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Study on ship emissions and countermeasures in Shanghai Port

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STUDY ON SHIP EMISSIONS AND COUNTERMEASURES IN SHANGHAI PORT

By

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DECLARATION

I certify that all the material in this dissertation 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 dissertation reflect my own personal views, and are not necessarily endorsed by the University.

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ABSTRACT

Title of Dissertation: **Study on Ship Emissions and Countermeasures in Shanghai Port**

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In the past two decades, China has developed into a major import and export trade country. With the emissions of air pollutants from ships becoming more and more serious, it affects people's life day by day. With the rapid construction of Shanghai port as a shipping center in China, more and more attention has been paid to the air pollution issues which focused on ship emissions and countermeasures.

Firstly, this dissertation reviews all the requirement of conventions, laws, regulations and normative documents from worldwide. Then analyzes the damage and formation principle of exhaust pollutants such as SO_X, NO_X, CO_X, PM and GHG from ships and highlights on the current situation and assessment of ship emission inventories of Shanghai port. To reduce air pollution, this paper analyzes and summarizes some studies from the perspective of technology, standard and policy.

Referring to some advanced and successful ports in the world we concludes the following approaches such as the implementation of shore power, the establishment of emission control area (ECA) and the combination of compulsory and incentive policy for energy saving and emission reduction. The successful experiences of Shanghai port are summarized and applied to many similar port cities in China to settle the air pollutant from ships.

Key Words: IMO, MARPOL, Ship emissions, ECA, Countermeasures, Air pollution

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LIST OF ABBREVIATIONS

Act	Activity time
A/E	auxiliary engine
AIS	Automatic Identification System
CARB	California Air Resources Board
CCS	China Classification Society
CH_4	Methane
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CO_X	Oxides of Carbon
DECA	Domestic Emission Control Area
DFDE	Dual-Fuel Diesel Engines
DPM	Diesel Particulate Matter
ECA	Emission Control Area
EEDI	Energy Efficiency Design Indicator
EEOI	Energy Efficiency Operational Indicator
EIAPP	Engine International Air Pollution Prevention
FCF	Fuel Correction Factor
GHG	Green House Gas
GHG Fund	Green House Gas fund
HC	Hydrocarbons
H.O.	Heavy Oil
IEC	International Electrotechnical Commission
IMO	International Maritime Organization
ISO	International Standardization Organization

LF	Load Factor
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
MARPOL convention	International Convention for the Prevention of Pollution from Ships
M/E	Main Engine
MEP	Ministry of Environmental Protection of China
MEPC	Marine Environment Protection Committee
NECA	Nitrogen Emission Control Area
NOAA	National Oceanic and Atmospheric Administration
NO_X	Oxides of Nitrogen
OGV	Ocean-Going Vessel
PM	Particulate Matter
$PM_{2.5}$	Particulate Matter less than 2.5 microns in diameter
PM_{10}	Particulate Matter less than 10 microns in diameter
ppmv	parts per million by volume
SCR	Selective Catalytic Reduction
SECA	Sulfur Emission Control Area
SEEMP	Ship Energy Efficiency Management Plan
SFC	Specific Fuel Consumption
SO_X	Oxides of Sulfur
VOC	Volatile Organic Compound

Chapter 1

Introduction

1.1 Background of the study

In recent years, with the rapid development of industry and economy in the world, the issue about air pollution is becoming more and more serious. Compared with the pollution caused by nature, human activities are the main causes of air pollution, which can be divided into industrial pollution, traffic pollution, agricultural pollution and domestic pollution. Transportation is the foundation of national economic construction. The characteristics of transportation which burning a large amount of fuel decides that it produces large amounts of emissions resulting in adverse effects on the atmospheric environment.

Transportation can be broadly divided into marine transportation, land transportation and air transportation of which marine transportation is the most important mode of international trade and it bears more than 90% of the world's trade (UNCTAD, 2015). In recent years, with the accelerated process of economic globalization, maritime transport has been rapidly developed, and the number of ships has increased dramatically. Some data show that the current air pollution caused by ship emissions has accounted for 10% of the entire air pollution. In addition, researchers from the

National Oceanic and Atmospheric Administration (NOAA) showed that ships oxides of nitrogen (NO_X) emissions per year accounted for nearly 30% of total global emissions. The other study showed that the ship oxides of sulfur (SO_X) emissions have reached 5% of the world's total emissions while SO_X emission has accounted for 30% of the local total emissions in some coastal ports.

China is a big country in the shipping industry with many ports and coastal and inland water resources. The statistics showed that ship emission SO_X and NO_X from vessels which berthing port in China accounted for 8.4% and 11.3% of the total pollutant emissions respectively by Ministry of Environmental Protection of China (MEP). From 2010 to 2016, the total amount of pollutants discharged by vessel has been increasing year by year as following Table1.1 in China. Shanghai, as China's economic center, its air quality problem became more and more serious. According to Table1.2, the throughput of container and cargo of Shanghai port for many years ranked the first place allover the world. While bringing great economic benefits to Shanghai, it also brought serious air pollution. The results monitored ship emissions showed that SO_X and NO_X accounted for 12.8% and 8.6% of total pollution emissions in Shanghai. Therefore, it is important for Shanghai to control air pollution and build a green port by studying the impact of ships on air quality in Shanghai.

Table1.1 - The amount of pollutants discharged by vessel 2010-2016 unit: 1×10^4tons

year	SO_X	NO_X	Ozonide	Toxic gas	Volatile organic compound (VOC)
2010	11.8	14.1	11	112	31
2011	12.7	14.6	11.4	116	32
2012	13.5	15.7	11.9	118	34

2013	13.8	15.9	12.6	123	35
2014	14.3	16.3	13.2	125	37
2015	14.9	16.7	14	128	39
2016	15.4	17.2	14.6	130	41

Data source: MEP

Table 1.2 - The throughput of Shanghai Port from 2007 to 2016

Year	Container volume/10K TEU	Cargo throughput/10 K TON
2007	2615.2	35278.9
2008	2800.6	36913.3
2009	2500.2	36501.5
2010	2906.9	42835.1
2011	3173.9	48442.3
2012	3252.9	50237.5
2013	3377.3	54302.4
2014	3528.5	53862.4
2015	3653.7	51332.6
2016	3713.3	51406.6

Data source: http://www.portshanghai.com.cn/jtwbs/webpages/server_teu.html

1.2 Objective of the study

The main air pollutants from ship emissions are SO_X, NO_X, Oxides of Carbon (CO_X), Hydrocarbons (HC), Particulate Matter (PM) and so on. The primary purpose of this research is to analyze the status of ship emissions in Shanghai port and give suggestion and countermeasures to reduce air pollution. The author believes that it is necessary to take further analysis and discussion on the technology, standard and policy for guiding Shanghai port.

The pollution from ships is not limited to a few cities such as Shanghai and Shenzhen in China. According to statistics, Chinese ports occupy eight of top ten largest ports in the world. And many ports concentrated in densely populated areas such as the Pearl River Delta, Yangtze River Delta, Bohai and other areas. So the air pollution of ships can easily cause adverse effects on public health and the environment. So the final purpose is to make clear the requirement of ship emissions from every aspect and then formulate efficient countermeasures which could be implemented for all the similar ports in China.

1.3 Methodology

The author performed a systematic wide range of literature review of International Maritime Organization (IMO) documents, international convention, journals and information on website on fuel and ship emissions reduction measures, based on a comprehensive search and analysis of published studies on shipping energy efficiency and ship emissions. The research takes example from international convention and operation mechanism and characteristics, and combined with the current domestic relevant laws and regulations through normative analysis, empirical analysis, comparative analysis and historical analysis method. The research methods of this paper are analogy, comparison and overview.

1.4 Main contents and structure

1.4.1 The main contents

First of all, with the analyzing of harmful gas composition and formation mechanism from ships emissions and further studying key factors on the impact of harmful gas generated, the laws, regulations, rules and norms of air pollution reduction at various levels are combed and studied. The necessity of reducing the emission of ships in Shanghai port is obtained.

Secondly, the dissertation in-depth analyzes and assesses the status of Shanghai port ship emissions and concludes that it is necessary and urgent to control the ship emissions

Finally, by comparing the advanced and feasible emission control schemes of major port countries in the world with the actual situation of Shanghai port, the optimum combination scheme of air pollution reduction for Shanghai port is found out.

1.4.2 Dissertation structure

This paper consists of six chapters. The first chapter is the introduction which introduces the background and significance of this paper and gives the chapter arrangement. The second chapter is the research on the legislation of ship emission. The mandatory requirements for the major sulfur reduction, nitrogen reduction and greenhouse gas (GHG) emissions involved in the regulatory system are analyzed. The third chapter is the research of ship emissions causes and control method. The current emissions from different aspects and methods of control are analyzed and studied. The fourth chapter is the status of ships emissions in Shanghai port. The composition and formation principle of air pollution emission are analyzed then the pollutant is calculated and evaluated. The fifth chapter is about the current and feasible ship emission control in Shanghai port. The sixth chapter is the summary and conclusion. The main contents and achievements are summarized and the feasibility of the countermeasures to reduce the air pollution emission of ships is put forward.

Chapter 2

Requirements for ship emissions worldwide

2.1 General requirements from IMO

In view of ship emissions impact on environment, the Marine Environment Protection Committee (MEPC) as early as 1988 formally launched to discuss and review the issue of preventing air pollution caused by ship. In September 1997, the IMO held a conference in London, adopting the 1997 protocol and annex VI (Regulations for Prevention of Air Pollution from Ships) of International Convention for the Prevention of Pollution from Ships (MARPOL convention). IMO issued a circulation about entry-into-force conditions of the 1997 protocol of MARPOL convention and annex VI in 2004, which came into force from May 19, 2005, mainly to control the SO_X and NO_X depleting substances from the ship emissions. The most important thing is that the sulfur content of ship fuel oil is lower than 4.5%. Main contributors to air pollution are SO_X and NO_X that relate to bunker fuel types and engine operating conditions. The SO_X emission limits restrict the sulfur content of the fuel and the NO_X emission limits restricts the operating conditions (i.e. Operating temperature) of marine diesel engines. Even though general SO_X and NO_X emission limits are introduced globally, tighter SO_X and NO_X emission limits are introduced in the designated ECA.

2.1.1 Requirements for sulfur

Subsequently, in 2008, the IMO adopted the amendments to the annex VI of MARPOL convention, which came into force from July 1, 2010. The requirement for sulfur content of fuel oil is not exceeding 4.5% before January 1, 2012 beyond the sulfur emission control area (SECA), while it is not more than 3.5% after January 1, 2012. The sulfur content is no more than 0.5% from January 1, 2020 which may be postponed until January 1, 2025 depending on the results of a report completed in 2018 on the fuel oil survey. The Convention requires that the sulphur content of fuel oil used by ships sailing in the SECA after July 1, 2010 shall not exceed 1%, and that the sulfur content of fuel oil should be reduced to 0.1% since January 1, 2015. Table 2.1 introduces the IMO regulations on ship's permissible sulphur content in fuel oil.(IMO, 2008)

Table 2.1 - IMO permissible sulphur content of fuel oil

Area	**Sulphur limits （%m/m）**	**Time**
Worldwide	4.5	Before January 1, 2012
	3.5	After January 1, 2012
	0.5	After January 1, 2020
SECA	1.5	Before January 1, 2010
	1.0	After July 1, 2010
	0.1	After January 1, 2015

Source: This report

From Table2.1, it is clear that the requirements of ship sulphur emissions will become stricter and stricter with the consciousness of environmental protection and development of technology.

2.1.2 Requirements for nitrogen

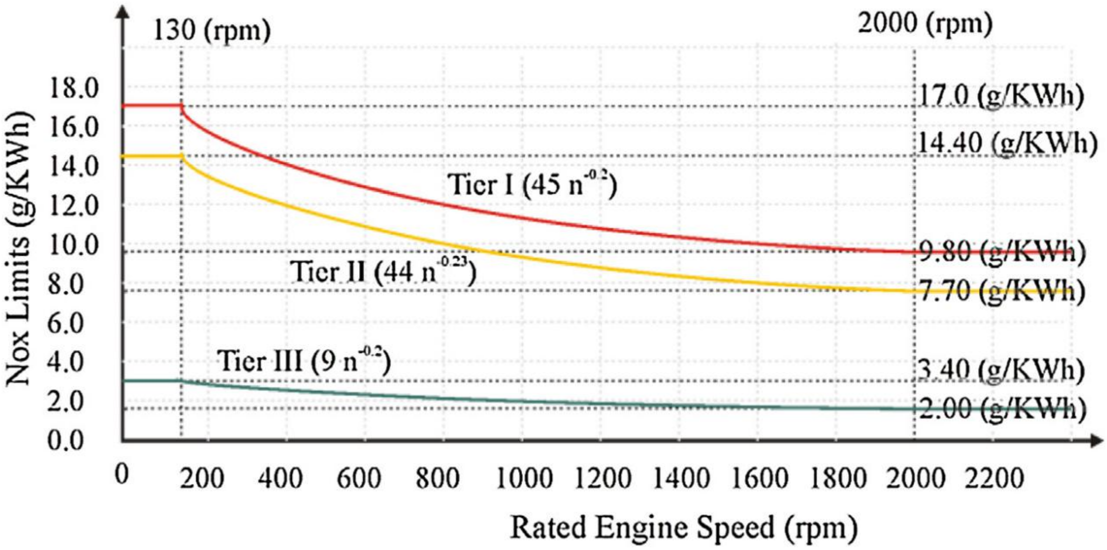

Figure 2.1 - Requirement of NO_X limits

Source: Lokukaluge, P.P. & Brage, M., 2016

The NO_X emission limits for marine diesel engines are proposed under the mandatory NO_X Technical Code[1] of MARPOL Annex VI. The NO_X emissions are divided into three different levels of Tier I, II and III that relate to engine speeds and installed dates. The detail of requirements illustrate in the Figure 2.1.

(1) Emission limit of Tier I (NO_X emission standard before amend):

①The 17 g/kWh, when n<130 r/min;

②The $45 \times n^{(-0.2)}$ g/kWh, when 130 r/min≤ n<2000 r/min;

③The 9.8 g/kWh, when n ≥ 2000 r/min;

Scope of application: Tier I standard applies to ships installed marine diesel engines

[1] These emission limits are through a survey/certification requirement implemented by introducing the Engine International Air Pollution Prevention (EIAPP) certificates for different types of marine engines.

built on January 1, 2000 or after and before January 1, 2011. Where: n is rated speed of engine.

(2) Emission limits of Tier II:

①The 14.4 g/kWh, when $n<130$ r/min;

②The $44 \times n^{(-0.23)}$ g/kWh, when 130 r/min $\leq n<2000$ r/min;

③The 7.7 g/kWh, when $n \geq 2000$ r/min;

Scope of application: Tier II standard applies to ships installed marine diesel engine built on January 1, 2011 or after. Where: n is rated speed of engine.

(3) Emission limits of Tier III:

①The 3.4 g/kWh, when $n<130$ r/min;

②The $9 \times n^{(-0.2)}$ g/kWh, when 130 r/min $\leq n<2000$ r/min;

③The 2.0 g/kWh, when $n \geq 2000$ r/min;

Scope of application: Tier III standard applies to ships installed diesel oil engine on or after January 1, 2016. The ship shall comply with the Tier III standard when the vessel is sailing in the Nitrogen Emission Control Area(NECA) designated by the IMO while the ship shall at least comply with the Tier II standard when navigating outside the NECA. (IMO, 2008)

2.1.3 Requirements for GHG

In July 15, 2011, the MEPC.203 (62) resolution passed amendments to annex VI of MARPOL convention about ship energy efficiency rules which determine the new ship energy efficiency design index (EEDI) and ship energy efficiency management plan (SEEMP) as regard new requirements for reducing GHG emissions. The EEDI was identified as the most important technical measure implemented by the IMO, designed to promote the improvement in energy use of marine engine and reduction of pollution. The index of different types are set up respectively in the lowest level of energy efficiency (after the complex calculation, each ship can determine the level of EEDI: the lower the index shows that the better the energy efficiency of ships is). The guidelines of the ship's energy efficiency entered into force on January 1, 2013 and took effect on 2015. From January 1, 2013, newly built ships whose gross tonnage are 400 or more than 400 must meet the relevant requirements of EEDI, and it reduces carbon emissions by 10%. From 2015 to 2019, 2020 to 2024 carbon decrease by 10% respectively. Till that time the reduction will reach the target 30% of the total emission.

There is also the ship energy efficiency management plan (SEEMP) adopted with the EEDI index at the same period. SEEMP is a measure to help ship companies or ships to improve energy efficiency in the operation of ships in a cost-effective manner. By utilizing the vessel energy efficiency operation index (EEOI) as a monitoring and benchmark tool, SEEMP provides an effective means of monitoring the efficient operation of ships and fleets. SEEMP helps fleet operators in ship operations in the process of measuring ship, and can be used for any change in the calculation of ship in the process of operation, such as optimization, more frequent replacement of voyage plan propulsion system clean, waste heat recycling system technological innovation or new equipment etc.. SEEMP urges ship owners and operators to consider the introduction of new technologies and practices in any phase of the quest to optimize ship operations.

Annex VI also prohibits the intentional discharge of ozone.

2.2 Requirements in advanced ports of the world

IMO data showed that the annual SO_X emissions of ships amounted to 6340000 tons, accounting for about 4% of all world emissions. In early 2009, the NOAA research report showed that the ship has become a serious source of air pollution: the current annual global maritime emissions of PM amount is equivalent to the 50% of global automotive emissions; 30% of annual global NO_X is from ships at sea. In order to further improve emission control standards, some countries and regions have submitted to IMO with more stringent emission standards for regional implementation and applied to the establishment of ECA to control ship emissions.

2.2.1 California, USA

On November 21, 2013, the California Air Resources Board (CARB) issued a notice of maritime 2013-1 which updated the marine notice in 2012. The notice reminded the Ocean-Going Vessel (OGV) fuel sulfur content and other operations to comply with the new regulations through the use of low sulfur fuel oil in the waters of California and the place away from the California coast line within 24 nautical miles. Compared with the 2012 notice, the requirement for sulfur content in fuel oil was further stringent. From January 1, 2014, the maximum fuel sulfur content limit for fuel oil was 0.1%.

2.2.2 European Union

The EU's implementation of the MARPOL convention annex VI requirement about no more than 0.1%[2] low sulfur fuel is in ahead of time 5 years comparing with IMO schedule. Since January 1, 2010, EU ports have begun to unilaterally enforce the mandatory use of low sulphur fuel which means that ships anchored in EU ports (including anchoring, mooring buoys, berthing ship) more than 2 hours shall use the

[2] this does not apply to ships stopped all machines and use shore power.

the fuel oil which sulfur content is no more than 0.1%.

2.2.3 Hong Kong area

In April 15, 2015, the Hong Kong Legislative Council passed the Rules[3] for air pollution control (OGV). From July 1, 2015, all ships must be used in accordance with the specifications of the fuel to berth in Hong Kong, that is, sulfur content in the fuel oil should not exceed 0.5% to reduce ship emissions of pollutants and improve air quality.

2.3 Laws and regulations in China

The Chinese government has issued the *Law about Prevention and Treatment of Air Pollution and Action plan for the prevention and control of air pollution* and other laws and regulations. At the same time, based on ISO 8217:2010, China formulated the second edition of *marine fuel oil* (GB/T17411-2012) in July 1, 2012, taking full account of the actual situation of marine fuel oil in our country and settling the national standards of the marine fuel sulfur content under 3.5% (m/m) conforming with international convention.

The law on the prevention and control of air pollution[4] defined that air pollutants emitted by motor vehicle and ships shall not exceed the prescribed discharge standards. To implement the law of the People's Republic of China on the prevention and control of air pollution, to promote the development of green shipping and energy conservation and emission reduction of ships, and to reduce air pollutants

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[3] This rules is about fuel used during berthing

[4] The new edition of the law modified in 29, August, 2015. Chapter 4, Part 3, Regulation 51 state the requirement.

emissions in key areas of China, this programmer designating domestic emission control area(DECA) is formulated. Through the establishment of ship air pollutant ECA control SO_X, NO_X and PM emissions, improving China's coastal areas along the river and especially the ambient air quality in the port city for the comprehensive control of air pollution. Setting up Pearl River Delta, Yangtze River Delta, Bohai (Beijing, Tianjin) waters ship DECA determine core ports to control the emissions of the area.

The MEP and the General Administration of Inspection and Quarantine issued the *Emission limits and measures for exhaust emission of Marine engine* (first and second stages of China) (GB15097 - 2016). If all the inland, coastal and the fishing vessels obey the new standards requiring the use of low sulfur fuel. Inland ship and ocean-river direct ship with GB 252 standard diesel fuel and the first stage of coastal vessels using sulfur content of not more than 5000 mg/kg ship fuel oil, the use of the second phase of sulfur content of fuel no more than 1000 mg/kg ship oil, will bring huge environmental benefits. All the ship has significant SO_2 and PM emissions reduction benefits. If the first stage of fuel oil does not exceed 5000 mg/kg, it is estimated that only the transport ship (not including fishing)will make the annual SO_2 emission reduction of about 540000 tons, PM emissions annual reduction of about 40000 tons by improving the quality of fuel sulfur content. If the sulfur content of the second stage is reduced to below 1000 mg/kg, it will continue to reduce SO_2 emissions by about 110000 tons and PM emissions by about 10000 tons.

China's coastal, along the river and port cities will be the main beneficiaries of the above-mentioned emission reduction benefits, which is of great significance to improve the air quality in these places and cities.

2.4 Shanghai local government requirements

Regulations of the Shanghai on the prevention and control of air pollution is the local regulation on the air pollution for vessels. This regulation[5] requires that vehicles and ships traveling in the city may not emit pollutants to the atmosphere exceeding the emission standards stipulated by the state or the city, and the motor vehicles and vessels running in this city shall not discharge visible smoke.

[5] Chapter 4, Article 38

Chapter 3

Feasible scheme for controlling ship emissions

3.1 The composition, formation principle and causes of ship emissions

The diesel engine appeared in 1892, and today more than 99% merchant ships are powered by diesel engine. The emissions of air pollutants from ship mainly come from engine emissions during navigation, berthing and cargo handling by combustion of diesel fuel (Yu, 2013).

The types of exhaust gases emitted by marine diesel engines are complex. They are mainly composed of combustion products and residual air, which can be divided into two categories: harmful ingredients and harmless ingredients. Harmless ingredients include carbon dioxide (CO_2), water vapor and residual nitrogen and oxygen, which have no direct harm to human beings. CO_2 will produce the greenhouse effect on the earth's climate. The harmful gas composition is also known as the main pollutants, such as NO_2, SO_2, CO, and PM. NO_X and SO_X can cause the most direct impact on the environment and human beings.

3.1.1 Particulate matter

Marine diesel engine emission sources and composition of PM are complex. The existing research shows that the PM of diesel engine is mainly from 3 aspects. The first is the tiny particles of fuel and lubricating oil because of insufficient combustion and itself accumulations which size is generally sub micron. The second is the fuel ash because it contains a large quantity of ash. After combustion of oil, ash emission formula particles whose size is between 200nm[6] ~ 10μm. The third is the two gaseous pollutants produced by combustion synthesis such as the formation aerosols of sulfur acid, sulfate, nitrate acid and nitrate from SO_X and NO_X combustion are discharged in the form of particles and the size is generally micron. In the chemical composition, the particles contain large amounts of black carbon, vanadium, nickel sulfate, sulfite, etc.. The sulfur content of fuel oil has a significant influence on PM emissions. At present, the quality of marine fuel oil is poor and the S content is high. Therefore, the amount of PM emissions from ships is significantly higher than that of vehicle emissions. The calculations show that when a medium or large container ship uses the fuel oil with 3.5% of sulfur and the output power is 70% of the maximum power the total amount of Particulate Matter less than 2.5 microns in diameter ($PM_{2.5}$) discharged by the ship is equivalent to 500 000 freight car with national IV emissions in one day (Fang et al., 2017).

3.1.2 Sulfur oxides

SO_X are mainly derived from sulfur contained in fuels, which are produced by combustion and discharged into the atmosphere by the formation of exhaust gases. The largest content of SO_X is SO_2. The chemical equation is as follows:

$$S + O_2 \leftrightarrow SO_2$$

[6] 1nm = 10^{-9}m

During the combustion process, sulfur in the fuels is converted into SO_2, and a small part is oxidized to SO_3[7], which is discharged with the exhaust gas. In the atmosphere, SO_2 can be oxidized to sulfuric acid fog or sulfate aerosol, which is an important precursor of environmental acidification. According to the navigation area, water area and port area environmental protection laws and regulations, the marine fuel is divided into ordinary diesel, distillate fuel oil and residual fuel oil. For our country, ordinary diesel sulfur content is less than 350 L/L which is generally used for inland ship. Distillate fuel oil is generally used for coastal ships and OGV when on the way inward or outward of port and requirement by environmental regulations of the sea and the sulfur content is generally less than 15000 L/L. At present, domestic and foreign ships mainly use residual fuel oil (also known as Heavy Oil(H.O.)). The H.O. is residual product of the oil refinery and its sulfur content is very high. The IMO provides the ship with fuel oil sulfur content of the most high limit value of 35000 L/L and 27000 L/L is the average of the world practical application. Therefore, the fuel sulfur content and different use result in the different emission of SO_X in different types of ship is as follows: OGV ≥ coastal ship > inland ship.

3.1.3 Nitrogen oxides

The NO_X emitted by ships refer to all kinds of nitrogen and oxygen compounds including NO, NO_2, N_2O_3, N_2O and NO_3. The formation of NO_X is mainly related to the nitrogen and oxygen in the air and the nitrogen in the fuel. If the nitrogen and oxygen elements come from the air, the NO_X is called the thermal NO_X compound; the NO_X produced due to the nitrogen from the fuel is called the fuel NO_X compound. Under normal circumstances, the nitrogen content is less than 0.02% in the ship fuel, so the emission of NO_X in the exhaust gas is mainly thermal NO_X, which is oxidized

[7] the ratio is about 15 to 1

by N_2 in the air at high temperature. NO accounts for 90% to 95% of NO_X. The formulas for generating NO are as follows:

$$N_2 + O \leftrightarrow NO + N$$

$$N + O_2 \leftrightarrow NO + O$$

$$N + OH \leftrightarrow NO + H$$

Among all NO_X, NO and NO_2 are most harmful to water, soil and air. NO is a major component of nitrogen oxides. Colorless gas NO is unstable and can rapidly change into NO_2 in the air. NO_2 is one of the main factors for the formation of photochemical smog, and also one of the chief culprits of acid rain. (Zhao, 2013).

3.1.4 Carbon oxides and GHG

CO is the product of insufficient fuel combustion, resulting from improper engine combustion chamber temperature and inadequate fuel air mixture ratio. CO_2 is formed in the combustion process of fuel oil. CO_2 emissions mainly depend on the fuel quality, combustion form, the output power and efficiency of the engine. HC composition is generally referred to CH_4, which is the product of unburned or incomplete combustion of fuel oil, and CH_4 emissions mainly depend on the type of fuel. The formula for generating are as the following

$$C + O_2 \leftrightarrow CO_2$$

$$C + O \leftrightarrow CO$$

$$C + H \leftrightarrow HC$$

CO is a colorless, odorless, tasteless, insoluble gas. CO_2 is a colorless, odorless gas with a slightly greater density than air. CO_2 is a GHG with the properties of heat absorption and heat insulation. CO_2 caused by environmental pollution increases in the atmosphere forming an invisible glass cover, so that the solar radiation to the earth's heat cannot spread to the outer space, causing the surface of the earth to heat up. The greenhouse effect will bring serious impacts on the earth's environment resulting in abnormal climate, increasing sea storms, melting glaciers, rising sea levels, destroying natural ecology, increasing diseases and insect pests, increasing land drought and desertification. GHG has become a focus of environmental protection recently. Scientific observations show that the concentration of the atmosphere has risen from 280ppmv before the industrial revolution to 379ppmv currently. The global average temperature has risen by 0.74 degrees in the past hundred years, especially in the recent 30 years.

3.2 ECA established through legislation

It is an efficient measure limiting the sulphur content to reduce the SO_X emission. IMO sets up ECA to reduce the pollution of ships. It aims to reduce emissions from ships in environmentally sensitive areas by developing stringent fuel and engine requirements. The ECA is a mandatory measure requiring the ship to use the low sulphur fuel. It is clear that SO_X emission reductions can reach much more 67%-97% in the ECA from the Figure 3.1. Figure 3.1 also shows the comparison of permissible sulphur worldwide as well as in ECA. At present, there are 4 ECAs approved by the IMO 2011 amendment of MARPOL annex VI, namely, the Baltic Sea area, the North Sea area, the North America sea area and the United States Caribbean Sea area as shown in the Figure 3.2. In addition, the European Union and the United States have adopted emission control measures for ships entering the EU waters and the United States Coast of California in order to protect the local atmospheric environment. The NECA and PM ECAs are North American emissions and US Caribbean Sea ECA including coastal area 200 nm[8] away from coastline .

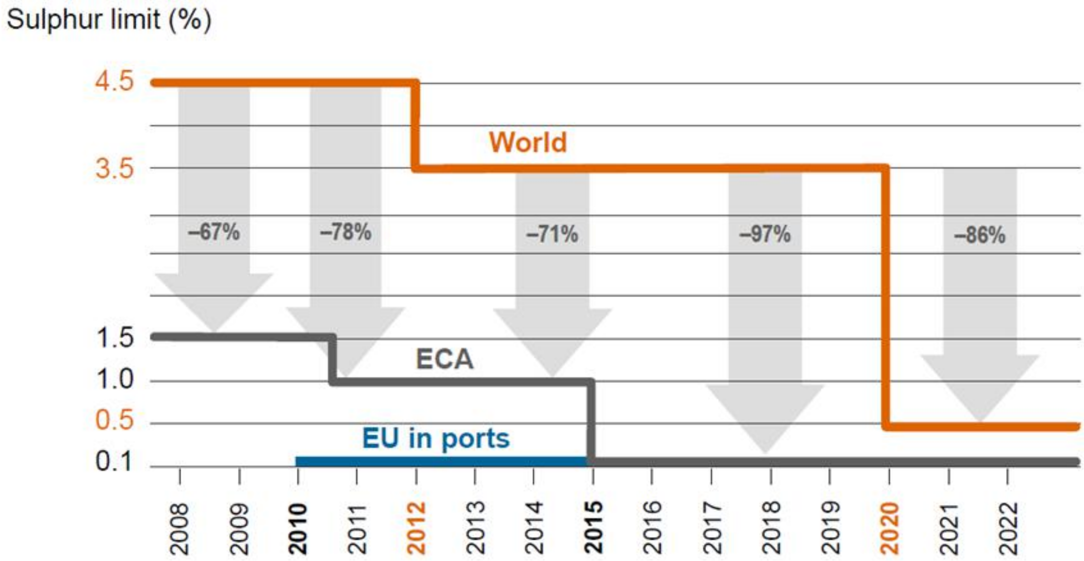

Figure 3.1 Permissible sulphur worldwide and in ECAs

Source: Data from 2008 amendment of MARPOL annex VI

Figure 3.2 ECAs designated by IMO

Source: Lokukaluge, P.P. & Brage, M., 2016

[8] nm = Nautical mile

3.3 The shore power for ships

3.3.1 Shore power advantage

Shore power refers to the vessel at the port of anchor, the closure of the ship's own generator and the use of the shore power supply facilities to provide power to the ship. The power input to the local power grid substation located in the port, and it relies on the power connection device to deliver to the ship. The use of shore power can greatly reduce air and noise pollution nearby port city. At present, some advanced ports in the world (such as Los Angeles, Goteborg) have adopted shore power technology to supply power to ships. Domestic shore power technology is still in its infancy, mainly in Shanghai, Lianyungang, Shekou, Chongqing, and they are trying put show power technology into practice. Shore power technology is an effective measure to reduce energy consumption and reduce noise in port. There are its advantages. (1)Emission reduction: the practical significance of shore power technology for the port is reduction of emissions. Berthing ships usually require 1 set of diesel generators for daily power. The capacity of marine diesel generator varies according to the tonnage of the ship. Taken 1000kW power unit as an example, when the ship stop the diesel generator replaced by shore power supply, the reduction emission is equivalent to the emissions of 1000kW diesel pollutants generated. (2)Energy saving: the ship's own generator fuel consumption 0.216kg/kWh, single unit power of 1000kW an hour burn fuel 216kg which is equivalent to standard coal 314.73kg. Such as shore power grid instead of the traditional diesel engine generator power supply can reduce the ship's part of the fuel consumption own power generation. If a ship calls port 12 times a year for 10 hours each time, it can save about 25.92 tons fuel oil. (3)Noise reduction; shipboard diesel generators are prone to noise pollution. After the shore power is taken, the noise pollution caused by the operation of the ship's own generator can be eliminated.(Yu, 2013)

3.3.2 Shore power technology

The shore power is supplied to the ship by an auxiliary shore box on the vessel and the connection of the electric. In general, the power provided as shore power is the rated power of the single generator on the ship which guarantees the power demand of all kinds of electrical equipment on the ship.

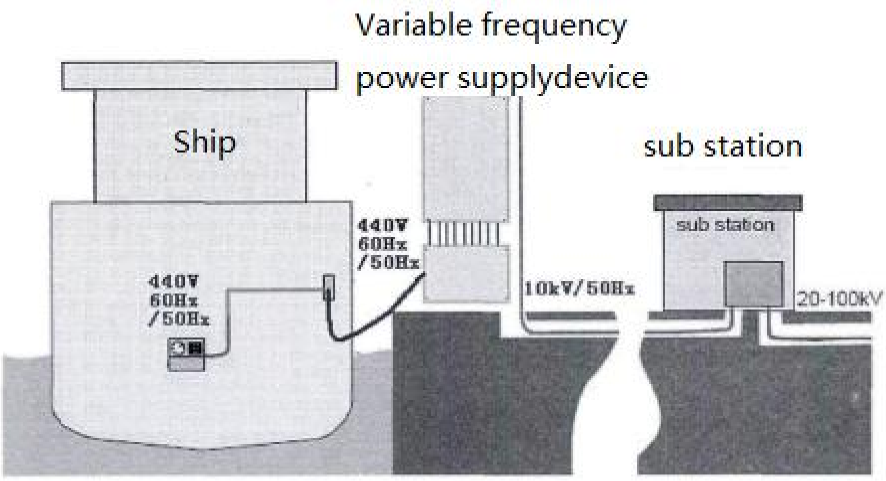

Figure 3.3 - A simplified picture of the ship and shore connection

Source: Yu, 2013

Terminals (providing shore power) and berthing vessels (receiving shore power) are each equipped with an onshore system. Ship shore power system consists of 3 parts: general socket screen, the shore connection screen, shore power box. Compared with the ship shore power system, shore power system terminal is relatively simple, mainly includes two parts: first is the shore power socket box for connecting cable from ships; the second is electric operating device: for handling and loading cable. For a more intuitive understanding of how ships are connected to shore power, a case study is given. The simplified picture is connected with the shore power diagram. From Figure 3.3 we can see, the first port substation power distribution of two, by the high voltage step-down transformer 20-100kV reduced to 6-20kV; between the port and dock, after reducing the power transmission through the laid in cable ditch buried cable finished. In addition, from the point of view of the user power supply system, connecting with the shore berthing of ships, ship and terminal substation constitute a simple power system; if the equivalent generator is simulated by the port ship system for substation, the ship is loaded (see Figure 3.4)(Yu, 2013, pp. 17-18).

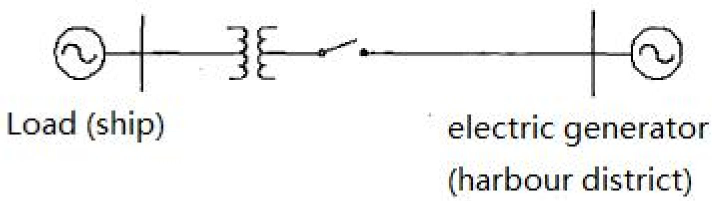

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Figure 3.4 - Mode of ship supplied by shore power

Source: Yu, 2013

3.4 Exhaust scrubber and exhaust gas treatment equipment

The treatment system can be designed and installed for ships, and the removal rate of ship exhaust emissions can reach 90%-99%. Marine desulfurization equipment is a ship exhaust emission device, and the purpose of it is to reduce the sulfur content in the exhaust. Since 2008, IMO formed a amendment of MARPOL convention, and published a stricter discharge standards, so many countries have been researching and developing waste gas desulfurization equipment. Also, many foreign manufacturers, such as MAN, WARTSILA, ALFALAVAL, YARA MARINE and other companies have researched and developed desulfurization systems, and till now, their products are already very mature. Although in China, the research started late, it realized rapid development, for instance the desulfurization equipment which designed and built by China AVIC SHIP can remove 99% of the desulfurizer. This equipment has been successfully applied to the ship built for Finnish owner. The desulfurization equipment in small volume is economical, and easy to install without causing secondary pollution to the marine environment.

Waste gas processing device is the best choice to meet the requirements of the convention. Ship waste gas desulfurization methods can be divided into dry process, half dry process and wet process. Dry desulphurization method takes calcium hydroxide or sodium bicarbonate as desulfurizer, the system is mainly composed of absorber, storage, supply device, processing equipment and control system, etc. However, the studies of dry and half dry desulphurization are under a slow rate of progress because of various technological and practical limitations. At present, most of the studies focus on wet desulphurization, and mainly on seawater desulphurization and caustic desulphurization

3.5 Energy efficiency

3.5.1 EEDI, EEOI and SEEMP

So far, IMO proposed mandatory technical measures, operational measures and market-based measures to promote the reduction of CO_2 emissions.

The technical measures are mainly to improve the rate of energy utilization from ship design to propulsion technology. At present, this measure mainly focuses on the new ship EEDI, which is calculated as follows:

$$EEDI = \frac{Engine \quad power \times SFC \times C_F}{DWT \times speed} \qquad (g\,CO_2 / ton - mile)$$

Where: SFC: certified specific fuel consumption; C_F: non-dimensional conversion factor; DWT: deadweight tonnage.

The EEDI consists of a relationship between environmental benefits and impacts due to CO_2 emissions (i.e. an expression of CO_2 emissions per ton-mile of transport work). This value is at the design phase of the ship calculated with respect to the ship capacity of the vessel. The EEDI, with the units of tone-CO_2/ton-NM, is also called "CO_2 design index".

A major portion of the ship operating cost relates to its fuel consumption and can approximately be 35%–70% of the overall vessel operating cost. Therefore, an appropriate fuel consumption reduction can reduce a significant portion of the operating cost and that eventually improves energy efficiency of the vessel and reduces the respective marine pollution. Operational measures are mainly aimed at existing ship CO_2 emission reduction through the SEEMP. By using the ship energy efficiency index (EEOI) as a monitoring tool and benchmark tool, SEEMP provides an effective means to monitor the energy efficiency of ships and fleets. EEOI formula is as follows:

$$EEOI = \frac{Actual \quad fuel \quad consumption \times C_F}{Cargo \quad mass \times sailed \quad distance} \qquad (g\,CO_2 / ton - mile)$$

According to the definition of EEOI, the smaller the EEOI value, the higher the energy efficiency. By reducing the fuel consumption per mile, raising the ship's deadweight, or using the low CO_2 emission factor energy, the ship's energy efficiency index can be achieved. The EEOI represents ship energy efficiency in the form of CO_2 emissions per unit of transport work that can evaluate fleet performance. Therefore, another name for the EEOI is the“Operational CO_2 Indicator.”

The SEEMP consists of a mechanism that has the ability to improve ship energy efficiency by monitoring the performance of a vessel over a certain period using the EEOI as a benchmark. This mandatory mechanism enforces to improve vessel operational conditions and implement more energy efficient technologies for the shipping industry. That consists of several required steps (i.e.planning, implementation, monitoring, self-evaluation and improvements) and plays an important role in improving energy efficiency in vessels at their operation phase. SEEMP helps fleet operators assess the energy efficiency. SEEMP promotes the ship owners and operators to consider the introduction of new technologies and practices in seeking to optimize any stage of ship operation process.(Lokukaluge & Brage, 2016)

An overview of emission control based on energy efficiency measures with respect to the possible situations of energy conservation in shipping at the operation phase is to overcome such industrial challenges discussed above.Vessels can achieve a considerable reduction in the respective fuel consumption by considering the possible situations of energy conservation.

3.5.2 Low speed navigation and large scale ship

On December12 2015, nearly 200 parties of the United Nations Framework Convention on climate change reached a new global climate agreement in Paris to plan for a global response to climate change after 2020. The Paris agreement point out that all parties will strengthen global response to the threat of climate change, to control the global average temperature higher than the preindustrial one within 2 ℃, and try to control the temperature increase within 1.5℃ (Wang, 2016). The world will soon achieve GHG emission standards, and achieve zero GHG emissions by the latter half of this century.

The speed of vessel has been shown to be a major variation for both shipping costs and emissions. Energy costs, speed reductions, and revenues are closely related because energy is an important cost item to operators and because speed reductions may provide substantial energy savings. For example, the maximum speed of 3E class container ship is 23, which is 2 knots lower than that of the previous E series container ship. This small difference between the engine power output requirements is reduced by 22%, and the engine power output is reduced, while the fuel consumption is also reduced according to the following formula.

$$P_E \propto V_S^3 \qquad P_E \propto Fuel \quad Consumption \qquad P_{E2} = \left(\frac{V_{S2}}{V_{S1}} \right)^3 P_{E1}$$

Where: P_E: Engine, Power V_S: ship speed. Thereby reducing engine speed can greatly improve fuel efficiency.

In order to describe the effect of large scale and low speed on the operation efficiency which determine the use amount of fuel oil, P/WV index is essential to judge the efficiency of traffic operation. For shipping, the minimization of P/WV can be stated by the following formula:

$$\left[\frac{\mathrm{P}}{\mathrm{WV}} \right]_{\min} = C_{\mathrm{f}} \frac{1}{2\mathrm{g}} \bullet \frac{4.84}{\nabla^{1/3}} V^2 \frac{1}{\eta_{\mathrm{p}}}$$

Where: C_f : non-dimensional, V: ship speed, ∇ :ship displacement, η_p : propeller propulsion efficiency.

Based on the above formula we can obtain $\left[\frac{P}{WV}\right]_{min}$ and there is a non-linear relationship between the operation efficiency and ship displacement and speed. The formula also explains why the ship load increasing while the speed reducing at the same time have positive effect on improving the ship operation efficiency.

3.6 LNG for ship propulsion

In order to comply with IMO rules, Liquefied Natural Gas (LNG) is becoming an interesting option for merchant ships. LNG is a competitive fuel in comparison to lower sulfur MDO and MGO, from both technical and economical points of view. New dual-fuel engines with thermal efficiency ranges from 40% to 50%. LNG was initially used as propulsion fuel in LNG carriers where the boiled-off gas produced inside the LNG tanks were used for propulsion in a traditional boiler or steam turbine systems and, at a later stage, in dual-fuel diesel engines (DFDE). LNG propulsion system seems as an economically interesting solution for ship types spending a long period of their sailing in ECA like handy size tankers and medium size RO-RO vessels. The aim is to study both the environmental and economic effects of the use of LNG options for reducing exhaust gases emissions from ships to comply with IMO rules.

The implementation of marine power system upgrades the using of clean fuel and liquefied gas energy, accelerating the pace of using LNG as the ship fuel. At the same time, the shipping industry should actively promote the upgrading of the engine of the ship, to achieve dual fuel driven mode. In July 2013, China Classification Society (CCS) issued guidance on the operation, performance and equipment of low sulfur fuel engines, providing technical support for the use of low sulfur fuel. According to the relevant departments, the ocean ship engine transformation and dual fuel drivers can help ship reduce emissions by more than 15% till 2027 (Liu, 2014).

3.7 Policy guidance

The government leads the shipping industry to reduce ship emission by subsidies, taxes and other economic incentives to promote the application of low sulfur fuel and clean technology to reduce SO_X, NO_X, PM and GHG. For example, there are many effective measures used by USA such as shore power subsidy policy, the Levy of NO_X emissions tax and related fiscal policies. These policies involve the diversion of low sulphur oil, the use of shore power, the promotion of LNG vessels, the use of exhaust scrubbers, and the reduction of ship speed. Market measures are the use of marine market to promote marine emission reduction. From the fifty-sixth session of the MEPC conference, the meeting will arrange the market measures in-depth discussion on the agenda. So far, there have been measures appear including a representative of the international maritime greenhouse gas fund (GHG Fund) and global maritime greenhouse gas emissions trading system.

3.8 Summary

Except the guidance and restriction of policies and regulations, it is also a key point to reduce ship emissions by using high and new technology, which can be divided into three categories: pre combustion treatment, treatment process engine combustion control and treatment after exhaust gas. There are many aspects which need in-depth to be reformed fuel power, ship structure, transportation mode ship design ideas and technology to reduce air pollution emissions. We need fully consider ways to reduce emissions of pollutants such as reducing the speed, improve the propulsion efficiency, improve the design and reduce the resistance. There are many technical measures to control exhaust pollutants such as emulsification of fuel oil, low pollution combustion chamber and the most mature and effective selective catalytic reduction method.

Chapter 4

Air pollution and ship emissions in Shanghai port

4.1 Introduction of Shanghai port

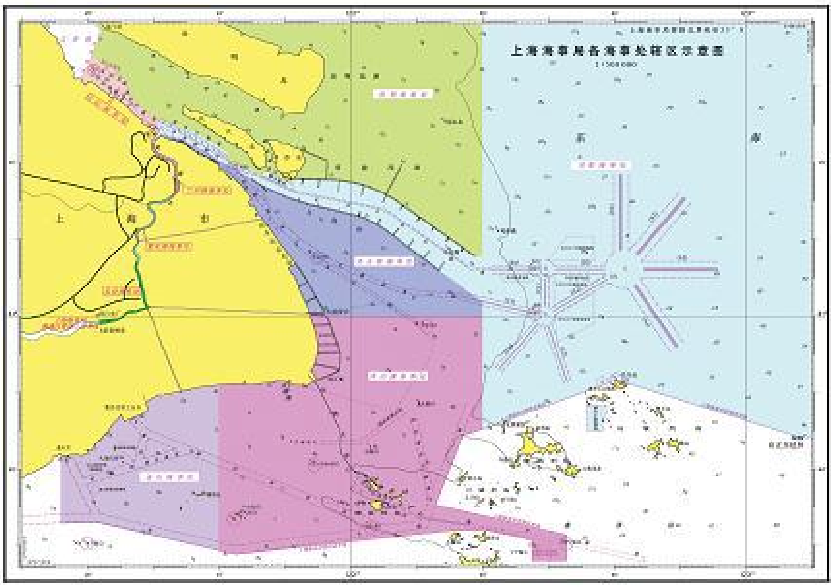

Figure 4.1 - Outer and internal waterway in Shanghai port

Source: http://www.shmsa.gov.cn/UploadFile/photo/msa8.jpg

Shanghai port, located in the downstream of the Yangtze River, is an international port at the junction of land and sea. A large number of containers are imported and exported via Shanghai in China. Shanghai port is a super hub, one of the fastest growing container ports in the world, and plays a key role in the global economic development. Shanghai port consists of outer and internal waters (see Figure 4.1). The outer waters are composed of Yangtze River Estuary, Hangzhou Bay, Huangpu River, Chongming Island, Yangshan Port waters and Green huashan anchorage. Internal waters are all inland waterways.

The coastal and inland ships accounted for the majority proportion of ships calling Shanghai. The OGV which occupied less than 3% in the total throughput of Shanghai port took up the largest air pollution among which the emission of PM, SO_X, NO_X and CO_X accounted for 60%, 68%, 53% and 54% of the total amount and all are more than half of Shanghai air pollution hazards from ships. In the same time, some research shows that ship emissions accounted for 7% of global NO_X emissions and 4% of global SO_X emissions. In addition, these emissions are more than 70% in the region where is less than 400 km away from coastline, generating a great threat to the local environment (Zhang, 2010). Among global emissions of CO_2, ship emissions have only taken up a small percentage of (3% of the total displacement), but in the hinterland of the narrow strait, port city, is not to be ignored.

4.2 Calculation of ship emissions

4.2.1 Flow chart of calculation

It is very important for Shanghai to find a suitable method calculating the emission. In this paper, the following dynamic calculation method based on the working condition of the engine is designed to assess the air pollution emitted by ships. Therefore, we must first determine the ship engine's particular(including the main engine (M/E), auxiliary engine (A/E) and boiler) under different working conditions such as the emission factor (EF), the corresponding engine load correction factor (LF) and oil correction factor (CF). Then the paper calculates the ship emissions combined with the running time of corresponding conditions (Act.). The flow chart is as the following Figure 4.2.

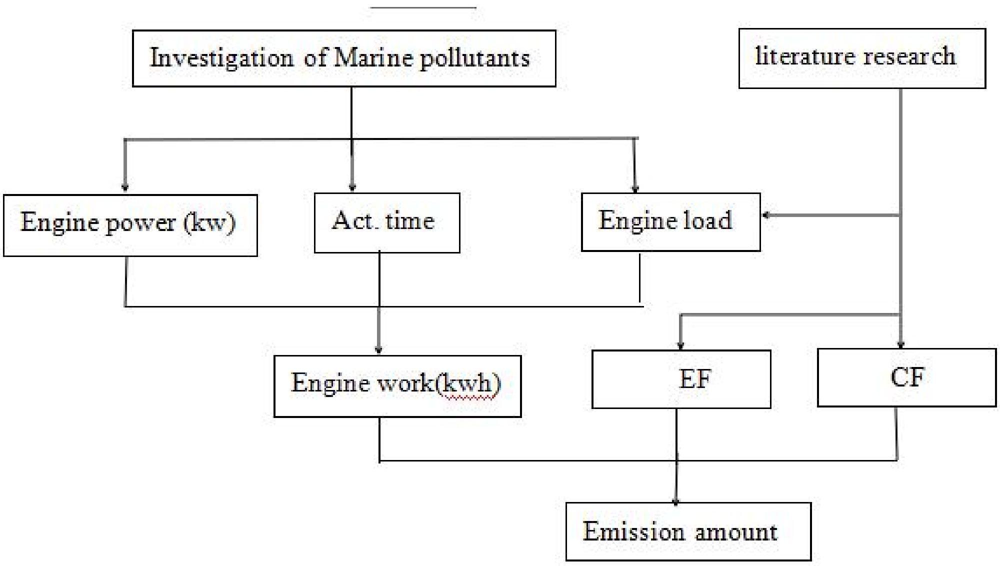

Figure 4.2 - Flow chart of calculating emission amount.

Source: This report

4.2.2 Formula of calculation

The formula of calculating ship engine work is as follows:

$$W = MCR \times LF \times Act \qquad (1)$$

Where: W: work done by ship engines, MCR: Engine rated power, LF: load factor (ratio of average load divide maximum load), Act: time of engine working actually.

The correction formula of emission factor is：

$$EF = EF_0 \times LLA \qquad (2)$$

Where: EF: the emission factor (g/kW·h), EF_0: initial EF, LLA: the low load adjustment factor.

The formula of marine engine emission calculation is：

$$E = W \times EF \times FCF \times CF \times 10^{-6} \qquad (3)$$

Where: E: the amount of emission one year (t/y), FCF: the fuel correction factor, CF: the emission control factor (the change after using the emission reduction measures).

4.2.3 Emission factor

As a member of the MARPOL convention, the emission factor of OGV in China should be close to the emission factor of CARB. Therefore, the emission factors of air pollutants inventory should be selected in Los Angeles port of the United States. In the calculation process, the M/E emission factor, A/E emission factor, boiler emission factor, and local fuel CF and LLA of Shanghai port are investigated.

Table 4.1, 4.2 and 4.3 gives the emission factor of M/E, A/E and boiler respectively of OGV. Different fuels will directly affect the air pollutant emissions of ships, especially the sulfur content in fuel. In some international study all fuel oil used is with 3.5% of sulfur content. However, the ship in Shanghai port, especially coastal vessel using clean fuel sulfur, sulfur content is 0.1% ~ 1.5%, so that the fuel emissions amendment by correction factor is necessary. Fuel correction factor is shown in Table 4.4. Referring to the experience of air pollutant emission inventory of Los Angeles port and Hong Kong port, the ship emission will increase when load of ship's M/E is less than 20%. In this paper, the low load correction factor of the M/E is introduced to refine the emission, as shown in Table 4.5. (Fu et al., 2012).

Table 4.1 - Emission factors of main engines of OGV g·kW^{-1}·h^{-1}

Speed of engine	PM_{10}	$PM_{2.5}$	DPM	NO_X	SO_X	CO	HC	CO_2	N_2O	CH_4
Low speed	1.5	1.2	1.5	17.0	10.5	1.4	0.6	620	0.031	0.012
Media speed	1.5	1.2	1.5	13.0	11.5	1.1	0.5	683	0.031	0.010

Table 4.2 - Emission factors of auxiliary engines of OGV g·kW^{-1}·h^{-1}

PM_{10}	$PM_{2.5}$	DPM	NO_X	SO_X	CO	HC	CO_2	N_2O	CH_4
1.5	1.2	1.5	13.0	12.3	1.1	0.4	683	0.031	0.005

Table 4.3 - Emission factors of boilers of OGV g·kW^{-1}·h^{-1}

Type of boiler	PM_{10}	$PM_{2.5}$	DPM	NO_X	SO_X	CO	HC	CO_2	N_2O	CH_4
Steam boiler	0.8	0.6	0	21	16.5	0.2	0.1	970	0.08	0.002

Table 4.4 - Correction factors of fuel oil

Type of fuel oil	S/%	PM	NO_X	SO_X	CO	HC	CO_2	N_2O	CH_4
Heavy oil	1.5	0.82	1	0.56	1	1	1	1	1
Diesel oil	1.5	0.47	0.9	0.56	1	1	1	0.9	1
Diesel oil	0.5	0.25	0.94	0.18	1	1	1	0.94	1
Diesel oil	0.2	0.19	0.94	0.07	1	1	1	0.94	1
Diesel oil	0.1	0.17	0.94	0.04	1	1	1	0.94	1

Table 4.5 - Correction factors of main engines under low loading

Load / %	PM	NO_X	SO_X	CO	HC	CO_2	N_2O	CH_4
2	7.29	4.63	1	9.68	21.18	1	4.63	21.18
3	4.33	2.92	1	6.46	11.68	1	2.92	11.68
4	3.09	2.21	1	4.86	7.71	1	2.21	7.71

5	2.44	1.83	1	3.89	5.61	1	1.83	5.61
6	2.04	1.6	1	3.25	4.35	1	1.6	4.35
7	1.79	1.45	1	2.79	3.52	1	1.45	3.52
8	1.61	1.35	1	2.45	2.95	1	1.35	2.95
9	1.48	1.27	1	2.18	2.52	1	1.27	2.52
10	1.38	1.22	1	1.96	2.18	1	1.22	2.18
11	1.3	1.17	1	1.79	1.96	1	1.17	1.96
12	1.24	1.14	1	1.64	1.76	1	1.14	1.76
13	1.19	1.11	1	1.52	1.6	1	1.11	1.6
14	1.15	1.08	1	1.41	1.47	1	1.08	1.47
15	1.11	1.06	1	1.32	1.36	1	1.06	1.36
16	1.08	1.05	1	1.24	1.26	1	1.05	1.26
17	1.06	1.03	1	1.17	1.18	1	1.03	1.18
18	1.04	1.02	1	1.11	1.11	1	1.02	1.11
19	1.02	1.01	1	1.05	1.05	1	1.01	1.05
20	1	1	1	1	1	1	1	1

4.3 Ship emissions in Shanghai port

Fu qingyan (2012) conducted a detailed investigation through a special questionnaire based on the basic information of vessels, fleet composition, distribution of deadweight tonnage in Shanghai port obtaining the M/E, A/E and boiler configuration, working conditions, relationship between ship tonnage and power, sailing routes, average speed and time in port and other key information. Spatial statistics and further study of automatic identification system (AIS) obtain the navigation path information of flow distribution and intensity. The numerical model required 1 km * 1 km grid for space precision units illustrated distribution of ship air pollutants and GHG emissions (Zhang et al., 2017). Through the extraction of AIS data, all routes of ships entering and leaving Shanghai port were obtained, and the ship emissions were assessed in terms of traffic density on each path. Comparing different conditions of emission share, it found that although the emissions of cruise ships in the outer waters main channel on cruise ships accounted for 77% to 83% of the total level. For example, the emissions of OGV is far higher than that of the ship in the inland and during berthing. However, due to ship emissions intensity in the dock and its close distance to the crowd, a direct impact on the area surrounding the crowd is more important. It is one of the major sources of local air pollution in center of Shanghai.

4.3.1 Emission sharing rate under different working conditions

The discharge of OGV under 4 different conditions is ranking from navigation, inward and outward berthing and cargo handling. The navigation condition is the main source of emission, accounting for 65% to 85%, as shown in Table 4.6. Ship emissions has become one of the major sources of air pollutants in Shanghai. The distribution of various pollutants and GHG emissions of the space show that the main import port channel emissions are relative to other waterways with serious pollution. The discharge of ships within and out of the port area is more important to the air quality in Shanghai.

Table 4.6 - Emission sharing rate of OGV under different working conditions %

Operating condition	PM_{10}	$PM_{2.5}$	DPM	NO_X	SO_X	CO	HC	CO_2	N_2O	CH_4

navigation	77	78	82	82	70	82	83	71	65	85
inward and outward port	12	12	12	12	12	12	11	12	12	11
Cargo handling	10	9	5	6	17	6	5	16	22	4
berthing	1	1	0.9	0.8	2	0.8	0.7	2	2	0.5
total	100	100	100	100	100	100	100	100	100	100

Source: Data from Fu, 2012

4.3.2 Emission sharing rate of different combustion equipments

Figure 4.3 - Emission sharing rate of different combustion equipments

Source: This report

The A/E is the main combustion equipment (except SO_2), and the share of the emission is about 50%. Boiler is the main equipment of SO_2, accounting for 53% of total emission. Figure 4.3 shows the proportion of different engine creating air pollution .

4.3.3 Emission sharing rate of types of ships

The ocean vessel is mainly divided into 9 types and the corresponding emissions ranking from large to small are as follows: container ships, other vessels, bulk cargo ship, oil tanker, RO-RO ship,chemical tanker, non transport ship, push tug, liquefied gas ship. Among them, the emission from container ships is the most important. The results show that, due to the large number of container ships and large ship type, they are the main species of pollutants discharged by OGV. Container ship accounted for 25% of the total number of OGV, the corresponding atmospheric pollutants and GHG emissions share rate is 54% ~ 60%

4.3.4 Emission sharing rate of sailing area

The research shows that different sailing area of ship emissions OGV much more than inland ship. As shown in Table 4.7, OGV which account for less than 6% of the total number of ships in Shanghai port have discharged 92% and 72% of the total PM and SOx, as well as The proportion of other atmospheric pollutants and GHG emissions as high as 70% or more. OGVs are the main sources of air pollution from ships in Shanghai port. OGV’s is 26 ~ 100 times as inland ship of ship emissions due to the OGV much higher engine power than inland ships.

Table 4.7- Emission sharing rate of sailing area in shanghai port %

Water area		Ship	PM_{10}	$PM_{2.5}$	DPM	NO_X	SO_X	CO	HC	CO_2	N_2O	CH_4
Outer water	OGV	5	92	92	92	74	97	73	72	71	75	71
	Inland vessel	55	2	2	2	7	1	7	8	8	7	8
Inter water	Inland vessel	40	6	6	6	19	2	20	21	21	18	22
total		100	100	100	100	100	100	100	100	100	100	100

Source: Data from Fu, 2012

4.3.5 Sharing rate of ship emissions in total air pollutant in Shanghai

According to the research[9] of Shanghai environmental monitoring center, the Air pollutant emission contribution is mainly concentrated in the SO_X and NO_X, respectively 12% and 9% in Shanghai and the direct discharge of the city's $PM_{2.5}$ share rate is 5.3%. OGVs are the main sources of ship emissions, and their share of SO_2, NO_X and $PM_{2.5}$ emissions to the city's emissions inventory reached 12%, 8.4% and 5.1% respectively. More than half of the OGVs are container ships.

4.4 Comparison of ship emissions between Shanghai and other typical ports

According to the statistics, 135000 OGVs have called Shanghai port in 2010, 143000 OGVs all the British (2007), 7556 OGVs Keelung (2009), 14000 OGVs Kaohsiung (2009), 4743 OGVs Losangeles (2010). Ship number of Shanghai port and British national total is far higher than other single port. As shown in Table 4.8, the emissions of Shanghai ocean ships are 4~29 times as large as those of Kaohsiung, Keelung and Los Angeles, and are in the same level of magnitude as those in the

[9] This data was calculate in 2010.

British. Analysis of NO_X and SO_X emission ratio shows that due to the port of Los Angeles and parts of the UK settled SECA according to the IMO, ship engines must use low sulfur oil, therefore the emission ratio SO_X and NO_X is less than that on the harbor, Keelung port and Kaohsiung port. Thus, after entering the port area, the ship converted to clean oil to improve the SO_X pollution in the air around the harbor area and the fairway plays an active role. Overall, air pollutant emissions from ports are directly proportional to the number and throughput of ships. (Fu, 2012).

Table 4.8 - Emission comparison among different typical ports times

port	OGV	PM_{10}	$PM_{2.5}$	DPM	NO_X	SO_X	CO	HC	CO_2	N_2O	CH_4
Los Angeles/2010	29	24	24	26	11	26	8	7	9	8	7
Kaohsiung/2009	10	7	7	9	5	4	5	4	4	3	0.9
Keelung/2009	18	16	17	21	11	10	11	11	9	8	2
England/2007	0.9	1	0.8		0.4	0.8		0.4	0.4		

Source: Data from Fu, 2012

Chapter 5

Ship emissions countermeasures in Shanghai port

5.1 Constraints on countermeasures

Control ship emissions except the requirements of ship installation with shore power device, installation of diesel particulate filter, exhaust gas recirculation system or selective catalytic reduction system and other mandatory implementation such as EEDI, SEEMP countermeasures, in certain areas, to develop and implement mandatory emissions policy is the effective control measures for ship emissions. In the developed areas, national or regional shipping port implementation of emission control measures can be divided into the following 3 categories. First, the establishment of ECA is implemented by the government or the IMO mechanism, which belongs to the international mandatory measures. Second, the berthing ships using low sulfur is implemented through the mechanism of government organization or local government in the EU. The United States and California forced oil berthing of ships using shore power, which belongs to the local compulsory measures. Third, incentive measures is using to the local area interest exchange ship emission reduction. (Peng & Q iao, 2014).

The characteristics of each policy and measure are different, and the results are shown in Table 5.1. In the table difficulty refers to the degree of difficulty for implementation of relevant policies and measures including policy formulation, review and promulgation of procedures.

Table 5.1 - The comparisons of characteristics and effect of the policy measures for ship emissions

Policy measures	Character	Regional coverage	Scope of vessels	Supervisory and Shipping cost	Supervisory capacity demand	Implementation and Preparation difficulty	Effect
Incentive	Non-compulsory	Regional or port waters	Few	Increase limited	Low	Low	Limit
Local mandatory	Compulsory	National or regional waters	Normal	Increase bigger	High	High	Good
International mandatory	Compulsory	National or regional waters	Most	Increase the biggest	Highest	Highest	Best

Source: This report

From the preparation difficulty perspective, the incentive policy measures covers the limited scope ship, and the shipping company cannot implement more stringent emission control requirements but policy formulation, review and promulgation of the procedure are relatively easy. The covering range of local mandatory policy measures of countries or regions increases, so does the difficulty in policy formulation, review and promulgation of procedures. International mandatory policies and measures are most difficult for review and promulgation and implementation.

Countries, regions or ports for policy choice for control ship emissions, should fully consider the construction supervision system to improve the regional environment and air quality, then policy preparation difficulty, time requirements, cost increase for the impact of international trade determine the corresponding policy types. The region scope policy involves implementation time.

5.2 Promote shore power

Shanghai port is the first port supply the shore power to the ships for coastal ports in China. There are two kinds of shore power supply.

5.2.1 Mobile land-based marine variable frequency power supply system

The frequency of China's power grid is 50 Hz, which is different from the frequency of most ships, therefore, international successful cases cannot be transferred to our ports. To develop the power system of the shore power conversion technology and design a mobile power supply system can enable application of multiple berth or port to transform alternating current power grid into 60 Hz AC for foreign ships and the domestic ships 50 Hz AC. The 50/60 Hz dual power supply is the best solution. Mobile variable frequency transformer power supply system is adopted in the second-phase wharf in Shanghai Waigaoqiao Terminal.

5.2.2 Fixed land-based marine variable frequency power supply system

The port of Shanghai with the equipment of the mobile land-based marine frequency transformer power supply system, at the same time, also in the new terminal positive build fixed frequency transformer power supply system. The sixth-phase wharf in Shanghai Waigaoqiao Terminal built in 2011 uses the shore power after and the high / low voltage power supply scheme. It can output between

440V and 6.6kV different voltages and realize the type of plug and play as the Figure5.1. Compared with the mobile land-based marine frequency transformer power supply system, fixed frequency transformer power supply system for ship access is simple, at low cost, at wide coverage, demanding the requirement of ISO and International Electrotechnical Commission (IEC), so it will become a popular trend of shore power in the future.

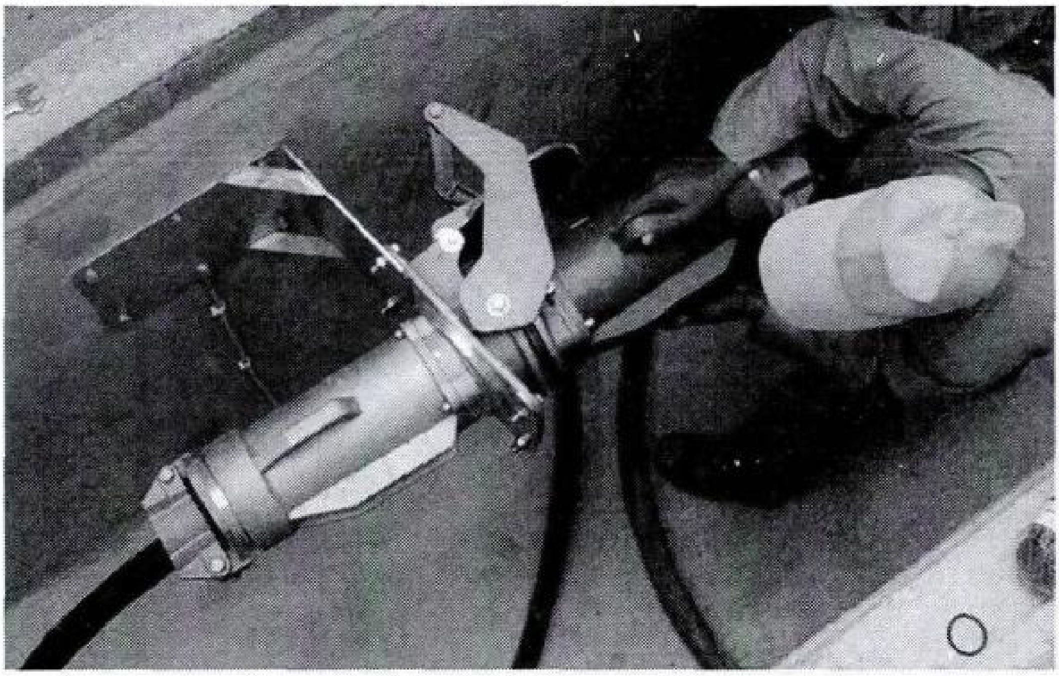

Figure 5.1 - Land-based marine variable frequency power supply system

Source : Yu, 2013

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5.3 Strengthening the implementation of DECA

The ECA system designated by the IMO aims to reduce ship emissions in environmentally sensitive areas by developing stringent fuel and engine requirements. On December 4, 2015, the Ministry of Transport of P. R.C. issued the Pearl River Delta, Yangtze River Delta, Bohai (Beijing, Tianjin and Hebei) marine DECA plan (see Table 5.2), for the establishment of ship emissions ECA first time in China control the SO_X, NO_X and PM emissions. SECA should be established first. In order to avoid the IMO long time of approval process, we can set up a domestic SECA. When the time is ripe, the NECA will be established. On February 1, 2016, the Ministry of Transport issued a unified deployment, and the Yangtze River Delta DECA came into force firstly from the April 1, 2016. Shanghai, Ningbo, Zhoushan, Suzhou, Nantong four core ports (see Figure. 5.2) implement the first phase measures at the same time. The ship during berthing in this areas using sulfur content is less than 0.5%m/m fuel. After the implementation of DECA the Pearl River Delta, Yangtze River Delta, Bohai waters ship emissions of SO_X and PM decreased by 65% and 30% respectively till 2020 (Li, 2016).

Table 5.2 - Sulphur content of fuel oil controlled schedule

Date	Sulphur content m/m	Application areas	Period of time
2016.01.01~2016.12.31	≤0.5%, or Equivalent alternative	Some port can meet the demands (voluntary)	Berthing except the first and last hour in port
	≤3.5%	The ports except the above in DECA (compulsory)	All the time
2017.01.01~2017.12.31	≤0.5%, or Equivalent alternative	Core ports (compulsory)	Berthing in ports
	≤0.5%, or Equivalent alternative	The other can meet the demand ports except the core ports in DECA (voluntary)	Berthing in ports
	≤3.5%	The ports except the above in DECA (compulsory)	All the time

2018.01.01~2018.12.31	≤0.5%, or Equivalent alternative	All the ports (compulsory)	Berthing in ports
	≤3.5%	The area except the ports in the DECA (compulsory)	All the time
2019.01.01~2019.13.31	≤0.5%, or Equivalent alternative	The areas in the DECA (compulsory)	All the time
From 2020.01 01	≤0.1%, or Equivalent alternative	In the DECA ; Enlarge the area; or further requirements	After the assessments before 2019.12.31

Source: Data from Ministry of Transport, 2015

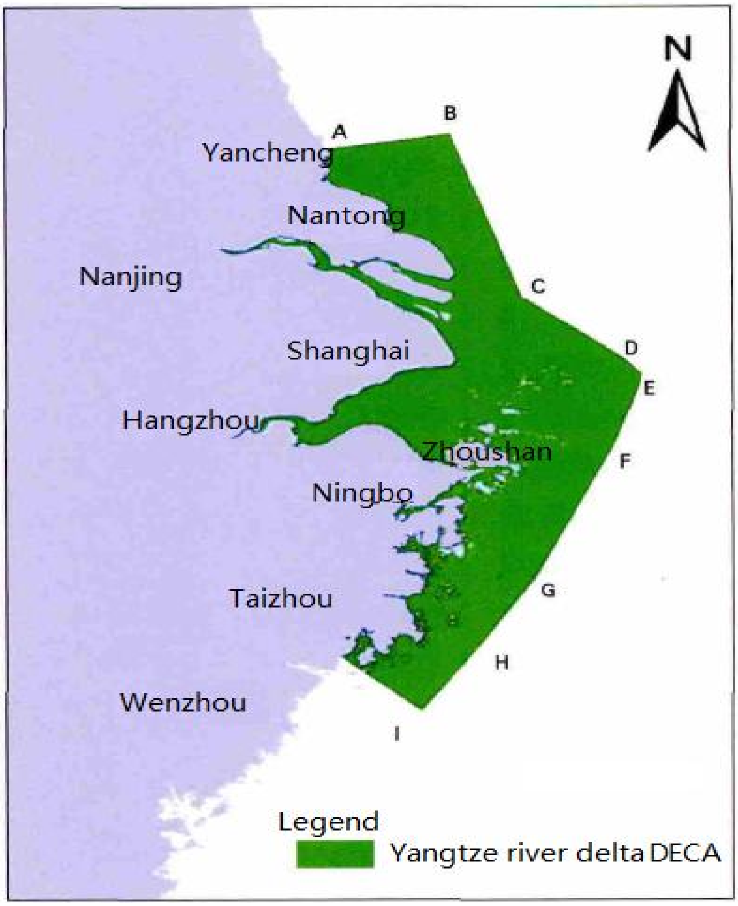

Figure 5.2 Yangtze river delta DECA

Source: Ministry of Transport, 2015

In Asia, China is the first implementation of the mandatory control policy areas of marine emissions. Port city is the most polluted areas by ships, followed by coastal cities. Therefore, it is urgent for us to establish a ship ECA for such a large number of people, ocean shipping, frequent shipping activities and environmental pollution problems caused by ship transportation.

5.4 Improve the fuel standard

Accelerate the promulgation and implementation of marine air pollutant emission standards, as soon as possible to develop mandatory oil standard and marine diesel engine emission standard of air pollutants, to strengthen introduction of the new production of ship diesel engine to carry out environmental protection supervision and management.

In view of the urgent situation China port and air pollution prevention and control from the ship make sure that the implementation of the *environmental protection law* and *air pollution prevention law* requirements, the MEP emission standards of ship engine, strengthen the emission control of pollutants from ships, marine air pollutant emission standards to fill the blank. According to reports, ships use the sulfur content of poor quality fuel is the biggest factor affecting pollution emissions. At present, China has 60-65% of marine fuel consumption for marine fuel oil, and a small amount of light diesel oil (ordinary diesel). According to the standard of marine fuel oil (GB/T17411-2012), at present, China's marine fuel oil has a sulfur content of 1-3.5% (10000-35000 ppm). Ships using high sulphur oil are like mobile thermal power plants that burn poor coal and have no tail gas treatment facilities. Overall, the main objective of the standard is to control the growth of pollutant emissions from the source and to reduce the amount of pollutants discharged by new ships. The provisions of marine fuel are applicable not only to newly produced ships, but to all vessels in use. According to the arrangement, the standard will be carried out in two stages. In the first stage, PM emissions will be cut by about 70%, and NO_X emissions will be cut by more than 20%. Compared with the status quo of China's ship engine emissions, the second stage will further reduce the PM and NO_X by 40% and 20% on the basis of the first stage.

5.5 Slow steam in port

The ship runs at a normal speed. From the survey data, the average speed of the Yangtze Estuary Deepwater Channel is 15 knots. The speed limit of the south passage of the Yangtze River estuary is 12 knots, and the speed limit of the Huangpu River is 8 knots[10]. The Huangpu River and Nancao waterway limit may be the first to ship navigation point, nitrogen is similar to the principle of energy saving and emission reduction. Therefore, the port of Shanghai may, in accordance with the survey, make a detailed speed limit provision for the speed of the ship.

5.6 Financial incentive mechanism

The government could establish a tax refund and subsidy mechanism to stimulate the shipowner update the ship equipment and use the low sulphur content fuel oil. This type policies have been adopted in Hong Kong and some west country and achieved good effect in the controlling of ship emissions. If the policies came into force in

[10] Accord to Regulation on navigation of Huangpu river in Shanghai port

Shanghai, and 25% of all the ship use the fuel oil sulphur content decrease from 0.5%m/m to 0.1% m/m ahead of time 3 years compared with the requirement of DECA, we can calculate the reduction of ship emissions sulphur is 20% total of the ship emission. The result is conservative outcome comparing with the maximum reduction 80% of the total emissions.

5.7 Establish and update ship emission inventory

The compilation of ship emission inventory is the main technical method for analyzing the source of air pollutants. It is the basis and prerequisite for scientific and effective prevention and control of pollution from ships. In 2002, the United States Environmental Protection Agency issued a "merchant to develop emission inventory (final report)", and estimates the list of major three engine emissions of ships, including HC, CO_2, NO_X, PM and SO_X etc.. The report also calculates emissions for different years. At the same time, the bulk cargo ship, container ship, general cargo ship, miscellaneous cargo ship, passenger ship, oil tanker, vehicle ship pollution of different types were measured and the sensitivity and uncertainty analysis.

Now, only Shanghai has worked out a comprehensive ship emission inventory. Periodic report list system introduced industry of "ship port air pollutant emission inventory guide" as soon as possible to organize forces to carry out the port ship air pollution basic research work, grasp the port ship exhaust emissions status, composition, causes, mechanism and control measures etc.. At the same time, port enterprises are required to submit periodic inventory data to the environmental protection department. (Wu, 2016).

In order to obtain accurate real-time data about the speed and route, it should introduce AIS into the use. For example, in order to reduce ship emissions, it is possible to set up ECA, ship deceleration zones or designated coastal areas for vessels calling, operating and navigating at Shanghai port. We can use the basic data through the ship AIS (such as engine rated power, the highest maximum sustained speed) and ship activity data (such as the actual speed, main engine load factor, distance, time of sailing, sailing berthing time) to estimate the port ship emissions. Therefore, the port authority should create a database of atmospheric pollutants to facilitate the inspection of berthing vessels.

Chapter 6

Summary and Conclusion

This paper discusses various emission reduction measures such as the utilization of shore power, the regulations for relevant fuels and the slow steam of ships. The author hopes that the ports through improving fuel quality standards and low carbon emission standards combined with the shore power in port, speed limit, carry out more stringent environmental policy. In order to ensure the sustainable development of ports, government subsidies and budgetary planning control should also be considered. Legal protection is essential for the successful implementation of the low emission policy and effective control of air pollution.

Any policy measures are needed to run smoothly, so incentive measures and compulsory measures need to be enforced gradually and at the same time points in parallel. The use of alternative energy measures to prevent air pollution is no exception. In addition, a good balance between international and domestic performance, the central and local government, the port enterprise and the management of petrochemical enterprises and other stakeholders needs, as well as the relationship between economic development and natural environment of sustainable development is the key to the smooth implementation of these policies. Although the laws and regulations are strict in Shanghai port, but institutional barriers may lead the implementation of emission regulation policies to delayed.

Construction of low emission ports usually requires the construction of advanced facilities or cleaner facilities in the port, so financial investment is critical. In view of this, how to balance air quality and economic feasibility is the key problem.

Air pollution prevention in Shanghai port, from the technology perspective, improves the ship tail gas treatment technology is the key point. Shipping companies can increase investment in seawater desulphurization equipment and Selective catalytic reduction (SCR) treatment technology to reduce emissions of SO_X and NO_X. From the operational perspective, the ship sails using LNG fuel and berthing shore power, and the ship reaches the standard of zero emission of SO_X and NO_X. From the management angel, we should improve the awareness of air pollution prevention of crew members, and strengthen the management of education and training. We will intensify training and education of air pollution prevention for crew members, standardize crew safety operation and maintain all kinds of waste gas treatment equipment on board.

After the analysis, Shanghai port, as the world's largest port has serious air pollution, the attention paid by current society and many feasible measures to further optimize the integration and development with the progress of the time. The development of comprehensive measures cannot use a single measure to control the pollution prevention purpose. In order to achieve the goal of low emission, local governments should actively communicate with the entire stakeholder group in the process of strategic planning and policy formulation. These stakeholders include port operators, ship and equipment manufacturers, fuel suppliers, environmental protection departments, legislative departments, regulators and so on. Obviously, in the development of low emission policy, some obstacles are inevitable, because formulating policies must consider the local government regulations, rules, and related to the geography, economic, financial and political background. In addition, for the sake of low emission and sustainable development of ports, stakeholders must work together to formulate punitive measures or ban, and implement incentive policies that can achieve economic viability, such as financial subsidies.

Although this paper only takes Shanghai port as the object of study, the above-mentioned emission reduction policies can be used for reference by other ports in China.

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