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Preliminary investigations on a simplified measurement method of nitric oxides emission during cold starting of diesel engine

SUMMARY

In the paper a concept of a simplified assessment method of amount of nitric oxides emitted by a ship diesel engine is presented together with preliminary investigations carried out to verify the proposed concept. The research was based on the requirements of IMO Technical Code on limitation of NO_x emitted from ship diesel engines.

INTRODUCTION

Compounds of nitric oxide group (NO, NO_2) marked NO_x belong to the most toxic gases produced by ship combustion engines in operation. About 5 to 7% amount of nitric oxides due to mankind activity come from ship combustion engines [6]. The compounds entering the atmosphere become assimilated with water and contribute to occurrence of acid rains. The nitric oxides (mainly NO_2) react also with ozone causing its degradation in upper layers of the atmosphere [2]. For that reason in 1997 International Maritime Organization (IMO) adopted Appendix VI to the MARPOL 73/78 convention on prevention of air pollution by ships [7]. Its integral part is the Technical Code on limitation of NO_x emission from ships [3] in which the limiting values of emission of nitric oxides are given for the ship engines produced or modernized after 1 January 2000. IMO also issued the circular titled Preliminary guidelines for application of NO_x Code [1] endorsing to verify NO_x emission in accordance with the recommended values before the date of entering in force the Appendix VI in question, i.e. 1 January 2003.

About 35% of older ship combustion engines fulfil the above mentioned strandards without any modifications. However to be sure that every engine complies with the limiting values of NO_x emission it should undergo the following surveys [3] :

- the preliminary survey before installation of the engine on board, which is usually carried out by the engine's producer
- the basic survey which is carried out after fitting the engine on the ship, but before putting it into operation, as well as when its major modification has been performed
- the periodical and intermediate surveys which should be carried out during relevant ship's surveys.

In the Code five methods for determination of NO_x emission are provided to test if the requirements are complied with, including the direct measurements on board.

The methods excellently fulfil their role in the case of measurements during stand tests performed by the engine producers. Much more difficult and costly is to carry out such tests directly on ships, e.g. during periodical or intermediate surveys. Therefore in the Code a simple and practical set of requirements is given for checking compliance with the limitations during the above mentioned surveys of the engines. In the Code it is provided a.o. that :

- it should be possible, for the shipowner, to directly measure NO_x emission from the ship engine during service
- it is necessary to collect a sufficient amount of data for calculation of the weighted average of the NO_x emission in order to show compliance with the standards in the case of applying the direct measurement method.

The set of requirements imposes some confines for determining NO_x emission. According to them the shipowners are allowed to elaborate their own detail procedures for direct measurements on board provided they would comply with the Code regulations. In the case of shipowners operating a small number of ships it would be rational to elaborate procedures which could limit costs by considerable shortening time of measurements thus saving fuel and engagement of ship crews.

CONCEPT OF A SIMPLIFIED METHOD OF MEASUREMENTS OF NITRIC OXIDES EMITTED FROM SHIPS

Measurements of emission of nitric oxides carried out on board in accordance with the cycles of the tests provided in the Code are troublesome and time-consuming. The shipowner's own detail procedures allowed by the Code are particularly important in the case of after-damage repairs during which the set values of the parameters responsible for emission of nitric oxides from the engine could be changed.

An effective solution could be to measure NO_x concentration just during the so-called cold engine starting without waiting for stabilization of all its working parameters. The concept is based on the assumption that the measurement taken during engine starting can give a picture of NO_x concentration during further operation of the engine. The cold starting of the engine is understood as the time from the start of engine to the stabilization of fuel consumption value.

Development of such a procedure requires a time consuming research. In general, such testing procedure should contain, a.o., the following :

1st determination of NO_x emission characteristics during engine starting in function of time, including determination of the time after which thermodynamically stable operation of the engine occurs that should be equivalent to the NO_x concentration of a constant value

2nd determination of NO_x concentration characteristics in different working points of the engine i.e. at different engine loads and rotational speeds

3rd determination of NO_x concentration characteristics as in points 1. and 2. but for different engine failures assumed to increase NO_x emission

4th finding a relationship between NO_x concentration - in function of engine load, speed, atmospheric conditions - and other parameters which could influence amount of NO_x emission.

In this paper results of preliminary investigations are presented, with a view to assess if elaboration of such procedure is possible.

DESCRIPTION OF THE INVESTIGATIONS

The investigations were performed with the use of a one-cylinder, two-stroke, crosshead diesel engine of straight-through scavening system. The engine was charged by means of the Roots blower independently driven by an electric motor of infinitely variable adjustment of rotational speed. The choice of the engine was justified by the following premises :

- lack of influence of other cylinders on NO_x concentration
- possible change of air excess value
- complete measurement instrumentation used for other tests
- its availability for the research in question.

The engine was admitted with Eko Diesel fuel oil. The fuel contains a very low amount of nitrogen which makes it possible to neglect influence of nitrogen content in the fuel on NO_x emission from the engine. The engine loading was realized by means of a water brake. The measuring equipment made it possible to measure NO_x concentration from and working parameters of the engine. In particular, values of the following parameters were measured :

- ✓ chemical composition of exhaust gase including NO_x content
- ✓ rotational speed of the engine and charging air blower
- ✓ engine torque
- ✓ charging air humidity and temperature
- ✓ charging air flow rate
- ✓ fuel consumption
- ✓ exhaust gas temperature.

To investigate influence of particular engine working parameters on NO_x concentration the ppm unit (parts per million) was assumed for NO_x content in exhaust gas, as the larger amount of exhaust gas the higher absolute number of NO_x parts, which next depends on the fuel carge. The NO_x concentration was measured by means of CPE (controlled potential electrolysis) exhaust gas analyzer.

The test engine was periodically indicated to confirm its unchanged technical state along with time. The tests consisted of two parts :

- ➔ the measurements during cold starting of the engine at a constant rotational speed and torque
- ➔ the measurements at a constant rotational speed and various water brake loading.

The first part of the tests consisted in starting the engine and rapid (for 3 to 5 min) loading it up to 25% of the rated torque value. 50% of the rated rotational speed was then established, i.e. 300 rpm at the rotational speed of charging air blower so controlled as to obtain the constant value of the air excess number : $\lambda = 4.8$. Such a large value of the air excess number results from the possibility of maintaining it on a constant level in the whole engine load range. The blower speed was continuously corrected to maintain the set air excess value. In the same time values of the engine working parameters were continuously recorded (except of fuel consumption which was measured periodically at every ca 6 min interval because the measuring method by means of a scaled measurement tank was applied). The result recording was completed when the fuel consumption obtained a constant value, i.e. after about 50 min.

The second part of the investigations consisted in recording values of the engine working parameters at 25%, 40%, 50%, 61% and 71% values of the engine rated output first during increasing and then decreasing the output step by step. At every loading state values the engine working parameters were recorded for 5 to 7 min. After the performed tests all engine systems were left inoperative for at least 20 h.

In the first part of the tests 10 observations were performed and 11 ones in the second part, however it was necessary to reject one observation out of each part of the tests due to a failure of the measuring equipment. The investigations were carried out in summer at different weather conditions.

DETERMINATION OF CHARACTERISTICS OF NO_x CONCENTRATION DURING COLD ENGINE STARTING

In accordance with [2] and [5] the emission of nitric oxides from the engine is decisively influenced by the combustion temperature and pressure, time of staying of nitrogen at such conditions as well as amount of nitrogen delivered to the cylinder. Therefore all engine working settings and parameters of influence on the above mentioned factors should also influence the emission of nitric oxides.

To investigate the influence of the engine working parameters on NO_x concentration during the engine starting all observed values of those parameters were grouped into a common matrix. Then the correlation analysis of the obtained measurement results was performed and diagrams of changes of the observed parameters in function of time were elaborated. The detail results of the investigations are given in [4]. From the investigations it results that the characteristics of the NO_x concentration during cold starting of the engine is constant in function of time, at given confines, (Fig.1). Particular measurement results deviate from the mean value by no more than 9%, if a single, obviously erroneous result is rejected, moreover the mean values of the particular observations do not deviate more than by 5.6% from the mean. The deviations could be due to the measurement inaccuracy.

Also, different atmospheric conditions during particular observations could be of some importance. Small deviations from the mean value could be caused by changes of environmental temperature and humidity. However it seems necessary to continue the investigations at a broader range of air temperature and humidity changes. During the performed tests it was observed that the value of NO_x concentration during the engine starting did not essentially depend on changes of other parameters which simultaneously changed their values e.g exhaust gas temperature and fuel consumption (Fig.1).

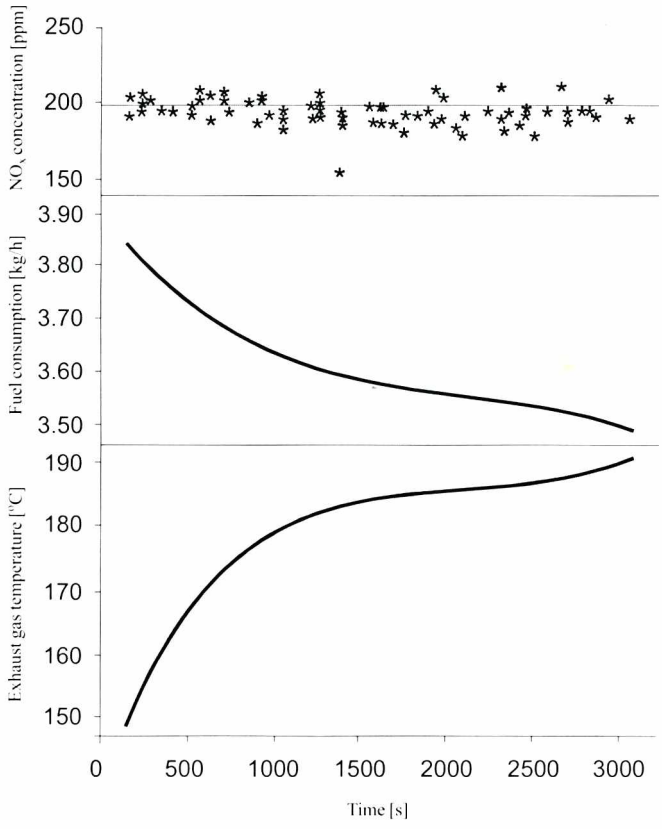

Fig.1. NO_x concentration [ppm], fuel consumption [kg/h] and exhaust gas temperature [°C] in function of time during cold starting of the engine

Hence it can be concluded that :

- it is possible to perform the NO_x concentration measurement in the initial period of the engine starting without any need of waiting for all engine working parameters become stationary
- such measurement could contain important information on NO_x concentration during further operation of the engine.

DETERMINATION OF NO_x CONCENTRATION CHARACTERISTICS IN DIFFERENT WORKING POINTS OF THE ENGINE

The investigations of NO_x concentration in different working points of the engine were performed at a constant value of the air excess number. Load increase of the engine at a constant rotational speed caused increasing concentration of NO_x (Fig.2) because the greater engine load the greater combustion pressure and exhaust gas temperature (Fig.3).

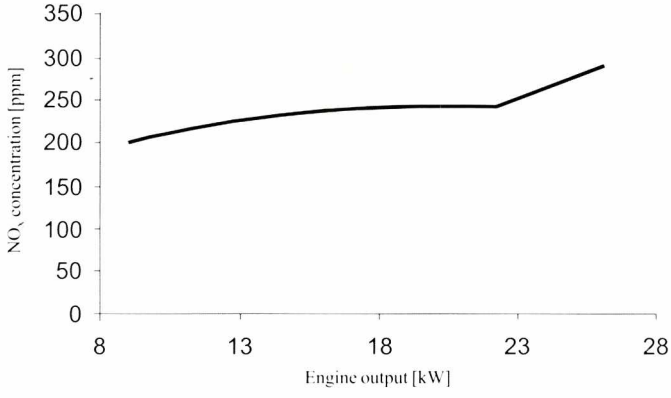

Fig.2. NO_x concentration in function of engine output at constant value of air excess number and engine rotational speed

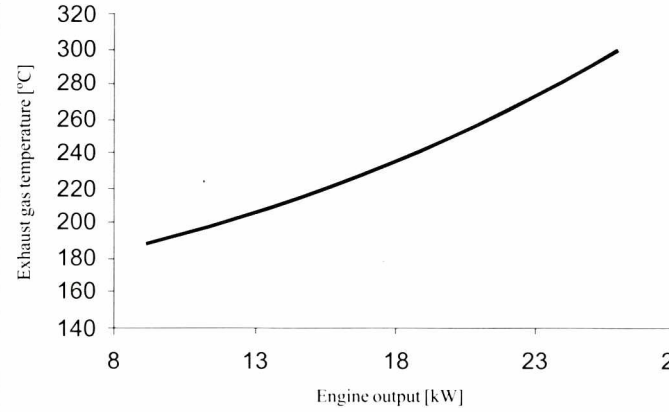

Fig.3. Change of exhaust gas temperature in function of engine output

The relationship between the NO_x concentration during the cold starting and NO_x concentration during further operation of the engine was also checked. The mean values of NO_x concentration in each observation of two parts of the investigations were compared. Figure 4 presents the mean NO_x concentrations in the second part of investigations (change of load at n = const.) against the mean concentration during the cold starting of the engine (the first part of investigations) in a given observation.

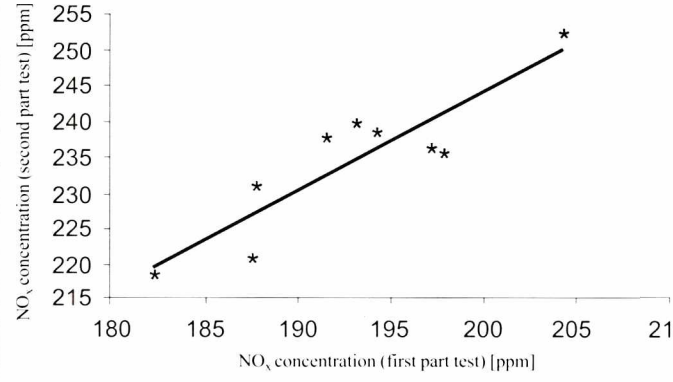

Fig.4. Relationship of the mean NO_x concentration obtained during the second part of investigations to the mean NO_x concentration obtained during the first part of investigations

An analysis of the obtained results makes it possible to assume that the NO_x concentration characteristics determined during cold starting of the engine can contain information on the concentration during its further operation as such relationship really occurs. Therefore it is necessary to more precisely determine the character of the NO_x concentration in function of the engine output. In the performed preliminary investigations this was not possible because of too low number of measurement points.

CONCLUSIONS

On the basis of the performed investigations the following conclusions can be offered :

- NO_x concentration in [ppm] during cold starting of the engine is constant in function of time with only small deviations from the mean value.
- NO_x concentration during cold starting of the engine does not essentially depend on other working parameters of the engine which have changed their values during the tests.
- A relationship of the NO_x concentration during cold starting of the engine and the NO_x concentration in other working points of the engine really occurs.

- The results obtained from the preliminary investigations make it possible to deem the assumption on possible estimation of NO_x emission from the engine on the basis of the measurements during its cold starting, to be correct.

- Further research is necessary to precisely determine the relationship between the NO_x concentration during cold starting of the engine and that during its further operation.

Appraised by Leszek Piaseczny, Assoc.Prof.,D.Sc.

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Conference

DIAGNOSTICS

Problems of technical diagnostics were the theme of 11th Conference held on 13 to 15 June this year in Borówno close to Bydgoszcz, dealing with :

Diagnostics of work machines and vehicles

and organized by Technical-Agricultural Academy of Bydgoszcz in cooperation with Gdańsk Regional Group, Utility Foundations Section, Polish Academy of Sciences, as well as Polish Society of Technical Diagnostics and State Professional High School in Piła.

39 papers were approved for the conference 25 of which were selected to be presented during the conference and the rest to be only published in the conference proceedings. The papers were prepared by 13 scientific research centres including an institute of Bielorussian Academy of Sciences and a university of Lithuania. Scientific workers of Bydgoszcz University of Technology and Agriculture most contributed to the conference program (13 papers) as well as Technical University of Częstochowa and Warsaw University of Technology (6 papers each).

Themes of the papers appeared very diversified. Only some of them strictly complied with the main topic of the Conference, i.e. diagnostics. The remaining ones dealt with the following problems :

- ★ modelling of technical objects and their operation
- ★ investigation and analysis of energy and fatigue processes
- ★ operational safety of technical devices, as well as
- ★ management of their exploitation and costs.

Due to that topical inconsistence interests of the conference participants were distracted.

FOREIGN conference

IMAM 2002

10th International Congress of the International Maritime Association of the Mediterranean (IMAM) took place at Crete on 13÷17 May this year.

13 papers of Polish authors took an important place among 100 papers prepared for the Congress by representatives of 22 countries.

Most Polish papers (8) were elaborated and presented by scientists from Gdynia Maritime University, namely :

- *Nonlinear control of course – unstable ship : experiments with a physical tanker model*
  by Morawski L., Pomirski J., Rak A.
- *Computer support methods of navigator decisions avoiding accidents at sea* – by Lisowski J.
- *The role of computer based training for marine engineers in increasing safety and reducing human factor error in the operation and maintenance of marine machinery*
  by Cwilewicz R., Tomczak L.
- *Organizational and legislative circumstances for requirements of safe human-machine system design*
  by Hempel L., MalinowskiT., Tarełko W.
- *System aiding setting up of human engineering requirements for designing of safe ship power plants*
  by Hempel L., Kotlicka M., Tarełko W.
- *Concepts of complex services in international transportation* – by Kubicki J.
- *Geographical information system for maritime purposes – ECDIS* – by Weintrit A.
- *Voyage data recorder – expectations and reality*
  by Wiśniewski Z.

Representatives of Polish Naval University presented 2 papers :

- ❋ *Diagnosing of naval gas turbines* – by Charchalis A.
- ❋ *Vibration analysis of unbalancing of gas turbine rotors*
  by Charchalis A., Grządziela A.

One paper was prepared by each author from :

- Technical University of Szczecin :
  - *Design constraints for reliability and safety of remotely operated vehicles* – by Graczyk T.
- Maritime University of Szczecin :
  - *The types of information in the process quality control in quality management systems* – by Wolnowska A.
- Gdańsk University of Technology :
  - *Model of seagiong ship risk assessment*
    by Brandowski A.

Two Polish participants of the Congress chaired its sessions, namely :

- ⅄ Prof. J. Lisowski of Gdynia Maritime University – the session on „Marine Engineering & Ship Equipment"
- ⅄ Prof. A. Charchalis of Polish Naval University – the session on „Accidents at Sea & the Human Factor".