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Notes and comments

The impact of marine engine operation and maintenance on emissions

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ABSTRACT

This paper examines the role of marine engine maintenance in reducing pollution. It tests four marine diesel engines, one constructed prior to January 1, 2000 and three after 2000. This paper explains how the condition of an engine's nozzles and faulty injection pressure significantly influence NO_x and CO emissions and describes both bench and onboard ship tests, on engines fitted with new or worn nozzles at different injection pressures. The tests showed that, when the engine constructed prior to 2000 operates under normal in-service conditions, the emissions are within limits, but, with a small fault in injection timing, the NO_x emissions exceed the limits. For the engines constructed after 2000, a fault in the maintenance of the nozzles increases the CO emissions to a high level.

1. Introduction

The quantity of SO_x generated during combustion is directly related to the sulfur content of fuel oil, although conservation and maintenance in engines can affect the formation of NO_x, CO, CO_2 and particulate matter (PM) produced in the combustion process (Lauer et al., 2009). Some combustion parameters have a particularly significant effect on the formation of NO_x and CO. Delayed injection leads to a lower pressure and temperature throughout most of the combustion, so NO_x production is reduced. Advancing the injection produces an input of fuel when the pressure and temperature in the combustion chamber are lower, which retards the start of the combustion and increases the quantity of fuel that enters during the ignition delay. On the other hand, the interaction between the sprays from individual nozzle holes has a significant impact on NO_x.

Here we present the results of trials conducted on marine diesel engines with maladjustments to the fuel injection system that allow study of engine behavior and NO_x emissions. It also investigates how changes in injection pressures and nozzle conditions influence the emissions.

2. Materials and methods

The work involves three tests looking at emissions of some medium speed engines with faults operating under conditions of between 25% and 100% loading that meet the International Convention for the Prevention of Pollution from Ships Annex VI MARPOL 73/78 Regulation 13 NO_x emission rule.

The first test was conducted on an auxiliary engine built prior to 2000 that did not meet the Annex VI NO_x emission limit. The other two were conducted on propulsion engines built after 2000 that met limit. To investigate the effect of maladjustment of the injection system, an advance in the injection timing from the engines' standard timing was introduced. The engines used had its injection system checked every 1000 running hours with measurements taken when in perfect operational

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condition, i.e., the injection system and other components had been recently revised and overhauled. Some mechanical parts were replaced, including the alternative trains. Once the engine was repaired, the first exhaust gas analysis was taken after running for 200 h; a period necessary to let the new parts become adjusted to the standard condition. A fault was introduced into the injection system, and measurements taken. All trials were performed with the engine on board, and the final set of measurements taken after advancing the injection by 4° in four of the eight cylinders.[1]

The engine had the following characteristics:

Type	4 stroke
Output	700 kW
Engine speed	750 rpm
Number of cylinder	8
Year of construction	1975
Cylinder displacement	14.7 dm^3
Compression rate	12.45:1
Maximum combustion pressure	104 bar

The NO_x values were done according to the Annex VI Technical Code the test cycle also provides the load sequence to be followed when undertaking an emission trial. This mean that results from one engine can be compared with those from other engines on a common basis.[2] All trials were performed under identical ambient pressure temperature, and air humidity conditions and with identical fuel compositions: ISO 8217, DMC grade, C = 86.5%, H = 13.1%, S = 0.060 and density = 0.86 kg/m^3. Because the engines generate of electrical energy, the measurements were taken from the power indicator on the electrical distribution board.

Thus, for each sampling cycle, the data for each loading regime of the engine were analyzed and recorded at a constant speed of 1500 min^{-1}. In addition, during the sampling, the exhaust gas was allowed to flow through the analyzer for at least 10 min for each trial cycle, made possible by conducting the trials on just one auxiliary engine and diverting the load fluctuations to the other auxiliary engines in service.

Both a Bacharach gas analyzer model 300 NSX and a TESTO 350 XL MARITIME were used. The Bacharach gas analyzer model 300 NSX and the TESTO 350 XL MARITIME are portable exhaust gas analyzers. To measure O_2, CO and NO_x, they use an electrochemical cell and a non-dispersive infrared detector for CO_2 measurement. To measure the ambient conditions, the humidity and temperature probes of the TESTO 350 XL MARITIME were used.

On board the ship direct measurements were taken of exhaust gases. The sampling point was positioned 0.7 m downstream of the turbo-blower exhaust. All tests were carried out at 25%, 50%, 75% and 100% of the maximum load, and one hundred samples were taken (Table 1). In the carbon balance method, measurement of fuel oil consumption is required. For on board measurement we have used FLUXUS F601 non-intrusive ultrasonic flow meters. The fuel oil measurement has been compared with the fuel oil rack reading and the test bench parameters from the engine manufacturer as an extra check. The fuel level in the tank was also recorded to measure the fuel consumption. All methods produced good agreement.

Both before maladjustment (A) and maladjustment (B), the following were held constant:

- T_a the intake air temperature (295 K); T_{scref} the charge air reference temperature (298 K), P_b barometric pressure (100.5 kPa), P_a the saturation vapor pressure of intake air (2.63 kPa a 295 K), R_a the relative humidity of intake air (40%), H_a the intake air humidity (6.579 [g H_2O/kg dry air]), the net specific fuel energy (42 MJ/kg) and the specific humidity of charge air (0.01071 kg/kg dry air).

The effect of the nozzle conservation state on the emissions of NO_x and CO in medium-speed diesel engines is tested using on-board and bench trials. The power ratings of the three engines were 883 kW, 956 kW and 1030 kW, and they had same bore (210 mm) and stroke (290 mm). The electrochemical cell technology instruments employed for measurement were from: BACHARACH, ECOLINE 6000, and TESTO 330-2. The chemiluminescence detection (CLD) instrument used was an Emmerson NGA2000, which is an approved type according to US Environmental Protection Agency (1999).

The trials employed new and used nozzles that have been in operation for 9000 h in real conditions with the types of distilled fuel customarily supplied in the market. The sensitivity of the flow to small imperfections of the inlet edge and the high-velocity flows present in diesel injectors led to the conclusion that even in nozzles with well-rounded orifice edges, cavitations will inevitably occur after a certain number of hours of operation (Dec, 1997; Chaves et al., 1995).

[1] A slight advance of the timing is a fault that is possible in engines because of the characteristics of its mechanical adjusting mechanism that makes it easy to make a mistake when adjusting the engine after repair work.

[2] Part 4 of ISO 8178 details the different tests cycles for a wide range of applications. The loads applied and weighting factors were according to the E2 cycle (constant speed propulsion engines).