Administration on meeting low sulphur fuel oil requirements for ships

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Administration on Meeting Low Sulphur Fuel Oil Requirements for Ships

By

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DECLARATION

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

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

(Signature): Zuo Longyu

(Date): June 29th 2018

Supervised by Professor Song Yongxin

Dalian Maritime University
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ABSTRACT

Title of Research paper:  
Administration on Meeting Low Sulphur 
Fuel Oil Requirements for Ships

Degree: MSc

IMO 2020 global sulphur limit for ships is coming closer, maritime administrations and other authorities shall be prepared with the new cap for better environment. The question that how to carry out a effective inspection shall be answered. This research paper discusses the relationship between air pollution and ship emission, marine diesel engine and its fuel. Policies and requirements establish by IMO, EU, USA and China are learned and the measures are compared. Shenzhen is taken for a case study, efforts made by local government and SZMSA are reviewed. For better and wider implementation, suggestions are provided in the end.

Key words: low sulphur oil; air pollution prevention; emission control area; maritime administration; Shenzhen
# TABLE OF CONTENTS

Declaration .......................................................... ii

Acknowledgement ...................................................... iii

Abstract ........................................................................ iv

Table of Contents ....................................................... vi

List of Tables ................................................................ viii

List of Figures ................................................................ ix

List of Abbreviations .................................................... xi

List of Abbreviations ........................................................ 7
List of Tables ................................................................. 8
List of Figures ................................................................. 9
1 Introduction .................................................................. 10
2 Air Pollution, Ship Emission and the Fuels .................... 13
   2.1 Air pollution and ship emission ................................. 13
   2.2 Methods to reduce ship emission ............................... 16
   2.3 Fuels .................................................................... 17
   2.4 Low Sulphur Fuel Oil .............................................. 19
## List of Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AQI</td>
<td>Air Quality Index</td>
</tr>
<tr>
<td>PRD</td>
<td>Pearl River Delta</td>
</tr>
<tr>
<td>IMO</td>
<td>International Maritime Organization</td>
</tr>
<tr>
<td>UNCTAD</td>
<td>United Nations Conference on Trade and Development</td>
</tr>
<tr>
<td>SO$_x$</td>
<td>Sulfur Oxides</td>
</tr>
<tr>
<td>MSA</td>
<td>Maritime Safety Administration</td>
</tr>
<tr>
<td>PRC</td>
<td>People's Republic of China</td>
</tr>
<tr>
<td>MEPC</td>
<td>Marine Environment Protection Committee</td>
</tr>
<tr>
<td>MARPOL</td>
<td>International Convention for the Prevention of Pollution from Ships</td>
</tr>
<tr>
<td>ISO</td>
<td>International Organization for Standardization</td>
</tr>
<tr>
<td>CCS</td>
<td>China Classification Society</td>
</tr>
<tr>
<td>ORB</td>
<td>Oil Record Book</td>
</tr>
<tr>
<td>EU</td>
<td>European Union</td>
</tr>
<tr>
<td>IBIA</td>
<td>International Bunker Industry Association</td>
</tr>
</tbody>
</table>
List of Tables

Table 1  Ship emissions in Shenzhen
Table 2  Methods to reduce ship emissions
Table 3  Requirements for marine distillate fuels
Table 4  Requirements for marine residual fuels
Table 5  IMO Emission Control Areas
Table 6  Sulphur content in fuel oil (EU Directive 2005/33/EC)
Table 7  Sulphur content in fuel oil (EU Directive 2012/32EC)
Table 8  Phases of China ECZs
Table 9  Sulfur content requirement for inland river ships oil
Table 10 Statistics of oil quality inspection (2017)
List of Figures

Figure 1   Hong Kong Air Pollutant Emission Inventory - Sulphur Dioxide
Figure 2   Price comparison: IFO 380 vs MGO
Figure 3   MARPOL Annex VI sulphur limits timeline
Figure 4   Existing ECA zones and possible future ECAs
Figure 5   China Emission Control Zones
Figure 6   Jurisdiction area of Shenzhen Maritime Safety Administration
Figure 7   Shenzhen Port data for recent 3 years
Figure 8   Oil sample quick detection equipment
Figure 9   Tail gas detection equipment
Figure 10  Online tail gas detection equipment
Figure 11  Inspection procedure
Introduction

Air is one of the essential natural resources, without which human could barely survive in the earth and easily perish for few minutes. Moreover, air is not only precious to human, but also to all creatures of nature, namely, the evolution of nature and the development of human society are inseparable from the air. However, with the rapid development of modern production, the massive use of natural resources such as coal and oil has caused different levels of pollution to the air, leading to an irreversible damage to air. Facts show that, in places where air pollution is serious, human health, the growth and development of animals and plants and ecology have been affected (Li, & Song, 2014, p2). As a result, the prevention of air pollution has widely received the attention of all countries.

Nowadays, shipping is the most typical mean of transportation of cargoes in international trade. The power plants installed on board are mainly the marine diesel engine that burn heavy diesel fuel and release a lot of air pollutants through exhaust gas during the voyage. The pollution caused by the exhaust emissions from marine diesel engines cannot be ignored, especially sulfur oxides (SO\textsubscript{X}) which have the most direct harmful impact on environmental and human. In many coastal port cities, shipping has become a major source of air pollution. Therefore, International Maritime Organization (IMO) adopted Annex VI to the International Convention for the Prevention of Pollution from Ships (MARPOL Convention) in 1997 to address air pollution from shipping. And through its Marine Environment Protection Committee (MEPC), more and more stringent standards for the sulfur content of ship fuel oil have been set by adopting the amendments to Annex VI, including requirements within emission control areas, in order to deal with the increasing number of vessels and the trend of larger ships. To have major health and environmental benefits for the world, particularly for populations living close to
ports and coasts, IMO (2018) has set a limit for sulphur in fuel oil used on board ships of 0.50% m/m (mass by mass) from January 1st 2020, aiming to significantly reduce the amount of sulphur oxide emanating from ships. “There is no turning back” was stressed by IMO Secretary General Kitach Lim ahead of the fifth session of the Sub-Committee on Pollution Prevention and Response (PPR) (Raun, 2018).

To meet the sulphur emission standards, ships can use low-sulphur compliant fuel oil (including gas and methanol). They may also use approved equivalent methods, such as exhaust gas cleaning systems (also called scrubbers). The implementation of IMO conventions and regulations is the most important step at any time, the 2020 global 0.50% m/m sulphur limit will be no exception. IMO(2018) declares that implementation is the remit and responsibility of the Administrations (flag States and port/coastal States), for example it is the individual State to set fines of sanctions, and ensuring the consistent and effective implementation of the global cap has been put in a high priority. However, many issues and problems are remained to be solved regarding to the authorities, ship owners, fuel oil purchasers, bunkers suppliers, and petroleum refineries.

The objectives of this research paper are to study the relationship between shipping and air pollution, provide outlines of the requirements of low sulphur oil for ships, review the methods to control ship emissions, and give suggestions for better implementation of sulphur cap.

Methodologies used in this paper are literature research, case study, and comparatively research. Author collects information and from books, periodicals, research papers and authority reports, forcing on the topic of ship-source air pollution (especially SOx emissions) and low sulphur oil. Shenzhen is selected to be the study case because it is the third largest container port in the world and there are
several advanced measures taken in its ports, meanwhile, it is easier for author to access to reliable data and information from Shenzhen Maritime Safety Administration (SZMSA). Different control plans learned from different states or areas are compared to achieve a better solution.
Air Pollution, Ship Emission and the Fuels

2.1 Air pollution and ship emission

International Organization for Standardization (ISO, ISO 4225:1994) defines “air pollution” in as:

Usually the presence of substances in the atmosphere resulting either from human activity or natural processes, present in sufficient concentration, for a sufficient time and under circumstances such as to interfere with comfort, health or welfare of persons or the environment.

In China, the Ministry of Environmental Protection (MEP, 2012) calculates Air Quality Index (AQI) based on the level of six atmospheric pollutants, namely sulfur dioxide (SO₂), nitrogen dioxide (NO₂), suspended particulates smaller than 10 μm in aerodynamic diameter (PM₁₀), suspended particulates smaller than 2.5 μm in aerodynamic diameter (PM₂.₅), carbon monoxide (CO) and ozone (O₃).

The sources causing air pollution can be classified into two categories basically: man-made sources and nature sources (Li, & Song, 2014, p5). Man-made sources are mostly related to the burning of multiple types of fossil fuel. Balkin, R. (2008) points out ships transport approximately 90% (by weight) of global trade in a cost and energy efficient way, however, the significant increase in world trade and international seaborne transport has also brought negative consequences through increased emissions of air pollutants and greenhouse gases.

For now, above 99% ships use internal combustion engine as power plants, mostly marine diesel engine burning heavy fuel oil. Take a low-speed diesel engine as an example, ship emissions include carbon dioxide (5.6%), sulfur dioxide (660 ppm),
hydrocarbons (122 ppm), carbon monoxide (45 ppm), nitrogen oxides (1220 ppm), and particulate matters (120 mg/m\(^3\)) when the engine running on residual fuels at 80% maximum continuous rating (Zhou, S., Xiao, Y. H., & Zhu, Y. Q., 2010, p 179-187).

Recent research (Johansson, Jalkanen, & Kukkonen, 2017) indicated marine diesel engines of ships involved in internationally trade produce about 9.7 million tons of sulfur oxides each year, accounting for 7% of the world’s total sulfur oxides emissions (Zhu, Tang, Li, & Zhao, 2016, p1). Study results show that the sulfur dioxide, nitrogen oxides and PM\(_{10}\) produced by shipping in the vicinity of China’s coastal waters in 2014 are about 879,800 tons, 1,378,400 tons and 117,300 tons, respectively (Wang, Z., Zhang, W., Peng, C.S. & Qin, C.H., 2018). Ye (2014) used activity-based approach to develop the 2010 PRD marine vessel emission inventory, utilizing Automatic Identification System (AIS) track data and the Lloyd’s Register of Ships (LRS) files. Her research results showed that SO\(_2\), NO\(_X\), CO, PM\(_{10}\), PM\(_{2.5}\) and VOCs were 6.3×10\(^4\), 14.4×10\(^4\), 1.7×10\(^4\), 8.1×10\(^3\), 7.5×10\(^3\) and 6.4×10\(^3\) tonnes, respectively. In Shenzhen, ship emission accounts for 58.9% of total SO\(_2\) emission of the city (Liang, Liao, Yan, Zhuo, & Xu, 2016), of which the ocean-going vessels contribute 90% . And earlier research (Yang, Yin, Ye, Wang, Zheng, & Ou, 2015) suggested emissions from container ships were the highest among various types of vessels.

<table>
<thead>
<tr>
<th></th>
<th>SO(_2)</th>
<th>NO(_X)</th>
<th>CO</th>
<th>PM(_{10})</th>
<th>PM(_{2.5})</th>
<th>VOCs</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>13600</td>
<td>23300</td>
<td>2200</td>
<td>1900</td>
<td>1700</td>
<td>1100</td>
</tr>
<tr>
<td>2013</td>
<td>13106</td>
<td>19992</td>
<td>2224</td>
<td>1411</td>
<td>1736</td>
<td>822</td>
</tr>
</tbody>
</table>

Source: made by author based on Yang et al.(2015) and Liang et al.(2016)
Not far away geographically, statistics (HKEPD, 2018) indicate that navigation and public electricity generation sectors were the top two sources of SO2 emissions, accounting for 49% and 46% of total SO2 emissions in the year of 2016 in Hong Kong, respectively.

Figure 1  Hong Kong Air Pollutant Emission Inventory - Sulphur Dioxide

Source: Environmental Protection Department of the Hong Kong Special Administrative Region (HKEPD), Retrieved April 20th 2018 from the World Wide Web:

https://www.epd.gov.hk/epd/sc_chi/environmentinhk/air/data/emission_inve_so2_C.html
2.2 Methods to reduce ship emission

The way of controlling SO\textsubscript{X} emissions can be the selection of low sulfur fuel, or flue gas desulfurization. In order to control the ship emissions, many methods are carried out in terms of administration, technology and operation.

<table>
<thead>
<tr>
<th>Type of control</th>
<th>Requirement</th>
<th>Pollutant</th>
<th>Measure</th>
<th>Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECA</td>
<td>Four ECAs in the world</td>
<td>SO\textsubscript{2}, NO\textsubscript{x}</td>
<td>Low sulphur oil, emission standards for NO\textsubscript{x}</td>
<td>North Sea, Baltic Sea, North American Coast and US Caribbean</td>
</tr>
<tr>
<td>Raise the design standards of ship engine and post-process for exhaust gas</td>
<td>Standards for ship main engine</td>
<td>NO\textsubscript{x}</td>
<td>Selective catalytic reduction, exhaust gas recirculation, exhaust gas scrubbers</td>
<td>US, EU</td>
</tr>
<tr>
<td></td>
<td>National or regional limit of sulphur content of fuel oil</td>
<td>SO\textsubscript{2}, PM</td>
<td>Low sulphur oil</td>
<td>US, EU, HK</td>
</tr>
<tr>
<td></td>
<td>Limit of sulphur content of fuel for oceangoing ships arriving in ports</td>
<td>SO\textsubscript{2}, PM</td>
<td>Low sulphur oil</td>
<td>Mandatory: US, EU; Voluntary: HK, Singapore</td>
</tr>
<tr>
<td>Fuel conversion</td>
<td>LNG</td>
<td>SO\textsubscript{2}, NO\textsubscript{x}, PM</td>
<td>LNG</td>
<td>Mainly in Norway</td>
</tr>
<tr>
<td></td>
<td>Onshore power</td>
<td>SO\textsubscript{2}, NO\textsubscript{x}, PM</td>
<td>Onshore power</td>
<td>Mandatory in California of US, available in main ports of US and EU</td>
</tr>
<tr>
<td>Operation</td>
<td>Slow steaming</td>
<td>SO\textsubscript{2}, NO\textsubscript{x}, PM</td>
<td>Saving the fuel</td>
<td>California, New York and New Jersey of US</td>
</tr>
</tbody>
</table>
2.3 Fuels

The overwhelming majority of marine power plants use liquid petroleum fuel oil and the choice of fuel is mostly an economic decision (Rowen, Gardner, Femenia, Chapman, & Wiggins, 2005, p3). Stopford (2009, p 225) conducted a study which showed oil cost took 76% of voyage costs. Marine fuels can be sorted into three kinds, two basic kinds are distillate fuels and residual fuels, the third kind is commonly called intermediate fuel oils (IFO) which are mixtures of these two. In the oil refining process, generally through the desulfurization process, the sulfur content in refined oil is much lower than that in crude oil. There are various types and grades of marine fuels used in engines and boilers and it is quite common that different suppliers use their own different in-house terminology. To communicate more effectively in this paper, definitions are accepted from Guide on the use of low sulfur fuel for ships (China Classification Society, 2013) and as follows.

- **Low Sulphur Fuel Oil (LSFO):** refers to distillate fuels that meet ISO8217:2010 standard except Sulphur content of less than 0.10% m/m.
- **Fuel Oil (FO):** refers to the conventional fuel oil (such as HFO and MDO) supplied by ships to main and auxiliary diesel engines and boilers while sailing outside the SOx emission control area except for LSFO.
- **Marine Diesel Oil (MDO):** refers to the distillate fuels that meet the requirements of ISO 8217:2010 standard except for LSFO.
- Heavy Fuel Oil (HFO): refers to residual fuels that meet the requirements of ISO 8217:2010.
- Marine Gas Oil (MGO): refers to distillate fuels that meet ISO8217:2010 standard with sulfur content of 0.10% m/m to 0.50 % m/m.
- Ultra Low Sulphur Fuel Oil (LSFO): refers to distillate fuels that meet ISO8217:2010 standard with sulfur content of less than 0.10% m/m.

ISO (2017) established standards for marine distillate fuels and residual fuels. Table 3 and Table 4 show the requirements related to oil quality control (laboratory testing) taken by SZMSA.

### Table 3  Requirements for marine distillate fuels

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Unit</th>
<th>Limit</th>
<th>Category ISO-F-</th>
<th>Test method and reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kinematic viscosity at 40 °C</td>
<td>mm²/s</td>
<td>Max</td>
<td>5.5 6 6 11</td>
<td>ISO 3104</td>
</tr>
<tr>
<td>Density at 15 °C</td>
<td>kg/m³</td>
<td>Max</td>
<td>- 890 890 900</td>
<td>ISO 3675 or ISO 12185</td>
</tr>
<tr>
<td>Flash point</td>
<td>°C</td>
<td>Min</td>
<td>43 60 60 60</td>
<td>ISO 2719</td>
</tr>
<tr>
<td>Water</td>
<td>volume %</td>
<td>Max</td>
<td>- - - 0.3</td>
<td>ISO 3733</td>
</tr>
<tr>
<td>Sulphur</td>
<td>mass %</td>
<td>Max</td>
<td>1 1 1 1.5</td>
<td>ISO 8754 or ISO 14596, ASTM D4294</td>
</tr>
</tbody>
</table>

Table 4  Requirements for marine residual fuels

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Unit</th>
<th>Limit</th>
<th>Category ISO-F-</th>
<th>Test method and reference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>RMA</td>
<td>RMB</td>
</tr>
<tr>
<td>Kinematic viscosity at 50 °C</td>
<td>mm²/s</td>
<td>Max</td>
<td>10</td>
<td>30</td>
</tr>
<tr>
<td>Density at 15 °C</td>
<td>kg/m³</td>
<td>Max</td>
<td>920</td>
<td>960</td>
</tr>
<tr>
<td>Flash point</td>
<td>°C</td>
<td>Min</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Water volume</td>
<td>%</td>
<td>Max</td>
<td>0.3</td>
<td>0.5</td>
</tr>
<tr>
<td>Sulphur</td>
<td>mass %</td>
<td>Max</td>
<td>Statutory requirements</td>
<td>ISO 8754 or ISO14596 or ASTM D4294</td>
</tr>
</tbody>
</table>


2.4 Low Sulphur Fuel Oil

Almost 100% of the sulphur in the fuel is oxidized to SOX in the exhaust gas and cannot be controlled in the combustion process, thus, the fundamental measure to reduce SOX emissions is to burn LSFO. However, it is not a silver bullet solution yet. The propulsion engines of most sea-going merchant ships select to operate on heavy oil for an economic decision because residual fuel oils are the cheapest (Rowen et al., 2005, p51). The low-speed diesel engines and many of the medium-speed ones can run on the heaviest grades of fuel. The change-over operation may also lead to
failure or even accident.

2.4.1 Price

The answer in IMO Q&A (2018) showed that the yearly average sulphur content of the residual fuel oils tested in 2016 was 2.58% while the worldwide average sulphur content for distillate fuel in 2016 was 0.08%. However, fuel prices are partly determined by sulphur content, and if the sulphur content in fuel is lowered from 3.5% to 1%, the price will increase by 10% to 20% (Sun, 2010, p198).

*Rotterdam bunker prices – IFO380 vs MGO*  
source: Ship & Bunker

![Diagram](https://www.shipandbunker.com/)

**Figure 2**  Price comparison: IFO 380 vs MGO


In 2016, global demand for high-sulphur fuel oil stood at almost 70% of overall bunker fuels. According to a Wood Mackenzie study (2017), global bunker fuel costs could rise by up to US$60 billion annually from 2020, in a full compliance scenario, when the IMO 0.5% sulphur cap for bunker fuels kicks in. In addition, the refining
process of fuel desulfurization consumes a lot of energy and creates new pollution, for instance, the desulfurization of 1 ton sulphur will release 6 tons CO$_2$(Sun, 2010, p198).

2.4.2 Safety threat
Allianz Global Corporate & Specialty(AGCS, 2016) reviewed that there have been unexpected safety implications connected with the use of low sulfur fuel, such as engine problems and power issues (e.g., Zhang, 2017; Pang, 2017), and had seen an increase in machinery claims in relation to fuel. Oil quality may be inconsistent due to the requirements on the sulphur content of the fuel used for ships arriving in the port varying in different region, and the change over of fuels with different sulphur content.

Luckily, these problem can be solved by technology development and market as the demands increase for sure.
3 Policies and Requirements of Using Low Sulfur Oil

International and national political aspects of shipping cannot be ignored (Stopford, 2009, p 89). Policies and requirements of using LSFO come from international level, regional level and state level.

3.1 IMO

Over the past half century, IMO has been working to reduce negative impact of shipping on the environment. To address the issue of air pollution from ship, the regulations for the Prevention of Air Pollution from Ships (Annex VI) to MARPOL Convention was adopted in 1997 and came into force on May 19 2005. A revised Annex VI was adopted in 2008 and entered in force on July 1 2010, introduced a global sulphur limit, with higher requirements in emission control areas.

![MARPOL Annex VI sulphur limits timeline](image)

**Figure 3** MARPOL Annex VI sulphur limits timeline


There are currently four ECAs established under MARPOL Annex VI for SO\(_X\) : the Baltic Sea area; the North Sea area; the North American area (covering designated
coastal areas off the United States and Canada); and the United States Caribbean Sea area (waters around Puerto Rico and the United States Virgin Islands).

Table 5  IMO Emission Control Areas

<table>
<thead>
<tr>
<th>Areas</th>
<th>Adopted</th>
<th>Date of Entry into Force</th>
<th>In Effect From</th>
</tr>
</thead>
<tbody>
<tr>
<td>North American (SO₂ and PM)</td>
<td>26 Mar 2010</td>
<td>1 Aug 2011</td>
<td>1 Aug 2012</td>
</tr>
<tr>
<td>(NOₓ)</td>
<td>26 Mar 2010</td>
<td>1 Aug 2011</td>
<td>*</td>
</tr>
<tr>
<td>United States (SO₂ and PM)</td>
<td>26 Jul 2011</td>
<td>1 Jan 2013</td>
<td>1 Jan 2014</td>
</tr>
<tr>
<td>(NOₓ)</td>
<td>26 Jul 2011</td>
<td>1 Jan 2013</td>
<td>*</td>
</tr>
</tbody>
</table>

* A ship constructed on or after 1 January 2016 and is operating in these emission control areas shall comply with NOₓ Tier III standards set forth in regulation 13.5 of MARPOL Annex VI.

Source: IMO, Retrieved May 3, 2018 from the World Wide Web:

Amendments to introduce further Emission Control Areas have been adopted to Annex VI since 2010. As Lim K.(2018) said “The lower global sulfur limit will have a significant beneficial impact on the environment and on human health”, many States showed the same determination.
3.2 Other foreign regions

3.2.1 California Air Resource Board (CARB)

In December 2007, the CARB approved “Control of toxic and air pollution from the auxiliary diesel engine used in ships calling to the ports of California”. This rule obligates the ocean-going vessels to meet the corresponding emission reduction requirements in stages. On October 16 2010, the rule became a law of California state, and entered into force since January 1, 2014. From then on, there are two options for ocean going ships to meet the requirements of the mandatory emission reduction: one is to power off the auxiliary diesel engine and use other power sources, of which the most feasible is to connect to onshore power; the other is to use
alternative control measures that can achieve the same emission reduction effect. In addition, it also stipulates the ratio of the number of times the ship uses onshore power to the total number of calling to the port. If the ship company can not meet the above requirements, the ship will be fined 1000 to 75,000 US dollar each time according to the situation.

3.2.2 European Union (EU)

The EU actively promotes policies on environmental protection and air pollution control measures by legislation as well (Zhu, et al., 2016, p6-8). Article 20 of the Treaty on the Functioning of the European Union (2012 consolidated edition) clarifies the principle of environmental protection. A series of amendments to the EU's directives are aimed at further adapting EU legislation to the latest international developments under the framework of MARPOL Annex VI. Apart from other things, the EU has implemented more stringent measures to limit the sulphur content of marine fuel oil in the SOx Emission Control Areas (SECAs).

EU SECAs shall include:

(1) the Baltic Sea area as defined in regulation 1.11.2 of Annex I of MARPOL;
(2) the North Sea area as defined in regulation 1.14.6 of Annex V of MARPOL;
(3) any other sea area, including any port area, for the purpose of these regulations, designated by the Secretary-General of IMO in the Merchant Shipping Notice.
Table 6  Sulphur content in fuel oil (EU Directive 2005/33/EC)

<table>
<thead>
<tr>
<th>Item</th>
<th>Standard (% m/m)</th>
<th>Enforcement date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Within SECA</td>
<td>1.5</td>
<td>Since August 1, 2006</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>Since July 1, 2012</td>
</tr>
<tr>
<td></td>
<td>0.1</td>
<td>Since January 1, 2015</td>
</tr>
<tr>
<td>Inland river vessels and ships at berth in Community ports</td>
<td>0.1</td>
<td>Since January 1, 2010</td>
</tr>
<tr>
<td>Passenger ships</td>
<td>1.5</td>
<td>Since January 1, 2006</td>
</tr>
<tr>
<td></td>
<td>0.1</td>
<td>Since January 1, 2020</td>
</tr>
</tbody>
</table>

Source: EU, 2005

Table 7  Sulphur content in fuel oil (EU Directive 2012/32EC)

<table>
<thead>
<tr>
<th>Item</th>
<th>Standard (% m/m)</th>
<th>Enforcement date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outside SECA</td>
<td>3.5</td>
<td>Since June 18, 2014</td>
</tr>
<tr>
<td></td>
<td>0.5</td>
<td>Since January 1, 2020</td>
</tr>
<tr>
<td>Within SECA</td>
<td>1</td>
<td>Before December 31, 2014</td>
</tr>
<tr>
<td></td>
<td>0.1</td>
<td>Since January 1, 2015</td>
</tr>
</tbody>
</table>

Source: EU, 2012

3.3 People's Republic of China (PRC)

The public health impact of exposure to air pollution in China is significant, for instance, Beijing cough is becoming more famous than the Roast Duck. Shipping ports are a major, and often overlooked, source of air pollution, and seven of the ten busiest ports in the world are located in China (Mao, 2016). To address the issue, China updated several related laws and regulations, such as *Atmospheric Pollution*
Prevention and Control Law of the People's Republic of China (2015 Revision),

3.3.1 China Emission Control Zone (ECZ)

Ministry of Transport (MOT, 2015) issued Implementation Plan of Ship Emission Control Zones in the Pearl River Delta, Yangtze River Delta and the Bohai Sea (Beijing-Tianjin-Hebei). Figure 5 shows the locations of these ECZs.
Figure 5  China Emission Control Zones

Table 8  Phases of China ECZs

<table>
<thead>
<tr>
<th>Date</th>
<th>Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>After Jan. 1 2016</td>
<td>Advantageous ports may implement the regulation that ships berthing at its port shall use fuel oil on board with a sulphur content $\leq 0.5%$ m/m. i.e., Shanghai carried out the regulation from Apr. 1st 2016, and Shenzhen carried out the regulation from Oct. 1st 2016.</td>
</tr>
<tr>
<td>After Jan.1 2017</td>
<td>Ships berthing at core ports (such as Shenzhen, Guangzhou and Zhuhai in Pearl River Delta) in ECZ shall use fuel oil on board with a sulphur content $\leq 0.5%$ m/m, excluding the first hour after berthing at the port and the last hour before departing from the port.</td>
</tr>
<tr>
<td>After Jan.1 2018</td>
<td>Ships berthing at all ports in ECZ shall use fuel oil on board with a sulphur content $\leq 0.5%$ m/m.</td>
</tr>
<tr>
<td>After Jan.1 2019</td>
<td>Ships entering in ECZ shall use fuel oil on board with a sulphur content $\leq 0.5%$ m/m.</td>
</tr>
<tr>
<td>before Dec.30 2019</td>
<td>Assessing the effectiveness of ECZ to decide the further actions, then decide whether to take the following actions: 1. Ships entering in ECZ shall use fuel oil on board with a sulphur content $\leq 0.1%$ m/m; 2. Expand the geographic scope of ECZ; 3. Other actions.</td>
</tr>
</tbody>
</table>

Source: Author

3.3.2 Inland waters
Besides coastal ports and waters, the population and environment also suffer from the ship-source air pollution. Inland river ships must use diesel oil that meets
standard requirements, and fuel oil reception and samples must be reserved when refuel, at the meantime, refueling operation should be record in the Oil Record Book (ORB). Maritime officials, most officers will check fuel oil reception and ORB, also get oil sample for further test. If illegal actions are found while inspection, the responsible person, the ship owner or the ship operator will be punished in accordance with relevant requirements, laws and regulations, According to related regulations and National Standard of PRC (GB), sulfur content and implementation date are as follows:

<table>
<thead>
<tr>
<th>Tier</th>
<th>Figure (not higher than)</th>
<th>Timeline</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>350</td>
<td>Jun. 30th 2017</td>
</tr>
<tr>
<td>II</td>
<td>50</td>
<td>Since Jul. 1st 2017</td>
</tr>
<tr>
<td>III</td>
<td>10</td>
<td>Since Jan. 1st 2018</td>
</tr>
</tbody>
</table>

Source: made by author based on related regulations GB 252-2015 <Normal Diesel Oil>
4 Administration and Efforts in Shenzhen

4.1 Shenzhen

Shenzhen is a city where the first special economic zone is located, which means it has the power to make local regulations according to Article 72 of the *Legislation Law of the People’s Republic of China (2015 Amendment)*. This city has 11.9 million permanent resident population and its GDP reached 1,949.26 billion yuan in 2016 (SZGOV, 2017). The Port of Shenzhen (Wikipedia) is a collective name of a number of ports spread along parts of the coastline of Shenzhen, Guangdong Province, China, separated by the New Territories and the Kowloon Peninsula of Hong Kong into two areas: the eastern port and the western port.

![Figure 6](http://sz.msa.gov.cn/Images/%E8%BE%96%E5%8C%BA%E5%9B%BE2017.jpg)

**Figure 6** Jurisdiction area of Shenzhen Maritime Safety Administration

Source: Shenzhen Maritime Safety Administration. (2018). Retrieved May 1, 2018, from [http://sz.msa.gov.cn/Images/%E8%BE%96%E5%8C%BA%E5%9B%BE2017.jpg](http://sz.msa.gov.cn/Images/%E8%BE%96%E5%8C%BA%E5%9B%BE2017.jpg)

Information office of Shenzhen Municipal People’s Government (SZGOV, 2017) stated that Shenzhen port has 152 berths altogether, including 47 container berths,
provided service to 236 international container routes and 48 feeder routes to other ports in the Pearl River Delta region. Shenzhen port is one of the busiest and fastest growing container ports in the world.

![Shenzhen Port data for recent 3 years](source)

Figure 7  Shenzhen Port data for recent 3 years

Source: Made by the author based on the statistics from SZMSA

4.2 Government department

Shenzhen government pays more attention on legislation of local regulations, local government rules, local regulatory documents and government investment (including subsidies), for example, the Green Convention of Shenzhen Port (People, 2015). For the implement aspect, basically, there three government organizations related to marine air pollution prevention, Shenzhen Maritime Safety Administration (SZMSA) under Ministry of Transport, Human Settlements and Environment Commission of Shenzhen Municipality (SZHEC) and Transport Commission of Shenzhen Municipality (SZTB) under Shenzhen government. Transport Commission of Shenzhen Municipality also acts as the Port Administration of Shenzhen
Municipality. SXMSA is in charge of ship and seafarer administration, SZHEC cares about AQI of the city and SZTB focus on port/terminal issues. They all make their best effort to conquer the marine air pollution within their power and sometimes they fight side by side.

4.3 Effort

Author review the effort put into the administration on low sulphur fuel oil on behalf of SZMSA, contributions from other parties will be mentioned as much as possible.

4.3.1 Handbook

For better implementation and administration, SZMSA came up with a handbook which defined target ship, procedure, key inspection items and other related issues such as “how to calculate berthing time”. The berthing time shall be calculated from the time when the first mooring line is attached, and the departure time shall be calculated from the time when the last mooring line is cast off. Ships shall keep fuel oil change over record, bunker delivery note (BDN), oil record book (ORB), and engine logbook and other fuel oil related documentation for inspection and verification by the relevant departments and agencies. Any ship encountering such circumstances as to render the application of the ECZ policy impracticable or unreasonable may submit a request for waiver or exemption to SZMSA. Ships may use equivalent approach to achieve the effectiveness of using low sulphur fuel oil. If an alternative method is used, except from Shore Power Supply or Liquefied Natural Gas, which should be approved by SZMSA and SZTB. Dong and Dong (2017) argued that a more detailed fine standard should be introduced as statutory fine range for ships use fuel that do not meet the standards or requirements is really wide (RMB 10,000 to 100,000 yuan) according to Paragraph 1 of Article 63, Article 64 and
Article 106 of *Atmospheric Pollution Prevention and Control Law of the People's Republic of China* (2015 Revision). For a more reasonable sanction and better practice, Shenzhen MSA carries out four levels of fine according Paragraph 1 of Article 8 and Article 9 of *Provisions of the People's Republic of China on Marine and Maritime Administrative Punishments* (2017 Amendment). Details are written in Appendix 1.

4.3.2 Oil quality inspection and result

Officials of SZMSA inspect oil quality particularly and together with Port State Control (PSC) / Flag State Control (FSC). In 2015, a special inspection of the ship's fuel oil quality were carried out by SZMSA officials, they inspected ships entered ECZ, bunker operation, local bunker companies and oil samples were sent to particular authorized lab. During the inspection, 212 ships were inspected for 67 times, 12 bunker companies were visited, 64 oil samples were tested. Assisted by SZMSA, SZHSE carried out a one month ship tail gas detection, to provide basis for developing a target ship standard, and accumulate experience for formal implementation of emission control measures. Draw lessons from EU, SZMSA maintains a high percentage of inspections to ensure that ECZ policies and requirements are implemented by ships and companies.

<table>
<thead>
<tr>
<th>Table 10</th>
<th>Statistics of oil quality inspection (2017)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inspection item</td>
<td>Unit</td>
</tr>
<tr>
<td>Inspection</td>
<td>ship-times</td>
</tr>
<tr>
<td>Sampling and sending to lab</td>
<td>ship-times</td>
</tr>
<tr>
<td>Average percentage of sulphur in sample</td>
<td>% m/m</td>
</tr>
</tbody>
</table>
### Noncompliance in sample ship-times

<table>
<thead>
<tr>
<th>Noncompliance in sample</th>
<th>ship-times</th>
<th>0</th>
<th>2</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average percentage of sulphur of Noncompliance in sample</td>
<td>% m/m</td>
<td>0</td>
<td>0.67</td>
<td>0.0512</td>
</tr>
<tr>
<td>Sanction</td>
<td>ship-times</td>
<td>0</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Sanction amount</td>
<td>thousand yuan</td>
<td>0</td>
<td>25</td>
<td>50</td>
</tr>
</tbody>
</table>


#### 4.3.3 Equipment

Funded by MOT and Shenzhen government, SZMSA spent RMB 1,797,000 yuan to purchase 6 sets of quick detection equipment in 2017. The model is Cube 100S portable X-ray fluorescence spectrometric instrument manufactured by Sunic-Ocean Marine Technology & Service Co., LTD. The quick test could be reliable because X-ray fluorescence spectrometry may be the most effective method in element analysis (Zeng, 2010, p427).

![Figure 8 Oil sample quick detection equipment](source: photoed by SZMSA officials)
SZHSE prefers tail gas detection, occasionally with the help of Unmanned Aerial Vehicle (UAV) telemetry sensor. According to preliminary estimation of accumulated test data, 0.5%m/m low sulfur oil may discharge 500mg/m3 SO\textsubscript{X} exhaust gas roughly, 3.5%m/m fuel oil may discharge 2000mg/m3 SO\textsubscript{X} exhaust gas roughly.

4.3.4 Research

SZMSA together with SZHEC applied to the municipal government for special research funds of 3.4 million yuan to carry out the “Ship Emission Control Areas emission monitoring capacity” project. This research addresses the issue of the
supervision of ships entering the Emission Control Areas from the second phase of January 1, 2019. After a lot of research, the authorities have screened the mainland and Hong Kong leading research institutions in the field of air pollution emission research, and jointly set up a high-level research team. The project research focuses on the international leading edge of the remote sensing technology of atmospheric emission from the City University of Hong Kong, the leading advantage of the research on the Atmospheric Emission Monitoring technology model of Fudan University, the analysis of the data of the ship's atmospheric emission and the advantages of information platform construction of Wuhan University of Technology. Through the research, SZMSA will set up a set of emission factor induction system, technology derivation model, data analysis and information supervision platform composed of a relatively sound monitoring system of marine emissions, in order to implement emission control measures to provide a strong technical support. SZMSA assists the SZHEC in carrying out the investigation of the air discharge monitoring and flue gas washing device for ship installation in Hong Kong, and puts forward reasonable suggestions for the application of the new technology in the ship's energy saving and emission reduction in Shenzhen city. The system is installed in ship’s funnel, which can continuously monitor emissions and transmit emission date to onshore monitor center.
4.3.5 Cooperation

Under the guidance of the China MSA, SZMSA has actively carried out communication and coordination work to promote regional cooperation in the prevention and control of air pollution emission from the Pearl River Delta region and Hongkong. After unremitting efforts, in December 23, 2016, the cooperation agreement on the Prevention and Control of Air Pollution in the Mainland and Hongkong (hereinafter referred to as the Cooperation Agreement) was signed in Shenzhen by China MSA and HKEPD. It has effectively implemented the requirements of the MOT, and promoted the emission control of the vessels in the region. Progress in the integration of action. The two parties set up a cooperative management working group to coordinate the implementation of the content of the cooperation agreement, set up a unified law enforcement process, standard and check ratio, greatly reduced the cost of communication between the supervision departments, promoted the efficiency of supervision, established the illegal notification mechanism, and the illegal emission of ships found in the process of law
enforcement. Shipping companies and dangerous oil supply enterprises are included in the notification contents, and serve as key inspection objects of all parties to form regional law enforcement efforts. Up to now, the two sides have dealt with the black list of 37 violated ships and 13 related companies, effectively enhancing the deterrent force of law enforcement. Under the framework of the Cooperation Agreement, through discussions and consultations with the Hongkong Environment Bureau, the Hongkong Environmental Protection Agency and the Shenzhen human settlements Commission, a studio is set up for the prevention and control of the air pollution in Shenzhen and Hong Kong to further effectively promote the integration of the emission control operations of the two places in Shenzhen and Hong Kong.
5 Recommendations

5.1 Cooperation

Air pollution is a global issue so the cooperation shall be unbounded. The Baltic Sea and North America ECAs are best examples. Counties in European Union, Canada, USA, and Mexico worked together for cleaner air. Cooperation can be among different states, cities and even different government department. It is very necessary and vital to see the whole picture. For the administration on low sulphur fuel oil for ships, too many parties are involved from distillation to burning or sampling. On October 27, 2017, Ministry of Transport and other 13 departments issued Guidance on Strengthening the Supply and Joint Administration of Marine Low Sulfur Fuel Oil. Ensuring compliance with the ship's low-sulfur oil supply has become the key to controlling the ship's air pollution both now and near future. This is a good start for the coming sulphur limit. A mechanism shall be established for information sharing and exchange, a universal format of BND and unique track number shall be introduced in accordance with guidance on best practice for fuel oil purchasers/users for assuring the quality of fuel oil used on board ships (MEPC.1/Circ.875). Easy access to the information about reliable bunker suppliers and traders shall be provided, like government website, and keep monthly update.

5.2 Legislation

Provinces and relatively large cities could use their legislate power to protect local environment. Environment protection, or in other words pollution, has a tight relationship with economic. More developed areas could set up their particular policies for promoting green shipping, for example ECZ, subsidy and tax reduction for using LSFO. A detailed standard of sanction shall be discussed and introduced for more reasonable implement and avoidance of corruption. If the penalty is not
strengthened, even if the proportion of inspection increases, the binding force on the ship or ship operator is still smaller. Only by combining the two pronged efforts to enhance the proportion of sampling, can we strengthen economic penalties and non-economic penalties. In January 2015, the EPA made economic penalties for the standards of sulfur content of marine fuels in the North American emission control area. The punishment measures mainly include two parts: first, the amount of punishment will be calculated by combining the economic benefits of eliminating violations and setting up two of the serious penalties of violation. The severity of the penalty includes the excess of sulfur content in fuel oil, the more the exceeding the standard, the more the amount of the baseline, and the number of violations. Each time the penalty interval is $2500 to $15000 each time, the more the number of violations, the more the penalty is above the interval. The two is to introduce adjustment factors to adjust the penalty amount for "violation severity". Its contents include the definition of intent or negligence, the definition of coordination degree, and the definition of the history of using illegal fuel. Three, it is not limited to fines. Sentencing or administrative detention should be made for bad plots.

5.3 Standardized

Standardized procedure of fuel oil quality inspection can ensure the effectiveness of work, as Author suggests one in Figure 11. Guidelines for inspection, especially sampling, shall be more practical and updated. For example, Guidelines for the sampling of fuel oil for determination of compliance with Annex VI of MARPOL 73/78. (MEPC.47/20) is referred for sampling in SZMSA document of administration on low sulphur fuel oil. However, that is for bunkering not for PSC, few officers went to inlet bunker manifold to get oil sample. It shall be replaced by Guidelines for onboard sampling for the verification of the sulphur content of the
fuel oil used on board ships. (MEPC.1/Circ.864). On higher level, a unified fuel verification procedure for different kinds of fuel oil samples was submitted to IMO by China (MEPC 71/5/9). A

![Flowchart of Inspection Procedure](image)

Source: Author
5.4 Research
Legislation shall base on In order to study the emission of pollutants from ships and their effects, we need to establish the emission inventory of ships in corresponding areas. Ship emissions list building can not only help us understand the ship pollutants discharge characteristics, analysis of pollutant emission trends, can also according to its discharge characteristics of the corresponding control policy, estimate the ship emissions of different emission scenarios. But has been used in the research of domestic models have various shortcomings, not make full use of AIS data calculated emissions inventory has great uncertainty, and most can only be used for specific research content, use much inconvenience. To meet the needs of more research, a common ship emission model is urgently needed. Will be based on AIS data, this study will ship emission inventory estimation model for modular processing, make its more generality, eventually get a can according to customer's requirements and different situations, to calculate the specific area, time, different kinds of ship under various conditions of different pollution emissions inventory model of species, to study the effect of ship emissions for air quality, make the pollution emission control area and ship management provide favorable support.

5.5 Technology
PSCO or FSCO can just wait on shore until the target ship arrives at anchor area or berth. Their judgement of the ship compliance is based on navigation log, ORB and asking. With the development of monitoring technology, computer science and internet technology. Officials’ work will be much easier if a online monitor device of low sulphur oil is on board. For now, a small modified such as local record of the temperature of fuel pipes can make a difference. Quick detection equipments save the time of both seafarers and maritime officers, what is more, ship masters can kick
away bigger problems while cost of lab testing could be saved more or less. The legal validity of their results may be accepted shortly after. Innovation is also needed by refiners for ensuring LSFO availability and maybe shipowners enjoy a lower bunker price.
6 Summary and Conclusions

SO\textsubscript{X} emission from shipping has a serious impact on human health and environment. It should be addressed by higher requirements of sulphur limit in ship’s fuel oil. The 2020 global sulphur cap will arrive on time as a irreplaceable solution to ship-source SO\textsubscript{X} emission. Several measures are taken by IMO, states and cities within ECA and ECZ, including scrubber, shore power, LNG and so on. Case study of Shenzhen port enlightens that legislation, economic methods, technology and cooperation are all need. With a deeper thinking for better and wider implementation of low sulphur fuel oil, author suggests different parties shall work together for the same goal. Standard and innovation are quite important for its success.
References


Atmospheric Pollution Prevention and Control Law of the People's Republic of China (2015 Revision), Standing Committee of the National People's Congress, 2015


(Word account: 8550)
Appendix 1

Slight level for circumstances of lighter punishments subject to law. To river boats 300GT or 150KW below/ inshore ships or oceangoing ships500GT or 750KW below, fine RMB 10000 yuan (included) to 12,000yuan. To river boats 300GT (included) to 1000GT or 150KW (included) to 500KW / inshore ships or oceangoing ships: 500GT (included) to 3000GT or 750KW (included) to 3000KW, fine RMB 12,000 yuan (included) to 15,000 yuan. To river boats 1000GT or 500KW and above/ inshore ships or oceangoing ships 3000GT or 3000KW and above, fine RMB 15,000 yuan (included) to 20,000 yuan.

General level for ships use fuel that does not meet the standards or requirements. To river boats 300GT or 150KW below/ inshore ships or oceangoing ships500GT or 750KW below, fine RMB 22,000 yuan (included) to 25,000yuan. To river boats 300GT (included) to 1000GT or 150KW (included) to 500KW / inshore ships or oceangoing ships: 500GT (included) to 3000GT or 750KW (included) to 3000KW, fine RMB 25,000 yuan (included) to 30,000 yuan. To river boats 1000GT or 500KW and above/ inshore ships or oceangoing ships 3000GT or 3000KW and above, fine RMB 30,000 yuan (included) to 35,000 yuan.

Relatively severe level for ships use fuel that does not meet the standards or requirements, which causes water traffic accidents of below general grade or general air pollution accidents. To river boats 300GT or 150KW below/ inshore ships or oceangoing ships500GT or 750KW below, fine RMB 30,000 yuan (included) to 40,000yuan. To river boats 300GT (included) to 1000GT or 150KW (included) to 500KW / inshore ships or oceangoing ships: 500GT (included) to 3000GT or 750KW (included) to 3000KW, fine RMB 40,000 yuan (included) to 45,000 yuan.
To river boats 1000GT or 500KW and above/ inshore ships or oceangoing ships 3000GT or 3000KW and above, fine RMB 45,000 yuan (included) to 50,000 yuan.

Severe level for ships use fuel that does not meet the standards or requirements, which causes water traffic accidents and air pollution accidents of general grade and above, or other circumstances of heavier punishment. To river boats 300GT or 150KW below/ inshore ships or oceangoing ships 500GT or 750KW below, fine RMB 45,000 yuan (included) to 100,000 yuan. To river boats 300GT (included) to 1000GT or 150KW (included) to 500KW / inshore ships or oceangoing ships: 500GT (included) to 3000GT or 750KW (included) to 3000KW, fine RMB 50,000 yuan (included) to 100,000 yuan. To river boats 1000GT or 500KW and above/ inshore ships or oceangoing ships 3000GT or 3000KW and above, fine RMB 55,000 yuan (included) to 100,000 yuan.

To river boats 1000GT or 500KW below/ inshore ships or oceangoing ships 500GT or 750KW below, use fuel that does not meet the standards or requirements, but not caused accidents, and positively cooperate with competent authorities in investigation, fine RMB 2,000 yuan (included) to 5,000 yuan. To river boats 1000GT or 500KW below/ inshore ships or oceangoing ships 500GT or 750KW above, use fuel that does not meet the standards or requirements, but not caused accidents, and positively cooperate with competent authorities in investigation, fine RMB 5,000 yuan (included) to 10,000 yuan.