Compliance with international emission regulations: Reducing the air pollution from merchant vessels

Bin Lin\textsuperscript{a}, Cherno-Yuan Lin\textsuperscript{b, *}

\textsuperscript{a}Merchant Marine Department, National Taiwan Ocean University, Keelung, Taiwan
\textsuperscript{b}Marine Engineering Department, National Taiwan Ocean University, Keelung 20224, Taiwan

Received 20 November 2004; accepted 26 January 2005

Abstract

In September 1997, the International Maritime Organization (IMO) adopted an international convention protocol to reduce air pollution from ships, in order to achieve sustainable maritime development. This protocol has been approved by 15 member countries and will be enforced in May 2005. Pollutants emitted from ships, such as nitrogen oxides, volatile organic compounds, sulfur oxides, etc. will be regulated by this convention through ship inspections and issuance of certificates. Ships belonging to maritime countries such as Taiwan, which sail around the world and berth in commercial ports, must obey this convention. This study has investigated possible strategies, which may be adopted by maritime countries to conform to this IMO convention in order to reduce the air pollution from ships. A sea-going ship must prepare EIAPP and IAPP certificates for inspection by port-state-control officials, when the ship is anchored at a maritime port. These port-state-control officials may also require the continuous detection and sampling of a ship’s emissions, while it is berthed at the port. Legislative support is necessary for successful implementation of these safeguards. It is suggested, therefore, that the administration of both navigational and environmental protection, in maritime countries, cooperate in the revision of relevant federal laws, to implement the provisions of the MARPOL 73/78/97 convention; in this way, the air pollution from ships can be effectively controlled. Installation of advanced detection equipment can effectively detect any ships’ violations of air pollution regulations. The Harbor Affairs’ Bureau should also establish a database of air pollution inspections for ships berthed within their harbor, requiring that ships’ equipment comply with the requirements of the MARPOL convention, for the reduction of air pollution.

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Keywords: Air pollution; Maritime country; MARPOL convention; IMO

1. Introduction

Promoting maritime traffic safety, while protecting the ocean environment, are important concerns in the global maritime field \cite{1}. Because more than 50\% of a ship’s operating expense is generally the cost of fuel oil, most of the world’s ship-owners use degraded residue heavy fuel oil in marine power plants, for fuel economy \cite{2}. These degraded heavy oils, however, contain high levels of asphalt, carbon residues, sulfur (which may amount to as high as 5 wt.\%) and metallic compounds, as well as having properties of high viscosity (up to 700 cst), low cetane numbers and low volatility \cite{3,4}. During the burning process in marine diesel engines, boilers, and incinerators, these fuels can produce significant amounts of black smoke, particulate matter, nitrogen oxides (NO\textsubscript{X}), unburned hydrocarbons (UHC), sulfur oxides (SO\textsubscript{X}), carbon monoxide (CO), carbon dioxide (CO\textsubscript{2}), etc. These pollutants, which may deplete the ozone layer, enhance the green-house effect, and produce acid rain are detrimental to the health of living beings and have attracted a great deal of public concern.
There are great differences between marine vessels and land vehicles, in respect to the fuel used and the size and horsepower of the engines. The emission control requirements for road vehicles are not suitable for marine vessels; thus, the emission control strategies and pollution prevention technologies applicable to ships must be given special consideration to effectively reduce the air pollution from ships [5].

The International Maritime Organization (IMO) is responsible for drafting various international conventions related to maritime affairs, with regulations covering navigation, marine rescue, and ships’ structural and equipment requirements. There are currently more than 150 countries belonging to the IMO, which is the most powerful international organization in the field of ocean shipping. The objectives of the IMO include sustaining safety in sea transportation, promoting navigational efficiency, and protecting the ocean environment. The Marine Environment Pollution Committee (MEPC), which is a sub-organization of the IMO, is specifically responsible for drawing up relevant regulations to prevent ships from polluting the ocean and the atmosphere [6].

With the rapid development of international commerce, the number of global shipping vessels has also increased. Pollution from these ships is of great concern, particularly, oil spills due to casualties at sea. To address this pollution, the IMO amended the 1973 International Convention for the Prevention of Pollution from Ships protocol in 1978, which is referred to as MARPOL 73/78. This protocol regulates the draining standards for used oil, sewage, and waste materials. Air polluting exhaust, from marine power plants, has also become a cause for concern within the international community in recent years.

The MEPC began examining ships’ air pollution in 1988. Consequently, a new air pollution addendum to MARPOL 73/78 was adopted in 1997, which is now referred to as MARPOL 73/78/97 [7]. These regulations to prevent ships’ air pollution include the following [7,8]: (1) emission standards for nitrogen oxides according to the power output of marine diesel engines and required installation of exhaust gas cleaning systems to reduce NOX emissions; (2) limits in sulfur content of fuel oil used in ships to reduce SOX emissions and requirements for exhaust gas cleaning systems or technologies to limit SOX emissions to 6.0 g SOX/kWh or less; (3) provision for vapor collection systems, or other vapor emission control systems to reduce the emissions of volatile organic compounds (VOCs); (4) Requirement for shipboard incinerators; (5) restricted use of CFC refrigerants, Halon, and other ozone-depleting substances.

The MARPOL 73/78/97 international convention will be enforced in May 2005 after being approved by the fifteenth member country in May 2004; the total tonnage of merchant vessels, owned by these 15 countries, now reaches beyond 50% of global tonnage.

Precursors to the formation of NOX during the combustion process are nitrogen and oxygen. These two components comprise 99% of engine intake air. However, a small percentage of nitrogen is oxidized to form various types of NOX. The production of NOX is primarily a function of combustion temperature and, if present, organic nitrogen in the fuel. It is also a function of the time, in which the nitrogen and excess oxygen are exposed to high gas temperatures, inside the combustion chamber of a diesel engine during the combustion process. This implies that the higher the gas burning temperature, the greater the amount of NOX formation.

A low speed engine, in general, tends to have more NOX formation than a high-speed engine. NOX is mainly composed of NO and NO2 and has an adverse effect on the global environment, causing such things as acid rain, destruction of the ozone layer and adverse health effects.

SOX emissions from diesel engines also pollute the atmosphere. The accumulation of sulfates on the earth’s surface may cause acidification, resulting in the deterioration of the ecology and human health. The amount of SOX emissions from a diesel engine, depends primarily on the sulfur content of the fuel oil used. The main method of controlling SOX emissions is to reduce the fuel oil’s sulfur content. Two other ways are to install an exhaust gas cleaning system and to add a biochemical additive to the fuel oil.

Some maritime countries have begun adopting suitable strategies to meet the requirements of the MARPOL 73/78/97 convention. An ocean-going ship may be inspected, and even punished, if the convention has been violated during its stay in the harbor of another country. It is important, therefore, for maritime countries to revise or draft relevant laws or regulations to meet the MARPOL 73/78/97 requirements; the ship owners of these countries must also be required to bring their equipment up to standard. Moreover, port-state-control officers may institute more stringent inspections of ships’ gas exhaust systems. The primary purpose of this study was to discuss revisions to the relevant regulations and laws, which control air pollution from ships, for maritime countries such as Taiwan. We have also evaluated the available current technology and equipment for the reduction of air pollution from ships.

2. Research methods

In order to draft suitable measures to reduce air pollution from ships, the authors visited major commercial harbors in Taiwan, including Keelung, Taitung, Kaohsiung, Hualien, and So-Au ports, to talk with the directors and inspectors of the Environmental Protection Departments of these ports. The collected comments and opinions from these officials included: the nationalities, numbers and exhaust gas condition of
ships at anchor; records dealing with air pollution and problems in executing exhaust gas inspections; and onboard equipment and certificates of ships complying with the MARPOL 73/78/97 convention. The authors also visited the captains and chief engineers of major maritime companies in Taiwan such as Yangming, Evergreen, Wan-Hai, etc. to collect relevant information and opinions, which included: the total number of ships, tonnage, marine diesel engine models, exhaust gas cleaning equipment used, fuel quality, amending strategies conforming to the MARPOL 73/78/97 convention, and the methods used by Taiwanese harbor officials when inspecting exhaust gas emissions.

Subsequent to this information gathering, a seminar was held to communicate strategies and possible amendments to laws or regulations related to the prevention of air pollution from ships. Officials from the Environmental Protection Administration, the Ministry of Transportation and Communications, major merchant harbor bureaus, the technical staff of major maritime companies, university scholars and professors, and representatives from research institutes, attended this seminar.

3. Statistical data

Taiwan is located in the middle of the Western Pacific and is a pivotal point for shipping lines crossing the Pacific Ocean. Due to lack of sufficient natural resources, Taiwan’s economy has grown by means of international trade, importing raw materials and exporting industrial products. Maritime transportation, therefore, plays an important role in Taiwan’s economic development, with merchant vessels carrying cargoes around the world. Ports in Taiwan can provide direct shipping services to America and south-east Asia, while extending to European countries and other parts of the world. In recent years, with the commencement of local and international trade markets in China, Western Pacific shipping services have been expanded to include a few Chinese ports. The costs for transporting cargoes from Taiwan to the ports of south-east China, including Shanghai, Linpo, Xiamen, and Fuchou ports, are significantly lower than to other areas in the Far East. From the maritime trade perspective, Taiwan can have a promising geographical advantage in the global shipping market, if adequate measures are taken.

During the 20 years from 1984–2003, Taiwan’s rapid economic growth was accompanied with a steady increase in marine traffic. The number of ships calling into Taiwan’s ports and passing through the Taiwan Strait has increased significantly. Every port in Taiwan has different performance records, depending on geographic location and operational style. According to an official report [9], 37,976 merchant vessels, along with 560.5 million gross tonnages, visited Taiwan’s major international commercial harbors in 2003; the volume of cargo handled reached 237.5 million tons, including 175.7 million tons of import cargoes and 61.8 million tons of export cargoes. Compared with 2002, the growth rate of the number of ships berthed, the gross tonnage and volume of cargo handled, in 2003, were +3.35%, +2.22% and −3.87%, respectively.

In 2003, the total number of ships visiting the three major ports in Taiwan, Kaohsiung, Keelung, and Taichung was 33,749, or about 1.35 times higher than in 1994. Kaohsiung port, the largest port in Taiwan, accounted for 49.71% of the total number of ships, 61.23% of the total gross tonnage shipped and 52.97% of the total volume of cargoes handled in Taiwan, in 2003. During the past 20 years, from 1984–2003, the number of the ships calling into the three major harbors not only increased, but also shifted towards more containers.

4. Measures currently in place to prevent air pollution

The current regulations controlling air pollution from ships in Taiwan, are based on the provisions of Article 8 of the “Exhaust Gas Standards of Air Pollutants from Mobile Vehicles” [10]. The provisions were amended and came into force in 1999 by order of the Environmental Protection Administration (EPA), Taiwan. The major contents of the provisions are as follows:

“The emission standards of particle pollutants from locomotives and ships shall comply with the values stated in the following:

For ships: the visual smoke opacity shall be less than 40%, equivalent to Lingoman no. 2, for main propulsion power of 3,000 kW and within 20 s from starting, but for main propulsion power less than 3,000 kW, within 10 s from starting.”

This enforcement method, for the above emission standards, is in accordance with “The interpretation of the Air Pollution Prevention Law” [11], which was adopted by the EPA in Taiwan. A harbor authority inspector carries out the inspection of exhaust gas from ships; the details of enforcement are described as follows:

“An inspection, either by visual judgment or instruments, of air pollutants in public spaces, from automobiles, shall be carried out by qualified and properly trained personnel holding a certificate of competence. The EPA, Taiwan, shall establish the above training methods. If any emission of air pollutants from a ship is over the stated standards, the EPA shall fine the ship”

In view of the above-mentioned regulations, the EPA in Taiwan are responsible for enforcing the exhaust gas pollution standards for ships, adopting the same emission standards of black smoke opacity as that
The emissions from the main marine diesel engines of seagoing vessels must comply with the regulations of the MARPOL 73/78/97 convention to prevent extraordinary air pollution, especially for NO\textsubscript{X} and SO\textsubscript{X} pollutants. This convention also established mandatory procedures for the testing, surveying and certifying of ships’ main marine diesel engines, for the purpose of emission controls. These provisions stated in this convention also enable designers, manufacturers, and ship-owners to ensure that their marine diesel engines conform to the emission control standards.

Thus, prior to installation, every marine diesel engine, in order to meet the applicable NO\textsubscript{X} emission standards, should have its NO\textsubscript{X} emissions measured on a test rig, in accordance with the specified MARPOL procedures. An Engine International Air Pollution Prevention (EIAPP) certificate will then be issued for the engine patent, to accompany every engine under this certification, throughout its life. After an engine has been installed on a ship, and the overall NO\textsubscript{X} emission performance verified as being within the required limits, an International Air Pollution Prevention (IAPP) certificate will be issued to that ship.

The Environmental Protection Department of every port in Taiwan is responsible for detecting air pollution from ships, especially NO\textsubscript{X} and SO\textsubscript{X} emissions, when ships are berthed in their ports. A ship berthed in a port will be subject to inspection by a port-state-control inspector, if the ship emits substances in violation of the MARPOL 73/78/97 regulations. It is impossible to detect NO\textsubscript{X} emissions from ships’ funnels; inspectors will, therefore, principally inspect the IAPP certificate and other documents on board the ship, related to the prevention of air pollution. If this vessel is found to have violated the MARPOL convention, a written report will be forwarded to the official authority, so that appropriate action can be taken.

As for the control of SO\textsubscript{X} emissions from vessels, the sulfur content of any fuel oil, used on board ship, must not exceed 4.5% on mass base. Also, when ships are within special SO\textsubscript{X} emission control areas, such as in the Baltic Sea or the England Channel, the sulfur content of any fuel oil, used on board ship, must not exceed 1.5% on mass base, or must have an exhaust gas cleaning system installed, to reduce the total SO\textsubscript{X} emissions to under 6.0 SO\textsubscript{X} g/kWh. Port inspectors may also need to collect fuel oil samples to analyze the sulfur content, if necessary.

Furthermore, some Harbor Affairs’ Bureaus in Taiwan have installed NO\textsubscript{X} and SO\textsubscript{X} sensors, to detect air quality around their port areas. However, it has been suggested that the present domestic regulations, regarding air pollution from ships, be amended. To comply with international requirements, the navigational and environmental protection maritime authorities must cooperate to amend relevant domestic laws and
regulations to meet the Annex VI provisions of MARPOL 73/78/97.

In addition, a harbor’s environmental protection authorities and those of its neighboring city, may coordinate the monitoring and detection duties for air pollution from ships by implementing advanced detection equipment. Once an air pollution violation has occurred, a penalty must be imposed on the ship’s master immediately. Collection of evidence for ships’ emission violations is generally difficult; when an inspector arrives to take photos of emissions, time may have lapsed and the evidence no longer obvious. Use of infrared cameras, or other advanced video cameras fixed near piers, may be effective for detecting pollution in such cases.

We also suggest that each Harbor Affairs’ Bureau should increase the number of inspectors and draw up a long-term plan, so that all inspectors are competent to control ships’ air pollution, according to the MARPOL regulations. Another method of persuading ships to reduce pollution emissions would be to establish a ships’ database of air pollution inspections. In this way, ships with records of air pollution violations would show as having more frequent inspections, thus reducing extraordinary air pollution.

6. Conclusions

The International Maritime Organization (IMO) adopted the MARPOL 73/78/97 convention to resolve the increasingly severe environmental air pollution from ships. The MARPOL convention will come into force in May 2005. The air-pollutants emitted from ships, particularly from ocean-going vessels, can be diffused over wide areas of the world. Diesel engines, because of their advantages in fuel economy, rigid structure, high thermal efficiency and high reliability, are the major power sources of marine power plants. The emissions from these marine diesel engines, such as nitrogen oxides, sulfur oxides and particulate matter are detrimental to both the global environment and living beings. The MARPOL 73/78/97 convention will be implemented to regulate emission standards, especially for nitrogen oxides and for diesel engines with a horsepower output above 130 kW.

Pollutants, emitted from marine diesel engines, such as SO\textsubscript{X}, PM, NO\textsubscript{X}, HC contribute largely to atmospheric air pollution, particularly in neighborhoods surrounding harbor areas. Hence, to avoid air pollution from exhaust gases, merchant ships must be required to install appropriate pollution reduction equipment to reduce emissions, as required by the MARPOL convention. A sea-going ship should also be required to display EIAPP and IAPP certificates, for inspection by port-state-control officials, when the ship is anchored at a port. Continuous detection and sampling, by port-state-control officials, may also be required, during the time a ship is berthed. Sufficient legislative support is another necessary step towards successfully reducing the air pollution from ships. The administrations of both navigational and environmental protection departments, in maritime countries, such as Taiwan, should cooperate in revising relevant federal laws, according to the provisions of the MARPOL 73/78/97 convention, in order to effectively control the air pollution from ships. Databases, for air pollution inspections of ships berthing at commercial harbors, may assist in highlighting those violating pollution standards. Advanced detection equipment may be installed, within harbor regions, for effective detection of air pollution violations. Compliance with the requirements of the MARPOL convention must be mandatory, for ships’ owners, in order to reduce the pernicious exhaust gases polluting the environment.

Acknowledgements

We are grateful for the financial support supplied by the National Science Council, Taiwan, ROC, under Contract no. NSC 88-EPA-Z-019-001. The authors also thank Mr. C. S. Chiu for his valuable suggestions during the preparation of this manuscript.

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