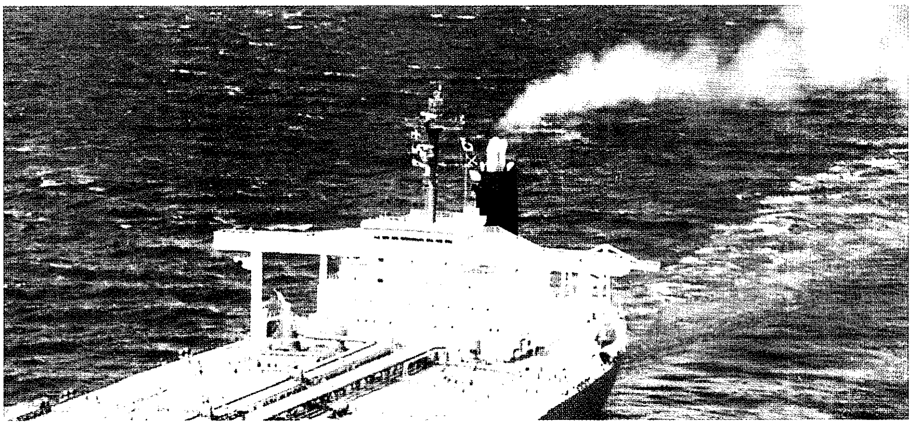
Technical Essay

The Control of NOx Emissions



Moves towards the control of NOx emissions

In recent years, the problem of environmental pollution has become a matter of growing concern around the world. This is partially reflected by the tendency towards instituting ever stricter controls on air pollution caused by exhaust gases. Common pollutants from exhaust emissions include carbon monoxide (CO), carbon dioxide (CO_2), nitrogen oxides (NOx), sulphur oxides (SOx), freon, and halons, amongst others. Of these, freon and halons have been attributed to the depletion of the ozone layer, while NOx and SOx are acknowledged as leading to the formation of acid rain. In addition, NOx and hydrocarbons, another common exhaust emission, are also cited as a major cause of photochemical smog.

Exhaust gases released from ships have not been exempted from these concerns, either. In 1990, the 30th session of the Marine Environment Protection Committee of the International Maritime Organization (IMO/MEPC 30) set target levels for reducing air pollution from ships after consideration of this issue had begun two years earlier. A list of and timetable for achieving these levels is shown in Table 1. Discussions have also been held by the IMO regarding the implementation of methods for monitoring and controlling NOx and other gas emissions from marine engines along with a wide variety of related measures. New requirements have been set forth in the draft of MARPOL Annex VI: *Regulations for the Prevention of Air Pollution from Ships* which is scheduled to apply to engines installed onboard ships on or after 1 January 2000. A *Technical Code on Emission of Nitrogen Oxides from Marine Diesel Engines* is being finalized as well which outlines in further detail the tests, inspections and certifications to be performed under the new MARPOL requirements. The proposed controls and Technical Code were since adopted at IMO/MEPC 40 held this past September.

Table 1 Target reduction levels of air pollutants from ships (IMO/MEPC 30, 1990)

Freon	80% of current level	By 1993
	15% of current level	By 1997
	Use prohibited*	By 2000
Halons	50% of current level	By 1995
	Use prohibited*	By 2000
SO_2	50% of current level	By 2000
NOx	70% of current level	By 2000
Volatile organic compounds (VOC)	70% of current level	By 2000
Regulations for incinerator exhaust gases		By 2000

* Total abolition

Technology for reducing NOx emission levels

Much effort has been placed on the development of effective methods to control NOx emissions in recent years. Measures for reducing such emissions can be broadly classified into two types:

(1) those which reduce the amount of NOx produced during combustion, and
(2) those which eliminate NOx emissions from exhaust gas.

NOx production can be reduced during combustion by decreasing maximum combustion pressure, injecting water into the combustion chamber, using emulsified fuel, or lowering combustion temperature, amongst others. Methods of removing NOx from exhaust emissions include the use of catalysts which are used to chemically treat NOx to form other less harmful substances. Most notable of these is the selective catalytic reduction (SCR) method in which exhaust NOx is combined with urea at high temperature to form water and nitrogen gas.

Approaches for reducing NOx given the greatest consideration for actual use onboard ships have consisted mainly of relying on SCR alone or employing SCR in conjunction with water emulsified fuel. These methods also have the least impact on engine performance during operation. Reductions in NOx emissions of up to as much as 90% are reportedly possible using these methods.

Summary of research by ClassNK

As increasingly stringent requirements are developed for reducing air polluting emissions, more accurate means of measuring and monitoring such pollutants are essential to the effective implementation of these requirements, especially at sea. However, a number of challenges still need to be resolved before accurate and practical techniques for measuring and controlling exhaust emissions from marine diesel engines can be adopted in actual practice. While technologies for measuring various emissions from land-based facilities are fairly well developed, much work still remains to be done before suitably comparable methods can be readily adapted to shipboard use on a regular basis.

One reason that accurate shipboard measurements pose such a challenge is the nature of the differences normally encountered in the operating conditions between land-based facilities and those at sea. Facilities on land make use of measuring equipment which is usually significantly larger than that available for use onboard ship and which can be used without regard for weather or other environmental factors. Shipboard conditions, on the other hand, often contrast sharply with those found on land as the operating environment is continually changing, both in terms of the sea and the ship. Consideration also needs to be given to the type of measuring equipment used for marine diesel engines, particularly large-scale, low-speed engines for ocean-going ships, as compared with that used for automobile engines and shore-based machinery. Such equipment must be not only be reliable, but practical and portable as well.

In response to this need, the ClassNK Research Center has carried out measurements on the exhaust emissions of thirteen different 2-stroke and 4-stroke marine engines of various sizes during shop and sea trials since 1993 in order to better understand the characteristics of

Table 2 Particulars of measuring devices used

Measuring principle:			CLD	ECC
Manufacturer:			Horiba, Ltd.	Testoterm GmbH & Co.
Type:			EXSA	testo33
Items measured:			NO_x, O_2	NO, NO_2, O_2, CO, SO_2
NOx	Measurement range (ppm):		0–2000	0–2000
NOx	Accuracy	Reproducibility	±1% FS	±1% FS
NOx	Accuracy	Drift	±1% FS/day	—
NOx	Accuracy	Temp. sensitivity	±1% FS/10°C	±1% FS/5°C
NOx	Accuracy	Response time	10 sec.	≤60 sec.
Sampling tube:			Heated	Heated
Dimensions (W × H × D, mm):			430 × 310 × 550	200 × 400 × 300
Approx. weight:			30 kg	8 kg

Note: Dimensions and weight include pre-processing equipment.

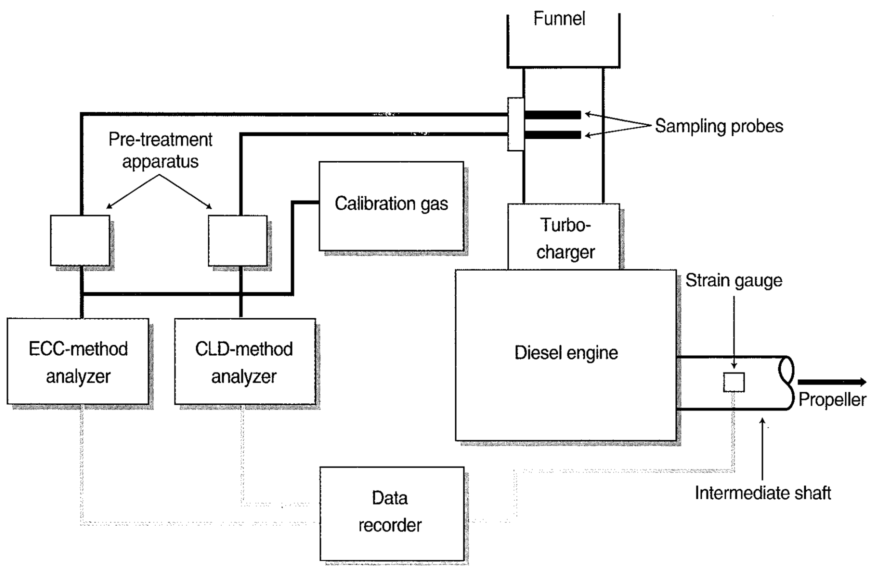


Fig. 1.1 Schematic diagram of measuring system

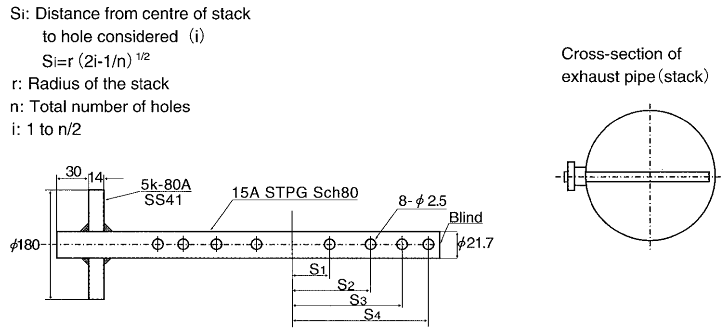


Fig. 1.2 Sampling probe initially used

NOx emissions as well as to develop more practical methods of measuring such emissions. Measurements have also been carried out on three diesel marine engines during actual operation at sea with the aim of understanding how NOx emissions from ship engines fluctuate under dynamic sea conditions. The data obtained from these results will also serve as means of assessing how exhaust emissions and engine performance change over time.

Two types of analyzers have been used and compared in these studies. One is the chemiluminescent detector or CLD method, while the other is the electrochemical measurement cell or ECC method. The two methods are based on differing measurement principles. In the CLD method, NOx levels are determined by measuring the light emitted when NO is converted to NO_2 in the presence of ozone. In the ECC method, on the other hand, changes in electrical resistance of the target gas are measured as it passes over electrochemical cells. An outline of the two methods is shown in Table 2. In order to understand better the relation between the volume of NOx emissions and the operating conditions of the engine, a variety of general performance tests were also conducted on each engine evaluated. Analysis of the measurements consisted of comparing the exhaust characteristics of each engine under shop and sea trial conditions, as well as examining objective methods of evaluating the amount of NOx emissions produced in each case.

Figure 1.1 is a schematic diagram of the measuring system used in these trials. The straight pipe portion of the flue from the turbocharger exhaust gas outlet to the inlet of the exhaust gas economizer and composite boiler serves as the sampling point for the exhaust gas.

Sampling is done by inserting a single-holed probe into the exhaust pipe and collecting samples of exhaust gas across the entire diameter of the pipe. A multi-holed probe was used in order to obtain an average distribution of gas density across the section of pipe being sampled. However, comparative tests with single-

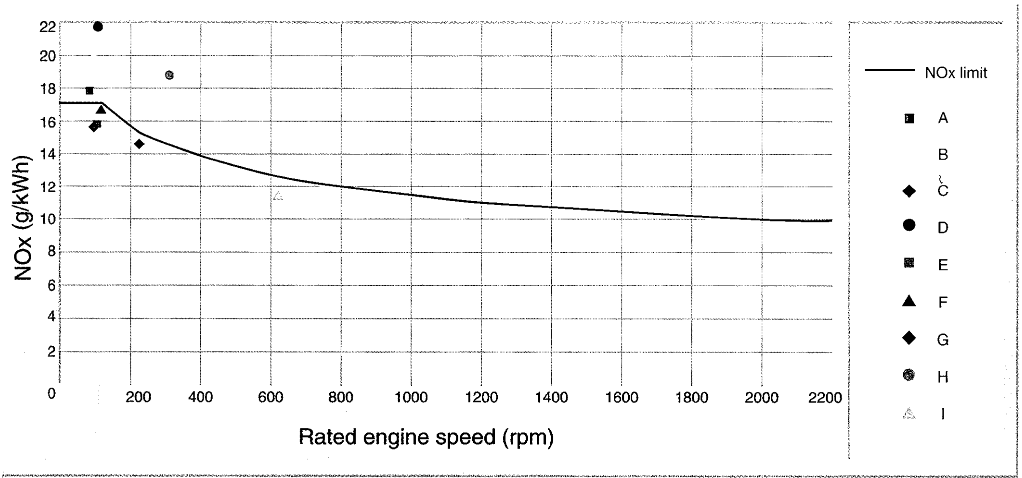


Fig. 2.1 Sample of measurement results obtained during shop trials of various marine engines using the CLD method. The solid curve indicates the NOx limits under MARPOL.

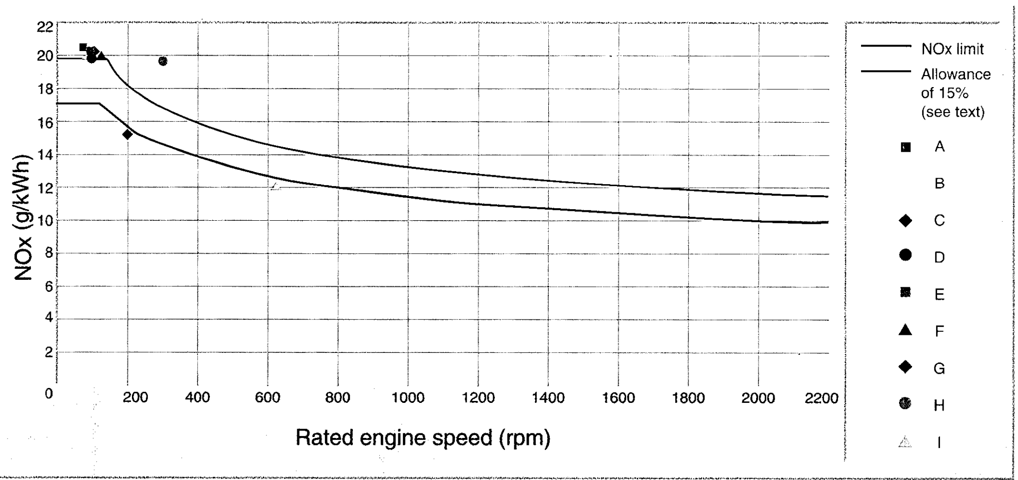


Fig. 2.2 Sample of measurement results obtained during sea trials of various marine engines using the CLD method. The solid curve indicates the NOx limits under MARPOL. The red curve indicates the 15% allowance for RM-grade fuel (see text).

holed probes showed essentially the same results being measured as those obtained with the multi-holed probe. A diagram of the multi-holed sampling probe is shown in Figure 1.2.

The results of shop and sea trial measurements made are shown in Figures 2.1 and 2.2, respectively. The NOx exhaust rates (g/kWh) for different engines (indicated as items A-I in the figures) during shop and sea trials are plotted. The IMO NOx control curve for engines for which no reduction measures are taken is superimposed on each graph. Figure 2.2 also includes a superimposed graph of the maximum values permissible (an allowance of 15%) in cases where RM-grade fuel (specified in ISO 8217) is used and measurements are made at sea using a simplified measurement method. As can be seen from the two figures, measures to reduce NOx emissions will need to be implemented for most of the diesel engines examined before they can satisfy the new requirements.

Differences in the measured values in both figures for the same engine can be attributed to a number of factors. First, engine operating conditions are highly susceptible to changes in sea and weather conditions. Further, engines do not operate at a constant rpm but are changing continuously. There are also fundamental differences in engine load and output between shop tests and sea trials making objective evaluation practically impossible because of differences in the measured values.

The results obtained thus far indicate that the CLD and ECC methods are comparable to each other, particularly under sea conditions (see Table 3). Given the greater portability of measuring equipment based on the ECC method and thus greater convenience in terms of shipboard use, this method is believed to be an appropriate alternative to the CLD based method currently recommended by ISO requirements.

Table 3 Comparison of measured results obtained with ECC and CLD methods under different rated engine conditions

	Engine :	A	B	C	D	E	F	G
Shop	ECC method (g/kWh)	—	—	—	1,779 (21.91)	1,467 (16.29)	1,670 (18.89)	1,561 (18.34)
	CLD method (g/kWh)	—	—	—	1,736 (21.38)	1,475 (16.45)	1,684 (19.03)	1,543 (18.12)
At Sea	ECC method (g/kWh)	1,617 (21.21)	1,524 (25.51)	1,655 (24.61)	2,090 (23.49)	1,549 (17.98)	1,660 (21.70)	1,597 (18.58)
	CLD method (g/kWh)	1,458 (19.12)	1,373 (23.01)	1,348 (20.06)	1,883 (21.16)	1,413 (16.41)	1,774 (12.94)	1,520 (17.72)

Conclusion

Measurements are currently being carried out and data collected and analyzed at regular times each year on one selected Japanese flag coastal service vessel and one ocean going vessel in order to gain better insights into how emissions change over several years of normal operation. Until now, there have not been many reported examples of regular measurements being taken for engines during shop tests, sea trials as well as actual operation spanning their new construction through first few years of use. The collection and analysis of such data will not only be indispensable to reviewing new NOx control standards both before and after they have been established, but essential to the development of consistently accurate and readily useable emissions measuring equipment which contribute to the effective reduction of NOx and other harmful pollutants ships at sea.

Appraisal of NOx emissions

The Society has already begun to carry out NOx assessment work from April of this year in order to realize a smooth transition to being able to issue statutory certificates (IAPP: International Air Pollution Prevention Certificate, and EIAPP: Engine International Air Pollution Prevention Certificate) when new mandatory controls set forth in MARPOL Annex VI go into effect on 1 January 2000. At this point in time, there are two types of NOx assessments: one in keeping with the issuance of statutory certificates when the new requirements go into effect, and a general assessment which is not based on these requirements. Since all assessments will need to be of the former type when the new requirements go into effect, in principle, it is necessary that all NOx assessments be conducted in accordance with the proposed test method which conforms with the draft Technical Code.