Control technology and supervision of sulfur oxide emission from ships

Keshun Li
CONTROL TECHNOLOGY AND SUPERVISION OF SULFUR OXIDE EMISSION FROM SHIPS

By

Li Keshun
The People’s Republic of China

A dissertation submitted to the World Maritime University in partial fulfillment of the requirements for the award of the degree of

MASTER OF SCIENCE

In

(MARITIME SAFETY AND ENVIRONMENTAL MANAGEMENT)

2021

© Copyright Li Keshun, 2021
Declaration

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

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

Signature:

Date:

Supervised by: Sun Deping

Dalian Maritime University

Assessor:

Co-assessor:
Acknowledgement

After 16 years, I once again entered the maritime safety and environmental management master program jointly trained by World Maritime University and Dalian Maritime University as a student. Although the life of graduate students for more than one year is short, it is the most unforgettable memory in my life. Looking back on this year, there are laughter, tears, success, failure, harvest and regret, Has become the most abundant memory in life. As the oldest person, it's not easy to take part in the entrance examination and interview. Thank you very much for the encouragement of Zhang Jinlei, Zhao Jian, Zhao Lu and other teachers of the United International College, which made me very lucky to participate in the project. Thank you for the financial support of Dalian Maritime University, the leadership of the College of marine engineering and the recommendation and support of the teachers from the teaching and research section of auxiliary machinery. As a teacher of Maritime University, I am honored!

First of all, I would like to sincerely thank my tutor, Sun Deping, for his careful guidance not only on the topic, research framework and writing ideas of the thesis, but also on the source and collection of data. In the process of writing the paper, Mr. Sun Deping gave guidance to the overall content and layout of the article, which had a great impact on me both academically and socially, and benefited me a lot.

I want to thank all the teachers who have taught me and tutored me. During this period, I went through the breakthrough of cowid-19 pandemic. Although many teachers did not teach face-to-face, I also learned management knowledge related to my major through the network. It is your strict requirements and selfless teaching that make me grow up and improve my comprehensive quality.

Finally, I would like to thank my parents, my wife and my daughter for their silent support. No matter how happy or sad I am, you can share and bear with me. You will always be the most precious treasure in my life.

Thanks to the authors of the references cited in this paper and the reviewers who took time out of their busy schedule to put forward valuable suggestions for revision.
Abstract
Title of Dissertation: Control Technology and Supervision of Sulfur Oxide Emission from Ships
Degree: MSc

With the rapid development of the global economy, the global shipping industry has achieved unprecedented development and become an important part of the global economy, with the characteristics of large carrying capacity and low operating cost. 90% of the international trade volume of the EU region is completed by ship transportation, while nearly 80% of the international trade volume of the United States is also completed by ship transportation. Based on economic considerations, most of these ships are driven by high-power diesel engines. Before the sulfur limit, the ships sailing in the global non SOx emission control area basically use cheap heavy residual oil, and the exhaust gas contains a lot of pollutants such as NOx, Sox and harmful particles. According to the statistical data of the International Maritime Organization (IMO) in 2014, the pollution caused by ship exhaust accounts for 5% - 10% of the total air pollution, and this data may even be as high as 40% in some port cities. Among them, the annual emission of Sox accounts for 13% of the total global emission. At present, a large number of Sox emissions from ships have seriously threatened human health and ecological environment. It is urgent to find out effective emission control measures. In view of this, the 70th session of IMO Marine Environmental Protection Committee decided to implement the regulation that the sulfur content of marine fuel should not exceed 0.50% m / m (hereinafter referred to as sulfur restrictions) worldwide from January 1, 2020, and issued relevant amendments, guidelines and circulars of MARPOL.

Strict emission regulations and policies will have a profound impact on the shipping market. In order to meet the requirements of IMO and all over the world for Sox emission control in ship exhaust gas, shipping companies must choose the best scheme and response measures to reduce Sox emission and reduce the impact on shipping as much as possible. IMO put forward suggestions to ship owners to deal
with SOx emission limitation: first, use low sulfur fuel oil (LSFO); The second is to install exhaust gas cleaning system (EGCS); The third is to use alternative fuels such as limited natural gas and LNG.

Although the three measures have been verified to meet the requirements, the shipping market is still facing a difficult choice in the three sulfur limitation measures after years of downturn. Focusing on the theme of IMO sulfur restrictions, this paper starts with three schemes of LSFO, EGCS and LNG fuel, covering the interpretation of regulations and standards, the analysis of advantages and disadvantages, cost, management and other aspects of the three schemes, the existing problems and Countermeasures of Sox emission regulation, so as to find a better solution for the industry. It can provide some reference for the major shipping companies to choose the appropriate response plan, and promote the safety of ship navigation and marine environmental protection.

KEY WORDS: sulfur regulations; sulfur restrictions; LSFO; EGCS; LNG; Countermeasures
# Table of contents

Declaration..............................................................................................................................I
Acknowledgement ..................................................................................................................III
Abstract................................................................................................................................IV
Table of contents.....................................................................................................................VI
List of Tables .......................................................................................................................... VII
List of Figures .......................................................................................................................... VIII
List of Abbreviations............................................................................................................. IX
Chapter 1 Introduction ...........................................................................................................1  
  1.1 Background .....................................................................................................................1  
  1.2 Evolution of SOx emission policy ..................................................................................4  
  1.3 Review of previous research .......................................................................................5  
  1.4 Objectives of research ...................................................................................................9  
  1.5 An Outline of Chapter Organization ..........................................................................10
Chapter 2 Research on low SOx emission reduction technology for ships .........................11  
  2.1 LSFO Technology ........................................................................................................11  
      2.1.1 Introduction of LSFO .............................................................................................11  
      2.1.2 LSFO features .......................................................................................................12  
      2.1.3 Risk of using LSFO ..............................................................................................15  
      2.1.4 Precautions against risks in using LSFO ..............................................................18  
      2.1.5 LSFO related regulations ....................................................................................21  
      2.1.6 Focus of PSC on LSFO inspection ......................................................................23  
  2.2 EGCS Technology .........................................................................................................27  
      2.2.1 Introduction to EGCS ..........................................................................................27  
      2.2.2 Risk analysis of installing EGCS .........................................................................33  
      2.2.3 Regulations on restrictions on the use of EGCS ...................................................37  
  2.3 LNG fuel technology .....................................................................................................39  
  2.4 Comparison of three control technologies ...................................................................44  
  2.5 Relevant suggestions ....................................................................................................54
Chapter 3 Sox emission regulation ......................................................................................58  
  3.1 Problems in supervision of Sox emission from ships ..................................................58  
  3.2 Supervision Countermeasures of Sox emission from ships .......................................61
Chapter 4 Conclusion and prospect ....................................................................................65  
  4.1 Conclusions ...................................................................................................................65  
  4.2 Expectations ..................................................................................................................66
References...............................................................................................................................67
List of Tables

Table 1  Indicators of LSFO in major global ports from January to September  13

Table 2  Storage and operating temperature of new LSFO  19

Table 3  Comparison of advantages and disadvantages of three systems  32

Table 4  Cost estimation cases of EGCS installation on existing ships  33

Table 5  Comprehensive evaluation of marine adaptability of clean energy  40

Table 6  Comparison of advantages and disadvantages of three schemes  45

Table 7  Comparison of cost recovery period of two schemes  51
List of Figures

Figure 1  Evolution of limitation policies for SOx emissions from ships  4

Figure 2  WAT / WDT test results of low sulfur oil  14

Figure 3  The fuel valve and broken spring  16

Figure 4  The filter and sludge  16

Figure 5  The oil separator and discharge pipe  17

Figure 6  The piston with reddish deposits  18

Figure 7  Open desulfurization system  29

Figure 8  Closed desulfurization system  30

Figure 9  Hybrid desulfurization system  31
List of Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PP</td>
<td>Pour Point</td>
</tr>
<tr>
<td>CCS</td>
<td>China Classification Society</td>
</tr>
<tr>
<td>DNV</td>
<td>Det Norske Veritas</td>
</tr>
<tr>
<td>HFO</td>
<td>Heavy Fuel Oil</td>
</tr>
<tr>
<td>MGO</td>
<td>Marine Gas Oil</td>
</tr>
<tr>
<td>MDO</td>
<td>Marine Diesel Oil</td>
</tr>
<tr>
<td>IMO</td>
<td>International Maritime Organization</td>
</tr>
<tr>
<td>LNG</td>
<td>Liquefied Natural Gas</td>
</tr>
<tr>
<td>MARPOL</td>
<td>The International Convention for the Prevention of Pollution from Ships</td>
</tr>
<tr>
<td>MEPC</td>
<td>Maritime Environment Protection Committee</td>
</tr>
<tr>
<td>USGS</td>
<td>United States Geological Survey</td>
</tr>
<tr>
<td>EGCS</td>
<td>Exhaust Gas Cleaning System</td>
</tr>
<tr>
<td>SOx</td>
<td>Sulfur Oxides</td>
</tr>
<tr>
<td>LSFO</td>
<td>Low Sulphur Fuel Oil</td>
</tr>
<tr>
<td>ECA</td>
<td>Emission Control Areas</td>
</tr>
<tr>
<td>ISO</td>
<td>International Organization for Standardization</td>
</tr>
<tr>
<td>WAT</td>
<td>Wax Appearance Temperature</td>
</tr>
<tr>
<td>WDT</td>
<td>Wax Disappearance Temperature</td>
</tr>
<tr>
<td>BIMCO</td>
<td>Baltic and International Maritime Council</td>
</tr>
<tr>
<td>LPG</td>
<td>Liquefied Petroleum Gas</td>
</tr>
<tr>
<td>BN</td>
<td>Base Number</td>
</tr>
<tr>
<td>PSCO</td>
<td>Port State Control officer</td>
</tr>
<tr>
<td>PSC</td>
<td>Port State Control</td>
</tr>
<tr>
<td>FONAR</td>
<td>Fuel Oil Non-Availability Report</td>
</tr>
<tr>
<td>IAPP Certificate</td>
<td>International Air Pollution Prevention certificate for Ships</td>
</tr>
<tr>
<td>OMM</td>
<td>Organizational Maintenance Manual</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>SCR</td>
<td>Selective Catalytic Reduction</td>
</tr>
<tr>
<td>PM</td>
<td>Particulate Matter</td>
</tr>
<tr>
<td>MPA</td>
<td>Maritime and Port Authority</td>
</tr>
</tbody>
</table>
Chapter 1 Introduction

1.1 Background

With the rapid development of global economy, international trade cooperation is increasingly strengthened, and the global shipping industry has achieved unprecedented development. Compared with railway, road and air transportation, ocean transportation is the most important mode of transportation to support international trade. According to the data of cost benefit analysis of emission reduction in shipping industry emission chapter published by Authors V. Andreoni, about 90% of the world's goods are transported by sea and are expected to continue to grow, but the serious pollution it brings can’t be ignored (Authors V. Andreoni et al. 2008). At present, there are more than 85000 ships with a tonnage of more than 100 tons in the world, of which more than 99% are powered by diesel engines (Zhou Song, 2010). Most of the ships sailing in the global non SOX emission control area before the sulfur restrictions were fueled with fuel with sulfur content of 3.5%. According to the investigation report of the US Environmental Protection Agency, during the combustion process, 95% of the sulfur in the fuel oil will be oxidized to SO2, 1-5% of SO2 will be further oxidized to SO3, and about 1-3% of sulfur will be discharged in the form of sulfate particles. SO2 and SO3 react with waste gas or water vapor in air to form corrosive sulfite and sulfuric acid. They are the main substances to form acid rain. Acid rain can acidify soil and water, destroy vegetation and buildings, and affect human and animal respiratory systems.

The report released by the International Association of Independent Tanker Owners shows that at present, the international shipping industry consumes about 2 billion barrels of fuel oil every year, and SOX emissions account for 20% of the global total emissions. In some port cities with developed shipping (such as Shanghai, Hong Kong, etc.), this proportion is even as high as 30% - 40%. In 2015, a survey, measurement and calculation from Shenzhen Academy of Sciences showed that if a medium and large container ship with sulfur content of 3.5% sails at 70% of the maximum power load for 24 hours, the Sox emission is equivalent to the pollution caused by 210000
trucks, and dozens of carcinogenic chemical pollutants will be produced (Yang Guoshuai, 2016).

According to the statistics of Eyring etc. the annual sulfide emission of marine diesel engine is about 6 million tons, and the SO2 emission is expected to increase by 42% by 2020 (Pang Hailong, et al. 2011). Experts from Lloyd's Register Quality Assurance estimate that the annual sulfide emissions from ships account for about 7% of the world's total sulfide emissions, accounting for more than 60% of the total SOx emissions from the transportation industry. The SO2 emitted by ships is not evenly distributed in the ocean, which has regional heterogeneity and temporal fluctuation. It will lead to high concentration and high frequency pollution in ports, Straits and sea areas with dense routes. According to statistics, 64000 people die of ship pollution related diseases every year in the world (J.J.Corbett, 2007). The environmental and health problems caused by SOX emission from ships can't be ignored, and have aroused widespread concern of the international community.

Due to its particularity, shipping industry has not been included in any international emission reduction agreements, including the 1997 Kyoto Protocol and 2015 Paris Agreement (D. Rutherford and B. Comer, 2018). On the one hand, the shipping industry has always been considered as the mode of transportation with the least environmental damage. On the other hand, it is also attributed to the following two special characteristics of the shipping industry:

(1) Globalization of policy implementation scope: shipping is an international mode of transportation, and ships sail between ports of various countries. The ship emission control policy can't rely on the national level policy, which will lead to the goal of disunity. For example, the development differences between developing countries and developed countries are caused by historical accumulation. The latter completed the industrial revolution and enjoyed the fruits of modernization development without paying any environmental protection price. However, developing countries still need to bear the pressure of economic development (Li Huiming, 2017)). Therefore, the emission regulation of shipping industry needs a global international organization to formulate a unified global standard.
(2) The closeness of policy framework: Based on the industry characteristics of globalization, it is difficult for the emission reduction policies of shipping industry to communicate with other industries (except air transport industry). Take carbon emission reduction as an example, some countries and regions already have mature carbon trading markets, such as the European Union and North America. They have incorporated some energy manufacturing industries such as electricity and steel into their own carbon trading markets. However, due to the flexibility of ship registration and leasing, the shipping industry is easier to avoid the regional carbon trading market, so it is difficult to be included in the regional carbon trading system (Yao Qian, 2019). In addition, due to the complex principal-agent relationship of shipowners, shipowners and carriers, there is a large number of separation between the main body of ship emission and the main body of ship ownership in the shipping industry. Therefore, it is difficult to be included in the existing carbon trading market, and an independent system suitable for its own characteristics is needed.

The air pollution caused by SO\textsubscript{x} emission from ships is a global problem. The control of ship emissions has become an issue of international cooperation, which can only be achieved through the cooperation among various countries. As an international organization to ensure the safety of maritime navigation and prevent marine pollution, IMO is mainly responsible for promoting maritime cooperation among countries. Therefore, the emission of shipping industry is mainly formulated and managed by IMO. IMO adopted amendments to MARPOL convention at the 73rd meeting of Marine Environment Protection Committee (MEPC) held in October 2018, announcing the implementation of sulfur restrictions from January 1, 2020. Although there are many voices of opposition, and some countries are pessimistic about the impact of the policy on economic benefits, they have not affected the pace of IMO’s promotion of the sulfur restrictions. It can be seen that the sulfur restrictions in 2020 will be the first step to limit the emission of ships, which will play a role in promoting IMO's work on the emission reduction of other air pollutants from ships. It is an urgent problem for shipping enterprises to deal with the sulfur restrictions.
1.2 Evolution of SOx emission policy

IMO's limitation on SOx emission from ships has undergone a series of historical evolution, as shown in Figure 1-1 (K. Cullinane and R. Bergqvist, 2014).

As shown in Figure 1, the earliest SOx emission policy can be traced back to the SOx emission control area (ECA) proposed in the annex of MARPOL convention in 2005, which is to detect and supervise the sulfur content of fuel oil of all ships sailing in the ECA area, and take the lead in setting up regional pilot in some countries and regions with strict environmental requirements (such as EU and North America). In 2006 and 2007, two ECAs were set up in the North Sea and the English Channel of the Baltic Sea. The sulfur content in the ECA was limited to less than 1.5%, and the sulfur content outside the ECA was not more than 4.5%. In April 2008, the Marine Environmental Protection Commission revised Annex VI of MARPOL to further tighten the limit of sulfur content, that is, from January 1, 2012, the upper limit of sulfur content in ECA region is 0.5%, and that outside the region is 3.5%.

In addition to the global sulfur limitation policies formulated by IMO, there are also some regional sulfur limitation policies and regulations. These Regulations are more stringent than IMO standards in the same period. For example, EU’s regional legislation not only includes IMO's SOx emission regulations, but also adds lower ECA SOx emission restrictions; The United States and Canada have also designated certain coastal areas as ECA, and applied to MEPC for approval of the amendment to
Annex VI of MARPOL, which specifies North American ECA: since 2012, the sulfur content of fuel used on ships operating in North American ECA shall not exceed 1%, and it shall be strengthened to 0.1% in 2015 (L. Johansson, etc. 2017). China is the first country in Asia to implement the mandatory ECA policy, and Hong Kong has taken the lead in implementing the 0.5% SOx emission limit in 2015. In the same year, the government explicitly proposed to set up ECA areas in the Yangtze River, Pearl River and Bohai Rim waters: from 2019, the 0.5% emission limit which was stricter than the IMO requirements at that time (Wu Jianguo, 2017), among which the Yangtze River waters had been implemented in advance on April 1, 2016. In the "implementation plan of ship air pollutant emission control area" released by the Ministry of transport in December 2018, the policy of China's SOx emission control area was updated, and the coordinates of relevant waters were adjusted. 0.5% SOx emission limit will be implemented in coastal control areas from 2019; From 2020, 0.1% SOx emission restriction will be implemented in inland river control areas (Yangtze River and Xijiang River trunk lines); From 2022, a more stringent 0.1% limit will be imposed on Hainan waters, and it is planned to extend the 0.1% SOx emission limit to all coastal control areas in 2025. From the point of view of the sulfur limitation scheme in the national control area, it is based on the compliance with the international convention, establishing appropriate control areas according to the actual situation, and taking more stringent emission restrictions on some waters.

However, the establishment of ECA area to control ship SOx emission only solves the pollution problem of the port and its adjacent waters, and the problem of ship SOx emission in the process of sea navigation has not been solved. Due to the regional emission control, a large number of shipowners adopted the way of bypassing ECA, which did not fundamentally solve the problem of SOx emission. Therefore, on October 26, 2016, MEPC's 70th meeting in London adopted the above-mentioned "sulfur restrictions" resolution, which reduced the original upper limit of 0.5% in ECA region to 0.1% and the original upper limit of 3.5% in global waters to 0.5%.

1.3 Review of previous research

At present, the research on sulfur limitation of shipping industry can be divided into
three stages, namely, the embryonic stage (before 2005), ECA stage (2005-2016) and global sea sulfur restrictions (after 2016). The research focuses on the regulation itself and three different countermeasures

1. The embryonic stage of policy making (before 2005)
The research in this period mainly focused on the exploration of ship SOx emission reduction policy and the research on the detection method of shipping SOx emission. Capaldo and others believe that SO2 in the atmosphere of most of the world's oceans and coastal areas mainly comes from ship exhaust emissions (K. Capaldo, etc. 1999). Lloyd's register studied the relationship between the sulfur content of marine fuel and the Sox content in tail gas, and found that the SOx emission of ship can be calculated indirectly from the sulfur content of marine fuel and fuel consumption, which laid a foundation for the calculation of SOx emission in the future (Lloyd's Register, 1995). Cooper conducted an empirical study on the impact of marine fuel on SOx emissions, and predicted that the EU would implement LSFO requirements in ports (D. A. Cooper, 2003).

2. Period of SOx emission control area (2005-2016)
During this period, the research mainly focused on dealing with the sulfur limitation policy in ECA area, such as changing oil, adding EGCS, switching to LNG fuel, bypassing ships and reducing speed.
In terms of oil change, Fagerholt etc. analyzed the strategy of replacing LSFO in ECA, and proposed that shipowners can choose long voyage or speed down in emission limited area to reduce more expensive LSFO consumption, but increase total fuel consumption and CO2 emission on some routes (K. Fagerholt, etc. 2015). Doudnikoff found that the total cost of shipping enterprises can be reduced, but the CO2 emission will be increased by slowing down in the ECA area and increasing the speed in the non ECA area without adding new ships (M. Doudnikoff, 2014). Wang Lu and Hao Junli summarized and analyzed the equipment support and potential risks when replacing LSFO (Wang Lu, 2010).
In response to the installation of EGCS, Jiang made an empirical analysis on the installation of EGC system, and found that EGCS is more suitable to be installed on
new ships than on old ships less than 4 years old (L. Jiang, 2014). When the fuel price difference is within 231 euro, it is more suitable to use the fuel change measures.

As an alternative to LSFO, the development and application of EGCS has attracted the attention of a large number of scientific research institutions. ENTEC pointed out that as early as 1991, Japan installed the first EGCS prototype on board (ENTEC, 2005).

In terms of switching to LNG fuel, Brynolf et al. analyzed the emission reduction effect of three countermeasures in ECA region through qualitative research, and especially pointed out that choosing LNG as an alternative fuel would produce a lot of methane emissions (S. Brynolf, etc. 2014). Acciaro used the real option method to analyze whether to switch to LNG fuel, and found that under the regulatory measures of ECA, delaying the switch to LNG fuel and wait-and-see is better than immediate switch (M. Acciaro, 2014). In addition, in the study of ECA emission limit standard, Chang et al. measured the SOx emission of Incheon port in South Korea, and concluded that the SOx emission of Incheon port with 1% sulfur limit has been reduced by 60%, and estimated that the 0.1% limit standard will significantly reduce by 93% (Y. T. Chang, 2014). Zhou Liang took Shanghai port as an example, analyzed the feasibility of ECA policy, and put forward some suggestions for its implementation (Zhou Liang, 2014).

In the aspect of global sea area sulfur limit, Thomas et al. found in the study of lowering the global sea area sulfur limit from 4.5% to 3.5% in the past that the lowering had no obvious effect on the global average sulfur concentration, only reduced it by 0.07% (M. Thomas, 2013). Therefore, they believe that driving policies should be formulated to promote voluntary emission reduction.

3. Global maritime sulfur restrictions (after 2016)

The global maritime sulfur restrictions has brought the research on ship SOx emission reduction into a new stage. At present, there are few studies on the new global sea area standard lower sulfur limit, mainly on the impact of policies on the marine fuel market and the comparison of countermeasures.

Lindstad et al. by comparing the operation mode and fuel consumption of different ship types, it is concluded that small ships are more suitable for oil change measures,
while large ships are more suitable for EGCS (H. E. Lindstad, 2017). Abadie et al. took fuel price, EGCS installation cost, ECA operation time, sailing days and remaining ship age as influencing factors, and conducted economic evaluation on LSFO and EGC installation (L. M. Abadie, 2017). It was found that the newer the ship, the longer the stay in ECA area and the longer the sailing days, the more suitable for EGCS installation investment.

CE Delft (2016) believes that the global LSFO supply in 2020 can be basically guaranteed, and emphasizes the feasibility of implementing the "2020 global sulfur restrictions" policy, which provides support for IMO to implement the policy (CE Delft, 2016). However, OECD / IEA (2016) believes that the world will face an LSFO gap of 5000 barrels per day in 2020 (OECD/IEA, 2016). Maike (2016) believes that Sox control measures are the most expensive policies issued by IMO at present, and "2020 global sulfur restrictions" may increase the cost of global shipping industry by 5 billion US dollars per year (Maike L. C, 2020). DNV GL (2016) compared and analyzed the advantages and disadvantages of open EGCS and closed EGCS, and considered that both of them have their own advantages in specific situations. Closed EGCS has a wide range of applications but high cost (DNV GL, 2016).

Tian Ming studied and compared several countermeasures, and concluded that the mainstream shipowners would choose LSFO, EGCS and LNG (Tian Ming, 2017). China Classification Society (CCS) has compared different design schemes of several typical ship types. According to its data analysis, in terms of initial investment cost, LNG and other alternative fuel schemes are about 2.5 times of EGCS scheme and about 45 times of LSFO scheme; In terms of operation cost, LSFO is about 1.3 times of EGCS and about 3 times of LNG and other alternative fuel schemes. In addition, the investment recovery cycle of LNG and other alternative fuel schemes is 2-3 years, and that of EGCS scheme is about 2 years (Shen Long, 2018).

Research on supervision and law enforcement. Wupeng mentioned that ships travel over vast oceans and rivers, which have the characteristics of wide distribution, flexible mobility and difficult to board during navigation. The existing way of collecting oil samples on board has been unable to meet the actual regulatory needs.
The establishment of ship emission control area will greatly promote the work of ship emission control; However, in order to comply with the relevant laws and regulations, the limitation of oil SOx emissions will greatly increase the operating costs of ships. It is inevitable that some profit-making shipping companies will continue to use heavy fuel oil in violation of the relevant laws and regulations. This requires the maritime authorities, as the first line of defense for supervision and management, to comprehensively organize and carry out the law enforcement inspection on the sulfur content of ship oil, and establish and improve the system mechanism of supervision and inspection. On the one hand, the maritime authorities need to strengthen the supervision and inspection of the ship's pollution prevention certificates, the records related to the ship's fuel oil and the fuel oil quality of the actual fuel. But it is more important to continuously carry out the research on monitoring technology related to ship exhaust emission, so that the monitoring ability of ship exhaust emission can be substantially improved, and the efficiency of ship exhaust emission supervision and inspection can be significantly improved with the help of technical progress.

1.4 Objectives of research
Since the implementation of IMO sulfur restrictions, for shipping enterprises or shipowners, although there are several paths to meet the relevant requirements, no matter which way they choose to achieve SOx emission compliance, they are more or less faced with some problems. What are the main features of the current options? What are the problems worthy of attention? How should shipowners deal with it? How to supervise the competent authorities and so on. Based on IMO and local regulations on sulfur restrictions, this paper analyzes the advantages and disadvantages, cost and management of LSFO, EGCS and LNG fuel, and introduces the existing problems and Countermeasures of Sox emission regulation, so as to find a better solution for the industry to deal with sulfur restrictions and provide some reference for major shipping companies to choose appropriate solutions, promote the safety of ship navigation and protect the marine environment.
1.5 An Outline of Chapter Organization

The structure of the paper is as follows:

1. Introduction. This paper mainly introduces the research background and significance, research status at home and abroad, as well as the main research purpose and content.

2. Research on low SOx emission reduction technology for ships. Firstly, the regulations of IMO, relevant countries and regions on the sulfur content of ship fuel and the restrictions on the use of EGCS are introduced. On this basis, it systematically introduces and compares the three most feasible technologies.

3. Problems and Countermeasures of ship Sox emission control.

4. Conclusion and prospect.
Chapter 2 Research on low SOx emission reduction technology for ships

In order to deal with the sulfur restrictions of IMO, considering the level of science and technology and economic cost, the shipping industry has reached a consensus on the control measures of Sox emission from ships, including the use of LSFO, the installation of EGCS, the use of LNG and other clean energy. In order to choose a suitable scheme for the shipping industry, it is necessary to understand the advantages and disadvantages of various schemes, and recognize the adaptability and limitations of technology. This chapter mainly analyzes the advantages and disadvantages, cost, management and other aspects of the three technical solutions, so as to provide some reference for the major shipping companies to choose the appropriate solutions according to their own needs.

2.1 LSFO Technology

2.1.1 Introduction of LSFO

As far as the source of LSFO is concerned, there are three modes of production and supply. First, the sulfur content of the residue produced by the distillation process of low sulfur crude oil can meet the 0.5% low sulfur fuel standard proposed by IMO. the market price of this LSFO is similar to that of 180 and 380 cst heavy oil, but the output of this LSFO is very small, far from meeting the fuel demand of the global shipping market. The second is to mix and blend low sulfur light fuel with high sulfur heavy fuel to meet the requirement of 0.5% sulfur content, and also to ensure the characteristics of fuel flash point and stability, in which the mixing proportion of light fuel should be more than 50% (Shen Long, 2018). The third is to use EGCS for desulfurization of high sulfur oil. This production mode needs to install new EGCS. Due to the long transformation cycle and large investment in equipment transformation in the early stage, there is no demand for this kind of product in the market.

The use of LSFO can directly solve the problem of SOx emission from the source. Xu Shanxiang mentioned that the foreign research on the influence of fuel sulfur content
on ship pollutant emission has been relatively mature, and the corresponding empirical formula has been formed (Xu Shanxiang, 2015). For example, foreign research shows that about 2% of sulfur in fuel can be directly converted into sulfate in particulate matter (PM), and the remaining sulfur can be converted into sulfide. The results show that the sulfur content of fuel used in marine diesel engine is reduced from 2.4% to 0.8%, and the corresponding PM emission is reduced from 1.0g/kwh to 0.5g/kwh (DNV, 2004). Yasuharu et al. Of Japan studied the NOx and particulate emission characteristics of mtu323 medium speed marine diesel engine with different emulsified fuels. The research shows that the sulfur content of diesel fuel is from 0.04% to 2.82%, and the specific emission of particulate matter can be increased by more than two times (Guo Xiaofeng, 2020). Man B & W company has studied the influence of sulfur content of marine fuel on particulate emission of marine diesel engine. The results show that the PM emission of diesel engine using high sulfur HFO is several times higher than that using low sulfur diesel.

2.1.2 LSFO features

After the introduction of sulfur restrictions IMO 2020, all parties concerned in the shipping industry have been arguing about the quality and specification of low sulfur fuel. In order to eliminate the disputes among all parties and ensure the smooth implementation of IMO 2020 sulfur restrictions, in September 2019, the international standards organization (ISO), together with ship owners, classification societies, traders, oil suppliers and fuel inspection institutions, worked out the guidelines for LSFO quality standards - ISO / PAS 23263, making it clear that ISO 8217 marine fuel oil is still applicable to LSFO, that is, in addition to sulfur content, the limits of other indexes remain unchanged.

In order to take the lead in this fuel oil revolution, governments, shipping companies, refineries and traders all over the world actively make use of their own resources, technology and other advantages to produce LSFO meeting the requirements of ISO 8217. Compared with high sulfur fuel, LSFO has the physical and chemical characteristics of low viscosity, low density, low flash point, low lubricity, low pour point, low sulfur content and low acid value. According to the different types of fuel
and production process, LSFO also has the problems of fuel compatibility, stability and catalyst powder.

2020 The LSFO supplied in the global market has the following characteristics:

1. There is a big difference in the index values

Due to the great differences in density, viscosity, flammability, Al + Si content, pour point and other properties of blending raw materials, and the different blending raw materials used in different regions, the index values of compliance LSFO in the final market are quite different. According to the statistics of LSFO quality of the world's major ports from January to September 2020, the compliance of global LSFO indicators is good, but the indicators are quite different, as shown in Table 1 (Guo Xiao Feng. 2020).

Table 1. Indicators of LSFO in major global ports from January to September

<table>
<thead>
<tr>
<th>Index</th>
<th>LSFO</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>minimum value</td>
</tr>
<tr>
<td>Kinematic viscosity / (50°C) cst</td>
<td>15</td>
</tr>
<tr>
<td>Density / (15°C) kg/m3</td>
<td>910</td>
</tr>
<tr>
<td>Sulfur content /%</td>
<td>0.15</td>
</tr>
<tr>
<td>Al + Si / (mg/kg)</td>
<td>1</td>
</tr>
<tr>
<td>Pour point /°C</td>
<td>-5</td>
</tr>
</tbody>
</table>

2. Low viscosity

Although the viscosity values of different LSFO vary greatly, the 50 °C kinematic viscosity of LSFO in some ports is even as high as 500 CST, but on the whole, the viscosity of LSFO is still far lower than that of high sulfur fuel. The average 50 °C kinematic viscosity of high sulfur fuel is about 350 CST, while the 50 °C kinematic viscosity of most LSFO is 15-200 CST. The 50 °C kinematic viscosity of LSFO with low sulfur crude oil and low sulfur residue as main blending materials is about 100-200 CST, and the 50 °C kinematic viscosity of LSFO with hydrogenation heavy oil and hydrogenation tail oil as main blending materials is about 15-60 CST.
3. High wax content

Although blended fuel meets the requirements in terms of sulfur content, it has a high wax content. The wax content can be determined by the pour point of low temperature flow characteristic index. Most of the pour points of LSFO are between 10 °C and 25 °C, but compared with the average pour point of 0 °C of high sulfur fuel, the pour point of LSFO is relatively high, which also shows that the wax content of LSFO is much higher than that of high sulfur fuel. Wax appearance temperature (WAT) or cloud point is the temperature at which wax crystals appear during fuel cooling, and wax appearance temperature T (WDT) is the temperature at which wax crystals disappear. Wax crystals precipitated at low temperature will cause filter and pipe blockage, which will directly lead to engine fuel shortage, and eventually cause fuel to stop flowing. Therefore, the detection of WDT / WAT is very important to manage and reduce the risk of fuel. Nearly 230 low sulfur fuel samples from different ports in the world were tested by WDT / WAT (Stanley George.). The results are summarized in Figure 2.

![WAT/WDT - VLSFO (2019-2020)](image)

Figure 2 WAT / WDT test results of LSFO

Source: Stanley George.
According to the data from October 2019 to December 2019, WDT is 12℃ higher than WAT on average. But in some cases, the gap between WAT and WDT is more than 30℃. The high gap indicates that this kind of fuel may contain a higher proportion of paraffin base oil.

4. Poor compatibility

The blending formula of different oil blenders in different regions is different. When two kinds of LSFO are mixed, there may be incompatibility, flocculation and sedimentation of asphalt, which will form sludge and block the fuel system, oil separator and filter. Compatibility mainly involves the use and operation of different fuels, and has nothing to do with the characteristics of the fuel itself. Even if the two kinds of fuel indicators are all compliant, incompatibility may still occur after mixing.

2.1.3 Risk of using LSFO

At present, the fuel system, machinery and equipment of ships are generally designed based on high sulfur heavy oil and marine diesel. Although ships have accumulated some experience in using super LSFO (0.10% m / m) in ECA area, they are still lack of experience in using LSFO (0.50% m /m) for a long time according to 2020 sulfur requirement. It is necessary to understand the hazards and risks of LSFO.

(1) The wear of silicon, aluminum and other particles in LSFO to engine. Generally, the content of silicon and aluminum in low sulfur fuel is more than 25 (mg /kg), while that in high sulfur fuel is less than 15 (mg / kg)( Zhou Song, 2015). These tiny particles are difficult to separate from the fuel, which is the main cause of abrasive wear in diesel fuel system.

(2) The influence of low lubricity and viscosity of LSFO on the engine

In the production process of low sulfur diesel, on the one hand, the sulfur content of the fuel is reduced, on the other hand, the lubricity of the fuel is greatly reduced, which is easy to cause the adhesion and wear of the high-pressure oil pump and the fuel injector of the diesel engine, affecting the service life, and may cause the oil leakage of the oil pump when it is serious; At the same time, low viscosity can cause wear of diesel fuel system and affect the normal operation of diesel engine, as shown in Figure 3.
(3) The influence of LSFO flash point on engine safety
IMO and other organizations clearly require that the flash point of marine diesel engine and boiler liquid fuel should not be lower than 60 °C. However, the flash point of some LSFO may be lower than 60 °C, which is a potential safety hazard.

(4) The influence of LSFO on the fuel switching process of power plant
Different from high sulfur fuel, low sulfur distillation fuel has low aromatic hydrocarbon content and poor solubility to asphaltene. When heavy fuel containing a large amount of asphaltene is converted to low sulfur distilled fuel, if the fuel is not switched properly, the plunger of high-pressure oil pump, inlet / return valve and injector needle valve will be stuck and worn due to the rapid change of temperature and poor lubrication of LSFO, resulting in diesel engine flameout and threatening ship safety; The filter may also be blocked due to poor compatibility between fuels, resulting in the shutdown of machinery due to lack of fuel, as shown in Figure 4.
(5) Hazards and risks of wax and asphalt precipitation

As a result, there is too much sludge in the storage tank and daily use tank, which is generally asphalt, wax and lime, resulting in the blockage of the slag outlet of the oil separator and the sharp decline of the oil separation effect, as shown in Figure 5. It will cause the blockage of the oil supply pipeline and the outlet of the discharge pipeline of the oil tank. In serious cases, the main engine and the generator unit will cut off the oil, and eventually the ship will lose power.

Fig. 5 The oil separator and discharge pipe

Source: Li keshun

(6) Harm and risk of low acid value and improper use of cylinder oil

We know that cylinder oil has many functions, such as creating a hydrodynamic oil film separating the piston rings from the liner; cleaning the piston rings, ring grooves, crown and lands, this is the main challenge for LSFO; neutralizing the sulfuric acid in combustion products to control corrosion, and so on.

Recently, a number of shipping companies have used LSFO to cause abnormal wear of cylinder liners. There are reddish deposits on the cylinder head (Fig. 6) (VPS., 2020). After the deposits appear, the wear is rapidly intensified, and the honing lines of cylinder liners disappear in a short time, followed by adhesion and fracture of piston rings and excessive liner wear. It confirms that the main cause is the cylinder oil poorly matched to the LSFO. This has required a change in the alkalinity (Base Number, BN) of the cylinder lube oil.
2.1.4 Precautions against risks in using LSFO

1) Strictly control the four links of LSFO installation, transfer, storage and purification.

2) In order to avoid fuel oil mixing, the fuel oil should be transferred and combined before refueling. In principle, the mixing ratio of ordinary fuel oil is not higher than 3:7. Considering the particularity of LSFO, it is recommended to refuel empty tanks, avoid fuel mixing to the maximum extent, and add fuel additives in advance according to the ratio, to improve the compatibility and stability of new refueling and residual oil in tank;

3) For the temperature control of fuel storage and lightering, the temperature of storage tank must be at least 10 °C above the pour point; The transfer temperature should be kept at 10 °C higher than the cold filter point of the fuel, which is the premise of normal transfer and the filter is not blocked (Ma Weibin, 2020). It should be noted that the temperature is not easy to be too high during storage, so as to avoid stratification, wax precipitation and change of chemical properties of fuel; When the fuel oil is in the sedimentation tank and daily use tank, enough temperature shall be maintained to ensure that the water is separated from the fuel oil, and the residual oil in the oil tank shall be strengthened. The storage time on board should not be too long, generally not more than 6 months;

4) When replacing with new fuel, in line with the principle of the less mixed oil, the better, reduce the mixing ratio, and try to use up the oil in the sedimentation tank and
daily use tank, so as to reduce the oil mixing in the oil change process;

4) While strengthening the monitoring of fuel temperature, strictly implement the separation principle of small flow continuous cycle.

For the storage and purification of LSFO, Alfa Laval manufacturer gives the comparison of LSFO viscosity and temperature, as shown in Table 2.

Table 2 Storage and operating temperature of new LSFO

<table>
<thead>
<tr>
<th>Viscosity @50℃</th>
<th>Storage temperature</th>
<th>Separation temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to 20 cSt</td>
<td>30℃</td>
<td>40℃</td>
</tr>
<tr>
<td>20 to 30 cSt</td>
<td>30℃</td>
<td>50℃</td>
</tr>
<tr>
<td>30 to 40 cSt</td>
<td>15℃ above PP</td>
<td>60℃</td>
</tr>
<tr>
<td>40 to 50 cSt</td>
<td>15℃ above PP</td>
<td>70℃</td>
</tr>
<tr>
<td>50 to 70 cSt</td>
<td>15℃ above PP</td>
<td>80℃</td>
</tr>
</tbody>
</table>

Source: courtesy Alfa Laval

2. Oil sample test and trial firing

1) During refueling, titration sampling must be carried out in the whole process, so as to ensure the representativeness of oil samples. After refueling, it is necessary to send it for examination in time. In view of the test report, in addition to the conventional sulfur content, acid value, pour point, flash point, ash, moisture and other conventional indicators to meet the standard, but also pay special attention to Al + Si, calcium, zinc, phosphorus content must also be within the standard range. According to laboratory experience, when calcium > 30 and zinc or phosphorus > 15, it is judged that the oil contains used lubricating oil. In addition, the upper limit of Al + Si is 60, which should not be greater than 15 (Ma Weibin, 2020).

2) If there is no test condition, the new fuel should be burned as soon as possible. The test should be carried out under good sea conditions. In use, observe the washing frequency of the fuel system filter, especially the self-cleaning filter, strengthen the inspection of the slag discharge condition of the oil separator, and compare the working parameters of the main and auxiliary engines before and after the oil change, so as to determine the actual use of LSFO.
3. strictly control the viscosity and temperature of fuel entering the engine

1）Diesel engine manufacturers generally require that MDO / MGO should not be lower than 2cst, 380 / 180 cst and HFO should be lower than 2cst 12cst, the maximum value should not be higher than 20cst;

2）During the conversion between HFO and MGO / MDO, attention should be paid to the viscosity change and the temperature change rate of the fuel inlet. The manufacturer usually recommends that the fuel temperature gradient should not be greater than 2℃/ min, so as to prevent the thermal shock and thermal expansion of the equipment and pipeline caused by the sudden change of oil temperature, and avoid the risk of pipeline filter blockage and the seizure of fuel pump, high-pressure oil pump and injector.

4. Reasonable selection of cylinder oil matching with LSFO

Taking man as an example, the sl2019-671 / Jap service Circular of LSFO gives the requirements for the use of cylinder oil: under normal circumstances, when using LSFO with sulfur content of 0.1-0.5%, the base value of 40-70 should be selected for the cylinder oil, and bn40 should be the first choice at the initial stage of use, which can be gradually increased to BN100 according to the lubrication condition; LSFO with sulfur content less than 0.1% is used, and LSFO with 15-25 base number is selected; In the initial stage, BN15-25 base number is preferred, and it can be raised to BN40 or even BN100 step by step according to the lubrication condition (Ma Weibin, 2020). In the early stage of replacing LSFO, most manufacturers suggest that the cylinder oil with high and low base number should be used alternately. Through comparison, the appropriate cylinder oil should be determined finally.

5. Strict scavenging box inspection system

The selection of cylinder oil with appropriate base number and the amount of oil injection should be determined by combining with scavenging port inspection. In the early stage of replacing LSFO, we must find more opportunities to continuously track and check the cylinder lubrication through scavenging port.

6. Keep sufficient spare parts for LSFO

In view of the special physical and chemical characteristics of LSFO, some diesel
engine manufacturers have upgraded and optimized the relevant parts, such as ceramic piston ring, LSFO special sleeve plunger couple, etc. According to the suggestion of the manufacturer and the actual situation of the diesel engine on board, the vulnerable parts can be stored in advance and replaced in time when they are worn, so as to ensure the safe and reliable operation of the diesel engine and lay the foundation for the safe operation.

2.1.5 LSFO related regulations

The control of ship emissions requires international cooperation, which can only be achieved through the cooperation among various countries. In order to control SO2 pollution from ships, many countries in the world have issued SOx emission regulations. At present, the regulations of SOx emission from ships come from two aspects: one is the regulations formulated by IMO; the other is the local laws and regulations. In general, local regulations are stricter than IMO emission regulations.

1. Resolution issued by IMO(Chen Weihua, 2019):

(1) IMO passed resolution mepc.280 (70), confirming that "sulfur content of ship fuel shall not exceed 0.50% m / M standard" will be implemented globally from January 1, 2020.

(2) Non compliant fuel for propulsion and operation is prohibited on board. IMO has passed resolution mepc.305 (73): Amendment to Annex VI of MARPOL - forbidding ships to carry non compliant fuel for propulsion and operation. The amendment will enter into force on March 1, 2020.

(3) Fuel oil sampling point setting is used on board. The onboard fuel system needs to set up appropriate sampling points to facilitate the sampling of in-service fuel on board. The setting of sampling points should meet the requirements of IMO "guidelines for on board sampling for fuel sulfur content verification" (mepc.1/circ.864 and draft amendments).

(4) Based on MARPOL Annex VI, the implementation plan of implementing the 0.50% fuel sulfur limit is formulated. In order to ensure the effective and unified implementation of the emission standard in mepc.280 (70), IMO has specially formulated a work plan to carry out the work from the preparation of fuel conversion,
compliance verification method, safety of using 0.50% LSFO, non obtainable report of compliant fuel, revision requirements of fuel standard, etc.

(5) Mepc.320 (74) guidelines for the unified implementation of 0.50% fuel sulfur limit based on MARPOL Annex VI in order to ensure the implementation of the unified implementation of 0.50% fuel sulfur limit based on MARPOL Annex VI, the resolution further improves the requirements for risk assessment and compliance supervision and control of ship implementation plan, aiming at providing reference for competent authorities, port States, shipowners, shipping companies, shipbuilders and fuel suppliers etc.

(6) IMO passed resolution mepc.324 (75), which amended Annex VI of MARPOL convention. The amendment is expected to come into effect on April 1, 2022. The main amendments are as follows: the definitions of in use sample and on board sample are added; New regulations on the setting of fuel sampling points; New regulations on the storage and inspection of fuel oil samples used on board and carried on board; Add the requirement that the competent authority should report required EEDI, maintained EEDI and their related information to IMO; Revise the fuel verification procedure for fuel samples in Appendix VI and IAPP certificate schedule.

2. On the EU requirements for fuel sulfur content:

(1) Ships berthed in EU ports (including mooring, mooring buoy and wharf berthing) for more than 2 hours shall not use marine fuel with sulfur content more than 0.10% m / m.

(2) Except for SOx control zone, from January 1, 2020, all ships sailing in the territorial waters, exclusive economic zones and pollution control zones of EU Member States shall not use marine fuel with sulfur content more than 0.50% m / m.

In other words,

For ships entering the EU, the time requirement for using marine fuel with sulfur content not more than 0.50% m / m will not be delayed.

(3) Except for SOx control zone, from August 1, 2006 to January 1, 2020, all scheduled passenger ships between EU Member States' territorial waters, exclusive economic zone and pollution control zone shall not use marine fuel with sulfur
content more than 1.50% m / m.

**2.1.6 Focus of PSC on LSFO inspection**

IMO passed resolution mepc.321 (74), Chapter 3 port state control guidelines of MARPOL Annex VI in 2019, which added relevant contents of LSFO inspection on the basis of resolution mepc.181 (59), and provided guidance for PSC to implement compliance inspection of Chapter 3 requirements of MARPOL Annex VI (Zhang Jianfeng). At present, IMO has issued a series of resolutions and circulars on LSFO, among which the relevant requirements related to PSC inspection are as follows:

When PSCO carries out LSFO inspection on ships according to the requirements of Chapter 3 of MARPOL Annex VI, it mainly carries out the following aspects:

1. **Initial inspection of ships required to carry IAPP certificates**

First of all, PSCO should determine the construction date of the ship and the installation date of the corresponding equipment, so as to determine which clause is applicable to Chapter 3 of MARPOL annex VI.

When PSCO is boarding the ship and introducing it to the master or the responsible crew, PSCO will check the following documents, and the relevant inspection requirements are as follows:

1. Check the international certificate for the prevention of air pollution (IAPP) issued in accordance with Article 6 of MARPOL Annex VI, including its appendix. PSCO will verify whether the IAPP certificate is correctly filled in and whether the specified inspection has been completed, so as to judge the validity of the IAPP certificate.

2. Check the approval documents issued in accordance with Article 4 of MARPOL Annex VI for all exhaust gas filtration systems or equivalent methods installed to reduce SOx emissions.

3. Check the exception and exemption approval documents issued according to Article 3 of Annex VI of MARPOL.

4. Check EGCS monitoring records. In addition, the EGCS log book including nitrate emission data and performance records will be checked. For the inspection of this document, when evaluating the discharge ratio and washing water records, PSCO may find that the data value of individual parameter points in the records exceeds the
specified discharge ratio or washing water limit, but it does not mean that EGCS does not operate according to the regulations, so it will not be regarded as unqualified evidence.

(5) Check the fuel delivery note and relevant samples and records that meet the requirements of MARPOL Annex VI Article 18. If the ship's fuel delivery note or sample does not meet the relevant requirements, the master or the responsible crew shall inform the flag state director as soon as possible, explain the relevant situation, and provide a copy to the port state authority and the fuel deliverer. Relevant documents shall be kept on board and PSCO will inspect them.

(6) When the vessel determines that it is unable to purchase compliant fuel oil, it shall notify the competent authorities of the flag state and the relevant port authorities of the destination as soon as possible, and submit the Fuel Oil Non-Availability Report (FONAR). Relevant documents shall be kept on board and PSCO will inspect them.

(7) In addition, if the fuel oil delivery note shows that the fuel oil meets the requirements, but the master proves that the fuel oil sample filled does not meet the requirements through independent testing, the master shall inform the competent authorities of the flag state, the competent authorities of the relevant port of destination and the fuel oil deliverer as soon as possible. Relevant documents shall be kept on board and PSCO will inspect them.

2. Initial inspection of ships equipped with SOx equivalent emission devices

If SOx equivalent emission devices are installed on board, PSCO will check the following documents:

(1) All equivalent methods on board have been properly recognized.

(2) Evidence that the fuel consumption unit on board has used the equivalent method described in the IAPP certificate.

(3) The fuel delivery note that can prove that the fuel oil is used for SOx equivalent emission device, or the document that the ship is exempted from emission test.

If the ship's EGCS cannot meet the relevant requirements, the master or the crew in charge shall notify the competent authority of the flag state as soon as possible, and provide a copy to the competent authority of the port state of the destination, and
formulate corresponding corrective measures according to the EGCS technical manual.

If this happens, PSCO will also check the relevant documents.

3. Initial inspection in ECA area

When the ship sails to the ECA area, the main points of PSCO inspection for LSFO include the following contents:

(1) According to Article 18.5 and 14.4 of MARPOL Annex VI, the fuel oil delivery note or other documents including oil record book part I kept on board shall prove that the sulfur content of fuel oil used on board shall not exceed 0.10%.

(2) According to Article 14.6 of MARPOL Annex VI, there should be a written procedure on board to show that the ship has completed the fuel conversion procedure before entering the ECA area, so as to prove that the ship uses fuel with sulfur content less than 0.10% in the whole ECA area.

4. Initial inspection of first port after leaving ECA area

When the ship berths at the first port after leaving the ECA area, PSCO pays attention to the LSFO inspection when boarding the ship

(1) According to Article 18.5 and 14.4 of MARPOL Annex VI, the fuel oil delivery note or other documents including oil record book part I kept on board shall prove that the sulfur content of fuel oil used on board shall not exceed 0.10%.

(2) According to Article 14.6 of MARPOL Annex VI, there should be a written procedure on board to show that the ship has completed the fuel conversion procedure after entering the ECA area, so as to prove that the ship uses fuel with sulfur content less than 0.10% in the whole ECA area.

2. Results of initial inspection

On the premise that the certificates and documents are valid, according to PSCO's overall impression and visual observation of the ship, it is confirmed that the ship is in good repair and maintenance condition, and then the ship will easily pass the initial inspection; However, if PSCO's overall impression of the ship and visual observation show that there is "obvious reason" to prove that the condition of the ship or equipment is seriously inconsistent with that stated in the certificate or document,
PSCO will further carry out a more detailed inspection.

Generally speaking, "obvious reasons" mainly include the following categories:

1. The certificate required by MARPOL Annex VI is lost or invalid;
2. The documents required by Annex VI of MARPOL are lost or invalid;
3. The equipment or device specified in the certificate or document does not exist;
4. The ship is equipped with equipment or installation not specified in the certificate or document;
5. According to PSCO's general impression and observation, the equipment or device specified in the certificate or document has serious defects;
6. There is information or evidence that the captain or crew is not familiar with the basic operations related to the prevention of air pollution;
7. The information shown in the fuel delivery note is inconsistent with Article 2.3 of the annex to IAPP certificate;
8. The equivalent device is not used as required;
9. After calculation, the delivered fuel quantity can't match the ship's sailing plan;
10. There are reports or complaints, or the fuel content detection equipment shows that the ship used non-conforming fuel during the voyage.

3. More detailed inspection

When PSCO goes through the initial inspection and has "obvious reasons" to prove that the condition of the ship or equipment is seriously inconsistent with the certificate or document, PSCO will carry out further detailed inspection. At this time, PSCO will expand the scope of inspection and conduct a detailed inspection on all equipment and systems that may cause air pollution. The inspection points mainly include: PSCO will check and verify whether the fuel used on board meets the requirements of Article 14 and Article 18 of MARPOL Annex VI; At the same time, pay attention to the records required by clause 14.6, so as to determine the fuel sulfur used by the ship in the emission control area

Or confirm that the ship has used other approved equivalent devices as required.

(2) If EGCS is used on board, PSCO will check the EGCS device and its monitoring system, and verify the correct operation of the device according to the inspection
procedures specified in OMM (shipboard inspection manual). In addition, PSCO will also verify

If the relevant records show that the operating parameters are inconsistent with the limits given in the approval documents, PSCO will check the emission ratio, pH / PAH, turbidity specified in ETM-A or ETM-B and other relevant parameters.

4. Defects that may cause retention

PSCO may judge the detention of the ship according to the following situations:

(1) Unable to provide valid IAPP certificate;
(2) If the ship is not equipped with SOx emission equivalent device, and the sampling test results show that the sulfur content of fuel exceeds the standard;
(3) If SOx emission equivalent device is installed on the ship, but the proof document of equivalent mode cannot be provided;
(4) When the ship is sailing in the SOx emission control area, it does not meet the relevant requirements of the emission control area;
(5) The crew is not familiar with the key operation procedures of pollution prevention.

5. Inspection of non-convention ships or ships not required to carry IAPP certificate

(1) If the ship does not have IAPP certificate, PSCO shall judge whether the ship condition and its equipment meet the requirements of the annex to the Convention. In this regard, PSCO should ensure that these ships are not given more preferential treatment in accordance with Article 5 (4) of MARPOL convention.
(2) If other certificates other than IAPP are available on board, PSCO shall consider them in the assessment.

2.2 EGCS Technology

2.2.1 Introduction to EGCS

IMO's regulations on sulfide emission control specifically specify that ships operating in specific areas can reduce Sox emission by reducing the sulfur content of fuel oil, and can also reduce SOx concentration of exhaust gas by installing exhaust gas post-treatment devices. At present, the most commonly used method to reduce SOx emission is burning LSFO. However, with the rise of international oil prices and more and more stringent emission regulations, the cost and difficulty of reducing the sulfur
content in fuel oil make people begin to pay attention to the post-treatment technology of ship exhaust gas.

There are many advantages in using exhaust gas scrubbing desulfurization technology for marine engines: (1) the desulfurization efficiency is high, which can generally reach more than 95% (Dong Wei, 2013); (2) It can remove most of the particulate matter and part of NOx in the exhaust gas; (3) The adaptability of the equipment is strong, which will not or will not affect the working performance of the diesel engine; (4) The operation and maintenance cost is low, and the operation is flexible, so as to avoid the potential safety hazard when changing the fuel. For ships, scrubbing desulfurization technology is considered to be one of the most promising measures to reduce Sox emissions from marine power plants. Ship desulfurization technology can be divided into wet and dry. At present, wet desulfurization technology is widely used in ship emission control, including open desulfurization system, closed desulfurization system and mixed desulfurization system.

1. Open desulfurization system

The open desulfurization system mainly uses the neutralization reaction between the alkalinity of natural seawater and the acid gas SOx in the waste gas to remove SOx. Due to the natural alkalinity of seawater, seawater washing is very suitable for ship exhaust gas desulfurization in terms of universality, economy and feasibility.
1. monitoring system  2. control system  3. seawater  4. exhaust gas after washing  
5. gas  6. deaerator  7. sludge tank  8. water treatment

Figure 7 Open desulfurization system

The marine open desulfurization system applied by Hamworthy-krystellon is shown in Figure 7. The system completely relies on seawater as the absorbent of SO2 without adding any alkaline substances. The actual operation of the system proves that it can achieve 90 ~ 95% SO2 and 80% particle removal rate (Hamworthy Krystallon, 2010). Moreover, the installation of the system can replace the muffler in the exhaust system of marine diesel engine and reduce the noise of the ship.

2. Closed desulfurization system

The desulfurization system mainly uses fresh water as circulating water and strong alkali as desulfurizer to absorb SO2 in waste gas. However, seawater is only used as cooling water in the whole cycle and does not directly participate in desulfurization reaction. Because the system is completely closed cycle, the fresh water involved in the reaction is not discharged to the sea, so the absolute sense of zero discharge is realized. At present, NaOH is generally used as the desulfurizer of closed desulfurization system, which has high desulfurization efficiency and can well meet
the strict emission regulations.

1. exhaust gas  2. seawater  3. treatment tank  4. sedimentation tank  5. reservoir  

Figure 8 closed desulfurization system

The closed fresh water desulfurization system in Wärtsilä is shown in Figure 8 (Torbjorn Henriksson, 2010). In order to verify the availability of the system under all working conditions, Wärtsilä artificially increases the power rapidly, and the SO₂ removal rate can reach 100%. At the same time, the sulfur content of the fuel is increased from 1.5% to 3.4%, and the SO₂ removal rate of the exhaust gas of the system can also reach 100%. The system can reduce the particulate emission by 60% and effectively reduce the noise level of ship operation. However, the closed desulfurization system needs to reserve a large space in the ship to store NaOH, and a large amount of alkali consumption will increase the operation cost. As the above problems can’t be solved, the closed system can hardly be accepted by ships. At present, few ships choose to install closed EGCS.

3. Hybrid desulfurization system

The hybrid desulfurization system can be flexibly switched between open mode and closed-loop mode. Seawater can be used as absorbent, and fresh water can be used to
add alkaline substances as desulfurizer. The mixed desulfurization system applied by Aalborg is shown in Figure 9 (AALBORG, 2011). The mixed desulfurization system adopts the double working mode of open desulfurization as the main mode and closed desulfurization as the auxiliary mode. When the ship runs in the sea area without SOx emission control area, the open desulfurization mode is adopted, while the port and other highly strict SOx emission control areas automatically switch to the closed desulfurization mode. Due to the adjustability of the dual system, it can’t only meet the requirements of high standard SOx emission, but also reduce the consumption of NaOH solution.

Figure 9 Hybrid desulfurization system

1. scrubber  2. detection system  3. treatment tank  4. sludge tank  5. pump

4. Comparison of three washing systems
The advantages and disadvantages of the three wet washing systems are compared in Table 3.
Table 3 Comparison of advantages and disadvantages of three systems

<table>
<thead>
<tr>
<th>Mode</th>
<th>advantages</th>
<th>disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open desulfurization system</td>
<td>1. Wash with seawater without adding any chemicals; 2. The system is simple in composition and does not need to store washing liquid and waste liquid; 3. Low investment cost, low operation cost and low management cost; 4. The absorption tower will not produce scaling, blocking and other operation problems, and the operation rate is high.</td>
<td>1. The consumption of seawater is large, which reduces the energy utilization rate; 2. After washing, the waste liquid is acidic and corrodes the equipment; 3. The direct discharge of waste liquid affects the environment; 4. increase the exhaust back pressure of diesel engine, which will affect the normal operation of diesel engine.</td>
</tr>
<tr>
<td>Close desulfurization system</td>
<td>1. It is not affected by sea water and can navigate in the global sea area; 2. The washing waste liquid is stored on the ship, which will not pollute the environment; 3. Less detergent consumption and less pump power required; 4. Low energy consumption, accounting for about 0.5% ~ 1% of diesel engine power.</td>
<td>1. The system composition is complex and the construction cost is high; 2. Use NaOH solution to increase operation cost; 3. The storage and transportation of NaOH will bring some safety problems.</td>
</tr>
<tr>
<td>Hybrid desulfurization system</td>
<td>1. It has the advantages of both open and closed systems; 2. Flexible switching, navigation in global waters.</td>
<td>The system composition is more complex, and the initial equipment investment and installation cost is high.</td>
</tr>
</tbody>
</table>

Generally speaking, due to the simple composition of the open system, the vast majority of shipowners choose the open system.

But at the same time, because the open system is suspected of pollution transfer, and a large number of acidic liquids are discharged in the port area, causing environmental pollution to the port area and other factors, many port countries prohibit the use of open system in the port.

At present, ship owners generally plan to use LSFO in the port; In order to achieve the same SOx emission level as using LSFO, high sulfur oil is used in the high seas and
open system is used to desulfurize the waste gas.

2.2.2 Risk analysis of installing EGCS

1 Issues to be considered when installing EGCS

(1) Economic evaluation

It includes the analysis of ship age, ship route and return on investment. The influencing factors include the price difference between HFO and MGO, the running time of EGCS in ECA, the output power of diesel engine, etc. Table 4 shows the cost estimation cases of ships with EGCS installed at present (Li Lei, 2019). It can be seen from table 4 that the economy of installing EGCS is better for ships with smaller age, larger diesel engine power and longer sailing time in ECA.

Table 4 Cost estimation cases of EGCS installation on existing ships

<table>
<thead>
<tr>
<th>Item</th>
<th>container ship</th>
<th>Aframax</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ship age (years)</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>route</td>
<td>Unlimited navigation area</td>
<td>Unlimited navigation area</td>
</tr>
<tr>
<td>ECA navigation rate</td>
<td>100%</td>
<td>60%</td>
</tr>
<tr>
<td>Diesel engine power</td>
<td>Single intake engine (8MW)</td>
<td>Main engine with multiple air intakes (13.7MW) and auxiliary engine (0.85MW * 3 sets)</td>
</tr>
<tr>
<td>EGCS type</td>
<td>Hybrid EGCS</td>
<td>Hybrid EGCS</td>
</tr>
<tr>
<td>Save money every year</td>
<td>12711000 euros</td>
<td>159Million euro</td>
</tr>
<tr>
<td>Investment return period</td>
<td>About 2 years</td>
<td>About 3 years</td>
</tr>
</tbody>
</table>

(2) Technical feasibility study

It includes ship type, power load, location of EGCS installed on existing ship, exhaust emission flow under maximum continuous power of fuel burning device (e.g. main engine and auxiliary engine), consultation opinions of fuel burning device manufacturer, risk analysis, flag state and national standard Port state requirements and other comprehensive factors determine whether to install EGCS and what type of EGCS to choose.
(3) After the installation of EGCS, the possible adverse effects on the ship should be considered.

The installation of EGCS will affect the ship in many aspects, including ship tonnage, deadweight, center of gravity, intact stability, damaged stability, fire control arrangement, outfitting number, bridge eye, acid proof paint treatment of hull plate near washing water discharge port, exhaust back pressure of diesel engine (affecting fuel consumption and NOx emission), review of NOx technical documents, fixed fire protection system capacity of engine room, main switch parameters of distribution board, EEDI review, etc.

(4) EGCS equipment selection, approval and certification, and procedures for exemption from reporting to flag state. The selection of EGCS equipment should be based on the ship space, EGCS type, washing tower type, approval and certification.

2. Risk of EGCS installation

Shipping enterprises choose to install EGCS, there are some risks objectively, from the current operation situation, mainly concentrated in the following aspects:

(1) The pressure of initial investment

The cost of equipment and labor for the initial installation of EGCS is high. In addition, the cost of ship suspension and subsequent maintenance during refitting should also be taken into account. The total cost of refitting is usually several million dollars. In addition, we should also calculate the loss caused by the ship's suspension and the subsequent maintenance and power cost increase. According to the current price difference between high sulfur oil and LSFO, large ships will recover the cost of installing EGCS in about one year, while small and medium ships can recover the cost in one and a half to two years. However, for large shipping enterprises with hundreds of ships, the one-time investment is often hundreds of millions of dollars, and this cost needs to be paid to equipment manufacturers and shipyards in a very short time, which will also bring great pressure to shipowners.

(2) Supply risk of EGCS manufacturer

Due to the large area and volume of EGCS, it is basically equivalent to installing a small chemical plant on the ship. However, in the initial design of the ship, the
installation of EGCS in the later stage was not considered. Therefore, the engine room height, chimney strength and drainage pipeline layout of the ship are quite different. EGCS needs to be specified. It is difficult to determine the supply cycle and the specific construction period. In addition, Wärtsilä and Alfa Laval, two enterprises with large market share of EGCS, hold a conservative attitude towards the production of EGCS. Although there are many orders, there is no large-scale expansion of production at present, and the production of orders may be delayed.

(3) Stability of EGCS
The exhaust gas desulfurization system needs to connect the exhaust pipes of the main engine, auxiliary engine and oil fired boiler into the EGCS. The back pressure of the desulfurization system is 980 PA, plus the back pressure of the muffler. In order to ensure the requirements of the equipment manufacturers for the exhaust back pressure (approximately 2940 pa), the layout requirements of the exhaust pipe will be very harsh, and it is likely that the layout requirements of all parties can’t be taken into account (Zhang Guofeng, 2019 ).The increase of exhaust back pressure will not only increase the fuel consumption of main and auxiliary engine, but also cause the surge of main and auxiliary engine supercharger and damage the supercharger. In addition, the installation of EGCS will bring an additional weight of 120-150 tons to the ship, which will also affect the stability of the ship. The crew are not familiar with EGCS and lack of operation experience. Once the ship's equipment fails, it is uncertain whether it will be exempted from burning high sulfur oil by the MSA, and the ship needs to keep LSFO, which will occupy the oil tank space and reduce the loading capacity.

(4) EGCS installation and emission compliance
At present, most of the installed EGCS are open-loop. For the open-loop devices, if it is proved that the direct discharge of pollutants and waste water pollutes the sea, the environmental protection regulations of various countries may have restrictions on this, and the ships need to be further modified. Based on this view, many countries or regions have adopted local legislation to restrict the use or emission of open EGCS. For the closed-loop device, how to deal with the pollutants such as sodium sulfite
generated in the process of using EGCS in order to meet the environmental protection requirements is still questionable. IMO has not issued the implementation rules of EGCS, just requiring EGCS to meet the requirements of the flag state. However, some ECA regional ports have made it clear that they will not accept the ship related solid waste disposal requests.

(5) Uncertainty in the global marine fuel market. According to the statistics of EGCS Association, some EGCS ships account for less than 5% of the global transport capacity (Zheng Qingguo, 2019). After the implementation of the policy, the vast majority of ships will use LSFO, which may lead to large-scale production of LSFO. Under the scale effect, the price of LSFO will go down, and the price difference between high sulfur oil and LSFO will be further narrowed, which will lead to changes in the calculation premise of installing EGCS. The economy of this measure needs to be reevaluated. And after LSFO becomes the mainstream, it is uncertain whether high sulfur oil with quality assurance can be provided in ports all over the world.

(6) The risk of this technology is uncertain. At present, the technology and stability of the equipment itself are not mature, and have not been widely verified by ship applications; This will put forward higher requirements for the crew to master the performance, use and maintenance of the new equipment, and it will be a new challenge in the case of less crew and fast work rhythm, which will bring greater risks. According to a circular issued by Gard association this year, some accidents have occurred within 10-15 months after the installation of the open EGCS, and the washing wastewater directly enters the engine room, ballast water tank or cargo hold due to the corrosion of the outboard discharge pip. There is no effective solution to the corrosion problem of open EGCS. As there is not enough practical experience in the use of EGCS on board, the potential safety hazards may not be fully exposed in the future. Therefore, only after the occurrence of new accidents can we continuously summarize the experience and formulate corresponding safety specifications and complete emergency plans.
2.2.3 Regulations on restrictions on the use of EGCS

Annex VI of MARPOL clearly states that ships can realize equivalent SOx emission by adding EGCS. However, ships that plan to meet the standards in this way must be approved by the flag state (Ma Weibin, 2020). The regulations of IMO, relevant countries and regions on the restriction of EGCS use are as follows:

1. IMO requirements for EGCS
   (1) According to the requirements of mepc.259 (68), ships can be equipped with EGCS according to scheme a or scheme B.
   (2) According to article 10.4.1 of "2015 guidelines for waste gas filtration system" of resolution mepc.259 (68), "the residues generated by waste gas filtration system devices shall be discharged to appropriate receiving facilities on shore, and shall not be discharged into the sea or burned on board", Article 16.2 of the 73 / 78 International Convention for the prevention of pollution from ships refers to "the substances prohibited from burning on board include the residues of the exhaust gas filtration system", and article 17.1 of the receiving facilities refers to "the parties shall ensure that adequate facilities are provided to meet the needs of ships using their ports"

   However, the hazardous classification and safe transportation conditions of the residues of the waste gas filtration system are not clear.

2. Requirements of the European Union on the use of EGCS
   (1) Direct (EU) 2016 / 802 (Article 5)) ships are not allowed to use fuel with sulfur content more than 3.5% unless closed-loop EGCS is used.
   (2) For the flag ships of EU Member States, EGCS shall be approved in accordance with the requirements of directive2014 / 90 / EU on marine products (MED).
   (3) Based on the research and test purposes of EGCS, the EU also puts forward the requirements of relevant reports, duration, emissions and assessment. See EU directive 2016 / 802 / EC for details.
   (4) For EGCS that use chemicals, additives, formulations and related chemicals in the system, unless the shipping company proves that the discharge of washing water has
no obvious negative effect and will not pose a threat to human health and the environment, the washing water shall not be discharged.

Water shall not be discharged into the sea, including enclosed wharves, ports and estuaries. (5) According to the provisions of direct (EU) 2016/802/EC, EGCS for continuous monitoring of SOx emission is required for ships sailing in EU waters, which means that the equipment approved according to scheme a is not suitable for use, unless it is equipped with a redundant SO2/CO2 system.

3. USCG requirements for EGCS:
USCG issued a letter "CG-CVC Policy letter 12-04" on July 1, 2012, notifying the methods and procedures of using EGCS. According to the relevant letter, if EGCS is used in emission control areas (ECAS) within the jurisdiction of the United States, the flag state authorities of ships flying flags other than the United States flag are required to submit a proposal to USCG and obtain acceptance.

4. US EPA requirements for EGCS:
(1) The discharge of EGCS washing water shall not contain oil, including oily mixture, and its harmful amount shall be determined according to 40 CFR Part 110.
(2) The sludge and residue from the treatment of EGCS washing water discharge should not be discharged into the water body, but must be sent to the shore receiving facilities.
(3) The continuous monitoring equipment of EGCS washing water must be calibrated regularly according to the requirements of the testing equipment manufacturer and EGCS manufacturer.

5. Chinese regulations on EGCS:
(1) If the ship uses EGCS, it is necessary to provide the product certificate of the system, and the information of the ship using EGCS should be filled in the IAPP certificate, including the start and end time of each use of EGCS, the position, longitude and latitude of the ship and the operator. It shall be recorded in the engine log or other relevant record books.
(2) It is forbidden to discharge open type EGCS washing water in inland river control area, port water area in coastal control area and Bohai Sea water area. The
requirements for the discharge of open type EGCS washing water in other coastal control areas will be announced and implemented in due time.

(3) It is forbidden to discharge the residue of EGCS washing water into the water or burn it on board. The ship shall record the storage and treatment of the residue of EGCS washing water truthfully.

(4) Hong Kong, China regulation on EGCS: recognized technologies (such as Sox scrubber) can be used to reduce Sox, at least as effective as using low sulfur marine fuel. The installation of these approved technologies on seagoing vessels can eliminate the need to convert fuel that meets the requirements. Based on the written exemption application for the use of these approved technologies, the master, ship owner or agent shall apply to the Hong Kong environmental protection department for the issuance of initial or subsequent certificate renewal exemption 14 days before arrival (i.e. the issuance of the certificate has nothing to do with RO and is directly contacted by the ship owner and the Hong Kong Environmental Protection Department). The exemption of no more than 3 years will be issued by the Hong Kong environmental protection department after satisfactory review of the relevant documents. If the use of LSFO will cause ship safety risks, an exemption for the period of stay may be granted with the consent of the Hong Kong authorities.

6. The Maritime and Port Authority of Singapore (MPA) will prohibit the use of open EGCS in Singapore waters from January 1, 2020. Before entering the waters of Singapore, the ship with combined EGCS should switch to the closed mode or MGO or MDO in time. For vessels flying Singapore flag, the emission reduction technology installed on the vessels must be approved by MPA.

2.3 LNG fuel technology

The use of shipping new energy is a long-term and complex system engineering. To study and judge the application prospect of clean energy, we need to comprehensively consider many factors: energy availability, economic acceptability, technology
maturity, environmental adaptability, regulatory completeness and so on. Based on this, the marine adaptability of LNG, LPG, methanol, dimethyl ether, biofuel, hydrogen, ammonia and other clean energy is analyzed, as shown in Table 5. It is found that LNG is relatively mature and may be applied in actual scale on ships (Guo Xiaofeng, 2019)

Table 5 Comprehensive evaluation of marine adaptability of clean energy

<table>
<thead>
<tr>
<th></th>
<th>LNG</th>
<th>LPG</th>
<th>methanol</th>
<th>dimethyl ether</th>
<th>Biofuels</th>
<th>hydrogen</th>
<th>ammonia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy availability</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Economic acceptability</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Technology maturity</td>
<td>5</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Environmental adaptability</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Regulatory completeness</td>
<td>5</td>
<td>2</td>
<td>4</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Comprehensive evaluation</td>
<td>4.6</td>
<td>3.2</td>
<td>3.6</td>
<td>2.2</td>
<td>3</td>
<td>3.2</td>
<td>2.8</td>
</tr>
</tbody>
</table>

1. Advantages of LNG as marine fuel

Compared with traditional fuel, LNG has the following advantages:

(1) Abundant reserves. At present, the conventional LNG resource in the world is estimated to be $1.45 \times 10^{14} \text{m}^3$, which can be exploited for 63 years based on the current annual consumption of $2.3 \times 10^{12} \text{m}^3$. LNG has become the fastest growing energy consumption in the 21st century, accounting for an increasing proportion in the global disposable energy consumption, accounting for nearly 25% of the world's energy consumption.

(2) Low cost and stable market: the calorific value of LNG is higher than that of other fuels, but its price is cheaper than that of other fuels. Shipping companies can save a lot of operating costs if they use LNG as fuel. Since LNG price is mainly measured by long-term supply price, its fluctuation range is small, while the price is lower than the international crude oil price level.
(3) Good safety. Firstly, the ignition point of LNG is 650°C, while that of diesel is only 220°C; Secondly, the concentration range of LNG explosion is 5% - 15%, and that of diesel gas explosion is 0.5% - 4.0%; Finally, the density of LNG is 55% of the air, and it will diffuse into the air directly after the leakage. If the sniffer is added, the leakage can be found in time, reducing the potential safety hazard.

(4) Good environmental protection. LNG is the cleanest fossil fuel. Compared with other fossil fuels, under the same energy output, LNG has the least pollutant emissions, almost no Sox and particle emissions, which fully meets the requirements of IMO Convention and regulations on Sox emissions.

(5) Operation convenience
The dual fuel engine developed by Wärtsilä has three operation modes: gas mode, diesel mode and backup mode. In gas mode, LNG is used and diesel is used for ignition. Once there is an alarm, it can switch to the fuel state instantaneously, automatically and smoothly under any power, and the engine power and speed remain stable without causing ship stall.
Based on years of experience in production, test, use and maintenance of dual fuel engine in Wärtsilä, under the premise of normal and standard use of engine, thanks to the clean characteristics of LNG, the maintenance interval of major moving parts and components of dual fuel engine is longer than that of diesel engine, and the service life is longer. Therefore, compared with diesel engine, it can save a lot of maintenance costs. Compared with diesel engine, the combustion of gas engine is much more peaceful and the vibration is small.

2. Disadvantages of LNG as marine fuel
Although the use of LNG fuel has significant advantages, the following problems still restrict the development and application of ship LNG power.
(1) The safety requirements of using LNG are strict, and the initial investment cost of equipment is high. In order to meet the safety of LNG powered ship, its access standard is different from that of ordinary ship, for example, independent engine compartment must be set up; LNG pipeline must adopt double shell, which can withstand both high pressure and low pressure; The investment cost of building LNG
The power plant is about 1/3 of the ship's cost, which is 6-10 million US dollars more than that of traditional power plant burning heavy oil.

(2) LNG filling and other supporting facilities are relatively backward. At present, a complete supply base and network have not been established for the filling facilities of liquefied LNG carriers.

(3) The endurance is weak. Since the energy per unit volume of liquefied LNG is only about 55% of the same volume of fuel oil, if all the ports where the ships can add fuel oil can be filled with liquefied LNG, the liquefied LNG ship should maintain the same endurance as the fuel oil ship, and its fuel storage space demand is about twice that of the fuel oil ship; If not all ports that can be equipped with fuel oil can be filled with liquefied LNG, the liquefied LNG ship should maintain the same endurance as the fuel oil ship, and its demand for fuel storage space is greater, which needs to occupy the volume of the ship originally used for carrying cargo. More importantly, it is a process of marine energy conversion to use liquefied LNG instead of conventional fuel oil. Usually, various obstacles faced by energy conversion will be highlighted in this process, and it is difficult for the industry to effectively remove these obstacles in the short term.

(4) There are still some problems in gas filling technology. Due to the influence of high tide and low tide, the berthing position of the ship can't be determined, and LNG transportation is difficult.

The delivery pipes are all low temperature pipes, which are not easy to extend and expand. There are still many technical problems to be solved in ship to ship refueling.

(5) From the perspective of LNG combustion, the Sox after LNG combustion can be considered as 0, and the reduction rate of Sox is 100%. However, it is worth noting that Sox of gas engine is not necessarily equal to zero, which is related to the design of the engine. Both Wärtsilä marine dual fuel engine and man dual fuel engine need oil to ignite. Therefore, when calculating the desulfurization effect of gas engine, the amount of pilot oil and sulfur content should also be considered. For example, when the power of Wärtsilä 7x62df engine is 35%, the consumption of pilot oil is 4.5 g / kWh, accounting for 3.3% of the total energy consumption; At 65% power, the
consumption of pilot oil is 2.6 g / kWh, accounting for 1.8% of the total energy consumption. According to the official data of Wärtsilä, the reduction effect of Sox is 99% (Ren Yuan, 2015).

According to Mann's product manual, the pilot oil of Mann's two-stroke dual fuel engine can be heavy oil or diesel, and the minimum injection quantity is 5%. The Sox emission reduction of man two-stroke dual fuel engine in gas state is 90% - 95%. If heavy oil is used as pilot oil at low load, it may not meet the Sox emission requirements.

It can be seen that the Sox emission reduction of the LNG scheme is related to the ignition mode of the engine, the usage of the pilot oil and the sulfur content, and there is also the possibility of not meeting the SOx emission.

(6) Imperfect policies and regulations

Sound supporting policies, regulations and standards are important obstacles to the use and promotion of new energy. IMO allows ships to use liquefied LNG as fuel through the international safety rules for ships using gas or other low flash point fuel (IGF rules), which came into effect on January 1, 2017. In addition, it also needs to provide corresponding use conditions and safety operation standards and specifications in the storage, transportation, filling and use of liquefied weather. At present, many classification societies and organizations have only issued some temporary Guidance Opinions for LNG fuel ships, and there is no unified caliber. It is only a brief overview of the characteristics of internal combustion engine power plant (Y. T. Chang, 2014), but no substantive unified standard is proposed for its storage, transportation, application and filling.

(7) Personnel skills

The crew needs to accept and actually have the skills of safe use of liquefied LNG, so that the liquefied LNG powered ship can have the basic conditions of safe operation. It is a common problem that the existing crew members lack the necessary training. Generally, the crew members do not have the skills to use liquefied LNG safely.

In a word, although LNG fuel technology [23] has obvious advantages in many aspects, as an emerging technology, it still has certain limitations to be used as marine
fuel.

2.4 Comparison of three control technologies

Through the above analysis, it can be seen that the three existing schemes to control Sox emission can meet the requirements of IMO sulfur restrictions. The cost, emission reduction effect and applicable ship types of these three schemes are different. It is difficult to simply say which scheme is the best. It is necessary to make a reasonable choice according to the characteristics of ship type and operation. Some foreign organizations and classification societies have proposed three schemes. The advantages, disadvantages and cost of the method are analyzed and compared, which can be used as a reference for scheme selection. The analysis and data in this paper are from "analysis of fuel alternatives for commercial ships in the ECA era" and DNV GL (Li Yuan).

1. Advantages and disadvantages of the three schemes

At present, the three methods to solve SOx in ship exhaust have their own advantages and disadvantages, and their advantages and disadvantages are shown in Table 6.
<table>
<thead>
<tr>
<th>control technology</th>
<th>Main advantages</th>
<th>Main disadvantages</th>
</tr>
</thead>
</table>
| LSFO               | 1. The initial cost is small, and the equipment and system need not be modified;  | 1. High fuel operation cost  
|                    | 2. High safety and reliability;  
|                    | 3. It can reduce about 80% of SOx.                                             | 2. The viscosity of low sulfur fuel is low, which reduces the combustion performance (atomization, pressure) and lubrication performance of the machine;  
|                    |                                                                                  | 3. Low sulfur fuel has low acidity and can not neutralize the alkalinity in the cylinder oil, which will precipitate calcium compounds;  
|                    |                                                                                  | 4. Incompatibility of high and low fuel during conversion, easy to produce sludge, etc                                                                 |
| EGCS               | 1. High sulfur HFO can be used;  
|                    | 2. Low fuel operation cost;  
|                    | 3. It can reduce the sulfur oxides by 90% ~ 95%.                               | 1. Space occupied by washing tower and lye tank;  
|                    |                                                                                  | 2. It is difficult to reconstruct the existing ships;  
|                    |                                                                                  | 3. New equipment and system are needed, and the cost of refitting is high;  
|                    |                                                                                  | 4. Additional electricity cost;  
|                    |                                                                                  | 5. Additional operating costs;  
|                    |                                                                                  | 6. Consumption of NaOH (may be classified as toxic goods);  
|                    |                                                                                  | 7. May affect the carrying capacity of containers and motor carriers;  
|                    |                                                                                  | 8. The port lacks sufficient EGCS residue receiving facilities;  
|                    |                                                                                  | 9. Maintenance and calibration of control and monitoring system                   |
| LNG                | 1) Clean (in addition to reducing SOx emissions, it can also reduce NOx and CO2 emissions);  
|                    | 2) The fuel operation cost is low;  
|                    | 3) It can reduce the SOx by 90% ~ 100%.                                         | 1. High safety requirements;  
|                    |                                                                                  | 2. High initial installation cost;  
|                    |                                                                                  | 3. LNG fuel tank takes up a large cargo space;  
|                    |                                                                                  | 4. It is difficult to reconstruct the existing ships;  
|                    |                                                                                  | 5. Fuel filling facilities are not perfect;  
|                    |                                                                                  | 6. The corresponding laws and regulations are not perfect                         |
2. Emission reduction effect of three schemes

(1) Use MGO with sulfur content less than 0.1%

NOx: selective catalytic reduction (SCR) device or exhaust gas cycle (EGR) can be used to reduce NOx emission when necessary, so as to meet the emission requirements of IMO tier III in ECA.

SOx and PM: due to less sulfur content and impurities in MGO, SOx and PM in emissions will be reduced. Compared with HFO with high sulfur content, MGO SOx can be reduced by 96%. The degree of PM reduction is not clear, and it is estimated that the reduction is about 50% - 80%.

CO2 and greenhouse gases: there is little difference in CO2 emissions caused by different types of fuel. In contrast, the calorific values of HFO and MGO are 5% higher, so when the same heat is generated, the MGO consumption will be reduced by about 5%, and the CO2 emission will be reduced accordingly.

(2) Using HFO

Using HFO and installing scrubber will significantly reduce SOx emissions, but it will reduce other aspects of emissions.

The degree is small.

NOx: the scrubber has little effect on NOx emission. This means that the NOx emission must meet the regulation requirements before the gas enters the scrubber.

SOx and PM: can reduce SOx about 96%, PM about 30% - 60%.

CO2 and greenhouse gases: will not reduce CO2 and greenhouse gas emissions. In fact, due to the additional back pressure (reduced thermodynamic efficiency) generated by the installation of the scrubber on the main engine and the additional auxiliary power required for the operation of the scrubber, the scrubber may slightly increase the overall fuel consumption of the ship, thus increasing CO2 emissions.

(3) Using LNG as fuel

NOx: the reduction of NOx depends on the type of engine. When operating in gas mode of Otto cycle engine, such as most medium speed diesel engines and Wärtsilä low speed engines, NOx emission will be significantly reduced by about 90%.

When gas fuel is used in diesel engine cycle, such as Mn low speed engine, the
reduction of NOx is limited. In this case, additional measures need to be taken to reduce NOx emission to meet the requirements of the rules. The typical methods are installing SCR or using exhaust gas cycle.

Sox and PM: when LNG is used as the main fuel, Sox and PM emissions are almost zero. Because LNG has almost no sulfur and only a small amount of impurities.

CO₂ and greenhouse gases: due to its high thermal equivalent and chemical composition, LNG will reduce CO₂ by 25% compared with fuel oil. But in the exhaust process, there will be some unburned methane produced in the Otto cycle engine. Methane is the main component of LNG, and its greenhouse gas impact is 25 times higher than that of CO₂. Therefore, methane escape offsets the impact of CO₂ emission reduction.

We need to reduce greenhouse gases. Compared with the fuel engine with the same output power, the total greenhouse gas emission of the gas engine operating under the diesel cycle can be reduced by about 22%.

3. Cost analysis of three schemes

Some maritime experts believe that LNG is the undoubted choice to meet the ECA requirements, because the relatively low price of LNG fuel will save considerable fuel cost for ship owners in the whole life cycle of the ship, and at the same time meet all the ECA emission requirements. The reason for this assumption is to believe that the initial investment can be recovered quickly by saving fuel cost. Similarly, supporters of exhaust scrubbers believe that it is the most economical way to continue to use low-cost HFO and EGCS at the same time. They also believe that the annual fuel cost savings will quickly recover the investment in the installation of EGCS.

The investor and the operator have different demands on which scheme to choose. The investor thinks that the scheme with the lowest cost is the best, while the operator thinks that the maximum safety and convenient operation and maintenance are the key factors. Therefore, a balance must be established among the demands.

The economic feasibility and cost effectiveness of the three schemes are largely determined by the type and operation mode of the ship. The factors that affect the economy and feasibility are: the time of operation in the ECA; The use of LNG
requires crew training and certification; Additional maintenance requirements and costs; Potential loss of goods and revenue; The ship route should be determined according to the fuel supply; And the most difficult determinant - predicting future fuel prices. In order to decide which method is the most suitable and economical, it is necessary to conduct a complete engineering study on the new construction or refitting of the target ship. The paper “Analysis of fuel alternatives for commercial ships in the ECA Era” uses the equivalent annual cost method to analyze the cost in the ECA era, which starts from 2015 and lasts for 10 years, assuming that the annual inflation rate is 2%, the discount rate is 14% and the interest rate is 6%. Taking medium-sized oil tankers and container ships as the target ship types, the equivalent annual cost of each scheme are obtained. In terms of construction cost, MGO is the lowest, followed by EGCS, and LNG is the highest. In terms of operation cost, when the oil price is high, the cost advantage of LNG scheme is obvious. With the decrease of fuel price in recent years, the cost advantage of using LNG as fuel is obviously lost, which becomes an expensive choice. At the same time, it can be found that the total cost of EGCS is the lowest among the three schemes. Another important fact is that in the above calculation and analysis, the annual operating cost savings have a greater impact on the equivalent annual cost than the construction cost. This is because, in the case of a container ship built in Asia, the annual fuel cost accounts for 70% To more than 40% of the ship's annual construction cost. In 10 years, even if the discount rate is 14%, a large amount of investment cost will be saved. For shipowners, the construction cost can be easily estimated, and the maintenance and operation cost can also be estimated more accurately. However, the fuel cost is based on many factors such as geopolitics, with great uncertainty. In addition, there are some hidden costs. Therefore, the annual cost of the ship is very variable, and it is difficult to estimate without in-depth analysis. The comprehensive analysis of cost can be based on different parameter variables, such as future fuel price, maintenance cost, design speed, engine size, etc. Yue Hong Taking 5000 cases of large container ocean going ships as an example,
about 90 tons of fuel oil are consumed every day. In June 2021, the average market price of ordinary ifo380 heavy oil is about 428.5 US dollars / t, and the price of LSFO is about 547.5 US dollars / t. The price difference between them is about 120 US dollars per ton. Therefore, it is estimated that after the full implementation of the "0.5% sulfur limitation" policy, a 5000 case ocean going container ship will need to pay an additional US $11000 per day for fuel cost. Based on 200 days of effective navigation in a year, the ship will pay an additional US $2.2 million per year for fuel cost (Yue Hong). In addition, the replacement of fuel oil also includes the transformation of ship equipment, which is also the cost pressure to be considered.

By adding EGCS, the high cost of engine and fuel supply system can be avoided, and the main engine can continue to use cheap heavy oil, so as to avoid all kinds of ship operation risks caused by replacing LSFO, as well as the huge reconstruction cost for using LNG as fuel, and save a lot of fuel cost for ship owners.

According to the guidelines for the selection of EGCS compiled by GLOSTEN for the U.S. Department of transportation, the investment and operation costs of ship exhaust gas EGCS can be divided into equipment purchase cost, installation cost, reagent cost, operation cost, power cost, distillate rectification cost, heavy oil heating cost and maintenance cost. Based on its cost accounting model, a 5000 container ship is used to install magnesium based seawater waste water taking gas desulfurization technology and equipment as an example, the annual fuel consumption of the ship's effective voyage is about 18000 tons (Yue Hong). In a certain period, the selling price of ifo380 fuel is $337 / t, and that of MGO fuel with sulfur content of 0.5% is $582 / t, with a price difference of $245 / t. The cost of magnesium based seawater flue gas desulfurization system is 10 million yuan / set, the installation cost is 5 million yuan / set, and the service life of the facility is 10 years. It will be installed in 2019 and run in 2020. The sulfur content of fuel type ifo380 is 2.7%. The desulfurization system uses powder with magnesium oxide content of about 90%. The domestic purchase price of magnesium oxide is 600 yuan / t, and the hydration rate of magnesium oxide is 90%. The cost of using reagent in each voyage accounts for about 1% of the fuel saving cost. According to the
international average wage level, the total wage of workers is about 2 million yuan per year, and the time for workers to operate the scrubber accounts for 65% of the total working time.

The power cost is 1% of the fuel saving cost, the distillate oil correction accounts for about 4% of the fuel saving cost, the heavy oil heating accounts for 0.8% of the fuel saving cost, and the maintenance cost accounts for 4% of the equipment purchase cost. After cost accounting, the annual operating cost of this type of scrubber only accounts for 12% of the fuel saving cost. Therefore, with the implementation of "sulfur restrictions", the cost of installing EGCS on 5000 container ocean going ships can be recovered within two years, and the accumulated net present value will reach 168.3 million yuan compared with burning LSFO after 10 years of operation. The British Petroleum Company, also said that the exhaust gas cleaning device is the cheapest way for large ships to meet the 2020 global sulfur limit of 0.5.

The application of clean fuel technology requires significant changes to the power system of old ships, which is more suitable for new ships. EGCS has high initial investment cost (market price is usually between US $1 million and US $4 million) and takes up a lot of space, but it can quickly realize cost recovery in a certain market environment. Based on the calculation method of Lloyd's register of shipping (LR) and LSFO, the cost recovery period of EGCS for bulk carriers, container ships and oil tankers is estimated respectively, and the cost recovery period of using liquefied LNG as power is calculated simultaneously. The default prices of LNG, heavy oil, 0.5% m / m LSFO and 0.1% m / m LSFO are 315, 390, 550, 600 and 376 US dollars / t respectively. The calculation results of cost recovery period are shown in Table 7 (Fan Wei, 2018). By comparison, it is found that the larger the tonnage of the same ship type, the shorter the cost recovery time of EGCS, which is significantly shorter than that of LNG and methanol fuel technology. However, the assessment does not consider all possible future operational factors. For example, in practice, 0.5% m / M fuel can be obtained by mixing, and the cost can be controlled within 1.2 times of heavy fuel.
4. Other issues to be considered in cost analysis

It is meaningful to make a simple analysis in the initial design stage of a ship, but it may still be misleading. Because some hidden costs are not included in the analysis, only when the preliminary development of ship design is completed, these costs can be revealed. For example, shipowners choose the EGCS. As mentioned above, currently medium speed engines (such as marine diesel generators) do not have built-in NOx reduction devices (EGR). In order to meet the NOx emission requirements, these engines must use selective catalytic reduction devices (SCR). However, if the content of Sox in the exhaust gas is too high, SCR can’t be used, but when the scrubber is used to remove Sox, SCR can’t work because the exhaust gas temperature is too low. Therefore, for marine diesel generator, the only feasible solution is to use MGO or LNG. In addition to HFO tank, MGO fuel system and MGO tank are also needed.

LNG powered ships can’t be refuel during cargo operation. This will increase the ship’s time in port, reduce revenue, and require higher speed to ensure the same shipping schedule. Other considerations are that in addition to loading LNG fuel, fuel oil (MGO) is also required to ensure that the ship can still operate in case of failure of
LNG fuel supply system or LNG supply can’t be guaranteed. The required fuel volume is at least half of the fuel volume required for the longest voyage to ensure that the ship can safely return to port at any time, which may be the fuel required for the whole voyage.

Some shipowners also consider the impact of emissions when making decisions. The report shows that using LNG fuel produces the lowest emissions, but the degree of reduction varies according to the type of engine, and these factors need to be considered when making decisions.

In addition, the following factors are not directly reflected in the cost analysis: what will happen to the LNG plant in 10-15 years? Maybe the technology is mature and can meet the requirements of reliability and safety.

The situation of the crew. LNG operation requires complicated training, and new crew members need to receive training.

How long can the scrubber last? This large and expensive equipment will be corroded, whether it needs to be replaced every 10 years.

If MGO is used by all ships in operation in 2020, will the price of MGO as the main product decrease or the HFO supply decrease.

What is the price trend of LNG in the future? At present, LNG supply is sufficient, and its price advantage is obvious compared with MGO. But when half of the fleet and most of the power plants, railways and trucks start to use LNG, how will the price change?

DNV GL has made a survey on the selection of existing ship emission reduction schemes, and made statistics on the use of LNG fuel and the installation of scrubbers around the world at the present stage. Statistics show that LNG is the first choice for new shipbuilding, which is more than twice the number of ships with scrubbers. 75% of the scrubbers installed are retrofits. Whether it is the use of LNG or the installation of scrubbers, luxury cruise, RO ro ships and ferries are the most active fields so far, accounting for almost 40% of all orders. Among them, the number of scrubbers installed in cruise refitting projects is the largest, but most of the small car passenger ferries choose LNG technology. At present, the number of LNG used and scrubbers
installed in container ships is almost the same, but if LNG preparatory orders are also included, the proportion of choosing LNG is larger. In the future, the operating experience of the scrubber will increase faster than LNG fuel.

The number of scrubber orders is almost double that of LNG orders in the identified projects (both operational and in order vessels / equipment are included).

In order to meet the requirements of the Convention on SOx emission, every ship owner is faced with the problem of choosing emission reduction scheme. At present, the three mainstream schemes have their own characteristics, so we need to make the most appropriate choice according to the actual situation. Many factors need to be considered in the selection of schemes, such as initial investment, construction cost, use cost, maintenance cost, loss of cargo space, convenience of use and maintenance and emission reduction effect. Detailed calculation is needed to compare the results of various schemes. In addition, there are some factors that are difficult to predict at present, such as the convenience of fuel filling and the change of fuel price. Even some schemes are not effective for some ship types and can’t achieve the purpose of emission reduction. All of these need to be considered as comprehensively as possible at the beginning of the design, imagine a variety of possibilities, and compare them one by one.

Based on the advantages and disadvantages, cost considerations of the three technical solutions, the world's major shipping companies currently hold different attitudes. At present, Maersk, CMA CGM, MSC, OOCL and COSCO Shipping have successively announced that they will promise to comply with the relevant regulations and give a preliminary compliance plan. At the same time, they also said that in order to meet the compliance requirements, they would consider levying or adjusting fuel surcharges according to the actual situation of each route to cope with this additional cost.

Maersk plans to comply with the new rules by using LSFO. The company said earlier that it would not invest in scrubbers given various operational concerns. At the same time, Maersk shipping said it would adjust the fuel surcharge to cope with the projected cost of starting using low sulfur fuel on January 1, 2020.
CMA CGM shows obvious support for LNG powered ship. In November 2019, CMA CGM announced that nine 220000TEU container ships will be equipped with LNG fuel engine system. At the same time, most of the fleet of CMA CGM will choose to use LSFO, and will consider adding EGCS to a small number of ships according to the technical reserve, actual cost, ship age and return on investment. In short: the main choice is to use LSFO scheme for compliance.

MSC supports EGCS. In September 2019, Mediterranean Shipping announced the order of 11 new generation 22000teu ships. Foreign media reported that EGCS will be installed on all the ships. It is believed that the production of clean fuel may not meet the demand of shipping industry.

OOCL will switch to LSFO in the second half of 2019 to meet the requirements of IMO.

COSCO said it was trying various compliance methods, including installing EGCS, purchasing LSFO and using LNG fuel. COSCO Shipping will reasonably reflect the cost of new fuel by introducing new fuel charges, levying fuel surcharges and adjusting the level of shipping freight according to the fuel consumption of each shipping area, the proportion of different high sulfur and low sulfur oil products during the transition period, the loading of ships and other comprehensive factors.

According to a survey conducted by UBS on the shipping industry, 68% of the respondents support the LSFO scheme, 21% of the respondents choose EGCS, 9% of the respondents choose to eliminate old ships that do not meet the requirements, and only 6% of the respondents are willing to choose alternative fuel schemes such as LNG. For the new shipbuilding response plan, the gap between the plans is small. Low sulfur fuel is still the most popular option, accounting for 37%, while LNG fuel and EGCS installation are supported by 24% and 21% respectively (Lv Changhong).

2.5 Relevant suggestions

With the implementation of IMO sulfur restrictions, oil companies, shipping
companies and ship oil supply enterprises should jointly explore the best scheme and Countermeasures of SOx emission control to ensure the safety and stability of water navigation.

(1) Apply for the state to issue supporting policies, actively encourage the construction of green ports, give appropriate rewards and subsidies to port and shipping related enterprises using LSFO, LNG or waste gas treatment devices, further strengthen the supervision and inspection of port fuel quality, actively promote the application of new energy-saving and emission reduction technologies on ships, and control and reduce the pollution emissions of ships arriving at the port.

(2) Shipping enterprises are encouraged to cooperate with domestic equipment manufacturers to actively develop ship exhaust treatment devices, increase investment in technological innovation, and reduce the manufacturing cost of relevant equipment, so as to better meet the requirements of IMO SOx emission restriction policy and reduce marine pollution.

(3) Strengthen cooperation with oil companies to ensure the establishment of resource channels. In view of the quality of LSFO, shipping companies should strengthen cooperation with oil companies, research and develop LSFO that meets the requirements of IMO emission control policy with the help of scientific research institutions, strive for a breakthrough in technology, encourage oil refineries to provide sufficient LSFO resources, and avoid the rapid rise of LSFO price.

(4) Shipping companies should choose the appropriate emission reduction path according to the actual situation of their own ships. On the whole, the above three schemes have their own characteristics. Shipping companies need to comprehensively consider the initial investment, construction cost, use cost, maintenance cost, loss of cargo space, convenience of use and maintenance, emission reduction effect of different ships according to the actual situation, and compare and calculate the comprehensive implementation effect of various schemes in detail. In addition, we should also consider the volatility of oil prices and the convenience of related port facilities, and objectively choose the appropriate emission reduction path.

In the short term, the installation of EGCS will become the choice of most ship
owners. This technology is relatively simple and reliable, and is not affected by the fluctuation of oil supply market and imperfect gas supply facilities. The initial investment cost and operation cost are between the other two schemes, which is a relative compromise and can achieve a short-term and stable response to SOx emissions. The supply of LSFO and LNG is difficult to be solved in the short term. On the one hand, the current price of LSFO is relatively high, and the industry predicts that the price of LSFO may rise sharply after 2020; On the other hand, LNG power will increase larger fuel tanks, and there should be reliable gas supply along the route, which requires a certain tendency of ship type and route. However, the installation of EGCS can continue to use heavy residuum and completely avoid the problems of LSFO and LNG supply limitation. Although the initial investment of installing EGCS is relatively high, it is estimated that the cost can be recovered in two years based on its relatively low operating cost [56]. In addition, compared with the uncertainty brought by the other two schemes, the installation of EGCS has the advantages of safety and reliability, which can completely avoid "going to hospital in a hurry".

In the long run, LSFO and LNG will fundamentally solve the problem of SOx emission from the source, and the effect will be thorough. Both of them will become the ultimate measures to solve the problem of SOx emission from ships in the future. Although at present, one kind of operation cost is high, and the other kind of initial investment cost is high, with the improvement of the refining market, the LNG power technology continues to improve, the cost continues to reduce, and the good performance of LNG in NOx and CO₂ emissions, both of them will have a very large market space in the future. The cost of using LSFO to retrofit the existing power system is not large, and the effect is thorough, and it does not need any tail gas post-treatment and monitoring. In addition, compared with the removal of sulfur by tail gas desulfurization on each ship, the centralized removal in the refinery is more concise and effective. In terms of LNG solutions, LNG power not only basically has no Sox emissions, but also can effectively reduce the emissions of carbon oxides and NOx.
Chapter 3 Sox emission regulation

3.1 Problems in supervision of Sox emission from ships

1. International level
(1) Ship Sox emission is one of ship source pollution. Different from the fixed nature of land pollution, ship pollution has strong mobility, and the sea area where pollution occurs can’t be determined, which makes it difficult for flag state to exercise jurisdiction. The existence of flag of convenience makes the difference between the registered owner and the actual controller of the ship higher, which is not conducive to the implementation of the international rules and standards for the control of Sox emissions from ships, and also causes many adverse effects on the overall control of Sox emissions from ships in the world. The laws and regulations of flag state on Sox emission control are not perfect. Most flag of convenience ships are actually controlled by shipping enterprises in developed countries, but they belong to the developing and employing countries (Liu Yuning.(2020). The control of Sox emission from ships is a complex and systematic work. However, due to the confusion in the identification of ship owners of these convenience flag ships, as well as the fact that most of the flag countries are developing countries, the political, economic and cultural level is relatively backward, and the monitoring technology and control system are not perfect, the implementation of sulfur restrictions is seriously affected.
(2) When the sulfur restrictions was formulated, there was a lack of evaluation and Analysis on whether the decision-making and index setting were legal, scientific and feasible, and the actual situation of the country was not fully considered when the IMO control measures were passively received.

2. National level
In response to Sox control measures, whether the ship chooses to use LSFO, add EGCS, or use LNG and other clean energy, it will increase the cost of ship operation and the workload of crew to varying degrees, and the ship side has insufficient power
to actively fulfill the relevant requirements of policies and regulations. Therefore, it needs the supervision of maritime department. However, it has been proved that there are still some problems in supervision

(1) There are some limitations in the government regulation of ship Sox emission control. At present, the supervision of ship's Sox emission mainly depends on the inspection of the sulfur content of ship's fuel oil. The specific method is to sample and test the ship's fuel oil. Due to the uneven level of on-site monitoring technology of the regulatory body, the monitoring technology of some ports still needs to be improved. The regulatory body can only monitor the ships arriving at the port, and can’t monitor the sulfur content of marine fuel and other relevant data and determine the quality of oil in a short time.

(2) The source supervision is not in place. At present, the parameters of LSFO are not clear, the supply market is not standardized, there is no supply of distillate type low sulfur fuel oil in many places, the current market is full of blended LSFO, and the oil quality is difficult to guarantee. Some small oil refineries do not strictly control the sulfur content of fuel, which is inconsistent with the fuel supply documents, and objectively causes the sulfur content to exceed the standard. In addition, the supply chain of fuel oil production is long and involves many regulatory departments. The function of the maritime administration is only to supervise the fuel oil used on board, while the source management requires the collaborative management of market supervision and management departments, ports and other government agencies. At present, there is less direct communication and cooperation and joint law enforcement among government agencies, which makes it difficult to effectively supervise the fuel supply enterprises.

(3) There is a lack of foreign regulatory means. According to Article 92 of UNCLOS, a ship shall be under the exclusive jurisdiction of its flag state on the high seas. Therefore, the use of non-conforming sulfur oil on the high seas should be under the jurisdiction of the flag state. However, due to the fact that a large number of ships are registered in flag of convenience countries, the control of ships in these countries is very limited, and there is no substantive punishment for the use of non-conforming
fuel oil on the high seas. In order to save costs, it is very possible for shipowners to use non-conforming sulfur oil on the high seas.

3. Shipping enterprise level

Shipping enterprises should respond negatively. As the series of control measures of ship Sox directly increase the operating costs of shipping enterprises, the negative psychology and conflict psychology of shipping enterprises are also reasonable, resulting in a series of problems, which makes the implementation of control policies more difficult. In addition, the crew didn't know it well. During the on-site inspection, the MSA found that the seafarers, as the specific implementation of control measures, are not sensitive to the air pollution caused by the use of high sulfur oil, and are not familiar with Sox emission control measures (Liu Yuning, 2020).

4. Third party participation is not enough

(1) Due to its strong professional and technical characteristics, maritime management often needs to deal with some classification societies, so as to better promote the implementation of conventions and laws and regulations. Classification societies, shipowners' associations, shipping alliances and other important third-party organizations participating in maritime governance have insufficient participation in ship Sox control and supervision, which also affects the implementation of the policy to a certain extent. On the other hand, Sox control measures have a direct impact on the interests of ship owners. In the process of policy formulation and implementation, they are more or less opposed by ship owners' associations and shipping alliances. When choosing various emission reduction measures, the original loose shipping alliance is split into different factions due to different positions, Therefore, the above third-party organizations have no motivation or ability to supervise the implementation of control measures.

(2) The participation of social supervision is not high. Due to the relatively backward supervision concept and low information transparency in some places, as well as the less direct contact opportunities of shipping industry in public life, the low degree of attention has resulted in the public's ignorance and indifference to ship Sox control measures. The public who is most concerned about the implementation of ship Sox
control policy is the crew. However, the interests of the crew are basically consistent with that of the shipping company, which is more resistant to the cost increase brought by the control policy, so it is difficult to play the role of social supervision.

3.2 Supervision Countermeasures of Sox emission from ships

1. International level

(1) Improve the relevant provisions under the framework of IMO
IMO should add provisions on Sox technical assistance in Annex VI. In order to protect the atmospheric environment, prevent, reduce and control the pollution of Sox from ships, countries directly or through IMO provide technical assistance to developing countries, including technologies related to desulfurization of ship fuel, production and use of EGCS and relevant industry experience. We may consider setting up a fund for Sox technical assistance under the framework of IMO [57]. In terms of technical assistance among developing countries, we can consider encouraging developing countries to conclude technical cooperation agreements on Sox of control vessels under the existing cooperation environment.

(2) Strengthen the supervision and guidance of IMO
As an international organization in charge of Sox emission control, IMO should also make use of the advantages of international organizations to guide the technical exchanges between countries on Sox emission control. By strengthening the exchange and interaction among countries on technical measures to control Sox emissions from ships, we will promote the transfer of sulfur limitation technology from developed countries to developing countries.

(3) Strengthen international cooperation
Considering the mobility of ships, it is a necessary measure for building a community of shared future for mankind to jointly control the air pollutants from ships through global linkage. It is necessary to rely on IMO, ASEAN, Asia Pacific port state control memorandum of understanding and other regional cooperation organizations to strengthen international and regional communication and dialogue, unify law
enforcement standards, reach cooperation agreements, and deal with problems through consultation. In particular, it is necessary to deal with the illegal disposal of ships using non-conforming fuel oil on the high seas, urge the flag of convenience countries to improve the awareness and ability of performance of registered ships, improve ship standards, and increase penalties.

2. National level

(1) Speed up the construction of laws and regulations

The existing domestic laws related to Sox emission should be revised to improve the legal level of ship Sox emission control. We should strengthen the follow-up study of international conventions, improve the relevant mechanism of transforming the requirements of international conventions and amendments into domestic laws, speed up the transformation process, constantly improve the ship Sox control requirements to adapt to the development of the new situation, formulate the implementation guidelines of the scheme in time, and guide the on-site law enforcement personnel to do a good job in daily supervision and inspection.

(2) Rational use of incentive policies

In view of the sulfur restrictions, it is suggested to introduce corresponding subsidy policies to help enterprises. Learn from the experience of European and American developed countries in using economic means to strengthen the control effect, set up special taxes or special funds.

(3) Strengthen the coordination of departments and form the joint force of supervision

First, strengthen the regional law enforcement linkage. It is suggested that according to the geographical location characteristics, the regional organization and coordination organization of ship air pollutants should be established, and the regulatory agencies should unify the regulatory requirements and regulatory standards, and regularly report the relevant regulatory issues. At the same time, it is suggested to establish a linkage law enforcement mechanism between neighboring countries or cities, explore the establishment of law enforcement information sharing system, share the results and penalties, increase the frequency of cross jurisdictional joint law enforcement, and strengthen the transfer of illegal cases.
Second, strengthen the coordination between departments. It is suggested to establish the information notification system of marine fuel supervision, improve the information communication channels, improve the multi department joint law enforcement system in the production, circulation and use of marine fuel, strictly manage the fuel suppliers, control the non-conforming fuel from the source, and form the supervision force.

(4) We will strengthen the use of science and technology and intensify law enforcement.

One is to increase the use of remote sensing technology. In the water area of emission control area, ship exhaust telemeter is widely used, and various carriers such as river crossing bridge, wharf crane, sea patrol boat and UAV are used to improve the monitoring ability of maritime department on ship exhaust emission.

The second is to clarify the treatment of non-conforming fuel. It is suggested to improve the handling of non-conforming fuel oil and diesel oil after the implementation of administrative punishment in combination with IMO port state supervision guidelines on emergency measures for handling non-conforming fuel oil, and set up non-conforming fuel oil receiving and disposal points in each port to ensure that the ship can leave the port after unloading the non-conforming fuel oil.

(5) Exploration on the establishment of trading market of ship SOx emission right

Many practices at home and abroad have proved that as one of the means of market control system, emission trading system can solve the above problems (Zhang Shiyou, 2020). It is quite necessary and feasible to explore the establishment of the trading market of ship SOx emission rights. It can mobilize the enterprises to fulfill the control requirements and strengthen the power of technological innovation by economic means, which has a huge role in promoting the implementation of emission control measures.

3. Shipping enterprise level

Improve the shipping company system documents and crew training. The shipping companies should strengthen the training for the crew to implement the new fuel oil standard and relevant operation procedures, ensure that the ship can effectively fulfill
the sulfur limitation compliance obligation in the actual navigation process, and pay full attention to the active factors of the crew in fulfilling the sulfur limitation compliance obligation.

4. Third party level

Strengthen publicity and guidance. To strengthen the education and training of law popularization for the public, we should make full use of traditional media and new media, publicize the purpose, significance and specific requirements of implementing the global sulfur restrictions, increase experience exchange and promotion and warning of illegal cases, and create a favorable public opinion environment for the work.
Chapter 4 Conclusion and prospect

4.1 Conclusions

(1) With the increasing types of LSFO products, the market is expanding day by day. For most ships that are not suitable for the installation of exhaust gas scrubber or LNG device, using LSFO will be the best choice for most ships to deal with the sulfur limit provisions, and also the most environmentally friendly practice.

(2) From the perspective of return on investment, the installation of waste gas scrubber is a more economical option in the short term for newly built or older large ships, but it is not the best choice to solve environmental problems in the long term because waste gas scrubber does not reduce pollutant emissions from the source. With the increasing requirements of environmental protection, the use of waste gas scrubber will be subject to more restrictive measures.

(3) In 2018, the 72nd session of IMO Marine Environmental Protection Committee (mepc72) adopted the preliminary strategy of greenhouse gas emission reduction, which made it clear that by 2030, the CO2 emission of each international shipping will be at least 40% lower than that in 2008, and at least 70% lower than that in 2050. Because the use of LSFO or waste gas scrubber can’t reduce greenhouse gas emissions, in order to achieve the goal of the preliminary strategy of greenhouse gas emission reduction, it is expected that the international community will provide more preferential policies for ships using LNG fuel in the future to encourage ship owners to build LNG powered ships. In the long run, the transition from heavy oil to LSFO and the final use of LNG and other clean energy will be the future trend.

(4) In terms of regulation, the sulfur restrictions increases the cost of shipping industry, which brings great confusion and challenges to shipowners. The formulation and implementation of maritime rules should be considered from the international, national, shipping enterprises, third parties and other aspects. The objective conditions and support capabilities that can be implemented and evaluated, including technical and economic feasibility, should be fully evaluated, and should not be too advanced.
The rules and standards should be revised timely according to the actual situation; IMO, relevant governments and industry organizations should coordinate and organize all forces to study the feasible path to achieve emission reduction, reduce industry confusion and uncertainty, and reduce the difficulty of shipowners in decision-making, implementation and operation.

To sum up, in order to meet the requirements of the Convention on SOx emission, each ship owner is faced with the problem of choosing emission reduction scheme. At present, the three mainstream schemes have their own characteristics, so we need to make the most appropriate choice according to the actual situation. Many factors need to be considered in the selection of schemes, such as initial investment, construction cost, use cost, maintenance cost, loss of cargo space, convenience of use and maintenance and emission reduction effect. Detailed calculation is needed to compare the results of various schemes. In addition, there are some factors that are difficult to predict at present, such as the convenience of fuel filling and the change of fuel price.

At present, LSFO will be the first choice for most ships in a period of time after the implementation of the sulfur limitation regulations. The installation of waste gas scrubber is the most economical measure for new or relatively new large ships in the short term, and the use of alternative fuels such as LNG will be the response measure in line with the long-term development consideration.

4.2 Expectations

The implementation of IMO 2020 sulfur restrictions will bring challenges to the shipping industry or the whole logistics chain. Of course, there will inevitably be various disorder in the initial stage, but it is an indisputable trend for the shipping industry to move towards "green". As long as all stakeholders make joint research, exploration and practice, increase collaboration and cooperation from the industry and industrial chain level, promote ship energy conservation and emission reduction, promote shipping technology upgrading and clean energy development, optimize the industrial structure, and realize the sustainable development of shipping and
environmental protection benefits.

References


Wu Jianguo. (2017). Regulatory requirements and impact of China's ship emission
control zone. China ship inspection. PP. 62-65


Maike L. C. A costly piece of regulation: SOx. [EB/OL]. [2020-01-09].
Chen Weihua. (2019). Regulations of IMO, relevant countries and regions on sulfur content of ship fuel and restrictions on the use of egcs.ccs. pp.35-38
Zhang Jianfeng. Key points of PSC for LSFO examination. CCS. Pp.28-31
Dong Wei. (2013). Experimental Research on the Scrubbing Efficiency of Marine Exhaust Gas Based on NaOH. Harbin Engineering University. Pp.5-6
Hamworthy Krystallon Presentation. 2010. Adapting to New Environmental Economics


AALBORG. (2011) EXHAUST GAS CLEANING [EB].


【50】https://www.sohu.com/a/351422128_seven hundred and ninety-six thousand four hundred and eighty-three


Li Yuan. Scheme selection for ships meeting SOx emission limits. Marine equipment / Materials & marking. pp. 45-52

Yue Hong. Background and Countermeasures of shipping sulfur restrictions. Marine equipment / Materials & marking. pp. 45-49


Lu Changhong. Selection of LSFO
http://www.simic.net.cn/news_show.php?id=215928