, and stay in port, models are set up respectively to calculate port information.

The characteristics of the basic unit formation include:

- The speed, route and distance of the ship at a single stage;
- The statistics of port data on the type, quantity, tonnage of ships, and the number of ships of the same type with different tonnages in and out of ports, accounting for the proportion of ships entering and leaving port each year;
- The rated power of the main and auxiliary engines of different types of ships under different navigational conditions;
- Average sea speed, fuel consumption and flight conditions of different types of ships;

According to different tonnage amount of each type of ship' length, width, the number of exhaust pipes, the exhaust temperature, the height of exhaust pipes above the highest deck level, height of highest deck level to sea level, the highest exhaust pipe information such as the distance from the bow, can also calculate to determine the characteristic information of all kinds of ships according to the types of similarity and other ship information.

3.2.1.2 Ship pollution emission Coefficient and Marine Engine Power

The pollution emission coefficient of the ship is the most basic parameter to calculate the emission data of the pollution source. The determination of the exact actual discharge coefficient is very important for the construction of an accurate emission source list. It is based on the practice and refers to the research fruit in the report "EU port shipping emissions", in accordance with the average speed of each process on sea speed, or the information based on similar type and vessel size, calculated by the interpolation method, and determined by tonnage (European Commission and ENTEC UK Limited,2002)). This research paper studies the pollution emission factors during the coastal navigation in LIAO NING Province. As Table 3.3 shown below:

Table 3.3 Pollutant discharge coefficient (g/kwh) for various types of vessels underway

status	index	Passenger ship	Ship with dangerous goods	Container Ship	bulk cargo	Oil tanker	Non-transport ship
navigation	NO_x	13.2	16.5	17.5	17.9	13.3	11.1
	SO_2	11.7	11.0	10.7	10.6	9.8	12.9
	CO_2	696	648	624	624	686	757
	HC	0.5	0.6	0.6	0.6	0.4	0.4
	PM	2.3	2.2	2.3	2.3	2.1	2.2

Source: European Commission and ENTEC UK Limited. (2002). Quantification of emissions from ships associated with ship movements between ports in the European Community. European Commission, DG ENV.C1, Rue de la Loi, 200, B-1049: Brussels.

According to the investigation of different models of ship main, auxiliary engine power rating, in the reference of the European Union, "the EU port shipping emissions" in the report research results, analysis to determine the vessels in different stages of the roads of main, auxiliary engine power rating, see Table 3.4.

Table 3.4 Rated main engine power (ME) and auxiliary engine power (AE) for different tonnage ships (Note: The values in parentheses in the Table refer to auxiliary engines)

Category	Tonnage	ME/AE(kW)	Consumption power of Generator (%)
			At sea
A37	<500	700/150	80(30)
	500~1k	900/187	80(30)
	10k~25k	5000/350	80(30)
	25k~50k	8000/500	80(30)

Source: European Commission and ENTEC UK Limited. (2002). Quantification of emissions from ships associated with ship movements between ports in the European Community. European Commission, DG ENV.C1, Rue de la Loi, 200, B-1049: Brussels.

3.2.2 Relationship between port throughput and Chinese MS system

From the pollutants emission coefficient illustrated in above Table 3.3 ships, we can see that there is no black carbon emission coefficient exists, so we cannot directly estimate ship black carbon emissions through this list of emissions. Therefore, this research paper will use the carbon dioxide emission coefficient given by the emission coefficient table and calculate the total amount of carbon dioxide emissions from the Table 3.4. The direct ratio between the total amount of carbon dioxide emissions and fuel consumption is the carbon dioxide emission factor 3.17(Psaraftis,2009), and the total amount of fuel consumption is obtained. Therefore, it can provide key parameters for the further calculation of the black carbon emission of ships.

3.3 Acquiring Ship amount and Navigation Information through AIS

3.3.1 Introduction of onboard AIS

AIS (AIS, AIS for short), as a new type of using electronic information navigation System, is managed by AIS by the base station server, access to information server, network management center server and monitoring software.

Through the help of AIS navigation, it greatly guarantees the workers' life safety at sea, and improve the ship navigational conditions of the global consciousness at the same time, and also let the relevant institutions supervision and management of vessels engaged in more convenient to get the ship information, so that the Marine environmental protection supervision and became more powerful.

The main functions of AIS are: directly identify the ship, assist in tracking the target, simplify the information exchange between ships, and provide other relevant information to avoid the collisions at sea. What's more, AIS can form electronic monitoring data on the shore-based basis, which can be provided to the shipping companies and staff in need, and can be used as the legal basis for administrative penalty and litigation.

The combination of AIS monitoring software science and technology of electronic chart achieved the information visualization of heading and routes, as well as name of the ships loaded with this system, improved the function of maritime communications, and provided a voice and text communication method with ship by AIS recognition, enhancing the global consciousness of the ship (Zhang, 2004). IMO group revised the SOLAS convention in the ninety s of the 20th century, according to the revised content, all types of ship sailing area all over the world completed the GMDSS (salvage system) configuration. After this regulation came into effect, it had a positive effect on the ships that were suffering from shipwreck, and effectively reduced the crew casualties and property losses. But this is a very passive approach, and it is not possible to predict and effectively avoid a shipwreck before a disaster occurs. As a result, all kinds of shipwrecks, such as ship collision, still occur frequently. Based on the passive disaster relief and unable to effectively control the shipwreck, the navigation safety of the IMO in 1999 on the 45th meeting to make further changes to the decision of SOLAS convention, the decision for prevention of accidents at sea, the effective protection of navigation safety problem, and proposed a bigger security information equipment configuration requirements of the ship. The AIS is one of the important ship information and safety equipments. SOLAS convention with AIS content came into effect through procedure, the system configuration began enforcing from the new build ship in 1st July, 2002, and require all the ships sailing in the sea install AIS equipment before July 1st , 2008.

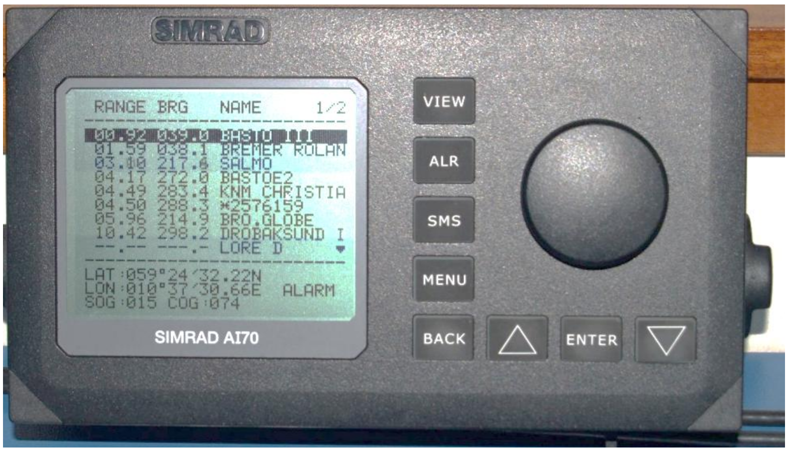


Figure 3.4 Shipboard AIS

Source: by author

3.3.2 Acquire ships information through AIS

Ships configurated with the AIS information can launch the ship information (including the master of the ship set ship status, types, tonnage, the port of destination, time, etc.) and navigation information (including ship speed, direction, position, etc.) to the coast radio station or other ships, so the coastal channel and the ships loaded with this equipment can receive the information, meanwhile it also can receive to other vessels of all kinds of information. Shore-based information can be used to monitor the ship in real time visually. Ships can exchange data with shore-based to obtain more information about other ships. AIS is composed of VHF, DGPS and a communication controller. The global satellite positioning system (GPS) provides the location and time information of the ship for AIS, while the other information is from other electronic equipment onboard ship. As a result, the power of AIS cannot be separated from other electronic devices. At the same time, the emergence of AIS technology has brought the maritime surveillance work to a new stage, which marks the arrival of the new era of ship information exchange.

In this research paper, the number and navigation state of the ships in the area are studied by means of the data of the ship to the ship's shore, which is used as the basic data to participate in the operation. Figure 3.5 shows the data regulation of shore-based AIS on ship information and navigational state.

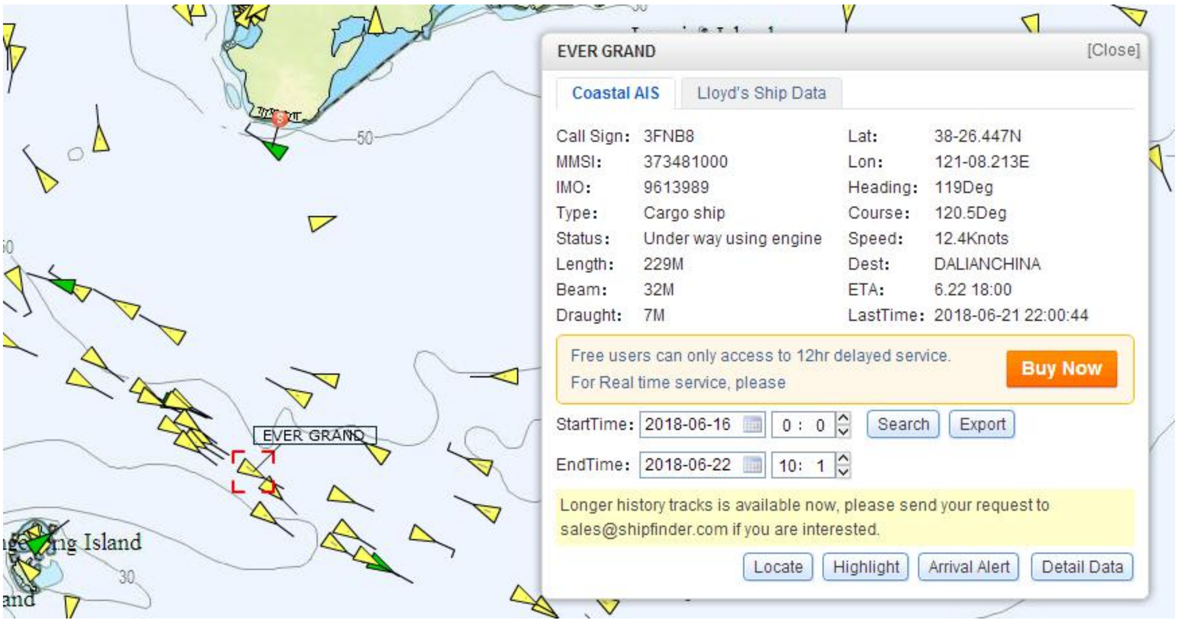


Figure 3.5 Ship Information Acquired through AIS

Source: http://www.shipfinder.com/

3.3.3 Application of AIS

This research paper studies the black carbon emissions of ships in the coastal route of LIAO NING province, and the information of ship in the area is indispensable. The AIS can conveniently provide the number of ships off the coast of LIAO NING, including the type and speed of the ship. This research paper will use the AIS records for a period of time of ship sailing position formed by the track diagram of the key monitoring area's location, area inside the corresponding period for each type of ship traffic, and based on the speed and the target area of AIS, the paper provide channel length calculation of ship after the time needed for the region, these parameters will be substitution follow-on formulae for estimation of the black carbon emissions.

3.4 Summary of the Chapter

This chapter introduces three basic measurement methods of black carbon, and gets to know the measurement of black carbon emission. Generally speaking, there are two ways of measuring the black carbon emission of ships in the region from the downside to upside and from the upside to downside. Bottom-up approach can derive the black carbon emissions based on every ship voyage data provided by AIS. By integrating the number of vessels within the region and their emissions, the total amount of black carbon emissions in this region can be calculated. This method can draw more accurate result. However, because of the differences in the ship main engine load, fuel quality and types of main engine, the amount of pollutant emissions is also different, and the practical operation of calculation and statistics is difficult. The top-down approach is based on a rough calculation of the total fuel consumption and estimated emission coefficient of a certain region, which is not very accurate, and only applies to the calculation of black carbon emissions of ships within a small range. The difficulty in the measurement of black carbon emissions from ships is due to the extensive correlation between black carbon and the ship’s navigational status and ship information. Different engine loads (or ship speeds), fuel quality, main engine type, and scrubbers can cause changes in ship pollution emissions. Therefore, a list of ship pollution arises at the historic moment. It can accurately reflect the values of ship pollution under different ship information and navigational status, and can be updated according to the collected emission data. It presents a complex ship pollution emission source in a concise manner, which greatly facilitates the monitoring of the black carbon emission of ships. The list of ship pollution emissions allows the ship's pollution emission values to be based on evidence. Although there is no black carbon emission coefficient in the pollution emission coefficient, this research paper can use the inventory model to launch the ship's fuel consumption, which will help to calculate the black carbon emission later. Another research tool that must be mentioned is the Automatic Ship Identification Device (AIS), which is an indispensable and outstanding system for modern shipping information systems and ship navigation. The AIS loaded on the ship can actively send this ship information and navigational status data to the shore in real time, thus forming real-time dynamic monitoring data on the system, which facilitates the acquisition of the number of ships and information obtained in this study, and provides strong support for the following computational research.

CHAPTER 4

Location Selection of Key Monitoring Area of Navigation Routes on LIAO NING Coast and Estimation of Ship Black Carbon Emission Volume in the Area

4.1 Location Selection of Key Monitoring Area of Navigation Routes on LIAO NING Coast

4.1.1 Information on Shipping Development in LIAO NING Province

The "LIAO NING Coastal Economic Zone Development Plan" approved by the State Council in 2009 has elevated the coastal economic development of LIAO NING Province to a national-level economic strategy. This plan proposes to integrate LIAO NING port resources and enhance the overall shipping and logistics competitiveness of the LIAO NING region.

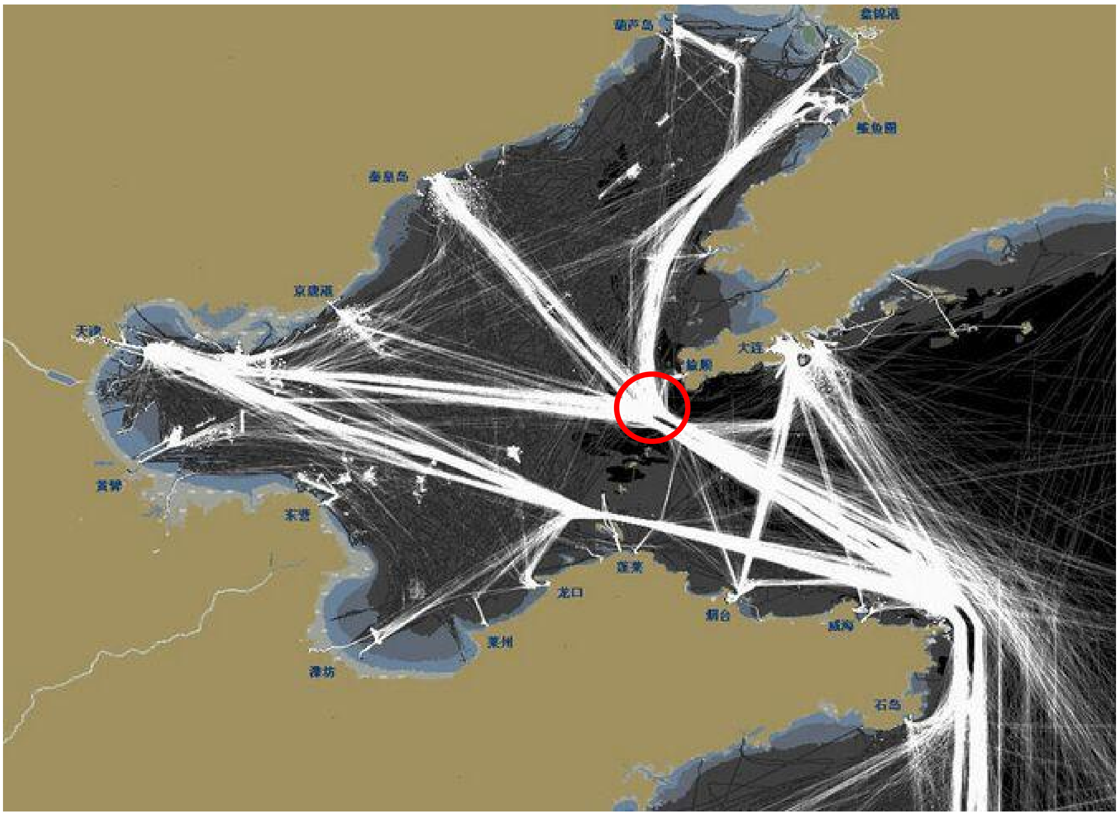
LIAO NING Province, which is located at the dividing line between the Yellow Sea and the BOHAI Sea, has more than 2,200 kilometers of coastline, up to 1,000 kilometers of which can be served as a port area. In addition, thousands of kilometers of deserted beaches and salt fields that have yet to be developed along the coast also make LIAO NING a huge space for economic development. The long coastline of LIAO NING Province is conducive to the transportation trend of large-scale sea vessels. Along with the construction of deep-water ports, it will inevitably promote the further development of the ports, and it will also turn LIAO NING into an international shipping and logistics center in Northeast Asia.

As a key shipping area with a large number of ports in LIAO NING Province, its coastal routes are densely populated, and the navigation routes are relatively concentrated. The main routes and their navigable capacity can be clearly obtained from the route charts, facilitating the selection of key monitoring areas and the simulation study of BC emissions from ships.

4.1.2 Ship Traffic Flow Chart of Navigation Routes along LIAO NING Coastline

The traffic flow of the ship in a certain period of time is formed by connecting successive positions of a ship passing through a period of time in a sequence. The traffic flow chart is a space distribution chart of all ships in a certain area for a period of time. It can reflect the ship's navigation density, the size of the traffic volume, and the rules of the route encounter. Tracks are distributed in certain water areas and can exhibit a variety of states, such as in-and-out traffic, passing traffic, and crossing-route traffic in the same waters. These are the spatial distribution properties of the traffic flow and are a reflection of the overall movement of the ship.

The traffic flow chart is a schematic diagram of the traffic flow integrated into the chart. It has two ways of expression: the first is to mark the ship's position with points to form a dense location information dot chart; the second is to use the line that connects the trajectories of ships to form a line graph. The traditional traffic flow chart is drawn using radar observation records and then processed by computer. The Maritime Safety Administration of the Ministry of Transport has now constructed a relatively complete network of AIS and radar base stations to form an accurate traffic flow chart through the computer's collection of ship location information. Take the example of Figure 4.1 below.



Ficgure 4.1 Ship Traffic flow Chart of Navigation Routes on LIAO NING Coastline (within the red circle is the LAO TIE SHAN waterway)

Source: Fengwu,W.(2016). Longkou - LVshun passenger roll route navigation safety assessment supplementary demonstration report. Unpublished research paper, Dalian Maritime University, Dalian, China

4.1.3 Location Selection of Key Monitoring Area of ship Black Carbon Emission along LIAO NING coastal Navigation Routes

According to the analysis of Figure 4.1, it can be seen that The LAO TIE SHAN Waterway is an important water area in the intersection of ship routes, and its traffic flow is relatively high. In this research paper, the LAO TIE SHAN Waterway is the key monitoring area of LIAO NING coastal route.

4.1.3.1 Shipping Information of the LAO TIE SHAN Waterway

The LAO TIE SHAN Waterway is an integral part of the BOHAI Strait, which is located in the north of the channel and communicates with the BOHAI Sea and the Yellow Sea. The LAO TIE SHAN Waterway is the northernmost and widest channel in the BOHAI channel, and the channel is northwest to southeast, with a length of about 45 kilometers and the deepest part of the LAO TIE SHAN landscape is 83 meters deep.

The LAO TIE SHAN Waterway is an important passageway for foreign ships entering and leaving the northern port of China: Tianjin port, Qinhuangdao port and BOHAI rim area. At the same time, as the "throat" of the BOHAI Sea, the LAO TIE SHAN landscape is the only way to get in and out of the ports of the BOHAI Sea. Because of its high wind, wave and flow, fog and merchant vessels pass water available width is only 5.5 nm, so it becomes one of the dangerous areas where vessel traffic density is high, the traffic flow is complex, and a lot of accidents occur.

4.1.3.2 LAO TIE SHAN Waterway Shipping Quantity

Figure 4.2 shows the ship's traffic flow chart in the first quarter of 2015 of LAO TIE SHAN Waterway (Wang, 2016). Figure 4.3 is the gate line section flow chart in the first quarter of 2015.

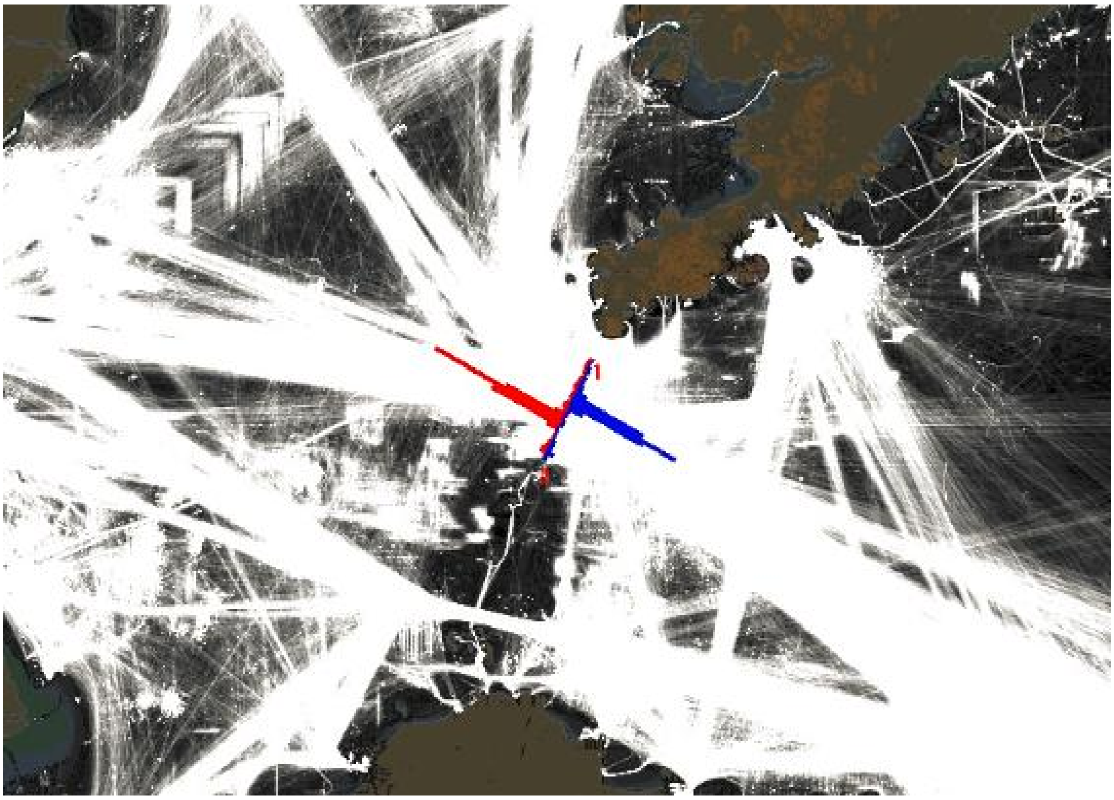


Figure 4.2 Ship track chart for the first quarter of 2015

Source:Wang,F.W.(2016).Longkou - LVshun passenger roll route navigation safety assessment supplementary demonstration report. Unpublished research paper, Dalian Maritime University, Dalian, China

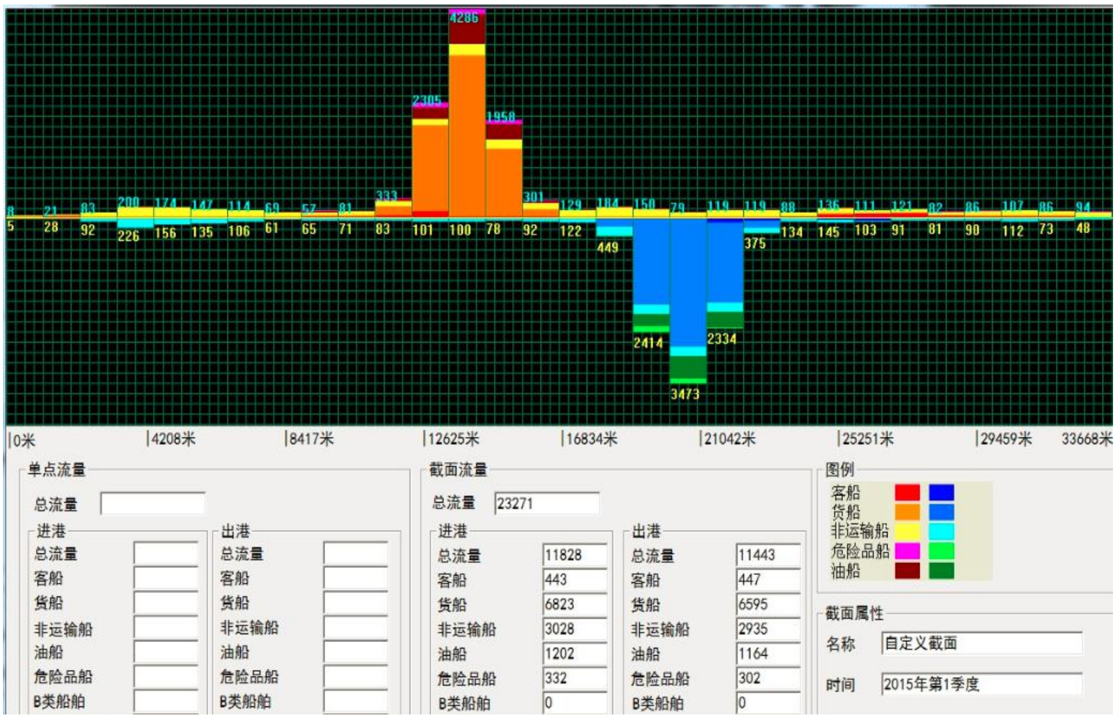


Figure 4.3 Cross-section traffic volume of the LAO TIE SHAN Waterway in the first quarter of 2015

Source: Wang,F.W. (2016).Longkou - LVshun passenger roll route navigation safety assessment supplementary demonstration report. Unpublished research paper, Dalian Maritime University, Dalian, China

From the Figure we know that:

(1) In the first quarter of 2015, there were 2,3271 vessels through the LAO TIE SHAN Waterway.
(2) About 7, 000 ships per month are sailing through the LAO TIE SHAN waterway;
(3) In the first quarter, there were 890 passenger ships, 13418 cargo ships, 5,963 non-transport vessels, 2366 oil tankers and 332 dangerous goods vessels.

(Note: The "ship" here is understood as "times of ship" and does not include the concept of the ship)

For the sake of convenience, this research paper selected the width of the study area is 36 nm, assuming the ship speed is stable at 12 kts, current rate is 0 kt, passing time of this region roughly is about 3 hours, thus the black carbon emission volume in 3 hours of the ship passed through this area will be included in the estimation results in this research paper.

4.2 Calculation Formulae and results of Black Carbon Emission

As the ship's engine load, fuel quality and constantly changing sailing conditions will affect the ship's black carbon emissions, accurate calculation of ship black carbon emissions in a wide area is difficult to achieve. In this research paper, the statistics and calculation of the ship traffic flow and fuel consumption in the key monitoring areas along the coast of LIAO NING Province and the black carbon emission coefficient are used to estimate the black carbon emissions within the target area.

4.2.1 General Formulae of pollutants Emission

The basic principles for the estimation formula for pollutant emissions from ships are the same, and are all related to the type of pollutants, and two basic parameters need to be used: the total amount of fuel consumed and the emission factor of the target pollutants(Wang,2013). It can be expressed by the following formula (4.1).

$$\mathrm{E_i} = \mathrm{FC} \times \mathrm{EF_i} \tag{4.1}$$

$\mathrm{E_i}$ indicates the emissions of i-contaminated substances; FC indicates the total fuel consumption; and $\mathrm{EF_i}$ indicates the emission factor of pollutants i.

This is the general formula for the so-called emissions of pollutants. It is estimated in a direct manner and this method can achieve relatively high accuracy in the case of maximum continuous work of the ship engine (that is, the engine is stably navigating at a high load) and the pollutant emission factor is very small. However, it is worth pointing out that the state of navigation of the ship changes in real time, and the pollutant emission factor EF_i under different engine loads will also change. In addition, the sulphur content of the ship's fuel will affect the emission of pollutants due to changes in the quality of the fuel. Therefore formula (4.1) is an ideal formula, it can reveal the basic concept of pollution emission calculation, but it is not suitable for practical operation.

Due to the practical inapplicability of the basic general formula of pollutant emissions, an improved formula (4.2) based on the basic formula was then adopted. Based on formula (4.2), and the uncertainty of pollutant emission factors was fully taken into account.

$$\sum_{t=h}^{n} E_h = FC_{i,j,k} \times EF_{i,j,k} \tag{4.2}$$

E_h represents the total annual black carbon emission of ship h; $FC_{i,j,k}$ is the total fuel consumption when the ship type of h is i, the engine load is j, and the fuel quality is k; $EF_{i,j,k}$ represents the black carbon emission factor of ship h when the ship type is i, the engine load is j and fuel mass is k. The relationship between the black carbon emission factors and the sailing status of different ships is shown in Table 4.1.

Table 4.1 BC emission factors of different types of ship, fuel quality and ship navigational status (Unit: kg/ton)

	Central Estimate			
	At sea HFO	At sea MDO	In port HFO	In port MDO
Tanker	0.38	0.228	0.95	0.57
Container	0.8	0.48	2	1.2
Cargo carriers	0.4	0.24	1	0.6
Bulk carriers	0.38	0.228	0.95	0.57
Tugboats		0.97		2.425
Passenger Boat	0.36	0.216	0.9	0.54

Source: Buhaug Ø et al (2009)

Table 4.1 The ship's black carbon emission factor under different ship types, fuel quality and navigational status is kg/ton (HFO is Heavy fuel oil, marine heavy fuel oil, the most used fuel in ships. MDO is Marine diesel oil, marine diesel oil Use when entering a specific sea area or port).

The ship black carbon emission factors in Table 4.1 show the ship's black carbon emission factors under different ship types, different navigational states, and different fuel quality. Due to data collection restrictions, the table uses average estimates (high estimates and low estimates are not involved) to represent the different sailing states of the ship (different engine loads) and to set the default engine load to low load conditions for ships in port state. The default engine load under the state of sea navigation is a high load state.

For the inventory assessment of global black carbon emissions, the ship dynamic information appearing in the IMO's GHG report is used. This report contains summary data of the average ship engine load and fuel quality of each type of ship (Buhaug ,2009). It is not difficult to see from the data that MDO fuel has a lower black carbon emission factor than HFO fuel. This table combines the differences in black carbon emission factors under different engine loads, i.e., different sailing states, to divide the state of navigation of the ship into two aspects, namely, port and sea navigation. For ships in port status, their auxiliary engines will operate at low loads and therefore will have a higher black carbon emission factor.

Since the improved formula and black carbon emission factors in Table 4.1 fully consider the impact of different types of ships, different engine loads and different fuel quality on black carbon emissions, formula (4.2) and Table 4.1 are used in this research paper to focus on the calculation of ship black carbon emissions in target region.

4.2.2 Formula to Calculate Emission Volume by Pollution List

The formula（4.3）for the applicable model system in the pollution emission list:

$$E_i = \sum_{jklm} S_{jkm}\,(\mathrm{GT}) \times t_{jklm} \times F_{ijlm} \qquad (4.3)$$

In the formula（4.3）, E_i is the total emission volume of the ith pollutant, $S_{jkm}(GT)$ is the daily consumption of the ship k fuel j in the operating mode m. t_{jklm} is the emission factor of pollutant i in operating mode m, engine type l, fuel j, and pollutant i in operating mode m, engine model l, and fuel j.

Since the emission coefficient of black carbon is not included in Table 3.2 cited in the literature, this formula cannot be directly used to calculate black carbon emissions from ships. However, this formula can be used in conjunction with the emissions from Form 3.3 and 3.4 to derive the total amount of fuel consumed in this calculation.

4.2.3 Other Calculating Formulae related with Black Carbon Emissions

Formula (4.4)：Formula:

$$\mathrm{FC} = \sum_{engine} SFC[\mathrm{g/kWh}] \times P[kW] \times LF[\%] \times T[h] \tag{4.4}$$

Formula (4.5)：Formula:

$$\mathrm{Emission} = \sum_{engine} EF[\mathrm{g/kWh}] \times P[kW] \times LF[\%] \times T[h] \tag{4.5}$$

In the formula, FC is Fuel consumption, SFC is Fuel consumption coefficient, EF is emission factor, P is engine power, LF is engine load factor, and T is operation time. The corresponding relationship between black carbon emission and ship engine load and fuel quality is shown in figure 4.4.

The two formulae above mainly focus on the calculation of ship fuel consumption and pollutant emissions under different engine types and loads. It is applicable to the study of black carbon emissions of individual ships under different operating loads. Because the number of ships in the region is relatively large, and the engine load and engine type are different, it is inconvenient to directly use this formula to calculate the total amount of emissions.

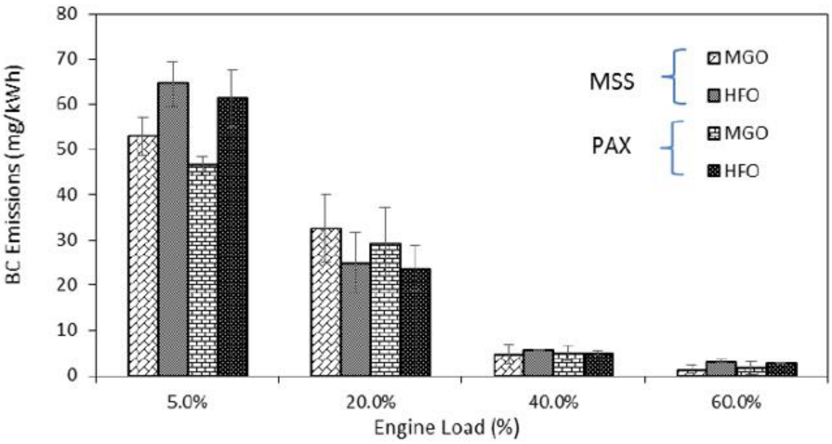


Figure 4.4 The Correspondence between Ship Black Carbon Emission, Engine Load and Fuel Quality

Source: Johnson,k.(2015). Final report: Black Carbon and Other Gaseous Emissions from an Ocean-Going Vessel Main Engine Operating on Two Fuels, College of Engineering-Center for Environmental Research and Technology University of California,California,USA

4.2.4 Estimation and Result

In order to facilitate the estimation, this research paper sets the fuel for all ships sailing in the key monitoring areas to HFO fuel, and the state of the ship is in the sea navigation state. According to the ship navigation requirements of the LAO TIE SHAN Waterway, the ship speed is set to 12 knots, and according to the main heading of the ship in the key monitoring area, the voyage of the ship within the monitoring area is chosen to be 36 sea miles, as shown in Figure 4.5. Therefore, it is estimated that the sailing time of each ship in the area is 3 hours.

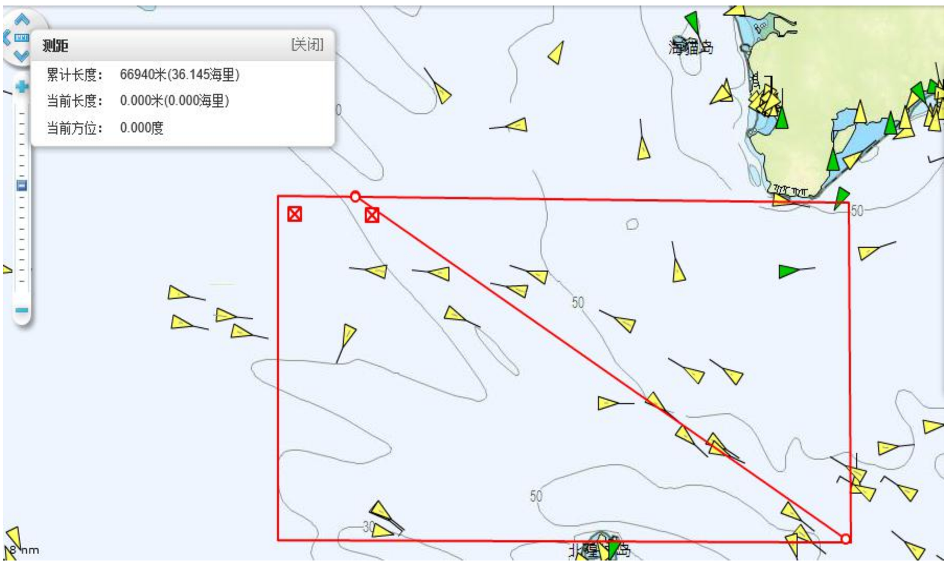


Figure 4.5 Measurement Figure of Shipping Navigation in LAO TIE SHAN Waterway

Source: http://www.shipxy.com/

Based on the settings above, this research paper uses the following steps to estimate black carbon emissions:

(1) Using formula (4.6) to estimate carbon dioxide emissions of various types of ships in the key monitoring areas in the first quarter of 2015

Total amount:

$$\text{Emission} = \sum\nolimits_{\text{engine}} \text{EF[g/kWh]} \times \text{P[kW]} \times \text{LF[\%]} \times \text{T[h]} \qquad (4.6)$$

Emission is E_{CO_2}, $\sum_{\text{engine}}$ EF [g/kWh] can be acquired from form 3.3, P[kW] and LF[%] can be acquired from form 3.4, each kind of ships amount can be acquired from Figure 4.3, T[h] is 3 hours.

From this calculation, the carbon dioxide emissions of ships in the key monitoring area in the first quarter of 2015 are shown in Table 4.2:

Table 4.2 Emission Volume of Carbon Dioxide (t)

Emission (t)	Passenger Ship	Cargo Ship	Non-Transport Ship	Oil Tanker	Dangerous Cargo Ship
E_{CO_2}	7953.6	107507.2	11776.1	20931.4	1071.8

(2) Using model formula (4.7) and carbon dioxide emissions of various types of ships to reverse fuel consumption;

$$E_i = \sum\nolimits_{jklm} S_{jkm}\,(\text{GT}) \times t_{jklm} \times F_{ijlm} \qquad (4.7)$$

$$\sum S = \sum\nolimits_{jklm} S_{jkm}\,(\text{GT}) \times t_{jklm}$$

$$\sum S = E_{CO_2} \div F_{ijlm}$$

E_i is E_{CO_2}, which has been acquired from form 4.2, F_{ijlm} is fuel CO2 emission factor, which is 3.17 acquired from appendix. From this, the fuel consumption of various types of ships $\sum S$ can be obtained as shown in Table 4.3 below.

Table 4.3 Fuel Consumption Amount(t)

consumption (t)	Passenger Ship	Cargo Ship	Non-Transport Ship	Oil Tanker	Dangerous Cargo Ship
Fuel consumption (HFO)	2509	33913.9	3714.9	6603	338.1

(3) Using equation (4.8) to estimate the total amount of black carbon emitted by various types of ships in the LAO TIE SHAN Waterway area during the first quarter of 2015;

$$\sum_{t=h}^{n} E_h = FC_{i,j,k} \times EF_{i,j,k} \tag{4.8}$$

$$\sum E_{BC} = FC_{i,j,k} \times EF_{BC}$$

$\sum_{t=h}^{n} E_h$ is $\sum E_{BC}$,ie, the total emission amount of black carbon, $FC_{i,j,k}$ is fuel consumption amount of various kind of ship, which was required from Table 4.3, and $EF_{i,j,k}$ is EF_{BC}, ie, the emission factor of black carbon, which was required from table 4.1. Therefore, the black carbon emissions of various types of ships estimated from this formula is shown in Table 4.4 below:

Table 4.4 Emission Volume of Black Carbon

Emission(t)	Passenger Ship	Cargo Ship	Non-transport Ship	Oil Tanker	Dangerous Cargo Vessel
E_{BC}	0.9	13.57	1.41	2.51	0.13

Therefore, the total black carbon emission in the first quarter of 2015 in the key monitoring areas of the LIAO NING coastal route estimated in this research paper has reached 18.52 tons.

4.3 Summary of this Chapter

This chapter is the core calculating section of This research paper, and it integrates the basic knowledge in the second chapter of the foreshadowing, and the site selection of the key monitoring areas and the calculation of the black carbon emissions of the ships in the region.

Firstly, use AIS to collect the location information to form clear route path diagram of 1 quarter of 2015 the LIAO NING province coastal of the ship. Through the track shipping routes of intensive and routes converged on the drawing and LAO TIE SHAN canal area we selected for this study of LIAO NING coastal lines ship black carbon key monitoring area. It introduces the LAO TIE SHAN shipping meaning and navigation condition on the coast of LIAO NING.

Then the calculation formulae involved in this research paper are introduced: the general formula for ship pollution discharge, the improved general formula, the model formula in the pollution emission list, and other formulae. Afterwards, according to the ship speed limit regulations for navigation on LAO TIE SHAN waterway, assuming that the speed of the ship is stable at 12 knots, the time for the ship to pass through the key monitoring area is estimated to be 3 hours from the length of the waterway area combined with the ship speed.

The use of other formulae in conjunction with the AIS statistics on the number of ships, as well as the emission coefficients of various types of ship pollution and the engine load under each state of the navigation to estimate the total amount of carbon dioxide emissions, and then substituted into the pollution emission model formula introduced in the first quarter of 2015, the LAO TIE SHAN Waterway Oil consumption of various types of ships in the waterway area. Finally, according to the ship's black carbon emission coefficient under different ship types, fuel quality, and navigational status, the results are derived by substituting the improved pollution emission calculation formula. As a result, the amount of black carbon emissions from ships in the LAO TIE SHAN Waterway in LIAO NING in the first quarter of 2015 was approximately 18.52 tons.

CHAPTER 5

Suggestions on Reduction of Ship Black Carbon Emissions

5.1 Rules and Policy restriction

Internationally, in November 1998, the MEPC held its 42nd meeting to discuss how to control the emission of greenhouse gases by ships. A draft "IMO Policy and Measures for Reduction of Greenhouse Gases on Vessels" adopted by the IMO's 23rd Congress in 2003. Three key options for black carbon emission reduction are proposed: controlling the design of ships, controlling the actual emission of greenhouse gas emissions from ship operations, and establishing a carbon market mechanism.

At the end of August 2014, the country held a low carbon development strategy seminar to discuss carbon trading and implementation programs. This method will be implemented in 2016 and will be established in 2020 to standardize China's carbon trading market(Zhou,2015).

Based on international laws and regulations, as well as the introduction of national policies, the following points are recommended for reducing black carbon emissions:

1. In the ship design process, the optimization of the ship's shape line is involved. The ship type directly affects the air resistance of the ship and reduces this force. Under the same conditions, the host's fuel consumption will be reduced. Through the study of the previous chapters of this research paper, the reduction of fuel consumption will reduce the emission of black carbon. There are many ways to optimize the hull shape, for example: According to the knowledge of fluid mechanics theory, optimize the structure of the ship, and establish the performance of the ship and the structure database.

2. Optimization of the surrounding flow field of the ship's hull. In order to reduce the drag of a water-skimming vessel, ships nowadays usually are constructed with bulbous bow to change the flow state of the bows. Through this, the resistance can be greatly reduced, which can be reduced by 8% to 11% at low speeds, and can also be reduced by 6% at high speeds. This can also greatly reduce the ship's fuel consumption.

3. Adjust the best speed. Advanced ship engines can automatically detect and adjust engine load through electronic technology to optimize fuel efficiency (Brown,2009). This type of engine is under technical research and is planned to be installed on newly registered ships and can detect the engine load of the ship in real time and perform automatic adjustment to ensure that black carbon emissions are effectively reduced. The fuel utilization rate is optimized by appropriately reducing the engine load at full load.

4. Exhaust gas purification technology. Exhaust purification can be used to reduce emissions from marine diesel engines.

5. Due to the pollution caused by the ship in the coastal areas, it is necessary to use high-quality fuel during the entry and exit of the ship and along the coast.

6. Develop new energy sources. Since entering the 21st century, the awareness of the energy crisis has clearly increased. The depletion of energy will bring great disasters to economic development. It is necessary to develop new energy. The development and utilization of new energy not only can alleviate the crisis, but also can effectively reduce the emission of pollutants.

7. Shore power is used during the berthing of the ship. During the period of coming to Port, electricity is provided via the shore, and the suspension of the main engine and auxiliary engine can reduce the fuel consumption of the vessel and achieve the purpose of energy conservation and emission reduction. If the diesel engine is stopped, then the ship will also stop emitting black carbon and other polluting gases into the surrounding environment. The surrounding environment and air quality of the port area will be significantly improved.

8. Pilot fuel selection program. The plan content is what kind of fuel can be specified as a pilot when the ship enters or exits the port. If you do not follow the rules, you will be charged a high fee.

9. The establishment of a control area(Liu,2015).

5.2 Emission Reduction Depended on Human Awareness

Although black carbon emissions are mainly determined by fuel consumption, the influence of human factors cannot be ignored. Because there are many situations that can be controlled by humans, fuel consumption can be reduced. There are two main factors that contribute to the increase of fuel consumption in coastal areas:

1. Shallow water effect: It refers to the phenomenon that the ship's hull caused by the ship's navigation in shallow water will greatly increase(Peng,2016). We assume that R is the resistance of the ship in the deep water area of the direct channel, and R_A is the resistance of the ship in the shallow water channel, so the two have the following relation:

$$R_A = K_A R \tag{5.1}$$

In the Formula:

K_A is Conversion coefficient of ship resistance. It's expression formula is:

$$K_A = 1 + \frac{0.0065V^2}{(h/T - 1)\sqrt{T}} \tag{5.2}$$

h---Navigation Channel depth
T--- Ship Draft
V---Actual sea speed

2. Narrow channel: It refers to a ship that travels in a narrow channel, because the two strings of the ship become very short with the straight distance along the shore, resulting in additional resistance to the ship. It is also because the narrow channel is more likely to have a water-holding phenomenon, so it will continue to increase the resistance of the ship. If the resistance of the ship in the deeper channel is R, the resistance of the ship through the narrow channel at the same speed is shown below.
3.

$$R_\alpha = K_\alpha R \tag{5.3}$$

In the Formula:

R_α ---Narrow Channel Resistance

K_α ----Resistance Conversion Coefficient

$$K_\alpha = 1.1\left[\frac{H}{n-\left(1+0.2\delta^2V^2\right)}\right]^2 \quad (5.4)$$

In the Formula:

δ ---Ships Square Coefficient

n---Waterway section modulus (Refers to the ratio of the water passage cross section of the waterway to the water inlet area of the mid-section of the ship).

The shallow water effect and the drag caused by the narrow waterway are all related to the speed of the ship. Therefore, the ship is able to control the speed of navigation through such water conditions, so it can reduce the additional resistance it receives to a great extent. It has never reduced its fuel consumption and has achieved the objective of reducing black carbon emissions.

5.3 Suggestions on Black Carbon Emission in coastal Water Area in LIAO NING Province

Through the analysis of the results of traffic flow charts, the BA YU QUAN port area in the north and the Dalian port area in the south have been selected as key supervision areas. At the same time, the Dalian port area is close to the city, and ship pollution will be particularly serious. Through studies on the factors affecting black carbon emissions, we learned that fuel consumption plays a decisive role in the development of black carbon. Therefore, the research on the emission reduction measures in the coastal areas of LIAO NING Province mainly focuses on fuel consumption, fuel quality, and human consciousness reduction, relevant suggestions were made accordingly.

5.3.1 Establish Black Carbon Emissions control Zone in Port area

According to the ship traffic flow chart, the ports with more vessels flow are BA YU QUAN Port and Dalian Port. Therefore, these two ports can be selected as the ship's air pollutant emission control zone to reduce the black carbon emission of the ship.

The establishment of a control zone requires the maritime authorities to strengthen the inspection of air pollution prevention certificates and oil record books, fuel supply documents and fuel oil. Supervise relevant inspection agencies on the quality supervision of marine engines and other related marine products.

(1) Ships entering or leaving Port require the use of high-quality fuel. In the previous section, the impact of fuel quality on black carbon emissions was analyzed and it was concluded that high quality fuel oil plays an important role in reducing black carbon emission factors.

(2) The ship uses port facilities for electricity during its stay in Port. After the ship arrived in Port, the pollutant emissions it had brought had been changed from dynamic to static. At this time, the power it needed was not limited to the original fuel, and it could already look for cleaner energy to replace the fuel consumption. The use of shore power can avoid the impact of pollutants generated by the auxiliary machine in the port during its stay and transfer it to the power plant. The reason for switching to shore power is that power plants have adopted large-scale and intensive equipment. The air pollution in the desulfurization, denitrification, dust removal, and defogging measures can be more effectively managed and controlled.

(3) Ships entering the control area are required to reduce the speed of the ship. The deceleration here refers to the energy-saving speed under which the host can safely drive and reduce the energy consumption to a large extent while reducing the load(Wu,1994). The deceleration control zone is mainly based on the discharge list of the port, and the emission inventory list needs some basic data of the ship such as the continuous load power of the engine, the maximum speed of the ship, the operational data of the ship such as actual speed, load factor, sailing distance, navigation, the time and the time of port suspension, the method for establishing the ship's emission list describes the specific method of establishment in Chapter 3, Section 3. In the end, these tasks mainly require the Port Authority to establish a corresponding air pollution database.

5.3.2 Relying on the crew member to reduce emissions on coast

The coastal coastline of LIAO NING is long and narrow, and the pollution produced by ships is extensive. Supervision requires a lot of manpower and material resources. Therefore, the regulatory resistance is greater, but the pollution of coastal waters cannot be ignored. Artificial awareness reduction plays an important role in such situations. When encountering shallow water effects and narrow waterways, the search for the optimal speed can reduce certain fuel consumption and achieve the aim of emission reduction.

The LAO TIE SHAN Waterway in the northern part of the BOHAI Straits is the main channel for Yellow Sea water entering the BOHAI Sea, but it is known as the Liaodong Shoal due to its narrow cross-section. The LAO TIE SHAN Waterway has a narrow channel, followed by a shallow water effect, and the LAO TIE SHAN Waterway is the only route between the ports of Tianjin, Qinhuangdao, YING KOU BA YU QUAN, and JIN ZHOU and other BOHAI Rim ports. There are many ships in the past. If all crew members' awareness of reducing fuel consumption is increased, than fuel consumption can be reduced when encountered with the same sea conditions.

The influencing factors above are mainly controlled by humans, so seafarers are required to have high-level driving skills. In order to reduce the extra fuel consumption, we need the crew to fully understand the coastal navigation environment. Currently, the main channels obtaining essential information are by means of the traditional paper charts, electronic charts and navigation notices. In order to improve the crew's awareness of environmental protection, college or crew training institutions are required to instill environmental awareness during the training of seafarers. This places higher requirements on the education of seafaring colleges. It not only develops seafaring technical competence, but also needs to cultivate awareness of environmental protection.

5.4 Summary of the Chapter

To study the control scheme of black carbon, the first thing to do is to study the factors, mainly including the engine load, fuel quality and the use of scrubber. The results of these factors were significantly different under different conditions. From the influence factors of engine load, the best speed is obtained, which is the consensus of shipping economic speed, because the reduction in fuel consumption can directly result in the reduction in waste gas. Better fuel is needed to reduce fuel consumption. Finally, based on the study of influenced factors, and combining the domestic and foreign studies of black carbon emission reduction, this chapter gives some suggestions on emission reduction of black carbon in shipping industry and on coastal waters in LIAO NING province. The port's proposal is mainly to use shore power, to change oil in the port, and to slow down the ship. Because of limited regulation in coastal areas, the emission reduction of human consciousness is still neede

CHAPTER 6

Conclusions and Suggestions

In this research paper, the black carbon emission of ships in LIAO NING coastal routes is studied in order to cope with the IMO's plan to implement pollution reduction measures. With the rapid development of transportation today, the major transportation industries, including shipping, are in the pursuit of interests and should also take responsibility for our living environment, making contribution to the purification of the earth's environment which has been eroded by kinds of pollution. As for the black carbon studied in this research paper, a large number of these pollutants have posed a threat to the Arctic sea ice. Although this threat comes mainly from the vessels in polar sea, a lot of black carbon emissions produced by vessel traffic in other sea have also posed a threat to environment and human health. Besides, along with the increasing call from IMO for reduction in ship black carbon emissions, we also have an obligation to have more responsibility to face up to it, and to study it, so we can deal with it.

Through the introduction of various properties and influence factors of black carbon in this research paper, the key monitoring area are chosen in coastal routes of LIAO NING province and the ship black carbon emissions in this area are estimated, reaching a value of 18.52 tons. For the wider shipping area and the uncountable amount of shipping, the earth's daily exposure to black carbon pollution and other marine pollution cannot be underestimated.

In combining with other literature data, the correlation between the black carbon emission volume and the quality of black carbon emissions and fuel is very big, and the use of low sulfur content, burning ash less distillate fuel can reduce black carbon emissions factor so as to effectively reduce black carbon emissions of the ship. Ship scrubbing filtering device can also reduce the emissions of pollutants such as black carbon, and regardless of the region in real-time control pollution emissions, so the more efficient vessel pollution emission filter also has strategic significance to reduce black carbon. What’s more, the advanced electronic technology applied in ship engine load automatic adjustment make the ship's engine load moment maintain minimum fuel consumption and maximum fuel efficiency is also the effective measures to reduce or control the ship black carbon emissions, so the research and development of new, environmentally friendly development direction of Marine engine can yet be regarded as an ideal. Currently, the most direct reduction is to limit the use of heavy fuel, especially in the polar regions, which have already been banned the use of heavy fuel. But for other vast expanses, the price of fuel and the shipping industry's profitability is limited, and cannot be fully implemented in a short period of time.

In general, to control and to reduce black carbon emissions need not only the effort of IMO and environmental research scholars, advanced planning schemes and countermeasures, development of more energy-efficient green ship equipment, but also more in need of the shipping practitioners with good professional ethics, actively cooperating and consciously abiding by the emission reduction policy.

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