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Air pollution from marine diesel engines and its application to MET [maritime education and training]

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AIR POLLUTION FROM MARINE DIESEL ENGINES AND ITS APPLICATION TO MET

By

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DECLARATION

I certify that all the material in this dissertation 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 dissertation reflect my own personal views, and are not necessarily endorsed by the University.

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ABSTRACT

Title of Dissertation: **Air Pollution from Marine Diesel Engines and Its Application to MET**

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Emissions from marine diesel engines, mainly nitrogen oxides (NOx) and sulphur oxides (SOx), can cause acid rain, global warming, and also have direct influence on human lives due to pollution of air.

Firstly, the background information of air pollution from ships is introduced which includes the kinds of emissions from marine diesel engines, problems caused by emissions, and emissions level from ships comparing with other kinds of sources. In the development of engineering technology, the vary methods for controlling the NOx, SOx are discussed. The concentration is put on the discussion of advantages, disadvantages regarding the cost, maintenance, efficiency, reduction level and consequences analysis relating to engine-related methods, fuel-related methods and aftertreatment methods.

Secondly, international legislation concerning the emission control from marine diesel engines by New Annex VI of MARPOL 73/78 is examined. Also, the major impacts upon fuel oil industry, engine builder, and shipping company were analysed regarding the SOx contents in the fuel oil, International Air Pollution Prevention (IAPP) Certificate, and exhaust gas monitoring system capable of recording and storing data.

To assist maritime academies and their teaching staff in organising and introducing courses for this new requirement of air pollution from ships, a new programme for

MET which consists of teaching objectives, outline, and detailed teaching syllabus has been developed. This programme can be used as separate short course, or as part of a coherence course connected to relevant IMO Module Course.

Keywords: Air Pollution; Emissions; Ships; MARPOL Convention; MET; Educational Training Programme.

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LIST OF ABBREVIATION

^{o}CA	Degree Crank Angle
CO	Carbon Monoxide
CO_2	Carbon Dioxide
EGR	Exhaust Gas Recirculation
HC	Hydrocarbon
HFO	Heavy Fuel Oil
IAPPC	International Air Pollution Prevention Certificate
IMO	International Maritime Organisation
LR	Lloyd's Register
MARPOL	International Convention for the Prevention of Pollution from Ships
MEPC	Marine Environment Protection Committee
MET	Maritime Education and Training
NCR	Non Catalytic Reduction
N_2	Nitrogen
N_2O	Dinitrogen Oxide
NO_X	Nitrogen Oxide
OECD	Organisation for Economic Co-operation and Development
PM	Particulate Matter
SCR	Selective Catalytic Temperature
SFOC	Specific Fuel Oil Consumption
SO_X	Sulphur Oxide
TDC	Top Dead Centre
T_{max}	Peak Combustion Temperature

Chapter 1
Introduction

The International Maritime Organisation (IMO), the United Nations specialised agency with responsibility for the safety of shipping and the protection of the marine environment, has adopted new measures which will reduce air pollution from ships, in the form of a new Annex VI to the International Convention for the Prevention of Pollution from Ships, 1973, as modified by the protocol of 1978 (MARPOL 73/78).

When the Annex VI enters into force, it will set limits on sulphur oxide (SOx) and nitrogen oxide (NOx) emissions from marine diesel engines and prohibit deliberate emissions of ozone depleting substances.

What will the impacts of this new Annex VI be on the different maritime parties? What is the present level concerning the content of NOx and SOx in the marine exhaust emissions and how best to comply with this new requirement? The basic answer is to educate and train of MET students and marine engineers at maritime academies.

1.1 Background of the study

Emissions from cargo ships powered by diesel engines are among the world's highest polluting combustion sources per ton of fuel consumed. According to the facts, world wide ship nitrogen emissions are equal to nearly half of the total emissions from the United States, 74% of emissions from the organisation for economic co-operation and development (OECD) Europe and 190% of those from Germany. Concerning the sulphur oxide, ship sulphur emissions equal to 43% of the total sulphur emissions from the United States, 53% of emissions from OECD Europe and 178% of those from Germany.

The concentration of contaminants such as sulphur, ash asphaltenes and metals in the residuals (or marine fuels) has increased over recent decades, especially since the 1973 fuel crisis when residual fuels were starting to be made using secondary refining technologies to extract the maximum quantity of refined products (distillates) from crude oil. 70%-80% of commercial shippers prefer to use the cheaper residual fuels.

Air pollution form ships was first brought to the attention of the maritime community by Norway in the late 1980's. By 1990 the subject was on the agenda of the IMO's Marine Environment Protection Committee (MEPC). A resolution was subsequently adopted to develop a new Annex to MARPOL 73/78 on air pollution from ships.

For many years, Lloyd's Register (LR) has undertaken a marine exhaust emissions research programme. A five-year programme of research, in which LR established emission measurement procedures for use on board ship, completed a demanding programme of shipboard measurement trials, formulated a series of emission factors for major exhaust emissions components and developed a methodology for translating generalised emission factors into overall estimates for both local and regional areas.

1.2 The aim of the study

As a teacher, I have worked in the Marine Engineering Course in Dalian Maritime University for 10 years. The students of this course can be awarded not only a BSc degree but also a 3rd engineer certificate of competence and can work on board international ships or domestic ships. So far, there is nothing to train or teach the students concerning the emission, and its control, from marine diesel engines.

Since the Annex VI of 1997 Protocol of MARPOL 73/78 dealing with air pollution from ships is not yet into force, although it was adopted last September, it is not a mandatory requirement. However there is no doubt that it will enter into force in the near future, and also it could be inserted into model course. It is useful and necessary to develop the new educational training programme relating to diesel engine emissions for MET institutes.

In this paper, firstly, the background information of air pollution from ships is introduced which includes the kinds of emissions from marine diesel engines, problems caused by emissions, and emission levels from ships compared with other kinds of sources. In the development of engineering technology, the varying methods for controlling the NOx, SOx are discussed. The concentration is put on the discussion of advantages, disadvantages regarding the cost, maintenance, efficiency, reduction level and consequence analysis relating to engine-related methods, fuel-related methods and aftertreatment methods.

Secondly, international legislation concerning the emission control from marine diesel engines by the new Annex VI of MARPOL 73/78 is examined. Also, the major impacts upon the fuel oil industry, engine builder, and shipping company are analysed regarding the SOx contents in the fuel oil, International Air Pollution Prevention (IAPP) Certificate, and exhaust gas monitoring system capable of recording and storing data.

To assist maritime academies and their teaching staff in organising and introducing courses for this new requirement of air pollution from ships, a new programme for

MET, which consists of teaching objectives, outline, and detailed teaching syllabus, has been developed. This programme can be used as a separate intensive short training course, or as part of a coherence course connected to the relevant IMO Model Course.

Chapter 2

Background to Air Pollution From Ships

A ship is in many ways different from other means of transportation. In addition to transport, various types of cargo or passengers, the ship also has to house accommodation and other necessary facilities for the crew. In many cases it has to be able to handle various types of goods in the harbours.

The ship should maintain its supply of energy during very varying conditions. The main engine, auxiliary engine and boiler, which burn fuel oil or coal to supply energy to the ships, cause emissions to the air. The low-speed two-stroke diesel engines, primarily used for propulsion as main engine, is found on large ships. The medium-speed four-stroke engines, used to generate electricity to run plants onboard, such as pumps and hydraulics, are used as auxiliary engines on large ships or used on smaller ships and ferries as the main engine.

For MET students and marine engineers to best understand the air pollution from ships, the emissions from ships and problems caused by them will be presented. The evaluation of air pollution from ships will be discussed in the last part of this chapter.

2.1 Air Pollution Caused by Emissions

For more than two decades, acid deposition, photochemical oxidants and other air-pollution problems have been a topic of scientific and political concern in the world.

Ships equipped with propulsion diesel engines burn heavy fuel oil with a high sulphur content and thus are a significant source of both NOx and SOx emissions. Because of the unfavourable effect of such emissions on the environment, the problems caused by them are mainly acidification, photochemical oxidants and global warming. The contents of emission, contributing to environmental problems are listed in table 2-1.

Table 2-1. Contents of Emissions Contributing to Environmental Problems

Problems	Acidification	Photochemical Oxidants	Global Warming
Gases	NOx, SOx	NOx, HC	CO_2, CO, N_2O

"Source: Danjoh, Y , 1993, page 8"

In this table, HC is hydrocarbon, CO_2 is carbon dioxide, CO is carbon monoxide, N_2O is dinitrogen oxide.

2.1.1 Acidification

The main chemicals that create acid rain are SO_X and NO_X. Acid rain usually forms high in the clouds where SO_2 and NO_2 react with water, oxygen and oxidants. This mixture forms a mild solution, sulphuric acid and nitric acid which are described by the following equations:

$$NO_2 + H_2O = H_2NO_3 \qquad (2\text{-}1)$$

$$2SO_2 + O_2 = 2SO_3 \qquad (2\text{-}2)$$

$$SO_3 + H_2O = H_2SO_4 \qquad (2\text{-}3)$$

About half of the acidity in the atmosphere falls back to earth through dry deposition as gases and particles. In some instances, these gases and particles can eat away the things on which they settle.

2.1.2 Photochemical Oxidants

Hydrocarbons and nitrogen dioxides act together under the influence of sunlight, forming photochemical oxidants. Most important of these oxidants is ozone, which causes damage to forests and vegetation.

2.1.3 Global Warming

Raised concentrations of CO_2, CO, N_2O disturb the thermic balance of the earth by re-reflecting the thermic radiation of the earth. This effect is called "greenhouse" which can cause global warming by about 5-6 percent of the expected temperature rise. At present, CO_2 from the burning of fossil fuel amounts to almost three times the quantity that plants of the planet are able to consume.

Apart from damage from acidification and photochemical oxidants, the environmental is affected by several types of direct gaseous damage. Nitrogen oxides damage trees and crops directly through leaves and pine needles, and may affect the health of sensitive groups of the pollution causing respiratory and other problems.

2.2 Emissions from Marine Diesel Engines

Emissions of sulphur and nitrogen oxides by diesel ships are extensive. In the diesel process, the combustion temperature is brought to very high levels, resulting in very low carbon monoxide. The emissions of carbon dioxide are very competitive due to the good thermal efficiency.

The disadvantage of the high temperature is the formation of nitrogen oxides. The amount of NOx which is formed in the cylinder is dependent on many parameters, the most important facts being the high temperature and pressure. But it is also influenced by the duration and the distribution of so-called hot spots in the combustion space.

About 80 to 90% of NOx is produced from the combustion of nitrogen contained in the intake air. The rest is contributed from the nitrogen contained in the fuel. The major component of NOx is NO which accounts for 80 to 90% of total NOx formed from the combustion whilst the other 10 to 20% is NO_2. NO will be further oxidised to NO_2 in the exhaust system and also in the atmosphere later.

SOx is entirely the product of combustion of sulphur contained in the fuel oil. This means that SOx in the exhausted emissions is affected by the quality of bunker fuel oil, not by the combustion process. SOx normally consists of mostly SO_2 and a small proportion of SO_3 (which is about 5%).

Hydrocarbons are formed, partly as a consequence of incomplete fuel combustion, partly from radical reactions in the combustion process. Particulate matter (PM) in the flue gases mainly consists of unburned carbon and ashes, but also contains tracer metals. In general the particles are small (90 per cent being < 1 micro) and are able to penetrate the finest cavities of the lungs and cause health problems. Carbon monoxide forms as a consequence of incomplete combustion. Table 2-2 gives the typical chemical compositions of exhaust gas from a modern low-speed diesel engine using normal marine fuel oil. Table 2-3 shows the specific emissions from marine engines with two-stroke and four-stroke.

Table 2-2. Typical Exhaust Composition for a Modern Low Speed Diesel Engines

O_2, %	N_2, %	CO_2, %	H_2O, %	NOx, ppm	SOx, ppm	CO, ppm	HC, ppm	PM, mg/m^3
14.0	76.2	4.5	5.1	1500	600	60	180	120

"Source: Zhou, 1993, page 2"

Table 2-3. Specific Emissions From Marine Engines with Two-stroke and Four-stroke

Engine Type	Load	NOx	CO	CO_2	HC	PM
Two-stroke	80%	17.7	0.2	600	0.8	0.9
	20%	17.1	0.6	1000	1.3	0.9
Four-stroke	80%	14.0	1.0	620	0.2	0.4
	20%	21.0	2.2	1120	0.4	0.6

"Source: Alexanderssor, 1993, page 93".

The Unit of emissions in this table is g/kWh.

2.3 Evaluation of Emissions from Ships

Emissions from land sources, including factories and motor vehicles, have been subjected to regulations for many years. However, ships which travel great distances have escaped emissions restriction, probably because the direct effect of these emissions on the lives of individuals is harder to perceive than that from diesel vehicles and power stations on land. So, the emissions from ships are not so clear as those from land source.

A report submitted by the Norway representative at the 29th session of the International Maritime Organisation (IMO) Marine Environment Protection Committee (MEPC) stated that ships release about 7% of the world's total NOx emissions and some 4% of the world's total SOx emissions.

According to another source, global emissions from ships were 4.58 million tons of SOx and 5.09 million tons of NOx world wide in 1993. Research conducted by the Ministry of Transport and Communications, Norway, found that Norwegian sea transport generated 20% of NOx of total emissions in 1996-1997 (Norwegian

Shipowners' Association, 1998, p1). The following are the tables showing the emissions from ships.

Table 2-4 Exhaust Gas Emissions from the World Fleet

Exhaust gas emissions from the world fleet	SO_2	NOx	CO	HC	CO_2
Global emissions from ships (mill. tons)	4.58	5.09	0.12	0.22	272
% of total global emissions	4.00	6.90	0.06	0.38	1.39

"Source: Norwegian Shipowners' Association, 1998, p1"

Table 2-5. Norwegian Domestic Emissions of Total Emissions

Norwegian domestic emissions of total emissions	CO_2	NOx	SO_2
Transport, total	32.2	57.1	11.8
Air transport	4.0	1.9	
Road transport	22.4	34.5	
Sea transport	5.6	20.0	

"Source: Norwegian Shipowners' Association, 1998, p1"

The amount of SOx in exhaust gases is directly dependent on the sulphur content of the fuel. Ships' engines are robust and effective engines which make it possible to utilise crude oil residues after the refining of petrol and diesel. There is a potential for improvement even in this area.

The Scandinavians have been rightly conscious of the harm being done to their forests by acid rain. The oil companies have defended the burning of high sulphur oil out at sea by saying that the sulphur products are immediately and safely re-absorbed.

Chapter 3

Development of Engineering Technology

In view of the growing public concern for the environment, the present decade is likely to become devoted to development which targets a reduction of the environmental impact of the engines. This development has to go hand in hand with further improvement of the reliability of the engines and the maintenance of the greatest possible engine efficiency.

Extremely low NOx emissions have been demonstrated in long-term service with many kinds of marine engines (MAN B&W Diesel A/S, 1993). A group of leading diesel engine manufacturers have put more attention on developing the next generation of lightweight, high thermal efficiency engines with lower NOx emissions (Takita, 1997).

For the need of developing the MET program relating to the air pollution and also for MET students and marine officers to well understand the emission reduction, an overview of the potential for emission reduction by different methods will be given in this chapter.

3.1 General Aspects of Emission Reduction

It is very important to have a variety of methods available for emission reduction, so shipping companies and marine engineers can choose the optimum methods under the given circumstances. Most likely, different ship types and engines will call for different ways to meet the requirements in the most cost-effective way without damaging engine reliability.

The factors which affect the emissions from a diesel engine are so many and sometimes not certain. Due to NOx, SOx and PM being the primary causes of air pollution from marine diesel engines, the analysis of how the fuel oil, lubricate oil and engine parameters affect the emissions is essential.

In diesel engines, nitrogen and oxygen are thermodynamically synthesised in the cylinder into NOx. The sources of the NOx are two streams: oxidation of the molecular nitrogen (N_2) of the combustion air at high temperatures (thermal NOx) and oxidation of nitrogen compounds in fuel (fuel NOx).

- **Thermal NOx**

The formation of thermal NOx depends on the concentration of the reactants nitrogen and oxygen, the temperature and the residence time. The process of NOx formation includes hundreds of reactions. The main point however is that the higher the temperature and the longer the residence time at higher temperature, the more thermal NOx will be formed.

As long as the NO is small, the formation speed may approximately be calculated by the next formula (Alexandersson, 1993, p182):

$$\frac{d(NO)}{dt} = \frac{A \times P \times (r-1) \times e^{(-\frac{B}{T})}}{r} \qquad (3\text{-}1)$$

Where: $\frac{d(NO)}{dt}$ Formation speed for NO

P Pressure (absolute, bar)

r	Air surplus
T	Temperature (absolute, K)
A, B	Constants

From the above equation, it can be easily found that $\frac{d(NO)}{dt}$ increases with the increasing of P, T. Table 3-1 serves as a further illustration of formation speed of NO within 1700K and 2900K. According to this table, the following diagram can be drawn. It can be seen that a temperature increase from 2300K to 2900K leads to a hundred fold increase in formation speed. All measures that reduce the magnitude and duration of high temperature peaks in the combustion chamber can reduce NOx formation.

Table 3-1 Formation Speed for NO

Pressure (bar)	r	Temperature (K)					
		1700	1850	2000	2300	2600	2900
1	1:10	0.0763	1.1765	10.87	344.8	4761.9	34482
	1:25	0.1965	2.5	23.25	714.28	10000	71428
	1:50	0.3922	5.0	40.0	1219.5	16667	125000
10	1:10	0.7633	11.76	108.7	3448.3	47619	344828
	1:25	1.9646	25.0	232.5	714.28	100000	714280
	1:50	3.9216	50.0	400.0	12195.1	166667	1250000

"Source: Alexandersson, 1993, page182"

Fig. 3-1a Formation Speed for NO (P=1 bar)

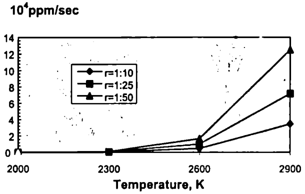
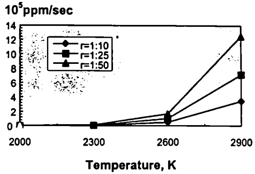


Fig. 3-1b Formaiton Speed for NO (P=10 bar)



- **Fuel NOx**

Nitrogen in organic compounds in the fuel tends to increase NOx emissions because nitrogen atoms released during combustion of the fuel enhance the reaction:

$$N+O_2 = NO+O \qquad (3\text{-}2)$$

thereby forming more NO. With a high content of nitrogen compounds (certain heavy fuels), about 10-20% more NOx will contribute to the total amount of emission. The main reason for the high fuel NOx is the effect of large amounts of inert compounds in the fuel (MAN B&W A/B, 1993).

As mentioned in the last chapter, the fuel sulphur content has a straight forward influence on SOx emissions: practically all fuel sulphur is emitted with the exhaust gases as SOx, mostly as SO_2 and a little as SO_3. So the SOx yield depends on fuel characteristics not on engine dimensions or engine parameters. Reduction of SOx emissions, therefore requires corporations among oil companies and all other related parties apart from engine builders.

3.2 The Strategies for Reducing NOx Emissions from Ships

As discussed above, it is the emissions of NOx, and also to a certain extent SOx, which constitute the main environmental problems caused by ships. So, the reduction of both NOx and SOx will be discussed in the following sections respectively.

There are a number of ways to reduce NOx emissions from marine diesel engines. They can be classified in three categories:

- **Engine-related Philosophy**

The best NOx reduction philosophy is of course to prevent the formation of NOx in the cylinder. This can be done by controlling the combustion, i.e., in principal, to reduce the peak combustion temperature and pressure. The main characteristics of the combustion process with lowing of NOx are:

1. Fuel Injection
2. Water Injection
3. Exhaust Gas Recirculation

- **Fuel-related Philosophy**

Through affecting or changing the fuel in such a way that emissions are reduced, this may be achieved, for example, by:

1. Changing the Fuel Quality
2. Water Emulsion in the Fuel
3. Non Catalytic Reduction (NCR)

- **After-treatment Philosophy**

This method means that exhaust gases are dealt with after combustion. As opposed to the fuel-related and engine-related philosophy, which prevents the formation of undesired substances, this method aims at eliminating already formed substances. If the two former methods fail to provide sufficient NOx reduction to meet stringent NOx regulations, after-treatment methods will be effective.

3.3 Methods for NOx Reduction of Marine Diesel Engines

Concerning the strategies used for lowing NOx, there are a number of ways available for both existing and newly built engines. The aim of this section is to describe, in more detail, some emission limiting measures applicable to ships.

3.3.1 Engine-related Methods

In-engine methods are such changes of the interior design of the engine and optimisation that aim at limiting the formation of NOx through oxidation of the nitrogen of inlet air. Some examples of proposed in-engine measures for reducing NOx are presented below.

3.3.1.1 Retarded Injection

Retarded fuel injection has been widely used on marine diesel engines and is considered as one of the most effective ways to reduce engine NOx emissions. This can be achieved mechanically or electronically. A tvpical example of an electronic fuel injection controller is the Electronic Unit Injector (EUI) which is controlled by a programmed micro-processor and has been successfully used and has improved the engine performance and emissions dramatically (Zhou, 1993).

The amount of NOx reduction depends on the retardation and on the fuel injection duration. The use of high fuel injection pressure can help the combustion to be completed as soon as possible to remedy the thermal efficiency loss caused by retarded injection, which can be achieved by increased atomisation (Alexandersson, 1993, page 185).

3.3.1.2 Water injection

It has for a long timebeen a well-known fact that additional water in the combustion room lowers the NOx (Paro, 1993). Different methods have been used, e.g. to inject the water into the intake air. The newest one being high-pressure injection of water at an optimum timing directly into the cylinder space.

The best approach for water injection is to inject water directly into the cylinder during the combustion period. The finely atomised water droplets vaporise immediately after being injected into the combustion chamber. The combined effect of vaporisation absorbing heat, relatively high molar heat capacity of water and reduced partial pressure of oxygen, brings down the peak combustion temperature. The injection timing is 20-70 degrees Crank Angle (°CA) before TDC (Top Dead Center) and duration 20 to 60 °CA varying with engine speed and load. At optimum condition, direct water injection into the combustion chamber is more effective than the injection to intake air. This method is possible to use for all kinds of fuels and the emission reduction has been very stable over time (Zhou, 1993).

3.3.1.3 Exhaust Gas Recirculation (EGR)

EGR is a tool for reducing NOx formation in the combustion process. It implies that a part of the exhaust gas from the engine itself is cooled down and mixed with the suction air to suppress the peak combustion temperature (Tmax).

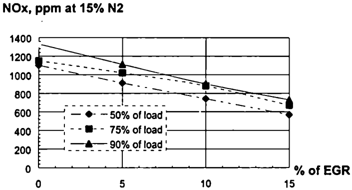
The following factors influence the effects of EGR:

- The heat capacity of CO_2 contained in the recirculated exhaust gas is about 25% higher than that of N_2 and O_2
- The lower partial pressure of O_2 in the combustion air can lead to a lower combustion temperature.

Figure 3-2 is the influence of exhaust gas circulation on NOx emissions which is conducted by MAN B&W (1993). Up to 20% of EGR has been tested on marine diesel engines and a 50% reduction in NOx has been achieved. Like most other measures for NOx control, EGR suffers a slight increase of specific fuel oil consumption (SFOC) due to the reduced combustion rate.

However, for marine engines, EGR has had its limitations due to the content of sulphur in the fuel. This method has been developed into a separate device in which the exhaust gas is cooled and the condensed water is removed due to the fact that this water is sour.

Fig. 3-2 Emission Reduction with EGR



3.3.2 Fuel -Related Methods

3.3.2.1 Mixing Water with the Fuel

This method is to burn emulsified fuel oil made by dispersing fine particles of a small quantity of water in fuel oil for engines utilising and atomising the combustion mechanism. The mechanism regarding the water particles in emulsified fuel oil may be classified into two, i.e., physical action and chemical action of water particles. The former includes the micro-explosion action and the air absorption effect. The latter includes the water gas reaction and the thermal decomposition suppression action.

Application of water in oil emulsion has been considered as a mutual technique for improving diesel engine combustion, thermal efficiency and emissions. So unlike other engine-related methods, burning emulsified fuel leaves the SFOC of the engine unchanged or even slightly decreased at less water emulsion.

Blue Star Line's experience of using emulsified fuel onboard ship illustrates that a maximum NOx reduction of 30% has been achieved (Zhou, 1993). At the same time, some other advantages by using emulsified fuels have been claimed due to the cleaner combustion reducing wear rates, and also savings in lubricate oil consumption.

3.3.2.2 Non Catalytic Reduction (NCR)

Non catalytic reduction converts NOx into N_2 and H_2O by direct injection of ammonia (NH_3) into the engine combustion chamber. NOx can react with NH_3 when the temperature is about 1000°C.

For such an application, two requirements have to be met:

- The reducing agent (NH_3) has to be injected on the completion of the main fuel combustion process since NH_3 is also combustible.
- NH_3 has to be distributed homogeneously through the combustion chamber to meet the high reaction speed.

According to Zhou (1993, p5), 4 times NH_3 is required to obtain a 50% reduction in NOx. This means that only 10-12% of ammonia is actively reacted with NOx and the rest probably burned off. The best NH_3 injection timing is found about 30-50 ^{O}CA after TDC to achieve the temperature for the reaction.

3.3.3 The After-treatment Method - Selective Catalytic Reduction (SCR)

An SCR plays the function of a reactor attached in the exhaust system, when ammonia or urea is introduced to react with NO and NO_2 in the exhaust gas and discharged in the form of water and nitrogen. This method has been proved that it can be used both for good fuels, like diesel oil, gas, and heavy fuel operation. The reduction rate in NOx can be more than 95%, so it can be considered as the most exceptional method for NOx emission to meet the future stringent regulations.

The operation temperature of SCR is about 250 to 400 °C. The position of the catalyst has a major effect on the NOx reduction (Vollenveider, 1994). If the installation location is before the exhaust turbine, the operation temperature can be easily maintained, but this arrangement has a high risk of turbine blade collision when the catalyst materials break off and also the increased exhaust flow resistance leads to a sluggish response of the turbine. If the system is located after the turbine, an electrical heater has been used to heat the exhaust gas to maintain the operation temperature.

3.4 The Method for SOx Reduction

Unlike the NOx, SOx are formed solely from a source through the oxidation of the fuel bound sulphur compounds. When fuel is burned almost all the sulphur is emitted to the air, while a smaller part is bound as sulphur in ashes and particles, i.e.:

$$\text{“Fuel S”} + O_2 = SO_2 \qquad (3\text{-}3)$$

then, SO_2 may be oxidised by means of O_2 to sulphur trioxide (SO_3),

$$2SO_2 + O_2 = 2SO_3 \qquad (3\text{-}4)$$

If there is to be sufficient time for the thermodynamic balance to stabilise in the flue canal, the SO_2 would be more or less completely oxidised to SO_3. In practice, however, only a very small part (1-5%) of the SO_2 has sufficient time to oxidise to SO_3. SO_3 cannot exist in a free condition, it leads to the forming of a mist of sulphur acid (H_2SO4) through a rapid reaction. For a given SO_3 content and moisture in the flue gas there is a temperature (so called acid dew point, approx. 110-160 ^{O}CR), which must not be gone below if condensation of sulphur acid is to be avoided.

3.4.1 Good Quality Fuel

Good Quality Fuel here refers to fuels with low sulphur content. Reduction of the sulphur content is essential for the control of SOx emissions because that is the only source of the sulphur. According to the International Federation of Shipmasters' Association (1997, P13), the typical sulphur content in current fuel is about 3.0%. Table 3-2 shows world sulphur averages (% mass) for viscosity ranges which account for in excess of 90% of the samples that DNV analyses.

Depending on the location of suppliers, the use of good quality of fuel with lower sulphur content will cause the fuel cost to go up. It provides a flexible application of exhaust aftertreatment and exhaust gas recirculation due to the reduced sulphuric acid corrosion.

Table 3-2 World Sulphur Averages (% Mass)

Year	1990	1991	1992	1993	1994	1995	1996
101-250 cSt	2.81	2.68	2.71	2.80	2.71	2.61	2.65
251-400 cSt	2.93	2.98	2.96	2.90	2.97	2.85	2.88

"Source: International Federation of Shipmasters' Association, 1997, p13".

In the above table, the Sulphur averages are under 50 °C Viscosity.

3.4.2 SOx Scrubber

The SOx scrubber is an economic alternative to reduce sulphur fuel. The principles of exhaust gas seawater washing for removal of sulphur lie in the inherent natural alkalinity of seawater. With a specially designed washing system, SO_2 in the engine exhaust can be dissolved in seawater, then discharged into the sea. Table 3-3 shows measured exhaust gas emissions. From this table, it can be seen that the scrubber could meet the SOx removal target of 85-95% and therefore a 50% reduction was achievable without any difficulty. As for the environmental impacts of the discharged particulate-containing seawater, the exposure time to marine organisms would thus be small, the toxic effect of the process water on the organisms would be neglected (MER, 1995, p29).

Table 3-3 Measured Exhaust Gas Emissions

Operating Condition	SO2 ppm	NO_X ppm	CO ppm	CO2 %	O2 %	HC ppm
Before Scrubber	497	1110	344	6.09	12.9	12
After Scrubber	48	1110	344	6.1	12.9	9

"Source: MER, June 1995, p29"

3.5 Discussions

3.5.1 Issues to Be Considered When Choosing the Relevant Methods

When different methods for the reduction of emissions are evaluated, a large number of factors must be taken into account. The list below gives a number of examples of questions which have to be considered.

- How does the method affect the following: NOx, SOx, CO, CO_2, PM, SFOC?

- Do problems concerning waste deposition occur, such as waste water from a scrubber or dust from filters?
- What is the cost of investments?
- What is the cost of operation?
- How long is the life of the equipment?
- How much space will the equipment need?
- How often will it be necessary to overhaul and exchange parts of the equipment?
- Are there any other installation requirements?
- Will the life of the engine be affected?
- Can the method be used in the whole working range of the engine?
- Which control equipment is required?
- Will the working environment be affected for crew and harbour personnel?
- Does the handling of the equipment require special training?
- In which development stage is the technique today?

3.5.2 The Consequences Analysis of Various Methods

According to the above discussion, every single method can reduce NOx emission more or less. For the shipowner or marine engineer to select the appropriate approach, the reduction rate of NOx emission and also the capital cost and running costs should be fully considered. The option of using which kind of device should depend on the cost effectiveness and the resources available.

3.5.2.1 The Engine-related Methods

From the points of view the engine-related methods as a whole, there are several advantages:

- They require no additional volume as they only involve an exchange of engine parts or design changes.
- The weight is not affected.

- The by-products concerning emissions of hydrocarbons, particles, and carbon dioxide are reduced.
- The maintenance needs should be about the same as for the fuel-optimised engine.
- No changes regarding operation are necessary. No influence of vibration or motions disturb the function.

There are, of course, some disadvantages to consider regarding the engine-related methods.

- The price of a new, low-emission engine is about the same as that of an economy engine. But additional costs should be allowed for concerning fuel consumption which is about 5-10% more at the same power output.
- The reduction rate is less than that by means of the SCR. The degree of reduction is of course related to the point of the engine. A high emission engine may be reduced by as much as 50%, while it may be more difficult to achieve a reduction on an engine which does not produce a lot of NOx.

Because of the practical problems associated with cooling and cleaning the exhaust gas before it is recirculated to the scavenge air side, a significant amount of development work is necessary to make EGR an attractive method. This method leads to an acidic, dirty and probably also oily sludge, which has to be disposed of.

For the retarded injection method, no specific engine modification is required. The amount of NOx reduction depends on the retardation and on the fuel injection duration. But the retarded injection has a significant adverse effect on fuel consumption. 1 ^{o}CA retarding increases the SFOC by 1%, so 10 to 15% of NOx reduction by this method has been recommended as the best potential reduction (Zhou, 1993). At the same time, retarded injection also increases the thermal load on valves, turbocharger and visible smoke level.

The non catalytic reduction method is not so satisfactory due to the high ammonia consumption. At present, the market prices for NH_3 and heavy fuel oil (HFO) are not very different, but purchasing the small quantities of NH_3 may lead to a somewhat higher price. In this way, an equivalent increase of SFOC would be more than 30 g/kW•h for achieving a NOx emission level of 20 g/kW•h. Of course, the capital costs and catalyst maintenance costs have to be added. So the low degree of utilisation of the ammonia means that the improvements will be necessary.

3.5.2.2 Fuel-related Methods

It is significant that the results of the fuel consumption in this method vary. Certain cases have shown fuel saving of as much as 6 %, while other cases have shown consumption increases of the same size. The net effect obtained depends on the optimisation and condition of the engine and on the fuel used.

High water mixture contents at low loads may lead to excessive cooling or forcing acid of air, so that the combustion becomes unstable and the formation of carbon monoxide and particles increases instead.

Emulsifying equipment is fairly easy to install in the fuel system of existing marine engines, but the injection equipment must inject a larger amount at a given engine output. If the mixing ratio is small, this can usually be handled with the existing injection equipment.

3.5.2.3 Selective Catalytic Reduction (SCR)

The installation of the SCR plant leads to a slight increase in the pressure-drop in the exhaust pipe and consequently a higher counter-pressure after the exhaust turbines of the main engines. There is a rive of the exhaust temperature of a few degrees.

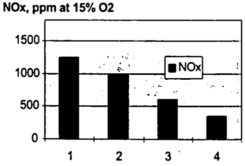
The weight increase of about 10 tons due to the equipment and ammonia will lead to a decrease load of the same size. With their proposed location on the deck, the ammonia tanks should not cause any disturbance.

An SCR does not affect the engine combustion and its thermal efficiency. But in an SCR, some of the SO_2 in the exhaust gases is oxidised to SO_3, which later will form H_2SO_3 or even H_2SO_4 when meeting with the water in the exhaust system. The acid causes rapid corrosion of the SCR system and other components in the exhaust system, so a certain amount of overdosing of urea is necessary. The running cost of this system is 7 to 10% of the fuel cost. The capital cost of installation is 30-60% of the engine cost (Zhou, 1993).

3.5.2.4 Combined Methods

The single approach of reducing NOx discussed above, suffers from an increase in fuel consumption, and/or requires a significant investment for the installation of the devices which is further followed by an increase in the costs of maintenance and running. To meet the stringent requirement for more reduction of NOx, the combination of some methods should be considered. If this is done, what will be the combined effect on emissions and on SFOC?

Fig. 3-3 NOx Reduction



"Source: MAN B&W A/S, 1993, P8"

Figure 3-3 summarises the test results carried out with slide type fuel valves, emulsified, and exhaust gas recirculation on 5S70 MCE engine (MAN B&W Diesel A/S, 1993). When using slide type fuel valves, combined with 50% water addition and 20% EGR, the NOx was reduced by 75%, but only a minor increase in fuel oil consumption at the normal firing pressure. From this figure, only 22% reduction of NOx was achieved when slide type fuel valves were used in the above condition.

In this Figure, the first result (No 1) is for reference, the second is for the slide valve only, the third is for slide valve + 50% water, the fourth is for the slide valve + 50% water + 20% EGR.

Chapter 4

A General Survey of Annex VI of 1997 Protocol of MARPOL 73/78

For stationary installations there are standards for primarily NOx, SOx and PM in most industrialised countries. Some countries also have their own standards for other substances, such as CO, HC. In September 1997, a new Annex VI to the International Marine Pollution Convention (MARPOL) 73/78 was agreed. This is the first international treaty to deal with the air pollution from ships. There are also some other regional emission standards concerning the ships. In this chapter, the aims, main features, the structure and format of new Annex will be highlighted, and its impact upon the shipping industry will be discussed.

4.1 Background to International Legislation Framework

The operative situation of a ship's engine in many respects is different from that of trucks or diesel power stations. The load when cruising at sea is generally constant and shipping is international as regards ownership as well as shipping routes. The marine emissions are so extensive that they affect large sectors of the environment, and there are reasons to contemplate standards also for ships. So a logical work is to try and bring about global agreements.

The introduction of Annex VI is on a more definite, and more advanced, footing. In 1988, IMO agreed that air pollution should be added to its work programme. A major five-year emission measurement research project, initiated by Lloyd's Register, has helped to quantify the extent of the problem and underpin the development of Annex VI. The Lloyd's Register's Marine Exhaust Emissions Research Programme comprises three phases. Phase I of the programme, completed in 1991, determined rates of discharge of the major gaseous components of the exhaust from marine diesel engines operating under steady state conditions. Exhaust emissions factors were determined for both medium and slow speed diesel engines in terms of both kg pollutant per tonne of fuel and g pollutant per kWh. Table 4-1 shows the emission factors for medium and slow speed diesel engines.

Table 4-1 Emission Factors for Medium and Slow Speed Diesel Engine (Unit: kg/tonne fuel)

Engine Type	NOx	CO	HC	CO_2	SO_2
Medium speed	59	8	2.7	3250	21.0*S
Slow speed	84	9	2.5	3165	21.0*S

"Source: IMO, 1993, p5".

In this table, *S = Sulphur content of fuel oil (% by weight).

Phase II of the research programme provides baseline data on the magnitude and characteristics of emission from diesel engines generated under transient operating conditions. This phase also assesses the influence of marine exhaust emissions on air quality in the vicinity of heavy shipping activity by two parallel lines, namely a programme of shipboard emissions measurement under transient operating conditions and a marine emissions quantification and environmental impact exercise centred on the port of Vlissingen in the Netherlands. Through this programme, relationships between engine load , engine speed, emission concentrations and mass specific emissions were identified. Comparison of the total mass of emissions generated during transient operations with those predicted whilst on passage indicated that the quantities of NOx significantly lower (IMO, 1993, p1).

Phase III was carried out in the English Channel during 1991. This programme quantifies the regional contribution of shipping to atmospheric pollution and detailed regional quantification and environmental impact exercises. The result showed a strong relationship between ship traffic density and pollutant emissions. The annual emissions of NOx, SOx, CO_2, CO and HC is as follows in table 4-2.

Table 4-2 Maximum, Minimum and Annual Emission for the Region

Emission Species	Minimum Emission Density ($kg/km^2/d$)	Maximum Emission Density ($kg/km^2/d$)	Annual Emission (t/year)
NOx	<10	88	$90.2*10^3$
SOx	<4	30	$36.4*10^3$
CO_2	<500	2700	$3.9*10^6$
CO	<2	9.8	$12.9*10^3$
HC	<0.5	3.0	$4.7*10^3$

"Source: Carlton, 1994, p158"

Corresponding emission values for shipping routes in the open ocean were 34 and 24 kg/km^2/annum respectively (Lloyd's List, 1996, p2).

In 1991, the IMO set reduction targets for NOx and SOx at 30% and 50% respectively by the year 2000. To reach these objectives, IMO started its work on Annex VI to MARPOL 73/78. The agreement was reached at IMO Conference of Parties to the International Convention for the Prevention of Pollution from Ships. The important reason why IMO took so long to adopt the new Annex was the involvement of oil companies in the negotiating process. Shipping is currently one of the few areas where the oil companies can find a market for high sulphur residual oils.

4.2 Main Features of Annex VI of 1997 Protocol of MARPOL 73/78

The Conference of Parties to the International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 (MARPOL 73/78) was held from 15 to 25 September 1997 at the headquarters of the Organisation. The Protocol of 1997 to amend the MARPOL 73/78 was adopted. The Conference also adopted the following resolutions:

Resolution 1 Reviews of the 1997 Protocol

Resolution 2 Technical Code on control of Emissions of NO_X from Marine Diesel Engines

Resolution 3 Review of NOx Emission Limitations

Resolution 4 Monitoring the World-wide Average Sulphur Content of Residual Fuel Oil Supplied for Use on Board Ships

Resolution 5 Consideration of Measures to Address Sulphur Deposition in North West Europe

Resolution 6 Introduction of Harmonised System of Survey and Certification in Annex VI

Resolution 7 Restriction on the Use of Perfluorocarbons on Board Ships

Resolution 8 CO_2 Emissions from Ships.

4.2.1 General Points of Annex VI

4.2.1.1 Entry into Force

Concerning the requirements, the 1997 Protocol will enter into force twelve months after the date on which not less than fifteen states, the combined tonnage of which shall not be less than 50% of the gross tonnage of the world's merchant shipping fleet, have become parties to the Protocol.

4.2.1.2 Substances Which Shall be Controlled Under Annex VI

Regarding the substances, Annex VI deals with the following matters:

- Emission of Ozone Depleting Substances such as CFCs, HCFCs, etc.
- Emission of NOx
- Emission of SOx
- Emission of Volatile Organic Compounds (VOCs)

- Incineration on board of Water or Other Matters Which Were Generated During the Normal Operation Of that Ship

4.2.2 The Main Features of Annex VI

4.2.2.1 The Application of Annex VI

The provision of Annex VI shall be applied to all ships, except where expressly stated in each regulation. Any kinds of ships, including fixed or floating platforms, are applied.

4.2.2.2 The Survey

Every ship of 400 gross tonnage or above, and every fixed and floating drilling rig and other platforms, are subjected to the survey and inspections. According to the 1997 Protocol of MARPOL 73/78, there are three kinds of survey:

- **Initial Survey**

The initial survey is that which is carried out before the ship is put into service or before the certificate is issued. It is endured that the equipment, system, fittings, arrangements and materials comply with the survey.

- **Periodical Survey**

This is carried out periodically at intervals specified by the Administration, but not exceeding five years. The contents of the inspection are the same as the initial survey.

- **Intermediate Survey**

This is carried out at least once during the period of validity of the certificate. It ensures that the equipment, system, fittings, arrangements and material comply with the requirements of this Annex and are in good working order.

The survey is implemented by officers of the Administration. However, the Administration may entrust the surveys either to surveyors nominated for the purpose or to an organisation recognised by it.

4.2.2.3 Certificate

After survey, the International Air Pollution Prevention Certificate is issued to:

- Any ships of 400 GT. or above engaged in voyages to ports or offshore terminals under the jurisdiction of other parties; and
- Platforms and drilling rigs engaged in voyages to waters under the jurisdiction of other parties to the Protocol of 1997.

Concerning the ships contracted before the date of entry into force of the Annex, the certificate is issued no later than the first scheduled dry-docking after the entry into force of Annex VI, but in no case later than 3 years after the entering into force of this Annex.

4.2.2.4 Inspection

A ship, when in a port or offshore terminal under the jurisdiction of another party to the Protocol of 1997, is subjected to inspection by officers duly authorised by such a party. This inspection is limited to verifying that there is on board a valid certificate, except in cases where there are clear grounds for believing that the master or crew are not familiar with essential shipboard procedures relating to the prevention of air pollution from ships. In this case, the party which carries out the control shall take such steps as to ensure that the ship shall not sail.

4.2.3 Regulations Concerning NOx, SOx

4.2.3.1 NOx Emission

According to Annex VI, the regulation on NOx applies to

- Each diesel engine with a power output of more than 130 kW which is installed on a ship constructed on or after 1 January 2000, and
- Each diesel engine with a power output of more than 130 kW which undergoes a major conversion on or after 1 January 2000.

But does not apply to:

- Emergency diesel engines, engines installed in lifeboats and any device or equipment intended to be used solely in case of emergency; and
- Engines installed on ships solely engaged in voyages within waters subject to jurisdiction of the state the flag of which the ship is entitled to fly, provided that such engines are subjected to and alternative NOx content measures established by the Administration.

In the operation of each marine diesel engine, one of the following requirements shall be satisfied:

1. The emission of NOx from each engine to which this regulation apply is within the following limit under the test cycle specified in appendix V of the Annex:

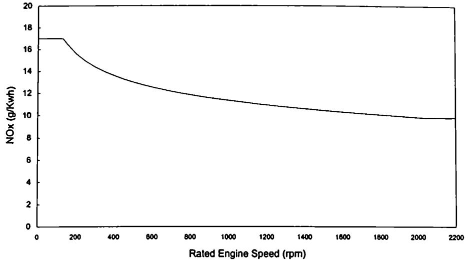
a. 17.0 g/kWh, where n is less than 130 rpm

b. $45.0*n^{(-0.2)}$ g/kWh, where n is 130 rpm or more but less than 2000 rpm

c. 9.8 g/kWh, where n is 2000 rpm or more

Where n is the rated engine speed.

Fig. 4-1 NOx Limit by Annex VI



2. An exhaust gas cleaning system or other equivalent method approved by the Administration, is applied to the engine to reduce NOx emissions at least to the limit specified above.

- **The Procedure of Survey**

The procedures of survey, including details of measurements and calculation of NOx emissions, are stated in NOx Technical Code. In principle, at the initial survey, the measurement of NOx emission is carried out on the test bed and an International Air Pollution Prevention Certificate (IAPPC) is issued by the Administration. With respect to engines which do not receive a survey on the test bed, the measurement is carried out on board which shall fully comply with the requirements of land-based measurement.

- **Technical File and Engine Parameter Record Book**

A Technical File, which indicates permissible ranges of adjustment or replacement which could affect the performance on NOx emission, shall be carried out by a ship.

When parts which could affect the performance on NOx emission are replaced, it shall be recorded on Engine Parameter Record Book.

4.2.3.2 SOx Emission

- **A Global Capping of Sulphur**

The sulphur content of any fuel oil used on board ships shall not exceed 4.5% by weight.

- **Special SOx emission control areas**

1. Areas, where the adoption of special mandatory measures for SOx emission from ships is required to prevent, reduce and control air pollution of SOx and its attendant adverse impacts on land and sea areas, are designated as "SOx Emission Control Areas".

2. Within "SOx Emission Control Areas", severer control of SOx emission is enforced and one of the following conditions shall be satisfied:

a The sulphur content of any fuel oil used on board ships shall not exceed 1.5% by weight.

b An exhaust gas cleaning system, approved by the Administration, is applied to reduce the total emission of SOx from ships, including both auxiliary and main propulsion engines, to 6.0 SOx/kWh or less.

With respect to special areas, these can be designated by the organisation in accordance with the criteria and procedure for designation of SOx Emission Control Areas contained in Appendix II of Annex VI. The Baltic Sea was designated as the first special area.

4.2.4 Fuel Oil Quality

Fuel oil for combustion purposes on board shall comply with the following requirements:

- The incorporation of small amounts of additives may be permitted;
- The fuel oil shall be free from inorganic acid
- The addition of the following substance or chemical waste into fuel oil shall be prohibited:

1. Substances which jeopardise the safety of ships or adversely affect the performance of machinery; or
2. Substances which are harmful to personnel; or
3. Substances which contribute overall to additional air pollution.

Details of fuel oil delivered to and used on board a ship of 400 GT. or above and a fixed or floating drilling rig and other platforms shall be recorded by means of a bunker delivery note. The bunker delivery note is to be accompanied by a representative sample of the fuel oil and shall be kept on board for inspection for 3 years. The local supplier shall provide the bunker delivery note and retain a copy of it at least for 3 years.

4.3 Format of the New Annex VI

The new Annex VI consists of three Chapters and a number of Appendices:

- **Chapter I - General** States that the Annex should apply to all ships and notes that the controls on emissions will not apply where any emission is necessary for saving life at sea or for securing the safety of a ship or where damage to the ship has occurred provided all reasonable precautions have been taken and there is no intent to cause damage.

- **Chapter II - Survey, Certification and Means of Control** covers requirements for ships to be surveyed to ensure they comply with the regulations; the issuing of Air Pollution Prevention Certificates to show a ship's compliance with the rules; and enforcement of the rules.

- **Chapter III - Requirements** for Control of Emissions from Ships covers the specific regulations regarding preventing air pollution from ships, as regards ozone depleting substances; nitrogen oxides; sulphur oxides; and volatile organic compounds. It also covers requirements for shipboard incineration; provision of reception facilities at ports to receive substances removed from ships; fuel oil quality; and requirements for drilling rigs and other platforms.

- **Appendices** include the form of the International Air Pollution Prevention Certificate; criteria and procedures for designation of SOx emission control area; information for inclusion in the bunker delivery note; approval and operation limits for shipboard incinerators; test cycles and weighting factors for verification of compliance of marine diesel engines with the NOx limits; and details of surveys and inspections to be carried out.

4.4 Major Impacts upon Shipping Industries

After six year of arguments and a lot of hot air from the IMO delegates, committees and environmental lobbyists, the definitive ruling on air pollution emissions from ships was reached. Furthermore, the MEPC (Marine Environmental Protection Committee) of IMO is requested to develop guidelines for monitoring the world-wide average sulphur content of residual fuel oil supplies. As far as the Special SOx Emission Control Area is concerned, the more stringent limits of SOx will be applicable (MER, 1996, p23). By the year 2000, the reduction of NOx for marine engines will be up to the 50% level. All of these requirements will have great impact on the shipping industry, which includes engine builders, fuel oil companies and shipping companies.

4.4.1 Impacts upon Engine Builders

When Rudolf Diesel formulated his original cycle concept, as set out in his patent in 1892, a prime mover of unprecedented economy was envisaged. This feature can be attributed to the inherent characteristics of the diesel cycle, namely the possibility of achieving an excellent efficiency by running at the highest cycle temperatures, and to burn low-cost residual fuels with high reliability (Vollenweider, 1991).

It is highly probable that by the end of this decade the emissions limits of marine diesels will become a decisive criterion in market competition.

One of the problems associated with attempting to reduce NOx is that fuel consumption usually increases. The attention that the engine builders focus on will be how to maintain SFOC levels while also radically reducing emissions of NOx and SOx, particularly during the problematic area of non-steady state engine operation.

There is an increasing demand for environmental technology. In particular, the following inquiries are being addressed to the engine builder (Vollenweider, 1991):

- A number of local authorities require a quotation of the expected exhaust emissions.
- From the point of view of customers, how can they cope with IMO emissions requirements and what kind of investment will be made in this respect.

To meet this market demand and the challenge from the international legislation, much attention has been put on the environmentally-friendly marine diesel engines by the leading marine engine builders. Among these, much more attention should be put on the International Air Pollution Prevention Certificate (IAPPC) by engine builders.

IAPPC is the International Air Pollution Prevention Certificate. It is the manufacturers responsibility to undertake the necessary tests, engine by engine., and provide the authorities of the flag state for the recipient vessel with the requisite documentation, so as to obtain the approval and the IAPPC.

The granting of the ship's own International Air Pollution Prevention Certificate (IAPPC) will be contingent on the IAPPC being provided with the engine. It is believed that the processes necessary to secure IMO engine certification will introduce added complexity to the final stages of engine preparation in the workshop, and carry the risk of delays in test bed trials.

Each engine will have to be delivered with a technical file required by Annex VI of 1997 Protocol of MARPOL 73/78. This file should specify all components considered to influence the engine's emission levels, thereby embracing the entire fuel injection system, injection and exhaust valve cams and timing, cylinder cover, piston with piston rod and shims, conrod and turbochargers (Tinsley, 1998). The prescribed file must also include adjustment data and tolerance for performance parameters, plus the detailed results of the emissions measurements carried out at the workshop trials stage. Recertification of each engine will take place every five years, and the technical file will follow the engine through its whole life.

4.4.2 Impacts upon Fuel Oil Companies

As far as SOx is concerned, the new Annex VI of the Protocol of MARPOL 73/78 has a global capping of Sulphur content of any fuel oil used on board, which is not more than 4.5% by weight. Also in "SOx Emission Control Area", the requirement of sulphur is not more than 1.5% by weight. Regarding the fuel oil quality on board ship, the bunker delivery note should be provided to the ship and be kept on board ship for inspection for 3 years. For the engine to meet the requirement, the low-sulphur content of fuel oil should be available throughout the world market.

Most of the oils delivered to ships are of comparatively poor quality. For several years, engine manufactures have spent a lot of time and effort to be able to run the engines on fuels with bad combustion characteristics and high sulphur content. Shipping companies have, in most cases, tried to obtain the lowest running cost possible for ships by burning the cheapest fuels.

The existing classifications of bunker oils do not take into account substances which may be significant from an environmental point of view. For example, a very common bunker quality does not cover the nitrogen content or sulphur content of the fuel oils.

To obtain a low sulphur content of fuel oil, three ways can be used:

- Low sulphur crude oil
- Mixing in desulphurized distillates
- Desulphurization of residual oil

Desulphurization of petroleum products is achieved by making the sulphur react with hydrogen to hydrogen sulphur. This reaction requires a catalyst and a temperature higher than 300 °C, which consumes about 0.15 kg hydrogen per kg sulphur (Alexandersson, 1993, p145).

4.4.3 Impacts upon Shipping Companies

When Annex VI of 1997 Protocol of MARPOL 73/78 comes into force, ships will need an IAPPC. Prior to its issuance, the shipping companies will need to confirm compliance with the applicable regulations.

Shipping will need to take measures to control the exhaust gas to meet an internationally agreed set of emission standards which include the engine aftertreatment method and depend on the specific engine and requirement. Also, the marine diesel engine will be needed to demonstrate whether it can comply with the requirement or not for both existing and new engines. One way of doing this is to install an approved exhaust gas monitoring system capable of recording and storing data. This data can be used to demonstrate the degree of compliance to relevant flag and port state authorities (MER, 1997a).

Portable gas monitoring equipment is not suitable for continuous monitoring purposes which is used for spot checks. Fixed or permanently installed systems can be configured to monitor and control the levels of a number of pollutants at various stages throughout the process with records of atmospheric discharges. Many systems are PC-based and have the capacity of displaying data in ppm, mg/m^3, mg/kWh or simply as a percentage. Some systems have on line calibration verification using sealed gas cells and filters, thus removing the need to carry a range of calibration gases. Monitors can be classified as two catalogues:

- **Extractive system**

The gas is analysed at a point remote from the source often after conditioning of the sample by filtering, drying, heating or cooling. The principle of this type is that the gas can be analysed by electrochemical cell, chemilnminescence, paramagnetic or optical radiation.

- **Cross-stack system**

This system is only for analysis by optical radiation and does not need conditioning.

The analysis by optical radiation is based on the amount of light energy absorbed by the molecules of a particular gas as a light source is passed through it. Each gas has a unique signature. The method popular with manufacturers is the one with electrochemical resistance of a gas as passed over it. The comparison of two kinds of systems is shown in table 4-3.

Table 4-3 Exhaust Gas Monitoring Systems

System	Advantages	Disadvantages
Extractive method	• Any number of different gases • Safe, remote area for processing • Few cross sensitivity, moisture	• Pipe work friction • Time delay
Cross-state method	• For large plant application • No need of air conditioning	• Max. 5 gases • Cross-sensitivity and particulate contamination

"Source: MER, 1997a, p12"

Chapter 5

The Development of a Programme for MET Academies Relating to Air Pollution from Marine Diesel Engines

There is no doubt that we live in a world of rules and regulations. These rules are made to regulate our activities. In the context of air pollution from marine diesel engines, they are meant to control emissions into the air in our marine environment. With the ever-increasing number of rules and regulations, it becomes more and more difficult to comply, so this is the reason why it is felt that proper education in the subject will help the marine industry to improve the environment in which we live.

The importance of including air pollution from marine diesel engines as an important subject of study for MET students and marine engineers will be highlighted in this chapter. The strategies of how to develop the MET programme for air pollution from marine diesel engines will be discussed. The outline of a proposed programme is presented in the last part of this chapter.

5.1 The Importance of Developing the Air Pollution Related Programme

In the long run, it is only a good and sound education system on the subject that will help to train people and for them to know their responsibility. Today, more than ever before, the question of control of the air pollution from ships has become important. Marine engineers and MET students should be taught about emissions and the problems caused by them along with the method of how to control NOx and SOx emissions from marine diesel engines.

Maritime Education and Training (MET) has evolved following technical developments in navigation, the need of expertise in the handling of dangerous goods, the application of computers on board ships and increasing concern regarding the pollution of the seas (Pardo, 1994).

Marine diesel engines designed and built before the mid-1970s were generally less fuel efficient and had relatively low NOx levels and, therefore, the emissions from marine diesel engines and the pollution in the air were not matters of much concern. As discussed in previous chapters, the combustion process in diesel engines is crucial in enabling them to achieve the best thermal efficiency. For example, in the context of large engines, i.e. engines having a bore greater than 160 mm, a thermal efficiency of between 44% and 50% can be reached. The larger the bore and the slower the speed, the better the efficiency will be and the more emission that will form.

During the last decade, many methods for emissions reduction have been developed. The technological development and the growing interest of the public and the media in environmental matters have produced a trend towards better trained seafarers with respect to controlling emissions to the air. In this regard, MET institutes should be ready to introduce updated material into their training programmes and to improve training systems in order to bring up to date the knowledge of seafarers with respect to new developments in the field of air pollution.

5.2 IMO Model Course

In order to assist developing countries in providing adequate training and to provide important information and knowledge in technological progress in the maritime sector, IMO agreed to develop model courses. In August 1984, the Government of Norway agreed to co-operate in the funding of the programme. These model courses can assist maritime training institutes and their teaching staff to include the new training courses in the curricula or to improve, update or complement existing material in cases where the quality and effectiveness of training courses are susceptible to improvement.

Since the Annex VI of 1997 Protocol of MARPOL 73/78 dealing with air pollution from ships is not yet into force, although it was adopted last September, it is not a mandatory requirement. However there is no doubt that it will enter into force in the near future, and also it could be inserted into model course. It is useful and necessary to develop the new training programme relating to diesel engine emissions for MET institutes.

5.3 The Strategies of Training Programme Development

The planning, design and development of a programme are closely related terms. Once a programme has been conceptualised, through the process of programme planning and incorporating a programme design, it may then be developed, usually to become a written document and finally to be implemented and evaluated. For our purpose, programme development is defined as the process of planning, constructing, implementing and evaluating learning opportunities intended to produce desired changes for trainees. This section will focus on an analysis of and the strategy employed for the training programme being developed, including development process and models.

5.3.1 The Development Process of a Training Programme

There are different processes to develop a training programme concerning different strategies. However the following four elements will usually be included in the development process (Forsyth, I ; Jolliffe, A and Stevens, D , 1995).

- **Gathering Information.** The process of gathering information to determine the focus, priorities and guidelines for the training programme.
- **Programme Development.** This will focus on the details of the training programme, consisting of the aims and objectives, their sequence and the delivery strategies.
- **Instructional Method.** There are three kinds of instructional strategies which can be chosen from.
- **Evaluation.** This will determine the process and procedure for evaluating the trainees and training programme.

5.3.1.1 Gathering Information

This is a way of determining the focus and priorities of the training programme. In this stage, the following items should be properly fixed:

- **Topic.** From the information having been given or collected, a short, general description should be determined which may be subjected to change.
- **Goals or Aims.** At the early stage, the goals should be fixed which outline the general or overall outcomes that have been set for the training programme itself. These goals are the ones suggested for the course and are not the trainer goals.
- **Audience or Trainee.** The more the trainee can be described, the more likely a relevant training programme can be developed. Information concerning the age, professional experience, academic level and working background of the trainee should be considered.

The trainee with a general education of 12 years who had high levels in mathematics, physics and other sciences can be taught the same subjects in a different way to somebody who has completed a general education of 8 years. The trainee with a few years experience as a ship's officer can be taught the same subjects in a different way to somebody who has served as a rating or has not had shipboard experience at all.

- **Programme Length.** This could be from one day (six hours) to one semester or even longer. This information is very important and valuable when or before the programme is developed.

This allocation should be based on the ability of the students or rather on the ability of a fictitious 'average student' to cope with a certain amount of information and on the effectiveness of the teaching to provide such information. Some flexibility should be left in the allocation of hours in the first 'run' of the programme. The number of hours for parts of a programme can be more strictly fixed through more improvement.

5.3.1.2 Programme Development

At this stages, the following items are very important and should be properly fixed.

- **Objectives.** The Objectives of the training programme are written and contained at a minimum statement of performance that indicates what and how the trainee will achieve the competencies set out in the programme. It is a statement about the trainee, not the trainer. It refers to the behaviour of the trainee and specifies what he/she needs to know. It also defines knowledge by indicating how the trainees are to demonstrate their knowledge. Usually, the objective is stated in terms of an end performance and so should be the description of that end performance, rather than a method for reaching it.

Educational objectives can be general (the trainee knows and understands his duties and performance on board ship) or specific (the trainee understands and is able to apply it to the particular task). Compared with aims (most general) and goals, the objectives are most specific. It must also be a realistic description of what can be achieved and should not reflect wishful thinking.

When the objectives are fixed, the following can be properly determined:

1. Programme content
2. Teaching methodologies
3. Types of training programme
4. Types of trainee evaluation
5. Evaluation procedures.

- **Programme Content**. The training programme content should be given more attention when the objectives are fixed. It should make sure that the topics of the programme that have been identified are those needed by the trainee rather than those the trainer thinks would be nice for them to learn. During this step, some of the other programmes should be checked to make sure there is no overlap.

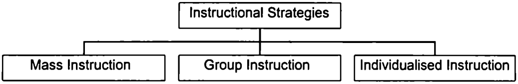
  The content of MET programmes confined to preparing students for shipboard service is mainly determined by STCW 95. If the graduate of an MET institute working in the maritime sector ashore needs some kind of training or short refresher courses when leaving the sea for the shore, the contents should be carefully selected.

- **Content Order**. The list of topics should be reviewed at this stage to see if a sequence can be determined or the topics arranged so that the knowledge of a previous topic is closely positioned. To make sure that the topics are arranged in this way the key topic is placed in the centre and lines can be drawn to all of its related topics.

5.3.1.3 Instructional Strategies and Methods.

The instructional strategies are those showing how the training programme will be delivered to the trainee. Many delivery options are open to be used, ranging from the lecture, discussion, simulation, seminar, practical work in the workshop, laboratory. They can all be categorised into three types of instructional strategy, namely mass, group and individualised instruction, as shown in Figure 5-1.

Fig. 5-1 Types of Instruction



"Source: Forsyth I ; Jolliffe, A and Stevens, D , 1995, p71)

- **Mass Instruction**

Mass instruction is the type of instruction where the information is provided to a large number of trainees by the teacher or trainer. This type of instruction is called 'teacher-centred' because teachers are in control of the instructional process.

- **Group Instruction**

Group instruction is where groups of about 30 trainees work together with the teacher. Here the teacher's role is that of facilitator or organiser in the teaching/learning process.

- **Individualised Instruction**

Individualised instruction is a learner-centred delivery strategy where the teacher acts as a facilitator of the learning process. Here the training programme and learning materials play an even more important role in the learning process as teachers cannot meet the needs of each individual trainee.

There are many factors which need to be taken into account when selecting the delivery strategy. The most important factors are:

1. Type of content being delivered. The teaching of concepts may have to be approached in a different way than the teaching of practical details.
2. Time length is available for this particular part of the programme.

5.3.1.4 Assessment and Evaluation

As part of a training programme, the assessment of the training programme should be developed to diagnose, prescribe grade, and evaluate the programme and trainee.

Diagnosis provides information about the trainees remediation needs. Grading follows the programme and shows what trainees have or have not learned. The evaluation provides the conclusions to determine if the trainees have learned anything new, and if the method of communication was effective.

Even during the planning stage of the training programme, the strategy how to test, assess and examine regarding the trainee's performance should be clear. At the same time, what information and tools which can be collected and employed regarding the effectiveness of the training programme should also be determined.

- **Assessing Trainees**

Assessing trainees is to collect information to determine and evaluate if the trainee has:

1. passed (has passed what)
2. reached a satisfactory standard (what are the standards?)
3. areas of weakness that need to be improved (what determines those weaknesses?).

The simple way to evaluate the trainees is the comparison. That is to compare what the trainees know after the programme with that they knew before the programme. At a more complex level, the assessment should consist of some information whether the trainees can apply this new information or skill or attitude in the settings that they know or in the familiar settings. At the most complex level, it will be checked whether the trainees can apply this new information or skill or attitude in settings that are new to them.

- **Assessing the Training Programme**

This is to collect the information to evaluate the training programme itself. The programme has to be evaluated to ensure that the role it was designed for was correct. The issues involved include:

1. The structure and presentation of the programme
2. The use of various presentation tools
3. The tasks set for the trainees

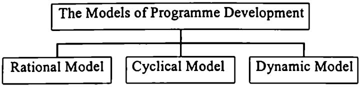
5.3.2 The Models of Training Programme Development

A model is a simplified representation of reality which is often depicted in diagrammatic form. The purpose of a model is to provide a structure for examining the variables that constitute reality as well as their interrelationship.

A model may be considered in many different ways, depending upon the purpose for which it is intended. Consensus about the relationships between programme elements, their order and their exact nature, have largely evaded those writing in the field of programmes.

The continuum depicts two extremes (see Figure 5-2). The rational or objectives models are sequential, rather rigid approaches to view the programme process, while at the other extreme may be found dynamic or interaction models, which view programme process as flexible, interactive and modifiable. In between, models gradually change from one type to the other (Print, 1993).

Fig. 5-2 The Models of Programme Development



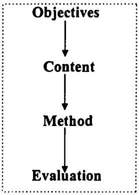
"Source: Print, 1993".

5.3.2.1 Rational Model

The Rational model emphasises the fixed sequence of programme elements, beginning with objectives, followed by content, method and finally evaluation (See Figure 5-3). In this pattern, objectives serve as a basis for devising subsequent elements, with evaluation indicating the degree of achievement of those objects.

The nature of the rational model, namely its logical, sequential structure, provides it with a useful base for planning and devising a programme. The Rational model provides a straightforward, time-efficient approach to meeting the programme task.

Fig 5-3 Objective Model



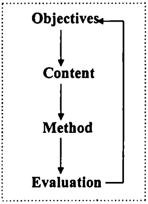
A significant weakness of the objectives model arises from the unpredictable nature of teaching and learning. The model prescribes specified objectives to be achieved, but often learning occurs beyond these objectives due to factors like new information becoming available.

5.3.2.2 Cyclical Model

The Cyclical model incorporates elements of both rational and dynamic models to provide a different approach to devising a programme. Generally speaking, The Cyclical model takes the programme development process as a continuing activity, constantly in a state of change as new information or practices become available (see Fig. 5-4).

Compared with the rational model, the distinctions between the elements of the cyclical model are less clear, because the cyclical models view elements of the programme as interrelated and interdependent. This model is flexible in that as the situation changes so corresponding changes are made to subsequent elements of the model.

Fig. 5-4 Cyclical Model



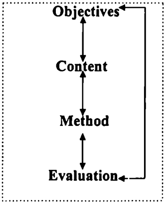
This model keeps the strengths derived from a logical sequential structure in the rational model by emphasising the role of aims, goals and objectives. It is also able to cope with new situations and consequently react to changing circumstances by emphasising the 'need' and 'demand'. But the weakness of this model is that once the cycle has been established, it is possible that the stimulus for change may originate from any programme element. The potential problem is the amount of time required to undertake an effective needs analysis.

5.3.2.3 Dynamic Model

The dynamic model or interactive model is one where the programme development can commence with any programme element and proceed in any order (see Fig. 5-5). Furthermore, the needs of trainees are seen as more important in determining programme planning than some predetermined set of information to be acquired.

The main weakness of the dynamic model is that the dynamic model appears confusing and lacking in direction because the development can proceed in any order. Another problem is the lack of emphasis placed on the construction and use of objectives.

Fig. 5-5 Dynamic Model



As a summary, it is important to say that no single model is the best and can apply to any programme. But the most appropriate model should be a clear, logical, prescriptive approach to programme development that will provide positive guidelines for development. Such a model should have a wide range of applicability, be straightforward in approach depending on the specific, real situation.

Concerning the development of engineering technology in marine diesel engines and the techniques of controlling emission, the training content of the training programme should be updated and modified. Also international legislation causes change in the training aims, objectives and training contents. So the cyclical model of the development can be used to develop the training programme relating to air pollution from marine diesel engines.

5.4 A proposed MET Educational Training Programme Relating to Air Pollution from Marine Diesel Engines

According to the discussion in the last section, the development procedure of the cyclical model starting with the training objective and followed by the logic sequence is used in this proposed educational training programme relating to air pollution from marine diesel engines. The following parts present this proposed educational training programme, namely **air pollution from marine diesel engines**, which consists of the framework and outline of the programme. The detailed educational training programme is listed in the last part of this section. The format of the IMO model course is used in this educational training programme.

5.4.1 The Framework of a Proposed Programme

- **Aim.** The course is designed for those persons who will operate the marine diesel engine on board ships or be in charge of shipping management in shore-based organisation objects.

- **Objectives.** The teaching objectives are designed so as to enable trainees and students to:

1. Gain knowledge about the background of air pollution from marine diesel engines, including the problems caused by emissions and the level and evolution of the emissions.
2. Know and understand the principles of emission formation and controlling strategies for different emissions

Know how to select the appropriate approach for particular case to reduce the emission.

Be able to competently operate and maintain the emission control devices and to secure permanent operability.

- **Entry Standards**

This programme is open to all persons who are watchkeeping officers, or at least are being trained for certificates of competency. Present officers may also attend to gain the knowledge of air pollution from marine diesel engines as an upgrading course.

- **Course Intake Limitations**

The course intake is limited, depending upon the teaching facilities and equipment for practical work. The intake limitations should be observed and not exceeded, otherwise the quality of the course will be diluted.

- **Staff Requirements**

The instructor(s) should be experienced personnel, qualified for training such a course, with sufficient teaching experience.

A laboratory technician should have sufficient experience for maintenance of the laboratory, along with assisting instructors in practical sessions.

- **Teaching aids, Facilities and Equipment**

1. A classroom to accommodate all trainees, including black (white) board, chairs and so on.
2. An overhead projector.
3. Relevant overhead projector transparencies.
4. Handouts, to be prepared by the instructor prior to course commencement.
5. A laboratory with a complete set of engines and its system. Emission control devices with sufficient space to accommodate the maximum number of intake trainees.

- **Teaching Methods**

1. Explanatory lectures on emissions and their control, related subjects as being outlined in the programme contents.
2. Practice in the laboratory which can demonstrate or explain the formation of NOx and the relationship between NOx and engines parameters. The use of computer aided learning tutorials and related exercises.

- **Text Books and References**

There have been insufficient textbooks and references for the training until now. The available resource are listed as followings:

1. Alexandersson, A (1993). *Exhaust Gas Emissions from Sea Transportation.* Gothenburg: MariTerm AB. **(T1)**

2. Danjoh, Y (1993). 'Prevention of Air Pollution from Ships', *International Conference on Maritime Technology Challenges in Safety & Environmental Protection, (November 1993: Singnpore).* Organised by a Association of

Singapore Marine Industries. Singapore: Association of Singapore Marine Industries. **(R1)**

3. Norwegian Shipowners' Association (1998). 'Ship and Environment: Emissions into the Air'. *Http://www.rederi.no/pub/shipenviron/air.html* (01/23/98). **(R2)**

4. IMO (1993). Marine Exhaust Emissions Research Programme. (BCH 23/7/1). London: IMO. **(R3)**

5. International Federation of Shipmaster's Associations (1997). 'DNV Marine Fuels - World Wide Sulphur Levels'. *IFSMA Newsletter*, December, p13. **(R4)**

6. MAN B&W Diesel A/S (1993). 'Primary Methods for Emission Reduction on Two-stroke Engines', *Meeting of Licensees 1993,* Paper No.17. **(R5)**

7. MER (1995). 'Can a SOx Scrubber Be an Economic Alternatives to Low Sulphur Fuel?'. *MER*, June, p29. **(R6)**

8. MER (1997a). 'Exhaust Gas Monitoring'. *MER*, February, p12. **(R7)**

9. Paro, D (1993). 'The Low-Emission Ship'. *International Conference on Maritime Technology Challenges in Safety & Environmental Protection, (November 1993: Singapore).* Organised by the Association of Singapore Marine Industries. Singapore: Association of Singapore Marine Industries. **(R8)**

10. Zhou, P L (1993). 'Marine Diesel Engine Emissions and Their Control', *International Conference on Maritime Technology Challenges in Safety & Environmental Protection, (November 1993: Singapore).* Organised by the Association of Singapore Marine Industries. Singapore: Association of Singapore

Marine Industries. **(R9)**

11. IMO (1997). 'Basic Facts about IMO', *Focus on IMO,* January. **(R10)**

5.4.2 The Outline and Timetable of the Proposed Educational Training Programme

According to the discussion above, a educational training programme, namely **Air Pollution from Marine Diesel Engines,** was developed. Table 5-1 shows the outline of this educational training programme, which can be conducted as a module for MET students in MET academies. This educational training course can also be used as a short intensive trining course for marine engineers working on board ship or technical personnel working at the ashore company. a timetable is shown in table 5-2.

The hours used in the following table are academic hours. One academic hour is equal to 45 minutes. Ex. in the table means the experiments conducted in the relevant laboratory. Due to the trainees' different backgrounds and education level, some of the content in this programme can be taken away or adjusted by the teacher or instructor if the trainees already have the specific knowledge. The training time can also be cut or adjusted.

Table 5-1 Outline of the Proposed Programme

Programme Content and Learning Objectives	Lecture Hours	Lab. Hours
1 Introduction to the Programme	1	
2 International Legislation	4	2 (Ex. 1)
2.1 Background to International Legislation Framework		
2.2 Main Features of Annex VI of 1997 Protocol of MARPOL		
2.3 Format of the New Annex VI		
2.4 Major Impacts Upon Shipping Industries		
3 Air Pollution from Marine Diesel Engines	5	
3.1 Definition		
3.2 Air Pollution Caused by Emissions		
3.3 Emissions from Marine Diesel Engines		
3.4 Evaluation of Air Pollution from Ships		
4 The Principles of Emissions' Formation	6	
4.1 The Working Process of the Diesel Engine		
4.2 Emission Formation		
4.3 The Relationship of Emission and Engine Parameters		
5 The Strategies for Lowering Emissions from Ships	4	4 (Ex. 2,3)
5.1 General Aspects of Emission Reduction		
5.2 Methods for NOx Reduction of Marine Engines		
5.3 The Method for SOx Reduction		
6. The Criteria to Select the Relevant Method	4	
6.1 The Factors to be Considered		
6.2 A Comparison Study of Different Methods		
6.3 The Criteria to Select Relevant Method		
Subtotal	**20**	**10**
Total	**30**	

Table 5-2 The Timetable of the Proposed Programme

Day 1	2	3
1. Introduction to the course 2. International Legislation	3. Air Pollution from Marine Diesel Engines	4. (Continued)
Experiment 1	3. (Continued) 4. The Principles of Emissions' Formation	Experiment 2

Day 4	5
5. The Strategies for Lowering Emissions from Ships	6. The Criteria to Select the Relevant Method
Experiment 3	Debriefing

The programme contains a series of experiments. The output of the programme covers learning objectives of that particular area. The names of the experiments are as follows:

- Experiment 1 (2 hours), The Measurement and Monitoring of NOx and SOx.
- Experiment 2 (2 hours), Engine-related Methods to Reduce the Emissions for Diesel Engines
- Experiment 3 (2 hours), Other Methods to Reduce the Emissions for Diesel Engines

5.4.3 The Detailed Teaching Programme 'Air Pollution from Marine Diesel Engines'

Programme Contents and Learning Objectives	Text Book	Reference
'Air Pollution from Marine Diesel Engines' (30 hours)		
General Objective: To gain knowledge and theory of air pollution from marine diesel engines and the method to control the emissions		
1. Introduction to the Programme		
1.1 IMO and its contribution to the shipping industry • explain the purpose of IMO • describe briefly the structure of IMO • explain how ship standards are maintained 1.2 Purpose of This Programme • list the issues to take into account in this programme • determine personal objectives for this programme		R10
2 International Legislation 2.1 Background to International Legislation Framework 2.2 Main Features of Annex VI of 1997 Protocol of MARPOL 73/78 • describe general points of Annex VI • requirements for entry into force • substances which shall be controlled under the Annex VI • the application of Annex VI		R10, R3

Programme Contents and Learning Objectives	Text Book	Reference
• Survey and Certificate		
• Regulations Concerning NOx, SOx		
2.3 Format of the new Annex VI		
2.4 Major Impacts upon Shipping Industries		
• comments on the major impacts of the new Annex VI of 1997 protocol of MARPOL 73/78 on the engine builders, ship companies and oil companies.		
3 Air Pollution from Marine Diesel Engines		
3.1 Definition	T1	
• explain what is meant by:		
Air pollution, Emissions, NOx, SOx, CHC, PM.		
3.2 Air Pollution Caused by Emissions		R1
• explain the main problems caused by different emissions		
• describe acid rain and its effects		
• explain the concept of photochemical oxidants		
• describe how the global weather is affected by the emissions		
3.3 Emissions from Ships	T1	R9
• generally introduce the basic ideas of emissions		
• explain the exhaust composition for modern marine diesel engines		
• describe specific emissions from marine engines		
• introduce the emission units commonly used		
3.4 Evaluation of Air Pollution from Ships		R1, R2
• describe the exhaust emissions form world fleet		
• comment on the contributions of marine emissions in air		

Programme Contents and Learning Objectives	Text Book	Reference
4 The Principles of Emissions' Formation		
4.1 The Thermal Process of Diesel Engines	T1	
• briefly give some ideas relating to the this programme (Tmax, Pmax, thermal efficiency, etc.)		
4.2 Emission Formation	T1	R5, R8
• explain the NOx formation (thermal NOx, and fuel NOx)		
• discuss the formation speed of NO, by using d(NO)/dt		
• explain the SOx formation		
4.3 The Relation between the Emissions and Engine parameters	T1	R5
• explain the factors affecting the NOx formation		
• describe the relationship between NOx and engine parameters		
• SOx and fuel sulphur		
5 The Strategies for Lowering Emissions from Ships		
5.1 General Aspects of Emission Reduction	T1	
explain and describe the concepts and principles to control NOx emissions		
1. engine-related philosophy		
2. fuel-related philosophy		
3. after-treatment philosophy		
• SOx controlling		
5.2 Methods for NOx Reduction of Marine Engines	T1	R9, R5
• describe the engine-related methods and state their main features		
1. retarded injection		
2. water injection		
3. exhaust gas recirculation (EGR)		

Programme Contents and Learning Objectives	**Text Book**	**Reference**
• explain the fuel-related methods including mixing water with fuel and non catalytic reduction (NCR)		
• describe the after-treatment method, namely selective catalytic reduction (SCR)		
5.3 The Method for SOx Reduction		R4, R6
• explain the methods which can control SOx :		
1. the selecting of good quality fuel		
2. SOx scrubber		
6 The Criteria to Select the Relevant Method	T1	R9, R4
6.1 The Factors to be Considered When Choosing the Relevant Method		
• list the name of factors which should be considered to select the different methods		
6.2 The Comparison Study of Different Methods		
• state the advantages and disadvantages for different methods		
6.3 The Criteria to Select Relevant Methods		
• emission reduction rate, the capital and running cost level		

Chapter 6

Conclusions and Recommendations

Emissions from cargo ships powered by diesel engines are among the world's highest pollution combustion sources per ton of fuel consumed. However, ships which travel great distances have escaped emissions restriction, probably because the direct effect of these emissions on the lives of individuals is harder to perceive than that from diesel vehicles and power stations on land. So, the emissions from ships are not so clear as those from land source.

Air pollution form ships was first brought to the attention of the maritime community by Norway in the late 1980's. By 1990 the subject was on the agenda of the The International Maritime Organisation (IMO). IMO's Marine Environment Protection Committee (MEPC) has adopted new measures which will reduce air pollution from ships, in the form of a new Annex VI to the International Convention for the Prevention of Pollution from Ships, 1973, as modified by the protocol of 1978 (MARPOL 73/78).

At another hand, extremely low NOx emissions have been demonstrated in long-term service with many kinds of marine engines. A group of leading diesel engine manufacturers have put more attention on developing the next generation of lightweight, high thermal efficiency engines with lower NOx emissions.

There is no doubt that Annex VI of MARPOL 73/78 will enter into force in the near future. The best answer to comply this new requirement is getting ready for maritime academies to educate and train MET students and marine engineers. To assist maritime academies and their teaching staff in organising and introducing courses for this new requirement of air pollution from ships, a new programme for MET, which consists of teaching objectives, outline, and detailed teaching syllabus, has been developed. This programme can be used as a separate intensive short training course, or as part of a coherence course connected to the relevant IMO Model Course.

As the conclusions, the maritime academies should put more attentions on the following things:

1. The new educational training programme, or training course concerning the air pollution from marine diesel engines should be added into the present lectures for the MET students as soon as possible. Also, it should be given to the present marine engineers as the update training course.

2. Concerning the development of engineering technology in marine diesel engines and the techniques of controlling emission, also international legislation which can cause the changes in the training aims, objectives and training contents, the training content of the training programme should be updated and modified at a certain period of time.

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