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INFLUENCE OF ECOLOGICAL REQUIREMENTS ON THE CHOICE OF EQUIPMENT FOR TREATMENT OF HOT GASES EMISSIONS FROM SHIP'S POWER PLANTS

ABSTRACT

Control of air pollution caused by ship's power plant and its reduction to the desired limits can be achieved in various ways. One of the most significant and acceptable at this stage of today's technological development is the catalytic converter operating on the principle of the selective catalytic reduction (SCR). Considering air pollution from ships, circumstances are rather complex. Namely, the International Convention for the Prevention of Pollution from Ships (MARPOL 73/78) in addition to the general and common rules concerning every kind of pollutants, anticipated specific provisions in the Annexes. For instance, Annex VI refers to the prevention of air pollution by smoke and gas emissions from ships and its adoption is expected not earlier than 2003, as it has to be signed by at least 15 countries, that is by at least the number of countries that own 50% of the world's gross tonnage. At present, only local and partial laws are in force, which are valid in the whole trading area (zone of economic interest) up to 200 Nm off the coast, with a requirement for ships built after 1995 to be fitted at least with a Selective Catalytic Reduction System (SCR).

KEY WORDS

hot gases emissiona, ship's power plant, selective catalytic reduction (SRC), air pollution

1. INTRODUCTION

The valid local laws, according to Table 1, limit the emissions of atmosphere pollutants, especially nitrogen oxides (NOx = NO and NO2) to 75 ppm (parts per million) at 15% of oxygen (O2) with a tendency of further reduction to 45 ppm. This limitation should be accepted also by UN, i.e. IMO, that is by all the signatories of MARPOL 73/78 Convention, including the Republic of Croatia.

Modern propulsion on ships are diesel-electric power plants. Fuel combustion in diesel engines is environmentally friendly, if NOx is excluded, as presented in Table 2. Carbon (II) – oxide (CO) and hydrocarbons (CH) are products of incomplete fuel combustion, which is solved in the engine itself. Carbon (VI) – oxide (CO_2) cannot be influenced, and sulphur oxides (SOx) depend on the amount of sulphur (S) contained in the fuel, which is already available on the market with S = 0.1-0.2% at reasonable prices.

Table 1 – Regulations on nitrogen oxide emission limits [1]

Country	NOx (ppm V)	1993
USA	25-75	State regulation
Japan	27	Tokyo area
France	100-150	Project regulation
Netherlands	37	1990 Act
Germany	73	1990 Act

Table 2 – Composition of exhaust gases [2]

MOTOR MAN B&W	
Type 10 K60 MC - S	17.4 MW
O_2	13.7%
CO_2	5.59%
H_2O	5.53%
SO_2	510 ppm
SO_3	35 ppm
CO	60 ppm
NO	1580 ppm
NO_2	80 ppm
CH	300 ppm
particles	120 mg/Nm^3

The upper limit of NOx emission in diesel engine exhaust gases may be achieved by means of a catalytic converter – reactor without having to modify the diesel engine. Catalytic converter operates on the principle of selective catalytic reduction (SCR) by mixing ammonium hydroxide (NH_3) or urea[1] with exhaust gases before passing through the catalyst at the temperature of 300-400 °C thus decomposing NOx into nitrogen (N_2) and water (H_2O) according to chemical reactions.

$$4NO + 4NH_3 + O_2 = 4N_2 + 6H_2O$$

$$2NO_2 + 4NH_3 + O_2 = 3N_2 + 6H_2O_2$$

O_2 has to be present in the process, and in the case of high temperatures (higher than 500°C) NH_3 burns before the reaction, thus re-generating NOx, whereas at lower temperatures (lower than 260°C) reaction will be slowed down and condensation will result. This may be fatal for the catalyst because of residue, especially if there is S in the fuel, since this creates ammonium sulphate $(NH_4)_2\ SO_4$ or ammonium hydrogen sulphate (NH_4HSO_4) [4].

Trial studies have proven that NOx emission can be reduced to 98% with simultaneous reduction of CO and CH by oxidation. The difficulties resulted from airborne particles that caused fall of pressure in the converter and its volume needed to be increased to 2-4 m^3/MW engine power. Regular SRC operation depends on the excess of air i.e. on O_2, requiring turbochargers with higher pressures of scavenging air (5-6 bar).

2. APPLICATION OF SCR TECHNOLOGY ON MARINE SHIPS

The application of reactors on ships required solving of certain issues: temperature in the reactor has to be guaranteed in storm as well, in manoeuvring and in emergency situations (plant failure); combustion, smell and condensation of NH_3 (NH_3 is toxic and explosive) must be prevented.

NOx emissions control system as presented in Figure 1 consists of two subsystems: NH_3 supply system and SCR process reactor system with adequate fittings and control system.

Ammonium hydroxide supply system (NH^3)

The system consists of a storage tank, evaporator, pipelines and valves. NH_3 is stored as a liquid under 20 bar pressure in the tank located on the deck and thermally insulated. It is fed into the reactor in the engine-room through a pipe with double walls for ventilation – de-aeration in case of leakage, complying with the regulations of classification institutes, since it is toxic and flammable. Therefore, the usage of urea in the form of white crystalline granules is recommended, which dissolves at a temperature of 133 °C. The volume of NH_3 injected into the engine exhaust pipe is controlled by a process computer according to the engine load curve, i.e. the NOx volume in hot gases is considered as function of load calculated in the engine test operation. The load curve is computer programmed and by means of an advance signal controls the volume of NH_3. The reason for selecting this method, rather than the one based on the NOx amount in hot gases is that a relatively big reactor volume results in reaction lag and great variability of NOx and/or output NH_3 concentration.

Maximal consumption of NH_3 is 5-6 g/kWh, and the smell after the reactor depends on the NH_3 concentration in hot gases, depending on the catalyst type and its characteristics (volume and efficiency as deciding factors) and as much as 10 ppm of ammonium hydroxide in exhaust gases is feasible. The risk lies in formation of sulphur acid (H_2SO_4) and this depends on the S content in the fuel, and whether conditions of SO_2 into SO_3 conversion in the catalyst are realised, when the temperature of exhaust gases and walls falls below 260 °C.

SCR system - process reactor

According to the necessary temperature (300-400 °C) and the process, SCR reactor needs to be installed for two-stroke engines in front of, and for four-stroke engines after the turbocharger in order to maintain a constant temperature regime. A reactor installed before the turbocharger is a component of the hot gases system, and can be of smaller dimensions for higher pressure of hot gases, especially at greater engine load.

Part of the scavenging air is brought from the scavenging collector and serves to aerate NH_3 in the static mixer, or water solution is brought – 520 g NH_3 per 1 kg H_2O at a temperature of 20 °C. This brings the NH_3 concentration below the bottom limit of explosiveness when injected in the exhaust pipe. The reactor is preheated by water vapour brought in from the steam generator through pipes wound around the reactor in order to prevent condensation and in order to prepare the reactor for operation as soon as possible after the ship had been moored in the harbour. The scavenging air is brought into the reactor from the input (warm) side of the cooler and when the reactor is not in service, and it serves as reactor "seal" – it prevents hot gases from entering and it prevents condensation, and speeds up the reactor activation.

The reactor is fitted with catalysts in the form of rectangular blocks of standardised dimensions 466 x 466 x 572 mm, that can be replaced as needed (durability of up to 8 years). These are cassettes made of steel plates, coated with titanium dioxide (TiO_2) or alloyed vanadium penteroxide (V_2O_5) [3].

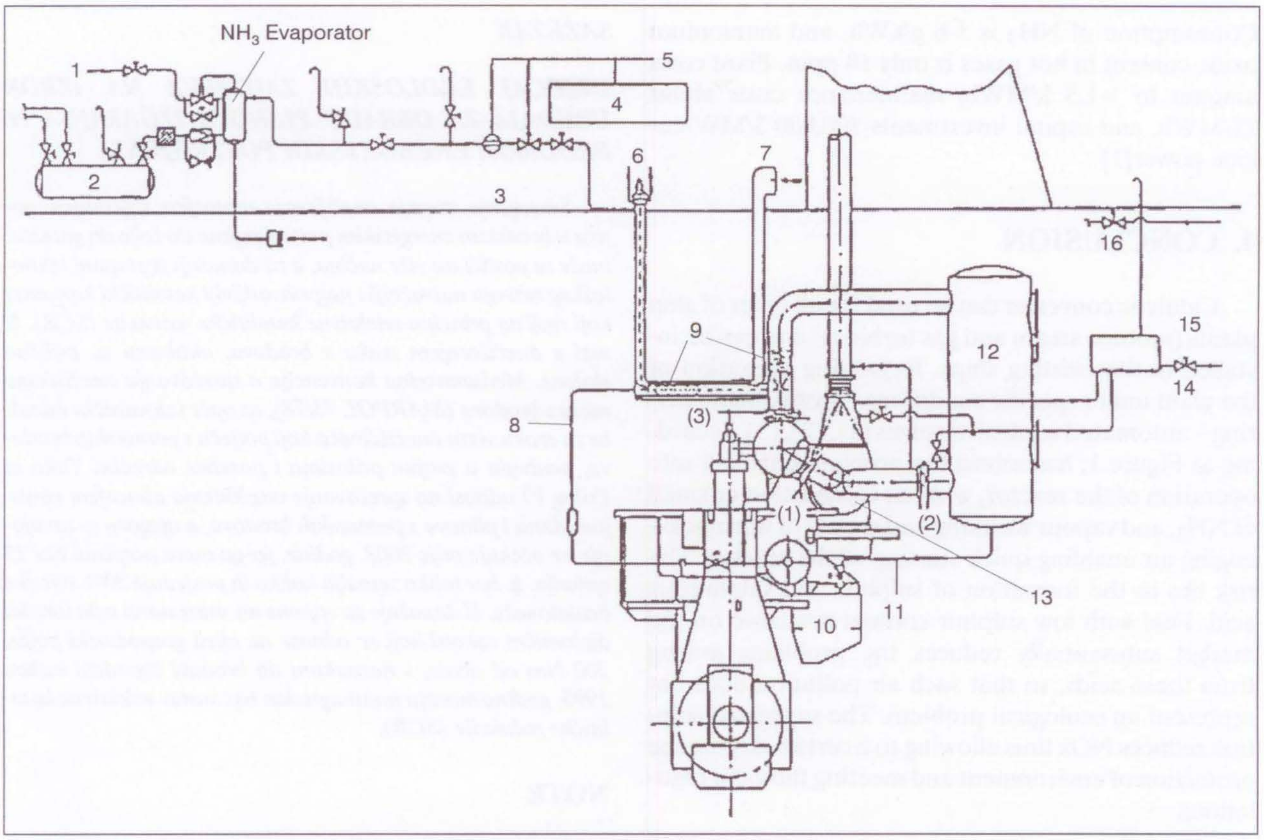

Figure 1 – NO_x emission control system

1 – vapour
2 – ammonium hydroxide tank
3 – deck
4 – process computer
5 – signal from the main engine reference point
6 – air output
7 – air input
8 – air for aeration
9 – static mixer
10 – air cooler
11 – air for heating and sealing
12 – SCR reactor
13 – turbocharger
14 – air for instruments
15 – NO_x and O_2 analyser
16 – air for purification

The installed hot gases pipeline with valves, (1), (2), (3), enables hot gases to enter the reactor or to bypass it. Valve (1) is open and valves (2) and (3) are closed when NOx control is not necessary, and vice versa. The valves are controlled automatically, and the closing of valve (1) is controlled by the difference in maximal temperature between the hot gases collectors and the entrance into the turbocharger. In case of sudden increase in the engine load (sudden acceleration of a ship in case of emergency or during storm), hot gases bypass the reactor temporarily, since hot gases temperatures are then higher than 500 °C.

The reactor is located on the adequate deck in the engine-room, and emission measuring and control instruments meet the requirements set by the harbour authorities, since the data are recorded automatically. The checks of the reactor show that there is practically no soot, for the removal of which a compressed air device has been installed. The use of diesel fuel with low S content and when S = 0.1-0.2%, the lower limit of the operating temperature in the reactor amounts to only 270 °C, and sealing air is not necessary since sulphur acid cannot be generated.

3. OBTAINED RESULTS

SCR system is still one of rare methods that can satisfy the maximal allowed volumes of NOx in hot gases using NH_3 or urea. It was calculated that in the hot gases from diesel engines there is about 1600 ppm at 15% O_2, but modern diesel engines provide about 1200 ppm at 13% O_2, so that the set requirements of 75 ppm NOx after hot gases processing are easy to realise. Studies prove the reduction of NOx by as much as 95%, dioxine 99%, CO and CH 10-20%. Pressure fall in the reactor is only 10-20 mbar, noise reduction 25-30 DB(A) and temperature fall about 10 °C.

Consumption of NH_3 is 5-6 g/kWh, and ammonium oxide content in hot gases is only 10 ppm. Plant costs amount to 1-1.5 \$/MWh, maintenance costs about 2\$/MWh, and capital investments 100,000 \$/MW engine power[1]

4. CONCLUSION

Catalytic converter can be used for all types of ship plants (motors, steam and gas turbines) and can be installed in the existing ships. Regarding operation of the plant under specific conditions – storm, manoeuvring – automated control of valves (1), (2), (3), according to Figure 1, has solved the problem enabling safe operation of the reactor, without combustion or smell of NH_3, and vapour warming and supply of warm scavenging air enabling quick starting of the reactor. The risk lies in the formation of sulphur and sulphurous acid. Fuel with low sulphur content available on the market substantially reduces the problems arising from these acids, so that such air pollution does not represent an ecological problem. The suggested solution reduces NOx thus allowing to a certain degree the protection of environment and meeting the valid regulations.

SAŽETAK

UTJECAJ EKOLOŠKIH ZAHTJEVA NA IZBOR UREĐAJA ZA OBRADU PLINOVA IZGARANJA IZ BRODSKIH ENERGETSKIH POSTROJENJA

Smanjenje stupnja onečišćenja atmosfere izgaranjem goriva u brodskim energetskim postrojenjima do željenih granica, može se postići na više načina, a za današnji je stupanj tehnološkog razvoja najvažniji i najprihvatljiviji katalitički konverter koji radi na principu selektivne katalitičke redukcije (SCR). U vezi s onečišćenjem zraka s brodova, okolnosti su prilično složene. Međunarodna konvencija o sprečavanju onečišćenja mora s brodova (MARPOL 73/78), uz opće i zajedničke odredbe za svaku vrstu onečišćivača koji potječu s pomorskih brodova, predviđa u svojim prilozima i posebne odredbe. Tako se Prilog VI odnosi na sprečavanje onečišćenja atmosfere emisijom dima i plinova s pomorskih brodova, a njegovo se usvajanje ne očekuje prije 2003. godine, jer ga mora potpisati bar 15 zemalja, tj. bar toliko zemalja koliko ih posjeduje 50% svjetske brutotonaže. U današnje su vrijeme na snazi samo neki lokalni djelomični zakoni koji se odnose na cijeli gospodarski pojas, 200 Nm od obale, s naznakom da brodovi izgrađeni nakon 1995. godine moraju imati ugrađen bar sustav selektivne katalitičke redukcije (SCR).

NOTE

1. Urea is white crystalline substance which contains up to 90% of nitrogen and the rest are nitrogen compounds.

LITERATURE

[1] **O. Grone**, *Original paper from factory MAN - B&W*, 1992.

[2] **G. Lofroth**, *Exhaust gas composition from diesel engine*, Environmental International 5, pp. 225-261, 1991.

[3] **P. Shoubye**, et al., *Emission from Large Diesel Engines*, 19th CIMAC Conference, Paper D 16, Florence 1991ł

[4] **I. Wallenweidel**, **A Eyres** & **RP Holbrook**. *IMarE paper* 04/1994