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Seagoing ship emissions at Chinese coastal port cities and countermeasures analysis : sample of Shanghai Port

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SEAGOING SHIP EMISSIONS AT CHINESE COASTAL PORT CITIES AND COUNTERMEASURES ANALYSIS -SAMPLE OF SHANGHAI PORT

By

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DECLARATION

I certify that all the material in this research paper that are 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.

(Signature): ....

(Date): ....

Supervised by: Dr. Wu Wanqing
Professor of Dalian Maritime University

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ABSTRACT

Title of Dissertation: **Seagoing Ship Emissions at Chinese Coastal Port Cities and Countermeasures Analysis –Sample of Shanghai Port**

Degree: **MSc**

At present, the situation of atmospheric pollution in China is extremely severe. The haze has become a frequent phenomenon. Under the siege of haze, cities in China launch campaigns on controlling motor vehicles, industrial factories, thermal power plants and other traditional sources of pollution. However, a governing blind area is ignored by coastal port cities of China – the pollution from vessels which has become an important source of urban air pollution.

The cargo throughput of Shanghai Port in 2013 was 776 million tons, rising by 5.5%; container throughput completed 33.62 million TEU, increased by 3.3% from the previous year; the international ships were exceeding 41,500. The Shanghai Port has had the largest port throughput in China for many years, as well as the largest in the world. Meanwhile, the berths of Shanghai Port spread along the coastline. Ships even run into the city center area along the Huangpu River. Moreover, as the Chinese largest city, Shanghai has a population of 24.15 million people; the average population density is up to 9,589 people per square kilometers, 16,828 people per square kilometers in the city center. It is the most densely populated city in China. Therefore, it is essential to take Shanghai as an example to study the marine gas emissions of coastal port cities in China,

In the paper, the author chooses the main pollutants -NO_x, SO_2, PM_{10} and $PM_{2.5}$ emitted by seagoing ships in Shanghai Port as research subject, using the method based on ship engine power to calculate the total gas emissions of the seagoing ships. The research shows that the main marine gas emissions of Shanghai Port in 2013 were as follows: SO_2, $3.64*10^4$t; NO_x, $6.18*10^4$t; PM_{10}, $0.49*10^4$t; $PM_{2.5}$, $0.45*10^4$t.

Meanwhile, the relevant study indicates that the land-sea breeze will transport ship emissions hundreds of kilometers to inland apparently. Even though the marine gas emissions mainly occur in the sea, they can also affect the air quality, human health and ecological environment of coastal and inland areas**.**

Shanghai Port is an international port with the largest cargo throughput and container throughput in the world. Its control measures on marine gas emissions are very limited -almost the minimum standard. It indicates in the paper that setting up the ECA is a long term solution for Shanghai Port to control the marine gas emissions.

KEY WORDS: China coastal port, seagoing ship, marine emission, annual emissions, Shanghai, measures

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LIST OF ABBREVIATIONS

CMEP	China's Ministry of Environmental Protection
PM	Particulate Matter
NRDC	Natural Resources Defense Council
HKUST	Hong Kong University of Science and Technology
HKEPD	Hong Kong Environmental Protection Department
AIS	Automatic Identification System
PATH	The Pollutants in the Atmosphere and Their Transport over Hong Kong mode
USEPA	U.S. Environmental Protection Agency
SCG	Starcrest Consulting Group
CARB	California Air Resources Board
SO_x	Sulfur Oxides
NO_x	Nitrogen Oxide
NMVOC	The Non-methane Volatile Organic Compounds
CO_2	Carbon Dioxide
MSA	Maritime Safety Administration
IMO	International Maritime Organization
EF	Emission Factor
DWT	The Deadweight Tonnage
MARPOL Convention	The International Convention of the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 relating thereto
MEPC	Marine Environment Protection Committee
ECA	Emission Control Area
SCR	Selective Catalytic Reduction
EGR	Exhausted Gas Recirculation

CHAPTER 1

INTRODUCTION

1.1 Background and significance of research

At present, the situation of atmospheric pollution in China is extremely severe, the haze has been seen frequently. In June of 2014, it was reported in the China environmental conditions gazette of 2013 issued by China's Ministry of Environmental Protection(CMEP) that only 4.1% of 74 cities in the first phase of the implementation of the new national monitoring standard on air quality proportion was up to standard, in which the concentration of nitrogen oxygen content (NOx) and particulate matter (PM) exceeds standard seriously, especially in China's coastal regions such as the Yangtze River Delta, the Pearl River Delta, and Beijing-Tianjin-Hebei area(CMEP, 2014).

Under the siege of haze, cities in China launch campaigns on controlling motor vehicles, industrial factories, thermal power plants and other traditional sources of pollution. However, a governance blind area is ignored by coastal port cities of China – the pollution from vessels, which has become an important source of urban air pollution.

On July 3, 2014, the Natural Resources Defense Council (NRDC) in Beijing issued a white paper on the pollution prevention of ships and ports. The data showed that the daily emissions of $PM_{2.5}$ of a large container ship using fuel oil with 3.5% sulfur content, running at 70% of the maximum power load, is equivalent to the sum of 500000 van day delivery(Liu, 2014).

According to the data of Hong Kong in 2012, ship emissions was the largest source of PM10, nitrogen oxide and sulfur dioxide in the whole city, which took over thirty percent of the former two pollutants and 50% of sulfur dioxide (Gao,2014). NOx, COx, SOx and particulate matter (PM), and other gas pollutants are seriously harmful to the human health and the environment. The SO_2 emitted by ships leads to the development of acid rain, which is not only harmful to human health, but also damaging the environment and ecological system. And the fuel with high sulfur content used by ships is the leading cause of the emission of $PM_{2.5}$. $PM_{2.5}$ has a strong penetrating power, which can go through alveolus walls after being inhaled, and can induce mutations in lung organisms even cancer. Therefore, it is a major cause leading to cardiovascular and respiratory diseases. America has assessed the risk of $PM_{2.5}$ emitted by marine diesel engine, it is shown in the research report that every increase of 10 micrograms per cubic meter in the air results in the probability of human cancer increased by 1% (Zhao, 2013).

Meanwhile, nitrogen dioxide of NO_x emitted by ships is an irritant to respiratory tract, which could damage respiratory tract seriously. Besides, the nitrogen oxides and hydrocarbons will have a complicated photochemical reaction under ultraviolet irradiation of strong sunlight, and forms the photochemical smog, which is one of the main causes of the disease such as bronchitis, pulmonary tuberculosis and the coronary heart disease (Peng, 2014).

Research shows that each year the death number of people with heart disease and lung cancer affected by marine polluted gases around the world is up to 60,000 people. While in East Asia (including China), the death cases of heart and lung cancer caused by ship emissions is estimated over 15,000 (Corbett, Winebrake, Green, Kasibhatla & Eyring, 2007). It was pointed out by the Hong Kong University in 2008, that the SO_2, NO_2 and PM_{10} emitted by commercial ships contributed to the premature deaths of 1,202 people in Hong Kong alone, while in the Pearl River Delta region (including Hong Kong and Macau), premature death toll was more than 1600 people. At the same time, additional hospitalization cases for cardiovascular diseases and respiratory diseases caused by ship emissions in the Pearl River Delta region were 8262 and 9702 respectively (Lai, 2013).

Based on the simulation model, the land-sea breeze will transport ship emissions hundreds of kilometers to inland apparently. Even though the marine gas emissions mainly occur in the sea, they can also affect the air quality, human health and ecological environment of coastal and inland areas (Eyring, 2010). The worse is that China's coastal port cities are densely populated areas, so the public health risk and environmental impact caused by air pollution of ships and ports are more serious than the other countries and regions.

The cargo throughput of Shanghai Port in 2013 was 776 million tons, rising by 5.5%; Container throughput completed 33.617 million TEU, increased by 3.3% from the previous year; the international ships was exceeding 41,500 (see chapter 2 section2.3). The Shanghai Port has had the largest port throughput in China for many years, also the largest in the world. Meanwhile, the berths of Shanghai Port spread along the coastline, ships even run into the city center area along the Huangpu River. Moreover, as China's largest city, Shanghai has a population of 24.15 million; the average population density is up to 9,589 people per square kilometers, 16,828 people per square kilometers in the city center, which is the most densely populated city in China (Shanghai Statistics Bureau, 2014). Therefore, it is essential to take Shanghai as an example to study the marine gas emissions of coastal port cities of China.

Pollutant emissions from ships operating include nitrogen oxides, sulfur dioxide, carbon monoxide, carbon dioxide, hydrocarbons, inhalable particle(NO_x, SO_2, CO, CO_2, HC, PM), etc. Considering the pollutants damaging the environment and human health are mainly concentrated in NO_x, SO_2 and PM (Liu, 2014), in this article I will mainly study the emissions of SO_2, NO_x and PM from operating ship in Shanghai to establish its overall emissions inventory, at the same time, analyze the dangers of ship emissions, and furthermore analyze the appropriate economic and feasible countermeasures.

1.2 Current research status on the marine gas emissions

1.2.1 China research status

There are more research work on the major air pollution sources in China such as power plants, industry and road mobile sources, but less on the research of ship emissions, let alone the study of ship emission source inventory. There is a big gap with foreign research. Currently, research conducted mostly focused on the characteristics of ship pollution and exhaust gas, mechanism of exhaust gas pollution, the emission control technology, detection technology of nitrogen oxides, etc, which are stuck in the qualitative analysis of ships emission, quantitative analysis of case study is relatively small. The establishment of regional ship emission source inventory is still very weak in both method and case study, and obviously lagging behind the foreign research.

At present, quantitative research on marine gas emissions has just started, only a few coastal cities developed a preliminary Marine Vessels Emission Inventory of local port with the reference to foreign research results. For example, Fu Qingyan and others, taking 1998 as a benchmark, calculated the NOx emissions and share rate of ships in Shanghai, but the authors did not estimate the emissions of other gases pollutants in the air (Fu, Chen & Qian, 2001). Later, Yang and others, developed a resolution of 1km×lkm grid of ship emissions inventory of Shanghai in 2003 based on the ship engine power, which greatly improved the precision of ship's inventory, and analyzed the spatial distribution characteristics of ship emissions (Yang, Kwan, & Lu, 2007), however its emission factors used in the calculation method adopted foreign data directly which was collected 10 years ago, research data and result is obsolete. Fu Lixin and others adopted the method based on fuel consumption, estimated the emissions amount of CO, HC, NOx and PM from inland river ships of China in 2002 (Fu & Cheng, 2005). Selecting Tianjin port as the research object, Jin Taosheng carried out a field study on transport ships within the port area, and then calculated the emission amount of ships in Tianjin port in 2006 using the emission factor method based on fuel consumption, pollutant types involved were NO_x, HC, CO and PM_{10}.They also predicted the ship emissions by 2010 and by 2020, which provided important basis for the local government to set relevant laws and regulations to control ship pollution (Jin, Yin & Xu, 2009). It should be pointed out that the calculation method of fuel consumption is a recognized one to build the Marine Vessels Emission Inventory, but this method has innate defects for it can only be used to estimate research other than research requiring accurate results. Moreover, the atmospheric emission source inventory of Qingdao was established from bottom to top by Liu Jing with port as a basic unit, and by using the composite source of atmospheric diffusion model based on geographic information system of Swedish International Development Cooperation Agency, the results showed that the ship emissions of SO_2 and NO_x to local atmosphere in Qingdao contributed 8.0% and 12.9% respectively to the atmospheric pollutants concentration (Liu, Wang & Song, 2011). However, they mainly used the emissions calculating software developed with the help of the Swedish International Development

Cooperation Agency, the calculation process is not open and transparent, the study can not be replicated, which impose the limitations and obstacles to the independent research on the technology to control air pollution from ships in China.

Study of marine vessels emission inventory in the Pearl River Delta region is relatively less, too. On the basis of database of the detailed shipping information and air pollutants in Hong Kong, Li Zhiheng established a parameter estimation method of ship pollutants emission inventory and estimated the ship pollutants inventory of Shenzhen in 2003. It was shown that ship emissions of SO_2 accounts for 58.62% of the mobile source of SO_2 emissions in the whole city of Shenzhen (Li & He, 2011). While a deep inspection of the calculation method reveals that it is only a simple linear regression through the analogy to the cargo throughput of the two ports and then gets the ship pollution emissions, which lacked a rigorous earnest study attitude. According to different characteristics of emissions of inland river ship and ocean ship, Zhang Lijun set up ship emissions inventory of the Pearl River Delta region by using the method based on fuel consumption and the method based on ship's engine power respectively, who found that the ship emission source is the largest contributing factor of non-road mobile source of SO_2, NO_x, CO and PM_{10} emissions (Zhang, 2010). Furthermore, Lu and others calculated ship emissions of the Pearl River Delta region between 2000 and 2009, and analyzed the changing trend of contribution rate, from the results, the contribution rates of ship emissions of SO2 and NOx in the Pearl River Delta showed a rising trend year by year (Lu, 2013).

In particular, many significant researches of ship emissions have been done by Hong Kong Environmental Protection Agency in recent years together with several local well-known universities, such as the Hong Kong University Science and Technology. Civic Exchange is a non-profit public policy research organization. In 2005, Civic Exchange was firstly interested in shipping and port related emissions (Loh, 2006), and since 2007, it has held a series of "green port" seminars for the related groups by gathering the research scholars, ship owners, government officials and fuel suppliers and others to carry on the discussion to reduce the emissions of shipping and ports pollutants. The goal is to promote the parties voluntarily participating and fostering local vessels to reduce pollutants, then explore the possibility to establish a specific low-sulphur-emissions control area with the government of the Hong Kong and

Guangdong province in waters of Hong Kong and the Pearl River Delta. Since 2005, Civic Exchange has created a platform for workers in different fields to share experience in reducing ship emissions, develop common reduction policy and promote control of ship emissions to promote Hong Kong and the Pearl River Delta region of ship emissions to publish research report, put forward a series of measures to reduce ship emissions reduction, leading to a two-year voluntary agreement on ship emissions reduction in 2011 - Fair Winds Charter (Yau & Lee, 2012), at the same time, in the following two years from January 1st 2011, oceangoing ships switch to use cleaner fuels when dock in Hong Kong, which is the world's first voluntary unsubsidized fuel conversion measures at berth. In addition, under the commission of the Hong Kong Environmental Protection Department, Hong Kong University of Science and Technology (HKUST) compiled a set of Marine Vessels Emission Inventory with 2007 as the base year covering the entire Hong Kong waters. In the process of making the inventory, ship automatic identification system (AIS) was firstly used to obtain high resolution ship activity information, meanwhile, the estimation method based on ship's engine power was used to get a grid Vessels Emission Inventory with high precision. For further assessment of the impact of ship emissions on air quality near the harbor, Simon and others from HKUST chose SO2 of ship emissions as the research subject, based on the Pollutants in the Atmosphere and their Transport over Hong Kong mode (PATH) established by Hong Kong Environmental Protection Department, they selected two weeks in July 2007 as the simulation time for simulation analysis, and compared with monitoring data of the SO_2 concentration over the same period. The results showed that in a specific location and weather conditions, ship emissions of SO_2 do have a certain influence on local air quality (Hong Kong Environmental Protection Department, 2012).

To sum up, domestic ship emissions research is generally still in its initial stage. Although some coastal cities have established a local port emission inventory, the estimate method adopted and emission factor mostly from foreign research results, combining with the data shortage of local ship activities, which couses the existent ship emissions inventory is a big uncertainty and unable to truly reflect the level of regional ship emissions of pollution. Besides, the analysis of these port cities does not focus on the analysis of countermeasures after getting the ship emissions inventory separating impact from countermeasure analysis artificially. And other studies of ship emissions control either focus on individual technical analysis or pay attention to one pollution source, neither make a whole analysis nor carry out an adaptability analysis on the ports.

1.2.2 Research status of other countries

By contrast, other countries paid more attention to air pollution from ships, the relevant research also started earlier. Among them, the United States and Britain have long study history of ports and ships emissions, and have done many important basic work, such as the establishment of ship emissions estimation method, the test in emission factors and research on activity data, establish and continuously update the ship emission source inventory in the local port. Some research scholars from other countries also study on the different levels of ship emissions according to their different research interests and goals.

For the United States, as early as in 1991, the U.S. Environmental Protection Agency (EPA) conducted a wide range of research on Engine power and emission factors of non-road mobile source, average Emission factors and activity data of ship emissions were acquired in different driving mode (namely full speed, cruising and deceleration) in accordance with the engine power of the ships and fishing boats (The United States Environmental Protection Agency [USEPA], 1991). Then, in 2000, the EPA has issued an analysis research report on commercial vessels emissions and fuel consumption data, it provides detailed information about the ship's classification, engine power distribution, activity pattern classification and emission factors estimation, etc, which lays an important foundation for ship emissions estimation of other countries and regions in the world (USEPA, 2000). Of all the ports in the United States, the ports of California have the most serious air pollution, especially the Los Angeles area. Relevant research has shown that the emissions contribution rate to SO_2 and NO_x of oceangoing ships for the Los Angeles area were 36% and 86% respectively. While in Santa Barbara (Pacific coast city in California), seagoing ships contributed one-third of the emissions in the region, almost equal to the sum of all land sources (Starcrest Consulting Group [SCG], 2009), thus the Environmental Protection Agency and the Los Angeles local environmental regulatory authorities all take seriously of ship emissions in the area. For a comprehensive understanding of ship Emissions in the ports of Los Angeles, the Starcrest Consulting Group of the United States has developed a complete set of the ports of Los Angeles inventory air emissions, and calculated the amount of air emissions from oceangoing ships, ports ships, cargo handling equipment, railway locomotive, and heavy truck and other sources in the ports of Los Angeles Port in 2008, covering six normal atmospheric pollutants (namely inhaled particulate matter, diesel particulate matter, hydrocarbons and carbon monoxide, nitrogen oxides, sulfur oxide) and three kinds of greenhouse gases (carbon dioxide, methane and nitrous oxide). Then they updated the Port of Los Angeles Emissions Inventory of 2010 (SCG, 2011). In 2009, the EPA also entrusted the ICF company to write a summary report on port related mobile source emission inventory method (ICF International,2009), introduced the detailed emissions estimation method and the selection of related estimation parameters of seagoing ships, ports ships, cargo handling equipment, railway locomotive and heavy transport vehicles emission source respectively. The three inventory research reports provided a detailed method to estimate emissions according to ship engine power and activity time, compared with the past estimation method based on fuel consumption, this method can effectively reduce the uncertainty of ship inventory and provides a new direction for the perfection of the shipping inventory. In addition, in order to obtain the local ship activity level data to the maximum, the California Air Resources Board (CARB) has launched a research on oceangoing ships, which surveyed the characteristic information and activity level data of all oceangoing ships arrived in port of California in 2006, such as load level, distribution of engine power, fuel usage, the running speed under different driving mode, etc. The acquisition of these information effectively fills the vacancy on characteristics information of ships and data on activity levels in the past, providing a possibility to further enhance the accuracy and reliability of the ship inventory (CARB, 2007).

In addition to the United States, Britain did more research on ship emissions. As early as in 2002, in order to have a better understanding of the ship's emission pollution, Entec company from British made a report of quantitative study on pollutants emissions from port ships of EU countries, which summarized the estimation method of ship emissions, and list the main source of ship characteristics data, has an important reference value (Entec,2002). Also in 2002, based on 2002 ship emissions inventory, Dore and other researchers used Lagrange atmospheric transmission statistical model to simulate the settlement of sulfur and nitrogen deposition in British area, on the basis, they set up a future emissions scenarios to assess the influence of ship emissions of SO_2 to the sulfur deposition in Britain in 2020. It is showed that if ship emissions rise at an annual rate of 2.5%, the contribution rate of sulfur deposition for the British increased from 9% in 2002 to 28% in 2020, suggesting that the impact of ship emissions on regional air quality cannot be ignored (Dore, Vieno & Tang, 2007). In 2010, using ship automatic identification system and the estimation method based on ship's engine power, Entec companies set up the ship emission inventory of UK waters in 2007. Pollutants covered by the inventory included sulfur oxides (SO_x), nitrogen oxide (NO_x), the non-methane volatile organic compounds (NMVOC), particulate matter (PM_{10}), fine particulate matter ($PM_{2.5}$) and carbon dioxide (CO_2), the ship types including ocean-going vessels, inland river ships, local ship and transport ship in transit, etc. The inventory considered the emissions of ship's main engine, auxiliary engine and the auxiliary boiler under different driving mode in a comprehensive way. On this basis, the Entec company took full advantage of ship activity history and the changing trends of data on shipping related activity level, established the historical inventory of ship emission source of British waters between 1990 and 2009, and predicted the port ship emissions by 2020. Besides, Entec company also used the qualitative method to analyze all kinds of ship activity level data and uncertain sources of emission factors, and made an overall evaluation on them (Entec, 2010).

In addition, some other scholars abroad with different research interests and goals made different levels of study on the port ships emissions. For example, Kesgin and Vardar studied the exhaust gas emissions from ships in Turkish straits (Kesgin & Vardar, 2001). Winther developed the national emission inventory for navigation in Denmark (Winther, 2008). Corbett made a global assessment on the mortality from ship emissions and port nearby residents (Corbett, Windebrake & Green, 2007). The Chamber of Shipping of British Columbia published a study report in 2007 on emissions inventory of oceangoing ships, which comprehensively analyzed of impact of oceangoing vessel emissions on local air quality and public health (The Chamber of Shipping of British Columbia, 2007).

In conclusion, the research work on ship emissions in foreign countries carried out earlier, and a mature progress has been made. Particularly in the development of ship emissions inventory, both America and Britain have already set up a complete development method of developing inventory, and have accumulated rich experience on the activity research data collection and emission factor test, also established a relatively perfect database of shipping activity information and emission factor, which provide a good technical and theoretical support for ship emissions research of Shanghai Port. Given the large differences in ship type, activity and fuel characteristics in between foreign ports and the Shanghai Port, when studying on Shanghai ship emissions, the inventory developing method established abroad can be widely learn from, on the other hand, the local actual situation also should be paid attention to, adjusting the emission factors correspondingly to make ship emission inventory reflect the actual vessel pollution state of Shanghai better. In addition, more attention should be paid to the research on the applicability of the Shanghai Port in the control countermeasure analysis of vessel pollution emissions.

1.3 Research target and content

1.3.1 The research target

This paper analyzes the continuous and vigorous development state and characteristics of port shipping in Shanghai. On this basis, annual gas emissions of ships in Shanghai Port are analyzed and calculated from 2010 to 2013. According to the calculated annual emissions, analysis and research on the share rate are carried out; the characteristics analysis of sea-going ships gas emissions are highlighted; further, the dangers of emissions of ships are analyzed in the paper. On the basis of the present limited control measures of vessel emissions in Shanghai, through analysis and study on practice and experience of other domestic and international ports, this paper tries to find out the further suitable control measures for Shanghai.

1.3.2 The research content

In this paper, the research mainly includes the following parts:

(1) Through literature review and field investigation by visiting Shanghai Maritime Safety Administration (one of administrative departments of Shanghai Port), the overall analysis of Shanghai Port is carried out, the actual context of Shanghai Port is shown as far as possible. Collect and analyze the ship traffic data from 2010 to 2013 of Shanghai Port, provide basic data for the calculation of ship gas emissions in the next

step.

(2) Analyze the control requirements of sea-going ships gas emissions in the world, China and Shanghai. Based on the annual traffic data of Shanghai Port, after selecting an appropriate calculation method, the annual ships gas emissions are calculated from 2010 to 2013, characteristics such as the share rate and the pollution category are analyzed according to the data. At the same time, a thorough analysis and research on the hazard of ship gas pollution are carried out.

(3) On the basis of detailed analysis of the harmfulness of marine gas in Shanghai Port, the priority of implementation of control measures in Shanghai Port is put forward. But the control measures of marine gas emissions in Shanghai Port are formulated on the basis of existing measures and the experience of other ports.

1.4 Research method and technical route

Through the method of literature research, comprehensive comparison, field investigation and data analysis, data and information are collected and induced. In particular, activity level data of ships in Shanghai Port are collected through the practical investigation and research. Through literature study and comprehensive reference to the Chinese and international ship emissions research, a calculation method of gas emissions suitable for ships in Shanghai Port is analyzed and chose, and on the basis of the actual activity level of ships in Shanghai Port, reasonable levels of the key factors in the calculation formula are put forward, so that the amount of annual emissions of marine gas in Shanghai is developed. After analysis of the characteristics of the emissions data and the comprehensive comparison of control measures and experience between domestic and international ports, the control measures of sea-going ships gas emissions which are suitable for the development and implementation in Shanghai Port are put forward.

In this paper, we study the technical route as shown in Figure 1.1:

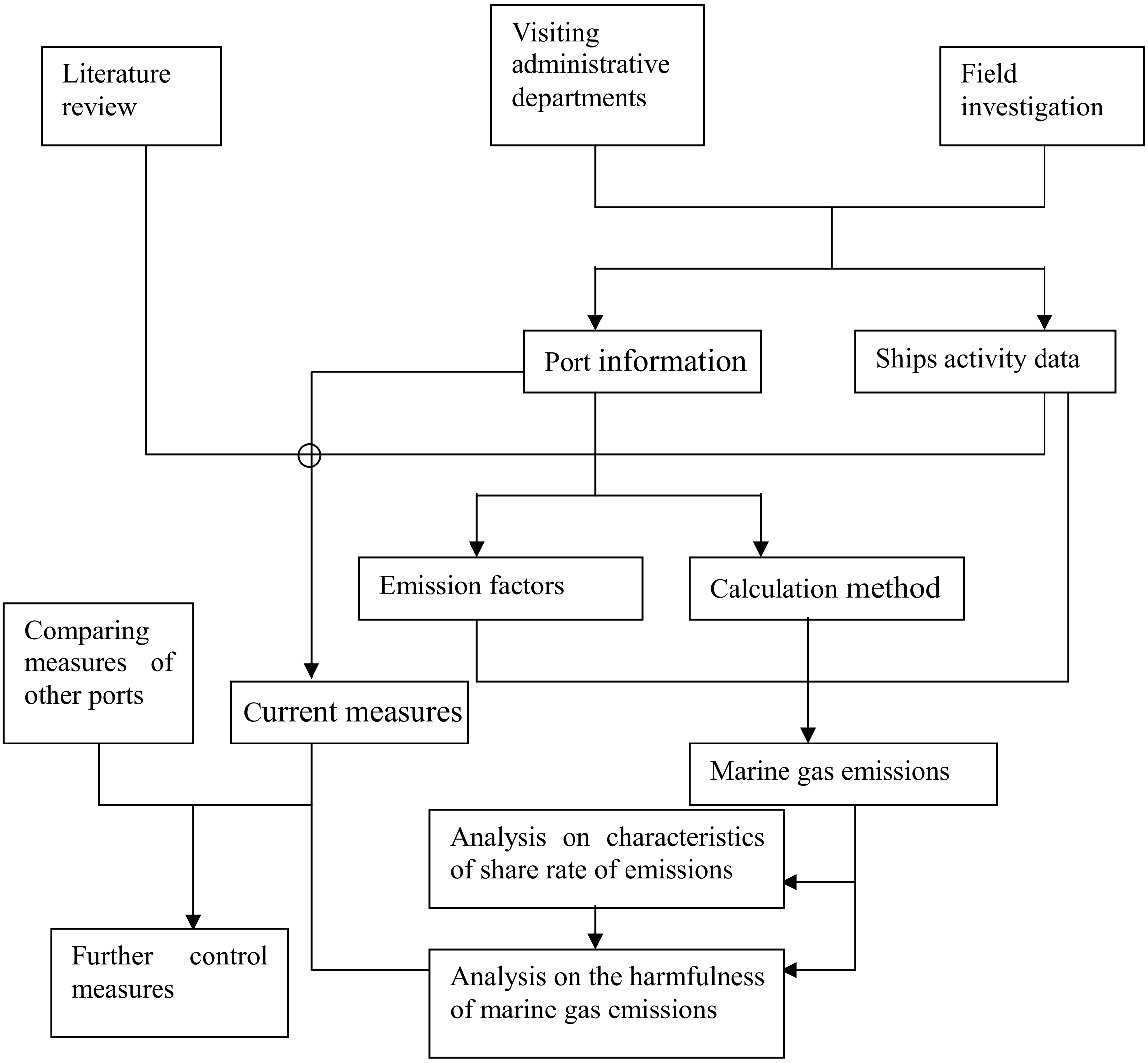

Figure 1.1- The technical route of the paper

Source: Author, compiled on May 9, 2015.

1.5 The structure of the paper

With commercial passenger and cargo transport ships as the main research subjects, this paper analyzes the main polluted gas emissions of sea-going ships in Shanghai Port, discusses the characteristics of emissions share rate and harmfulness of different types of ships, and tries to establish effective control measures in Shanghai Port. The paper structure is as follows:

The first chapter puts forward the research background of the paper, analyzes the significance of the research on ship gas emissions in Shanghai, refines and studies the research achievements of domestic and foreign scholars on vessel pollution emissions, analyzes their insufficiency, and draws lessons from them. The research goal and research content of this paper are established and analyzed. The research methods are summarized and the technology route of this paper is established.

In the second chapter, through visiting Shanghai MSA for field research and information gathering, the literature and data are analyzed. Generally the Shanghai Port is introduced; the geographical features of Shanghai Port in the area of the Shanghai city and its waters are preliminarily analyzed; characteristics of Shanghai Port and the ships at berth are studied. The throughput and ships traffic data of Shanghai Port from 2010 to 2013 are collected. And the data characteristics of all kinds of ships entering and leaving Shanghai Port are analyzed.

The third chapter puts forward research scope of ship emissions in this paper, specifically, focusing on the studied type of ships and emitted gases. And then the actual characteristics of Shanghai Port and the characteristics of different calculation methods are considered comprehensively; the scientific calculation method of the seagoing ship pollution emissions are analyzed and put forward. With the input of the data got in the second chapter, and then the total annual pollution emissions of ships in Shanghai Port are calculated. Through the analysis of the share rate, the emissions characteristics of polluting gases of all kinds of ships are studied. Finally, the dangers of polluting gases emitted from sea-going ships are researched and analyzed.

The current compulsory requirements of marine gas emission of ships in and out of Shanghai Port are analyzed in the fourth chapter, as well as the technical and other kinds of measures set up and applied to the Shanghai Port. Measures and experiences on controlling vessel pollution emissions of other ports are selected and analyzed; then further control measures accessible to the Shanghai Port are put forward.

There come the research results of this paper in the fifth chapter: Container ship pollution emissions are the main source of ships emissions in Shanghai Port; Now the control measures to ship pollution emissions in Shanghai Port are very limited, and there are still many effective measures that can be used.

CHAPTER 2

ANALYSIS OF THE SHANGHAI PORT AND STUDY ON TRAFFIC FLOW OF COMMERCIAL SHIPS

Note: *Except for a few data references, all data in this paper are collected from Shanghai Maritime Safety Administration (Shanghai MSA, one of administrative departments of Shanghai Port and commercial transport ships in navigable waters), especially the ship traffic flow data -the annual statistics is done by Shanghai MSA and submitted to the China National Statistics Bureau. So the data in this chapter are of absolute authenticity and credibility. But making notes here also is to explain the APP format in this chapter.*

This chapter provides the studies for Shanghai Port ship gas emissions, mainly on characteristics analysis of traffic flow in Shanghai Port, docks and ships. By visiting the Shanghai MSA for field research and information gathering, then the literature and data are analyzed, aiming at an analysis of the geographical characteristics of Shanghai Port in the area of Shanghai city and its waters. Furthermore, the characteristics of Shanghai Port and ships at berth are studied. Through collecting data on port handling capacity and ships traffic flow in Shanghai Port from 2010 to 2013, the paper summarizes the data characteristics of all kinds of ships in and out of Shanghai Port and provides basic data for calculating the ship gas emission.

2.1 General introduction of the Shanghai Port

Shanghai Port is located in 31 ° 14 '00 "N, 121 ° 29' 02.95" E (the site of mast of clock tower in Shanghai Customs building), the central part of China's coastline of mainland, and the southern bank of the Yangtze River estuary. Shanghai faces the sea and rivers, and its hinterland covers the Yangtze River Delta and all the Yangtze River basin. With its rich resources, developed economy, dense population, convenient land and water transportation, Shanghai Port enjoys an exceptionally geographical environment and marine conditions.

Shanghai Port has a wide economic hinterland. The city of Shanghai where the port located in is one of the largest centers of economy, science and technology, trade, finance, shipping and culture in China. Shanghai has a solid industrial foundation and a complete range of light and heavy industrial systems, such as metallurgy, machinery, chemical industry, electronics, shipbuilding, instruments and meters, textile, light industry, medicine, etc. 60% ~ 70% of import and export goods of Shanghai are transshipped through port, which is mainly coal, metal ore, ore material, oil, steel and general goods etc. Transit hinterland include 7 provinces and regions namely Jiangsu, Zhejiang, Anhui, Jiangxi, Hunan, Hubei, Sichuan, transit goods of these provinces via Shanghai Port make up 50% of cargo throughput of the Shanghai Port **(**Shanghai MSA, 2015**)**.

2.1.1 Shanghai Port waters range and waterways

The waters of Shanghai Port refers to the sea waters and inland river waters, the former including the Yangtze River estuary and the north shore of Hangzhou bay, the Huangpu River waters, Shanghai international shipping center-Yangshan deepwater, anchorage waters out of the Yangtze River esrtuary waters and Lvhuashan waters; the latter including all the inland waters except for the waters above in the area of Shanghai city **(**Shanghai Water Area Environmental Management for Ship Pollution Prevention and Control Measures (revised draft) (2014)**)**. The jurisdiction diagram was taken by the author on May 20, 2015 in the VTS of Shanghai MSA, which can be completely regarded as the sketch map of Shanghai Port and water area. This diagram covers all registered ports and waters in Shanghai. As shown in Figure 2.1.

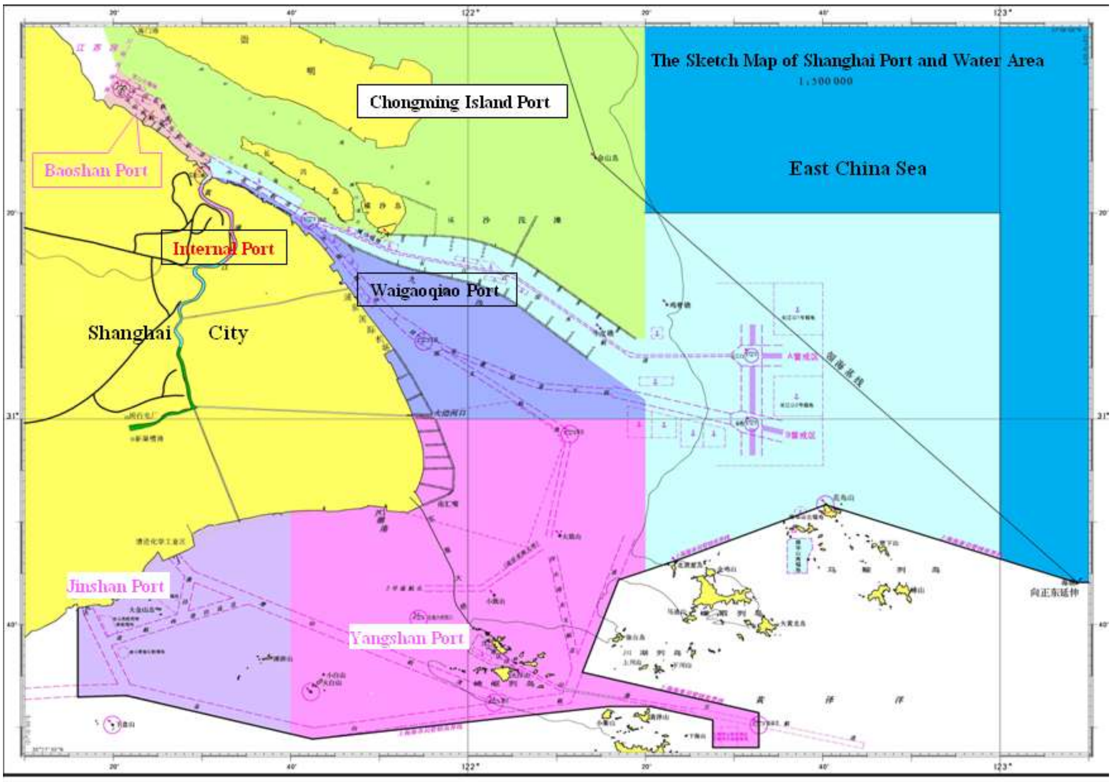

Figure 2.1- The sketch map of Shanghai Port and water area(map of Shanghai MSA jurisdiction area)

Source: Author, took photo on May 20, 2015 in the VTS of Shanghai MSA and edited on May 23, 2015.

At present, the navigational course from the sea into the docks along the Yangtze River and the Huangpu River consists of the main channel of Yangtze River Shanghai section, the auxiliary channel and channel of small vessels. Main channel includes the Yangtze estuary deepwater channel, Waigaoqiao channel and Baoshan channel. Auxiliary channel is the lower and upper section of Nancao channel.

Vessels can pass in and out of the Yangshan Deepwater Port district through the eastern and western entrances. Ships can sail along the Jinshan channel and Caojing eastern and western channel to go in and out of the Jinshan docks and Caojing chemical industrial docks.

2.1.2 Characteristics of coastline, port and berth

According to the geographical location, Shanghai Port mainly covers Jinshan port located in the north shore of Hangzhou bay waters and port of Caojing chemical industrial area, Shanghai international shipping center Yangshan Deepwater Port, Waigaoqiao port area, Baoshan port and Chongming Island Port along the Yangtze estuary coastline, and the harbor waters on both banks of the Huangpu River, as well as all inland ports related to all inland waterways except for the waters above in Shanghai. Besides, the anchorage of the Shanghai Port is mainly the Yangtze River esrtuary anchorage out of the Yangtze River estuary and Lvhuashan anchorage.

The length of Shanghai coastline is 119.7 km, especially rich in the coastline of the Yangtze River and the Huangpu River (Zhou, Liu & Yin, 2011). As a result, there are a large number of ports, and the main ports are thick with docks. There are Baogang port, Chongming passenger port, international cruise terminal, Luojing oil depot, Luojing ore port, Luojing general goods port , etc, in the area of Baoshan port. In Waigaoqiao port area, there are Shanghai oil refinery, coastal oil depot, NO1 to 6 Waigaoqiao port area. The banks area of the Huangpu River covers the Zhanghuabang, Jungong road, Gongqing, Gaoyang, Zhujiamen, Minsheng and Xinhua port areas. Each port is thick with docks, according to the statistics of the Shanghai MSA in 2013, there are 789 main ports in Shanghai, 437 other terminals (Shanghai MSA, 2014 b).

Shanghai Port has a great variety of docks, which can be berthed by almost all types of ships currently, including bulk carrier, container ship, the significant carrier, ro-ro ship, passenger ship, bulk chemical ship, oil tanker, liquefied gas carrier, general cargo ship, etc. In the main ports of Shanghai, there are 161 bulk carrier berths, 105 oil tanker berths, 59 container ship berths, 12 barge berths, 7 workboat berths, 10 tug berths, 36 chemical tanker berths, 20 liquefied gas carrier berths, 138 general cargo ship berths, 62 ro-ro ship berths, 66 passenger ship berths, and 172 other berths, (Shanghai MSA, 2014 b). As shown in the figure 2.2 (Note: multi-function berths such as chemical berth able to berth oil tanker, chemical tanker and liquefied gas carrier are count once in each type of berth in the statistics).

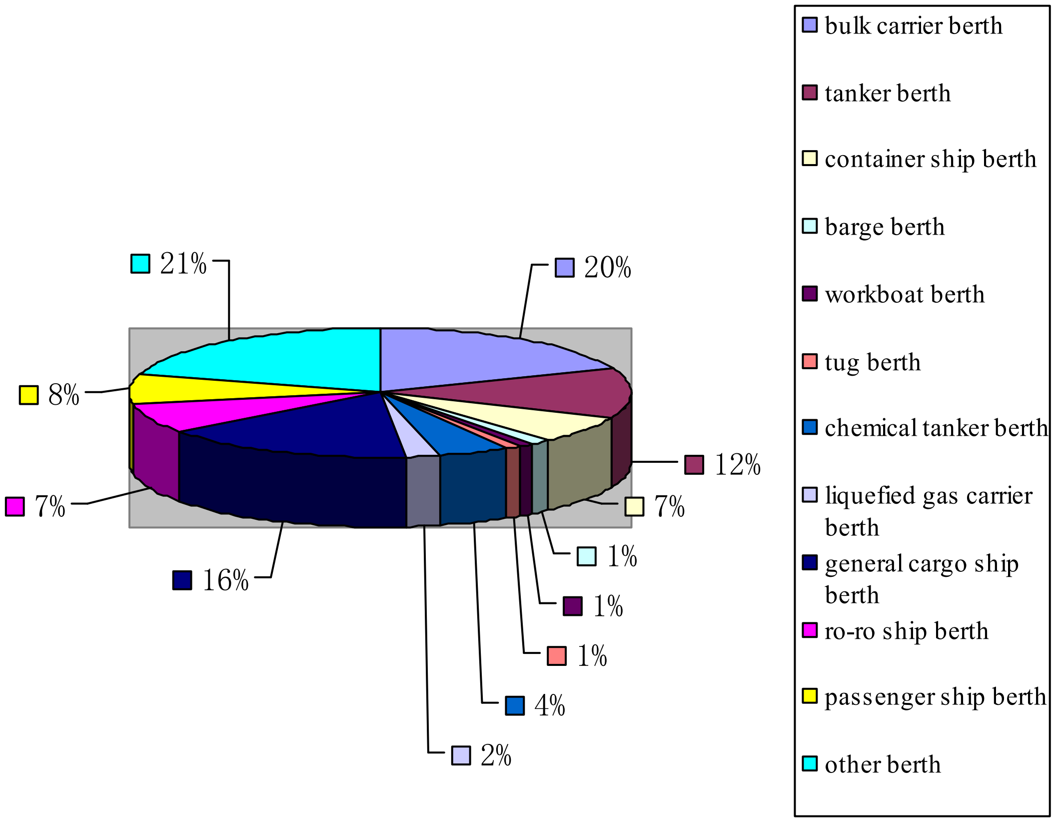

Figure 2.2 - Categories of berths in Shanghai Port

Source: Author, compiled on May 23, 2015

As shown in figure 2.2, the bulk carrier berth has the highest proportion of Shanghai Port, achieving one fifth of the total number of berths. The following two types are general cargo ship berth and oil tanker berth. As a worldwide famous port with a huge container throughput, container ship berth only accounts for 7% of total number of Shanghai berth, which fully illustrates the efficiency of container berth in Shanghai Port. In addition, the passenger ship berth and ro-ro ship berth constitute a large percentage of berths in Shanghai. Thus it can be seen that Shanghai Port depends on bulk carrier berth, liquefied carrier berth, container berth and ro-ro ship berth, and covers a variety of other ships berth, with complete functions, which forms the basis for Shanghai to build a huge world-class port.

2.2 Division of Shanghai Port

For the convenience of further recogniting Shanghai Port, the author divides the Shanghai Port according to the geographical position, and then introduces them respectively. With the southern bank of the Yangtze River estuary as a boundary, Yangshan harbor area in the southern coastal waters of Shanghai Port and coastal port along northern part of Hangzhou Bay waters are called Coastal Port by the author. Port on both sides of the Yangtze River along the shoreline within the territory of Shanghai Port is External Port. Located in downtown Shanghai, with Huangpu River running through the city into the Yangtze River, port on both banks of the Huangpu River is called Internal Port.

2.2.1 Coastal Port

At present, main coastal port of Shanghai includes the Shanghai international shipping center-Yangshan Deepwater Port, Jinshan Port which is located in the north shore of Hangzhou Bay waters, and Caojing Chemical Port.

Yangshan Deepwater Port is situated in the confluence of the Yangtze estuary and Hangzhou Bay, close to the Yangtze estuary in the north. There are 16 container berths, 5600 meters long and 42 meters wide (for large container ships berthing); there are 5 refined oil berths, 100 thousand tons, 5000 tons and 2000 tons respectively; one 100 thousand tons LNG berth; eight passenger ship berths; and three general cargo ship berths. There are a two-way six lanes bridge- Shanghai East Sea Bridge between the Yangshan Port and the Luchao Port (Shanghai MSA, 2015). As shown in the figure 2.3.

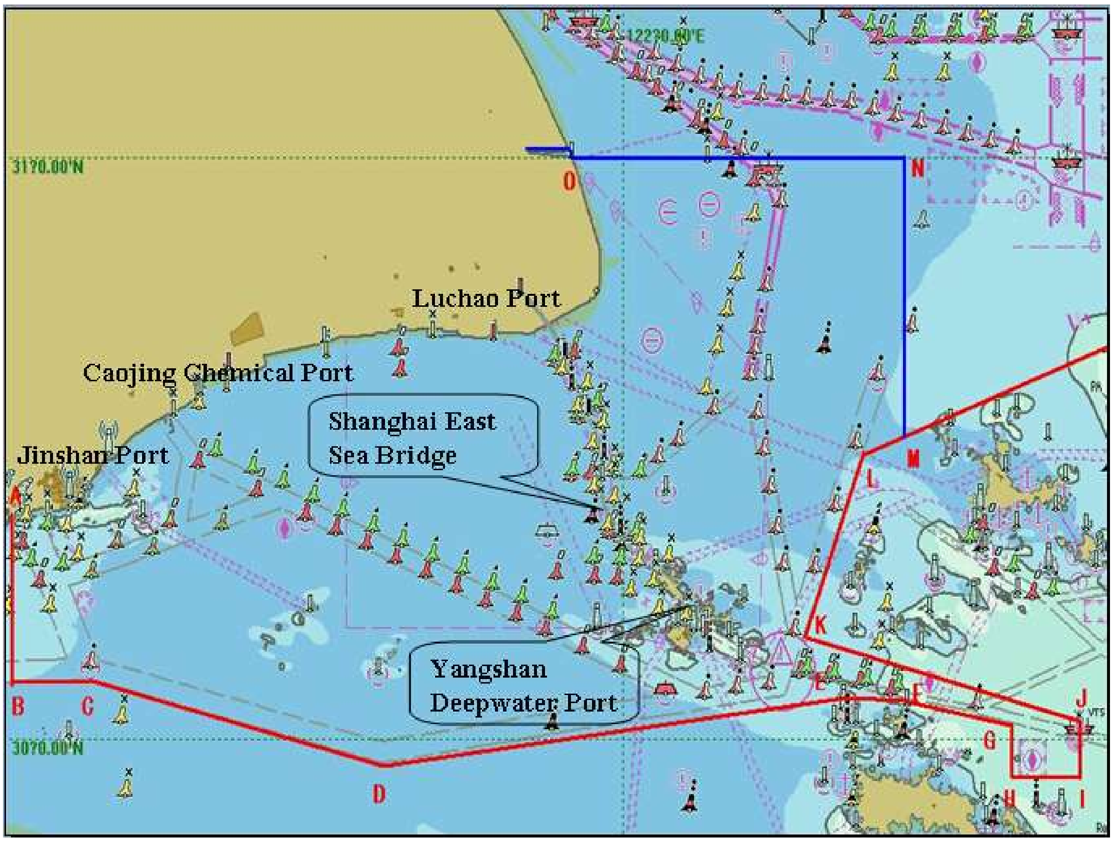

Figure 2.3- Map of Yangshan Deepwater Port and waters nearby

Source: Author, took photo on May 20, 2015 in the VTS of Shanghai MSA and edited on May 23, 2015.

Located at the southernmost tip of the coastal line- the north shore of Hangzhou Bay (see Figure 2.3), Jinshan Port consists of chemical berths centralizing the function of loading and unloading bulk oil, chemicals, liquefied gas of berths and the coal berths respectively. Caojing chemical port is located in the north of Hangzhou Bay along the Shanghai coastal line, between Jinshan port and Luchao port (shown in figure 2.3). The port has 23 bulk chemical berths, including thirteen 5,000tons, ten 10,000 to 50,000 tons. Besides, there are one 35,000 tons and three 2,000 tons coal berths **(**Shanghai MSA, 2014 b**)**.

2.2.2 External Port

The Shanghai section of Yangtze River is located in the Yangtze River estuary, the total length is 65 nautical miles (Shanghai MSA, 2015). With the Huangpu River as the boundary, the southern bank is dense with berths, mainly including the Waigaoqiao Port in the eastern part of the Yangtze River and the Baoshan Port in the western part. Chongming Island Port lies in the north. These ports constitute the external port of Shanghai.

Baoshan Port has the bulk ship berths, general cargo ship berths and passenger ship berths, totally 107 berths. Chongming Island Port has fewer commercial transport berth, more major carrier berth, passenger ship berth and repairing yard berth. Waigaoqiao Port relies mainly on container ship and oil tanker berths, with a small amount of bulk ship berth and other functional berths -a total of 83 berths (Shanghai MSA, 2014 b).

2.2.3 Internal Port

The Huangpu River runs through the city of Shanghai, the total length within the territory of Shanghai is about 113 km, about 60 kilometers through the city. Along both sides of the Huangpu River, Shanghai has built more than 500 berths of different sizes. The length of the berths lines is close to 100 km (Shanghai MSA, 2015). The Huangpu River is a river port with harbor nature, many Chinese coastal ships and international navigation ships sail on the river, and berth on downtown Shanghai.

The amount of berth above designated size (docked by 5000 to 80000 tons ships) is as many as 74, covering bulk carrier, general cargo ship, passenger ship, chemical tanker, oil tanker, workboat, public service ship and tug, and many other ships berth (Shanghai MSA, 2015).

2.3 Port throughput and times of ships entering and leaving port

2.3.1 Port throughput from 2010 to 2013 and analysis on its characteristics

Shanghai became the port with the largest cargo throughput in the world dated from 2005, the annual throughput of goods is 443 million tons. Shanghai had the largest container throughput in the world in 2010, the annual container throughput is 29.069 million TEUs (Zhao, Zhang & Ma, 2013). Since then, Shanghai has been the No.1 port in the world both in cargo and in container throughput for many years.

According to annual statistical data of Shanghai MSA, in 2010, cargo throughput of Shanghai Port was 653 million tons. 2011 has seen an increase by 11.8%, the cargo throughput was 730 million tons. In 2012, there was a rise of 0.8% compared with the year earlier; the cargo throughput was 736 million tons. In 2013, annual port cargo throughput grew by 5.4% with 776 million tons (Shanghai MSA, 2014 a). As shown in the figure 2.4.

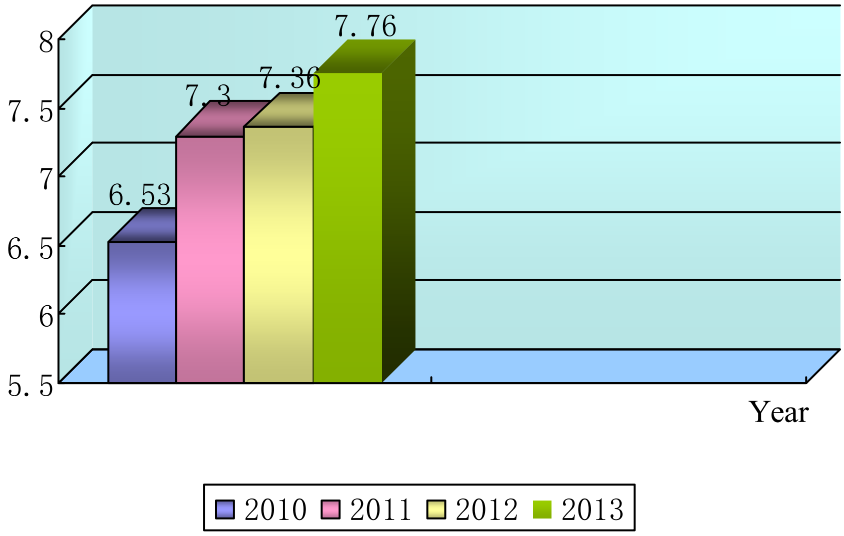

Figure 2.4 - The developing trend of the cargo throughput of Shanghai Port (unit: 10^9 tons)

Source: Author, compiled on May 24, 2015 and data from Shanghai MSA.

As shown in Figure 2.4, the cargo throughput of Shanghai Port has grown for years. In 2011, Port cargo throughput had the fastest increase speed of 11.8%, which is two fold of it in 2013. Compared with the year of 2011, cargo throughput of 2012 only had a minor adjustment.

Based on the annual statistical data of Shanghai MSA, the container throughput of Shanghai Port in 2010 was 29.069 million TEUs. In 2011, there was a growth of 9.2% from the earlier year, the annual port container throughput was 31.74 million TEUs. 2012 saw an increase of 2.5%, the annual port container throughput was 32.529 million TEUs. In 2013, the increase was 3.3%, yearly port throughput of container was 33.617 million TEUs (Shanghai MSA, 2014 a). As shown in the Figure 2.5.

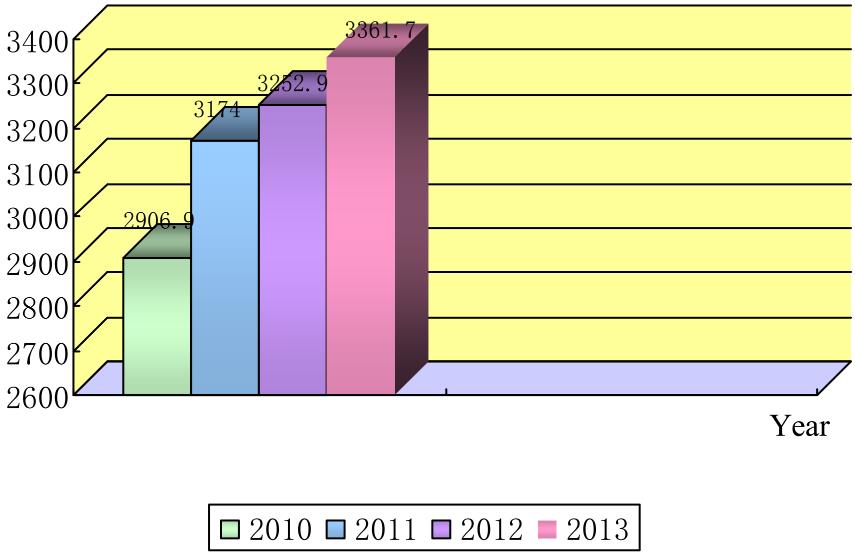

Figure 2.5 - The developing trend of the container throughput of Shanghai Port (unit: 10^4TEU)

Source: Author, compiled on May 24, 2015 and data from Shanghai MSA.

As shown in figure 2.5, in 2011 the container throughput of Shanghai Port increased the most rapidly, and achieved 30 million TEUs for the first time. Then in 2012 and 2013, the increase of container throughput remained constant.

According to the annual statistical data of Shanghai MSA, Shanghai Port handled 1.385 million passengers from ships in 2010. The number rose slightly by 0.4% in 2011 with annual 1.39 million passengers. In 2012, there was a climb of 10.1% compared with the year earlier; the annual passengers' throughput was 1.53 million. And in 2013 with the growth of 78.8%, annual passengers soared to 2.736 million (Shanghai MSA, 2014 a). As shown in the figure 2.6.

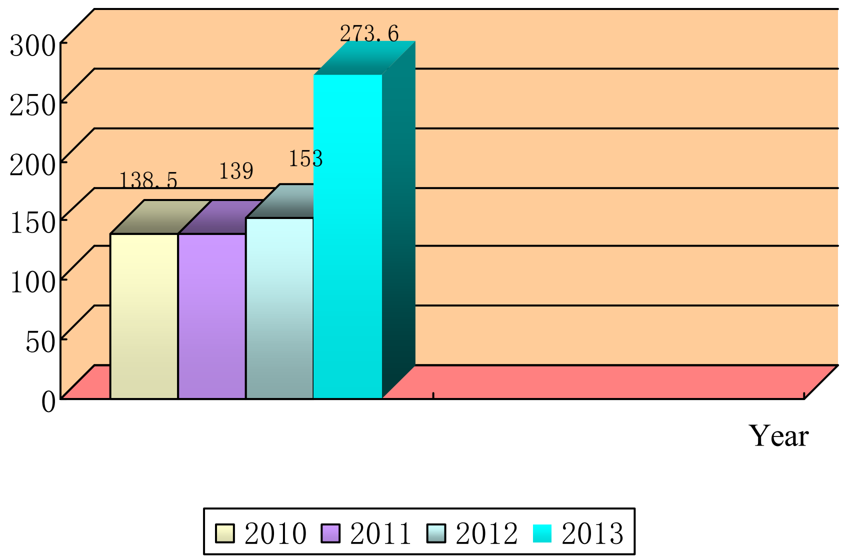

Figure 2.6 - The developing trend of the passenger transport of Shanghai Port (unit: 10^4 people)

Source: Author, compiled on May 24, 2015 and data from Shanghai MSA.

As shown in figure 2.6, the increase of annual passengers of Shanghai Port in 2011 is slow. It was not until 2012 that the number grew rapidly. And in 2013 the port passenger transport rose sharply, the number was almost the twice of it in 2010.

2.3.2 Times of ship entering and leaving Shanghai Port from 2010 to 2013 and the analysis of its characteristics

According to annual statistical data of Shanghai MSA, there were 1.6525 million ships in and out of the Shanghai Port in 2010. Among them, there were 40,600 international ships, 87,600 Chinese coastal ships and 1,524,300 Chinese inland river ships. In 2011, there were 1.9522 million ships in and out of the Shanghai Port, of which there were 43,100 international ships, 100,800 Chinese coastal ships and 1,808,300 Chinese inland river ships. In 2012, the number of ships in and out of Shanghai Port was 1.8589 million including 42,100 international ships, 105,200 Chinese coastal ships, and 1,711,600 Chinese inland river ships. The total number of 2013 was 1.6488 million. Among them, the number of the international ships was 41,500; Chinese coastal ships was 109,200; and Chinese inland river ships was 1,498,100 (Shanghai MSA, 2014 a). As shown in the table 2.1.

Table 2.1 - Times of ships entering and leaving Shanghai Port from 2010 to 2013 (unit: ten thousand ships)

	2010	***2011***	***2012***	***2013***
International ships	4.06	4.31	4.21	**4.15**
Chinese coastal ships	8.76	10.08	10.52	**10.92**
Chinese inland river ships	152.43	180.83	171.16	**149.81**
total	**165.25**	**195.22**	**185.89**	**164.88**

Source: Shanghai MSA. (2014a). *The annual list of ship entry and exit history of Shanghai Port from 2010 to 2013*. Shanghai: Author.

As shown in table 2.1, the annual traffic flow of international ships fluctuated slightly. After the growth of 6.40% in 2011, the number fell slightly with its overall traffic flow stabilized at about 40,000 ships. There were a constant increase in the number of Chinese coastal ships; 2011 saw a dramatic growth of 15.07%, and in 2011, it has been stable at more than 100,000 ships.

For further analysis of data characteristics of the ships entry and exit history in Shanghai Port, the author classifies the international ships entry and exit the Shanghai Port from 2010 to 2013 according to the ship types, namely bulk carrier, oil tanker, container ship, tug, chemical tanker, liquefied gas carrier, general cargo ship, and passenger ship, count their numbers of entry and exit the port respectively and illustrate in the table 2.2.

Table 2.2 -Times of international ships entering and leaving Shanghai Port from 2010 to 2013 (unit: ships)

	2010	2011	2012	2013
bulk carrier	4915	5364	5392	5459
tanker	1130	1125	1253	1216
container ship	28564	30628	29809	29326
tug	359	362	342	332
chemical tanker	760	758	721	657
liquefied gas carrier	395	417	400	401
general cargo ship	4229	4264	3877	3732

passenger ship	224	223	260	397
total	40576	43141	42054	41520

Source: Author, compiled on May 24, 2015 and classified and processed the data from "*The annual list of ship entry and exit history of Shanghai Port from 2010 to 2013*" (See the source of table 2.1).

As shown in table 2.2, the annual container ships entry and exit history of Shanghai Port between 2010 and 2013 sometimes rose and sometimes fell, but the number kept in the first place, maintaining on over 28000 ships, far more than the sum of other types of ships. The number of bulk carriers and general cargo ships maintained in the second and third place, about 5000 and 4000 ships one year respectively. Other type of ships with outstanding annual number is oil tankers, more than 1000 ships.

Similarly, times of the coastal ships entering and leaving the Shanghai Port between 2010 and 2013 can be classified, according to the ship types -namely bulk carrier, tanker, container ship, tug, chemical tanker, liquefied gas carrier, general cargo ship, and passenger ship. They are counted from the annual list of ship entry and exit history of Shanghai Port from 2010 to 2013 respectively and illustrated in the table 2.3

Table2.3 -Times of Chinese coastal ships entering and leaving Shanghai Port from 2010 to 2013 (unit: ships)

	2010	2011	2012	2013
bulk carrier	13865	14032	12678	12867
tanker	6274	9823	11995	13718
container ship	15688	17026	17976	18719
tug	10762	17257	27794	31025
chemical tanker	2947	2881	2960	2751
liquefied gas carrier	234	204	240	120
general cargo ship	32066	33238	24952	21493
passenger ship	5781	6379	6567	8537
total	87617	100840	105162	109230

Source: Author, compiled on May 24, 2015 and classified and processed the data from "*The annual list of ship entry and exit history of Shanghai Port from 2010 to 2013*" (See the source of table 2.1).

As shown in table 2.3, the types of ships with higher annual number in Shanghai Port are general cargo ship, container ship, bulk carriers, tug and tanker. General cargo ship had obvious advantages, until 2012, it is overtaken by tug. After that, the tug maintained the first place, which demonstrated that the tug in Shanghai Port is in great demand, and the need is growing rapidly. The annual of container ships and bulk carrier ships were all more than 10,000. Since 2012, oil tanker has keep annual ships number over 10,000.

Due to the similar characteristics of international ships and Chinese coastal ships when calculating the ship pollution gases emission especially in selecting emission factor, these two kinds of ships are merged and collectively known as seagoing ships berthed in Shanghai Port. At the same time, the author consolidates the data of table 2.2 and 2.3 to form statistics of different types of ships entry and exit history of Shanghai Port from 2010 to2013. Detail is shown in table 2.4.

Table 2.4 -Times of different types of ships entering and leaving Shanghai Port from 2010 to 2013 (unit: ships)

	2010	2011	2012	2013
bulk carrier	18780	19396	18137	17315
tanker	7404	10948	13211	14080
container ship	44252	47654	47302	46887
tug	11121	17619	28123	31278
chemical tanker	3707	3639	3617	4027
liquefied gas carrier	629	621	641	486
general cargo ship	36286	37503	28695	25206
passenger ship	6014	6601	6953	8923
total	128193	143981	146679	148202

Source: Author, compiled on May 24, 2015.

It is shown in table 2.4 that the number of container ships entry and exit history of Shanghai Port is still very outstanding, stay the first place steadily. Due to the large number of coastal ships, the annual number of general cargo ships is also high. The annual number of bulk carriers is relatively stable with fairly high proportion in the annual total number. Others remarkable are tug and tanker.

As the same kind of ships have different tonnage distribution, for the convenience of a detailed identification of features of sea-going ships in Shanghai Port, meanwhile preparing for the calculation of marine gas emissions in Shanghai Port in the next chapter, the author collected and classified the seagoing ship of Shanghai Port according to the types and the deadweight (DWT) from 2010 to 2013, and expressed in table 2.5-2.8, respectively.

Table 2.5 -Times of sea-going ships of different type and tonnage entering and leaving Shanghai Port in 2010 (unit: ships)

Types of ships	total	Below 3000DWT	3000-5000DWT	5000-10000DWT	10000-29999 DWT	29999-100000 DWT	Above 100000 DWT
bulk carrier	18780	231	4478	1370	2741	9011	949
tanker	7404	2584	1983	464	928	1172	273
container ship	44252	432	7275	4569	9139	13677	9160
tug	11121	9632	513	318	637	21	
chemical tanker	3707	130	2570	273	546	187	1
liquefied gas carrier	629	2	298	70	140	64	55
general cargo ship	36286	17864	10540	2054	4109	1669	50
passenger ship	6014	3220	1751	294	588	156	5
total	128193	34095	29408	9413	18827	25957	10493

Source: Author, compiled on May 24, 2015 and classified and processed the data from "*The annual list of ship entry and exit history of Shanghai Port from 2010 to 2013*" (See the source of table 2.1).

Table 2.6 -Times of sea-going ships of different type and tonnage entering and leaving Shanghai Port in 2011 (unit: ships)

Types of ships	total	Below 3000DWT	3000-5000DWT	5000-10000DWT	10000-29999 DWT	29999-100000 DWT	Above 100000 DWT
bulk carrier	19396	193	4135	1398	2795	9902	973
tanker	10948	5042	2710	552	1105	1247	292

container ship	47654	500	7529	4770	9539	14909	10407
tug	17619	15832	495	418	835	39	
chemical tanker	3639	97	2524	261	522	232	3
liquefied gas carrier	621		258	83	165	59	56
general cargo ship	37503	18071	10981	2201	4402	1822	26
passenger ship	6601	3460	1971	328	655	186	1
total	143981	43195	30603	10010	20019	28396	11758

Source: Author, compiled on May 24, 2015 and classified and processed the data from "*The annual list of ship entry and exit history of Shanghai Port from 2010 to 2013*" (See the source of table 2.1).

Table 2.7 -Times of sea-going ships of different type and tonnage entering and leaving Shanghai Port in 2012 (unit: ships)

Types of ships	Total	Below 3000DWT	3000-5000DWT	5000-10000DWT	10000-29999 DWT	29999-100000 DWT	Above 100000 DWT
bulk carrier	18137	126	3253	1325	2651	9715	1067
tanker	13211	6627	3062	644	1289	1192	397
container ship	47302	337	8035	4992	9983	13304	10651
tug	28123	26746	336	335	669	37	
chemical tanker	3617	268	2470	220	439	220	
liquefied gas carrier	641		233	89	177	61	81
general cargo ship	28695	12635	8604	1958	3915	1543	40
passenger ship	6953	3317	2122	424	847	239	4
total	146679	50056	28115	9986	19971	26311	12240

Source: Author, compiled on May 24, 2015 and classified and processed the data from "*The annual list of ship entry and exit history of Shanghai Port from 2010 to 2013*" (See the source of table 2.1).

Table 2.8 -Times of sea-going ships of different type and tonnage entering and leaving Shanghai Port in 2013 (unit: ships)

Types of ships	Total	Below 3000DWT	3000-5000DWT	5000-10000DWT	10000-29999 DWT	29999-100000 DWT	Above 100000 DWT
bulk carrier	17315	89	2896	1275	2550	9615	890
tanker	14080	7575	3752	624	1248	796	85
container ship	46887	12	8563	5194	10388	11921	10809
tug	31278	30198	245	274	549	12	
chemical tanker	4027	208	2647	253	505	414	
liquefied gas carrier	486		176	49	99	75	87
general cargo ship	25206	10984	7038	1828	3656	1658	42
passenger ship	8923	4352	2548	563	1125	331	4
total	148202	53418	27865	10060	20120	24822	11917

Source: Author, compiled on May 24, 2015 and classified and processed the data from "*The annual list of ship entry and exit history of Shanghai Port from 2010 to 2013*" (See the source of table 2.1).

By comparing the data in table 2.5 to 2.8, in addition to the rapid growth of individual data, the changes of the distribution in different types and DWT levels from 2010 to 2013 are slight. As the data in table 2.5-2.8 is mainly used in the calculation of the third chapter, the author will not do any other detailed analysis here.

2.4 Summary of this chapter

By visiting Shanghai MSA, the author carried out field investigation and data collection, formed the basis of the data and material in this chapter. In this chapter the author focuses on in-depth analysis of the Shanghai Port, identifies the geographical characteristics of the Shanghai Port by waters, course and coastline of Shanghai Port. And a general research on the characteristics of berths is conducted. Research shows that Shanghai Port has a great variety of berths and comprehensive functions, mainly depending on large bulk carrier berth, liquefied gas carrier berth, container berth and passenger ship berth, which forms the basis of the construction of a world-class port for Shanghai.

For further research and analysis, according to geography characteristics, with the junction of the Yangtze River and the East Sea, the junction of the Yangtze River and the Huangpu River, Shanghai Port is divided scientifically and reasonably into coastal port, external port and internal port. The coastal port gives priority to container berth, oil tanker berth and chemical tanker berth. The external port is mainly bulk carrier berth, passenger ship berth, container berth and large piece carrier berth. The internal port still occupies an important position in Shanghai Port, depending on general cargo ship berth and other berths. It is shown that there are differences among the function of the three regional ports, which constitute a good basis of balanced and orderly development of Shanghai Port.

The throughput and the traffic flow of ships entry and exit history of Shanghai Port from 2010 to 2013 are analyzed in this chapter after gathering data from Shanghai MSA. From the three aspects of the cargo throughput, container throughput and passengers transport, this chapter projects the development of Shanghai Port in the nearly four years. At the same time, from the three aspects of ship sailing area, ship type and ship's tonnage respectively, the author analyzes the characteristics of the ship traffic flow of Shanghai Port from 2010 to 2013, providing the data foundation for calculation of marine polluted gas emissions of Shanghai Port in the next chapter.

CHAPTER 3

RESEARCH ON MARINE GAS EMISSIONS OF SHANGHAI PORT

Referring to the method of constructing ship emission source inventory of European and American countries and Hong Kong, as well as domestic research results related, this chapter selects Shanghai Port as a typical research subject, and on the basis of the data of the annual Shanghai Port cargo throughput and different types of ships entry and exit history acquired in the second chapter, the author divides the ship emission source scientifically, and then chooses the main polluting gas from ships, in order to set up the polluting gases emission inventory of main types of ships in Shanghai Port from 2010 to 2013.

After establishing the ships gas emissions inventory of Shanghai Port, this chapter fully identifies the general characteristics of vessel emissions in Shanghai Port, analyzes the share rate of the existing ship types in gas emissions and the specific characteristics of all kinds of polluted gas emitted by ships. By studying the characteristics of share rate of all kinds of marine polluted gases, this chapter also analyzes correspondingly the harmfulness of the pollutants.

3.1 Research scope of ships gas emissions in Shanghai Port (type of ships and categories of polluted marine gases)

As the important reference and basis of the research on marine gas emissions of countries or regions in the world, the USEPA published an analysis report on emissions and fuel consumption of commercial ships in 2000, which divide the ship emissions into NO_x, SO_2 and PM, HC, CO, CO_2, O_2, etc (USEPA, 2000). Because the impact of greenhouse gases is involved as a global environmental problem, which covers a large geographical scope, they will not be objects of this article. Ship greenhouse gases emitted by ships are mainly CO, CO_2 and HC (Fu, 2008). It is illustrated in the white paper on prevention of the ship and port pollution issued by the Natural Resources

Defense Council (NRDC) in Beijing that the majority of commercial ships are driven by large compression ignition engine, its gas emissions primarily are PM, SO_x, NO_x, etc, which are also harmful to human health (NRDC, 2014). Therefore, this paper will choose the gas pollutants-NO_x, SO_2, PM_{10} and $PM_{2.5}$ emitted by vessels in operation in Shanghai Port as research subject.

Besides, the International Maritime Organization (IMO) has passed four ship emissions control area since 2005, aiming at reducing and controlling the ship emissions of gas pollutants such as sulfur oxides, nitrogen oxides and particulate matter, etc (Li & Li, 2010), which can also indirectly verify that these three pollutants are the main polluted emissions of ships, whose hazards to the health of crew and port residents and environment have been taken seriously by European and American countries.

In this paper, the range of research on ships in Shanghai Port is within the administrative management limit of Shanghai MSA (one of the main administrative departments in Shanghai Port); the ships berthed in the coastal port, the external port and the internal port of Shanghai Port from 2010 to 2013 are separately studied; ships in transit sailing through the waters of Shanghai or nearby are not included in the research of this paper. The paper researches on commercial ships except the ships for military use and public service and fishing boats, they are separated into international ships and coastal ships in accordance with their navigation areas, while they are divided into bulk carrier, tanker, container ship, tug, chemical tanker, liquefied gas carrier, general cargo ship and passenger ship.

3.2 Calculation of marine gas emissions in Shanghai Port

3.2.1 Calculation method

From the content of the second chapter, it is known that the Shanghai Port has a great variety of vessels, because of its differences in function and design of all kinds of vessels, their pollution emissions characteristics can make a big difference. Therefore, when studying marine vessels emissions, the actual characteristics of Shanghai Port and the difference of emissions among all kinds of ships should be taken into consideration, then the calculation method is chosen scientifically and reasonably.

Based on comprehensive analysis of the predecessors' research on ship emissions, there are generally three calculation methods- based on fuel consumption, based on the freight turnover and based on ship engine power (details in chapter1, section 1.2). It should be pointed out that the calculation method based on fuel consumption is an approved method to establish the ship emissions inventory, but it has inherent defects. According to this method, the navigation of ship entry and exit history is simply seen as a whole state, adopting a unified engine load, ignoring the different working condition of ships in different stages entering or leaving the port. Therefore, the results of this calculation method possess a great uncertainty, which is more suitable to estimate the vessel emissions. The calculation method based on freight turnover is similar to the method based on fuel consumption, its main problems is that, to some extent, it ignored the different emission features of ships with different engine power, and is generally used for the calculation of inland river ships pollution emissions (Cai & Zhang, 2014).

By way of conclusion, this paper adopts the method based on the ship's engine power to calculate the ships emissions of Shanghai Port. In 2000, the EPA published the report-*Analysis of commercial marine vessels emissions and fuel consumption data*, which put forward a rigorous calculation method of the commercial vessels emissions. It built up the foundation of calculating ship emissions for other countries or regions in the world. Until now more than a decade has past, so far the research on the marine emission worldwide is still on the basis of this method. Thus, referring to the EPA research report, this chapter uses the calculation method of ship engine power based on the classification of ship, the distribution of engine power, different operation time and characteristics of ship diesel engine under different driving modes (USEPA, 2000). The specific calculation formula is as follows:

$$E_{a,b,c}=C_a*\sum(P_a*EF_{a,b,c}*T_{a,c}) \qquad (3.1)$$

In the above formula, a, b, c represent the types of ship, engine power and the navigation mode respectively; $E_{a,\ b,\ c}$ means the total amount of pollutants emissions($t\cdot a^{-1}$) of a ship of type a with the engine power of grade b under the navigation mode c; C_a is for annual number of arrival of ships of type a; P_a is for engine output power (kW) of ships of type a ; $EF_{a,\ b,\ c}$ represents emission factor ($g\cdot kW^{-1}\cdot h^{-1}$)of ships of type a with the engine power of grade b under the navigation mode c; $T_{a,c}$

means the movement time (h) of ships of type a under the navigation mode c.

It should be pointed out that the report of the EPA was developed in 2000, the data involved in statistics showed the characteristics of ships in 1990s, which are out of date. Therefore, although the calculation method developed by the EPA is serious and scientific, its methods of developing ship emission factor (EF) can no longer be applicable of current sea-going ships. As to the ship emission factors, this paper refers to the data developed by the ICF, as shown in the table 3.1.

Table 3.1 - Ship emission factors (unit: $g \cdot kW^{-1} \cdot h^{-1}$)

Engine type	sulphur content of fuel	SO_2	NO_x	PM_{10}	$PM_{2.5}$
Main engine	2.7%	10.29	18.10	1.42	1.31
Main engine	1.0%	3.62	17.00	0.45	0.42
Auxiliary engine	2.7%	11.98	14.70	1.44	1.32
Auxiliary engine	1.0%	4.24	13.90	0.49	0.45

Source: ICF International. (2009). *Current methodologies in preparing mobile source port-related emission inventories - Final Report.* Virginia: Author.

At the same time, the research shows that average sulphur content of fuel oil used by ships entering and leaving coastal ports of China is 2.6% (NRDC, 2014). Through linear regression calculation of data from table 3.1, marine gas emissions factors of Shanghai Port then are obtained, as shown in the table 3.2. (Note: Currently, there is no local emissions factor data of China)

Table 3.2 -Marine vessels emission factors of Shanghai Port (unit: $g \cdot kW^{-1} \cdot h^{-1}$)

Engine type	sulphur content of fuel	SO_2	NO_x	PM_{10}	$PM_{2.5}$
Main engine	2.6%	9.90	18.04	1.36	1.26
Auxiliary engine	2.6%	11.52	14.65	1.38	1.27

Source: Author, compile on May 26, 2015.

3.2.2 Data analyzing and inputting

This paper collected data of ships entering and leaving the Shanghai Port from 2010 to

2013, in terms of time sequence, input data of 2010 firstly, calculate marine gases emissions in Shanghai Port in 2010.

As described in section 3.2.1 of this chapter, elements that need input the calculation formula are: **annual arrival times of different types of ships, output engine power of ships, ship emission factors, and movement time of ships**.

Division of ship types is in section 2.3.2 of chapter 2, as well as the statistics in annual times of seagoing ship entering and leaving Shanghai Port (see table 2.5).

When calculating the marine gas emission of seagoing ships in Shanghai Port, the ship engines adopted in the calculation mainly includes the main propulsion engine (main engine) and auxiliary engine (main generator). It needs to be pointed out that rated power of ship engine are not the same, for the convenience of calculation, they need to be classified into different ranks and then counted respectively. As the ship must submit the information of tonnage rather than the engine power when applying for the clearance formalities, at the same time, it is found by the EPA that there is a certain relationship between the engine power and the tonnage of ship through a large amount of statistical research. Therefore, the paper applies the relational tables between the engine power and the deadweight tonnage (DWT) of ships established by Ye Siqi in the paper -"*study on ship emission characteristics and impact on the regional air quality in the Pearl River Delta*". Firstly, the relational table established by Ye Siqi is more reliable and suitable for actual situation of ships entering and leaving Chinese ports; secondly, the report of the EPA is developed in 2000 and its data are in the 1990s which are out of date. Specific relational table about the engine power and the deadweight tonnage of ships in Shanghai Port in this chapter is as shown in table 3.3.

Table 3.3-Relational table about the engine power and the deadweight tonnage of ships in Shanghai Port

Types of ships	Main Engine power（kW）	Power ratio of main engine and auxiliary engine	auxiliary engine (kW)
chemical tanker			
Below DWT 5000	1390	0.211	293
DWT 5000-9999	2905	0.211	613

DWT 10000-29999	5211	0.211	1100
DWT 30000-49999	8636	0.211	1822
general cargo ship			
Below DWT 5000	1491	0.191	285
DWT 5000-9999	2663	0.191	509
DWT 10000-29999	5462	0.191	1043
Above DWT 30000	11939	0.191	2280
bulk carrier			
Below DWT 30000	5111	0.222	1135
DWT 30000-99999	10659	0.222	2366
Above DWT 100000	13804	0.222	3065
container ship			
Below DWT 10000	2931	0.22	645
DWT 10000-29999	11423	0.22	2513
DWT 30000-99999	60973	0.22	13414
Above DWT 100000	64898	0.22	14278
liquefied gas carrier			
Below DWT 10000	2878	0.211	607
DWT 10000-29999	4200	0.211	886
Above DWT 30000	13540	0.211	2857
tanker			
Below DWT 10000	2905	0.211	613
DWT 10000-29999	4200	0.211	886
DWT 30000-99999	12533	0.211	2644
Above DWT 100000	25704	0.211	5424
tug	2290	0.222	508
passenger ship	3150	—	188

Source: (Ye, 2014)

Output power of ship engine refers to the consumption of rated power of the ship sailing under specific navigation mode, equals to the engine rated power multiplied by the ratio of ship engine load. For further research, this paper firstly defines the ship navigation model, according to the ship's speed, the navigation model of ships entering and leaving the Shanghai Port is divided into four categories: cruising mode, safe cruising mode, mobile berthing mode and anchoring mode (Note: The upper limit speed of Huangpu River channel is 8 knots, the southern channel of the Yangtze River estuary is 12 knots, for the details to see the section 4.4.3 of chapter four). As shown in the table 3.4.

Table 3.4 -The division of navigation model of seagoing ships in Shanghai Port

Navigation mode	Definition of characteristics	Navigation speed
cruising mode	Sailing in open water or channel at normal speed	Over 12 knots
safe cruising	Slow down the speed or run into speed limit area to ensure the safety	8-12
mobile berthing	Operate the engine frequently in order to berth on the terminal	0-8
anchoring	Complete berthing, main engine is closed, conduct shipping operation	0

Source: Author, compiled on May 26, 2015.

It is shown that there is a functional relationship among the ratio of ship engine load, the navigation mode and the type of ships (Ng, Loh & Lin, 2013). The ratio of the engine load in the report on ships gas emissions data published by the EPA of the United States in 2000 is empirical value. And in many following studies, this data is using simple empirical ones. For instance, when Yang developed vessel emissions inventory of Shanghai Port in 2003, he set engine load ratio of ships under cruising, berthing and anchoring mode as 0.8, 0.2 and 0.2 respectively. When developing the ship emission inventory of Shanghai Port in 2010, Fu carried out a survey, but all the ship's engine load ratio is still mainly on empirical value. These research based on the empirical value of engine load ratio, to a great extent, will increase uncertainty in the calculation of the marine gas emission. However, Ng put forward a calculation method based on the ships' Automatic Identification System (AIS) tracking ship data in real time when he studied the vessel gas emissions inventory of the Pearl River Delta, which greatly enhances the precision of ship engine load ratio. Because of the time limit of the research, this paper will directly refer to Ng's data, as shown in table 3.5 and 3.6.

Table 3.5 -The ratio of main engine load of different types and DWT ships in Shanghai Port

Types of ships	Normal speed	Slow speed	Berthing speed
chemical tanker			
Below DWT 5000	0.5	0.418	0.025
DWT 5000-9999	0.5	0.418	0.024
DWT 10000-29999	0.5	0.403	0.024

DWT 30000-49999	0.5	0.416	0.024
general cargo ship			
Below DWT 5000	0.5	0.361	0.03
DWT 5000-9999	0.5	0.361	0.03
DWT 10000-29999	0.5	0.362	0.033
Above DWT 30000	0.5	0.361	0.031
bulk carrier			
Below DWT 30000	0.5	0.267	0.028
DWT 30000-99999	0.5	0.306	0.023
Above DWT 100000	0.5	0.299	0.022
container ship			
Below DWT 10000	0.524	0.14	0.02
DWT 10000-29999	0.513	0.135	0.02
DWT 30000-99999	0.478	0.108	0.02
Above DWT 100000	0.473	0.109	0.02
liquefied gas carrier			
Below DWT 10000	0.5	0.375	0.024
DWT 10000-29999	0.5	0.375	0.025
Above DWT 30000	0.5	0.375	0.025
tanker			
Below DWT 10000	0.5	0.446	0.025
DWT 10000-29999	0.5	0.384	0.023
DWT 30000-99999	0.5	0.337	0.022
Above DWT 100000	0.5	0.382	0.023
tug	0.5	0.569	0.02
passenger ship	0.8	0.6	0.3

Source: (Ng, Loh & Lin, 2013)

Table 3.6 -The ratio of auxiliary engine (main generator) load of different types and DWT ships in Shanghai Port

Types of ships	Normal speed	Slow speed	Berthing speed	stop
chemical tanker				
Below DWT 5000	0.43	0.297	0.35	0.265
DWT 5000-9999	0.43	0.297	0.35	0.265
DWT 10000-29999	0.43	0.297	0.35	0.265
DWT 30000-49999	0.43	0.297	0.35	0.265
general cargo ship				
Below DWT 5000	0.43	0.31	0.517	0.224
DWT 5000-9999	0.43	0.31	0.517	0.224
DWT 10000-29999	0.43	0.31	0.517	0.224
Above DWT 30000	0.43	0.31	0.517	0.224
bulk carrier				
Below DWT 30000	0.43	0.242	0.403	0.121
DWT 30000-99999	0.43	0.242	0.403	0.121

Above DWT 100000	0.43	0.242	0.403	0.121
container ship				
Below DWT 10000	0.026	0.038	0.063	0.023
DWT 10000-29999	0.265	0.38	0.601	0.258
DWT 30000-99999	0.115	0.163	0.256	0.097
Above DWT 100000	0.109	0.155	0.243	0.092
liquefied gas carrier				
Below DWT 10000	0.43	0.174	0.206	0.156
DWT 10000-29999	0.43	0.174	0.206	0.156
Above DWT 30000	0.43	0.273	0.322	0.244
tanker				
Below DWT 10000	0.43	0.174	0.206	0.156
DWT 10000-29999	0.43	0.174	0.206	0.156
DWT 30000-99999	0.43	0.279	0.329	0.249
Above DWT 100000	0.43	0.283	0.334	0.253
tug	0.43	0.27	0.45	0.216
passenger ship	0.45	0.45	0.45	0.45

Source: (Ng, Loh & Lin, 2013)

As to ship emission factors, research shows that when the vessels sailing in a lower speed, the low output power of ship engine leads to a rising intensity of unit pollutant emission, thus when calculating the ship emissions, a low load adjustment coefficient usually need to be multiplied to correct the amount of ship emissions under low load (SCG, 2009). In this paper, the load ratio lower than 0.2 (20%) of sea-going ships is corrected with low load correction coefficient, it refers to the research report of the ICF of America, as shown in Table 3.7

Table 3.7 -Low load correction coefficient of ship engine

Ship engine load ratio	SO_2	NO_x	PM
0.01	5.99	11.47	19.17
0.02	3.36	4.63	7.29
0.03	2.49	2.92	4.33
0.04	2.05	2.21	3.09
0.05	1.79	1.83	2.44
0.06	1.61	1.60	2.04
0.07	1.49	1.45	1.79
0.08	1.39	1.35	1.61
0.09	1.32	1.27	1.48
0.10	1.26	1.22	1.38
0.11	1.20	1.17	1.30
0.12	1.18	1.14	1.24
0.13	1.14	1.11	1.19
0.14	1.11	1.08	1.15

0.15	1.09	1.06	1.11
0.16	1.07	1.05	1.08
0.17	1.05	1.03	1.06
0.18	1.03	1.02	1.04
0.19	1.01	1.01	1.02
0.20	1.00	1.00	1.00

Source: (SCG, 2009)

Movement time of ship refers to the time of ships in the process of entering and exiting the port sailing under different mode. Data here need to be input is the running time of ships in the process of entering and leaving the Shanghai Port sailing under cruising mode, safely cruising mode, mobile berthing and anchoring mode respectively. It should be pointed out that, when calculating the overall marine gas emissions of seagoing ships in Shanghai Port, the times of ships under berthing mode is half of statistical data in table 2.4, because ships only berth once in the process of entering and leaving the port. It is shown in studies that the average time of ships entering and leaving Shanghai Port is 1 hour (Fu, 2012) and average berthing time is 0.41 days (Ding, 2013).

3.2.3 Calculation results

Inputting the data of the elements of section 3.2.2 into formula 3.1, total amount of marine gas emissions of Shanghai Port in 2010 can be acquired, as shown in the table 3.8.

Table 3.8 -Marine gas emissions of seagoing ships in Shanghai Port in 2010(unit: ton)

Type of ships	SO_2	NO_x	PM_{10}	$PM_{2.5}$	total
chemical tanker	266.68	284.93	32.28	29.83	613.72
general cargo ship	2359.81	2708.17	300.98	278.12	5647.08
bulk carrier	3064.57	5760.23	461.34	426.58	9712.72
container ship	22066.70	45171.88	3507.05	3246.04	73991.67
liquefied gas carrier	78.62	127.45	10.17	9.40	225.64
tanker	1000.05	1566.50	125.34	115.90	2807.80
tug	772.97	1144.48	97.75	90.21	2105.41
passenger ship	588.44	1169.95	89.05	82.47	1929.91
total	30197.84	57933.60	4623.96	4278.55	97033.95

Source: Author, compiled on May 27, 2015.

As shown in table 3.8, ships emissions of SO_2, NO_x, PM_{10} and $PM_{2.5}$ of Shanghai Port in 2010 is 3.01*10^4t, 5.79*10^4t, 0.46*10^4 t and 0.43*10^4t respectively, total pollutants are 9.70*10^4t.

Similarly, inputting the traffic flow data of ships in different types and different gross tonnage entering and leaving Shanghai Port from 2011 to 2013 into formula 3.1, then the ships gas emissions in Shanghai Port can be gotten respectively, as shown in the table 3.9 to 3.11.

Table3.9 -Marine gas emissions of seagoing ships in Shanghai Port in 2011(unit: ton)

Types of ships	SO_2	NO_x	PM_{10}	$PM_{2.5}$	total
chemical tanker	251.29	401.44	32.72	30.24	715.68
general cargo ship	2431.55	3866.16	316.00	292.00	6905.72
bulk carrier	3709.38	6117.59	489.08	452.25	10768.30
container ship	28751.87	49824.11	3867.73	3579.89	86023.60
liquefied gas carrier	76.39	126.86	10.10	9.34	222.69
tanker	1213.56	1975.38	159.17	147.15	3495.27
tug	1224.63	1813.22	154.87	142.92	3335.65
passenger ship	716.47	1284.14	97.74	90.52	2188.88
total	38375.14	65408.92	5127.41	4744.32	113655.79

Source: Author, compiled on May 27, 2015.

Table3.10-Marine gas emissions of seagoing ships in Shanghai Port in 2012(unit: ton)

Types of ships	SO_2	NO_x	PM_{10}	$PM_{2.5}$	total
chemical tanker	238.41	378.12	30.95	28.60	676.08
general cargo ship	1966.42	3148.29	256.24	236.82	5607.77
bulk carrier	3575.78	5916.56	472.08	436.56	10400.97
container ship	27504.26	47647.83	3699.44	3424.10	82275.64
liquefied gas carrier	85.70	143.04	11.35	10.50	250.60
tanker	1412.86	2291.82	185.06	171.07	4060.82
tug	1954.75	2894.24	247.20	228.13	5324.32
passenger ship	754.67	1352.62	102.95	95.35	2305.60
total	37492.84	63772.52	5005.29	4631.14	110901.79

Source: Author, compiled on May 27, 2015.

Table3.11 -Marine gas emissions of seagoing ships in Shanghai Port in 2013(unit: ton)

Types of ships	SO_2	NO_x	PM_{10}	$PM_{2.5}$	total
chemical tanker	298.12	479.02	38.90	35.96	852.00
general cargo ship	1832.28	2950.45	239.30	221.19	5243.22
bulk carrier	3437.32	5693.33	453.99	419.84	10004.47
container ship	26377.60	45682.46	3547.47	3283.42	78890.95

liquefied gas carrier	78.73	132.21	10.46	9.67	231.08
tanker	1189.29	1889.71	154.52	142.78	3376.30
tug	2174.08	3218.98	274.94	253.73	5921.72
passenger ship	968.50	1735.86	132.12	122.37	2958.85
total	36355.91	61782.02	4851.70	4488.95	107478.59

Source: Author, compiled on May 27, 2015.

Content and data in the above tables from 3.8 to 3.11 will be analyzed and studied in section 3.3 of this chapter.

3.3 Analyses of characteristics of the results

3.3.1 Analysis of characteristics of each polluting gas

On the basis of ships gas emissions of Shanghai Port in 2010, the distributions of SO_2, NO_x, PM_{10} and $PM_{2.5}$ emitted by seagoing ships are $3.01*10^4$t, $5.79*10^4$t, $0.46*10^4$t and $0.43*10^4$t, accounting for 31.1%, 59.7%, 4.8% and 59.7% respectively of the total pollutants, as shown in figure 3.1.

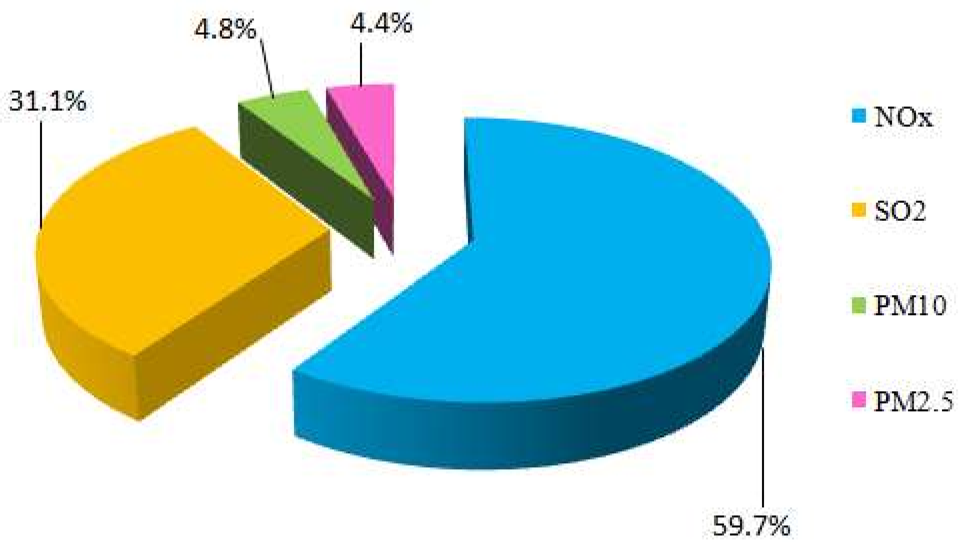

Figure 3.1 -The percentage of marine gas pollutants of Shanghai Port in 2010

Source: Author, compiled on May 27, 2015.

As shown in figure 3.1, the NO_x emission of sea-going ships in Shanghai Port is the highest, overtaking half of the sum of all pollutants. The one in the second place is SO_2, which also occupies a large proportion (31.1%) in all pollutants. Therefore, the main polluting gas emissions in Shanghai Port are NO_x and SO_2.

3.3.2 Analysis on share rate of different types of ships

In 2010, the total emissions of all kinds of ships in Shanghai Port are as follows, chemical tanker 613.72 t, general cargo ship 5647.08 t, bulk carrier 9712.72 t, container ship 73991.67 t, liquefied gas carrier 225.64 t, tanker 2807.80 t, tug 2105.41 t, passenger ship 1929.91 t. The proportions of different types of ships emissions are shown in figure 3.2.

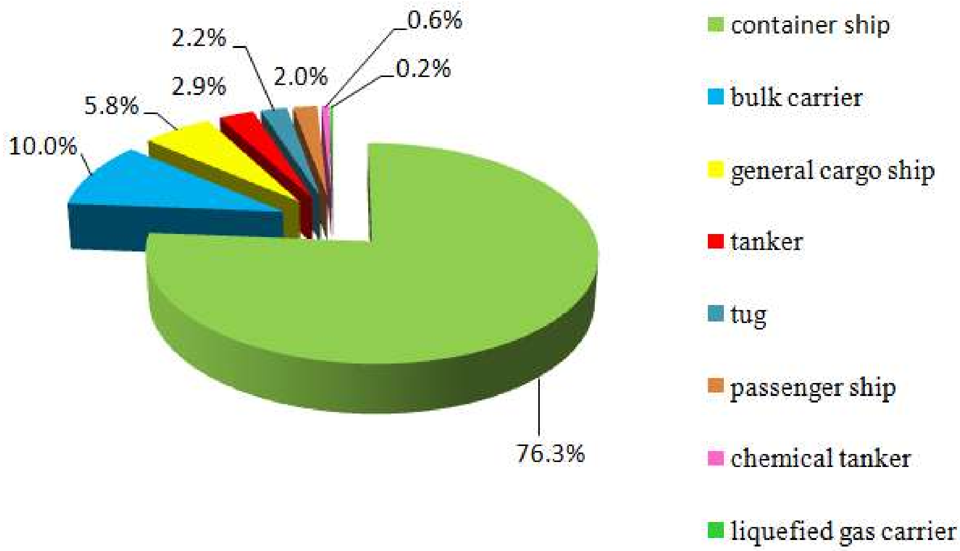

Figure 3.2 -The proportion of marine gas emissions of different types of ships in Shanghai Port in 2010

Source: Author, compiled on May 27, 2015.

As shown in figure 3.2, among various types of ships, emissions of container ships is the highest, representing over three-quarters of the pollutants. This results from the prosperity of container ship transportation in Shanghai Port, which is on the top of times of ships entering and leaving port among different types of ships (See figure 2.4), especially the international container ship with large engine power. Following two types are bulk carrier and general cargo ship, making up 10.0% and 5.8% of the total emission respectively. It should be pointed out that the proportion of bulk carrier emission is high, but its times of entering and leaving ports are relatively less than the general cargo ship, which suggests that medium and large bulk carrier (with large engine power) have a higher proportion in times of entering and leaving ports. Bulk carrier is one of the main contributing types of ships to cargo throughput of Shanghai Port. To some extent, it proves that relationship between shipping freight and marine gas pollutants exists. The emission of other ships which makes up 22% of total times of ships entering and leaving the Shanghai Port is less than 10% of the total emission.

Analysis of the pollution share rate of each type of ships with the SO_2 and NO_x emission is shown in figure 3.3.

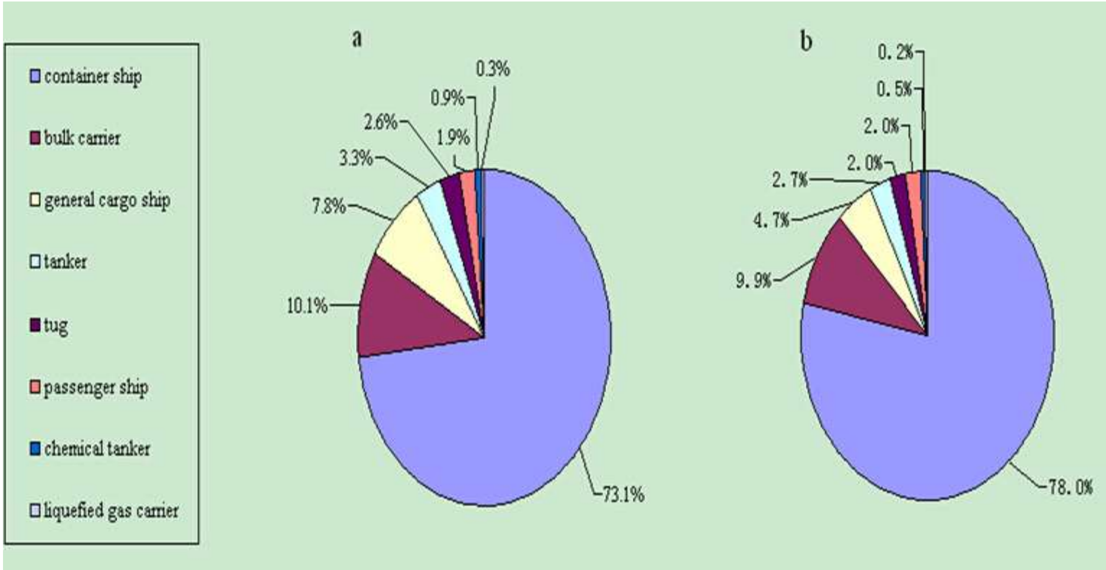

Figure 3.3 -The share rate of SO_2 and NO_x emitted by each type of ships in Shanghai Port in 2010

Source: Author, compiled on May 27, 2015.

As shown in figure 3.3, the container ship contributes the most to SO_2 and NO_x emissions in Shanghai Port. Its share rates are 73.1% and 78.0% respectively, corresponding with the share rates of total pollutants in figure 3.2, which shows again the significant influence of container ship on the marine gas emissions in Shanghai Port due to its huge number of times entering and leaving port and high power engine. This is followed by the bulk carrier and general cargo ship. But the NO_x share rate of general cargo ship is obviously lower than SO_2 share rate, which shows that engine power of general cargo is relatively smaller than bulk carrier and container- although its times of entering and leaving port is far more than the bulk carrier. This is because almost all marine diesel engines with high power are pressurized and inter-cooled, engine thermal efficiency is high, diesel burns more completely, at the same time, the rotation speed of the low speed diesel engine is much slower, reaction time of nitrogen and oxygen in the air cylinder is longer, thus, in the condition of high temperature, high pressure and rich oxygen, the generation of NOx will be relatively large. In addition, the contributions of the SO_2 and NO_x emissions from oil tanker, tug and passenger ship are also very large. Especially, the tugs mainly help large ships to enter and leave port, with the high frequency and large engine power. They need to raise concerns of Shanghai Port.

3.3.3 Analysis on the development of annual gas emissions

From the data of table 3.8-3.11, annual gas emissions of seagoing ship in Shanghai Port from 2010 to 2013 are $9.70*10^4$t, $11.37*10^4$t, $11.09*10^4$t and $10.75*10^4$t . 2011 saw a great growth in the total emission increased by 17.22%. In the following years, annual total pollutants fell generally, by 2.46% and 2.46% respectively in 2012 and 2013. According to the table 2.4, the times of seagoing ship entering and leaving the Shanghai Port from 2010 to 2013 are 128,193, 143,981, 146,679 and 143,981 respectively; the total times are increasing year by year. It shows that there is a structural adjustment of the ship types in Shanghai Port.

Specific situation is in table 2.4, which shows that the types of ships with obvious change in the times of entering and leaving Shanghai Port from 2012 to 2013 are tug and general cargo ship -tug increasing year by year, while general cargo ship reducing year by year with the decline rate 23.49% and 12.16% respectively. This suggests that the sharp drop of times of general cargo ships entering and leaving Shanghai Port is the primary reason of lower annual gas emissions of seagoing ship in Shanghai Port.

It can be predicted that if the structural adjustment of ship types in Shanghai Port sustain, annual marine gases emissions of seagoing ships in Shanghai Port will fall gradually.

3.4 Summary of this chapter

After dividing the types of marine gas emissions scientifically and reasonably, the author selects NO_x, SO_2, PM_{10} and $PM_{2.5}$ with great harmfulness to the city environment and the public health as the main research subject of this chapter. And the research limit is the seagoing ships within the Shanghai Port, which are classified in terms of the sailing area and the function of ships respectively.

By comparing the three calculation methods of marine gas emissions, the author picks up the method based on ship engine power to calculate the annual polluted gas emissions in this chapter, and then carefully analyzes each elements using the method, selects the emission factors scientifically, divides the ships' navigation modes, and studies the ship engine load ratio, etc.

After inputting each element into the formula, annual marine gas emissions of seagoing ships in Shanghai Port are calculated from 2010 to 2013. The author has carried out the share rate analysis on the gas categories and ship type, and analysis on the development of annual marine gas emissions of seagoing ships in Shanghai Port. It is shown in studies that container ships contribute greatly to marine gas emissions of Shanghai Port. Meanwhile, it is predicted that after the structural adjustment of types of ships entering and leaving Shanghai Port, the annual ship emissions would fall gradually.

CHAPTER 4

COUNTERMEASURES TO CONTROL MARINE GAS EMISSIONS IN SHANGHAI PORT

This chapter focuses on summarizing and analyzing the existing measures of controlling marine gas emissions in Shanghai Port, including mandatory requirements and technical supporting measures. At the same time adopting comprehensive literature review, this chapter summarizes and refines countermeasures and experiences of other Chinese and international ports on ships emissions. Through comparing and combining with the actual characteristics of Shanghai, the author refers to the measures which is suitable for Shanghai and put forward further controlling measures that Shanghai Port should adopt.

4.1 Mandatory requirements on controlling marine gas emissions of Shanghai Port

China has not set forth a law or regulation specifically for controlling marine gas emissions. But as a member of the IMO, China signed the International Convention of the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 relating thereto (MARPOL Convention), including annex VI of the convention.

4.4.1 International conventions

International ships entering and leaving the Shanghai Port must comply with Annex VI-Regulations for the Prevention of Air Pollution from Ships -of MARPOL Convention formulated by IMO.

Since the 1980s, the Marine Environment Protection Committee (MEPC) of IMO has been committed to the improvement of air pollution caused by the vessels. Over 20 years' development, an international convention of prevention of exhausted marine gases has formed, which is MARPOL annex VI-Regulations for the Prevention of Air Pollution from Ships, which covers ship emissions criteria and relevant technical guidelines. As one of the parties of the convention, the convention has formally entered into effect in China (Zhou, 2014). Therefore, international seagoing ship entering and leaving China ports are required to abide by the above rules, including the Shanghai Port.

The content of Annex VI includes the requirements on controlling the emissions of NO_x, SO_x, and PM, allow contracting states to submit a proposal to the IMO for the establishment of a marine gas emission control area (ECA), within the emission control area, the control to the emission of international seagoing ships is more strict. According to the convention, on the global scale, prior to 1st January 2012, limits on sulphur content of any fuel used on board ships is 4.5% m/m (mass percent); Since 1st January 2012 limits on sulphur content of any fuel used on board ships is 3.5% m/m; after 1st January 2020 limits on sulphur content reduced to 0.5% m/m. In emission control area, from 1st July 2010, limits on sulphur content of any fuel used on board ships is 1% m/m; And since 1st January 2015, the limits will tighten further to 0.1% m/m (IMO, 2013 a). As shown in table 4.1.

Table 4.1 -Limits on sulphur content of any fuel used on board ships

Outside an ECA established to limit SOx and particulate matter emissions	**Inside an ECA established to limit SOx and particulate matter emissions**
4.5% m/m prior to 1st January 2012	1.5% m/m prior to 1st July 2010
3.5% m/m on and after 1st January 2012	1% m/m on and after 1st July 2010
0.5% m/m on and after 1st January 2020	0.1% m/m on and after 1st January 2015

Source: IMO. (2013a). *MARPOL how to do it*. London: Author.

At the same time, Annex VI also limits the NO_x emissions. It is regulated in the convention that there are three tiers under control on the NO_x emission on a global scale: Tier I was the past NO_x limits, implemented by the shipping industry before 2000; Tier II NO_x standard for engines installed on ships constructed on or after 1st January 2011 is a reduction of 15.5%- 21.8% from Tier I levels; Tier III NO_x standard for engines installed on ships constructed on or after 1st January 2016 shall be a reduction of 80% from Tier I levels. For the emission control area, the NO_x Tier III applies at present

(IMO, 2013a). As shown in table 4.2.

Table 4.2 - Standard for emission of NOx by marine diesel engines

Tier	Ship construction date (on and after)	Total weighted cycle emission limit (g/kWh) n= engine's rated speed (rpm)		
		n < 130	n= 130-1999	n≥2000
I	1st January 2000	17.0	$45*n^{-0.2}$ eg., 720rpm-12.1	9.8
II	1st January 2011	14.4	$44*n^{-0.23}$ eg., 720rpm-9.7	7.7
III	1st January 2016	3.4	$9*n^{-0.2}$ eg., 720rpm-2.4	2.0

Source: IMO. (2013a). *MARPOL how to do it*. London: Author.

At present, there are 4 global emission control areas designated by the Annex VI, the Baltic Sea region and the North Sea region in Europe, North America area, the Caribbean region of the United States (MARPOL Convention (2011)), the two emission control areas of the Baltic Sea and the North sea are only controlling the SOx emissions; while emissions control area of North American and the Caribbean controls the SOx, NOx and PM emissions. Waters under the jurisdiction of the Chinese government has not set up emissions control area, including the Shanghai Port and its waters (Zhu, 2014). As shown in figure 4.1.

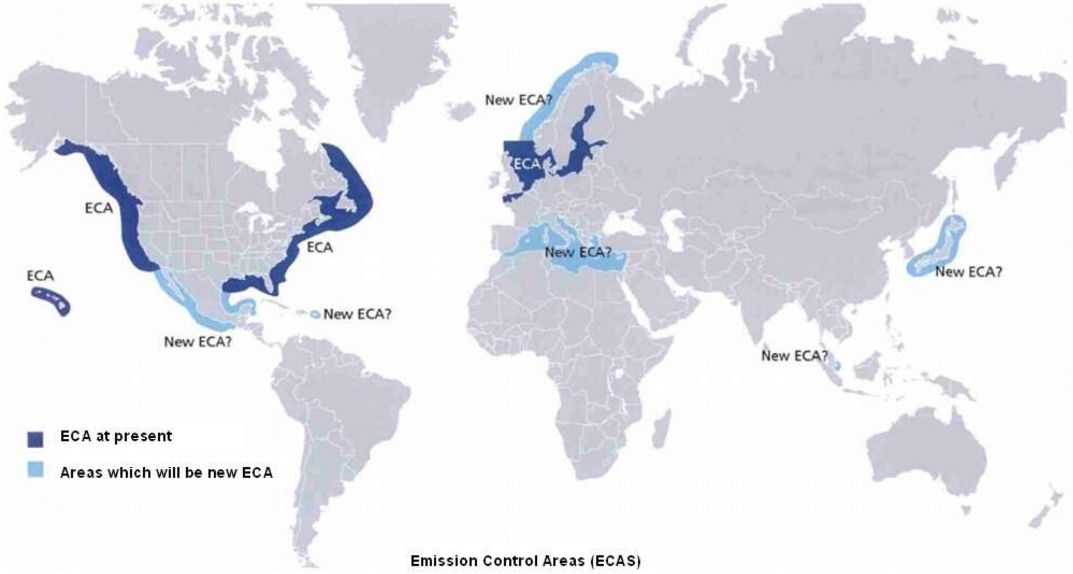

Figure 4.1 - The international ECAs

Source: (Zhang, 2014).

4.1.2 Domestic rules

It is regulated in the Marine Environment Protection Law of the People's Republic of China (Marine Environment Protection Law) that within the sea areas under the jurisdiction of the People's Republic of China, any vessel and relevant operation shall not be in violation of the provisions of this Law from discharging pollutants, waste, ballast water, vessel garbage and other harmful substances into the sea (Marine Environment Protection Law (1999)).

Water Pollution Prevention and Control Law of the People's Republic of China (Water Pollution Prevention and Control Law) regulates that the vessel shall be equipped with appropriate anti-pollution facilities and equipment in accordance with the relevant regulations of the state, and possess legally effective certificates and documents of prevention of water pollution (Water Pollution Prevention and Control Law (2008)).

In the Atmospheric Pollution Prevention and Control Law of the People's Republic of China (Atmospheric Pollution Prevention and Control Law), atmospheric pollutants emitted by ships shall not exceed the emission criteria (Atmospheric Pollution Prevention and Control Law (2000)). But the law did not mention the specific emission criteria, which points to relative rules without a clear delimit.

It is regulated in the Regulations on the Administration of Prevention and Control of Pollution to the Marine Environment by Vessels (Vessels Pollution Prevention and Control Regulation) that the ship's structure, facilities, equipments shall be in conformity with the relevant technical specifications of prevention and control of pollution to the marine environment of China as well as demands of the international conventions concluded or participated by the People's Republic of China (Vessels Pollution Prevention and Control Regulation (2009)).

Thus it can be seen that China didn’t formulate specific laws or regulations on marine gas emission criteria for international seagoing ships entering and leaving waters under the jurisdiction of Chinese government, but still using regulations of international conventions as technical criteria. As to Chinese coastal ships, although China's domestic laws and regulations set relative administrative management rules, there are no detailed emission criteria on specific ship emissions. The only one national standard ship gas emission is the effluent standard for pollutants from ship (GB 3552-83) promulgated in 1983, but it just aims at only for controlling the emission and disposal of waste water and garbage of ships (Tang, 2014).

In recent years, the MSA of Ministry of Transport of the People’s Republic of China established the statutory inspection rules for ships and offshore facilities - technical rules of statutory inspection on Chinese coastal ships, as mandatory rules of domestic seagoing ships, which covers the technical standards of ship emissions.

In the statutory inspection rules for ships and offshore facilities - technical rules of statutory inspection on Chinese coastal ships, it is regulated that since 1st September 2009, sulfur content of any fuel used by Chinese coastal ships should not be more than 4.5% m/m. NO_x emissions of diesel engine of ships constructed on and after 1st September 2009 should be controlled within the limits prescribed in table4.3. Table 4.3 is shown as follows.

Table 4.3 - Standard for emission of NO_x by marine diesel engines （Chinese coastal ship）

Ship construction date (on and after)	Total weighted cycle emission limit (g/kWh) n= engine's rated speed (rpm)		
	n < 130	n= 130-1999	n≥2000
1st September 2009	**17.0**	**$45*n^{-0.2}$**	**9.8**

Source: China MSA. (2008). *Statutory Inspection Rules for Ships and Offshore Facilities - Technical Rules of Statutory Inspection on Chinese Coastal Ships*. Beijing: Author.

In addition, the research institute on environmental standards of China's Ministry of Environmental Protection has completed the limits and measurement methods of gas emissions of vessel compression ignition engine (the first and second stages of China) (draft) ", and on August 15, 2014 the ministry completed the comment collection. But it does not perform substantial controlling function in the gas emission of Chinese coastal ships (Kuang, 2014).

4.2 Current measures of Shanghai Port

4.2.1 Local acts and regulations of Shanghai city

On September 1, 1996, Shanghai government announced the NO.8 Bill to implement the Regulations on the Administration of Prevention of pollution to the Marine Environment by Vessels in waters of Shanghai Port. It is regulated that, the ship structure and equipment of preventing the marine pollution, shall be in conformity with the requirements of relevant national criteria, and hold the corresponding effective antipollution certificate (Ding, 2013). However, it mainly focuses on controlling oil, bulk toxic liquid, sewage and waste emissions from vessels.

Until September 26, 2014, Shanghai government launched the Shanghai Water Area Environmental Management for Ship Pollution Prevention and Control Measures (revised draft), which improved the emissions of ships, increased the control on air pollutant emission of the ships. The draft requires that the fuel used by ships sailing, berthing or operating in Shanghai Port water area shall comply with the relevant provisions of China and Shanghai city, while international ships shall also meet the requirement of the international conventions that China joins. In addition, the anti-pollution structure, equipment, facilities of Chinese and foreign ships shall be correspondingly abide by the laws, regulations and the relevant national norms and standards of China government, and relevant international conventions concluded or joined by the People's Republic of China.

It is obvious that the revised draft still refers to national laws and regulations of China and the international conventions China joining, does not made particular or higher criteria to the marine gas emissions in Shanghai Port. Meanwhile, actually the draft doesn't have a real control function of the marine emission in Shanghai Port because it is still in the stage to solicit opinions.

4.2.2 Technical measures

In 2010, Shanghai Port developed the first mobile shore-based marine high power supply system with variable frequency and pressure, and in March of 2010, the trial succeeded in the container terminals in phase two of Waigaoqiao port area. The system is mainly composed of substation, power supply system of frequency and pressure conversion, extension cable, ship electric connection equipment. 380V/50Hz electricity of shore-based power grid, after frequency and pressure conversion system, the current and voltage raises to 60 Hz and 440 V respectively, then with nine cable connecting with ship power system, supplies for ship electricity (Bao & Zhang, 2010).

In addition, in the construction of terminals in phase six of Waigaoqiao port area, 17 high-voltage electric box of 10 kV / 2000 kVA are arranged on the1008 m long berth, the input of power supply of variable shore power is 10 kV / 50 Hz, the output voltage is 440 V, the output frequency is an option of 50 Hz or 60 Hz. The device of frequency and pressure conversion is installed within the container, or placed on a shore or barges. Frequency conversion power on berth can cover the international seagoing ships of China Shipping Container Lines (Bao, 2010).

In addition to the container terminal, Wusong international cruise terminal and the international passenger port (Waigaoqiao port area) of Shanghai reserved space for the power supply device and electric cable channel during construction, preparing facilities for the use of shore power.

In summary of above analysis, there are mandatory controlling requirements on marine gas emissions of ships entering and leaving Shanghai Port both in the international conventions set by the IMO and laws, regulations of China government, Shanghai Port has already have trial on marine shore power technology gradually (only in Waigaoqiao port area at present), but obviously these are minimum international standards for control of marine gas emissions. While as the port with the biggest cargo throughput and container throughput in the world, it is apparent that Shanghai Port should not just meet the international minimum standards in management and control of marine polluting gas emissions It can neither match with the status of NO.1 port in the world, nor cope with the serious problem of exhaust gas pollution of ships bringing with such a huge cargo throughput in the Shanghai Port.

4.3 Research on controlling measures and experiences of other ports

4.3.1 Chinese ports

In 2011, Hong Kong actively promoted voluntary agreement on reducing the marine gas emissions - Fair Winds Charter- which was signed by 18 ocean shipping companies, and promised that all ocean-going ships berthed at the Hong Kong port would use fuel with low sulfur content as far as possible by the end of 2012. For the continuation of Fair Winds Charter to the improvement of air quality in Hong Kong, the Hong Kong government began to introduce a three-year program of changing fuel when berthing on September 26, 2012 (Ma, 2014), and cut half of use fees on port facilities and beacon to the oceangoing ships which switch to fuel with sulfur content not higher than 0.5% in port of Hong Kong.

While on September 20, 2013, in Shenzhen, the government issued "the promotion plan on air quality of Shenzhen", which put forward the relevant incentive policy (Peng & Hao, 2014). For the construction of shore power supply facilities, the Shenzhen government provided local subsidies on the basis of current special funds in the energy-saving and emissions-reducing program rewarded by the Ministry of Transport of China, in order to make the total subsidy and reward accounting for 50% of the construction cost of the shore power system. Since January 1, 2014, oceangoing ships using low sulfur fuel (before December 31, 2014, sulfur content is less than 0.5%; after 1 January 2015, sulfur content is less than 0.1%) during berthing period, are rewarded 75% of the fuel price difference by the financial subsidy, and then evaluate the effect of subsidy policy, subsequently adjust the subsidy scheme according to the evaluation conditions.

4.3.2 International ports

As the introduction in section 4.1.1 of this chapter, IMO reviewed and passed the four marine gas emissions control area- the Baltic Sea area and the North Sea area in Europe, North America area and the Caribbean area in America, ships entering and berthing at these areas must meet special gas emissions standards promulgated by the IMO. Except for submitting proposals to relevant international organizations to form a globally recognized international control measures, many ports of European and American countries have taken many other control measures on marine gas emissions.

At present, the EU implemented mandatory emissions-reducing measures on berthing ships to use low sulfur fuel. Since January 1, 2010, ships moored in the EU ports (including anchoring, lie at pontoon, berthing) more than 2 hours can not use fuel with sulfur content more than 0.1% (this requirement does not apply to ships stopping all the machines and using shore power); after docking, ships should convert into low sulfur fuel as soon as possible (sulfur content is less than 0.1%), and before sailing, ships should delay switching to high sulphur fuel as far as possible; Fuel conversion operations shall be recorded on the log (Peng & Hao, 2014).

The California state of America carried out the compulsory emissions-reducing measures on January 1, 2014 to enforce berthing ships to use shore power. It is requested in the Chapter 17 Section 1 Subsection 7.5 part 93118.3- " control of toxic air pollutants of auxiliary diesel engine of oceangoing ships berthed in California ports " of the California law that container ship (ships of the same company berthed in California port for more than 25 times a year), passenger ship (ships of the company berthed in California port more than 5 times a year) and refrigerator carrier must increase the proportion of switching off the engine and using shore power when berth at the California port since January 1, 2014. The law regulated that the proportion of times of ships of shipping companies using the shore power when berth at each California port out of the total times of ships berthing at the California port should reach 50% during 2014 and 2016, which reach 70%during the period of 2017 to 2019, 80% after 2020. If the ships can not meet the above requirements, each time a fine of 1000-75000 dollars will be imposed according to the circumstance (Li, 2015).

Given that ships sailing at low speed will reduce gas emissions, since January 1, 2006, the Long Beach port of the United States launched "green flag" program of reducing the speed of ships voluntarily joined by shipping companies, encouraging ships sailing within 20 n mile near the coast (which extended to 40 n mile in 2009) to slow down the sailing speed under 12 kn (Yang, 2013). The maritime exchange center of southern California was in charge of detecting and recording the ship sailing speed, and with 12 months as a time unit, doing statistics of implementation conditions of the "green flag program". If ships berthed at the Long Beach port 100% implement the "green flag program" in 12 months, they will receive the green flag as a award to the environmental protection achievement; If the ratio of ships of a shipping company implementing the "green flag program" reached 90% within 12 months, the port will reduce 15% of charges the next year.

Above all, the control measures on marine gas emissions all over the world can be divided into: Economic incentive policies, namely provide economic subsidies for ships taking various measures to reduce the marine gas emissions; Technical supporting policy, mainly are the development of shore power technology, by supplying shore power to ships to reduce emissions; Local enforcement policy, namely mandatory measures made by the local port or local ports group to reduce gas emissions of ships berthed; International mandatory policy, namely made by the local port or local ports group then submitted to the international organizations and approved by them to reduce marine gas emissions policy, at present mainly implementation of emission control areas (ECA) reviewed and passed by the IMO after being proposed.

4.4 The further measures that Shanghai Port could take

As mentioned in section 4.2, currently controls on the marine gas emissions from vessels entering or leaving Shanghai Port are very limited. As the world's largest port in the cargo throughput, Shanghai Port almost completely ignores this problem. Taking all measures taken by other domestic and international ports into consideration, Shanghai Port can take more measures, including shore-based power technology, fuel conversion, slowing down ship’s speed, technology of exhausted marine gas disposal, setting up ship emissions control area (ECA), etc, as well as some incentive or mandatory policies combined with the actual conditions.

4.4.1 Shore power technology

Now marine fixed shore power system, the barge type shore power system and mobile shore power system have been put into practical use, which proves that these technologies are available. Some key difficulties, such as the differences of terminal and ship's electrical system, frequency and pressure conversion technology which affected use of shore power, have been worked out. Meanwhile, container ships are asked to stop auxiliary engines and accept shore power supply berthed in Shanghai Waigaoqiao port area in 2010 as a trial. So, in Shanghai Port it is mature to develop the marine shore power technology.

It is shown that in most cases, the gas emissions from ships which use the shore power is just 0.3% of those from ships using auxiliary engine. While, in any cases, marine air emissions of ships using shore power when berthing will be reduced by 92.8%, among which the NO_x by 99%, the PM by 83% to 97% (Ding, 2013). At the same time, the use of shore power will basically solve the problem of the funnel smoke pollution and noise, which will produce larger social and environmental benefits.

But the marine shore power technology is only available to ships in the period of berthing, unable to reduce the gas emissions when ships entering or leaving ports.

4.4.2 Fuel conversion

Fuel conversion measures mainly refer to the change to low sulfur fuel or liquefied natural gas (LNG) when ships are entering or leaving ports. Now it is quite popular to change the common marine fuel into low sulfur fuel.

The density of SO_2 and particles mainly consisting of sulfate in ship’s funnel gas is proportional to the volume of sulphur in the fuel oil. Therefore, even without any emissions control equipment, to switch to low sulfur oil alone can also reduce the emissions of SO_2 and PM of the ship directly. It has been shown that as sulfur content of marine fuel declines from 2.7% to 0.5%, SO_2 emissions will be reduced by 82%, and the PM emissions will be reduced by 75%; As sulfur content of marine fuel down to

0.1%, SO_2 and PM emissions will fall by 96% and 96% respectively (Zhou, 2014). But there is no study showing that using low sulfur fuel can lead to the reduction of ship's NO_x emission obviously.

Although now the LNG powered ship is not very common, the European and American countries have begun to research and develop and promote it actively, especially the application in the inland river ships and the seagoing ships. At present, LNG is a recognized green fuel, and using LNG as marine power can almost completely reduce the emissions of SO_2 and PM, and 85% ~ 90% of NO_x emissions (Zhu, 2014), which is fully compliant with emissions requirements of SO_2 and NO_x in international conventions and national strict laws of countries on marine gas emissions. But it is impossible for the Shanghai Port to require international seagoing ships to be equipped with LNG power. It is more reliable to request inland river ships and seagoing ships operating within port to be powered by LNG in the Shanghai Port.

4.4.3 Reducing speed of ships entering and leaving port

By reducing ships' sailing speed to reach the target of controlling the marine gas emissions, to some extent, the effect depends on the reduction margin of speed, the type of fuel and ship engine. The rule is that a 10% drop in ship speed can lead to a 15-20% reduction of the fuel consumption, thereby marine gas emissions will also be reduced accordingly (SCG, 2012).

Currently for the safety of navigation, Shanghai Port carried out a speed limit in some channels, for example, it can not overtake 8 knots in the Huangpu rive, and 12 knots in the south channel of the Yangtze River Estuary. In other waterways, such as Yangtze estuary deepwater channel, Yangshan deepwater channel and Jinshan channel, there is no speed limit, and ship's average speed can reach 15 knots (Fu, 2012), of course, in these channels Shanghai Port can also limit ships' speed besides the container ships.

4.4.4 Technology of exhausted marine gas disposal

Exhaust gas scrubbers can remove SOx, particles and other pollutants of the engine exhausted gas. Over years, the technology has been successfully used in industrial field, but the popularity rate on ships is still very limited. The test results show that the scrubber can greatly reduce the SOx emissions, and the removal rate is higher than 90%;

and could efficiently reduce PM emissions, removal rate is about 30% ~ 98% (DNV, 2013). Therefore, as long as the design is proper, the pollution caused by the use of high sulphur fuel can be worked out by scrubbers to meet the demand of fuel sulfur content of 0.1% in ships emission control area (ECA), but the NOx emissions cannot be controlled by scrubbers.

At present, some of other technologies to control the exhausted NOx emissions are also introduced in the shipping industry, including selective catalytic reduction (SCR), exhausted gas recirculation (EGR). SCR is a technology of controlling NOx installed in the rear of the engine, which can convert NOx into N_2 and water under the action of catalyst and ammonia. According to different operating conditions, the SCR devices on the ship can remove 70% to 90% of NOx, and ideally over 90%. Now it is recognized as the only technology of NOx emission reduction that can be used for all types of ships and ships' engines (IMO, 2013b).

Similar to SCR, EGR technology has been successfully applied in NOx emission control of motor vehicles. It shows in practice that even if the fuel with high sulphur content is in use, EGR also can remove 75% of NOx, and also can meet IMO level III standard on ships' nitrogen oxides emissions in the case of a single application of the technology. If fuel with high sulfur content is used, EGR and the scrubbers are suitable to be installed, sulfate and particles of the exhausted gas will be removed instead of coming back to the engine, to meet the NOx and SOx standard of ECA (IMO, 2013 c).

Due to the fact that seagoing ships entering Shanghai Port may also sail to the European and American countries, where there are a lot of ship emission control areas, so it is feasible for Shanghai Port to request gradually that international ships must be equipped with exhausted gas disposal technology. At the same time, with the maturity of the technology and the gradual decline of the cost, Shanghai Port should promote their use in domestic sailing ships at the right time. But it should be pointed out that exhausted gas disposal technology and fuel conversion measures in section 4.4.2 have certain overlaps, which should be taken into consideration when Shanghai Port starts to implement vessel pollution emissions control measures.

4.4.5 Setting up ship emissions control area (ECA)

It should be pointed out that to set up the ECA is currently the most effective measures of controlling vessel pollution emissions.

North America emissions control area is the only comprehensive ECA, it also limits the SOx and NOx emissions. In 2020, compared with areas without ECA scheme, it is expected to reduce 23% of NOx emissions, 74% of $PM_{2.5}$ and 86% of SOx; By 2020, it is also expected to reduce premature deaths 5500 to 14000 people, 3800 emergency cases, and 4.9 million cases of acute respiratory; By 2030, it can reduce 31000 people of premature deaths; its overall health benefits are expected to reach about $47 billion to $110 billion; By 2020, the total cost of the North America ECA is expected to be about $3.2 billion (USEPA, 2010). Thus, the ECA policy is also very economic. It is estimated that after the North Sea and Baltic ECA in Europe implement low sulfur fuel standards, their health and environmental benefits will be four times of the cost. North America ECA carried out a strict standard of NOx, SOx and PM emissions, which brings 10 times benefits higher than the cost.

Shanghai could ether set up the ECA through local legislation like California state of America or submits a proposal to IMO to set up the ECA of ships and carries out international compulsory measures after being approved by IMO. Now the latter method is more common and easily recognized. It should be pointed out that, Shanghai Port had better apply for ECA in the form of Yangtze River Delta port group, which is easier to be approved. By using this method, Chinese government needs to apply to the IMO and supply the following information (Peng, 2014): the clear description of ECA and reference charts with the marked areas; the type of controlled gases, for example NOx, SO_2 and particulates; the affected residents area; the assessment report on the impact of marine emissions in the suggested ECA on the neighboring environment; the suggested area for ships emission control and related meteorological materials of the suggested ECA and the threatened population and environment; ships' sailing conditions in proposed ECA, including the navigation model and density of ships; the measures implemented on controlling pollution source; and the instructions on the relative cost of reducing marine emissions and the impact on the shipping economy related to international trade compared with the control measures on land.

The above analysis shows that it is a trend for Shanghai Port (or the Yangtze River

Delta port group) to set up the ECA to implement the ship pollution emissions control measures. It can not only avoid the conflict between requirements on the fuel conversion and the exhausted gas disposal technology, but also compensate the fault of shore power technology, meanwhile in the long run and from the economic perspectives, its environmental and social benefits will be several times of the cost. Shanghai. Of course, Shanghai Port needs to clarify its development strategy and balance the relationship between economic development and environmental benefits. If the strategy of Shanghai Port focuses on economic development, it is suitable for Shanghai to adopt the flexible measures to control marine gas emissions, through mixing above measures, and providing some economic subsidies or port discounts scientifically and reasonably, then Shanghai Port will gradually transit to implement the international compulsory ECA and other compulsory measures.

4.5 Summary of this chapter

Through the literature review in this chapter, it is concluded that controls on marine gas emissions in Shanghai Port is very limited at present. Ships entering and leaving Shanghai Port mainly obey the rules of the MARPOL convention and regulations of Chinese coastal ships, control measures of Shanghai Port are almost the lowest international standards.

However, Hong Kong actively promotes ships fuel conversion, offers discount of port fees; Shenzhen port provides subsidies for the construction of marine shore power, and subsidies for the price difference of fuel conversion of seagoing ships entering and leaving port; some ports in Europe and the United States push for mandatory emissions-reducing measures on marine gas emissions which are higher than the criteria of international convention.

Shanghai Port as the largest port in the world, the times of seagoing ships entering and leaving the Shanghai Port are significantly huge. So it is necessary to use the experience of other ports to take further measures to control the marine gas emission of ships. Through comprehensive study, in this chapter the author sums up the controlling measures which are suitable for Shanghai Port, such as the development of shore power technology, fuel conversion, reducing ship speed, disposal of marine waste gas, setting up emissions control area, etc. By analyzing the characteristics of the various control measures and the actual situation of Shanghai Port, the author points out that setting up the ECA is a long-term solution to marine gas emissions in Shanghai Port.

CHAPTER 5

SUMMARY AND CONCLUSION

The paper analyzes and summarizes the current research situation of marine gas emissions in China and in the world, puts forward the main research goal to analyze and calculate total gas emissions of Shanghai Port from 2010 to 2013. Focusing on the current control measures on marine gas emissions of seagoing ships in Shanghai Port, the author explores and refines other measures and experience of ports of China and European and American countries, and chooses suitable measures according to the actual characteristics of Shanghai Port, then puts forward further control measures that Shanghai Port could take. The specific research process and conclusion of the paper is as follows.

First of all, after visiting Shanghai MSA, the author collected and organized the data and information of Shanghai Port, berth and ships enter and exit history. Through reviewing and sorting up these data, the paper performs a general introduction and identification to Shanghai Port. And research shows that the bulk carrier berth has the highest proportion of Shanghai Port, achieving one fifth of the total number of berths. The following two types are general cargo ship berth and oil tanker berth. As a worldwide famous port with a huge container throughput, container ship berth only accounts for 7% of total number of Shanghai berth, which fully illustrates the efficiency of container berth in Shanghai Port. In addition, the passenger ship berth and ro-ro ship berth constitute a large percentage of berths in Shanghai.

In order to build a data foundation for the calculation of annual marine gas emissions of Shanghai Port from 2010 to 2013, the author carefully organizes the data of port throughput and traffic flow of ships entering and leaving Shanghai Port from 2010 to 2013 which are collected from the Shanghai MSA. In particular, the author seriously classifies the traffic flow data of ships entering and leaving Shanghai Port from 2010 to

2013 according to the navigation area, ship type and ship tonnage -the three aspects. Statistics show that in addition to the rapid growth of some individual data, the changes of the distribution in different types and DWT levels of ships entering and leaving Shanghai Port from 2010 to 2013 are slight.

Based on the report of data analysis of emissions from commercial ships and fuel consumption published by the USEPA and the white paper on prevention of ships and ports pollution issued by the Natural Resources Defense Council (NRDC), the author chooses the main pollutants -NO_x, SO_2, PM_{10} and $PM_{2.5}$ emitted by ships as the research subjects, and sea-going ships within Shanghai Port as the main research scope in the time period from 2010 to 2013. By comparing, the author selects the method based on ship engine power to calculate the total gas emissions of the seagoing ships in Shanghai Port. After a detailed and deep analysis of each element in the calculation formula and inputting each data to calculate, the annual Shanghai ships pollution gas emissions between 2010 and 2013 are acquired.

The study indicates that annual gas emissions of seagoing ship in Shanghai Port from 2010 to 2013 are $9.70*10^4$t, $11.37*10^4$t, $11.09*10^4$t and $10.75*10^4$t . 2011 saw a great growth in the total emission increased by 17.22%. In the following years, annual total pollutants fell generally, by 2.46% and 2.46% respectively in 2012 and 2013. According to the table 2.4, there is a structural adjustment of the types of ships in and out Shanghai Port. The specific situation is, that the types of ships with obvious change in the times of entering and leaving Shanghai Port from 2012 to 2013 are tug and general cargo ship -tug increasing year by year, while general cargo ship reducing year by year with the decline rate 23.49% and 12.16% respectively. This demonstrates that the sharp drop of times of general cargo ships entering and leaving Shanghai Port is the primary reason of lower annual gas emissions of seagoing ship in Shanghai Port. And it can be predicted that if the structural adjustment of ship types in Shanghai Port sustain, annual marine gases emissions of seagoing ships in Shanghai Port will fall gradually.

Meanwhile, research shows that the NO_x emission of sea-going ships in Shanghai Port is the highest, overtaking half of the sum of all pollutants. The one in the second place is SO_2, which also occupies a large proportion (31.1%) in all pollutants. Therefore, the main polluting gas emissions in Shanghai Port are NO_x and SO_2. And the container ship contributes the most proportion to SO_2 and NO_x emissions in Shanghai Port. Its share rates are 73.1% and 78.0% respectively. Moreover, among various types of ships, emissions of container ships are the highest, representing over three-quarters of the total pollutants. This results from the prosperity of container ship transportation in Shanghai Port, which is on the top of times of ships entering and leaving port among different types of ships (See figure 2.4), especially the international container ship with large engine power. Following two types are bulk carrier and general cargo ship, which make up 10.0% and 5.8% of the total emission respectively.

Shanghai Port is an international port with the largest cargo throughput and container throughput in the world. After the study of international conventions and Chinese regulations as well as collecting and organizing the data of Shanghai Port, the author finds that its control measures on marine gas emission are very limited, almost the international minimum standards. By analyzing and refining the measures and experiences of other ports, and combining with the reality of Shanghai Port, the study sorts out that there are several further measures on gas emissions of seagoing ship which are suitable for Shanghai Port, including marine shore power technology, reducing speed of ships entering and leaving port, and exhausted marine gas disposal technology. Meanwhile, the study shows that setting up the ECA is a long term solution for Shanghai Port to control the marine gas emissions.

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