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WATER-IN- FUEL EMULSION AS A PRIMARY METHOD TO REMOVE NOx FROM DIESEL ENGINE EXHAUST GAS

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ABSTRACT
The exhaust emissions from large marine diesel engines on ocean going vessels contains among other pollutants a significant amount of Nitrogen Oxides (NOx) wich are the main by product of combustion and they contribute to acid rain as well as the formation of harmful ground-level ozone and photochemical smog. The manufacturers of the marine vessel engines and the shipbuilders have responded to the demands to reduce vessel emissions by improving the operation of the engines and by incorporating emissions control technologies in the design of new vessels. NOx formation is suppressed by water present in the combustion chamber. Water can be introduced in various ways, for example by humidification of the combustion air or by injecting water or steam directly into the combustion chamber, or as water-in-fuel emulsion. If water is evaporated inside the combustion chamber the adiabatic combustion temperature (heat load) is reduced as a result of the higher molar heat capacity of water compared to air. The lower temperature and the better fuel distribution are leading to a lower formation of NOx. This paper describes method to reduce nitrogen oxides from exhaust gas of the slow speed marine diesel propulsion engine B&W-5L90MC using Oil-in-Water emulsificationon[1] and VIT (variable injection timing) adjustment after emulsifier shuting off. The efficiency of the Water - in - Fuel emulsification system was tested on engine room full mission simulator Kongsberg ERS-L11 MAN B&W-5L90MC–VLCC Version MC90-IV which is installed on Faculty of Maritime studies in Split. The results are illustrated by figures and graphs which shows approximately 20% NOx reduction in exhaust gas

Keywords: marine diesel engine, exhaust emissions, NOx, Oil-in-Water emulsification

1. INTRODUCTION

The exhaust emissions from large marine diesel engines on ocean going vessels contain among other pollutants a significant amount of Nitrogen Oxides (NOx). Shipping consumes some five per cent of global oil consumption [1,2] which leads to global NOx emissions of about 12.57 million tonnes per year – about 15% of total global NOx emission from fosil fuels. NOx is created when oxygen in the charge air reacts with the nitrogen in the air and in the fuel at high temperatures in the combustion chamber of the diesel engine. Fuel is injected at high pressure into the combustion chamber towards the end of the compression stroke. When the fuel ignites the flame front travels rapidly into the combustion space and uses the compressed air to sustain the ignition. Temperatures at the envelope of the flame can exceed 1300 ^{o}C, although the mean bulk temperatures in the combustion chamber is much lower. At these localized high temperatures molecular nitrogen in the combustion air is oxidized and oxides of nitrogen (NOx) are formed in the combustion chamber. Oxidation of molecular nitrogen

[1] The results presented in the paper have been derived from the scientific research project „New Technologies in Diagnosis and Control of Marine Propulsion Systems“ supported by the Ministry of Science, Education and Sports of the Republic of Croatia.

in the combustion air comprises of about 90% of all NOx, while the other 10% is the result of oxidation of the organic nitrogen present in the residual fuel oil. The NOx formation rate is highest with a high combustion temperature, poor premixing and long fuel duration. The International Maritime Organisation (IMO) has adopted a convention for control of air pollution from ships (Marpol Annex VI). Regulation 13 of Annex VI. establishes NOx emission limits applicable to propulsion and auxiliary engines greater than 130 kW installed in ships constructed on or after January 1, 2000. Maximum Allowable NOx Emissions for Marine Diesel Engines as per mentioned regulation are defined as follows: for engine speed n <130 rpm 17 g/kWh, for engine speed 130 ≤ n < 2000 rpm 45xrpm $^{-2}$ g/kWh and finaly for engine speed n ≥ 2000 rpm 9.8 g/kWh. There are several developed techniques to reduce the shipping emissions. Most commonly used techniques for reduced NOx emissions are internal engine adjustments, which include several methods for optimizing the combustion conditions and fuel injection and charge air characteristics in terms of nitrogen oxides emissions. With these modifications a reduction of 30 % in NOx emissions can be achieved [3]. For further reduction of nitrogen oxides the most potential techniques are water injection to the engine process by direct injection, water-fuel-emulsion or humid air and exhaust gas recirculation. With exhaust gas recirculation the NOx reduction potential is 35-50 %, with direct water injection and fuel-water-emulsion 50-60 %. Most effective technique for reduction of nitrogen oxides is post treatment of the exhaust gas after the NOx formation in the combustion chamber which involves reducing the NOx with ammonia into nitrogen and water vapor in the presence of a catalyst. This technique is called selective catalytic reduction (SCR) and can reduce NOx levels up to 90 % without fuel consumption penalty [4] .

2. WATER-IN-OIL EMULSIFICATION

An emulsion is a mixture of generally immiscible liquids (phases), such as oil and water. During the process of emulsification, the disperse phase (e.g. water) is introduced into the liquid phase (e.g. oil). By the application of high shear, the particle size (droplet size) of the disperse phase is reduced. The smaller the particle size, the more stable is the generated emulsion. Additional stability can be achieved by the introduction of surfactants or stabilizers. Introducing water into the fuel lowers the combustion temperature due to water evaporation. When the water in the fuel-water emulsion evaporates, the surrounding fuel is vaporized, too. This increases the surface area of the fuel. The lower temperature and the better fuel distribution are leading to a lower formation of NOx. The water can be added by forming a fuel/water emulsion in two ways: unstabilized (inline emulsification of water into the fuel prior to injection) and stabilized (manufacture of a stable fuel/water emulsion to be used as a drop-in fuel alternative)

3. FUEL OIL SYSTEM DESCRIPTION

Fuel oil system is shown in figure 1.Two supply pumps (1) take suction from the heavy fuel oil service tanks or from the diesel oil service tank through an justable 3-way valve. The supply pumps discharge to the venting tank (2) at a pressure of approx. 4 bar. The total amount of fuel oil supplied to the venting tank is measured by a flow meter (3) equipped with a by-pass valve. Situated between the fuel oil meter and circulation pumps is a Fuel-Water Emulsion Control Unit (4) which is designed for emulsification of the fuel. One very important thing to remember when adding water to the fuel is that to maintain the same engine power, the fuel link must increase for about 1 - 2%. Therefore all the parameters or limits depending on the fuel link position must be adjusted (with the same relative values as the actual water fraction). Fuel oil circulation pumps (5) take suction from the venting box and/or the fuel oil supply pumps and discharge to the fuel oil circulating line, supplying fuel oil to the injection system of the main engine. The circulating line is equipped with two steam heated fuel oil heaters (6), one backflush fuel oil filter and one bypass filter (7). The capacity of heaters is sufficient for the max consumption for the main engines and the diesel engines.

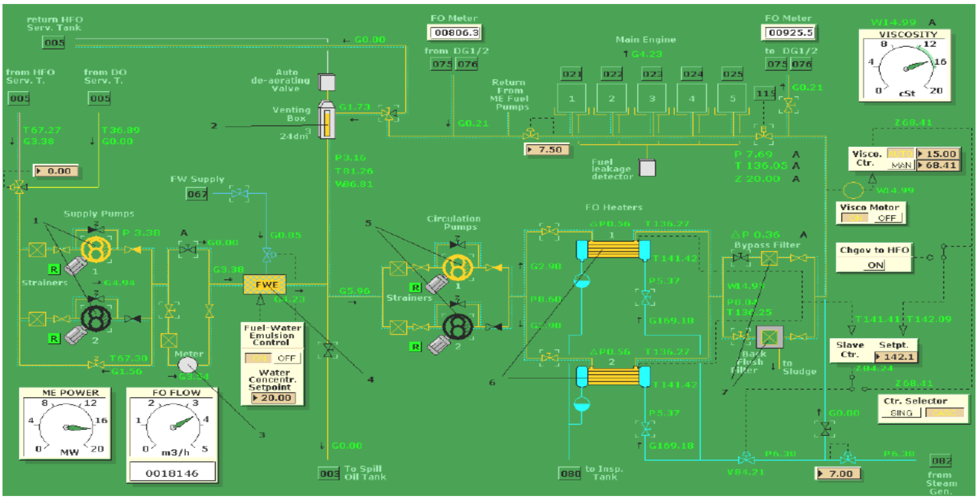

Figure1. The structural diagram of ship's Fuel Oil System with installed Fuel-Water Control unit process, variables and parameters

4. TESTING RESULTS OF EFFICIENCY OF WATER-IN-OIL EMULSIFICATOR

The efficiency of the Emulsification system was tested on engine room full mission simulator "Kongsberg ERS-L11 MAN B&W-5L90MC–VLCC Version MC90-IV" which is installed on Faculty of Maritime studies in Split (main engine MAN B&W-5L90MC which was used for this simulation was already predetermined to met Regulation 13 of the MARPOL 73/78, Anex VI what can be clearly from Fig.2, section A). The results are illustrated by figures and graphs acquired to following scenarios: simulation was started with emulsifier adjusted on 20% water introduction with result of 12.64 g/kWh NOx content in the exhaust gases and 197.59 g/kWh of fuel oil specific consumption (SFOC) (Fig.2, section A).

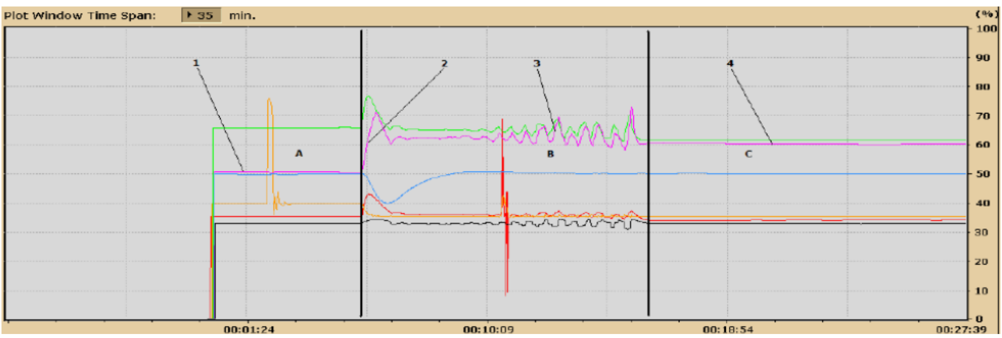

Figure 2. Presentation of different engine condition and parameters oscilation after termination of emulsification)

A - Engine condition with emulsifier under 20% water introduction
B - Engine condition after termination of emulsification but with retarded injection timing
C - Engine condition after correction of injection timing
1 - NOx content with 20% water introduction
2 - NOx content increasement after termination of 20% water introduction
3 - Engine unstable condition due remained retarded injection timing
4 - Engine condition after injection timing correction

For fuel oil pumps adjustment 50% Collective adjustment was used. The collective adjustment is used to compensate the quality of the supplied fuel (emulsion). Reducing the collective setting by 10%

would advance all fuel pumps by 0.8^0 of fuel rack. Set points of super VIT was as follow: starting point = 53% ; break point = 68% and ending point 80%. After approximately 6 minutes emulsifier was shutt down purposly by operater and oscilation of monitored parameters was observed. Due retarded injection timing, wich are necessery for emulsion use, all monitored parameters become unstable (Fig.2, section B). After VIT adjustment on following values: starting point = 40%, break point = 52% and ending point = 61% all parameters become stable (Fig.2, section C) with result of 15.07 g/kWh NOx content in the exhaust gases and 184.53 g/kWh of SFOC. From fig. no.2 is clearly visible that 20% water introduction in to fuel reduce NOx content for approximately 16.1% Also specific fuel oil consumption slightly increased for about 6.6% also due to water introduction and maintenance of constanr rpm and shaft power. Today fuel oil systems with emulsifiers mainteaned desired viscosity by increasing of preheating temperature on aproximately 150°C which today become normal working temperature. Roughtly can be saied that each 1% of water introduction means 1% reduction of NOx content in exhaust gas emission.

5. CONCLUSION

Air pollutions from shipping are of special concern at the moment. The largest environmental problems related to shipping are caused by SO_2 and NOx emissions. The amount of NOx emissions produced by the ships sailing is about 12.57 million tonnes/year. [1,2]. IMO has set emission standards for NOx emissions from marine vessels that came into force in May 2005. According to this standard the limit for NOx emissions is in range from 9.8 to 17 g/kWh depending on the engine speed, with higher limits for slower engines. These limits are quite weak in terms of effective NOx reduction. Engine manufacturers have prepared their engines to meet the NOx standards for several years now by the introduction of internal engine adjustments and modifications which include several methods for optimizing the combustion conditions and fuel injection and charge air characteristics in terms of nitrogen oxides emissions. With these modifications a reduction of 30 % in NOx emissions can be achieved. For further reduction of nitrogen oxides the most potential techniques are water injection to the engine process by direct injection, water-fuel-emulsion or humid air and exhaust gas recirculation.The efficiency of the emulsification system was tested on engine room full mission simulator Kongsberg ERS-L11 MAN B&W-5L90MC–VLCC Version MC90-IV which is installed on Faculty of Maritime studies in Split. The results shows aproximately 20% NOx reduction in exhaust gas afer water introduction in to fuel oil. Roughly water/fuel emulsions 1% NOx reduction for every 1% of water to fuel ratio.

6. REFERENCES

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