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Ship emission control and onboard management

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SHIP EMISSION CONTROL AND ONBOARD MANAGEMENT

BY

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DECLARATION

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

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

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Date: July 20, 2016

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ABSTRACTS

Title of Research paper: **Ship Emission Control And Onboard Management**

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This paper analyzes the IMO MARPOL Convention Annex VI emission requirements, and the emissions from diesel engines, proposes measures to comply the MARPOL Convention Annex VI, including the development and application of key technologies of emission reduction, the control of the ship fuel quality, the energy conservation and others to control emissions from marine engines. The exhaust emissions mainly include nitrogen oxides (NOx), sulfur oxides (SOx), carbon oxides (COx), Hydrocarbons (HC) and Particulate Matter (PM), of them, the NOx, SOx and CO_2 have the most direct impacts on the environment and human health. This paper discussed the control of NOx, SOx and CO_2 emissions respectively, so as to promote compliance of international conventions and improve environmental protection.

In addition to the use of alternative fuels, measures to reduce NOx emissions are mainly adding water technology, exhaust gas recirculation technology, low NOx injector technology, selective catalytic reduction techniques, etc. The use of low sulfur fuel is a fundamental solution to the SOx emissions, but there will be many additional questions, a lot of refining and use of low sulfur fuel will lead to a global surge in shipping costs and carbon emissions. Ship need a equivalent way of flue gas desulfurization device to reduce SOx , which is low-cost, without additional pollution. By analyzing the two formulas of EEDI and EEOI, this paper proposes relevant measures from the aspects of ship design and operational management to reduce carbon emissions.

KEY WORDS: Ship Emissions reduction, MARPOL Convention Annex VI, ECA, NOx, SOx, GHG, Control Measures, Ship Management.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ECA	Emissions Control Area
EEDI	Energy Efficiency Design Index
EEOI	Energy Efficiency Operational Indicator
EGR	Exhaust Gas Recirculation,
EU	European Union
GHG	Green House Gas
IEC	International Electrotechnical Commission
IMO	International Maritime Organization
ISO	International Standardization Organization
LNG	Liquefied Natural Gas
MARPOL	International Convention for the Prevention of Pollution From. Ships, 1973 as modified by the Protocol of 1978
MEPC	Marine Environment Protection Committee
PM	Particulate Matter
SCR	Selective Catalytic Reduction
SECA	SOx Emissions Control Area
SEEMP	Ship Energy and Efficiency Management Plan
SNCR	Selective Non-Catalytic Reduction

CHAPTER 1
INTRODUCTION

1.1 The situation of pollution from ship emission.

Maritime transport, as currently the most important mode of transport in international trade, has undertaken more than 80% of global trade transport tasks. Since 2000, with the accelerated process of economic globalization, maritime transport has been got rapid development, the number of the ships in operation has increased dramatically. Data shows that air pollution caused by exhaust emissions from ships currently has occupied 10% of total air pollution. In addition, the study from the National Oceanic and Atmospheric Administration shows that nitrogen oxide emissions from ships at sea accounted for nearly 30 percent of the total of global nitrogen oxide emissions; another study shows that sulfur oxide emissions from ocean-going vessels has reached 5% of the world's total emissions, and in some coastal ports, sulfur oxide emissions from ships has accounted for 30% of the total local emissions. Air pollution from ships has reached a very high point that cannot be ignored.

Exhaust emissions from marine diesel engine are complex, which are mainly composed from the products of combustion and the remainder air, there are harmful ingredients and harmless ingredients. Harmless components include carbon dioxide, water vapor, residual nitrogen and oxygen, in which the CO_2 has no direct harm to humans, it is generally seen as harmless components, but it will produce the greenhouse effect for the Earth's climate; harmful components, also known as polluting gas components, mainly are nitrogen oxides (the NOx), sulfur oxides (the SOx), carbon oxides (the COx), HCs and Particulate Matter(PM), wherein the nitrogen oxides and sulfur oxides have the most direct impacts on the environment and human.

1.2 Measures to control ship emission.

In order to effectively control ship emissions, to reduce the adverse effects of harmful gases on the environment and human health, the International Maritime Organization (IMO) MEPC40 meeting adopted the MARPOL73 / 78 Convention 1997 Protocol in 1997, and added Annex VI rules by new form to prevent air pollution from ships, the rules took effect since May 19, 2005.

Many countries made a lot of researches on the control of marine exhaust emissions, proposed air pollution controlling measures and improved air quality through researching ship exhaust gas abating technologies, over the years they accumulated a wealth of experience in the prevention and control of air pollution from ships. Among them, the establishment of emission control area (ECA) is one of the more effective measures. Emission Control Areas can be divided into sulfur (SOx) emission control area and nitrogen (NOx) emission control area.

Improving the marine power plant design and working situation is also a very good way to reduce waste gas emission. There are many measures and technologies in this field to control ship emission pollutants, for example, using low-pollution combustion chamber and selective catalytic reduction are recognized as the most mature and potent methods. To sum up, these technologies can be divided into three categories: pre-combustion process, the combustion process in the engine and exhaust treatment process.

CHAPTER 2

Ship emission pollutants and their hazards

2.1 The characteristic of atmospheric pollutants

2.1.1 Nitrogen oxides

Nitrogen oxides from ships is a generic term for the various nitrogen oxides, including NO, NO_2, N_2O_3, N_2O, NO_3 and so on. The generation of nitrogen oxides from marine engine is mainly related to nitrogen and oxygen in atmosphere, and nitrogen in the fuel. NOx generated from the nitrogen and oxygen in the air is called thermal type nitrogen oxides; NOx generated from the nitrogen in the fuel by burning is called fuel type nitrogen oxides. In general, the nitrogen content in the fuel used by vessels is less than 0.02%, and therefore NOx emissions is mainly thermal type from atmospheric nitrogen and oxygen. In various nitrogen oxides, the content of NO takes up 90-95% of the total.

Usually nitrogen oxides pollution that we mentioned refers to NO and NO_2 pollution. In all of the nitrogen oxides, NO and NO_2 are harmful for water, soil and air. NO is the main component of nitrogen oxide, which is a colorless gas and has a mild irritation, high concentrations can cause human and animal nervous system disorders and respiratory disorders. NO is unstable, it rapidly converts to NO_2 in air, creating irritation. NO_2 is reddish brown gas at 21.1 ℃ with irritating odor. NO_2 is corrosive and have physical stimulation, people with respiratory system problems, such as asthma, are more susceptible with nitrogen dioxide. It can impair development of lung, especially for children. Long-term inhaling NO_2 even leads to lung tectonic change. In addition, NO_2 is a major factor for the photochemical smog and acid rain.

2.1.2 Sulfur oxides

Sulfur oxides is mainly generated from the sulfur contained in the fuel, after combustion, SOx is discharged to the atmosphere with exhaust gas. The largest content in SOx is SO_2, SO_2 is a colorless gas with a pungent odor, density is bigger than air, easily liquefied, it is soluble in water. SO_2 is a toxic gas, has the potential impact on humans if the concentration in the atmosphere is more than 0.5 ppm; if it is 1 to 3 ppm, most people begin to feel stimulated; when reached 400 to 500 ppm, person becomes ulcers and pulmonary edema until suffocation. SO_2 and dust in the atmosphere has a synergistic effect, when the atmospheric SO_2 concentration is 0.21 ppm, dust concentration is greater than 0.3mg / m^3, they can increase the incidence of respiratory diseases, with chronic conditions deteriorating rapidly. SO_2 damages the organization within the leaves of plants, causes the leaves to turn yellow. Acid rain formed by the SO_2 can acidify water quality, destruct the ecological system of water balance, lead to the death of plankton, and can affect reproduction of fish. In addition, acid rain is also seriously harmful for the forest, and soil acidification will lead to reduction of crops.

2.1.3 Carbon oxides

Carbon oxides include CO, CO_2 and other hydrocarbon components CH_4, and so on. CO is produced from incomplete combustion of fuel in the engine combustion chamber, or improper mixture ratio of fuel and air, such as insufficient air. When the engine has enough scavenging air, CO will continue to burn, so the amount of CO emission is not too much. CO_2 is formed in the combustion process of the fuel, CO_2 emission depends on the fuel quality and form of combustion, output power and efficiency of the engine and so on. Hydrocarbon composition generally refers to CH_4, which is unburned fuel or incomplete combustion products, CH_4 emission depends on the type of fuel and so on.

CO， Carbon monoxide， is a gas which is colorless, odorless, tasteless, insoluble in water. Under standard conditions, carbon monoxide density of 1.25g / L, and almost same density (standard conditions 1.293g / L) with air, this is one of the factors prone to gas poisoning. After the CO come into the body, and combine with blood hemoglobin, binding hemoglobin with oxygen quantity drastically reduced, resulting in body tissue hypoxia phenomenon. Mild CO poisoning, headache, dizziness, insomnia, blurred vision, tinnitus, nausea, vomiting, malaise, tachycardia, transient fainting and other symptoms; severe poisoning when the patient quickly into a coma due to respiratory paralysis and death, survivors are rescued who may get severe complications and sequelaes.

CO_2，Carbon dioxide， is a colorless, odorless gas, the density is slightly larger than the air, it can be dissolved in water to get carbonic acid, in the fresh air content of about 0.03%. When the content is too high, it will stimulate the respiratory center, causing shortness of breath, and will cause headaches, confusion and other symptoms to varying degrees. Carbon dioxide is a greenhouse gas, and has the characteristics of heat insulation. Environmental pollution is caused by the increase of CO_2 in the atmosphere to form an invisible glass, solar radiation to heat the planet, and it unable to diverge into outer space, causing the earth's surface to heat. Warming will bring serious impact on the global environment, resulting in erratic weather, increased ocean storms; melting glaciers, rising sea levels; ecological damage, pests and diseases increase; land of drought, desertification and serious. Greenhouse gas issue has become a focus of environmental protection in recent years. Scientific observations indicate that the Earth's atmosphere before the Industrial Revolution, CO_2

concentrations rose from 280 ppm to the current 379 ppm. The global average temperature rise 0.74 ℃ in a hundred years, especially in the past 30 years, rapid warming.

2.2 The hazards of ship emissions in exhaust gas

The rapid development of industrial civilization brought not only great wealth and benefit for mankind, but also the billion tons of waste gas and waste discharge into the atmosphere each year, causing the survival atmosphere of the human become a toxic air garbage libraries. When the harmful gases and pollutants in atmosphere reaches a certain concentration, it will bring great disaster to human beings and the environment.

2.2.1 Hazards to human health

The variety of air pollutants enter the body through a variety of ways, producing multiple effects on the human body, the main harmful ways of air pollutants to human are: surface contacting, contact the surface of the body then get hurt; foods and drinking water contain atmospheric pollutants, causing poisoning; inhaling air pollutants, results in disease. Air pollution hazards on human health includes two types: acute and chronic. High concentration of pollutants in the air, after a person is exposed for some time, will immediately cause poisoning phenomena or other symptoms, this is the acute hazard; chronic hazard refers to people in long-term low concentrations of air pollutants, with the contaminants accumulating, leads them to the occurrence of illness.

2.2.2 The impact on the ecological environment

Air pollution have serious harm on crops, forests, marine and terrestrial animals. Serious air pollution can cause living creature poisoning or depleting to death; slowing the normal development of organisms; reducing crops resilience ability to pests and diseases and so on. Air pollution damages animals mainly through respiratory infections and food contaminated by the atmosphere, resulting in animal's physical weakening, and even death. In a variety of harmful gases, sulfur dioxide, chlorine and hydrogen fluoride cause the most damaging for plants in the growing season, long-term contacting atmosphere pollution will damage the foliage, reduce photosynthesis, damage internal structure of plant, cause plants to wilt until death. For example, there are 5.3 million hectares of nation's grain production reduced in 1993 in China, it is due to atmospheric pollution (acid rain and fluorine-based pollution).

2.2.3 Damage to the material substance

Air pollution damage to the substance of the material mainly refers the corrosion of architecture exposed to air, such as rust on the surfaces of fluid pipes or metal buildings due to the corrosion, ancient relics and water pipes weathering and so on.

2.2.4 Impact on the global atmospheric environment

Effects of atmospheric pollution on atmospheric environment has gone beyond the national borders, the harm on global atmospheric environment throughout the world due to the impact of air pollution is recognized in three remarkable performance areas: Ozone layer being depleted even damaged, acid rain corrosion and global warming. These issues are closely related to survival and development of humans, if cannot be controlled in time, they will bring catastrophic harm to the entire planet.

CHAPTER 3

Control measures and calculation methods on exhaust emissions

3.1 Conventions of IMO and Control measures in some countries

3.1.1 Annex VI of MARPOL 73/78 Convention

Since the marine diesel engine emissions are becoming more and more serious to environment, in order to effectively control ship emissions, reduce the adverse effects of harmful gases on the environment and human health, IMO adopted the "MARPOL 73/78 Convention on International Prevention of Pollution from Ships" in September of 1997 at the Assembly of States Parties. The new Annex VI "rules to prevent air pollution of ships main engine emissions " is required strictly. IMO corrected "marine diesel engine NOx emission control technology rules", which is in Annex VI in "MARPOL73 / 78 Convention" in 2008, and the amendment was taken into effect at July 1, 2010. The amendment has developed three different levels of control standards according to the year of building ship.

The air pollution was addressed on the agenda in the 1997 MARPOL conference and was included in the 1997 MARPOL Protocol. Later on, the protocol was adopted as a new Annex VI of the MARPOL Convention and entered into force on 19 May 2005. The regulations with regards to different air pollutants and/or shipboard operations which are related to air quality are highlighted in Annex VI. Correspondingly, prohibitions made on the emissions of ozone depleting substances, which include halons and chlorofluorocarbons (CFC), are defined in the Annex VI. In addition to having set limits on sulfur oxide emissions from ship exhausts, the provisions which grant permission of establishing SECA are also included in the Annex in order to enforce more stringent controls over sulfur emissions, e.g., the Baltic Sea Area was designated as a SECA in the Protocol, and the North Sea was adopted as SECA in July 2005. Furthermore, other than those measures taken against SOx emissions, Annex VI also sets limit on emissions of nitrogen oxides which are mainly generated from diesel engines onboard ships. It is worth noticing that both aforementioned gases emissions are two general portions of the Kyoto Protocol greenhouse gases.

3.1.2 Regional control measures

3.1.2.1 ECAs--- Emission Control Areas

Emission Control Areas can be divided into sulfur (SOx) emission control area and nitrogen (NOx) emission control area. MARPOL Annex VI set limitation for SOx emissions in ship exhaust gas, also set a global cap of sulfur content in the fuel, and set up the provisions of the SECA.

At present, there are several sulfur emission control areas, firstly, the Baltic Sea SECA and the North Sea SECA, they began to operate in May 2006 and in November 2007 respectively. From then on, in sulfur emissions control area, ship must use low sulfur fuel that sulfur content is less than 10000 ppm. Since January 1, 2015, ship must use fuel that sulfur content is less than 1000 ppm. Then, the United States and Canada set up “Emission Control Areas” within main coastline 370 km range, and entered into force in August 2012, becoming the world’s third emission control area. Emissions of nitrogen oxides (NOx), sulfur oxides (SOx) and particulate matter will be controlled in the zone. Ships must begin to enforce more stringent standards of sulfur oxides emission from 2015in this area; in 2016, new ships must install advanced pollution control equipment to meet more stringent standards of NOx emissions Tier Ⅲ, the

United States and Canada waters will also be the first NOx "Emission Control Areas."

3.1.2.2 Some coercive measures against ship emissions

The EU implemented emission reduction measures, the mandatory use of low sulfur fuel by ships in the harbor. From January 1, 2010, a ship moored at EU ports (including anchor, buoys, berthing) for more than 2 hours shall use fuel oil not exceed 0.1% sulfur content (This requirement does not apply to vessels using shore power with all machines stopped); engine should be converted to low-sulfur fuel oil (sulfur content not exceeding 0.1%) as soon as possible after berthing; before sailing the ship should try to postpone switching to high-sulfur fuel; fuel conversion operations shall be recorded in the logbook.

On January 1, 2014, California began to implement emission reduction measures, the mandatory use of shore power for ships in the harbor. Based on the characteristics that most port air pollutants come from ships sailing arrival and departure the port, and operations in harbor, in order to reduce pollutant discharge by ships, the United States not only established the North American Emission Control Area, but also passed through higher waste gas emission requirements for vessels berthing in California, where economic development and air quality requirements are both higher. California Code Title 17 Section 7.5, subsection 1 of section 93118.3: “control of toxic air pollutant from auxiliary marine diesel engines of vessels berthing in California” become mandatory from January 1, 2014, ships must continue to increase the ratio of using shore power, including container ships (one shipping company’s ships anchored in the port of California more than 25 times per year), cruises (one shipping company’s ships anchored in the port of California more than 5 times per year), and refrigerated cargo ships. In the law, the times of a shipping company’s ships using shore power in California ports should reach 50% of the total times they anchor in these ports during

2014-2016, and reach 70% during 2017-2019, 80% after 2020. If the a shipping company's ships do not meet the above requirements, one ship each time in port is liable to a fine of $1000 to $75,000 depending on the circumstances.

3.1.2.3 Some incentive measures for ships to reduce emission

To improve the quality of environment, a number of shipping developed regions or ports took incentive measures for the ships in port, such as the Port of Long Beach in United States, Singapore, China's Hong Kong Special Administrative Region, and so on.

First, "Green Flag Scheme" of Port of Long Beach.

In view of the rule that ship low-speed sailing helps to reduce atmospheric emissions, since January 1, 2006, Port of Long Beach began to implement "Green Flag Scheme" encouraging low speed navigation, shipping companies are voluntary to participate in. The scheme encourages ships to sail under the speed 12kn within the scope of near coast 20 n mile. When shipping companies paid attention to environmental protection by participating in the "Green Flag Scheme", in return, the Port of Long Beach reduces port charges of these shipping companies. Port of Long Beach takes Point Fermin lighthouse as the center and the radius was 20 nmile (in 2009 extended to 40nmile). In this semicircle waters, Ships voluntarily reduce sailing speed to participate in the "Green Flag Scheme". The Southern California Marine Switching Center is responsible for detecting and recording the navigating speed of ships within the range, and makes statistics every 12-month to monitor ships performing "green flag plan". If a ship in the port of Long Beach 100% implemented the "Green Flag Scheme" within 12 months, she will obtain a Green Flag Environmental Achievement Award; if a ship performing "Green Flag Scheme" reached the proportion 90% within 12 months, the port charges within next year will reduce 15%. In 2012, more than 83% of the ships decelerated when sailing within 40 nmile range; nearly 96% of the ships implemented slow steaming within 20 nmile range. By the end of 2012, more than 200 shipping companies obtained incentive relief of port charges, while diesel pollutant emissions associating with port operations reduced by 75%.

Second, Singapore's "Green harbor Plan ".

In order to encourage the local shipping industry to use clean energy and reduce carbon emissions, to protect the environment, the Singapore Maritime and Port Authority in 2011 announced the implementation of "the Singapore Maritime Green Plan". "Green Harbor Plan" is one of three components of "the Singapore Maritime Green Plan". The implementation of "Green Harbor Plan" is for the ships anchoring in Singapore harbor. The ships using recognized emission reduction technology or switching to low-sulfur fuel oil in the harbor, according to standards of "MARPOL Annex Ⅵ", will be given a reduction of 15% port charges.

Third, "Fair Winds Charter" in China's Hong Kong Special Administrative Region.

In 2011, a total of 18 ocean-going companies signed a "Fair Winds Charter", promising that ocean-going vessels in the port of Hong Kong will change to use low-sulfur fuel (sulfur content no higher than 0.5%) as far as possible in two years. In 2011, a total of 3616 ocean-going vessels switched to low sulfur fuel at the port of Hong Kong, accounting for 11% of the annual total ocean-going vessels calling the port of Hong Kong, and reduced sulfur dioxide emissions about 890 t. At the time of 2-year period expires, with the joint efforts of the members, for the continuation of the beneficial effects of the implementation of "Fair Winds Charter", and for the continuation of improvement of air quality in Hong Kong, the Hong Kong SAR government announced the "2012--2013 budget" in February 2012, it is recommended that ocean-going vessels switching to low-sulfur fuel (sulfur content no higher than

0.5%) berthing at the port of Hong Kong will be given half of the relief of port facilities and light dues, this is called “berthing vessel oil change plan”.

3.2 Calculation methods on exhaust emissions

“MARPOL” Convention Annex VI set specific restrictions on SOx and NOx emissions in marine diesel engine exhaust gas, it is a major point of MARPOL Convention Annex VI that how to accurately and effectively identify marine diesel engine exhaust gas SOx and NOx emissions.

3.2.1 To determine the exhaust emissions of sulfur oxides in the product.

As described above, sulfur oxides in marine diesel engine exhaust emissions comes from the fuel, and the sulfur in fuel completely transforms to sulfur trioxide in engine cylinder combustion process and other subsequent combustion process. Thus, in principle, the amount of sulfur oxide emissions in the exhaust gas is unnecessary to be measured directly, it can be determined by the method of chemical equilibrium calculation:

$S + O_2 = SO_2$

$2S + 3O_2 = 2SO_3$

In the MARPOL Convention Annex VI, SOx emission is calculated according to the equivalent amount of SO_2 to be generated. In the Convention, in SECAs, the sulfur content of fuel oil shall not exceed 1.5%, the SOx content in exhaust gas should not greater than 6.0g / kWh (converting into SO_2 in calculation). Thus, after determining the sulfur content of fuel components in laboratory, the computational methods can fairly accurately determine the amount of SOx emissions.

It should clearly indicate that the majority of marine diesel engine manufacturers are claiming that their low-speed diesel engine, especially large two-stroke diesel engine, can be fueled with a sulfur content of 5.0% fuel, and fuel companies usually only provide a guaranteed sulfur content not exceeding a maximum value, while in MARPOL Convention Annex VI, the sulfur content of marine fuels were made clear provisions.

3.2.2. To determine the exhaust emissions of nitrogen oxides in the product.

It can be seen from the mechanism of NOx generating that its amount is rarely affected by the amount of nitrogen in the fuel component. The main factors affecting the NOx generation lay in diesel engine cylinder combustion process, namely the structure of the diesel engine, working parameters in process, operating conditions, the quality of work of each auxiliary equipment and systems. That is, the generation of NOx is not only related to diesel engine design and form, but also related to their working purpose, working environment, maintenance and technical management. At present, we cannot determine the specific amount of NOx generated directly by calculation, and it can only be determined by combining methods of measuring, analyzing and calculation, it is different with determining the content of SOx in exhaust gas.

CHAPTER 4

Measures to control NOx

4.1 The key factors impacting NOx formation

Since most of the NO emission from diesel engines is thermal type NO, so the main factors that influence NO production are temperature, oxygen concentration and the length of high temperature duration. In diesel engine working process, higher gas temperature, greater oxygen concentration and longer duration all will cause generating more amount of NOx. The three main factors and parameters have relation with engine injection system parameters, intake and exhaust system parameters, structural parameters and the performance of each auxiliary equipment and systems, and other related content. The temperature and oxygen concentration play a decisive role in the generation of NOx: the higher temperature inside diesel combustion, the greater the oxygen concentration, and the longer residence time of gas in the high temperature area, the more NOx emissions will be generated. Next, this paper will make a detailed analysis of the diesel engine that has been put to use from the three aspects: fuel injection system, intake system, and structural parameters.

4.1.1 Fuel injection system

The role of fuel injection system is to inject fuel into the cylinder at very high pressure in a very short time, to achieve mixing and combusting of fuel and air. The mixture and combustion quality of combustible gas will directly affect the NOx emissions, and fuel injection timing, injection pressure, injection rate, the number and diameter of the orifice are all decisive to mixture and combustion of combustible gas.

4.1.1.1 Injection timing

Fuel supply advance angle is the crank angle from the beginning that fuel injection pump supplies fuel to the TDC position that piston reaches in the compression stroke; injection advance timing refers to the crank angle from the beginning that fuel injector injectors fuel to the TDC that piston reaches in the compression stroke. In practical application, both were generally referred to the injection timing.

Typically, marine diesel engine has been determined the optimum injection timing through a test in the factory. Injection timing is relative to the piston top dead center, it mainly impacts fuel amount injected into the cylinder in the ignition delay period of the diesel engine, thereby affects the maximum combustion pressure and temperature. Other things being equal, if the injection advance timing is increased, that is, more fuel injected into the cylinder before gas combustion, obviously, it will lead to the increased formation of premixed gas before combustion, once ignited to combustion, the pressure and temperature inside the cylinder will have a sharp rise, the increased maximum combustion temperature has favor to the formation of NOx. Conversely, if the injection advance timing is reduced, as close to the top dead center or even after top dead center, despite the pressure and temperature rise at the end of the compression stroke, creating combustion conditions for the fuel injected during ignition delay period, but followed by the piston over the top dead center and goes down, thereby increases the volume of the cylinder, even though more premixed combustion gas and sharp rise of pressure and temperature after combustion, but the maximum pressure and temperature are reduced, thereby the NOx generation amount is suppressed and reduced.

4.1.1.2 Injection Pressure

Currently, marine diesel engine fuel injection applies primarily plunger pump injection system and electronically controlled common rail injection system. Plunger pump injection system are most widely used, formed by the high pressure pump, high pressure tubing and injectors, it can produce 60-300MPa high pressure in high-pressure fuel pump.

More mature applications of Electronically controlled common rail injection system models are Sulzer RT-flex diesel engine series and MAN B&W ME series. Sulzer RT-flex diesel engine series inject fuel oil via a common rail. The common fuel oil rail is a cylindrical device, which is connected with the cylinders, the fuel in the common rail is pressurized to l000 bar high pressure, then injects to each cylinder with solenoid valve opening and closing. MAN B&W ME series diesel engine, its fuel injection pressure has reached more than 800bar. Increased injection pressure can improve fuel atomization, thus form a good mixed combustible gases. But a lot of experimental studies have shown that the increase of injection pressure has more complex impact on NOx generating, specifically in the following two aspects:

First, the injection pressure increase is conducive to enhancing the penetration of fuel fog beam, which leads to the amount of air involved by fog beam increase, combining with more fuel in initial combustion, maximum temperature and pressure in combustion chamber will rise, thus facilitating the formation of NOx;

Second, the increased injection pressure improves atomization of fog beams, so combusting speed increases. The injection pressure increasing also can delay the injection timing. In a short, it reduces NOx emissions. The modern intelligent diesel achieve lower NOx emissions by increasing the injection pressure.

4.1.1.3 The nozzle diameter and number

Injector nozzle diameter directly affects the fuel injection pressure, the length and shape of injection hole determine the shape of the fog beam after fuel injected into the cylinder. Effective means to achieve diesel engine high-pressure injection in current stage are to carefully select small orifice, porous nozzles while improving the fuel pump supply pressure. Reducing the nozzle diameter is conducive to improve the atomization quality, and to improve the uniformity and fineness of fog beam, ensuring more complete combustion. But thus also leads to increased combustion intensity, so that the cylinder maximum temperature and pressure are increased, then NOx emissions increase. In addition, the number of nozzle holes impacts the amount of fuel participating in mixed combustion, reducing the number of nozzle holes will help to reduce the initial amount of fuel injection, thereby suppress the maximum combustion temperature and pressure, but reducing the number of nozzle holes will inevitably result in prolonged injection duration, thus exacerbate to after combustion and loss economy.

4.1.1.4 Injection rules

Injection rules refer to the changing relationship that the injected fuel amount changes according to the cam angle turning per unit in injection process. For direct injection engine, the injection rule has significant impact on the progress of the combustion, in order to ensure direct injection diesel engine has a higher thermal efficiency, and overcome their high maximum combustion temperature and large amount emissions, direct injection diesel engine fuel injection rules should have the characteristics of the following two aspects:

First, in the ignition delay period, in the precondition that the maximum explosion pressure meets requirements, the amount of fuel injected into the cylinder should as little as possible to avoid excessive fuel combusting altogether, causing excessive maximum combustion temperature;

Second, in the pre-combustion period, the amount of fuel injected into the cylinder should be appropriate, so as to control the generation of NOx and combustion noise. For plunger injection system, one of the main factors affecting the fuel injection rules is cam-shaped line and effective working part. Shown in Figure 4.1, the line-shaped cam 1 is steeper than cam 2, so the corresponding injection rate is large.

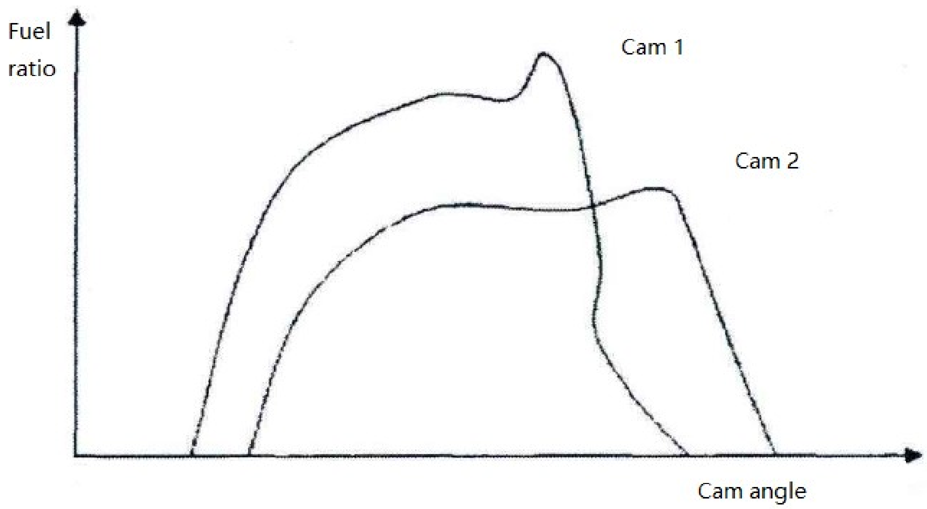

Figure 4.1 Contrast Figures of Fuel Injection Rate of Cams with Different Line Shapes

Source: Marine diesel engine, Text book published by DMU Press

When increased injection rate, injection duration can be shortened, so as to improve the quality of fuel atomization and mixing of oil and air, to shorten the combustion duration and reduce harmful emissions other than NOx. But this will lead to the ratio between early fuel injection quantity and post-injection quantity increases, thereby the amount of fuel participating in premixing combustion increases, so that the total duration of combustion is more closer to top dead center, the maximum combustion temperature and pressure rise, therefore, the amount of generated NOx increases.

For the electronically controlled common rail injection system, it abandoned the traditional form of a high-pressure pump, high-pressure tubing and injector which supply a pulse fuel, instead, it use the electronic control technology, so the injection rate can be arbitrarily controlled according to actual conditions, thus ensuring the diesel engine to run at optimum conditions, then reduce NOx emissions.

4.1.2 Air intake system

4.1.2.1 Air intake pressure

Improving diesel engine cylinder intake air pressure can increase the air density in cylinder, and thus can increase the amount of injected fuel, increase the mean indicating pressure and mean effective pressure of the diesel engine, and can achieve the purpose of lifting economy. At current stage, the majority of marine diesel engine have adopted exhaust gas turbocharger technology, and are developing toward the direction of high pressurized turbocharger. Supercharging pressure level can be expressed with dimensionless pressure ratio π_b:

$$\pi_b = P_k / P_o$$

Where: Pk is supercharging pressure;

Po is atmospheric pressure under environmental conditions or turbocharger inlet pressure.

After using turbocharger, the inlet pressure is increased, the supply amount of air is increased, the intake air temperature rises, the average temperature in the entire cycle increases, combustion is complete, thereby can reduce the generation of HC and CO, particulate emissions are also reduced by about 50%. But for supercharger without intermediate cooling, since the intake temperature is high, the combustion temperature is also increased, then cause increased NOx. Only using supercharger with intercooler, the intake air temperature is reduced to the same extent of the non-supercharged diesel engine, thus not only reduces the heat load of the diesel engine, but also lowers the maximum combustion temperature, then reduces NOx generation, and improves engine power and economy.

4.1.2.2 The intake air temperature

Intake air temperature of the diesel engine is related with two main factors, the ambient temperature and the cooling degree of the supercharger intercooler. Reducing the intake air temperature means the temperature at the end of compression decreases, thereby suppress the combustion temperature, this is conducive to inhibit the formation of NOx. Therefore, the high performance air cooler can increase the cooling degree, it plays a positive role to reduce NOx emissions.

4.1.2.3 The intake air humidity

When the engine intake air humidity increases, the moisture contained in the air increases, water is vaporized due to absorb the heat of pressurized air and cylinder wall surface, the gas temperature is reduced in cylinder, the compression end temperature decreases, so that it can suppress the combustion temperature, and reduce emission rate of NOx. The method of spraying humidification water to reduce nitrogen oxide emissions is to use the principle that endothermic evaporation can reduce the temperature of the gas inside cylinder, to achieve the reduction of NOx emissions.

4.1.3 Engine structural parameters

The main structural parameters in diesel engine affecting NOx emission comprises: the form and structure of combustion chamber, compression ratio and cylinder diameter.

4.1.3.1 The structure and shape of the combustion chamber

In diesel engines, the formation and combustion of mixed gas are closely related to chamber type and structure. In current stage, most of marine diesel engine combustion chamber is open-type, and is direct injection mode. Such diesel engine has bigger excess air factor, has ignition delay duration, maximum combustion temperature inside cylinder is high, which are conducive to the formation of NOx. Open type combustion chamber commonly use shallow dish-shaped concave top piston, combining with the inverted bell-shaped cylinder cover, or shallow top piston fitting with flat bottom cylinder cover. Combustor bears mixing and combustion of fuel and air, and therefore, when the diesel engine is designed, the adaption of combustion chamber and the fuel injection system, intake system, etc, is taken into account, so in the course of the diesel engine in use, replacement of combustion chamber parts must comply with the relevant technical requirements.

4.1.3.2 The compression ratio

Compression ratio is a structural parameter which has great influence on engine performance, the effective compression ratio usually refers to the ratio between the cylinder volume and the compression chamber volume when at the instantaneous moment intake and exhaust valves are all closed. Marine diesel engine compression ratio is usually between 12-18, within a certain range, increasing the compression ratio can promote oil and air mixing, and gas in cylinder will has a greater expansion capacity of working, which will help to improve the economy and power of the diesel engine. However, increasing the compression ratio will also increase pressure and temperature at the end, the maximum combustion pressure and temperature will also rise, then promote the formation of NOx. Reducing marine diesel engine compression ratio can get the smooth combustion and reduced the maximum combustion temperature, thereby can reduce and suppress the generation of NOx, but this will make the economy and power of the diesel engine loss, and the diesel engine cold starting performance will also be affected.

In addition, other structural parameters of diesel engine, such as cylinder diameter, degree of supercharging, will also impact diesel engine's nitrogen oxide emissions. For diesel engines already in use, their structural parameters are generally fixed, so do not need to discuss them. It should be noted that some diesel engines will take the appropriate measures or technical means to further reduce NOx emissions, these measures or devices may refer to fuel emulsification, exhaust gas recirculation, humidification with water, selective catalytic reduction, etc. Therefore, the parameters of such measures or devices will also affect NOx emissions in practice.

4.2 MARPOL Annex VI limits on NOx

MARPOL Annex VI limits on NOx is divided into three stages, calling Tier I, Tier II and Tier Ⅲ. For Tier I stage, according to the 1997 Protocol of MARPOL73 / 78, since January 1, 2000, for the marine diesel engine output power exceeding 130kW, according to their different speeds, have different restrictions of NOx emission respectively as the following:

(1) when the engine speed n <130r / min, NOx emissions should be less than 17.0g / kWh;

(2) when the engine speed n is 130r / min≤n≤2000r / mm, NOx emissions should be less than 45.0 $n^{-0.2}$ g / kWh;

(3) when the engine speed n> 2000r / when min, NOx emissions should be less than

9.8g / kWh.

This restriction has been implemented since May 19, 2005 in global wide. From January 1, 2011, implemented the Tier II (NOx emissions reducing 16-22% than the Tier I), from January 1, 2016, implemented Tier III (NOx emissions reducing 75% than the Tier I) in Emission Control Areas. NOx emission limitations are specified in table 4.1:

Table 4.1 MARPOL Convention Annex VI about the NOx emission limits

	n(r/min)	NOx (g/kWh)
TIER Ⅰ (Since May 19, 2005, Worldwide)	<130 130-2000 >2000	17.0 $45.0n^{-0.2}$ 9.8
TIER Ⅱ (Jan 01, 2011 or later, Worldwide)	<130 130-2000 >2000	14.4 $44.0n^{-0.23}$ 7.7
TIER Ⅲ (Jan 01, 2016 or later, in ECA)	<130 130-2000 >2000	3.4 $9.0n^{-0.2}$ 2.0

Source: MARPOL CONVENTION ANNEX VI

Such limitations are also illustrated as IMO NOx emission reduction milestones in figure 4.2

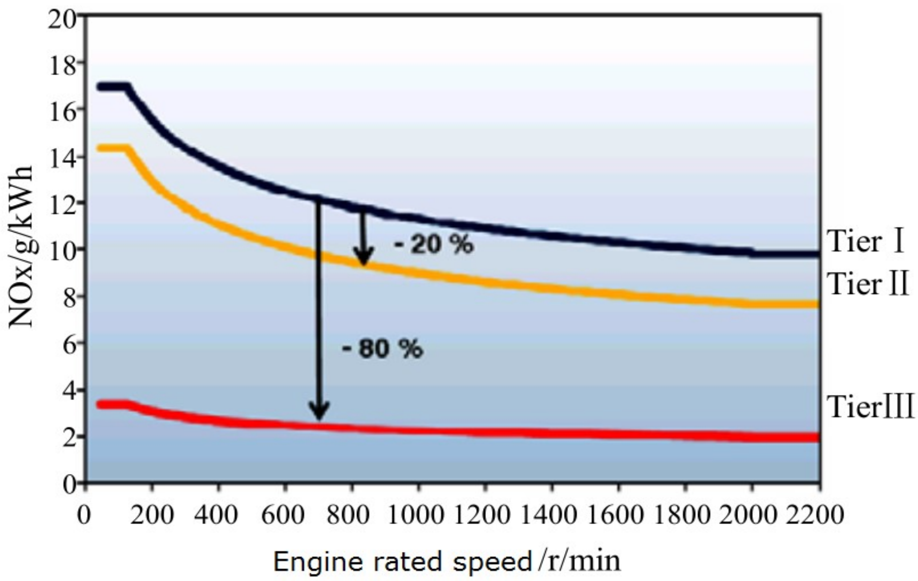

Figure 4.2 IMO NOx emission reduction milestones

Source: Yang Z.M. (2007). Reflections on the IMO diesel NOx emission control development trends, Shanghai ship building, 2(70), 46-48.

4.3 Marine diesel engine NOx emissions control technologies

In order to meet the requirements of IMO conventions, on the one hand, improving the quality of diesel fuel can reduce harmful substances emission in exhaust gas, on the other hand, additional emissions control measures are necessary, namely inside the control (primary control) and external control (secondary control). Internal control is to take action before combustion of the combustible mixture to reduce emissions, including the inside and outside EGR (Exhaust Gas Recirculation) technology, optimizing of the diesel engine's design and operating parameters, wet method to reduce NOx and other technologies . Engine outside control is based on the inside control, to take measures to purify exhaust gases produced by combustion, further to reduce pollutant emissions, including SCR (Selective Catalytic Reduction), absorption method, and so on.

Improving fuel quality will surely reduce NOx emission. Decreasing sulfur and nitrogen content in fuel can effectively reduce emissions of NOx and other pollutants, will also increase the performance and life of the exhaust gas treatment system. Nitrite salts and peroxides added into diesel engine fuel, can increase ignition performance, make combustion easier and more complete, help to reduce the in-cylinder pressure and temperature, to reduce NOx formation. The use of alternative fuels, such as alcohols, hydrogen and natural gas to replace diesel fuel, can also reduce NOx emissions.

4.3.1 Engine inside control technologies

4.3.1.1 EGR technology.

The basic principle is to introduce the exhaust gas into the engine scavenging manifold, this can lower the cylinder temperature during combustion, thereby reduce the formation of NOx. However, this method will increase fuel consumption, reduce combustion efficiency, and EGR system makes ship power plant more complicated, increases the burden of ship operators, so the technology is still not popularized.

4.3.1.2 Optimization of the diesel engine design and operating parameters.

To improve the combustion system, optimize air supply and intake system to lower the maximum combustion temperature, these measures can achieve the purpose of reducing NOx emissions to a certain extent, but in practical applications the effect is not obvious.

4.3.1.3 Wet method reducing NOx technology.

Injecting into the combustion chamber a amount of water, or mix some water with the fuel, so as to lower the maximum combustion temperature, thus reduce NOx emissions from diesel engine. In fact, these technologies are developed around the maximum combustion temperature and oxygen concentration during the engine operation, at present, modern marine diesel engine using inside control technology can substantially meet the emission requirements. But when the emission standards are more stringent, such measures cannot meet the requirements.

4.3.2 Engine outside control technologies

Such technologies reprocess the exhaust gas which is to be discharged into the atmosphere, so as to further reduce the content of harmful substances in the exhaust gas, although these methods do not affect the efficiency of the diesel engine, and the effect is good, but they need extra equipments which will increase economic costs. Engine outside control technologies usually include SCR(selective catalytic reduction) technology and SNCR (selective non-catalytic reduction) technology.

4.3.2.1 SCR method

Developed by the United States, SCR technology is an important measure to reduce NOx emissions of marine diesel engine. SCR using Urea (ammonia) as reducing agent has been applied on some ships in the 1990s. The technology will not affect the efficiency and the fuel consumption of the diesel engine, can reduce more than 85% NOx emissions, as well as it can reduce the noise. Principle of SCR process reducing NOx emissions is: under the aid of a catalyst, use ammonia as reducing agent to treat NOx in the exhaust gas, selective catalytic reduction reaction will occur between ammonia and NOx, the products are harmless N_2 and H_2O. Related chemistries are as follows:

$4NH_3 + 4NO + O_2 = 4N_2 + 6H_2O$

$8NH_3 + 6NO_2 = 7N_2 + 12\ H_2O$

Typically, an SCR system include a drug storage and delivery system, and a control system. Since the SCR reactor tower need to accommodate multiple layers of catalyst plate, so it is bulky and takes up more space.

The method works well for NOx removal, can meet emission standards IMO regulations, is a feasible measure of NOx purification of marine diesel engine. German when carrying out the exhaust emission purification research programs, the federal government, Siemens in cooperation with users and manufacturers developed SCR technology, SI-NOx unit is successfully used in marine diesel engine for NOx emission reductions. The first set of SI-NOx was installed in Germany in 1995 onboard a ro-ro ferry NILSDACKE with a main engine burning heavy oil, after using the NOx emissions from 15g /kWh dropped to 2g /kWh. However, because of the need to accommodate multi-column reaction SCR catalyst plate, it takes up more space.

SCR technology is still appearing many problems in industrial applications. Most obvious drawback is the system volume and high investment costs. Basic SCR volume is as big as engine itself, investment costs accounted for 5%-8% of the ship, which is half of main engine, and running cost is also high. For ships, the space is very limited, too large size will increase the burden of the ship, high investment and operation costs make users not willing to accept. In addition, in the case that diesel fuel contains higher sulfur, small amount of SO_2 in exhaust gas occurs reaction with NH_3, to generate $(NH_4)2SO_4$ which will clog the reaction channel. SCR technology is only adopted in the most high environmental demanding area, using in general vessels are more difficult.

4.3.2.2 SNCR method

Using SNCR technology is more stringent to temperature, can only be used between 800 ~ 100 ℃. However, marine diesel engine exhaust emissions cannot reach such high temperatures, in order to achieve such reaction, ammonia or urea is injected into the cylinder as reductant in diesel fuel combustion process. The chemical reaction occurring in the cylinder are as follows:

$4NO + 4NH_3 + O_2 = 4N_2 + 2H_2O$

$4NO + 2CO(NH_2)_2 + O_2 = 4N_2 + 2CO_2 + 4H_2O$

SNCR technology has been relatively mature, utilization of reducing agent is more effective than in the SCR process, not only no need catalyst, and SNCR process does not require the establishment of additional reactors, so it has small volume, lower investment and operation costs. However, effect of this method for NOx control is not ideal, generally only can remove 30% -50% of the NOx. Therefore it has been widely used in power plants only, and has not been popularized for the marine diesel engine yet.

4.3.2.3 Adsorption method

Let gas mixture contacts with suitable porous solid, apply unbalanced molecular attraction or chemical bond existing on solid surface, remain some certain component of the mixture on the surface of the solid, this process separating the gas mixture is called gas adsorption. Typical adsorbent adsorbing NOx are molecular sieve, activated carbon, silica gel and various acids and the like. Adsorption purification method has a high NOx removal rate, equipment needed is simple and easy to operate, no catalyst needed, and other advantages. However, due to adsorbent's low absorption capacity, much adsorbent is needed, so the equipment has large volume. The sorbent needs regeneration, so the process does not have continuity. Therefore, this method is suitable for the case of a small amount of low concentration NOx in exhaust gas to use, not suitable for the purification of marine diesel engine exhaust gas.

4.3.2.4 Non-equilibrium plasma technology

Following nanotechnology, non-equilibrium plasma technology has become the new hotspot of the world in recent decades, many countries have focused on the research and development of non-equilibrium plasma technology. The plasma chemical removal technology of NOx with ionized gas discharge is a new technology developed from the seventies of the last century, is recognized as one of the most promising technologies. In engineering practice to reduce emissions of harmful substances, these are two measures are developed, electron beam irradiation method and pulse corona technology.

Electron beam radiation method was first proposed by Ebara Company and Japan Atomic Energy Research Institute (JAERI), and is widely recognized as the most promising new emission control technology. Using the electron beam to irradiate emissions, large amount of O atoms, O_3 and other active particles will produce in the exhaust gas, these particles react with SO_2, NOx and added NH_3 in the exhaust gas of gas, to generate sulfur-nitrate complex salt, so as to achieve the purpose of reducing harmful emissions. Researchers in Japan, United States, Germany, Poland, Russia, China and other countries engaged in the research and development of this technology, established various system about 30 sets. With different scale experiments, using different means of demonstration, made a lot of research on running process of the electron beam method (such as way of electronic beam irradiation, type of denitration agent, quality of byproducts, etc.) and the main equipment (such as exhaust gas quenching tower, reactor, byproducts collector, electron accelerator, etc.), basically grasped of the principles and parameters of denitration technology in the exhaust gas. While this technology in industrial application still has many problems: The system device is bulky, primary investment cost is high, energy consumption is high, requires setting cement layer on external equipment to protect from X-ray radiation of electron beam, needs to add ammonium absorbers, there is a big security risk, the byproduct of ammonium salt is in small particles, easy to absorb water and difficult recovery.

CHAPTER 5

Measures to control SOx

Different from NOx, sulfur content in fuel is the only source of SOx, during the fuel icombustion, almost more than 95% of sulfur are emitted into the air, and the remaining approximately 5% of sulfur present in the ash or particles in the form of sulfate. With the IMO and regional regulatory requirements becoming more stringent, currently the available measures to reduce SOx emissions in effective programs include: the use of low sulfur fuel, the installation of exhaust gas cleaning apparatus, the use of alternative fuel, and so on.

In order to reduce the ship exhaust gas sulfur oxides pollution to the atmospheric environment, the most direct way is to reduce the sulfur content of ship fuel, IMO and some developed countries in European and American passed through the relevant laws and regulations on the sulfur content of marine fuel oil, and set a limit value of the standard to be implemented. In addition, in recent years, some domestic and foreign marine equipment manufacturers and research institutes have carried out extensive research and development work in the ship sulfur control technology.

5.1 Ship SOx (sulfur oxide) emission control regulations and supervision

Facing with serious air pollution by exhaust emissions of sulfur oxides from a large number of ships, many international and regional organizations have made legislative restrictions on vessel sulfur oxide emissions. Due to lower fuel sulfur content is the most direct and effective way to reduce emissions, so IMO, the United States Environmental Protection Agency, the European Environment Agency have made increasingly stringent limits specified for the sulfur content of ship fuel (as shown in Figure 5.1).

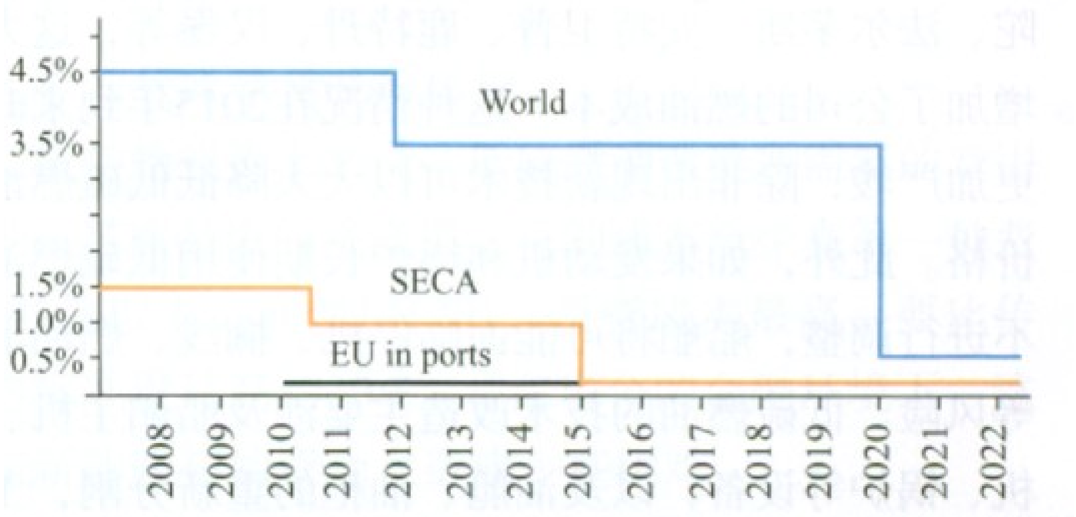

Figure 5.1 Limits for the sulfur content of ship fuel in different areas with the year.

Source: Sun H.D. (2012). On the emission control of SOx, World shipping, 35, 8(206), 51-54.

In IMO MARPOL Annex Ⅵ(the Convention entered into force in 2005), for ships sailing in the US and Europe SECA, fuel sulfur content is limited to the standard content 1.5%, but from 2015 onwards, when the ships enter SECA, they have to reduce the sulfur content of fuel oil by 90% compared to the previous standard, which makes the ocean-going ships engaged in international trade face severe pressure to reduce emissions. Furthermore, in addition to the current provisions of IMO SECA, the coastal waters of Mexico coast, Alaska coast, Singapore, Hong Kong, Australia, Tokyo and other areas are also about to become SECA, or have become SECA, in future all worldwide coastal waters may will be designated as SECAs, this will play an important role in promoting the development of marine sulfur oxide emissions control technologies.

The determinants of how much sulfur oxides emissions from ship are on how much sulfur content in fuel, so sulfur oxide emissions control is mainly around the sulfur content of fuel oil bunkering, compared to nitrogen oxides control, content of sulfur oxides emissions regulation are simpler. So long as the ship is put in service, bunkering of the fuel will always in existence, therefore, regulations of sulfur oxides control will run throughout the entire period of operation of the ship.

Typically, a ship refueling process is made after application from the ship, fuel oil supply company assigns tanker to the agreed port within the time to refuel for the ship, so there is a direct contact between the fuel supply company and refueling ship. In order to achieve sustained and effective supervision under the supervision system of sulfur oxide emissions, the authorities need to order the fuel oil supply company and the refueling ship company to submit their refueling contents, including refueling time and refueling port, tanker name, quantity, sulfur content, viscosity and density of fuel and so on.

5.2 The key factors of impact to generate SOx

Ships SOx emissions in exhaust are primarily produced from the sulfur oxidating by fuel burning. Sulfur forms of existence in marine fuel are mainly hydrogen sulfide, simple substance sulfur and various organic sulfur oxides, these sulfur can be precipitated and further oxidized to SOx even at lower temperature. SOx mainly includes SO_2, and a small amount of SO_3. When the excess air ratio is large and under conditions of complete combustion, about 0.5% -2.0% of the SO_2 will be further oxidized to SO_3, the conversion rate will gradually decline with the increase of sulfur content in fuel.

Sulfur oxide formation mechanism is relatively simple, as one component of a ship fuel, the sulfur can precipitate and react at lower temperature, in the fuel combustion process it will be quickly oxidized to form SO_2 and other sulfur oxides, the reaction process is fast with little intermediate. As the generating mechanism of sulfur oxides is different from nitrogen oxides, emissions of sulfur oxides only come from the sulfur's oxidation in the fuel, so accordingly, the content of sulfur in fuel plays a decisive role for generation and emission of sulfur oxides. In order to reduce emissions of sulfur oxides from marine diesel engine, the most direct and effective measure is to use low sulfur fuel.

5.3 Marine diesel engine SOx emissions control technologies

At present, SOx emissions control technologies in China and abroad have been in real application onboard ships, according to the principle, they can be divided into low-sulfur fuel, alternative fuel, dry desulfurization and wet desulfurization, total of four categories

5.3.1 Low-sulfur fuel

In recent years, in order to control atmospheric environment pollution by sailing vessels, IMO promulgated a series of laws and conventions. In the control of sulfur oxides, MARPOL Convention Annex VI has made clear and specify request on sulfur content of fuel oil for international voyages, and designated the North Sea, the Baltic Sea and the English Channel and other areas as the SECAs, made further limits on the sulfur content of fuel oil.

Low sulfur fuel technology is a processing technology to remove sulfur from fuel oil by refining fuel in refinery, as the most direct way to reduce ship SOx emissions, it was considered as a mainstream technology to solve the ship SOx emissions problem. Many ships sailing in the SECA, such as the North Sea and the Baltic sea, modified their fuel systems to adopt low sulfur fuel, combining with Selective Catalytic Reduction (SCR) technology, ships can achieve desulfurization and denitrification simultaneously. However, IMO has not completed feasibility assessment concerning the availability of low sulfur fuel, the major ports around the world cannot guarantee adequate supply of refining fuel oil. In addition, refining low-sulfur fuel oil will not only consume more energy, produce large amount of carbon emissions, increase refining costs, but also lead to fuel flashpoint and lubrication performance degradation, so that it cannot meet the IMO prescribed limits of for minimum flash point of marine fuel oil (60℃). Therefore, low-sulfur fuel technology will increase the ship operating costs, impact navigation safety, and shorten the life of marine diesel engine.

However, for existing ships, due to the small investment for equipment retrofitted to use low sulfur fuel, so when price gap between high and low sulfur fuel (as shown in Table 5.1) is less than 250 EUR dollars, and ships sailing time in the SECA is short , the existing ships will still choose low sulfur fuel to meet the ship SOx emissions regulations, although added certain fuel costs.

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Table 5.1 Fuel price list with different sulfur content in Europe between 2009-2020 (by quantity) .

YEAR	PRICE EUR $\cdot t^{-1}$			GAP IN PRICE	
	1.50%	1.00%	0.10%	1.50%~0.10%	1.00%~0.10%
2009	166.56	178.72	425.80	259.24	247.08
2010	281.75	293.91	492.11	210.36	198.2
2015	399.60	411.76	656.24	256.64	244.48
2020	424.74	434.34	705.83	281.09	271.49
2025	466.38	—	752.99	286.61	—

SOURCE: European Maritime Safety Agency，2010

5.3.2 Alternative Fuels

Alternative fuel technology refers to taking the new clean energy, such as liquefied natural gas (LNG), methanol, bio-fuels, as marine fuel to substitute traditional fuel oil. Such fuels have a more prominent environmental performance, can effectively reduce SOx and NOx, particulate matter (PM) and other emissions in the ship exhaust gas, and fuel prices are relatively cheap, and can help to reduce operating costs, so this type of technology is gradually being applied to marine power plant. However, currently in the aspects of cylinder lubrication, methane leaks, security and others of pure gas engine and dual-fuel engine, there are still some key technical problems to be solved. The space required by LNG fuel storage tank is about 3 to 4 time as big as the diesel tank of ship, and ship building costs will increase about 8% to 20%. In addition to North European area, the supply infrastructures of alternative fuels in majority of the world's ports is not perfect, there is difficulty in bunkering, storage and lightering. In addition, study shows that LNG economy depends on the price difference with HFO and the proportion of sailing in the SECA. Therefore, alternative fuel technology is still only in the Nordic region and short sea shipping routes transport, the actual application cases on large ocean-going merchant ships are less.

5.3.3 Dry desulfurization technology

Dry desulphurization technology take the lime-based material (such as calcium carbonate, lime, calcium hydroxide) as adsorbent to remove SOx in the ship exhaust gas. According to reports, in 2010, the German Couple Systems Company and MAN B&W jointly carried out related research, has formed Dry EGCS desulfurization system, as shown in Figure 5.2. The system does not involve liquid, so there is not solid wastes generated (such as sodium sulfate, calcium sulfate) which may need stored onboard and unloaded to shore, so it does not produce secondary pollution of the marine environment. Almost without reducing the exhaust gas temperature, the desulfurization efficiency can reach 99%, and PM removal efficiency is about 60%, so the dry desulfurization system can be directly installed downside the engine turbine charger, and will be in favor of the subsequent installation of SCR systems, then achieve further implementation of simultaneous desulfurization and denitrification from ship exhaust gas. However, since the gas-solid reaction rate is low, to achieve the same result with the wet desulfurization, sorbent in dry desulfurization system requires a longer exposure time to process the exhaust gas. In addition, the dry desulfurization system equipments are bulky, they take up more effective cargo space in ship, thus limited the application of this technology onboard real ship.

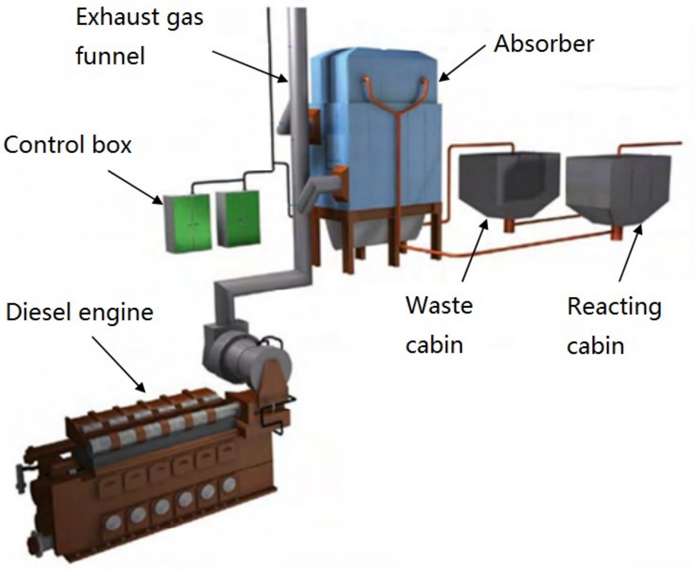

Figure 5.2 Schematic Dry EGCS dry desulfurization system

Source：Ralf Juergens. First operational experiences with a combined dry desulphurization plant and SCR unit downstream of a HFO fueled marine engine. CIMAC Congress，Shanghai，2013.

5.3.4 Wet desulfurization technology and hybrid desulfurization system

Wet desulphurization technology is based on the principles of acid-base neutralization, it takes sodium hydroxide solution, magnesium-based seawater and others as raw materials, to absorb SOx by spraying into the exhaust gas and wash it, to achieve ship gas desulphurization. Depending on the circulation patterns of detergent, wet desulfurization system can be divided into open sea water systems, closed freshwater systems and hybrid desulfurization system. Open seawater system applies natural alkalinity of seawater, to convert SOx into sulfites and sulfates, washing waste can be discharged into the sea after post-processing of separation, aeration, dilution and others, the separated sewage mud, oil residue and others are stored onboard until landing recovery.

Closed freshwater system neutralizes SOx in the exhaust gas by adding sodium hydroxide to the fresh water, the washing waste liquid can be used in recycling by centrifugation, re-adding alkaline and cooling. The separated particulate matter is stored in the sludge storage tanks, so to achieve closed desulfurization process.

The hybrid desulfurization system is a combination of open seawater system and closed freshwater system, achieve flexible switching between seawater and freshwater washing mode, so as to get better adaption to the needs of the ship sailing.

Hybrid desulfurization system have both advantage of open and closed systems, which can conform to different environmental needs of navigation, and can reduce the amount of lye in storage and the secondary environmental pollution, but it has more complex structure and operating system, also needs higher initial investment costs, and the transformation process is vulnerable to ship space constraint of the original exhaust pipe.

5.4 About setting up SECA

Since the beginning of the 1980s, the Marine Environment Protection Committee (MEPC) in International Maritime Organization (IMO) has been working to improve air pollution from ships, and developed the MARPOL Convention. MARPOL Annex VI Article 14 stipulates the sulfur content of any kind of fuel used on board and the time limits of compliance, meanwhile, stipulates the same content about control in SECA. On the basis of MARPOL Annex VI, the EU, North America, China and China's Hong Kong area enacted relevant laws and regulations for the ship SECA.

5.4.1 The EU SECA

EU “SOx Emission Control Area”(SECA) refers to:

1. North latitude 57 ° 44.8’ Lola Strait angle paralleling with adjacent Baltic of Neah Bay boundary, the Gulf of Finland and the entrance to the Baltic Sea;
2. SOx control area in North Sea;
3. any other sea areas, including the port area.

Taking these regulations as stardards, SECA is specified in Merchant Shipping Notice by the Secretary-General. On the technical level, EU issued decrees concerning the control of emissions from ships, mainly the EU 2005/33 / EC and 2012/32 / EC.

Ship fuel sulfur content standards are shown in Table 5.2 and Table 5.3

Table 5.2 EU 2005/33/EC sulfur content standard of ship fuel oil

Date of implementation	Sea area	Standard (% of quantity)
Aug, 2006	Baltic Sea	1.50
Aug, 2006	Passenger ship in EU	1.50
Aug, 2007	English Channel and North Sea	1.50
Jan, 2010	River and sea ship among port in EU	0.10

Source: http://www.epa.gov/otaq/fuels/dieselfuels/regulations.htm

Table 5.3 EU 2012/32/EC sulfur content standard of ship fuel oil

Area	Standard (% of quantity)	Date of implementation
Out of SECA	3.50	Jun.18, 2014 aft
	0.50	Jan.01, 2020 aft
In SECA	1.00	Before Dec.31, 2014

	0.10	Jan.01, 2015 aft

Source: http://www.epa.gov/otaq/fuels/dieselfuels/regulations.htm

Analysis of Table 5.2 shows that the EU 2005/33 / EC amendment standards of bunker fuel sulfur content applicable to the waters and scope is gradually expanding. The EU 2005/33 / EC also proposed amendments to the vessels operation and moored anchorages in EU ports that, from January 1, 2010, the fuel sulfur content must not exceed 0.10% m / m. EU legislation put MARPOL Convention 73 / 78 Annex VI 2008 amendment, on the same implementation of sulfur content, to five years in advance. But the ship owners are against the implementation time, then delayed six months.

Analysis of Table 5.3 shows that the EU will implement more stringent restrictions on the sulfur content of marine fuel in SECA. Starting from January 1, 2015, the waters under the jurisdiction of the EU will implement the standards of 2012/32 / EC amendment, meaning in emission control areas, ship fuel sulfur content must not exceed 0.10%. EU law declared that since 2020, sulfur emissions standard outside ECA is 0.50% for All ships, regardless whether the IMO global standard will be postponed to 2025.

In summary, the EU put SECA complying standards of MARPOL73 / 78 Annex VI provisions ahead of time; the EU Directive amendments for application of ship fuel sulfur content and scope of the waters is gradually expanding; in SECAS, the ship SOx emission standards are more stringent.

5.4.2 The North American SECA

North American Emission Control Area entered into force on August 1, 2012, the area includes the Pacific coastal waters, the Atlantic, Gulf of Mexico coastal waters and the waters of the Hawaiian Islands. Caribbean Emission Control Area of American is the fourth control region of the world, passed in July 2011, deferred to implement from January 1, 2014. The Emission Control Areas cover Puerto Rico and the US Virgin Islands coastal waters. North America and the Caribbean region only implement control standards of SOx emission before, and implemented the IMO Tier III of NOx emission standards form 2016. US Environmental Protection Agency adopted a new fuel rules in December 2009 allowing US domestic production and sales of the fuel with maximum sulfur content of 1.00% (by quantity), the fuel is used for these vessels that the engine per cylinder displacement is greater than or equals to 30 liters). The new rules ban the production, sale and use of fuel with sulfur content exceeding 1.00% (by quantity), unless the ship can take action to ensure meeting the equivalent emission requirements. From 2015 onwards, the North American ECA required ships to use the marine fuel with maximum sulfur content 0.10% m/m. Since January 1, 2007, all vessels in California waters must use clean fuel, sulfur content cannot exceed 0.50%; since January 1, 2010, fuel sulfur content standard reduced to 0.10%. Since 2013, Canadian requires for vessels traveling within North America ECA and the Canadian territorial sea waters (inside north latitude 60°), the maximum sulfur content of marine fuel is 1.00%; from January 1, 2015, for ships traveling in these waters, the largest fuel sulfur content must not exceed 0.10% (by quantity).

In summary, in the waters under the jurisdiction of the California, vessels must use clean fuel, fuel sulfur content standards compliance is ahead of IMO time; in the North American 60° latitude ECA waters and Canadian territorial waters, marine SOx emissions standards are requested to executive in strict accordance with the Convention. Since 2016, the North American emission control area will control nitrogen oxide emissions simultaneously.

5.4.3 China SECA

Any fuel oil sulfur content for vessels sailing in China coastal should not exceed 4.50% (by quantity). For ships on international voyages, China MSA requires the implementation of MARPOL Annex VI 2011 Amendments, and proposed specific monitoring measures. Hong Kong Government and the Local Government in cooperation made researches and feasibility studies to establish Asia's first ship ECA in the Pearl River Basin. In July 2013, Hong Kong Legislative Council passed the "2013 Air Pollution Control", and became effect from January 1, 2014. The Hong Kong Government launched the "Fair Winds Charter" policy to encourage ocean-going vessels to switch to cleaner fuel at berth in Hong Kong. In February 2014, it announced that it would "wind charter" extended until the end of 2014. In 2015, Hong Kong legislative forces "berthing change oil", requires ocean-going vessels moored in Hong Kong to switch to ultra-low sulfur fuel, that is, the upper limit of sulfur decreased from 0.50% (by quantity) to 0.005% (by quantity).

Shanghai environmental protection department found ships berthing in port of Shanghai produced significant atmosphere environmental impact from the exhaust emissions. Shanghai People's Congress proposed the development of ship emission standards of Shanghai, or supplying shore power to reduce the ship exhaust impact on the Shanghai environment.

To sum up, Chinese domestic coastal voyages still perform lower sulfur emission standards; on the sulfur content and time limit of using cleaner fuels, Hong Kong implemented stringent requirements than the IMO Convention standards. "Pearl River Delta" area and Shanghai are pushing forward the establishment of stringent emission standards for ships.

CHAPTER 6

Measures to control CO_2

The energy shortage and greenhouse gas emissions have become increasing prominent today, effectively reducing the ship energy consumption and effectively controlling carbon emissions are particularly important. To effectively reduce greenhouse gas(GHG) emissions and control air pollution, IMO took active measures in the field of shipping. In July 2011, IMO Marine Environment Protection Committee (MEPC) made MARPOL73 / 78 Annex VI amendment in the 62nd Session, introduced ship energy efficiency terms, this is the first measures to reduce greenhouse gas emissions from international enforcement in the field of maritime transport. Amendments was implemented from January 1, 2013. The ship energy efficiency provision includes two aspects: new ship Energy Efficiency Design Index (EEDI) and all operational ship energy efficiency management plan (SEEMP). Discussion on the ship energy efficiency measures to reduce CO_2 emissions in EEDI and EEOI two aspects.

6.1 Ship Energy Efficiency Design Index (EEDI)

In order to protect the environment , the new ship Energy Efficiency Design Index (EEDI) was proposed by Marine Environment Protection Committee (MEPC) in the 56th General Assembly in 2007, mandatory standards of EEDI was implementedsince January 1, 2013.

Energy Efficiency Design Index (EEDI), it refers to the ratio between social beneficial was created by shipping (cargo transport) and the pay of environmental cost in ship design. Energy Efficiency Design Index (EEDI) formula is quite complex, but we can use a more practical and simple formula to analyze the number of index, namely:

$$EEDI = \frac{\text{Engine Power x SFC x } C_F}{\text{Capacity x Speed}}$$

To improve the energy efficiency of the ship, the key point is to understand the relationship between the EEDI and energy efficiency measures, simply, which element will affect the EEDI value in the energy efficiency measures. The purpose to study Energy Efficiency Design Index is to know how to reduce EEDI.

By simple formula of EEDI, there are five key factors that can impact the EEDI values , they are:

a. Capacity (indicating the amount of loading of the ship);
b. Speed (speed indicating in no wind case);
c. Engine Power (showing power of a ship sailing under the rated ship speed);
d. C_F (means conversion factor dimension between no unit fuel consumption and no unit CO_2 emissions, the parameters reflect the quality of marine fuels);
e. SFC (average power of fuel consumption rate under the maximum continuous power).

Carbon conversion factor C_F can reduce the value of the EEDI, which is mainly related to the quality of fuel. Since the ship speed is directly affected by the ship's main engine power, thus ship's EEDI is directly determined by the ship's load and the rated power. Adding load will decrease the formula value by increasing the value of the denominator, but increasing load will certainly increase the power of the ship, the numerator in formula also increases, so that EEDI increases. Ship power and load is a 2/3 times relation, therefore, requires appropriate load and speed to balance the ship's power in new ship designed, to control the EEDI index.

6.2 Ship Energy Efficiency Operational Index (EEOI)

Ship Energy Efficiency Operational Index (EEOI), it reflects the operational energy efficiency of ships. In 2005, IMO has been proposed relational requirements. In MEPC 53rd meeting, the relevant documentation requires definitions and formulas of EEOI Index. Although EEOI is not enforced at present, but many shipping companies are beginning to consider the operational index of the ship's CO_2 emissions, Some large shipping companies in Europe provide practicing data of EEOI for IMO. And made certain improvements and programs, so that the index has been further improved.

Ship Energy Efficiency Operational Index is the ratio between the amount of carbon dioxide emissions and the total weight multiplying transportation distance while ship is transporting. According to the definition of EEOI, the smaller EEOI value, the higher of the energy efficiency of the ship.

6.2.1 Early ship EEOI calculation method

Marine Environment Protection Committee proposed and adopted the "Ship Energy Efficiency Operational Indicator voluntary use of temporary guidelines" at 59th meeting. The interim guidelines proposed calculation method of EEOI in single voyage, as shown in equation below:

$$EEOI = \frac{M_{CO2}}{M_{cargo} \times D}$$

Where: Mcargo: total load weight (t); D: Shippers distance (n mile); MCO2: carbon emissions arising from the exercise of shipping.

CO_2 emissions equal to the total various fuel FC consumed by ship's main engine, auxiliary engines and boiler multiplying the number of such fuel's CO_2 conversion factor.

6.2.2 Latest ship EEOI formula.

In July 2009, MEPC at its 59th meeting, adopted the "Ship EEOI Voluntary Guidelines for the application". The guidance states: Ship Energy Efficiency Operational Index, formally applied to practical aspects of the operation of the ship, by the formula to calculate the actual greenhouse gas emissions from ships. As shown in equation below:

$$EEOI = \frac{\sum_i FC_i \times C_{Fi}}{M_{cargo} \times D}$$

Where: i: fuel type; FCi: the corresponding amount of fuel consumed in ship sailing (t); C Fi: CO2 emission factor; Mcargo: shipping cargo capacity (t); D represents the exercise of shipping time distance (n mile).

From the above expression can be seen to reduce CO_2 emissions can reduce EEOI value directly, which means that the ship energy efficiency is improving.

6.3 Recommended ship emissions restriction methods

6.3.1 Basing on EEDI recommendations.

Basing on means of various parameters in EEDI formula, there are following recommendations:

6.3.1.1 Improving ship design.

Optimization of hull lines. Optimization of hull lines directly affects the ship resistance, and thus affects fuel consumption of main engine. Sensitivity of EEDI formula indicates that, reducing fuel consumption, will reduce the EEDI index, and will reduce carbon emissions.

Reducing the air resistance of the ship superstructure. When the ship's upper layer is large, offshore wind is large, air resistance cannot be ignored, the energy consumption of ship will increase.There are many ways to reduce air resistance of vessels, such as elongating arrangement of superstructure, etc.

Optimization in hull surrounding flow field. With the installation of bulbous bow, it changes the flow state. Large vessels use nasal bow technology, reducing 6% to 11% resistance on average, thereby reducing the EEDI value of the ship.

Optimization of propeller design. Now some new technology propeller can save energy. Such as using low-speed propeller, using a coaxial counter-rotating propeller technology, additional free rotation of the impeller propeller can save consumption. To analyze EEDI sensitivity formula, to reduce the fuel consumption rate (SFC), will reduce the numerator value, thereby reducing the EEDI value. Optimization of propeller and lower fuel consumption technology: front duct, propeller boss cap fins and other measures, according to the statistics show that energy saving of about 5% to 7%.

6.3.1.2 Optimizing ship speed, reducing to economic speed.

Engine power is proportional to the cube of the ship speed, there is a specific relations formula among ship speed, engine power and fuel consumption, it is determined by matching relationship between the vessel, engine and propeller during ship designing phase:

$$P_e = A \cdot V_s^3$$

Where: Pe is Effective power(kW), A is a constant, Vs is ship speed.

Since the propeller power consumption is approximately proportional to the cube of the speed, so reducing the speed with a small amount can save a lot of fuel consumption. When the speed reduced by 20%, the required engine power can be reduced by about 50%, which can greatly reduce the total fuel consumption of main engine.

The relationship between actual fuel consumption and the engine (ship) speed also is a positive cube. Accordingly relationship can be found to reduce the speed of ship. In order to significantly reduce the fuel consumption of the ship, to further reduce CO2 and other greenhouse gas emissions from ships.Low speed steaming for shipping companies, it is a kind of energy saving measures most convenient operation. No huge initial investment cost, easy to adjust and change the ratio of spin-down and low cost. Therefore,lots of ship reduce the speed to reduce CO_2 emissions in the short term, the optimal choice of reducing a ship operating costs. Deceleration reduces fuel consumption efficiently, the ship can find the lowest fuel consumption and speed by computing, but the low load operation, component wear will increase, so should be considered;

6.3.1.3 Fleet capacity structure optimization, route optimization.

Fleet capacity structure means the composition of the fleet of ship types. Optimize the transport structure, to achieve the purpose of energy saving fleet, primarily means according to the route cargo fleet operators, rational planning the proportion of ship in large vessels and small ships, (typically, the unit of large ships tons of fuel consumption CO_2 emissions and lower smaller vessels, large vessels has the advantage of energy saving); When the ship's investment is permitted, to maximize the proportion of energy-efficient low-emission vessels in fleet, eliminate high fuel consumption , high emissions and old ships.

By optimizing the use of ship routing system, shipping routes and arrivals time to optimize and reduce the number of ships out of port and in port time, which can not only reduce costs, but also reduce greenhouse gas emissions. At the same time, by ocean currents and weather forecasts, strengthen to track transoceanic sailing ship, to help ship to choose the best routes to reduce unnecessary power consumption.

6.3.1.4 Optimization of ships' ballast water management.

Deadweight of the ship is certain, ballast water cause to reduce the ship's loading capacity. Loading is in the denominator position EEDI formula, effectively increasing the amount of ship's loading,it has great significance for EEDI index. Now there are some ships without ballast water , that can increase the loading of the goods, thereby reducing the EEDI index.

6.3.1.5 Improvement of marine propulsion systems.

Data show that: the use of high-pressure injection technology is the future direction of development of marine diesel engine, this technique can maintain a high and stable injection pressure over the entire operating conditions of the diesel engine, the diesel combustion process is stable with clean burning. Now new diesel engine' fuel injection, valve driving and cylinder lubrication mostly use electronic control technology to improve the diesel engine performance in low fuel consumption and low-speed operation. In addition, the use of dual-fuel diesel engine not only can effectively reduce the fuel consumption and operating costs, but also can improve engine efficiency and reduce greenhouse gas emissions. Under certain speed, engine power will decline, not only can reduce fuel consumption, but also can greatly reduce the EEDI value.

6.3.1.6 Ships load utilization.

A reasonable amount of cargo stowage and cargo loading can improve operational efficiency, get the largest utility of the ships energy, so that energy consumption per ton of cargo is the least, greenhouse gas (GHG) emissions goes to a minimum. From the EEDI formula we know that EEDI is inverse with ship cargo capacity, the more cargo capacity, the little EEDI, and the lower the ship's CO_2 efficiency index, then the less damage to the environment. There are various measures improving ship load efficiency, shipping companies can achieve it through planning rational routes to ensure adequate freight resources on the routes, or make full use of the same resources, enhance business cooperation between the same route, share ship space with other companies, try to avoid idling. Improving ships loading utilization rates, especially for large vessels, will reduce exchanges between ports.

6.3.1.7 Exhaust heat recovery.

Currently, diesel engines are the most widely used in ships, mainly because the diesel engine not only has the highest thermal efficiency as a heat engine, but also has good performance at fast starting, part load operation, safety and reliability, the light weight, big power range (from a few kilowatts to tens of kilowatts), and a series of other advantages. At present, the development trends of marine diesel engine are low-speed, high-power energy-saving long-stroke. Such engine can reduce fuel consumption per unit of power output, can save fuel costs while also reduce ship emissions of greenhouse gases.

Ship main engine in running will dissipate a lot of heat, if heat is not effectively utilized, will greatly reduce fuel efficiency of the engine, and increase greenhouse gas emissions from ships. Ship main engine during operation produce large amounts of exhaust gas, taking about 30% of the heat, if this part of energy is comprehensively utilized, Energy saving items P_{eff} in EEDI calculation formula will increase, the total EEDI value will be reduced. For example, which is more popular topic now, to capture the thermal energy of the exhaust gas in some way and convert it into electrical energy, such as by thermoelectric conversion technology, transferred into the ship power station to be used, or this part of low-grade thermal energy can be converted into high-grade heat source to use directly. Such measures can play a role in energy conservation.

The most common way to use the ship heat is the exhaust gas boiler, hot steam can meet the daily needs of the ship. However, in such a way only a very small part of the waste heat is recovered. Therefore, in order to further improve the utilization of waste heat of the ship, the ship has begun to adopt waste heat recovery system of main engine, waste heat is utilized to generate electric power for the ship, so that can get the full use of waste heat energy. Engine waste heat recovery system is usually composed of a set of exhaust gas turbine plant and a steam turbine plant driven by steam boiler, the two turbines drive a separate generator to produce electricity for use in ship. The power generator be used as a daily generator to supply electric power, the main generator can be stopped when sailing. Such a waste heat recovery system not only improves the efficiency of ship fuel, reduces CO_2 emissions from ships, but also provides the ship backup power to ensure the stability of the ship operations.

To further improve the efficiency of waste heat recovery system, multiple sets of intelligent turbo charging system can be used in conjunction, which is combination use of intelligent electric supercharging system and smart exhaust turbo supercharging system. Typically, the gas flow and pressure of the exhaust turbocharger system will change basing on the actual power of the ship main engine. When the total pressure of exhaust gas turbocharger system is low, the smart electric supercharging system will be used to increase the pressure of the exhaust gas. When the exhaust gas pressure is high, indicating excessive amount of exhaust gas, then the smart electric supercharging system can utilize the excess gas pressure to generate electricity.

6.3.1.8 The use of new energy sources.

New energy means various energy sources different from the traditional energy sources (coal, oil, etc.), such as wind, solar, biomass, LNG and nuclear fusion energies. With these new energy sources, ship emissions factor (C_F) will reduce, the ship will obviously reduce carbon emissions. In today's energy depletion situation, development and utilization of new energy sources have been very necessary

6.3.2 Based on EEOI management

6.3.2.1 The use of shore power.

When ship is moored in the port, the dock electric power can be connected to supply the ship. Ship generator engine can stop working, this can reduce the total amount of fuel consumed in the formula (FC_i), thereby reduce EEOI value. IMO have proposed to the International Standardization Organization (ISO) and International Electrotechnical Commission (IEC) that new ports must be prepared to provide shore power equipment and technology. The world's first implementation of the shore power technology is in Los Angeles, the first port to use shore power technology to provide berthing electricity. When the ship docked at the Port of Los Angeles marina, diesel generators can shut down, shore power is delivered to the ship. When using shore power technology, the ship stopped the generators, this will stop emissions of greenhouse gases, then the air quality surrounding port area will be improved.

Use of the ship berthing of the ship when the onshore power supply, the measure first, technology is more mature; the second is the port and shipping companies in the technology and equipment facilities renovation has strong operational and easily can be realized It is an ideal alternative measures. However, the port and shipping companies have a one-time large investment and renovation of facilities and equipment. In addition, ports also need to further coordinate ship and China's current policy of power supply (electric power load, sales policy).

To promote the ship using shore power during in port, to encourage the implementation of port building ships using shore power equipment needed, and encourage ships to use shore power policy. The most important thing is, not because of too many ships using shore power to increase the burden on businesses (including shipping companies and port enterprises). For example, vessels need to increase the use of shore power port equipment, and increase the cost of the equipment should the government and the companies jointly pay; vessels using shore power can be properly implemented system of incentives during the promotion, and the vessels using shore power equipment included in the design specifications. Of course, even these two measures to achieve full, but also far enough, because the production of energy and port activities related to the consumption of contaminated urban environment not only in the harbor, or not primarily in the harbor, but outside the harbor. To avoid contamination in the port caused by internal, but also to solve the pollution problem in the outer harbor.

It is worth noting that the ship is not primarily environmental pollution in the harbor, but outside port, because the vessel during moored actuated merely auxiliary engine(generator), but before and after the ship into port, is included in the entrance channel and start sailing from shore when the engine is, the fuel consumption is much larger than the auxiliary. Undoubtedly, the ship during the environmental pollution is far greater than during the berthing, and always before the ship into port in offshore sailing into the river port is also possible through densely populated areas, therefore, to regulate the movement of vessels can not be limited to inner Harbor, should also include outside port, especially in coastal areas.

6.3.2.2 Using high-quality marine fuels and developing new fuels.
Currently the world's ship fuel used, fuel standard (carbon, sulfur) of a total of 19 species. Common ship fuel sulfur content select approximately 27 000ppm, any ship in order to save fuel costs and the use of heavy oil, heavy fuel oil sulfur content of up to 450 00ppm. From EEOI formula analysis, good quality and less fuel consumption converted into carbon, so EEOI value decreases. The US Port of Los Angeles, the Port of Oakland jointly implementing referred to as "pilot fuel of choice" program. Reducing gas emissions from ships 400t, reduce local air pollution. We recommend the use of new energy, hydrogen, LNG, solar energy, wind energy compared to conventional petroleum fuel is cleaner, more environmentally friendly. At present, these technologies have begun to promote the use of the ship.

6.3.2.3 Improving the level of organization and management of shipping. Management of the operation of ships reflected in transport rates above, such as reducing the load rate of the ship. EEOI formula M represents cargo shipping cargo capacity, the increase in cargo volume, decreases EEOI value. Shipping companies to promote large-scale, intensive direction, enhance the operation of the ship organizational efficiency, reduce greenhouse gas emissions from the management level.

6.3.2.4 Improving ship cargo load factor.

Owner combined to form large-scale, efficient logistics system. So that when the ship transporting goods can shorten the transport distance, EEOI formula denominator, there is a transportation distance (D), fully loaded transport distance increases, the index will reduce working ship. Make full use of computers, the Internet, to improve the load factor of the ship.

6.3.3 Other management measures.

6.3.3.1 Main engine installing ALPHA electronic cylinder oil lubricator.

There are two cylinder oil system transformation plan can be adopted: First, abandon the existing mechanical lubricator, to install ALPHA electronic lubricator; the other is mounting ALPHA lubricator, and using it together with existing mechanical lubricator.

Reconstruction marine main traditional mechanical cylinder oil lubricator, to install new electronic ALPHA lubricator, ALPHA use electronic injection timing, thus saving a large number of cylinder oil. The system provides 40 ~ 50 bar of hydraulic pressure to the lubricator from the pump station control unit controls the fuel injection valve to complete oiling. Currently, most use a relatively new mode of operation --ALPHAACC. In this operating mode, the fuel injection with the operating status (such as load and fuel amount) of the change, both optimum lubrication, and reduce the consumption of cylinder oil. After the installation of ALPHA electronic fuel injection device, by inspection, measurement, comparison and research, we can found a good oiling effect and comprehensive monitoring capabilities. What is more, ALPHA electronic fuel injection device plays a large role to reduce cylinder oil consumption, to keep clean piston and cylinder wall, to improve the quality of the engine smoke, and to reduce air pollution.

6.3.3.2 Using energy-efficient hull paint

Use energy-efficient hull paint to reduce the frictional resistance of the ship outside plate with sea water to some extent, to reduce the fuel consumption of the engine. International Paint antifouling paint series energy saving, energy-using fluoropolymer paint decontamination patented technology, provides a smooth, low-power paint surface, even if the organic matter cannot be adsorbed thereon, or is only loosely adsorbed and can be easily removed . After contact with water hull paint to reduce the coefficient of friction, reducing friction, reducing the scale of the engine throttle rack at the same speed of the engine, the load is reduced, while at the same sea conditions, and same speed of the engine, reducing the slip loss rate, speed is increasing and fuel consumption is reduced. Practice shows that the use of new energy-saving paint, ship slip loss rate is low, engine of fuel kept in a good range. Dry dock inspection shows that hull paint does not fall off, there are no parasite and other sea creatures on the surface, after high-pressure water rinsing it,it is shines as new, so achieved the desired energy savings.

CHAPTER 7:

Summary And Conclusions

The international community have paid attention to the question of air pollution from ships for a long time, with the number of ships increasing in maritime transport, air pollution from ships has reached very high point that cannot be ignored. Marine diesel engine harmful emissions in the exhaust gas is one of the main causes of air pollution, they have direct or indirect harmful impacts on human and environment. Diesel's status as main engine of the ship will not be a fundamental change in the future for a long time， we have to develop new technologies to reduce ship emissions. In the current level of technology, in order to obtain consistent emissions with the requirements of the Convention, we should try to use the combination of methods of measuring and calculating emissions, to strengthen the management of the ship, to use advanced technologies, to improve or install anti-pollution equipments.

MARPOL Convention Annex VI reflects the human conscious awareness of environmental issues in a positive meaning. The Convention Annex VI specifically limited SOx and NOx emissions in marine diesel engine exhaust gas, the Convention's major point is that it accurately and effectively determined the standards of emissions. In addition, many countries in Europe and other regions set up emission control area to control the exhaust gas, China should also consider the establishment of ECA.

Intelligent diesel engine performs perfectly on gas emission; for ordinary engines, engineers should improve management or adopt relevant equipments to reduce harmful emissions.

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