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# Research on sulfur emission control of ships in China

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# RESEARCH ON SULFUR EMISSION CONTROL OF SHIPS IN CHINA

By

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# DECLARATION

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

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

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ABSTRACT

Title of Dissertation: **Research on Sulfur Emission Control of Ships in China**

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Marine transport has played a huge role in supporting and promoting the development of global trade. However, the serious pollution it brings could not be ignored, especially the problem of sulfur emissions, which could affect the balance of ecosystems, causing serious harm to agriculture, forests, aquatic resources and buildings.

IMO has paid attention to the problem of sulfur oxides emissions for a long time, adopting the Annex VI 2008 Amendments of MARPOL 73/78 Convention to stipulate the standards of sulfur emissions in ECAs and other areas respectively.

The shipping industries have devoted much time to the research on technology of sulfur emission reduction on ships, including using low sulfur fuel oil, exhaust gas cleaning system and new resource. However, the Chinese manufacture has scarcely grasped advanced technology, while the shore electricity was gradually installed in some Chinese ports.

In China, the state government and local administration have adopted lots of policies in accordance with IMO Convention on the basis of Chinese marine pollution. In addition, the supervision of the MSA in sulfur emission control would be also analyzed.

The conclusions are addressed on the basis of the applicability of different technologies and the condition of shipping market.

**KEY WORDS:** sulfur emissions, reduction, technology, China, shipping, policies

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| | |
|---|---|
| $NO_X$ | Nitrogen Oxides |
| $SO_X$ | Sulfur Oxides |
| ppm | Parts per million |
| EU | European Union |
| MARPOL | International Convention for the Prevention of Pollution From. Ships, 1973 as modified by the Protocol of 1978 |
| DWT | Dead Weight Tonnage |
| MSA | Maritime Safety Administration |
| IMO | International Maritime Organization |
| | European Union |
| ECA | Emissions Control Areas |
| EPA | Environmental Protection Agency |
| SECA | Sulfur Emissions Control Areas |
| TEU | Twenty-foot Equivalent Unit |
| $NO_X$ | Nitric Oxide |
| PM2.5 | Particulate Matter2.5 |
| CO2 | Carbon Dioxide |
| LNG | Liquefied Natural Gas |
| MGO | Marine gas oil |
| HFO | Heavy Fuel Oil |

| | |
|---|---|
| IMF | International Monetary Fund |
| EPA | United States Environmental Protection Agency |
| SSB | Ship Safety Bulletins |
| CSD | China Shipping Database |
| CTD | China Transportation Department |
| HKEPD | Hong Kong Environmental Protection Department |
| EMSA | European Maritime Safety Agency |
| DEPA | Danish Environmental Protection Agency |
| EGCSA | Exhaust Gas Cleaning Systems Association |
| IEA | International Energy Agency |

# CHAPTER 1

# INTRODUCTION

## 1.1 Shipping development brought about pollution

Marine transport is the most important mode of transport in international trade currently, and the number of ships would grow with the increase of the world economy. Compared to the railway, road and air transport, the ship has advantages of higher capacity and lower freight, so about 90% of the cargoes in the world were transported by ships and the percentage was expected to continue to grow. (V. Andreoni, 2008) The International Monetary Fund predicted that the growth rate of world economy in 2017 would be 3.5%, and it would reach 4% in 2020. (IMF, 2017) According to statistics provided by Bremen Maritime Economics and Logistics Institute, it showed that the number of ships owned by world merchant fleet was 50,064, and the total DWT was 163,547 by July 1, 2014. (Manivannan N, 2014) The prospects for shipping industry would continue to be strong.

The growth of international trade would encourage the shipping industry, and the increase in marine capacity would also promote the increase in international trade, so the relationship between marine transport, new shipbuilding and the world economic growth is meaningful. Marine transport has played a huge role in supporting and promoting the development of global trade, but the serious pollution it brings could not be ignored.

As maritime transport has undergone a rapid development, the number of ships has increased dramatically as well, and the data showed that the ship emissions have occupied 10% of air pollution by 2010. (Wang, 2010) Moreover, it showed that sulfur oxides emitted by ships accounted for 5% of the world's total emissions. In addition, in some coastal ports, sulfur oxides emitted by ships accounted for 30% of the total local emissions, so the air pollution caused by ship was stringent. (Du, 2010)

## 1.2 Hazards of sulfur emission from ships

The fuel oil used by ships would emit $NO_X$, $SO_X$ and other harmful gases because of poor quality, while $SO_X$ has become the most serious pollution to the atmospheric environment. The source of $SO_X$ was different from that of $NO_X$, and it came from the impurity sulfur in the fuel only. When the fuel was burned,95% of the element was released into the atmosphere in the form of gaseous $SO_X$, and the remainder of the sulfate was present in the form of ash or particulates. Sulfur existed in the fuel oil in the form of both organic and inorganic states, the combustion of which would be oxidized into sulfur dioxide, which would be further oxidized into sulfur trioxide under certain conditions. In theory, if the combustion was sufficient, the vast majority of sulfur dioxide would be oxidized to sulfur trioxide, but the actual discovery showed that sulfur trioxide only occupied 1% to 5% among the marine engine exhaust. (Zhou, 2006)

Sulfur dioxide is strong in irritating colorless gas, and it is easy to dissolve in the human blood and other forms of viscous liquid. If the volume concentration of $SO_X$ reached 20ppm, it would stimulate human eyes and cause cough. Long-term exposure to the body in the high concentration of Sulfur dioxide would lead to chronic poisoning, as well as the loss of ability in smell and taste. If the volume concentration of sulfur dioxide increased to 400 ppm further, it would make people's breathing blocked, and might cause respiratory irritation, chest tightness, bronchitis, asthma, knitting emphysema, and even death. In addition, excessive sulfur dioxide in the atmosphere could form acid rain, affecting the balance of ecosystems, causing serious harm to agriculture, forests, aquatic resources and buildings. (Wang, 2010)

According to the research of EU, the sulfur dioxide emissions of ships in Europe sea area increased year by year. If no measure was adopted, it was estimated that the European ship sulfide emissions would grow by 40% or more from 2000 to 2020. (Ren, 2016)

## 1.3 Objectives of research

The primary purpose of this research is to illustrate which mode is suitable for different ships through comparing different technologies of sulfur emission reduction. The subsequent objective would give suggestions on the basis of analyzing the supervision mechanism of reduction in the ship's sulfur emission in China.

## 1.4 Methodology

The related literature was widely reviewed, including international conventions, IMO documents, articles from academic thesis, contemporary journals, books and information from websites. Opinions were exchanged and advice was taken after visiting various oil companies, and shipping companies. Furthermore, the data supplied by MSA and Dalian Maritime University help to analyze this condition sulfur emission in China more definitely.

## 1.5 Structure of this dissertation

This dissertation consists of six chapters. Chapter two discloses the current regulations for sulfur emission reduction by analyzing the related MARPOL Convention and the directives of EU and North America, and highlights the regulations would become more and more stringent. Chapter three provides an overall analysis of sulfur emission of ships in China, emphasizing the severe situation especially in large coastal cities. Chapter four introduces three modes installed on ships that were considered to reduce the $SO_X$ emissions effectively, as well as shore electricity. Chapter five mainly concentrates on the measures adopted by Chinese administration, which include the policies and suggestive supervision in terms of sulfur emission reduction of the ships in China. Finally, the last chapter is about the overall summaries and conclusions.

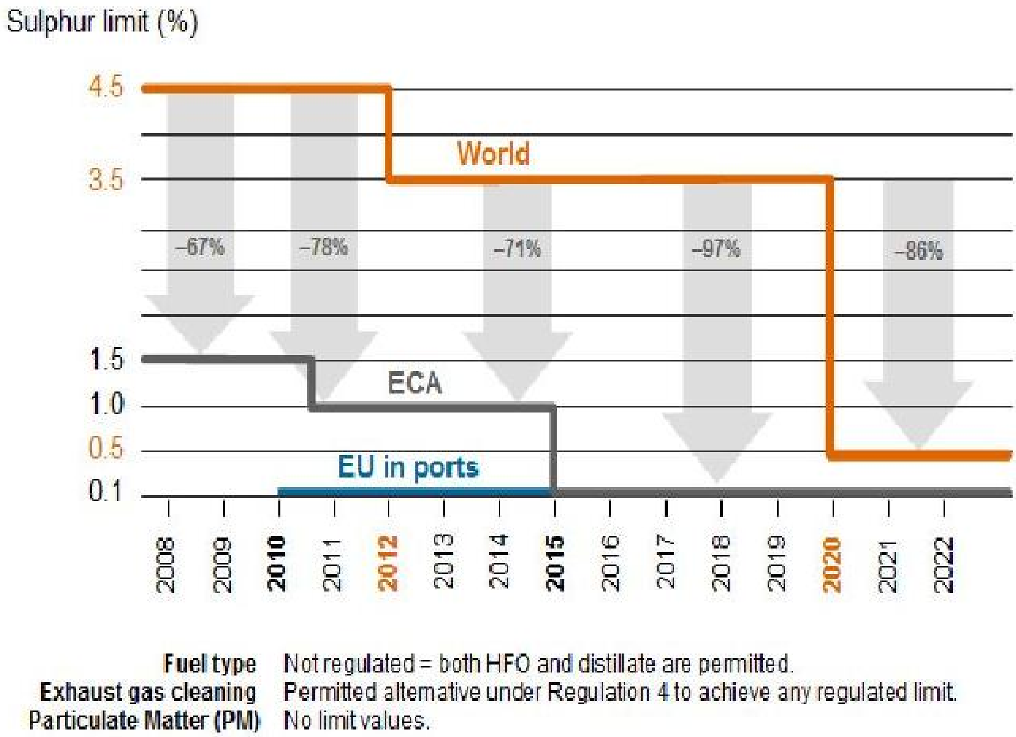
# CHAPTER 2

## Analysis of regulations for sulfur emissions reduction of ships

### 2.1 MARPOL Convention for sulfur emissions reduction of ships

The Annex VI of 2008 Amendments of MARPOL 73/78 Convention adopted by the IMO has been put into force since 1 July 2012. As the Article 14 clearly shows (Figure 2.1), for the area out of SECA, the maximum fuel sulfur content should be 3.50% after January 1, 2012. Moreover, it should be under 0.50% after January 1, 2020. The Convention stipulates that the implementation of the standard of 0.50% should be reviewed before 2018, and if the shipping industries could not be complied with, the standard described should enter into force on 1 January, 2025. (IMO, 2011) Nevertheless, on October 27, 2016, IMO agreed to limit the sulfur content of ship fuels to under 0.5% by 2020 mandatorily after intense discussions and arguments at the MEPC 70.

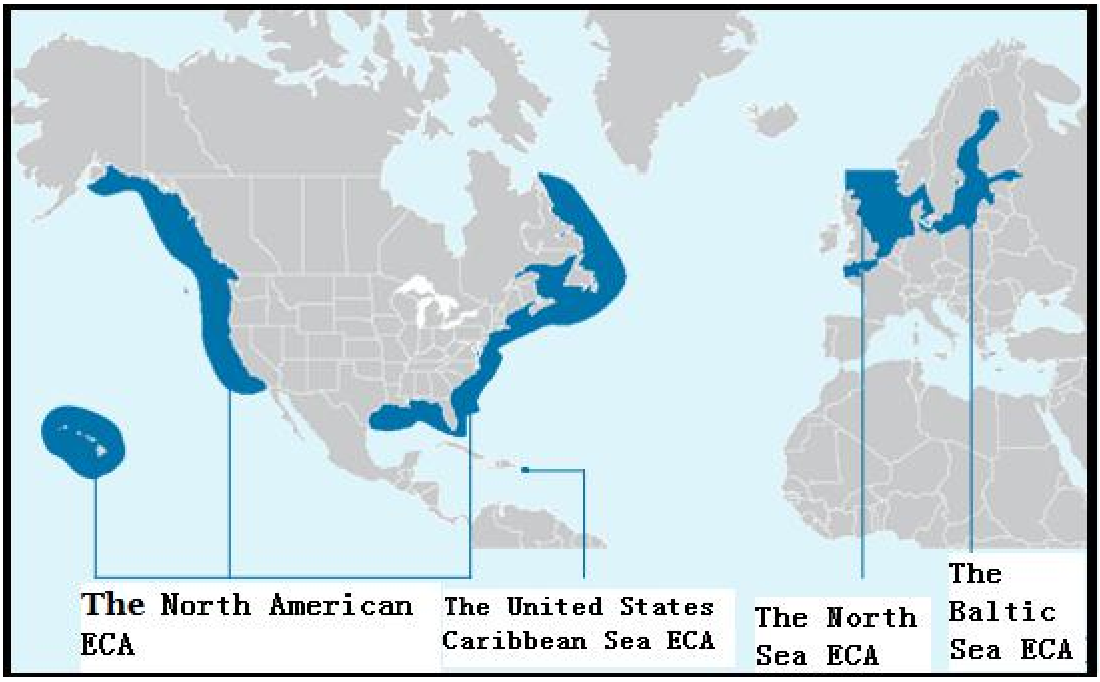
**Figure 2.1 Time table of enforcing sulfur emission control**




**Source: Annex VI of 2008 Amendments of MARPOL 73/78 Convention**

In terms of SECA, from 1 July 2010, the maximum fuel sulfur content should not be more than 1%. Moreover, from 1 January 2015, sulfur content should not be more than 0.1%. As is illustrated Figure 2.2, it is necessary to note that the control areas include the Baltic Sea ECA, the North Sea ECA, the North American ECA and the United States Caribbean Sea ECA.

**Figure 2.2 The geographical location map of ECAs**




**Source: Annex VI of 2008 Amendments of MARPOL 73/78 Convention**

## 2.2 EU directive for sulfur emissions reduction of ships

The sulfur oxide emissions control areas of EU mainly include the Baltic Sea EC and the North Sea ECAs. In addition, passenger ship sailing between ports within EU, inland vessel and seagoing ships sailing in Inland River should also obey the corresponding regulations. The EU promulgated relevant laws of ship emissions control from the technical level, the EU Council Directive2005/33/EC (EU, 2005)and EU Council Directive 2012/32 / EC (EU, 2012), which were regarded as the main standards, as is shown in Table 2.1 and Table 2.2.

**Table 2.1 The Standards for sulfur content of ship fuel oil in 2005/33/EC**

| Effective date | Applicable sea and scope | standard |
|---|---|---|
| August 2006 | The Baltic Sea | 1.50 |
| August 2006 | Passenger ships sailing between ports of EU | 1.50 |
| August 2007 | The English channel and the North sea | 1.50 |
| January 2010 | Inland vessels and seagoing vessels sailing between ports of EU | 0.10 |

**Source: EU Council Directive2005/33/EC**

**Table 2.2 The Standards for sulfur content of ship fuel oil in 2012/32/EC**

| scope | standard | Effective date |
|---|---|---|
| Within the ECAs | 3.50 | After 18 June,2014 |
| | 0.50 | After 1 January,2020 |
| Out of the ECAs | 1.00 | Before 31 December,2014 |
| | 0.10 | After 1 January,2015 |

**Source: EU Council Directive 2012/32 / EC**

Table 2.1 illustrates the sulfur content standards of EU Council Directive2005/33/EC cover more sea area and the scope has gradually expanded. In terms of ships anchoring in EU ports and anchorage shall, it also proposed that the maximal fuel sulfur content should not exceed 0.1%from 1 January 2010, which was earlier than MARPOL 73/78 Annex VI 2008 amendment for five years. But the implementation time was delayed by six months due to the owner's objection.

Analysis of Table 2.2 showed that the EU implemented more stringent restrictions on marine fuel sulfur content. From January 1, 2015, the EU-controlled sea area has implemented the standard of EU Council Directive 2012/32 / EC, that is to say, in the ECAs, the ship fuel sulfur content should not exceed 0.10%. The EU also stated that by the year 2020, all ships in the emission control area should obey a sulfur emission standard of 0.50%, regardless of the global standard of IMO, which was earlier than the provisions of MEPC 70.

In summary, the EU implemented the requirements of MARPOL73/78 Convention Annex VI in advance. In addition, EU Council Directive2005/33/EC is applicable to more sea area and the scope has gradually expanded. Moreover, in the sulfur emission control area, the ship sulfur oxidation emission standards were more stringent.

## 2.3 North American directive for sulfur emissions reduction of ships

The North American ECAs entered into force on August 1, 2012, including the Pacific Rim waters, the Atlantic, the Gulf Coast waters and the Hawaiian waters. The United States Caribbean Sea ECAs were the fourth control area, covering the waters along the coast of Puerto Rico and the United States Virgin Islands. It was adopted in July 2011, and came into force on January 1, 2014.

The US EPA promulgated a new fuel rule in December 2009, stipulating the United States should produce and sell fuels with a maximum sulfur content of 1.00%, unless the ship took post-treatment measures to ensure that the equivalent discharge requirements were met.

From January 1, 2015, the North American ECAs required ships to use marine fuels with a maximum sulfur content of 0.10%. (EPA, 2015) Since January 1, 2007, all ships in California must use fuel oil with sulfur content under 0.50%, which must be reduced to 0.10% from January 1, 2010. (Li, 2008) In May 2013, Canada required that the maximum sulfur content should be 1.00% in North American ECAs and

Canadian territorial waters within north latitude 60 degrees. From January 1, 2015, ship's maximum sulfur content of fuel should not exceed 0.10%. (SSB, 2013)

### 2.4 More attention to the reduction of sulfur emission

More areas have begun to implement appropriate standards before the enforcement of Annex VI of 2008 Amendments of MARPOL 73/78 Convention. As environmental protection is related to human health and sustainable development, more and more countries are beginning to pay attention to the issue of pollutant emissions, especially the ship's pollutant emissions, which causes an expansion of the sulfide emission control area. Tokyo Bay of Japan, Malacca Strait Singapore, Panama Canal, the Turkish Strait and the Marmara Sea and other countries and regions would decide to join the SECAs. The Hong Kong Government passed a bill in 2015 to classify areas within 12 nautical miles from Hong Kong as emission control areas, which implemented sulfur content under 0.5% in July 2015. It is very worthwhile to make concessions to the shipping industry through the Convention and actively promote the relevant incentives or subsidies, so that the heavy polluting ships could be actively reformed and preceded to green shipping. (Xu, 2015)

# CHAPTER 3

## The state of sulfur emission from ships in China

### 3.1 Development of Chinese shipping

**Table 3.1 World 's top 20 ports in 2013(by cargo throughput)**

| Rankings | | | Port | 2013 (10,000 tons) | 2012 (10,000 tons) | Growth (%) |
|---|---|---|---|---|---|---|
| 2013 | 2012 | Trend | | | | |
| 1 | 1 | → | Ningbo-Zhoushan | 80978 | 74400 | 8.84 |
| 2 | 2 | → | Shanghai | 77600 | 73600 | 5.43 |
| 3 | 3 | → | Singapore | 55958 | 53801 | 4.01 |
| 4 | 4 | → | Tianjin | 50000 | 47700 | 4.82 |
| 5 | 6 | ↑ | Guangzhou | 45512 | 43500 | 4.63 |
| 6 | 7 | ↑ | Suzhou | 45430 | 42800 | 6.14 |
| 7 | 8 | ↑ | Qingdao | 45000 | 41465 | 8.53 |
| 8 | 10 | ↑ | Tangshan | 44620 | 36500 | 22.25 |
| 9 | 5 | ↓ | Rotterdam | 44046 | 44153 | -0.24 |
| 10 | 9 | ↓ | Dalian | 40840 | 37400 | 9.20 |
| 11 | 12 | ↑ | Yingkou | 33000 | 30107 | 9.61 |
| 12 | 17 | ↑ | Hedland | 32600 | 24134 | 35.08 |
| 13 | 11 | ↓ | Busan | 32456 | 31204 | 4.01 |
| 14 | 13 | ↓ | Rizhao | 30917 | 28100 | 10.02 |
| 15 | 15 | → | Qinhuangdao | 27260 | 27100 | 0.59 |
| 16 | 16 | → | Hong Kong | 26982 | 26928 | 0.20 |
| 17 | 14 | ↓ | South Louisiana | 25875 | 27890 | -7.23 |
| 18 | 18 | → | Kwangyang | 23503 | 23734 | -0.97 |
| 19 | 19 | → | Shenzhen | 23398 | 22800 | 2.62 |
| 20 | 20 | → | Yantai | 22802 | 20300 | 9.14 |

Source: Global Port Development Report (2013), SISI.

As is illustrated Table 3.1, from the perspective of global port development, seven of the world's top ten ports in China, and ten of the world's top 20 ports belong to China. Moreover, Chinese top ten ports accounted for 26% of the global throughput. (CSD, 2014) Compared with other large port areas in the world, Chinese top seven ports are in a densely populated area with frequent ship activities, and air pollution caused by ships may have a greater impact on the health of residents accordingly.

From a domestic vertical development point of view, since the twenty-first century, Chinese shipping industry has made a rapid development. According to the Transport Industry Development Statistics Bulletin of 2015, there were 31,259 ports in China, including 5,899coastal ports, accounting for 18.87% of the total. Besides, there were 2,221 ports with 10,000 tons and above, accounting for 7.1% of the total. (CTD, 2015)

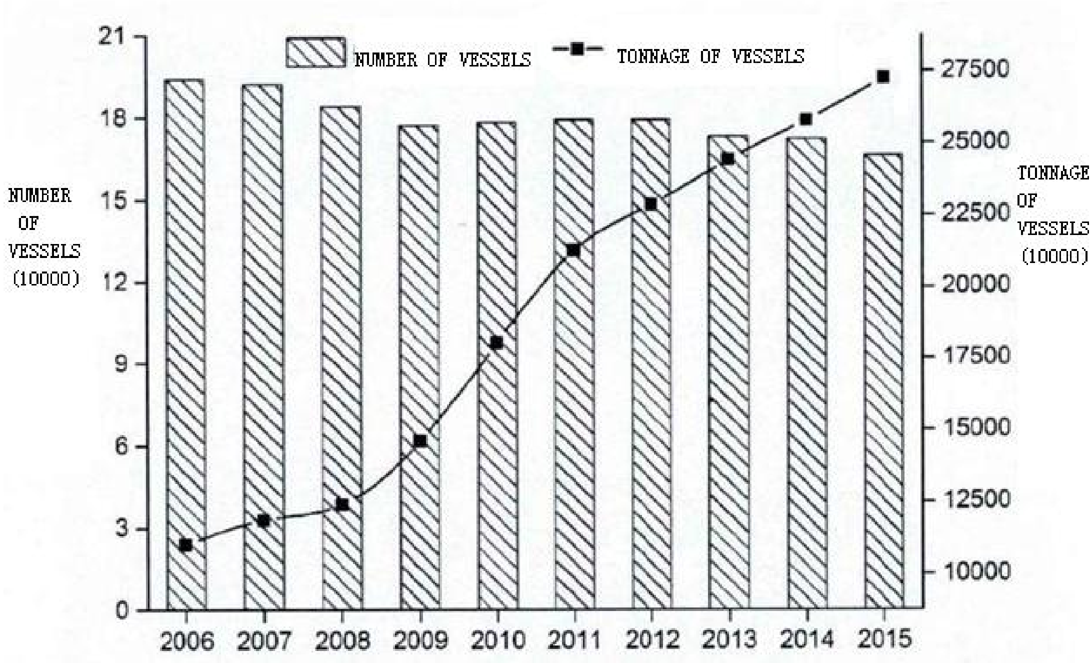



**Figure 3.1 Trends of number and tonnage change of inland water transport vessels (2006-2015)**

**Source: Chinese shipping research data**

As is illustrated in Figure 3.1, the trend of the number and tonnage of domestic vessels from 2006 to 2015 has shown an upward trend in the past decade, from 110 million tons in 2006 rising to 27.24 million tons in 2015. The current shipping industry was also the pillar of the world's transport industry, which was the main channel for trade between countries. (Zhang，2014)

## 3.2 Condition of sulfur emission from ships in China

In terms of shipping in China, emissions caused by ships and port facilities was still increasing, and prevention of emissions was relatively lagging behind, which has not met the needs of environmental protection in economic development. Some ships mostly burned heavy fuel with high sulfur content, whose price was pretty low, but it could bring about to environmental pollution and human damage indeed.

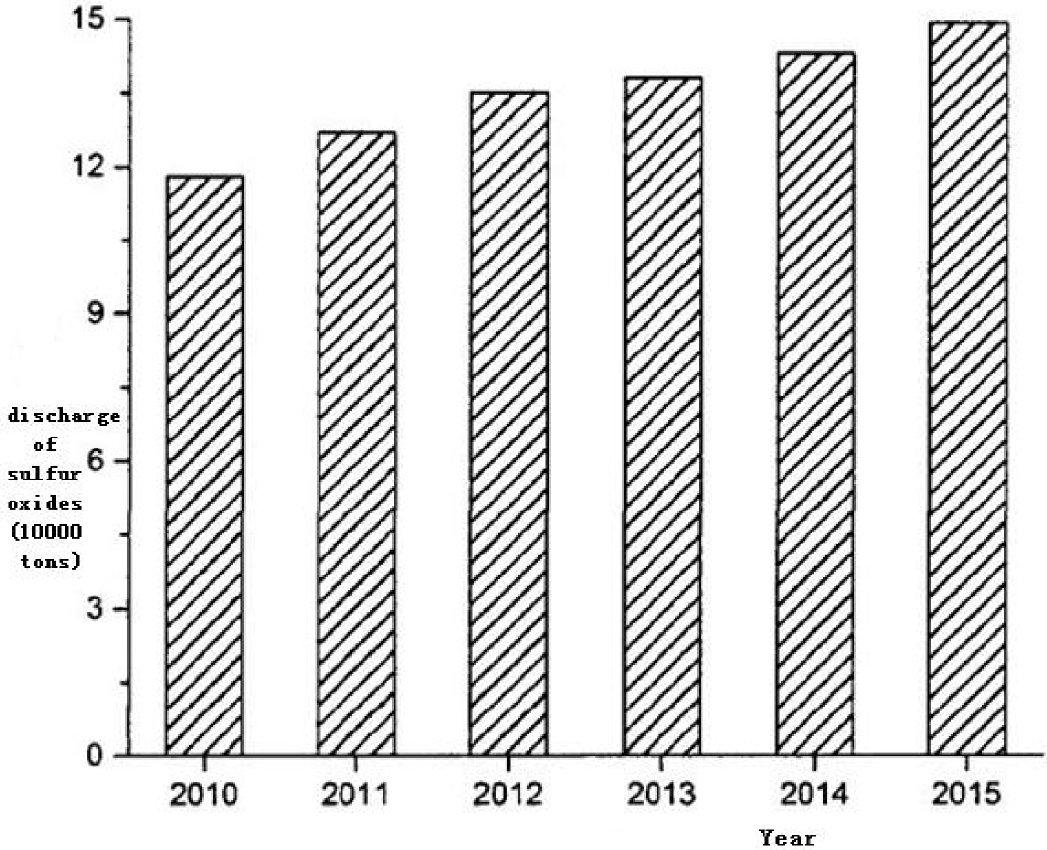



**Figure 3.2 The total gas pollution from ship emission of China (2010-2015)**

**Source: China's Ministry of Environmental Protection**

As a result, the pollution problem caused by the ship has become increasingly prominent. As is illustrated Figure 3.3, according to the statistics of China's Ministry of Environmental Protection, from 2010 to 2015, China's total ship pollutant emissions showed an increasing trend. The $SO_X$ emissions of berthing ship accounted for 8.4% of the total national emissions of pollutants. At present, the control level of ship emissions in China's coastal ports is relatively backward; besides, the air quality of coastal cities was declining, and air pollution was becoming increasingly serious, especially in the Yangtze River Delta, Pearl River Delta. (Xu, 2016)

### 3.3 State of sulfur emission from ships in some coastal cities

The seriousness of sulfur emission from ships was illustrated by analyzing the research data of Hong Kong, Shenzhen and Shanghai.

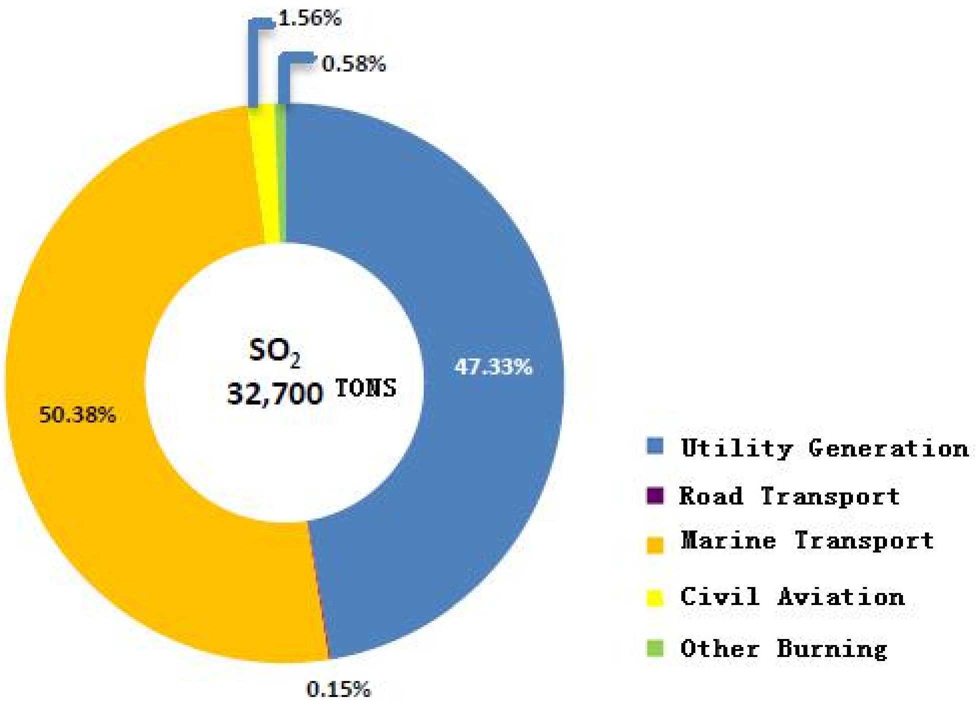



**Figure3.3 The proportion of Hong Kong's total emissions in 2012**

**Source: Research data of HKEPD**

From 1990 to 2007, the sulfur dioxide from land-based pollution sources in Hong Kong decreased by 53%. Nevertheless, the sulfur dioxide emitted by ship pollution sources increased by 48%. According to the data surveyed by Hong Kong Environmental Protection Agency, the ship is the city's largest source of sulfur dioxide emissions in the city's total emissions, accounting for 50% in 2012. In 2013, sulfur dioxide emitted by sea transport accounted for 42% of the total sulfur dioxide emissions in Hong Kong. Although the situation has become better, it also needs more improvement. （HKEPD， 2012）

Secondly, according to the results of pollutant source analysis in Shenzhen, the sulfur dioxide emissions from ocean-going vessels is 16,000 tons, accounting for 67% of the total emissions of the city in 2012. Undoubtedly, ship emission is the largest source of sulfur dioxide emissions. （Hak-kan La，2013）

Thirdly, according to the emission inventories prepared by the Shanghai Environmental Monitoring Center, the $SO_X$, $NO_X$ and PM2.5 emissions of Shanghai port accounted for 12.4%, 11.6% and 5.6% respectively of the total emissions in 2010. （Fu, 2012）

In short, it is urgent to adopt measure to control $SO_X$ emission because it has damaged the quality of air to a great extent.

# CHAPTER 4

## Technologies for reducing sulfur emissions of ships

The promulgation of the new conventions and related laws shows that reducing sulfur emissions and protecting the environment are the common aspirations of people and governments, which is an irreversible trend. Therefore, taking measures to reduce $SO_X$ emissions is an important issue for designers, producers, seafarers and fuel suppliers of ships. So far, there have been three modes installed on ships, which were intended to reduce the $SO_X$ emissions effectively, and they are using low sulfur fuel, installation of exhaust gas cleaning system and the use of LNG as substitute fuel. In addition, shore electricity was a mode that was installed in shore, and it could also reduce sulfur emission effectively.

### 4.1 Low sulfur fuel technology

Low sulfur fuel technology refers to directly using the fuels with sulfur at a highest limit of 0.1%, which mainly included low sulfur marine gas oil, low sulfur marine diesel oil and low sulfur heavy fuel oil.

#### 4.1.1 Advantage of low sulfur fuel oil technology

Low sulfur fuel is the simplest solution. In terms of the heavy fuel oil system, the initial investment of low sulfur fuel oil solution was pretty low, and the cost of maintenance was nearly equal to that of heavy fuel oil system. A lot of small vessels in SECAs, such as tug, yachts, dredger, did not have enough space for LNG or wash desulfurization tower, so the low sulfur oil is the most appropriate solution. (Xu, 2015)

### 4.1.2 Disadvantage of low sulfur fuel technology

There were two problems in implementing low-sulfur fuel technology.
Firstly, the quantity of the low sulfur heavy fuel oil that could meet the standard of EU is so small that it would not meet the requirement of the market. As a result, ships could only add low sulfur light fuel oil, such as low sulfur marine gas oil and low sulfur marine diesel oil in a few ports in the world instead, such as Gibraltar, Falmouth, Antwerp, Rotterdam, Hamburg, etc. Moreover, the price of low sulfur light fuel oil was much more expensive than that of low sulfur heavy fuel oil, so it could greatly increase the company's fuel cost. It was estimated that this situation would become even more severe after the year 2020, unless new technology can significantly reduce the price of low sulfur heavy fuel oil.

Secondly, if the low sulfur light fuel oil was used in medium and low speed diesel engines of ships without transformation for a long time, it would put higher demands and greater safety risks on ship fuel conversion and equipment. The characteristics of the low sulfur light fuel oil mainly included high calorific value, low density, low viscosity, poor lubrication, low flash point and low sulfur content. The viscosity of low sulfur light fuel oil is lower than that of traditional fuel oil, and it may make it unable to reach the required operating temperature for the nozzle and pump for a long time, resulting in mechanical wear and tear. If the engine and boiler use low sulfur fuel without adjustment for a long time, the ship may face downtime, stranding, fuel leakage and other risks. (Jiang, 2014)

As long-term use of low sulfur light fuel oil may have a certain impact on the operation and service life of the equipment, it is necessary to implement technological transformation ships on the relevant equipment, which was shown in Figure 3.1.

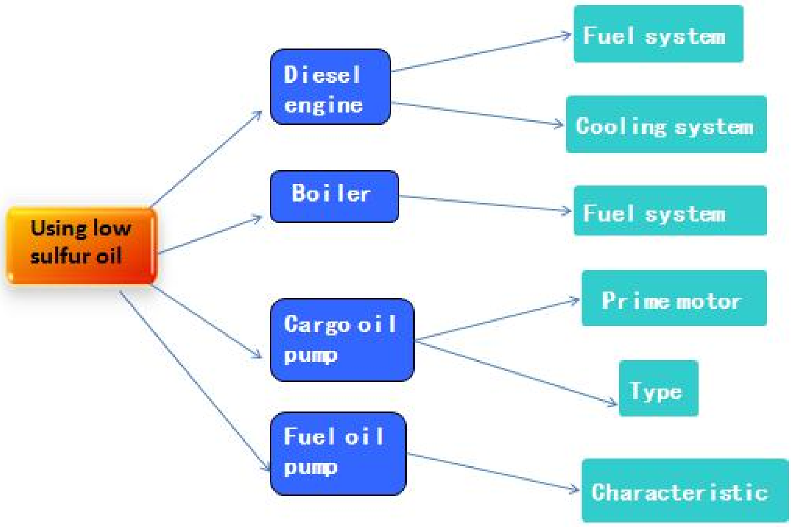



**Figure 4.1 The impact on marine equipment of using low sulfur fuel oil**

Technical transformation of low sulfur oil system mainly involves ship's oil supply system, ship auxiliary equipment, boilers and other equipment. In addition, ship's oil supply pipeline also needs appropriate adjustment; otherwise, the entire ship oil system would be affected. At present, most of the ships are using heavy oil for combustion. In contrast, the physical and chemical properties of low sulfur light fuel oil were obviously different, and simple fuel switch needed to be invested for the transformation of related equipment to meet the long-term use. As was estimated, the cost of transformation on a large bulk carrier boiler was about 1hundred thousand euros; if it is the transformation of a large crude oil, the cost would be even higher.

(Dai, 2007)

In short, the future conservation costs would be an amount of expenditure, which needs some budget preparation. For the ship owner using the low sulfur oil technology, the cost of the transformation and the cost of adding low sulfur oil may bring about many problems and risks. (Purvin & Gertz, 2009)

### 4.2 Installation of exhaust gas washing equipment

The MARPOL Convention Annex Ⅵ recommended that the ship could use low sulfur fuel oil or an exhaust gas cleaning system certified by the relevant authority. That is to say, the ship's main engine and auxiliary equipment can burn heavy fuel with a sulfur content of 3.5% or 4.5%. However, it must meet the emission standards of 0.1% in low sulfur control area after the exhaust gas cleaning system. As it was calculated, for fuel with sulfur content of 3.5%, if the exhaust gas cleaning system could remove 98% of $SO_X$, it is equivalent to burning fuel with sulfur content of 0.1%. (Xu, 2013)

So far, the ship's exhaust gas cleaning system has mainly included two categories, which were dry desulfurization system and wet desulfurization system. Due to the special requirements of the ship, the wet system has become the first choice for cleaning exhaust gas, occupying almost 100% of the entire market ship exhaust gas cleaning.

#### 4.2.1 Dry desulfurization

Quick lime ($CaCo_3$, CaO) or calcium hydroxide ($Ca(OH)_2$) was used as adsorbents to desulfurize directly with sulfur oxides. The product of desulfurization is dry, so it is called dry desulfurization technology, whose advantages are illustrated below. Firstly, the desulfurization efficiency is very high, which is up to 95%. Secondly, the dry desulfurization technology device is simple with low power required. Thirdly, the temperature of exhaust gas just decreases a little after dry desulfurization system treatment. Last but not least, there is no waste discharge in the dry desulfurization system, which would not cause secondary pollution. (Ralf Juergens, 2013)

However, dry desulfurization system also has some problems. As the exhaust emissions need to pass through the reaction absorption tower, and the size and weight of the whole device was relatively large, the ship needed to be modified before normal operation. Moreover, renovation technology on the old ships would be more difficult. In addition, the dry desulfurization technology required a large number of solid adsorption particles, which need to be installed on the ship, so that a large volume of equipment with high weight would occupy the ship space, which was one point limiting the technology application on ship.

The dry desulphurization system developed by Couple Systems was the only dry scrubbing desulfurization system for ships. The desulfurization unit was approved by the Lloyd's Register of Shipping in April 2011. The system used calcium hydroxide particles as adsorbent, which was suitable for plant of 1 to 60 MW power. Due to the use of dry washing, the system would not discharge any pollutants to the sea during operation. So far, the system has been installed on the "MS Timbus" container ship, reducing 99% of the $SO_X$ and 80% of the PM emissions, but the amount of $CO_2$ emissions increased by 10%. (Lloyd's, 2013)

### 4.2.2 Wet desulfurization

Wet desulfurization technology is based on the principle of acid and alkali neutralization, using seawater, fresh water-sodium hydroxide solution, magnesium-sea water as raw material to absorb the $SO_X$ in the exhaust gas in order to achieve ship gas desulfurization. Depending on different circulation of detergent, the wet desulfurization system could be divided into open seawater system, closed fresh water system and mixed desulfurization system.

#### 4.2.2.1 Open seawater system

Open seawater system refers to the adoption of the alkalinity of seawater to absorb the $SO_X$ of ship exhaust gas, converting it into sulfite and sulfate. As a result, the washing waste was discharged into sea after separation, aeration, dilution and other aspects of treatment, while the separation of sludge, oil residue were still restored on ship until shore recovery. (Andreasen Anders，2007)

Foreign companies such as Hamworthy, Marine Exhaust Solutions, DuPont BELCO have developed an open seawater desulfurization system. The Krystallon desulfurization system developed by Hamworthy has been installed on the cruise ship named Zaandam of Holland America Lines. (Caiazzo G, 2013) On this ship, when the engine was burned with heavy fuel oil with sulfur content of 3.5% on the 21MW engine, it would consume $70m^3/(MW\cdot h)$ sea water with alkalinity of 2300μmol/kg. The efficiency of desulfurization was about 98%.Open seawater system used natural seawater with high efficient desulfurization, which did not need to store a large number of lye with the ship. Moreover, the system structure was simple with low operating costs. (Langella G, 2013)

But there were the following problems. Firstly, the desulfurization efficiency depended on the alkalinity and temperature of the seawater. When the ship sailed in coastal areas, ports, canals and river estuaries, the alkalinity of seawater would decrease, so would the desulfurization efficiency. Secondly, the seawater consumption is large, causing high pump energy consumption, which accounted for about 2% to 3% of main diesel engine power. (DEPA, 2013) Thirdly, acid washing waste was discharged into the sea, destroying the balance of $HCO_3^-/CO_3^-$, increasing $CO_2$ emission, which may cause secondary environmental pollution. (Kjølholt Jesper, 2012)

#### 4.2.2.2 Closed fresh water system

Closed fresh water system refers to the addition of sodium hydroxide in fresh water to neutralize the $SO_X$ in the exhaust gas. The washing waste could be used circularly after being separated, replenished with lye and cooled, and the separated particles are stored in the sludge tank. (Wärtsilä，2010)

In fact, Wärtsilä, Klaveness Clean Marine and other companies have invented desulfurization device using this principle.

For example, the device produced by Wärtsilä has been installed on the chemical ship named "Suula", the desulfurization effect and washing waste could meet the strict standards of IMO in the SECAs. When the ship's diesel engine was using high sulfur fuel whose sulfur content was more than 3.50%, the desulfurization efficiency could be up to 98%. Compared with the open system, the closed freshwater system relied on sodium hydroxide solution to dispose of the exhaust gas.

The desulfurization effect was stable, the freshwater circulation was small and the energy consumption was low. In addition, all of the impurities were stored on ships, achieving the "zero emissions". (Hao, 2015)

But the system also has the following problems. Firstly, the installation and storage of sodium hydroxide pipes and compartments should be specially treated to increase the safety, which would occupy the effective cargo space of the ship. Secondly, the system would consume a large amount of fresh water, so the continuous operation time was limited, which was difficult to meet the needs of continuous high sea navigation.

#### 4.2.2.3 Hybrid desulfurization system

The hybrid desulfurization system is a combination of open seawater desulfurization systems and closed fresh water desulfurization systems, and it could switch between flexible seawater washing and fresh water washing mode in order to adapt to the actual sailing needs of ships. So far, Alfa Laval Aalborg, Yara Marine Technologies and other companies have developed hybrid desulfurization system. The Ro-Ro ship named "Ficaria Seaways" developed by Alfa Laval Aalborg installed hybrid desulfurization system in 2009. The results showed that the desulfurization efficiency was 98% to 100%. (Jens Peter Hansen, 2012)

The hybrid desulfurization system takes the advantages of open and closed systems into account, which could meet the needs of different navigation environments, reducing the storage capacity of the lye and secondary environmental pollution. However, the structure and operation of such systems were more complicated and the initial investment cost was higher, so the transformation process was liable to be limited to the original ventilation pipe of the ship.

### 4.2.3 Short summary

In summary, wet desulfurization has the most promising prospects in sulfur oxide emission control technology. Companies such as Wärtsilä, MAN B&W, Alfa LavalAalborg, Hamworthy, Clean Marine and DuPont have developed exhaust gas desulfurization products that meet the needs of the market, achieving good results on practical application. (EGCSA，2012)

If the ship adopted an exhaust gas desulfurization device, it was estimated to be equal to increasing the cost of fuel oil by 50 to 100 yuan per ton, which was just 1/10 of the cost of heavy oil desulfurization directly. The economic advantage of installing exhaust gas desulfurization device was obvious. Although the initial cost was large, it could avoid the huge renovation of the oil and fuel system of the ship. In addition, the operating cost is obviously lower than that of using the low sulfur fuel. This is because the price gap between high sulfur fuel oil and low sulfur light fuel oil was pretty large. As a result, the cost of price gap for one to four years could cover the cost of installing exhaust gas desulfurization device, which had great social and economic benefits. (Hao, 2015)

However, the initial investment of adding exhaust gas cleaning system was pretty large. For example, the cost of a closed exhaust cleaning system for a diesel engine rated at 9,960 kW is approximately 574,800 yuan. In addition, for larger ships, the cost of renovation is greater. (Zhou, 2014)

## 4.3 Alternative fuel technology

Alternative fuel technology refers to using the LNG, methanol, bio-fuels and other new clean energy as the representative of the fuel instead of traditional marine fuel oil combustion technology.

As a qualified alternative fuel, it should meet the basic requirements below. Firstly, the fuel should have more prominent environmental performance, which could effectively reduce the ship emissions of $SO_X$, $NO_X$, PM2.5 and other emissions. Secondly, it should have a wealthy storage, so that it could meet the requirement of enough market consumption. Moreover, the fuel prices should be relatively cheap, helping reduce operating costs. In short, it should meet the requirements of both of the operation of the ships and the increasingly stringent emission regulations.

Liquefied Natural Gas is clean, convenient and efficient energy, the current development and situation of which could basically meet the requirements above. Global large-scale use of clean fuels is the trend. In order to actively deal with the upcoming LNG power ship, the shipping industry has conducted lots of research. Europe and the United States are the pioneers of the development of LNG power ship. In 2000, Norway began operating the first LNG power ship named "Glutra". Since then, more and more LNG power ships have been constructed. According to the statistics in October 2016, there were 86 LNG power ships sailing and 93 orders of new LNG power ships orders in the world. In recent years, shipping industries have been active in building infrastructure and related facilities in order to speed up the layout of LNG adding stations and promote the development of LNG power ship. (Xu, 2017)

#### 4.3.1 Advantage of LNG

First of all, compared with fuel oil, liquefied natural has large resources. As is estimated, the world's conventional natural gas resource was about 400 trillion to 600 trillion $m^3$. If it should be exploited to the same quantity as that of 2008, it was estimated that the existing natural gas could satisfy 60 years of mining.

Secondly, the price of LNG is cheaper than that of fuel oil. According to a research of Jiangsu MSA in China, a cargo ship loaded with 2,000tons sailing in Jinghang Great Canal consumed 60 tons of diesel oil per year. If the fuel was transformed into LNG, the fuel cost would save 20 thousand euros per year. In summary, using LNG as the main fuel for the ship can save a considerable amount of fuel costs for the ship owners. (Brynolf S., 2014)

Thirdly, natural gas is a kind of clean fuel. In terms of natural gas, more than 90% of the ingredient is methane, and the rest is a small amount of ethane, propane, butane and so on. Methane has a carbon-hydrogen ratio of 1/4, which is the lowest carbon-hydrogen ratio. That is to say, LNG has pretty high energy, and it could release the equivalent quantity of heat with less $CO_2$ emissions. So if LNG was used as fuel on ships, the $CO_2$ emissions can be lower than the use of fuel oil by 25% to 30%. Moreover, natural gas would be pretreated before being liquefied, and the carbon dioxide, moisture, hydrogen sulfide and other sulfides in original natural gas could be removed in the process of purification, which means that there is almost no sulfur in the LNG, so there was nearly no SOX emissions in burning LNG. (Michele, 2014)

### 4.3.2 Disadvantage of LNG

However, there were several disadvantages for the use of LNG as fuel.

Firstly, it may cost a lot on transformation for old ships. Moreover, LNG was stored in a liquid form on ship and it would require a special storage compartment, which occupied the available space of the ship. As it was estimated, the space required for the vessel to store the LNG fuel is about 3 to 4 times the amount of diesel fuel, and the construction cost could increase by about 8% to 20%. (Panasiuk Irina, 2013)

On the other hand, the use of LNG has not been popular currently. There was not enough gas station supplied in the world. At present, except in Northern Europe, the supply infrastructure for LNG has not been constructed perfectly in most of the ports in the world, so the installation, storage and transport for LNG were difficult.(Savcuka Z., 2013)In addition, the research shows that, the economy of LNG depends on the price gap between LNG and HFO, and the proportion of SECAs in the route. (Cullinane Kevin, 2014) Therefore, LNG has been only used in short-distance maritime transport of Nordic region and the passenger roll transport with fixed route by now. Few cases were used in large ocean transport ships.

## 4.4 Comparison of the three technologies above

In terms of the initial investment, the low sulfur fuel reform required the least amount of cost, followed by the exhaust gas cleaning system, which would cost nearly 5 times more than that of low sulfur fuel. Moreover, the initial investment of LNG is the highest among the three modes, which is higher than the traditional design by about 30%. (Guo, 2012) In financial environment currently, it would put difficulties on the initial investment of the new shipbuilding. However, in terms of the operating costs, the cost of LNG would be the least, and that of lowsulfur fuel would be the highest.

It would take the cost of luxury cruise ship named VIKING LINE sailing between Nordic ports as an example. The annual operating costs of the three modes were shown respectively in Figure 4.2. Although the prices of fuels were floating, the research could illustrate the point below. The cost of using MGO was as high as 3 million euros per year, which was much higher than the other modes. (VIKING LINE, 2012) In addition, the operating cost of exhaust gas cleaning system was pretty high because of the adoption of sodium hydroxide and fresh water.

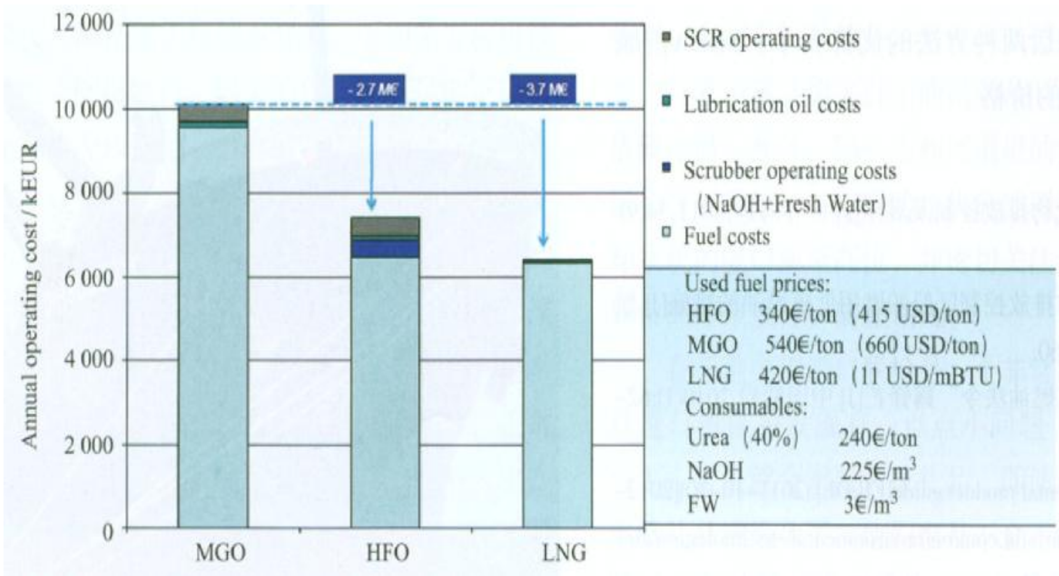



**Figure 4.2 Operating costs of different fuels**
**Source: Hao, 2015**

As can be seen from figure 4.2, for ships sailing within the SECAs for a long time, the initial investment of the exhaust gas cleaning system and LNG was much cheaper than the operating cost of low-sulfur fuels, especially from the point of the whole life cycle of a vessel. However, at present, the shipping condition is very grim, the ship owners would not increase their initial investment because of the lack of money, and they were more willing to use low sulfur fuel. But in the long run, the first two methods should be more promising. In terms of the modes of LNG and cleaning system, there are two main factors in comparing the economic advantages. Firstly, if the proportion of SECAs in the whole ship route is higher, the mode of cleaning system would be more cost-effective. Secondly, if the price gap between of LNG and heavy high-sulfur fuel is larger, the mode of LNG would be more cost-effective. At present, both of the prices of high sulfur fuel oil and LNG fluctuate at high level, and the prices of them were different around the world. Therefore, the uncertainty of using LNG on ships depended on the price gap between LNG and petroleum fuel. According to international market analysis, the growth rate of fuel oil prices in the future would be much higher than that of natural gas. (Ren, 2016)

Some Chinese ships has installed the exhausted gas cleaning system or used LNG as energy sources, however, only small piece of equipment used for sulfur emission reduction on ships was developed by Chinese shipping industry, which signals more attention should be paid to the marine scientific research.

## 4.5 Shore electricity

The technologies introduced above were all measures implemented on ships. In addition, shore electricity was one of the methods used for reducing sulfur dioxide emissions from ships. The ships could get power through linking the shore electricity instead of ship auxiliary power generation, which may cause more emissions.

Compared with burning HFO, the use of shore electricity could significantly reduce $SO_X$ emissions to some extent.

Some major ports of United States and the EU have built facilities of shore electricity. In addition, the California of United States enacted related law to force ships to use shore electricity. Since January 1, 2014, the mandatory use of shore electricity in California Code has come in effect, requiring that the ship berthing ports of California should enhance the proportion of using shore electricity gradually. (Hao, 2015)

China has made a lot of attempts in the field of shore electricity, and the Ministry of Transport promoted the use of the energy-saving emission reduction technology. Many regions have issued programs to promote the use of shore electricity. Ministry of Transport made it clear in the "Implementation Plan of Ship and Port Pollution Control during 2015-2020" that by 2020, 90% of public service ships harbor tugs should use shore electricity; While berthing at the major ports, 50% of the ports using container ships, passenger rolling ships and cruise ships should have the special ability of supplying shore electricity. (Cai,2017)

The main problem in the promotion of shore electricity in China mainly existed in technique, standard, planning and institution, thus resulting in pretty poor construction of shore power facilities.

Firstly, most of the existing terminals have not taken into account the construction of shore-based facilities during construction, so that neither the space nor the electricity required for the wharf could meet the requirement of constructing shore electricity facilities. The installation of shore power facilities needed to modify the project, when facing greater difficulties in approval. At the same time, the cost of higher electricity capacity was pretty high, and the port enterprises could not bear the cost currently.

Secondly, there was no internationally uniform standard for the electricity of the ship's shore. Moreover, the cost of retrofitting the shore was pretty high. At present, the type of high-voltage electricity in most of the world's major ports was 6600V/60Hz, which was adopted by large container ships and semi-submersible vessel equipped with electric propulsion system. Other ships adopted low voltage electric system with 440V/60Hz low voltage electric system. Generally, domestic port adopted electric system with 380V/50Hz, and the installation of shore electricity should also be equipped with both high-voltage inverter and low-voltage inverter. In addition, for the shipping company, the cost of transforming interface connecting shore electricity on ships was also high. (Xu, 2015) Therefore, in the absence of mandatory provisions, the shipping companies were not willing to install interface on ships. As a result, the huge investment in port construction of shore power equipment was invalid, which also reduced the willingness of port enterprises to invest in the construction and operation of shore electricity facilities.

Thirdly, when the ship was connected to the shore electricity, since the capacitance of shore and ship were not compatible, the shore electricity could not be used directly. So it needed to adjust the settings before turning off the marine generator. Similarly, when ships leaved ports, the marine generators should be started before disconnecting the shore electricity. When the seafarers connected or disconnected the shore electricity, the marine generator was running, giving the operator a huge security risk, so the operation would cost a long time. The current shipping market is in a downturn, in the absence of mandatory regulatory requirements and subsidy policies, and the volition of the shipping companies to use shore electricity is not high.

Lastly, the total electricity consumption of large domestic ports was very large. If the container ships, passenger ships and cruise ships all used shore electricity, the port would suffer from a higher consumption of electricity in total. In particular, China is currently urging the development of the shipbuilding industry, so the electricity consumption of a large cruise ship may reach the level of a small city, which means the connection to shore electricity would have a huge impact on the related cities.

In summary, the cost of China's promotion of using shore electricity was pretty high. The lack of legal mandatory policies, unified standard and safety were also the reasons why port enterprises were not willing to assume more responsibilities in the poor shipping market.

# CHAPTER 5

## Measures of sulfur emission reduction from ships in China

### 5.1 State policies on sulfur emission control of ships

The authorities have stipulated the quality standards for marine fuel oil mainly from three aspects, which were host law, technical standards and normative documents.

#### 5.1.1 Host law

The prevention and treatment of air pollution in the People's Republic of China came into force on January 1, 2016, and it stipulated the standard of sulfur content of marine oil as is shown below.

In terms of inland vessels and river-sea ships, they should use diesel oil, which should meet the standard of GB252-2015, which stipulated that the sulfur content should not exceed 0.035% before 30 June, 2017, while it should not exceed 0.005% since1 July, 2017. More strictly, sulfur content should not exceed 0.001% since 1 July, 2018. In short, the sulfur content stipulated by GB252-2015 was more stringent than that stipulated by MARPOL Convention.

In terms of other ships, there was no clear requirement for coastal ships. However, it should meet the requirements of MARPOL Convention. In addition, the prevention and treatment of air pollution in the People's Republic of China encouraged the related administration set ECAs to limit the pollution emissions.

### 5.1.2 Technical standards

Firstly, domestic maritime shipping statutory inspection technical rules and inland river ship statutory inspection technical rules stipulated that the sulfur content of ship fuel oil should not exceed 3.5%, which was a mandatory requirement. Secondly, it was also stipulated by the nationally recommended standard of marine fuel oil (GB/T17411), which was in accordance with the international standard ISO8217. The sulfur content of the distillate marine fuel oil should not exceed 1.5%, except for the emergency engine, while the sulfur content of the residual marine fuel oil should not be more than 3.5%.

### 5.1.3 Normative documents

According to the “Notice to strengthen the relevant matters concerning the quality inspection and management of ship's fuel oil”, Chinese MSA stipulated that the ship fuel supply unit should provide the fuel required to meet the standard requirements. For example, it should meet the requirement of “Marine fuel oil”(GB/T 17411), which stipulates that the fuel supply unit of the ship should ensure that the fuel supplied should not have an effect on the safety of the ship or on the performance of the machine, any additives or chemical waste causing more pollution to the air was permitted.

In addition, on January 1, 2016, China delimited the first Sulfide Emission Control Area, which included the Pearl River Delta, the Yangtze River Delta and water column around Bohai Sea. The implementation of the SECAs meant that China was the first area limiting the use of low-sulfur fuel oil in Asia. The details about the provisions were illustrated below. (Xu, 2017)

**Table 5.1 Time table of Chinese SECAs**

| | |
|---|---|
| Since January 1, 2016 | The ship should strictly obey the requirements of the existing international conventions, domestic laws and regulations on sulfur oxides emission control. |
| | Some ports in the SECAs were encouraged to implement measures, which included the sulfur content of fuel oil should not exceed 0.5% during the berthing. |
| Since January 1, 2017 | The vessel should use fuel oil with sulfur content under 0.5% during the berthing in the core ports area of the SECAs. |
| Since January 1, 2018 | The vessel should use fuel oil with sulfur content under 0.5% m / m during the berthing in all of the ports area of the SECAs. |
| Since January 1,2019 | Ships entering the emission control area should use fuel oil with sulfur content under 0.5%. |
| Measures after assessment (Before December 31,2019) | The following actions should be adopted after assessment:<br>1. Ships entering the emission control area should use fuel oil with sulfur content under 0.1%.<br>2. Expand the geographical scope of the emission control area.<br>3. Other further initiatives. |

**Source: Xu, 2017**

The establishment of the ship emission control area will have a positive effect on improving the surrounding air quality of the coastal areas, especially the port cities, and promoting the green energy and a healthy development of ships.

## 5.2 Local policies

So far, some provinces have introduced policies on controlling the sulfur emission, among which Hong Kong was in the forefront of the other coastal provinces and cities and played an exemplary role.

### 5.2.1 Hong Kong policies

The Hong Kong ship emission inventory study was completed in 2012.The results showed that the largest contribution of ship emissions in Hong Kong were ocean-going vessels. As foreign and local studies have pointed out ocean-going ship emission is serious threat to the public health, with 13 shipping companies in Hong Kong taking the initiative to sign the Fair Winds Charter voluntarily, promising to use low sulfur fuel oil with sulfur content of under 0.5%in 2011. After several years' operation, there have been 18 large-scale shipping companies to become member companies to improve the air quality near the port, such as Maersk Line, Fahrenheit, COSCO, and Orient Overseas.

With reference to the successful experience of foreign countries, voluntary schemes with government grants were often the first step in promoting compulsory measures. In September 2012, the Hong Kong Government started to launch a subsidy scheme to encourage ocean-going vessels to switch to low-sulfur fuels with a sulfur content of less than 0.5% during berthing by reducing the charge for port facilities and light. Nonetheless, the ship operators still had to assume 50% to 80% of the cost of clean fuel conversion. At the same time, companies such as Maersk Line believed that companies participating in the fuel conversion program and those who do not participate in the program should bear different operating costs, which was unfavorable to fair competition. As a result, the members of the Fair Winds Charter hold the idea that some corresponding mandatory regulations should be introduced in Hong Kong. (Wu, 2013)

The Air Pollution Control Regulation, which came into effect on 1 July 2015,seeks to stipulate that ships should use clean fuels while parking in Hong Kong to reduce the emissions of ocean-going vessels and improve the air quality. The regulated fuel specified in the regulation included low-sulfur marine fuels with sulfur content of not more than 0.5%, liquefied natural gas or other fuels approved by the Environmental Protection Agency.

### 5.2.2 Policies in the Pearl River Delta Area

However, when Hong Kong imposed stricter fuel specifications on offshore vessels in accordance with regulations, ocean-going vessels may continue to burn heavy oil with higher sulfur content in domestic ports and even an increase in the number of berthing ports in order to reduce fuel costs, so that the problems of domestic ship pollution become more serious, which further threatened the public health. For example, many ships may emit more pollution while berthing at Shenzhen or Guangzhou port before or after docking to Hong Kong's ports. Therefore, it is necessary to introduce laws and regulations governing the ship and port emissions in following the pace of Hong Kong, in particular to promote the pilot scheme in

Guangdong Province.

Due to geographical reasons, Hong Kong's air pollutants affect the Pearl River Delta. Therefore, in September 2012, the Science and Technology Research Institute published a study entitled "Healthy Price: Pearl River Delta Ship Emission Control Program", together with Hong Kong University of Science and Technology and the University of Hong Kong. It estimated the amount of air pollutant emitted from ocean-going vessels in the Pearl River Delta region, the spread of pollutants and the impact on public health. In addition, it also established the SECAs in the Pearl River Delta waters, requiring ships to use fuels not exceeding 0.1% sulfur content, which would reduce the number of additional deaths caused by ship emissions by 91%. (Wu, 2013) In fact, the "Hong Kong Fresh Air Blueprint" launched by the Hong Kong Government in 2013 clearly pointed out that the establishment of ECAs in the Pearl River Delta was the long-term goal of regional ship emission reductions. (Cai, 2017)

In addition, under the influence of Hong Kong policies, some local policies were promulgated by some provinces with large ports. On February 7, 2014, "Guangdong Province air pollution control action program" was promulgated in Guangdong to ensure a good air quality and establish the target of pollution reduction. In the same month, the Guangdong Provincial Department of Transportation promulgated the "Guangdong Green Port Action Plan (2014-2020)", which aimed to achieve energy efficiency and lower the emission of $CO_2$. (Yang, 2016) Both of the programs required green transport and reductions in emissions from ships and port equipment; Besides, it also called for a strengthening cooperation between Guangdong, Hong Kong and Macau to control ocean-going emissions.

### 5.2.3 Policies in Shenzhen

In September 2014, Shenzhen announced the "Interim Measures for shore electricity facilities and marine low-sulfur fuel oil", deciding to draw on the Hong Kong "Fair Wind Charter" by investing in 200 million as annual financial subsidies to encourage shipping enterprises to use environmentally friendly low sulfur fuel (not more than 0.5% sulfur content) and shore electricity facilities. The funds would be used mainly for the construction of shore electricity facilities and the subsidy of low sulfur fuel oil. Shipping companies who were interested in the subsidy program must apply to join the "Shenzhen Port Green Convention", signing the annual commitments of using shore electricity or low sulfur fuel oil. It is expected that the annual reduction of sulfur dioxide emissions would be about 6,000 tons after the implementation of the relevant subsidy, and it could further improve the quality of air in Shenzhen. (Feng, 2016)

### 5.2.4 Policies in Shanghai

As the world's largest port, Shanghai promulgated "Shanghai Air Pollution Prevention Regulations" in July, 2014. The regulations set out a series of mandatory measures to control air pollution at ships' ports and clarified the regulatory responsibilities of the relevant government agencies. It stressed that the Shanghai Port should "promote the construction of the terminal shore-based power supply facilities and low sulfur fuel oil supply facilities. Moreover, it also included terms for penalties. For example, if a ship was traveling in the city with the pollutants exceeding the standard to the atmosphere or emissions of visible black smoke, it may be fined. Shanghai Environmental Protection Bureau was responsible for the organization and implementation of the Ordinance. It was predictable that "shore electricity" would be the focus of Shanghai's development in the future. According to the "Shanghai Clean Air Action Plan (2013-2017)", Shanghai planned to carry out a shore electricity pilot plan at Wusongkou International Cruise Terminal and Yangshan Guandong International Container Terminal. At the same time, Shanghai also established a "green partnership" with the Los Angeles Port under the framework of the Energy and Environment, which planned to promote the shore electricity of Shanghai through information exchange, technology and experience shared between the two ports. (Yang, 2016)

In short, the advanced policies adopted by some coastal provinces could provide a good guideline for Chinese shipping industry, especially for the coastal cities.

### 5.3 Suggestive supervision of MSA

In terms of MSA, it was suggested to supervise from the following procedures.

#### 5.3.1 Ships using low sulfur fuel

Some important points should be paid attention to in terms of the ships using low sulfur fuel.

##### 5.3.1.1 Checking certificates and document

Firstly, ship certificate, including Ship Nationality Certificate, Ship Inspection Certificate, International Oil Pollution Protection Certificate, International Air Pollution Protection Certificate and Safety Management Certificate and Ship Oil Pollution Emergency Plan should be inspected.

Secondly, it is necessary to focus on the inspection of ship log by verifying whether the records of the date, time and location of oil change were complete, and by checking whether the location of the oil change and the sulfur content of the fuel met the requirements of the emission control area, and whether the record of the fuel inventory in each fuel tank was complete.

Thirdly, it is important to check whether the relevant record of low sulfur fuel was consistent with the contents of the fuel supply document.

#### 5.3.1.2 Checking fuel conversion process

Firstly, it is necessary to verify whether there was a written fuel conversion procedure on ship, and whether the procedure complied with the requirements of the ship safety management system; Secondly, the fuel conversion operation record should be complete.

#### 5.3.1.3 Ship fuel machinery and pipeline inspection

Firstly, the marine engine should change low sulfur fuel oil timely in the specified areas, which were in accordance with the requirement of ECAs. The important point was checking the relevant conversion valve to confirm whether the low sulfur fuel oil was used.

Secondly, in terms of the generators and boilers, it could confirm the low-sulfur fuel conversion by verifying the relevant conversion valve of the fuel system that had been converted to.

Secondly, there were parameters showing use of low sulfur fuel in cabin control room generally, and the inspector could check the relevant parameters of the instrument to confirm whether the ship has been using low sulfur fuel.

#### 5.3.1.4 Inspection of fuel sampling

Sampling should be made from the pipeline outlet of fuel tank, the fuel pump outlet, the pipeline before the main engine and generator, and fuel circuit. The sampling location and quantity should be marked on the bottle, which should be sealed.

### 5.3.2 Inspection of alternative measures

MSA officers could check the ship's certificate of alternative measures to determine whether the alternative measures used by the ship met the relevant requirements of the emission control area preliminarily.

#### 5.3.2.1 Certificate inspection

The ship adopting alternative measures should obtain a certificate issued by the relevant recognized organization in order to prove the equipment could meet the requirements of sulfur emission.

In terms of ships using exhaust gas cleaning system, the device shall be approved by the organization and be issued with the product certificate, which should be noted in the remarks column of International Air Pollution Protection Certificate.

In terms of ships using clean energy, the permitted clean energy should be noted in the remarks column of International Air Pollution Protection Certificate.

In terms of ships using shore electricity, the connecting device should be inspected by a recognized organization with a relevant certificate.

#### 5.3.2.2 Document inspection

For ships using alternative measures, the documentation of the ship's records should be checked to verify the actual use of the equipment.

Firstly, in terms of ships using exhaust gas cleaning system, MSA officers should check the following items.

① There should be a corresponding procedure to start the device.

② The MSA officers should check whether the time and location of using exhaust gas cleaning system meet the requirements of the emission control area.

③ Whether there is a product certificate of the exhaust gas cleaning system.

④ The MSA officers should verify if there is a record on the relevant operator equipment on board.

Secondly, for dual-fueled ships, the MSA officers should check the record of time and location of changing fuel, which should meet the requirements of the emission control area.

① Whether the clean energy and fuel use records were in complete specification.

② Whether the clean energy stock could meet the consumption of the emission control area.

③ There should be clean energy and fuel conversion procedures.

④ Whether the clean energy stock could meet the consumption of the emission control area.

Lastly, in terms of ships using shore electricity, MSA officers should check the following items.

① Whether the ship has relevant operating procedures of shore electricity.

② Whether the information of using shore electricity was recorded in the log completely, and whether it was consistent with the actual situation.

③Whether the start and end time of using shore electricity met the requirements of the emission control area.

④ Whether there were personnel responsible for the operation of the shore electricity.

⑤ Whether there were user manual and safe operating instructions provided by the shore.

**5.3.2.3 Checking the effectiveness of alternative measures**

In terms of ships using exhaust gas cleaning system, the related device should be in normal working condition;

In terms of ships using clean energy, the clean energy combustion device should be in normal working condition, and could be switched quickly and effectively.

In terms of ships using shore electricity, the ship should meet the conditions of using shore electricity, and the related documents should be available.

Most importantly, if the ship’s emission could not meet the relevant requirements of the emission control area in the case of safety protection and equipment failure, it should provide evidence of timely Maritime Report and record of relevant information in the log.

#### 5.3.2.4 Punitive measures

For ships using substandard fuel oil or other alternative measures, they should be punished in accordance with one or more of the following ways, which should be on the basis of related International Convention and laws.

① Warning education.
② Correcting violations.
③ Stranding.
④ The ships should be punished according to Article 106 of "the People's Republic of China Air Pollution Control Law".

In short, the MSA should inspect the ship from aspects of certificate， record， document， equipment and operation in order to insure the ship obey the rule of SECAs.

# CHAPTER 6

# CONCLUSION

With a rapid development of marine transportation, the problem of sulfur emission by ships should not be ignored. According to the Annex VI of 2008 Amendments of MARPOL 73/78 Convention and some other regulations of ECAs, the requirement of sulfur emission reduction was more and more stringent. It is necessary to promote the relevant incentives or subsidies, so that the ships with a heavy pollution could be actively reformed and transformed to green shipping.

It is important to take measures to reduce the amount of $SO_X$ emissions for designers, producers, seafarers and fuel suppliers of ships. The modes of using low sulfur fuel, installation of exhaust gas cleaning system, and the use of LNG as substitute fuel and shore electricity all have advantages and disadvantages. Every ship should have a suitable solution according to the ship condition and sailing lines on the basis of economic efficiency and safety.

At present, the control level of ship emissions in China's coastal ports is relatively backward, and the air quality in coastal cities was declining, and air pollution was becoming increasingly serious. Although several policies and supervision methods have been adopted to control sulfur emission from ships, our current technology was still lagging behind compared with that in the EU and America.  A small piece of equipment used for sulfur emission reduction on ships was developed by Chinese shipping industry, which signals more attention should be paid to the marine scientific research.  In addition, the MSA should inspect the ship from aspects of certificate，record，document，equipment and operation in order to insure the ship obey the rule of SECAs.

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