JANUSZ ŁEPKOWSKI, D.Sc.,M.E.
Technical University of Gdańsk
Faculty of Mechanical Engineering
Chair of Combustion Engines and Compressors

Evaluation of NO_x emission from marine diesel engines in the light of IMO new draft limitations

SUMMARY

In the paper the present state of NO_x emission from marine diesel engines is evaluated. IMO proposals of NO_x limitation for new ships and the relevant engine test cycles are reviewed. The NO_x emission level at maximum continuous rating of different two-stroke and four-stroke diesel engines, currently available on the market, are presented. The weighted specific NO_x emission from those engines is estimated in accordance with the ISO 8178 test cycles and compared with the IMO new draft limitations.

The paper presented at XVIIth International Symposium on Ship Power Plants, Szczecin, 1995

INTRODUCTION

Elaboration of the annex to MARPOL 73/77 Convention, titled „ Prevention against air pollution from ships including fuel quality", is continued within the International Maritime Organisation for several years. Proposals of the permissible NO_x (nitric oxides) content in exhaust gases of marine diesel engines were adopted at the 24th session of the IMO-BCH Subcommittee, held in 1994 [1].

A total NO_x emission from a fuel oil combusting engine(during a relevant test cycle and with appropriate measurement methods applied), calculated as the total weighted specific emission converted to NO_2 equivalent, is to comply with the limitations given in Tab.1 against the engine's rated speed.

Tab. 1. NO_x emission limit values proposed by IMO-BCH Subcommittee

Engine rated speed [rpm]	NO_x emission limit value [g/kWh]
$n < 130$ $130 < n < 2000$ $n > 2000$	≤ 17 $\leq 45\ n^{-0,2}$ $\leq 9{,}84$

The test cycles adopted in the proposals are in accordance with the ISO 8178 standard, part 4. The cycle E2 (Tab. 2) is valid for ship main engines working with constant speed , but the cycle E3 (Tab. 3) - for the engines working in compliance with propeller characteristics. The cycle D2(Tab. 4) is applicable to auxiliary engines driving electric generators.

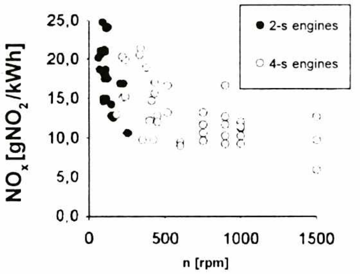
In spite of the long-lasting and complicated legislative procedure leading marine engine producers have already started intensive investigations on how to adjust their products to the expected limitations. In many publications information may be found dealing with different methods of depressing NO_x emission. Sometimes the information comprises evaluation of technical and economic aspects of application of the methods. However, amounts of emission from the marine engines, actually produced and those in service, are not publicly known. That is why it is hard to determine how much NO_x emission of engines of particular groups has to be lowered to fit the new limitations, and in consequence which of the emission reducing methods are the most applicable. This paper is aimed at extending the information on the problem in question.

EMISSION OF NITRIC OXIDES AT ENGINE RATED LOADING

In very few publications one can find information on the NO_x emission from marine engines. It is presented there in different ways either in function of engine loading within some its field of operation or in a given point only (usually this is the point of MCR, maximum continuous rating). As a rule the emission is expressed as a volumetric NO_x content in exhaust gas at a given oxide content.

To make further comparisons possible, emission amounts, obtained from the literature sources [2, 3, 4, 5, 6, 7, 8], are converted into the proposed standard unit [g NO_2/kWh] and in Fig. 1a, 1b the emission from 2-stroke and 4-stroke engines under rated loading is presented versus engine rated speed and specific fuel oil consumption, respectively.

a)



b)

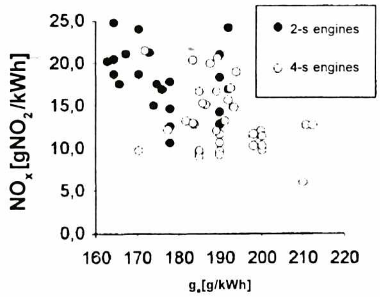


*Fig. 1. NO_x emission content in exhaust gas from marine engines under their rated loading versus: **a)** rated speed n [rpm], **b)** specific fuel oil consumption g_e [g/kWh]*

Though a rather high dispersion of the emission values can be observed , the lower engine's rated speed (which is bound usually with growing size of the engine) the greater NO_x emmision (Fig. 1a). This can be justified first of all by a longer staying time of reacting substances in high temperature zones during combustion. It is hard to find any definite relationship between NO_x emission and the specific fuel oil consumption g_e , (Fig.1b) , but a tendency could be observed of growing NO_x emission value with decreasing g_e value (i.e. with increasing efficiency).

Estimation of the weighted value of NO_x emission from marine engines during E2, E3 and D2 test cycles

The data presented in Fig. 1., in spite of being converted to the units compatible with the ISO standard, do not allow to compare the estimated emission levels with those proposed by IMO.

The reason is that weighing factors and relationships between emission and engine load are different, as they depend on assignment of an engine to a given type group.

Therefore to obtain even an approximate picture of the phenomenon, it is necessary to estimate the weighted specific value of NO_x emission relevant to a given engine test cycle (Tab. 2, 3, 4).

Tab. 2. Weighing factors for main engines of ships of any length, working with constant speed

E2 test cycle

Rotational speed	100%	100%	100%	100%
Power	100%	75%	50%	25%
Weighing factor	0,2	0,5	0,15	0,15

Tab. 3. Weighing factors for main engines of ships of any length, working acc. to propeller characteristics (curve)

E3 test cycle

Rotational speed	100%	91%	80%	63%
Power	100%	75%	50%	25%
Weighing factor	0,2	0,5	0,15	0,15

Tab. 4. Weighing factors for electric generator engines , working under jump loading

D2 test cycle

Rotational speed	100%	100%	100%	100%	100%
Power	100%	75%	50%	25%	10%
Weighing factor	0,05	0,25	0,3	0,3	0,1

The calculations were carried out for all those marine engines whose data on changing NO_x emission with changing engine load were known to this author. For the engines the weighted emission value was estimated in accordance with a relevant test cycle (E2, E3, or D2) and compared with that under rated load (MCR).

The calculation results are presented in Tab. 5, 6 and 7, where engines are characterized by their stroke number, rated speed and cylinder bore. Other details are omitted as this paper is aimed at providing a general trend only.

Tab. 5. Comparison of the weighted, specific NO_x emission value during E2 test cycle and that under rated load (MCR)

Speed n [rpm]	Cylinder bore D [mm]	NO_X (MCR) [g/kWh]	NO_X (E2) [g/kWh]	NO_X(E2) / NO_X(MCR)	Stroke number
100	800	21,1	17,6	0,834	2
100	900	16,8	15,2	0,905	2
117	600	11,7	11,3	0,966	2
117	600	11,7	13,0	1,111	2
119	670	24,2	21,6	0,893	2
150	550	12,7	13,4	1,055	2
227	450	16,9	12,8	0,757	2
426	570	9,8	11,6	1,180	4
750	320	10,7	11,8	1,100	4
900	200	9,2	9,4	1,022	4
1000	200	11,4	12,6	1,105	4
1000	255	10,2	10,6	1,039	4

On the basis of these results one can state, however being aware of all the conventionality of such statistical considerations, that the weighted value of emission from marine engines, which ISO-E2 test cycle is applicable to, is practically equal (within ± 12% discrepancy range) to the emission value under rated load (MCR).

Tab. 6. Comparison of the weighted, specific NO_x emission value during E3 test cycle and that under rated load (MCR)

Speed n [rpm]	Cylinder bore D [mm]	NO_X (MCR) [g/kWh]	NO_X (E2) [g/kWh]	NO_X(E2) / NO_X(MCR)	Stroke number
97	900	18,3	19,5	1,066	2
97	900	14,9	18,1	1,215	2
97	900	14,6	19,2	1,315	2
100	700	11,2	12,1	1,080	2
103	800	21,0	21,7	1,033	2
117	600	11,5	12,8	1,113	2
117	600	14,9	17,1	1,148	2
150	670	14,2	18,1	1,275	2
426	570	9,8	12,8	1,306	4
900	250	16,6	16,4	0,988	4
1000	200	11,4	14,9	1,307	4

The weighted value of emission from the engines, which E3 test cycle is applicable to, is in average about 17% greater than the emission value under rated load (MCR) (within ±10% discrepancy range). Similar calculations were carried out for the engines which D2 test cycle is applicable to, i.e. electric generator driving engines.In Tab. 7. therefore only 4-stroke engines with typical parameters of the engine group were taken into account . In this case the weighted emission value is about 7% greater than the emission value under rated load (within ±5% discrepancy range).

Tab. 7. Comparison of the weighted, specific NO_x emission value during D2 test cycle and that under rated load (MCR)

Speed n [rpm]	Cylinder bore D [mm]	NO_X (MCR) [g/kWh]	NO_X (E2) [g/kWh]	NO_X(E2) / NO_X(MCR)	Stroke number
750	320	10,7	10,7	1,000	4
900	200	9,2	9,5	1,033	4
1000	200	11,4	12,6	1,105	4
1000	255	10,2	10,6	1,039	4
1500	200	6,0	6,9	1,150	4

On the basis of the weighing factors given above the emission values were recalculated assuming the following standard working conditions:

- for 2-stroke engines: in compliance with propeller characteristics (curve)
- for 4-stroke engines with rated speed up to 600 rpm: at constant speed (E2 test cycle)
- for high-speed 4-stroke engines: electric generator drive mode (D2 test cycle)

The results are presented in Fig. 2. where a curve of the emission limitations proposed by IMO is also drawn.

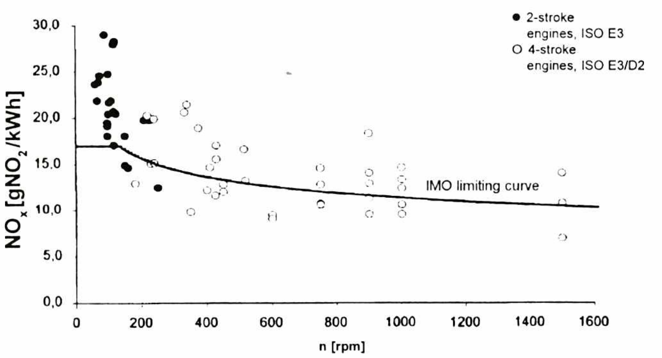


Fig. 2. The weighted, specific NO_x emission from marine engines (tested in accordance with ISO E2, E3 and D2 cycles) compared with the IMO draft limitations

It can be observed from the comparison that the emission from 2-stroke engines is the most difficult case, where a substantial reduction of the emission is necessary (even as much as by 50%). This may be hard to achieve by using the so-called primary methods without lowering either engine efficiency or its specific power. But as far as the 4-stroke engines are concerned it may be sufficient to reduce the emission by about 20÷30%. It is worthwhile to mention that many engine types offered recently on the market already comply with the IMO proposals.

In Fig. 3, in addition to the investigations reported above, a difference is given of the weighted, specific NO_x emission values from the same main engine depending on its working mode: that in compliance with propeller curve and that at constant speed.

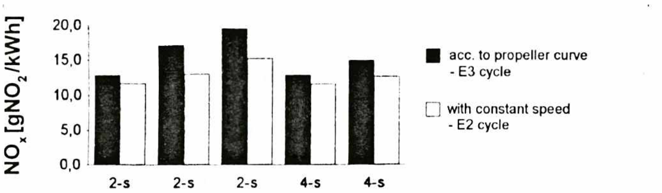


Fig. 3. NO_x emission values from the main engines working in compliance with propeller curve (E3 test cycle) compared with those from the same engines working with constant speed (E2 test cycle)

It can be seen in Fig. 3 that application of both 2-stroke and 4-stroke engines in propulsion systems with a controllable pitch propeller leads to a lower NO_x emission during ship operation than in those with a fixed pitch propeller. Although the phenomenon is widely observed [3], a general conversion of the propulsion systems cannot be expected only for the reason of adhering to the requirements of toxicity standards.

CONCLUDING REMARKS

At the actual stage of elaboration of the annex to MARPOL 73/77 Convention it was adopted that the emission standards have to deal only with engines intended to be installed in new ships. The new standards will not concern any existing object at the moment of their entering into force. So the engine producers have a sufficient time to introduce appropriate changes to their products. Therefore it may be expected that new generations of engines fulfilling new standard requirements will appear soon. As all technical and economical aspects connected with establishing permissible emission levels are well known to the expert group which prepare the new standard the limitation method just proposed is a very moderate version of that initially intended. Nonetheless, the limiting levels adopted are considered as the first step only in establishing effective prevention measures against pollution of air from ships. Undoubtedly it has been decision makers' intention to avoid broad application of the expensive methods of reducing NO_x emission such as e.g. the selective catalytic reduction (SCR).

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Appraised by Andrzej Balcerski, Assoc.Prof.,D.Sc.

Conferences

MARINE TECHNOLOGY ODRA '95

On 20÷22 September 1995 Pomeranian Prince's Castle in Szczecin hosted Ist International Marine Technology Conference ODRA'95 which was organized by common efforts of Faculty of Marine Technology (Technical University of Szczecin), British Wessex Institute of Technology, Polish Academy of Sciences, The Association of Polish Maritime Industries, Polish Register of Shipping, President of Szczecin Province and Bureau Veritas.

125 experts representing shipbuilding industry and ship research centres, many of them from abroad (Denmark, Egypt, Finland, France, Greece, Spain, Japan, Germany, Norway, Portugal, Russia, Great Britain and Italy) participated in the conference.

74 papers prepared by 60 authors of the a.m. countries and China, and 71 papers by Polish authors were presented during several plenary sessions and 16 topic sessions.

Proceeding of the conference showed that many Polish achievements in marine technology are comparable with those of the countries of much longer maritime tradition. Therefore it seems that Szczecin was properly selected as the conference location and Szczecin Shipyard, one of the best in Europe, was worthwhile to be presented.

The conference was accompanied by a technical exhibition where the latest developments of several firms in CAD/CAM technology were presented.

As the conference ended with full success the organizers intend to prepare the next such meeting, Marine Technology ODRA'97, in two years.