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Study of ship air pollution control in Caofeidian Port

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STUDY OF SHIP AIR POLLUTION CONTROL IN CAOFEIDIAN PORT

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 Dissertation: **Study of ship air pollution control in Caofeidian Port**

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It is known to us all that 80% of the cargo are transported by ship. Air pollution from ships, which is becoming more and more serious especially in many ports, has become a big problem in China. At the same time, Chinese people are paying more and more attention to air quality after they experienced fog and haze weather.

Caofeidian port is an important part of "Jing-jin-ji" port in Bohai Sea which is a half-enclosed bay. Open since 2005, it is a port to export and import energy (such as coal, crude oil, natural gas), raw materials (such as ironstone) and other products (such as steel, cement) for North China and abroad. There are many old and low standard ships docking at this port. At the same time, it is one of the emission control area in China where Heibei MSA has been taking a lot of measures to regulate ship emissions. But unfortunately, ship shore power is not widely used there.

This paper is a study of air pollution control measures in Caofeidian port, comparing with other domestic and international ones. It is trying to explain law and regulations dealing with the air pollution, to show air pollution conditions in Caofeidian port, to illustrate regulatory methods and results of Hebei MSA, and analyze the necessity and possibility of using ship shore power by learning the experience of other ports.

KEY WORDS: Air pollution, shore power, Caofeidian Port, China, emission control area, regulation measures.

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LIST OF ABBREVIATIONS

AIS	Automatic Identification System
COSCO	China Ocean Shipping Company
CAAP	Clean Air Action Plan
CCS	China classification Society
DPM	Diesel Particulate Matter
DWT	Dead Weight Tonnage
ECA	Emission Control Area
ECZ	Emission Control Zone
EPA	Environmental Protection Agency
EU	European Union
IAPP	International Air Pollution Prevention
IMO	International Maritime Organization
IOPP	International Oil Pollution Prevention
MSA	Maritime Safety Administration
MEPC	Maritime Environment Protection Committee
PSC	Port State control
SDIC	State Development Investment Corp
UK	United Kingdom
U.S.	United States

Chapter 1 Introduction

1.1 Study Background

Maritime transport is not only an important means of cultural exchange in the world, but also a natural transportation Avenue. With the increasing number of ships, the air pollution caused by ships is becoming more and more serious. Ship air pollution has come to a situation that cannot be ignored, especially in some ports and straits with large ship flow and dense shipping route. Just as Zhou et al (2010, p.179) notes, the pollutants discharged by ships are even the main sources of pollution in these areas.

Since the 70s of last century, shipping industry in China has entered a period of prosperity in twenty-first Century after a short period of initial development, a foundation period, a rapid development period, and finally has made remarkable achievements. However, compared with the composition of the world ship, there are obvious defects in the structure of our country (see Table 1.1)

Table 1.1- Composition of ship structure in China in 2012

Ship type	Number	transport capacity	Age of ship	Capacity increase (%)
Dry bulk carrier	1618	49 million 400 thousand tons	8.2	15.2
Container ship	149	448 thousand standard box	12.5	
Tanker	1290	9 million 820 thousand tons	6.9	11.4

Chemical tanker	261	997 thousand tons	6.1	17.9
Liquefied gas carrier	67	175 thousand tons	9.3	13.7

Source: Ministry of Transportation. (2013). Analysis report of domestic coastal freight ship capacity in 2012.

1.2 Marine Diesel Engine Pollutants

With the development of the research on road diesel vehicles, the advanced combustion strategy and exhaust after treatment technology have been widely used, so that the emission of pollutants has been effectively controlled. However, Shipping activities at port are highly pollutive, and over 95% of the world's shipping fleet is diesel engine powered (Acciaro, 2014), with even modern marine engines producing higher emissions per power output than regulated on-road diesel engines. Coupled with a wide spatial distribution, the implementation of tail gas control is difficult. Therefore, the emission problem of marine diesel engine is becoming more and more prominent. According to the statistics of IMO, the world's diesel powered ship discharge 10 million tons NO_x and 8.5 million SO_x to the atmosphere each year (Li et al, 2010).

1.3 Objectives of Research

Internal combustion engine exhaust contains particulate matter, nitrogen oxides, carbon monoxide, benzene, sulfide, aromatic hydrocarbons and olefins and other harmful gases, which seriously threaten human health, and the most important of which is PM and NOx. Particles are usually formed by hundreds of volatile and semi volatile substances on the carbon core, which can cause inflammation of the body, and cause asthma and heart and lung disease (Øyvind et al, 2003). NOx can cause symptoms such as cough, respiratory tract infections and asthma, and decrease lung function. Especially children, even if a short time exposure to NOx can also cause cough, sore throat. What is more serious is that the NOx in the exhaust gas will produce two pollution photochemical smog under certain conditions, which will cause more harm to the human body. NOx has become one of the main sources of air pollution. Nitrogen oxides include many species, including NO, NO_2, N_2O_3, N_2O, N_2O_5 and so on. Most of NOx in diesel exhaust is NO, with a small amount of NO_2. NO is a colorless gas, whose toxicity is not large, but in the atmosphere will be slowly oxidized into NO_2. NO_2, as a brown irritant gas, when inhaled into the lungs, it can be combined with the water of the lungs to produce soluble nitric acid. This can be a stimulating effect, which may cause severe emphysema under certain conditions. Meantime, in the strong sunlight, NO_2 will produce photochemical reaction, which is the formation of secondary pollution (Liu, 2006). According to Wang's research in 2009, Marine ship emissions is the main source of nitrogen oxides (NOx). In 2007, the amount of NOx form ocean ship emissions is 25 million tons, accounting for 15-30% of global NOx emissions (Corbett & Kohler, 2008)

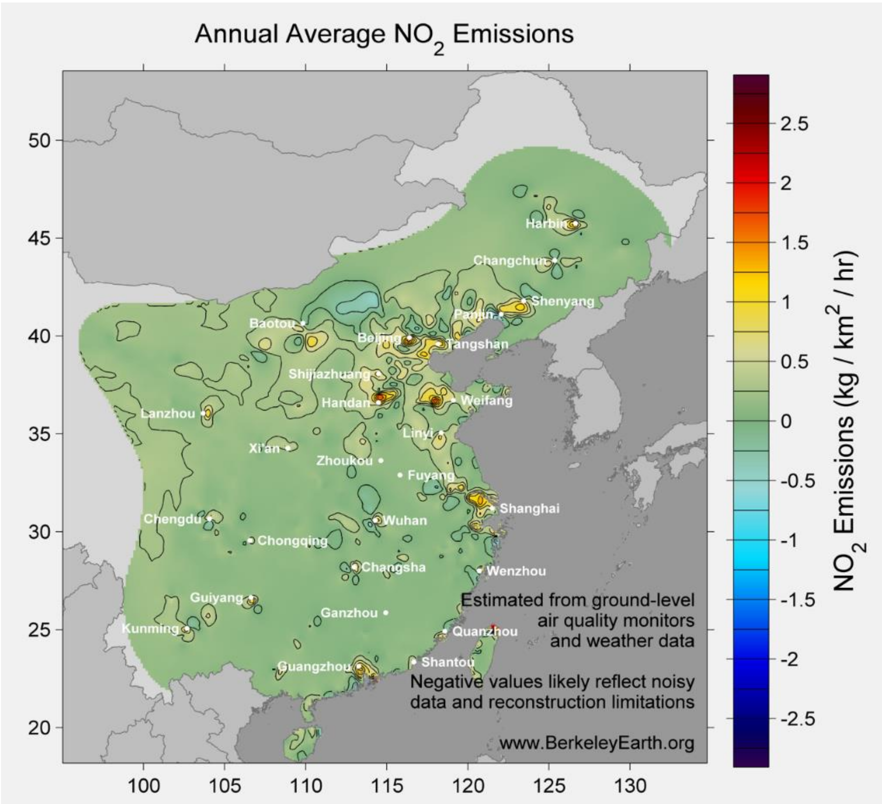
Combustion of sulfur in the combustion engine produces SO_2, which is slowly oxidized to SO_3 in air. SO_2 is a colorless gas with strong hydrophily. After the combination of sulfur dioxide and water to form nitrite, it is very irritant on the human nose and mouth mucosa. If the concentration of SO_2 in the air is too high, it will cause dyspnea, respiratory tract swelling, chest tightness and other symptoms. In general, the combustion of SO_2 emissions in the atmosphere for only a week or so. But when it comes to water vapor and become sulfurous smog, it can stay in the atmosphere for a long time (Cape, et al, 2003). When docked at berth, ships still need internal generators for basic functions, such as lighting, chilling, refrigeration, cooling, heating, pumps, fans, emergency equipment, and so on. So dealing with this global problem is urgent and necessary.

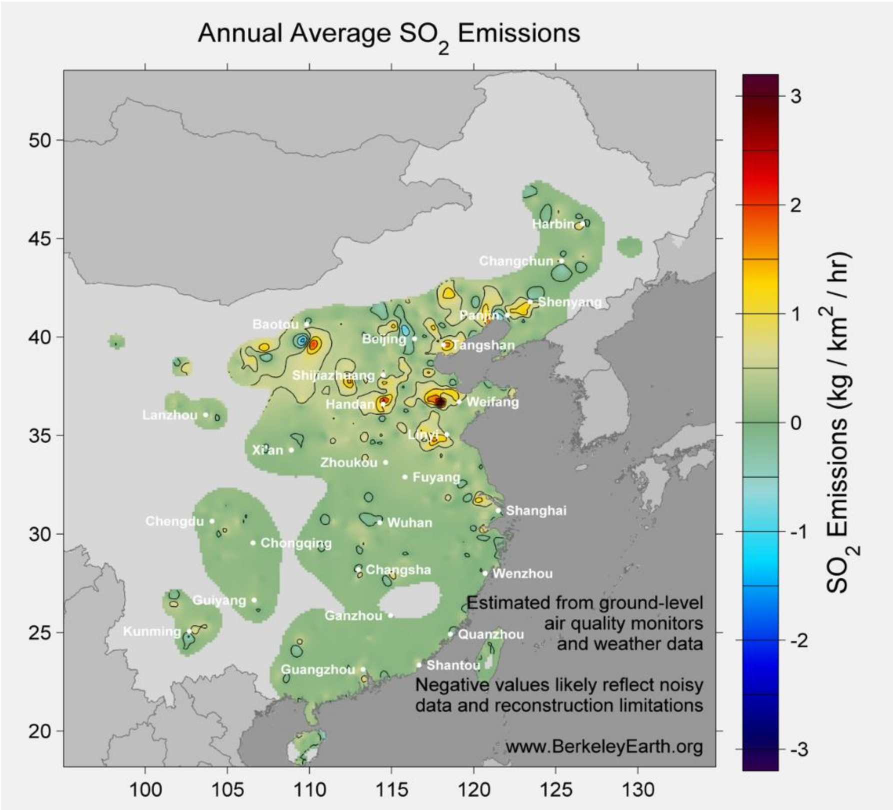
Beijing-Tianjin-Hebei regional integration is a hot issue in recent years. Represented by Shougang, a large number of heavy industrial enterprises will be relocated from Beijing to Caofeidian port. At the same time, Caofeidian port will cooperate with Tianjin port to build the largest dry bulk port in north China. At that time, there will be a sharp increase in the number of ships, followed with the ship emission problems.

1.4 Distribution of NOx and SOx Emissions

In April 2014, Berkeley Earth began a major new effort to collect and analyze the world's air pollution data. They have analysis and data for 16 months, April 2014 through August 2015 and found that 1.6 million people are dying every year from air pollution in China. Figure 1.1 is the distribution datagram of NOx and SOx emissions from April 2014 to August 2015.

Figure 1.1- Distribution datagram of NOx and SOx emissions in China





Source: http://berkeleyearth.org/air-pollution-overview/.

We can see from the pictures that NOx and SOx emission in Tangshan is about 1.25 and 1.5 kg per km^2 per hour. What's more, the main areas where the amount of NOx and SOx emission is larger than other places can be divided into 3 categories: coastal cities, cities in Hebei provinces, and cities in Bohai rim areas. So ship air pollution in Bohai rim areas may be very serious.

1.5 Main Content and Methodology

Based on the special situation of Caofeidian Port, the author have widely reviewed the relevant literature, including some related international conventions and regulations, IMO documents, domestic laws in China. In accordance with the requirements of the emission control area and the documents of Hebei MSA, the study also gives regulatory guidance in Caofeidian Port. What's more, it shows some examples of using shore power in some Chinese ports, in order to compare and analyze the possibility of that countermeasure in Caofeidian Port. Some data and ideas come from shipping industry agencies, articles in journals, essays in CNKI, IMO instruments, news online, and unpublished lectures and handouts. It is worth mentioning that some important data and documents from Caofeidian Maritime Safety Admistration are confidential, so they do not appear in the article in detail.

The study carried out research by consulting policy and laws, data collection, comparing typical domestic and overseas cases and cost benefit analysis, etc. The dissertation consists of six chapters. Chapter I is introduction, the background, the hazard of air pollutants, the objectives, the methodology and the structure of the essay. Chapter II is to introduce the laws and regulations in IMO, in China and abroad. Chapter III is about the managements of ship air pollution, including the policy of ship air pollution control abroad, introduction of emission control area, supervision measures and results of Caofeidian MSA. Chapter IV is to analyze the shore power technology and list the application examples. Chapter V is the physical truth in Caofeidian Port, a measure to estimate cost-benefit and possibility of using shore power. And the last chapter, Chapter VI will be the conclusion of this essay.

Chapter 2 Laws and Regulations on Ship Air Emission Control

2.1 The IMO MARPOL Convention

International Maritime Organization (IMO) is a specialized agencies responsible for maritime navigation safety and the prevention of marine pollution from ships. It is also an international organization that promotes the improvement of maritime safety, marine pollution and marine technical cooperation between governments and transport industries. In the MARPOL (73/78) convention, we can find that:

> Annex VI is appended to the Protocol of 1997 to amend the International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 relating thereto, which was adopted by the International Conference of Parties to the MARPOL Convention in September 1997. Annex VI entered into force on 19 May 2005.

The MARPOL convention is one of the most important international maritime environmental conventions in the world. The aim of the Convention is to reduce the pollution to the ocean, the discharge of oil and the emission of harmful gases into the atmosphere to a minimum. All ships flying the flag of a Contracting State, regardless of where they sail, shall be required to comply with the requirements of the MARPOL Convention, and each Contracting State shall be liable for the ship registered in its territory. There are six annexes in the MARPOL Convention, which are related to different types of ship pollution. Annex VI is related to ship air pollution.

2.1.1 Provisions of the MARPOL Convention on NOx Emissions

Limits of NOx emission from marine diesel engines are regulated in Chapter III regulation 13 of MARPOL annex VI. There are three Tiers or Stages. Tier I was amended in Annex VI of the 1997 edition, while Tier II&III can be found in the amendment in 2008. Table 2.1 illustrates the newest requirement of MARPOL VI.

Table 2.1 - Emission limits of NOx in MARPOL Annex VI (g/(kw·h))

TIER (Stage)	Implementation date	NOx Emission Limits		
		n<130	130≤n<2000	n≥2000
I(b)	2000	17	$45*n^{-0.2}$	9.8
II	2011	14.4	$44*n^{-0.2}$	7.7
III(c)	2016	3.4	$9*n^{-0.2}$	1.96

(a)Each marine diesel engine with a power output of less than 130kW installed on a ship is not included.

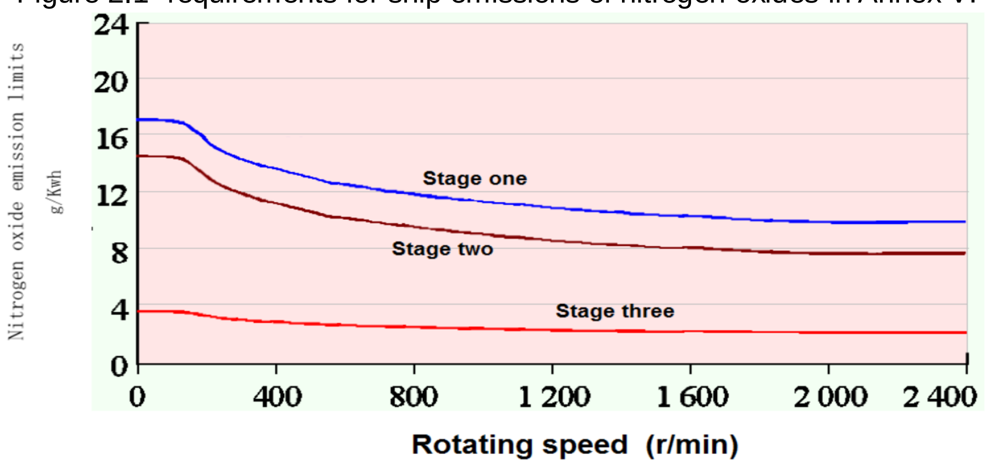
(b) Appendix VI was formally incorporated into the Convention in 2004, but it aims at a marine diesel engine that is installed ship on or after 1 January 2000.

(c)Tier III is only implemented in emission control area. And "n" in the table represents for the engine rated speed(r/min).

Source: Drawn by myself according to MARPOL Annex VI.

According to the table, we can draw a diagram (see figure 2.1) between rotating speed (r/min) and the NOx emission limit, which reflects the function between them.

Figure 2.1- requirements for ship emissions of nitrogen oxides in Annex VI



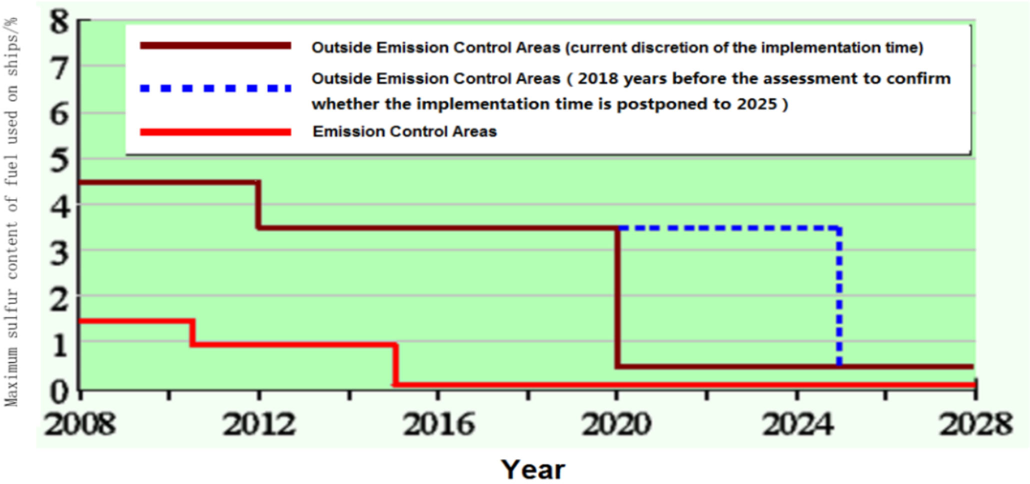
Source: Peng, C. S., & Qiao, B. (2014). Policy measures and practice of controlling air pollution emissions from ships.

2.1.2 Provisions of the MARPOL Convention on SOx Emissions

Limits of SOx emission from marine diesel engines are regulated in Chapter III regulation 14 of MARPOL annex VI. The ordinance is mainly achieved through the operation of diesel engines, while the regulation 13 is achieved by controlling the performance of the diesel engine.

Globally, the sulfur content limit has reduced from 4.5% (45000ppm) to 3.5% (35000ppm) science January 1, 2012, and there will be a further reduction 0.5% (5000ppm) by January 1, 2020. IMO regulations allow countries to establish emission control areas (ECA). Vessels navigating in the ECA need to comply with more stringent fuel sulfur levels. Since July 1, 2010, vessels entering the ECA are required to use a fuel with a sulfur limit content of 1% (10000 ppm), and this limit went down to 0.1% in 2015. See figure 2.2.

Figure 2.2- Upper limit of sulfur content in fuel oil control requirements of ships in Annex VI



Source: IMO. (1978). *The International Convention for the Prevention of Pollution From Ships.*

2.2 International Regulations on Ship Air Emission Control

2.2.1 Regulations of U.S. Environmental Protection Agency

The U.S. Environmental Protection Agency (EPA) issued the Engine Emission Limitation Tier 2. This standard applies to the vessel resisted in U.S. with Cylinder scavenging capacity (V_d) of 2.5-3.0 dm^3, and it entered into force in 2007. Compared with the Tier 1 Limit value of IMO, there is a 25%-40% reduction of NOx. And the limit values of NOx+CnHm, CO, PM are included. Table 2.2 shows all the limit values of EPA Tier 2.

Table 2.2 - Emission limits for 1 and 2 types of engines

swept volume(d^3)	category	NOx+CnHm (g/(kw·h))	PM (g/(kw·h))	CO (g/(kw·h))
2.5≤5.0	1	7.2	0.20	5.0
5.0≤15.0	2	7.8	0.27	5.0
15.0≤20.0	2(<30MW)	8.7	0.50	5.0
15.0≤20.0	2(>30MW)	9.8	0.50	5.0
20.0≤25.0	2	9.8	0.50	5.0
25.0≤30.0	2	11.0	0.50	5.0

Where category 1 is referred to marine engine with Single cylinder emission D<5dm^3, P≥17KW; while category 2 is referred to marine engine with Single cylinder emission 5dm^3≤D≤30dm^3.

Source: Emission Regulations of EPA from the internet:

https://wenku.baidu.com/view/09205d8add3383c4bb4cd262.html.

As respect to SOx, North America joins the SOx ECA, which requires to use diesel oil with sulfur content of not more than 0.05% (500 ppm) from 2007. By 2012, this part of the ship will also convert the use of ultra-low sulfur diesel (0.0015% or 15 ppm).

This is consistent with the road vehicle fuel quality requirements in the U.S.

2.2.2 EU Standard

The engine is classified according to the single cylinder displacement and net power, and its standard requirements are consistent with the standard of American marine engine. In addition to the relevant regulations of the IMO, Sweden has also developed a number of auxiliary means for encouragement and punishment. For example, Swedish authorities impose a different rate of pollution tax on ships entering their waters, according to the actual NOx and SOx emission value of the diesel engine on the ships (Wu, 2008): full levy for emission value which is greater than 12 g/ (kW * h); proportional taxation for that between 12 g/ (kW * h) and 2 g/ (kW * h); and minimum levy for that less than 2 g/ (kW * h).

2.3 Regulations on Ship Air Emission Control in China

In order to prevent and control air pollution, protect and improve the living environment, protect human health, and promote the sustainable development of our economy and society, in September 1, 2000, China has implemented Law of the People's Republic of China on the prevention and control of atmospheric pollution (2000). Motor vehicle emissions to the atmosphere shall not exceed the prescribed emission standards in Regulation 32. What's more, in July 30, 2008, the GB/T15097- 2008 standard for the measurement of exhaust emissions from marine diesel engines was published by China State General Administration of quarantine and inspection, which was implemented in February 1, 2009. This standard is applicable to the bench measurement of marine engine emissions, and the measurement method can be applied mutatis mutandis on board.

At the same time, as a member of IMO, China strictly enforces the provisions of Annex

VI of the MARPOL convention. In order to implement the annex VI of the MARPOL convention, CCS published the guidelines for testing and inspection of NOx emissions from marine diesel engines in 2000. Non road mobile diesel engines with rated net power of not more than 37 kW refers to emission standards of GB 20891-2014, namely Method for Measuring Exhaust Emission Limits of Diesel Engines for Non-road Mobile Machinery. Since October 1, 2014, any non-road mobile diesel engine approved for the discharge of pollutants shall comply with the requirements of the third phase of this standard (Deng, 2014). Since October 1, 2015, the standard stops the manufacture and sale of second stages of non-road mobile diesel engine. For all the manufacture and sale non-road mobile diesel engines, their exhaust emissions of pollutants must meet the requirements of the third phase of this standard. Since April 1, 2016, it urged to stop the manufacture, import and sale the non-road mobile machinery with the diesel engine of second phase. And all non-road mobile machinery manufactured, imported and sold shall be fitted with a diesel engine in accordance with the requirements of the third phase of this standard.

Although the relevant departments of China have promulgated a variety of marine diesel engine emission standards, most of these are recommended industry standards, not mandatory standards. So, until now, there is no strict management of marine diesel engine emissions in China. The Environmental Standards Institute in Environmental Protection Department is developing Emission standard of air pollutants for marine diesel engines. Some local governments have also begun to look for solutions to reduce air pollution in ports and ships. In February 2014, the Guangdong Department of transportation issued the "Guangdong green port action plan (2014-2020)". This plan set up energy efficiency and CO_2 emission reduction targets, ensuring that by 2015, there had been 5 or more ports to become green star terminal. By 2020, there will be more than 100 green terminals.

2.4 ECAs in China

The requirements of 4 global ECAs are illustrated in 2.2. Meantime, in December 4, 2015, Ministry of Transport issued the "Implementation plan to treat Pearl River Delta, Yangtze River Delta, and Bohai (Hebei, Tianjin, Liaoning) Rim as ECZs ", designated 3 Emission Control Zone (ECZ), and clarified emission control requirements for ships navigating within ECZ. At the same time, China put forward the concept of "core port area" with the establishment of ECZ. There are two major aims to establish "core port area". One is to divide ECZs into 2 levels, in order to distinguish between the control requirements. The other is that the core port areas can provide stricter emission control requirements in the context of a unified set of emission control requirements. Based on the study of air pollutant emission inventory in Hongkong in 2007, 4 measures are evaluated to reduce ship air emissions in Hongkong and Pearl River Delta port areas, and the results are illustrated in table 2.3.

Table 2.3- Reduction potential of pollutant under the four types of emission control measures in Hongkong and the Pearl River Delta region

Measures	Emission reduction amount	
	SO2	PM
(a). Oceangoing ships switch to low sulfur oil on port (0.5% sulfur content)	3.9%	2.9%
(b). Oceangoing ships switch to low sulfur oil in Hongkong waters (0.1% sulfur content)	9.6%	8.3%
(c). Establish emission control areas(100 miles from the coast of Hongkong)	95%	85.3%
(d). Slow down the speed of Oceangoing ships to 12 miles in Hongkong waters	1.4%	1.3%
Criterion Emission Amount	141920 t/year	16433 t/year

Source: Booth & Fung. (2013). *Working Towards a Quality Living Region—A Pearl River Delta Emission Control Area.*

It is obvious that setting up the ECAs is the most effective measure to reduce ship air emissions in Hongkong, followed by using low sulfur oil and slowing down the ship speed. Also, the amount of ship emissions is very large, with a great potential of reduction. By referring to some other dates and experience, Chinese government has made some detailed rules in domestic ECZs.

Since January 1, 2016, ships should strictly enforce the existing international conventions and domestic laws and regulations on the control of atmospheric pollutant emissions from ships. Since January 1, 2017, ships which are berthing in the core port can only use fuel with the sulfur content less than 0.5%. Since January 1, 2018, ships which are berthing in the ECZs can only use fuel with the sulfur content less than 0.5%; while since January 1, 2019 ships entering in the ECZs can only use fuel less than that sulfur content. The emission control requirements of ECZ in China are lower than that of ECA, which requires that the upper limit of the sulfur content of the fuel is 0.5%, but there is no special NOx emissions control. According to the document, Caofeidian Port in one of the "core port area" in Jing-Jin-Ji ECZ. In January 29, China MSA has issued a circular on strengthening the supervision and administration of marine emission control zones, which included the Maximum sulfur content, inspection requirements, administrative penalty, and alternative measures. Based on the requirements of ECA and ECZ, China and foreign countries have made a lot of supervision measures, which will be illustrated in the next Chapter.

Chapter 3 Supervision Measures on ECA and ECZ

The International Maritime Organization has approved 4 ECAs, namely Baltic ECA, the North Sea ECA, North America ECA and Caribbean ECA. Along with ECZs in China, there are many typical supervision measures in these areas. In these chapter, these measures are explained both in China and abroad. Moreover, as a member of Caofeidian MSA, my colleges and I have made up a regulatory guidelines by referring to laws and these regulatory methods.

3.1 Current Situation of Air Pollution Control in International Port

There are developed areas or ports taking measures to encourage ships for emission reduction there, such as Green Flag Program in Port of Long Beach, Green harbor project in Singapore and “Fair Winds Charter” in Hong Kong (Peng, 2014). Meantime, there are many action projects all over the world.

3.1.1 San Pedro Port Cleaning Action Plan

The port of Los Angeles was the first to establish Environmental Protection Department in 1972 of the U.S. It is one of the important departments of port development planning management, and its main responsibility is to carry out environmental impact assessment of construction projects. Port of Long Beach once was the worst air quality in the United States. According to the report of International Port Association (2008), California Air Resource Broad predicted that 70% of the potential cancer risk is from diesel particulate matter. So in March 2006, Los Angeles port and Long Beach port reached an important partnership. At the same time, combined with the south coast air quality management department, the California Air Resources Board and the ninth areas of United States Environmental Protection Agency work together to improve the air environment quality of southern California residents, which was called San Pedro port cleaning action plan. Its purpose is to reduce the health risks of port operations, accelerate the implementation of existing energy-saving emission reduction means. Project standards and source standards are set up. There are 3 levels in the standard, namely the source specific performance standards, project specific standards, and the San Pedro Bay standard. The Gulf of San Pedro standard provides a precise requirement for health risk reduction: By 2020, in the community located in the ports with discharge sources, there will be an 85% reduction of cancer risk caused by Diesel Particulate Matter (DPM), and set up the emission reduction goals of the DPM, NOx and SOx by the year of 2014 and 2023. For independent project of each port, special requirements were set up. Also, health risk assessment and mitigation measures are proposed. CAAP has developed a more detailed requirements such as heavy vehicle, ocean going vessel, port equipment, working ship and railway locomotive. Each item is refined to specific time and specific values to provide reliable and detailed emission reduction plans. Table 3.1 shows the emission inventory of Los Angeles in 2011.

Table 3.1 - Emission Inventory of Los Angeles in 2011 (ton/year).

	PM10	PM2.5	DPM	NOx	SOx	CO	CO2	HC
Oceangoing vessel	174	153	148	3821	1275	447	231914	220
harbor boat	35	33	35	879	1	382	51901	72
Harbor	25	23	23	831	2	446	145409	69

machinery								
Train	30	28	30	1052	6	196	69505	55
Heavy truck	23	21	22	1406	4	348	348555	66
Total	287	258	258	7879	1287	2037	847311	482

Source: San Perdo Bay Ports clean air action plan 2010.

From the means of implementation, the main method is to write control measures into the lease treaties and use the method to mitigate the impact. In addition, tax incentives, financial incentives, voluntary action, government loan guarantees are also common means of implementation, of which leasing regulations, tax incentives, financial incentives are proved to be the most effective ways. Furthermore, the port has also set up a science and technology improvement team to evaluate potential projects and emission reduction technologies.

3.1.2 Clean Air Initiative and Port Air Management Program in New Jersey Port

New York New Jersey port is the largest port on the east coast of North America. Located in the northeast of the United States, it is one of the zero NOx emissions areas established by the United States environmental protection agency. Ministry of Commerce of the New Jersey port is the competent department of six marine cargo terminals. The port is responsible for the largest consumer demand for goods transport in the United States, and makes every efforts to become a sustainable port.

New York New Jersey port set up two strategies to improve air quality, including compliance with regulations and voluntary initiative. In order to meet the growing demand for freight, the Ministry of Commerce plans to invest nearly 2 billion in the next ten years to re configure the existing terminals, deepen the port channel, and improve the Inland Waterway berths. The investment will not only create an efficient and cost-effective port, but also improve air quality and energy conservation. These improvements include the installation of infrastructure, supporting electric crane, enhancing regional railway capacity. In addition, tenants invested heavily in electric cranes, modern port equipment and cleaner fuels to improve air quality. EPA and Northeast port diesel Association has developed Voluntary Regional Strategy and EPA Clean Port Development Plan to help the development of the independent industries.

3.1.3 Rijnmond Regional Air quality Management Action Plan in Rotterdam

Air quality in Rijnmond, Holland has improved over the past 30 years, but according to the latest data, the emissions increase exceeds the limit value. The forecast shows that if action is not taken, the emission value of PM and NOx will exceed the European air quality standard. To solve this problem, the Rijnmond Executive Council and the government has developed supporting measures to mitigate air pollution in the Rijnmond area, namely Rijnmond Regional Air quality Action Plan. This plan includes the Rotterdam air quality management measures, the Council's air quality management plan, Rotterdam urban air quality management measures and the Rotterdam Port Authority air plan.

The project works closely with the administration and other parties, such as business people. In order to establish the control measures, the top management Steering Committee organized five task groups to manage the road traffic, shipping, railway, industry and du. The clean air strategy is affected by air quality, cost, feasibility, side effects and time limits. In the joint efforts of the five groups, a total of 100 strategies were formulated, of which 34 were considered to be possible. The purpose of the strategy is to use local and regional approaches to change air quality. Among them, the local strategy includes the provision of shore power for ocean going vessels, and the establishment of low emission areas in cities. However, Regional strategies include pushing the EU to develop more stringent standards. These 34 strategies will be implemented in phases, including immediate, short-term and long-term.

3.1.4 Green Port Planning of Sydney Port

Under the Commonwealth of Australia government, the environmental protection administration has set up a series of laws and regulations on environmental protection, which is in accordance with the UNCLOS. To some extent, the Ministry of environment has a one vote veto on port planning and construction (Jin, 2008). In the use of energy, there are restrictions on the use of diesel in Sydney port, and there are requirements of the use of local energy supply (mixed heat and electricity), the use of fuel that can reduce greenhouse gas emissions for port cargo handling equipment and vehicles (Such as liquefied propane gas, liquefied natural gas, compressed natural gas, fuel cells and bio fuels). Also, there are power connections from shore to ship.

From the mode of transportation, Sydney port encourages staff to reduce the use of private cars, and supplies bicycles to reduce greenhouse gas emissions. For the operation of vehicles, hybrid fuel or energy efficient vehicles are selected. Other measures such as reasonable arrangement of trucks in and out of port, increasing freight transport by rail or water are used to prevent greenhouse gas emissions caused by stagnation. Port Authority attaches great importance to environmental management in port planning and construction. They develop practical measures to ensure the maximization of environmental interests, to achieve the best economic benefits while achieving economic benefits.

The four famous ports in the world have taken measures and standards based on their own emission characteristics in the green planning, the control of the atmospheric pollutant emission. What they all have in common is that they have set up a special research team to assist the local government in the formulation of the air pollution cleaning program. For example, the promotion of the use of shore power technology, clean fuels, strict standards and implementation guidelines, etc. These are significant reference value for Caofeidian Port in the management of ECZ and the use of shore power.

3.2 Current Measures of Ship Air Pollution Control in Caofeidian Port

Caofeidian Port is one of the ECZs in Bohai Gulf, whose direct administration section is Caofeidian MSA. Founded in 2006, it is one of the four sub-branches in Hebei MSA. The Antifouling sector is the competent department on ship air pollution control while each law enforcement unit is the policy executor, examiner and penalty unite (Caofeidian Government Website, 2016). Although Caofeidian MSA has made recommendations to local governments many times on developing incentive mechanism to ship owners and ship companies if they take measures to reduce ship air pollution, the local government and port companies are unwilling to do so. As a result, Caofeidian MSA has to formulate mandatory rules to ships berthing in this port.

In January 29th, 2016, Maritime Bureau of the Ministry of Transport issued “the Notice of the People's Republic of China on Strengthening the Supervision and Administration of ECZs”. According to the Notice, Hebei MSA conducted a special inspection on the ECZ, including routine inspection, supervision and inspection of the use of low sulfur fuel, inspection of the substitute measures for the use of ships, inspection of oil supply operation site, inspection of oil supply companies and fuel sampling inspection. After the special action in April 14th, 2017, my colleges and I made a summary and guideline in order to form a long-term supervision mechanism.

3.2.1 Inspection of Main Certificates and Documents

This is a preliminary examination of the total inspection, which includes 10 kinds of certificates and documents. That is: nationality papers of ship, IOPP, International Certificate of energy efficiency, IAPP, oil record book, ship fuel supply document, fuel conversion program, engine room log book, log book and ship fuel sample. This study will take the inspection guideline of IAPP, oil record book and engine room log book as examples.

(1) <u>Inspection of IOPP</u>

International navigation ships with 400 gross tonnage and above and all fixed and mobile drilling platforms and other platforms; and all domestic vessels with a total tonnage of 400 tons or more and any mobile platform should be included (MARPOL 73/78, p.40).

Check points: (i). Check whether the vessel holds the IOPP certificate and the sub-page as required and whether the certificate has been tested in accordance with the requirements within the validity period; (ii). Whether the relevant structural equipment of the ship is in conformity with the records of the IOPP certificate; (iii). Whether there are notes in the chronicle of IOPP certificate when the ships use clean energy such as liquefied natural gas or other low emission ship fuel as an alternative; (iv) for ships using tail gas treatment device, whether there are endorsement in the note bar.

(2) <u>Inspection of Oil Record Book</u>

According to MARPOL annex I Appendix III, where there are 150 or more tons of oil tankers and non-oil tankers with a total tonnage of more than 400 tons, there shall be part I of the oil record book.

Check points: (i). whether the relevant work is accurately recorded; (ii). Focus on H records and combined with the engine log to understand the situation of fuel refueling and fuel storage capacity. Through the refueling records, check the information of ship's corresponding documents for the oil, including the sulfur content, fuel filling quantity, etc.; (iii). Focus on checking the quantity, time and location of bilge water treatment in the engine room. For example, we can check the D record, and the oil and water treatment equipment should not exceed the rated maximum processing capacity of the device; (iv). Check the receiving and processing of residual oil; and (v). C is a content recording sludge and other oil residues, such as residue oil and waste oil leakage, etc. It should be recorded once a week.

(3) Inspection of Engine Room Log Book

Check points: (i). For ships requiring conversion of low sulfur fuel, whether or not the date, time, latitude and longitude of the ship and fuel sulfur content, the quantity of low sulfur fuel, oil change operation personnel and other information are recorded in the engine log book as required. It is possible to verify whether the vessel has been operated before entering Caofeidian Port according to the latitude and longitude information of the oil change record; (ii). For ships using shower power, whether the time, location, operators and other information are recorded in the energy log; (iii) For dual fuel powered ships using clean energy such as liquefied natural gas or other low emission ship fuel as an alternative, whether the quantity of fuels, date and time, latitude and longitude, operators and other information are recorded in the engine log; (iv). For ships using tail gas treatment device, whether the above information are recorded in the energy log. Fuel consumption records can be used to verify whether the vessel complies with the oil change regulations

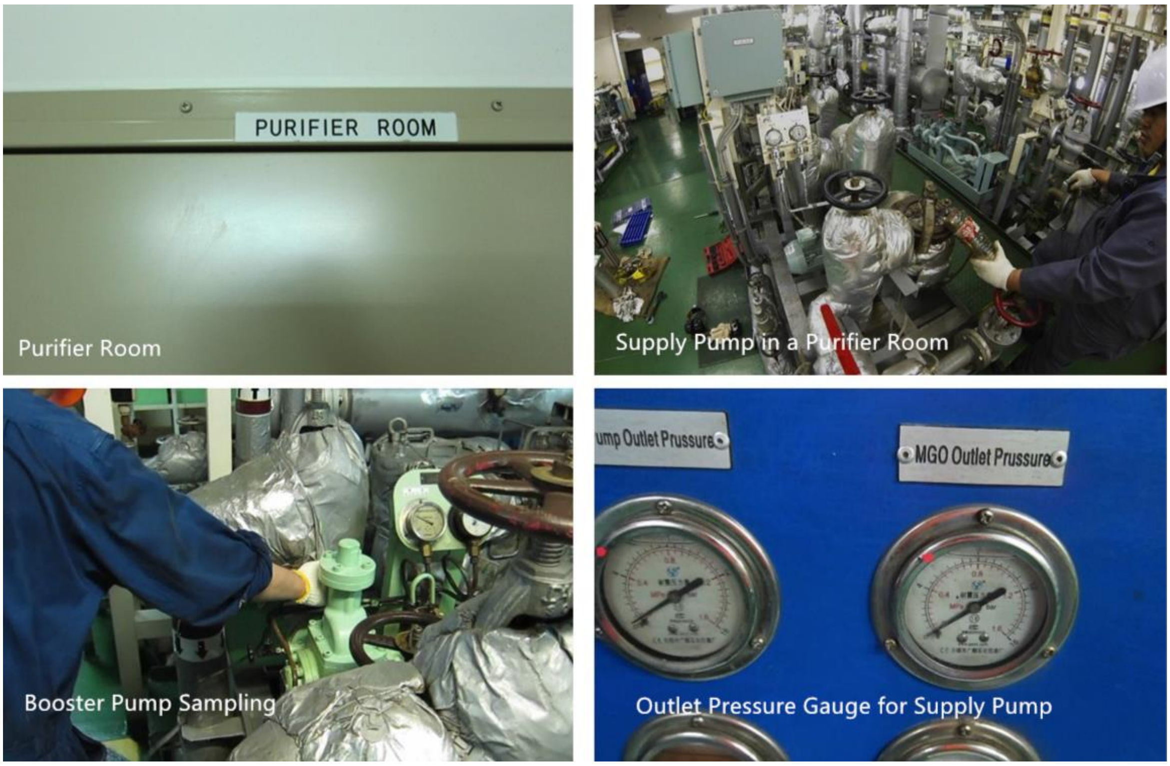
3.2.2 Inspection of Related Equipment

Engine room fuel lines can be provided by the crews. In conjunction with the engine's fuel piping diagram, the crew is required to check the relevant piping system to see if the ship is using low sulfur fuel. If there is a conversion of low sulfur fuel and high sulfur fuel conversion valve or switch control, the conversion or switch should be verified to see whether it is pointing to the use of low sulfur fuel.

The core skill of our MSA supervisor in fuel inspection is ship fuel sampling, which can be complex and dangerous. Barber's (2016) teaching materials told us that the best sampling position should be the last sampling point before the engine, such as the last filter, fuel supply pump, circulating pump, removable pressure gauge, sub engine room, the last second or third filters, etc.

Figure 3.1 - Sampling in Final Filter

Figure 3.2 - Other sampling positions



Source: Taken by myself.

Above two pictures show good positions for sampling, which is taken by my colleges and me. However, we also have got some poor sampling locations such as fuel oil daily tank, settling tank, fuel flushing pump and transfer pump, etc. Sampling operations, especially removing the filter, pressure gauges, etc., should be operated by the cabin crew who is familiar with the engine room equipment.

3.2.3 Auxiliary Verification Method

<u>(1) Inspection on related temperature and viscosity</u>

Under normal circumstances, the temperature and viscosity of low sulfur fuel is relatively low (Zhou, 2011). Table 3.2 and table 3.3 give some characteristics of maritime fuel.

Table 3.2 - Marine Residual Fuels: viscosity, sulfur content, pour point

Marine Residual Fuels												
Parameter	**Unit**	**Limit**	**RMA 30**	**RMB 30**	**RMD 80**	**RME 180**	**RMF 180**	**RMG 380**	**RMH 380**	**RMK 380**	**RMH 700**	**RMK 700**
Density at 15℃	Kg/m³	Max	960	975	980	991	991	991	991	1010	991	1010
Viscosity at 50℃	mm²/s	Max	30	30	80	180	180	380	380	380	700	700
Water	%V/V	Max	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.	0.5	0.5
Sulfur	%(m/m)	Max	3.5	3.5	4.0	4.5	4.5	4.5	4.5	4.5	4.5	4.5
Aluminium + Silicon	mg/kg	Max	80	80	80	80	80	80	80	80	80	80
Flash point	℃	Min	60	60	60	60	60	60	60	60	60	60
Flash point, summer	℃	Max	6	24	30	30	30	30	30	30	30	30
Flash point, Winter	℃	Max	0	24	30	30	30	30	30	30	30	30

Table 3.3 - Marine Distillate Fuels: Viscosity, Pour Point

Marine Distillate Fuels						
Parameter	**Unit**	**Limit**	**DMX**	**DMA**	**DMB**	**DMC**
Density at 15℃	Kg/m³	Max	-	890.0	900.0	920.0
Viscosity at 40℃	mm²/s	Max	5.5	6.0	11.0	14.0
	mm²/s	Min	1.4	1.5	-	-
Water	%V/V	Max	-	-	0.3	0.3
Sulfur	%(m/m)	Max	1.0	1.5	2.0	2.0
Aluminium + Silicon	mg/kg	Max	-	-	-	25
Flash point	℃	Min	43	60	60	60
Flash point, summer	℃	Max	-	0	6	6
Flash point, Winter	℃	Max	-	-6	0	0
Cloud point	℃	Max	-16	-	-	-
Calculated Cetane Index		Min	45	40	35	-

Source: National standard marine fuel oil. (2012). GB 17411-2012.

According to the figures, we can turn to fuel temperature, viscosity meter. Figure 3.3 shows several common fuel temperature, viscosity meter on board.

Figure 3.3 - Several common fuel temperature, viscosity meter

Source: Taken by myself.

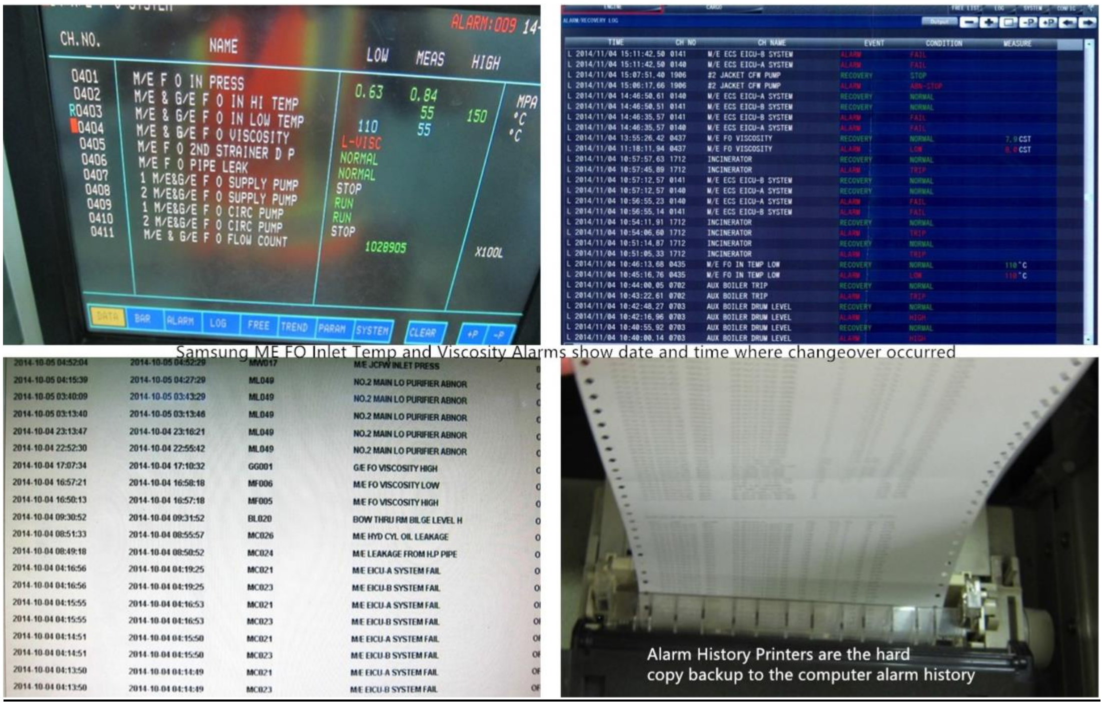
(2). Inspection on the temperature history trend of engine, auxiliary engine, boiler

With the development of technology, in order to record the latest oil temperature change curve, there is history record of fuel oil temperature near the fuel entrance of the ship main engine, auxiliary equipment and boiler. Some can replay a few hours, and some can replay a few days. Because of the different temperature of low sulfur and high sulfur fuel when they come into the main engine, auxiliary machine and boiler, it can be verified preliminary whether the ship has conducted oil change operation through checking the fuel temperature curves.

(3). Fuel temperature and viscosity alarm at the entrance of main engine, auxiliary engine and boiler

In general, the main engine, auxiliary machine and boiler are equipped with fuel temperature, viscosity alarm device, which can record fuel alarm information. When low sulfur fuel and high sulfur fuel switch, it will usually trigger fuel alarm. Ship oil change operation can be verified through the retrieval of fuel temperature, viscosity alarm record. (See figure 3.4).

Figure 3.4 - Fuel temperature and viscosity alarm



Source: Taken by myself.

3.2.4 Detailed Inspection of Alternative Measures

(1). Instrument inspection of alternative measures

The Correlation device should be tested and certificated to demonstrate that the equipment can meet the requirements of IMO. For example, the types of clean energy should be labeled in the IOPP for ships using clean energy; while the tail gas treatment device shall be examined by an authorized organization or institution and endorsed in the IOPP if the ship has been installed the equipment.

(2). Verify the actual use of the equipment

The practical application can be found in the log file on board. For ships using shore power, the following information should be kept on board: Operating procedures, start and end time in the engine log book, personnel information on shore power operation, safety operation guide. For ships using clean energy, the location and quantity of clean energy should also be recorded in the relevant documents.

The inspection is very similar with above ones for ships using tail gas treatment device. Meantime, for international navigation ships, the exhaust emission of the tail gas treatment device can be sampled and examined to confirm its emissions is in accordance with the "2015 Guidelines for Exhaust Gas Cleaning System”(MEPC.259(68)).

3.3 Supervision Results and Difficulties

3.3.1 Supervision Results

From January 1, 2017 to March 31, 2017, special inspection activities have been carried out by Caofeidian MSA on ship air pollution. During these 3 months, the total number of ships berthing at Caofeidian Port is 2683, and 87 of which are inspected, accounting for 3.2% of the total number. Among the inspected vessels, there are 34 international ships and 53 domestic ships which have 6 deficiencies. At the same time, marine fuel quality inspection has been carried out 36 times and only one ship was fined by 29000RMB because of the substandard fuel in the ECZ. 11 refueling operation has been inspected with 2 of which were sampled. Also, some questionnaire surveys were sent to Ship Survey Administrations, shipping companies, and ship oil supply enterprises.

3.3.2 Supervision Difficulties

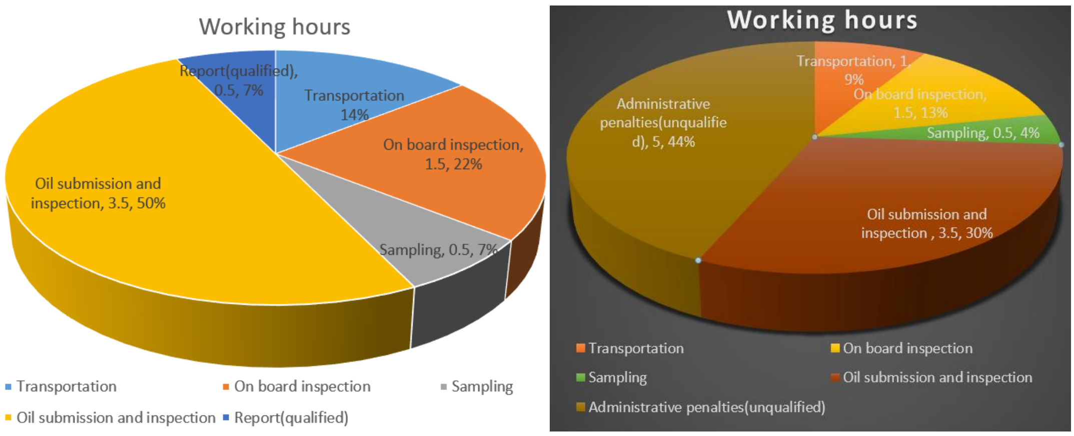
Through special inspection activities, my colleges and I have found several difficulties in fuel sampling inspection and on-the-spot supervision. First of all, there is no mature ship selection mechanism, so it is difficult to find suspect vessels. Secondly, there is not enough skilled supervisors to conduct fuel sampling and the inspection time is limited on board. Thirdly, if the inspected ship is about to leave Caofeidian Port, it is hard to collect evidence of fuel oil quality.

It is obvious to see that the Inspection rate is too low compared with other countries. According to Feng & Zhu's (2016) research, before 2015, the proportion of ship fuel sampling was 0.1%. Half of the ships used illegal high sulfur fuel. However, the inspection proportion has increased to 10% by contracting states in North Sea and the Baltic Sea after 2015. As a result, only 5% of ships were found not in accordance with the provisions of oil. In addition, more and more countries are trying to use remote sensing technique to inspect ships with high emission. Denmark, Germany, Belgium, Sweden are examples. Remote sensing technology can make better use of human resources and other resources. The ship violation rate is 2% to 3% lower than other countries if there is a remote sensing.

Lack of law enforcement officer is another problem in Caofeidian Port. The working hours of Caofeidian government is 7 hours a day, and the average berthing time of ships in Caofeidian Port is 36.4 hours, that is, 1.5 days. The pie chart below illustrates the average time of ECZ on-the-spot supervision and at least 2 supervisors are required to conduct an inspection.

It is shown to us that oil submission and inspection occupies the majority of time (4 hours) in the case that fuel sulfur content is qualified. However, if the ship breaks the law, then administrative sanction costs nearly half of the working hours of law enforcement officials. What's more, the total waiting time for ship owner or agency increases dramatically to 11.5 hours, which may contribute to a delayed ship.

Figure 3.5 - Working hours of supervisor in ECZ inspection



Source: Drawn by myself.

However, according to the document of China MSA, only the ships in core port area (Jing-Jin-Ji) are forced to use low sulfur fuel after January 1, 2017. That means ships in other 10 ports of Bohai rim ECZ such as Dalian, Yingkou & Yantai, the mandatory requirement can be postponed until 2018. But air pollution has regional and long-distance transmission characteristics. Coupled with the mobility of the ship, there is a need for the implementation of regional joint prevention and control. Relying on a single port cannot solve the problem. Although Caofeidian Port has meet the requirements of ECZs, the air quality will still not be improved as long as other ports in Bohai rim refuse to play ball. So an effective and efficient way to deal with air pollution should be accepted by the public. This settlement will be analyzed in the following chapter.

Chapter 4 introduction on Shore-to-ship Power Supply System

It is supported by Winebrake's (2009) research that reducing the sulfur content of fuel can reduce the air pollution of ships. If the sulfur content of fuel decreased from 4.5% to 0.5%, total hydrocarbon emissions will be reduced by 18%, CO emissions will drop by19%, and NOx will drop by 8%. But there are many drawbacks of using low sulfur fuel both to ship owners and ship engines. We are looking for a more cost-effective and environmental solution.

4.1 The Defects of Using Low Sulfur Fuel Oil

The defects can be divided into economic and technical aspect.

4.1.1 Increased Fuel Costs of Shipping Companies

Fuel costs are a major component of operating costs, accounting for approximately 20%~30%. In 2008, COSCO fuel costs accounted for 26.8% of operating costs, while Maersk Group's fuel costs accounted for 26% of operating costs. In the period of shipping downturn, controlling the cost of fuel is an important measure to control the total cost of shipping enterprises. Heavy oil (380 Cst) is used by diesel engines and auxiliary boilers during navigation of most ocean going ships and coastal freighters when anchoring and berthing if there is no major overhaul. Shanghai heavy oil (380 Cst) offer for 2130 RMB/t, No. 0 diesel offer for 4700 RMB/t (June 20, 2016 offer). The price of diesel is more than twice as heavy oil. According to the CCS survey, if the fuel sulfur content reduced to 0.5%, the shipping company fuel costs will increase by 40 USD/t; if reduced to 0.1% and below, the fuel costs are significantly increased to 60 USD/t.

At present, fuel systems and machinery for large ships are designed based on heavy oil, and they have to be transformed according the standards formulated by low sulfur fuel. According to the CCS survey of COSCO, the rebuilding cost of a 5250TEU container ship manufactured in 1997 was RMB1 million. In the current downturn in the shipping industry, the use of low sulfur fuel will face great difficulties and resistance (Notteboom, 2011).

4.1.2 The Failure Rate and Maintenance Cost of Diesel Engine and its Auxiliary Equipment Are Improved

There is a pair of important parts in the high pressure oil pump of marine diesel engine. When the plunger, sleeve and diesel engine are running, they are both relatively moving at a relatively high speed. The use of high sulfur content of fuel can improve the lubrication performance, and reduce the plunger sleeve's wear. However, if the diesel engine uses lower sulfur content fuel, the plunger sleeve's wear will cause fuel leakage. Also, when the injector is in the use of low sulfur oil, because the sulfur content is small, pintle nozzle matching parts are in a poor lubrication of the working environment, which could cause the jam of Cut Off Level in Slide-valve Fuel Injector.

When the ship enters the discharge control area, it is necessary to use the low sulfur oil in advance. When changing to low sulfur oil, because of low viscosity and low temperature, the diesel engine fuel system will be thermal shock (Adamkiewicz & Drzewieniecki, 2011). And the High pressure fuel pump and oil-fuel injector needle-valve are prone to jamming.

The use of low sulfur oil can also affect the combustion performance of diesel engine. When using low sulfur oil, the high pressure oil pump plunger sleeve lacks lubrication and becomes increasingly worn, resulting in leakage of high pressure oil pump and a reduced pressure of high pressure oil pipe. At the same time, the amount of fuel entering the injector is reduced. As a result, the temperature of the cylinder decreases and the effective power goes down. The propulsion efficiency of the ship's power plant is reduced.

4.1.3 Reducing the Reliability of Ship Power Equipment

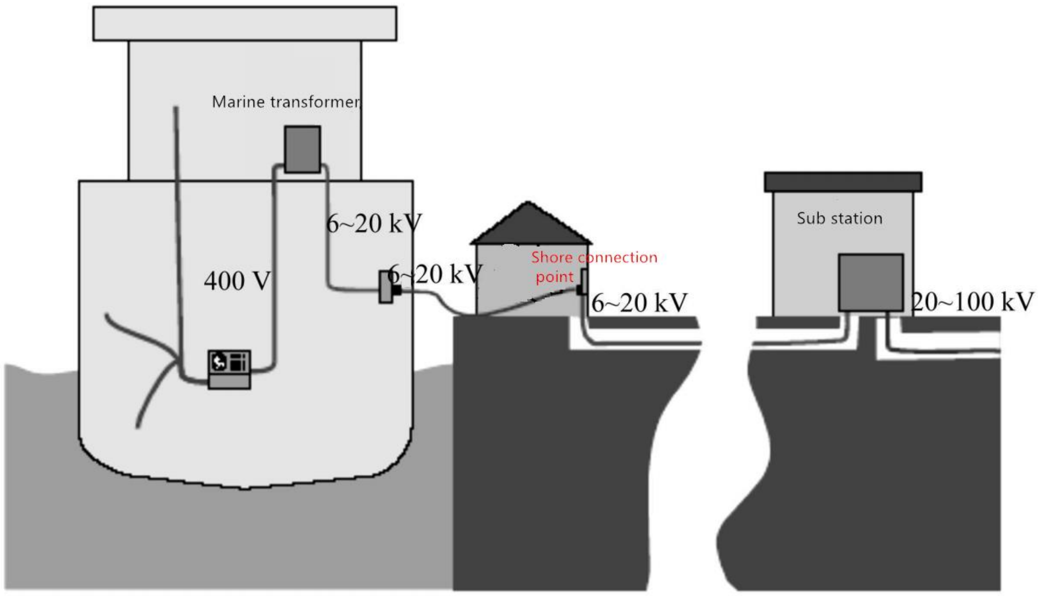
The reliability of the ship runs through the entire design, manufacture and operation of the ship. If we use fuel with low sulfur content in ECZs, for marine main engines, it is easy to lead to ignition difficulties, speed instability and further the operating system failure; for boiler, it is easy to cause combustion failure and ignition failure. In addition, the flash point of low sulfur oil is low, so it is easy to volatilize into oil and gas gathering in the furnace in engine room temperature, causing the furnace explosion. Taking all of these above into consideration, shore-to ship power supply system is safer, environmental friendly and maybe cost-effectiveness.

4.2 Introduction on Shore-to ship Power Technology

4.2.1 Basic Principle of Shore-to ship Power System

The so-called shore-to ship power technology is that when the ships are berthing at the port, stop using the ship's generators, and switch to land power supply. Shore power, also known as ‘cold ironing’, ‘alternative power supply’, ‘shoreside power’, and ‘onshore power’, reduces air pollution from ships in the port area through electric feed to the ships from onshore (Zis et al., 2014). Power is supplied to the ship's electrical equipment through the ship's shore connection box and connected cables. In general, the power supplied to the shore by the terminal is the rated power of a single generator on the ship. This ensures that the electricity power can meet the demand of various electrical equipment. Figure 4.1 is the schematic diagram of shore power connected by a ship.

Figure 4.1 - Schematic diagram of shore-to ship power supply system



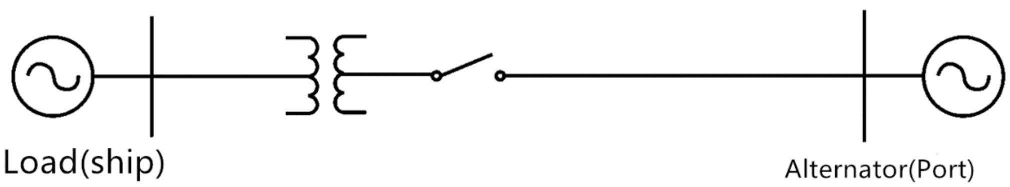
Source: Li & Sun (2006). Research on marine shore power technology.

We can see from the picture that electric energy is distributed again by transformer substation in the port. And the voltage is reduced the transformer from 20 ~ 100 kV to 6 ~ 20 kV. Between the port and dock, the electric energy transmission after decompression is accomplished by the cable laying in the cable trench. There is a socket box at the shore connection point of the terminal. One side of the interconnecting cable is connected with the dock socket box and the other side of it is connected with the socket screen for ship. In this way the shore power can be delivered to a ship.

The terminal and the ship each have a dedicated shore power system. The shore-to ship power supply system consists of 3 parts. The first is the socket screen, which is usually located in the stern, and used to connect the cable from the pier. The second is the shore power connection screen, which feeds the power from the socket screen to the shore box. Also, this screen has other functions such as phase sequence detection; power, current, kWh indication. The third is shore electric box, which will power the entire ship power grid (Paul & Chavdarian, 2009).

In addition, considered from the user's point of view, when the shore power is connected to the ship, a simple power system is composed between the dock substation and the ships. If the substation of the port area is simulated by equivalent generator, the ship system is load (See figure 4.2).

Figure 4.2 - Schematic diagram from the user's point of view



Source: Li & Sun (2006). Research on marine shore power technology.

The ship of each country, in addition to special vessels, their AC power system is basically as follows: three-phase AC 450 V / 60 Hz, three-phase AC 6.6 kV / 60 Hz, and 400 V / 50 Hz. Therefore, the existing international shoreline approach generally includes 3 methods, that is, low voltage shore power/low voltage ship load, high voltage shore power/low voltage ship load, high voltage shore electricity/high voltage ship load.

There are several typical ports where these 3 kinds of power supply modes are used.

For the first kind (low voltage shore power/low voltage ship load, 60HZ): Pontoon type power supply device is used in Los Angeles port to supply power to a small amount of container liner ships. For the second kind, (high voltage shore power/low voltage ship load, 50HZ): Göteborg Harbor uses a fixed-type power supply to supply cruises and Ro-Ro ships. For the third kind (high voltage shore electricity/high voltage ship load), there are examples like Long Beach Container Terminal and Los Angeles Container Terminal.

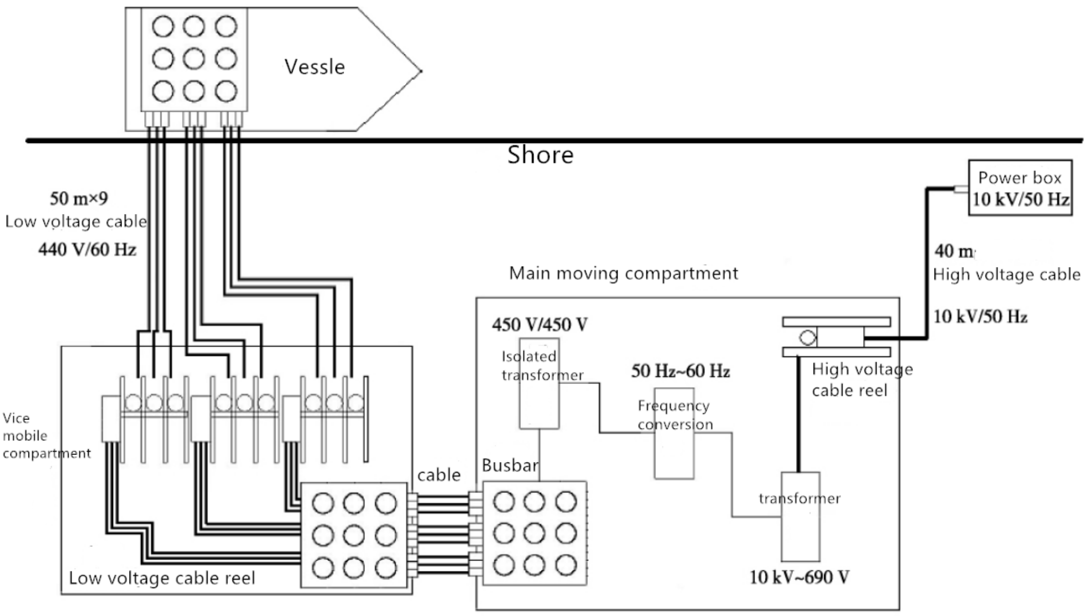
4.2.2 Shore-to-ship Power Technology in Shanghai Port

China's power grid frequency is 50 Hz, which is different from most of the ships' electrical frequencies. Coupled with the busy operation of Chinese ports, shore-to ship power supply system cannot have a big change in infrastructure. So Pontoon type or stationary type system is not suitable for this condition. Therefore, the success of the international case cannot be moved to our port.

Developing a power frequency conversion technology suitable for power system in China, and designing a set of mobile variable frequency transformer power supply system to apply multiple berths or terminals is the best solution. Shanghai Waigaoqiao Phase II project port uses a Mobile Variable Frequency Transformer Power Supply System.

The main structure of the Mobile Variable Frequency Transformer Power Supply System adopts the port standard configuration container form to facilitate the moving by the port lifting equipment (such as container front hanging). Due to high and low voltage distribution, flexible connection configuration requirements, the main body is divided into two parts, namely main and secondary moving module. Pressure and frequency conversion devices and high-voltage cable reel are installed in the main mobile cabin, while the low-pressure cable reel is mounted on the sub-moving compartment (Bao & Jiang, 2010). And the figure 4.3 is the system composition diagram.

Figure 4.3 - System composition diagram of Mobile Variable Frequency Transformer Power Supply System



Source: Bao & Jiang (2010). Research and Practice of Shanghai Port: shore-to ship power supply system.

Meantime, Shanghai Port is also actively developing fixed shore-based marine variable frequency power supply system. In the construction of the Waigaoqiao Project VI in 2011, at the beginning of the project design, the use of shore power has been considered throughout the project. The entire terminal set up a total of four high-voltage electrical connection for the use of shore power, and use high / low voltage power supply program, which can output 440V and 6.6kV different voltage to achieve converting while inserting. Compared with the Mobile Variable Frequency Transformer Power Supply System, the access of Fixed Marine Variable Frequency

Transformer Power Supply System is simple with wide coverage and low cost. It meets the ISO / IEC international standards, and will become the future development trend of shore power.

4.3 Shore-to-ship Power Cost

Each port has its own unique history, layout, business atmosphere, docked ship type, mode of operation, local air quality problems and the surrounding environment. Therefore, the cost of building a terminal for a Shore-to ship power equipment will vary widely, with the major cost of a its infrastructure (Tzannatos, 2010). The cost of delivering electricity from the local grid to the terminal is between $ 160,000 and $ 48 million, depending on the location of the port, the type of ship, the voltage and frequency requirements.

The cost of technological transformation required by the ship mainly includes the cost of purchasing the equipment, equipment installation costs and other expenses (maintenance and other expenses). The cost of technological transformation is analyzed as follows.

Shore-to ship power system mainly includes: Socket Screen (including connecting cable), Shore Connection Screen (including marine step-down transformer) and Shore Connection Box. One of the main electrical equipment of the Shore-to ship power system is the marine transformer. The marine transformer is used to reduce the pressure. For example, the l0kV is reduced to 400V. The main function of the shore electric box is the secondary distribution of the power after the buck, while the socket box used to connect the cable from the terminal.

The cost of the commonly used marine transformer (0.5-2MW) is $5-12 million; the cost of the Shore Connection Box is $ 50 thousand; the cost of the socket is $30 thousand. And there will be a higher cost on shore-to-ship power system transformation and non-shielded transformer installation. In general, the cost of installing a ship's shore electricity system is $ 80,000 to $ 160,000 (including the transformers). So, the cost of the transformation of the system can be formulated as follows;

Total Cost=the cost of purchasing equipment (transformer, shore power box, etc.)+equipment installation cost + other expenses.

By using the above formula, the average cost on shore-to-ship power system transformation can be approximately $ 400 thousand. If the terminal uses low voltage (440V) to provide shore power to the ship, the ship is directly connected to the dock 440V socket box through the cable. Using this kind of shore connection, the ship does not need to install the marine transformer, the cost of technological transformation can be reduced.

The port (wharf) uses different supply voltage to provide shore power to the ship, and the cost of electricity supply will vary greatly, depending on the nearest distance from the ship's cable to the power point and the conditions of the port. If we have to dig trenches, and the cable distance is longer, then the power supply cost will increase greatly. The cost of a typical port cable trench (laying the cable in the ground) is $ 130-195/m, and the cost of the high voltage electrical (l0kv) is $ 12-20/m. In the port area, the distance between the ship's outlet and the nearest power supply point is between 30-500 meters (Yu, 2013). Between the terminal connection point and the ship, the connecting cable is the same type of soft cable as the sling cable of the harbor area. The cost of the commonly used sling cable (l0kv) is $16-32/m.

However, if ships use a frequency of 60 Hz electricity, the shore must convert the electricity standard from 50 Hz frequency to a frequency of 60 Hz. The cost of the frequency conversion device is roughly in the range of $ 38-65 million to meet the demand for power supply. Typically, a frequency conversion device can supply power to multiple terminals. Based on the above theory, the average cost on shore-to-ship power system transformation will be around $1.65 million. It should be pointed out that the expansion of port substation and capacity is not included. It is assumed that the port area has sufficient electric power, fully able to meet the needs of the ship on the shore. Obviously, the initial investment cost of implementing the shore-to-ship power system in the port is very high.

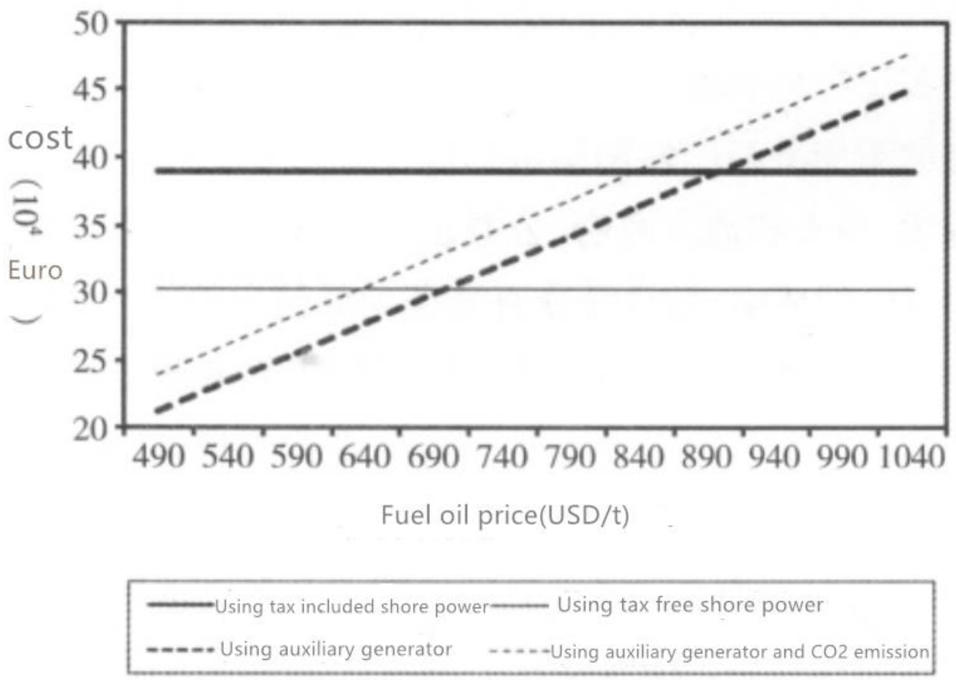
4.4 Practice of Foreign Ports in Extension of Shore-to-ship Technology

At present, Shanghai port, Lianyungang port, Shenzhen port and other ports have carried out application and practice of shore-to-ship technology. However, there is no mature and accepted approach to the sharing of investment in these equipment, sharing of the use-cost and sharing of the electricity purchase.

4.4.1 Treatment of Goteborg Port

There are many factors that affect the input and output analysis of shore power technology, which mainly include the oil price, the cost of the equipment, the price of electricity and the carbon emission. In the long run, oil prices will continue to rise, while the cost of the equipment will continue to decline with the increasing transformation demand. In addition, the Europeans in promoting the process of reducing emissions, pay attention to the application of financial and economic means. A typical method is to remove the tax on the use of shore power on ships and to impose a carbon tax of 15 euros/t of carbon dioxide emissions (Peng, 2012). In such circumstances, the break - even analysis of using shore power in Göteborg Port is shown in Figure 4.4., taking into account the application costs of shore power in both cases (taxable electricity price and tax-free electricity price). Also, when a ship is using a traditional auxiliary machine to generate electricity, the changes in fuel prices and CO_2 emission tax (15 euros/t) is taken into consideration.

Figure 4.4 - Break - even analysis of using shore power in Göteborg Port



Source: Peng. (2012). The experience analysis of using shore power technology in foreign ports.

When the price of shore electricity is used in taxable terms, if carbon tax is not levied, the fuel oil price should be $ 910/t, in order to achieve break-even point; if carbon tax is not levied, the fuel oil price should be 705 US dollars/t, and the break-even point will be achieved. In order to encourage shipping companies to use shore electricity, the government of Sweden, approved by the European Union, has reduced the tax rate for the use of shore power from SEK 0.28/kWh to SEK 0.05/kWh from November 1, 2011.

In the early 2011, European Sea Port Association and EC Shipowners Association required that, in revising the 2003/96/EC Directive, the European Community Energy Products and Electricity Tax Framework, exempt the tax on the use of shore power by harbor ships. In April 2011 when the EU amended the Directive 2003/96/EC, it has been confirmed that this part of the tax will be expected before December 31, 2020.

4.4.2 Treatment of New York/New Jersey Port

In New York/New Jersey Port, Broolyn cruise terminal has been equipped with shore-to-ship power supply facilities, for power supply of the Carnival cruise company's "Queen Mary 2" cruise ship. Terminal power supply equipment and facilities cost $ 14 million 900 thousand. Among them, the New York / New Jersey Port invested 12 million US dollars, the US Department of Environmental Protection invested 2.9 million US dollars. Carnival Cruise Company spent $ 4 million on the "Queen Mary 2" cruise ship to use shore power transformation.

The Economic Development Department of the municipal authorities responsible for managing the cruise terminal and the New York Electricity Authority, which is responsible for the supply of electricity, signed a five-year cooperation agreement with Carnival Cruises. New York electricity costs $ 0.28/kWh, among which Carnival Cruises paid $ 0.12/kWh, and the Economic Development Department and New York Electricity Authority paid the rest (Peng, 2012, p.13). There are also some other ports such as Port of Prince Rupert and Port of San Francisco use the similar method to support the construction and use of shore power, which has good reference value to Caofeidian Port.

Chapter 5 Feasibility Analysis of Shore Power in Caofeidian Port

Caofeidian Port was constructed in 2003 by using the method of Sea reclamation. By the year 2013, 210 km^2 land have been constructed from the sea. Along with JingTang Port to form Tangshan port area, it has the seventh throughput around the world (Tangshan Government Website, 2017).

5.1 Basic Information of Caofeidian Port

5.1.1 Ship Conditions and Throughput

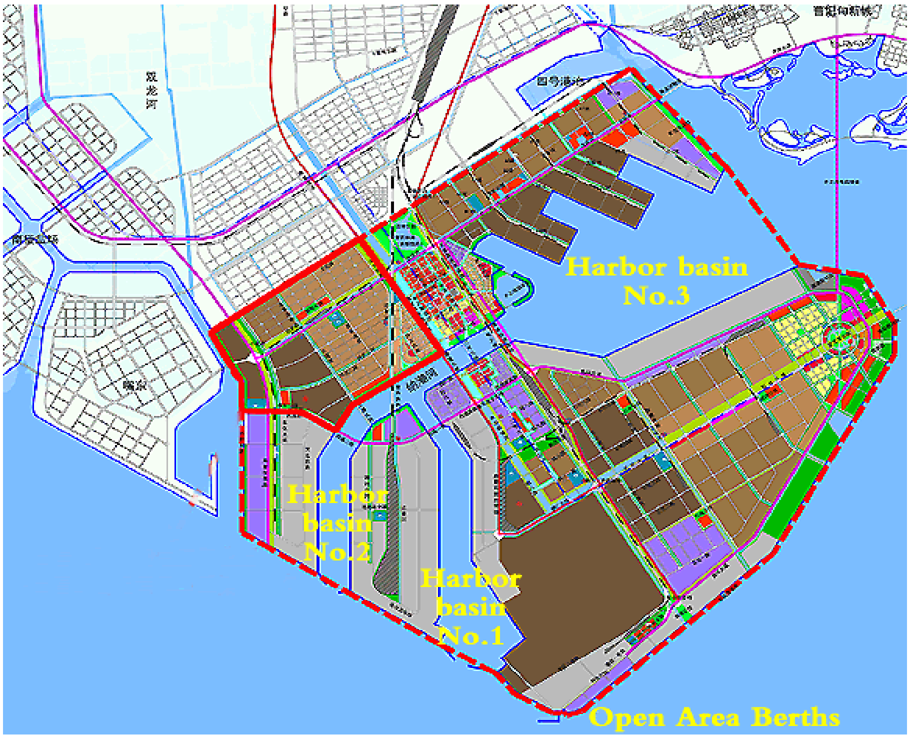
According to the ship management system developed by Zhongchuang Company (2016), there are 150 million tons of imported goods and 100 million tons of exported goods in 2016. There were around 27000 times voyage visa in Caofeidian MSA, among which there are 8900 domestic ships and 1871 international ships. The rest ships are engineering ships and transportation ships which are basically not out of the port and are required vessel visa many times per week. This Chapter mainly analyses the domestic ships and international ships which are conducting freight transport.

As stated in Chapter 1, the majority kind ships in Caofeidian Port is bulk carrier, so the LNG and container ships only accounts for less than 10%. For liquefied petroleum gas ship, from the security considerations, they cannot access to shore power. As for bulk carriers, the route is not fixed with the long ship age. That means ship owners have to pay a lot in shore power transformation and the utilization ratio of shore power is relatively low. However, the long berthing time is advantage. Wang (2016) stated that berthing time of large bulk cargo ship can be up to 48h.

5.1.2 The Distributions of Berths

The geographical coordinates of Port Caofeidian are 38°55' N, 118°30' E. There are 3 harbor basins in Caofeidian Port (See figure 5.1). Harbor Basins No.1 and No.2 are mainly for dry bulk cargo, such as coal, steel and water slag, and the container terminal is in Harbor Basins No.1. Harbor Basin No.3 is transporting liquid chemicals, wood, and mechanical products. The crude oil berths (300,000 tons level), the ore berths (400,000 tons level) and the LNG berth(250,000 tons level) which is 150,000 tons level are constructed in Open area where are in the front of the whole port, which is called Diantou.

Figure 5.1 - The distributions of berths of Port Caofeidian



Source: Image.baidu.com.

5.1.3 Service Condition *of Shore Power*

After communicating with the terminals in Caofeidian Port, only in the tugboat terminal, SDIC terminal, and Tongyong terminal are there shore power equipment for tugs. Except for them, there is no shore power equipment in other terminals. Meantime, all the ships berthing in Caofeidian Port are not equipped with tail gas filtering device.

5.1.4 Main Fuel Supply Companies

In the year 2016, Caofeidian MSA has investigated 3 main marine oil supply companies in Caofeidian port. The questionnaires include oil type, sulfur content, Kinematic viscosity, annual sales, and so on, which can be found in table 5.1.

Table 5.1 – Main marine oil supply companies in Caofeidian Port

Company name	**Oil type**	**Oil number (GB/T17411)**	**Sulfur content (%)**	**Kinematic viscosity （mm^2/s）50℃**	**Annual sales(t)**	**Price (RMB)**
Hongda refueling tanker	Residual fuel oil	RMD 15 (120#)	0.37	108	8000	2980
		RME 25 (180#)	0.42	147	10000	3010
	Distillate fuel oil	DMX (-10#)	0.03	4.2	200	5400
		DMA (0#)	0.03	3.9	600	5550
Zhongran Marine fuel limited company	Residual fuel oil	RME 25 (180#)	0.48	164.81	70000	3050
		RMD 15 (120#)	0.46	98.29	16000	3100
	Distillate fuel oil	DMA (0#)	0.08	5.9	6500	5300
Shuntong marine fuel limited company		DMA (0#)	≤0.2	2.52	500	5400
		DMX (-10#)	≤0.2	2.52	200	5600
		DMC (10# or 20#)	≤0.2	3.49	20	5350

Source: Drawn by myself.

It is obvious that the sulfur content of marine oil which is for sale in Caofeidian Port is less than 0.5%. Meantime, the sales of residual fuel oil (accounting for 92.8%) is much larger than that of distillate fuel oil (7.2%). That means if ships come to

Caofeidian ECZ without using low sulfur oil, the ship owner can find somewhere to buy near Caofeidian Port.

5.2 Economic Benefit Analysis

Theodoros (2012) has analyzed the benefits of shore-to-ship power strategically. He found that from an environmental point of view the benefits are significant, but that financial challenges remain. Due to the difference between oil and electricity, there are significant differences in the economic benefits of the two standard shore-to-ship power system.

5.2.1 Shore Power Using Low-voltage Constant Frequency Standard

Take one bulk carrier terminal for example. The terminal has 4 large bulk carrier berths, and there were 1000 domestic bulk carriers (less than 10,000DWT) berthing in the year 2016. We assume that:

a. The shore power utilization is 0.2;
b. The average berthing time is 15 hours;
c. The ship consumes 900 kWh each time;
d. The current wholesale price of light diesel oil is about 5,500 RMB/t;
e. The fuel consumption of marine generators is 300 g/(kW·h);
f. City for the terminal price is 1.0 RMB / (kW·h). Then we get a simple estimate of the return on investment.

The annual fuel costs is about $1000*0.2*5500*900*300*10^{-6}$=297000RMB

But if the shore power is used, the annual electricity costs ship-owners about 180,000RMB. As a result, 117,000RMB is saved. However, 6 shore power connection points are needed to cover the 4 berths, with 600,000RMB cost for 10 years. So the annual return on investment is 57,000RMB.

5.2.2 Shore Power Using High-voltage Constant Frequency Standard

We still take the bulk carrier terminal as an example. There were 2000 international bulk carriers (more than 20,000DWT) berthing at that terminal in the year of 2016. We also assume that:

a. The shore power utilization is 0.2;

b. The average berthing time is 40 hours;

c. The ship consumes 30,000 kWh each time;

d. The current wholesale price of low sulfur fuel (sulfur content less than 0.5%) is about 3,000 RMB/t;

e. The fuel consumption of marine generators is 300 g/(kW·h);

f. City for the terminal price is 1.0 RMB / (kW·h). Then we get a simple estimate of the return on investment.

The annual fuel costs is about 2000*0.2*3000*30000*300*10^{-6}= 10,800,000 RMB

With the use of shore power, the annual electricity costs ship-owners about 2000*0.2*30000*1=12,000,000RMB. As a result, the annual return on investment is -1.2 million RMB. What's more, the 4 berths need to build four sets of shore points for high voltage frequency conversion, and each shore power point costs about 8 million RMB. The annual depreciation cost is about 3 million 200 thousand RMB with 10 years' depreciation. So the annual loss is about 4 million 400 thousand RMB.

As the Low-voltage constant frequency system does not need frequency conversion, so the construction cost is low. Coupled with the berthing ships use light diesel fuel with high cost, which contribute to a high price of electricity, so the construction and use of Low-voltage constant frequency system is cost-effective. However, High-voltage constant frequency system needs very expensive equipment, and ocean-going vessels can use low-cost heavy oil or low sulfur oil whose electricity generation price is low. In a word, at this stage, high-voltage frequency conversion shore power is not economically viable in Caofeidian Port.

5.3 Environmental Benefit Analysis

5.3.1 Current Study on Air Pollutants Emission Inventory from Commercial Ships

It is no doubt that shore power increases sustainability and reduces the environmental impact of shipping activities at berth (Salomon, 2009). If the shore power were used by all ships, there would be little air pollution caused by ships. So the key points is the evaluation of the total amount of ship air emission in Caofeidian port. Greece and Sweden, Norway and the UK build their own emissions list by dividing the country's fuel sales into domestic shipping supply and international routes supply (Winther, 2008). For example, in Greece, Ernestos Tzannatos (2010) studied the NOx, SO_2, PM and CO_2 emissions from domestic and international routes over the past 25 years (1984-2008) based on fuel sales. The average annual growth rate of Greek ship emissions inventories for the past 25 years was 2.85%, and the total emissions of NOx, SO_2, PM and CO_2 in 2008 were 12.9 million tons. And the calculation of typical Port emissions inventories by load calculation method has been described by Tzannatos and Isakson (2001), etc. They each studied Piraeus Port and Gothenburg Port.

It should be noted that the calculation of ship emissions inventory based on fuel consumption in the process needs a wide range of data, such as ship load, ship sailing distance, fuel consumption, and emission factors. These data are statistical data with a lot of uncertainty factors, making the results of the study differs a lot. In recent years, with the development of AIS (Universal Ship-borne Identification System), a new method has been developed to calculate the ship's emission inventory, that is, the bottom-up dynamic method. The method is to use AIS to collect real-time navigation data such as ship speed, navigation time and location information of ocean-going vessels, calculate the emission list and make use of the ship's position information to make the spatial distribution of ship's emissions.

5.3.2 Calculation of Air Pollutants Emission Inventory

In general, the calculation of the activity level is used to calculate the ship's emissions. It is based on a function relation of the energy of the ship's main engine, ship auxiliary and boiler output (kW*h) multiplied by their corresponding emission factor. In the calculation, the emission factors are measured by g/kW*h, and the corresponding emission factor correction coefficient is also needed. The formula 5.1 is the basic formula of the ship emissions based on the calculation of the power, and formula 5.2 is the formula for calculating output energy of main engine, auxiliary engine and boiler when the ship is in a state of navigation.

$$E_i = Energy \times EF \times FCF \times CF \tag{5.1}$$

Where: E_i is emissions for certain types of pollutants (unit: g);

Energy is the energy consumed by the ship in a running state (unit: Kw*h), and its specific calculation method is given in formula 5.2;

EF is the emission factor of this pollutant, the unit is g/ kW * h;

FCF is the fuel correction factor, a dimensionless unit;

CF is the emission correction factor, also a dimensionless unit.

$$Energy = Load \times Act \tag{5.2}$$

Where：Load is the load power of the ship main engine, the ship auxiliary machine or the boiler in a certain ship running state. For the ship main engine, the load power is multiplied by the maximum continuous rated power (MCR) of the ship's mainframe and the load factor (LF) of the ship in that operating condition;

Act is the time of the ship sailing, the unit is: h;

And: Load = MCR × LF (5.3)

According to the calculation method of the ship emission inventory established above and the ship AIS data, the calculation model of ocean-going ship emission is established by Matlab. Table 5.1 gives the results of every pollutant calculated by Song Yanan (2015).

Table 5.2 - Pollutant emission inventory in Tangshan Port 2013 (t)

Ship type	PM_{10}	$PM_{2.5}$	NOx	SOx	CO	HC	CO_2
Bulk carrier	3136	2872	47399	32791	3650	1512	1893877
Container Ship	2436	2284	38368	25801	3009	1259	1497366
Tanker	606	552	7921	6758	615	260	392914
General cargo ship	771	707	10501	8115	815	347	472481
Other	590	540	8087	6269	625	26	362895
Total	7598	6956	112216	79743	8713	3640	491943

Source: Song Yanan (2015). Study on emission characteristics and emission inventory of inland and offshore ships.

At the same time, the throughput in Caofeidian Port is 60% of which in Tangshan Port Area, and the amount grew nearly 5.9% each year (Tangshan Government Website, 2017).

So, we can estimate the pollutant emission inventory in 2016 in a simple way. For example, the total emission of NOx is $112216*0.6*1.059^2=75521$t. And according to the hypothesis in 5.2 section that the shore power utilization is 0.2, we can estimate the environmental benefit shown in Table 5.2.

Table 5.3 - Pollutant emission inventory in Caofeidian Port 2016 (t)

Ship type	PM_{10}	$PM_{2.5}$	NOx	SOx	CO	HC	CO_2
Total emission	5113	4681	75521	53667	5863	2449	331077
Environmental benefit	1023	936	15104	10733	1173	490	66215

Source: Drawn by myself.

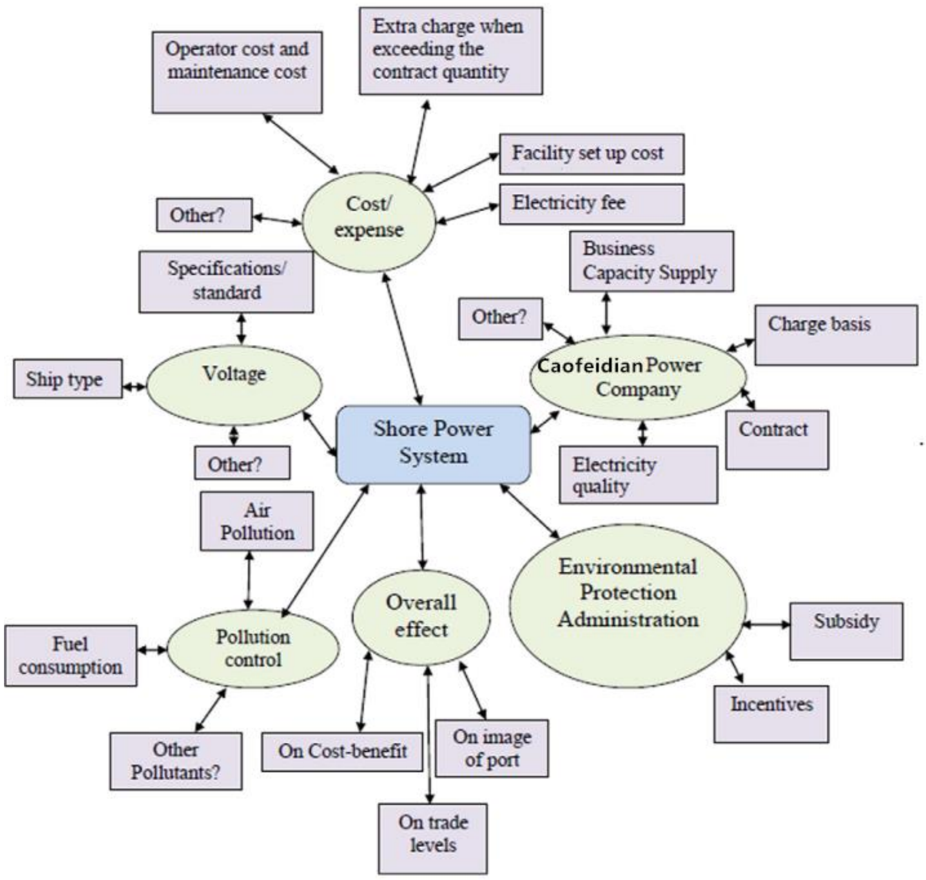
5.4 Factors Affecting the Use of Shore Power in Caofeidian Port

First of all, the construction and operation of shore power equipment facilities experience still need to be further accumulated. At present, China has issued the relevant norms of shore power facilities construction, but the acceptance specification has not yet been introduced. After the completion of the project in Caofeidian Port, problems may often occur in the connection of the real ship.

Secondly, cruise terminals, passenger terminals, RO-RO terminals and container terminals are the best places priority to promote the use of shore power technology. However, the main ship type in Caofeidian Port is bulk carriers. From the economic aspect, only the domestic liners are suitable for using shore power. What's more, the Hebei Port Group Co does not want to invest too much on the reformation of wharf power system and the construction of shore power equipment with very low profit.

Finally, the use of shore power effectively reduces the emissions of air pollutants in the port area, thus protecting the environment in the port area and its surrounding areas and facilitating the environmental protection objectives of local governments. It is clearly unfair that the cost of using shore power is borne by the port enterprises alone. The tax incentives, law enforcement of Tangshan Government will play an important role in the implementation of shore power technology. The use of shore power technology is a complex topic in Caofeidian Port, and other context are shown in a spider diagram (see figure 5.1).

Figure 5.2 - Context of shore power in Caofeidian Port



Source: Tseng, P. H., & Pilcher, N. (2015). A study of the potential of shore power for the port of Kaohsiung, Taiwan: to introduce or not to introduce?

5.5 Other Emission Reduction Technology

Except for the use of low sulfur oil and shore power technology, there are also some other air emission reduction measures for ships.

5.5.1 Using LNG Fuel

LNG fuel has the characteristics of clean and high calorific value. Compared with other fuel with the same calorific value, CO_2 emission can be reduced by 15% ~ 20%, NOx emission of 80% ~ 90%, and there is almost no SOx emission. LNG fuel system does not need post-processing to meet the most stringent emission standards, so it is a widely recommended way to reduce emissions.

The use of LNG as a fuel mainly involves the modification of the engine, gas tank and gas supply system. After years of development, the core equipment of LNG fuel power ship - LNG engine (pure gas and dual fuel engine) has matured. The world's diesel giant Luo Luo, Wärtsilä and MAN have developed the corresponding products and put into use in bulk, so there is no technical problem with the use of LNG fuel in ships.

However, because of the security requirements of LNG, the cost of refitting or building is relatively high. Also, consideration should be given to the cost of LNG fuel supply, the additional cost due to the reduction of freight, etc. Therefore, it is suitable for ships sailing in ECA area for most of the time and LNG price is lower

5.5.2 Tail Gas Post - treatment Technology

SCR technology and exhaust gas washing technology are mainly adopted in tail gas post - treatment technology (Cobb, et al, 2010). Among them, SCR technology is used to reduce NOx, while exhaust gas washing technology is used to reduce SOx and PM. At present, the SCR technology of medium high speed diesel engine is very mature, and the SCR technology of low-speed machine has also made great progress, which began to load a large number of ships. The price of tail gas post – treatment equipment varies a lot due to the different type of ships. But only for the modification expenses of the same type of ships, replacement of low sulfur fuel costs the lowest, followed by the installation of tail gas post - treatment equipment, and LNG fuel conversion costs highest.

The specific way of ship air emission control in Caofeidian Port needs to be determined in light of the specific circumstances of the ship. According to the British Lloyd's survey, the ship-owners are liable to use low sulfur in short term (around 5 years), install exhaust gas washing device in mid-term (5 to 10 years), and use LNG fuel in long term (over 10 years). However, the majority of ships in Caofeidian Port are bulk carriers with long ship age and bad conditions, and domestic ECA standard is relatively low compared with international ones, so they prefer to use low sulfur oil for maybe more than 10 years. As a result, the shore power technology is most likely to be promoted first compared with other new technologies.

Chapter 6 Conclusions

Under the Bohai rim ECZ requirements, the use of low sulfur fuel is the major treatment methods. But the maritime supervision and sampling test will bring heavy work tasks to Caofeidian MSA. The professional skills of administrative law enforcement officers are uneven, added with unfamiliar sampling techniques, long testing and administrative penalty time. Even if a ship is not detained, it is likely that the ship will be delayed. So, portable sampling devices and simple penalty procedures are needed of Caofeidian MSA.

However, although the shore power has proved to be a good choice in many international and domestic ports, it will still take a long time to be fully adopted in Caofeidian Port. The provision and use of shore power may result in economic losses for shipping companies and port companies, many of which are reluctant to use shore power. It seems that tax incentives and government subsidies are best method to help shipping companies and port companies to reform or build their shore power facilities. So Caofeidian MSA and other environmental organizations should try their best to give the local government some advice and solutions.

For Tangshan Government, a detailed cost-effective benefit analyses should be carried out by professional organizations. Equipment costs, electricity cost, labor cost, maintenance cost and other possible costs should be taken into consideration. For shipping companies and port companies, they can first try liner as examples to use shore power.

Under the current situation, the most effective way to deal with air pollution control in Caofeidian Port is the use of low sulfur fuel. Caofeidian MSA has increased sampling frequency and thoroughly implemented laws and regulations of Ministry of Transport and IMO. Its supervisory experience will be helpful to other ECZs in China.

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