Solution to Reduce Air Environmental Pollution from Ships

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ABSTRACT: Exhaust gas emissions from ships are increasingly polluting the air environment seriously. Therefore, the MARPOL 73/78 Annex VI is applied for all ships from 2017, Annex VI provided that the concentrations of NOx,SOx CO contained in ship's exhaust gases must be less than 6.4 g/kWh, 0.6 g/kWh, and 5.5g/kWh respectively. Today, there are many solutions to reduce pollution emissions from exhaust gas of ships, such as improving combustion, using oil emulsion, using biofuel,…However, these solutions also have a handful of disadvantages such as being unable to thoroughly resoulve problems, high cost, and very difficult to improve the quality of ship exhaust gas emissions for old ships.

Exhaust gas treatment method uses a centralized treatment system where exhaust gas from the thermal engines is taken in a centralized treatment system before discharging into the air. After centralized treatment system, in comparision with raw exhaust gas, soot can be reduced by 98%, NOx can be reduced by 75%, SOx can be reduced by 80%. This method of treatment is not only low cost, good quality but also make marine heat-engines still use traditional fuels as well as need not improve its structure.

1 INTRODUCTION

Shipping is by far the most important mean of transport today, with approximately 90% of the global cargo. Shipping intensity in tons per km is growing at rates of 4 to 6% yearly [5] even in a recession scenario, and is estimated to continue this path, as shipping is recognized as the most cost effective means of transport. In this scenario there is an increasing consideration for the environmental impact of shipping. IMO leads the international exhaust emission regulations for ships that may be waived on its endorsement by member states or superseded by more stringent local regulations [5], in certain coastal and port areas are being applied (ECA Emission Controlled Areas). Existing ECA's are the Baltic Sea, the North Sea, the coasts of the USA and Canada. ECA's in discussion are the coasts of Mexico, Black Sea, Mediterranean Sea (2014) and the Bay of Tokyo (2015).

IMO's 1997 protocol to amend MARPOL 73/78 added Annex VI -Regulations for the Prevention of Air Pollution from Ships. This entered into force on 19 May 2005. Regulation 14 included a 1.5 % limit on the sulphur content of fuel to be used in a SOx Emission Control Area (SECA). Alternatively the use of an approved Exhaust Gas Cleaning System to reduce the total emissions from the ship to an equivalent level of 0,6g SOx/kWh was permitted.

For the reduction and monitoring of green house gases (GHG) emissions the IMO developed and adoption regulations, such as "Interim Guidelines for Voluntary Ship CO_2 Emission Indexing for Using in Trials (2005)" [5] and "Guidelines for Voluntary use of the Ship Energy Efficiency Operational Indicator

(EEOI-2010)" [5]. GHG emissions covered in these regulations include carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). The EU implemented similar regulations setting limits on marine emissions, such as EU Sulphur Directive 2005/33/EC, setting limits for SO_x and PM emissions from marine traffic in EU territorial waters and the setting up of Emission Control Areas (ECA) in line with MARPOL 93/97 Annex VI [5]. The international and European legislation gave a real intent to reduce maritime pollution through reductions of SO_x, NO_x, PM and CO_2, as well as CO, volatile organic compounds (VOC; including methane) and N_2O.

This paper presents a technology utilized for the abatement of sulphur oxides, particulate matter and nitrogen oxides based on a centralized treatment system as exhaust gas from the thermal engines is taken in a centralized treatment system before discharging into the air.

Figure 1. Typical exhaust gas composition – medium speed four stroke engine using HFO

2 EMISSION FROM MARINE THERMAL ENGINES

Significant amounts of the concerning emissions are produced from the main diesel engines used to provide propulsion and generate power. Other sources, such as onboard incinerators and boilers, can contribute to emission levels from ships, depending on their operation, but these are at relatively low levels compared to those produced from the main power and propulsion diesel engines [5]. The emissions levels from marine engines typically depend on five factors, which are:
1 Type of fuel being consumed;
2 engine type;
3 engine efficiency;
4 power and propulsion drive configuration;
5 operation and workload of the engines.

Marine fuels are heavier, more viscous than their land based equivalents, traditionally with longer carbon chains and higher sulphur mass content. The three most commonly used marine fuels are marine diesel oil (MDO); marine fuel oil (MFO) and heavy fuel oil (HFO). Figure below introduces correlation between the air, fuel and lubricant consumption rate to the emission of toxic substances in exhaust gas of a four stroke marine diesel engine with medium speed using HFO containing 2,2 % sulphur [5].
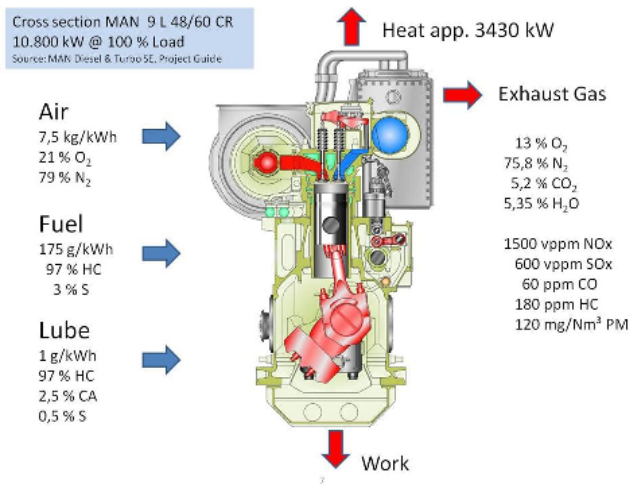
## 3 EXHAUST GAS CLEANING PROCESS

3.1 *Process reduces NOx in the exhaust gas*

The SCR process makes it possible to reduce the level of nitrogen oxides by means of the reactions shown in a broad temperature range between about 160 °C and just under 600^0C, depending on flue gas conditions and catalyst type. High selectivities of almost 100 % are obtained in the reaction of ammonia and, if required, NO_x conversions of well above 90% can be achieved.

Nitrogen oxides are reacted stoichiometrically with urea according to the following reactions [2,3]:

$$NO + NO_2 + (NH_2)_2CO \rightarrow 2N_2 + CO_2 + 2H_2O \quad (1)$$

$$(NH_2)_2CO + H_2O \rightarrow 2NH_3 + CO_2 \quad (2)$$
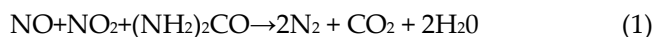
The major part of the nitrogen oxides, which is generally present as NO, is reacted according to the following reaction [2,3]:

$$4NO + 4NH_3 + O_2 \rightarrow 4N_2 + 6H_2O \quad (3)$$
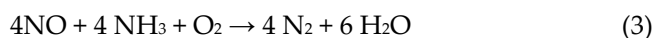
As long as a mixture of NO and NO_2 is present, the following somewhat faster reaction proceeds in parallel [2,3]:

$$NO + NO_2 + 2NH_3 \rightarrow 2N_2 + 3H_2O \quad (4)$$
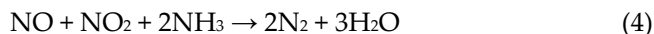
In principle, these reactions can also be carried out without catalyst in a small temperature range around 900^0C. However, under these conditions a significant proportion of the ammonia is burned to form nitrogen oxides, which severely impairs the efficiency in respect of ammonia consumption and the achievable NOx conversion.

Usually catalysts for treating NO_x are based on Cu-Zeolite alloy in form of catalytically active anatase. This support material is acid-resistant and is therefore particularly suitable for use in acid flue

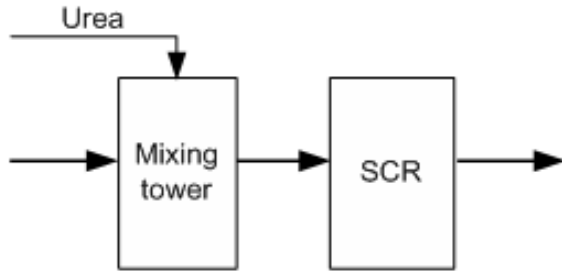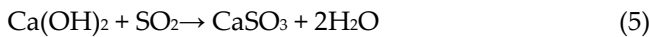gases. System for NOx cleaning process is taken in figure 2.

Figure 2. NOx cleaning system

3.2 Process reduces SOx in the exhaust gas using Calcium Hydroxide

The large-scale proven processes for the desulphurization of flue gases are based these days on absorptive processes. Normally lime based materials such as hydrated lime [$Ca(OH)_2$] are in use. Particularly in small and mediumsized combustions dry and semi-dry processes based calcium hydroxide are well established because of the lower capital costs, the operating safety and the smaller footprint compared to wet processes. These units are operated at temperatures between 80^0C and 250^0C based on the fact that a preferably high amount of the latent available heat is used for generating steam. The lower operating temperature, the more exhaust gas heat can be used, especially if the combustion unit is used as a combined heat and power unit. For that reason low temperatures are preferred. The selected operating temperature depends in the first place on the concentration of the acidic exhaust gas components SO_2, HCl and HF as well as on the concentration of the hygroscopic salts formed with the absorbens.

For temperatures below the dehydration temperature the reaction step for calcium hydroxide with SO_2 can be described as follows [2,3]:

$$Ca(OH)_2 + SO_2 \rightarrow CaSO_3 + 2H_2O \qquad (5)$$

Aside other reactions are taking place:

$$Ca(OH)_2 + SO_2 + O_2 \rightarrow CaSO_4 + H_2O \qquad (6)$$

$$Ca(OH)_2 + SO_3 + H_2O \rightarrow CaSO_4 + 2H_2O \qquad (7)$$

which means that during the absorption of sulphur oxides calcium sulphite and calcium sulphate are generated..

3.3 Process reduce soot in the exhaust gas

Process of cleaning soot in exhaust gas is implemented in soot removal device which is type of porous layers and water spray (scrubber). This equipment consists of a rectangular tank where porous layers made by copper alloy are placed inside and watered (shown in figure 3) [4].
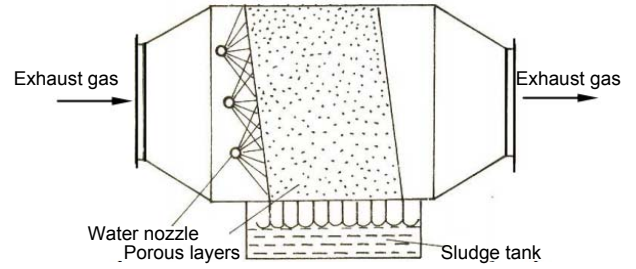

Figure 3. Scrubber

Principle of soot cleaner is as follows: Exhaust gas is leaded into scrubber, through the porous layers after moistering, soot will stick to the surface of the porous layers while the exhaust gas goes through it. Almost all soot will be swept away into sludge tank. The amount of soot remaining on the surface of porous layers will be periodically washed with water.

The exhaust gas going throught the porous layers losses its energy because of aerodynamic resistance of porous layers, this loss is difined as follows [5]:

$$\Delta p = \xi H \frac{\rho_k v_k^2}{2 S_0 d_t}, mmH_2O \qquad (8)$$

$$d_t = \frac{4 S_0}{S_a}, m \qquad (9)$$

$$Re_k = \frac{4 \rho_0 v_k}{\mu_k S_a} \qquad (10)$$

If $Re_k < 80$: $\xi = \frac{400}{Re_k^{0,85}}$; $80 < Re_k < 400$: $\xi = \frac{70}{Re_k^{0,45}}$;

$Re_k > 400$: $\xi = \frac{16,5}{Re_k^{0,2}}$;

where: ξ rate of aerodynamic resistance force of porous layers; H porous layer height, m; v_k velosity of exhaust gas throught porous layers , m/s; ρ_k density of the exhaust gas, kg/m^3; S_0 sectional area of 1 m^2 hollow, m^3/m^3; d_t equivalent diameter of porous layer, m; S_a exposed surface area of 1 m^3 porous layer, m^2/m^3; μ_k dynamic viscosity of exhaust gas, Pa.s.

Capacity of water spray into equipment is usually in range $0,15 \div 0,51$ l/m^3. Effect of soot cleaning can be up to 90% with soot sizes $\delta > 2 \mu m$.

Effect of soot cleaning is determined by [5]:

$$\eta = 1 - \exp(- \frac{\pi}{\alpha(1+\alpha)(S_0 - q_n)} \frac{H}{d_o} Stk) \qquad (11)$$

$$Stk = \frac{v_k \delta^2 \rho_b}{18 \mu_k d_0} \qquad (12)$$

Where: α experimental constant dependent on porous material; d_0 special parameter of porous phases, m; $q_n = S_a \delta_m$, m³/m³; δ_m thikness of water membrane on surface of porous layers, mm; Stk Stoke standards for soot and exhaust system with special parameter d_0 of porous phase, mm. Raschig phase, saddle-stitched Berl, intalox phase d_0=12,7mm, α =0,192; berl phase, Raschig phase, Pall phase d_0=25,4mm, α =0,19.

In order to increase the ability of removing soot in exhaust gas, soot and water can be loaded opposite charge. Soot paticles are positively charged in a device named PM charge, then are let into the second chamber where water is negatively charged. As a result, soot paticles are attracted by water due to Coulomb attraction with high efficiency. In this chamber, most of soot with small size are kept. Soot treatment diagram by charging method is described in figure 4
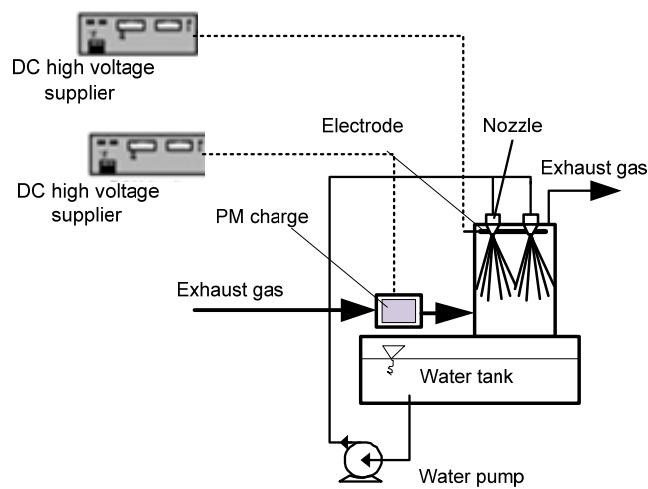

Figure 4. soots treated by PM charge

Soot treatment efficiency by electromagnetic force: [1]

Where water is neutralization and shoot is charged:

$$\eta_E = 2{,}89 \left(\frac{C_C . q_M^2}{3\pi^2 \mu d_M v_k \varepsilon_0 d_w^2} \right)^{0,4} \qquad (13)$$

Where soot and water are charged:

$$\eta_E = -4 \frac{C_C . q_M q_w}{3\pi^2 \mu d_M v_k \varepsilon_0} \qquad (14)$$

Total Soot treatment efficiency is determined by the following formula [1]:

$$\eta_{TB} = 1 - \frac{N}{N_0} = 1 - \exp\left[-0{,}3 \frac{Q_w}{Q_k} . \frac{h}{d_w} \frac{v_w}{(v_w - v_k)} . \eta \right] \qquad (15)$$

Where: N: density of soot after filtration chamber, kg/m³; N_0: density of soot on filtration chamber, kg/m³; Q_k: exhaust gas flow into the treated chamber (m³/s); Q_w: flow of water injection into treated chamber, (m³/s); d_w: diameter of droplets, m; h: height

of the scrubber, m. v_k: velosity of the exhaust gas flow, m/s; d_w is particle diameter of water, m; d_M is diameter of soot, m; C_C: the Cunningham slip; μ is the viscosity of air (kg/m.s); q_M: charge of soot, C; q_w is charge of water, C; ε_0 is allowed vacuum coefficient.

4 CENTRALIZED TREATMENT SYSTEM

Figure 5 shows a diagram of exhaust gas treatment system which is used for treating exhaust gas of thermal engines on laboratory of Marine engineering faculty of VMU. The system consists of three treatment chambers, they are A chamber, B chamber and C chamber.
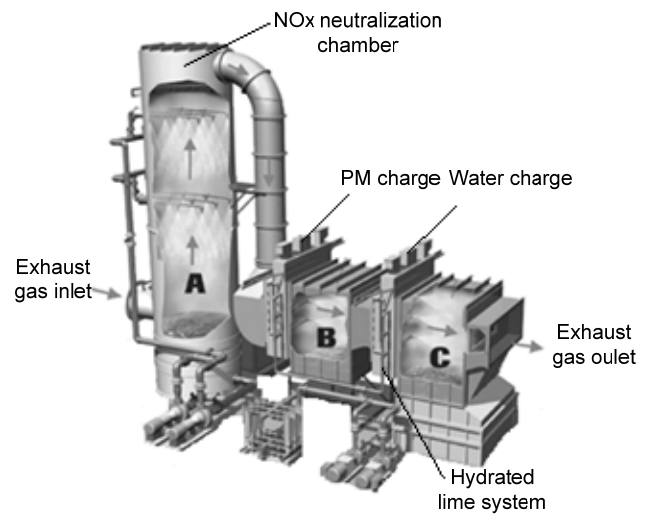

Figure 5. Centralized treatment system

A chamber is NO_x neutralized chamber using urea solution. Second chamber is SO_x neutralization chamber using hydrated lime ($Ca(OH)_2$), in which soot is treated by neutralized water and soot charged. The third chamber is chamber where soot is removed by charging soot and water oppositely.
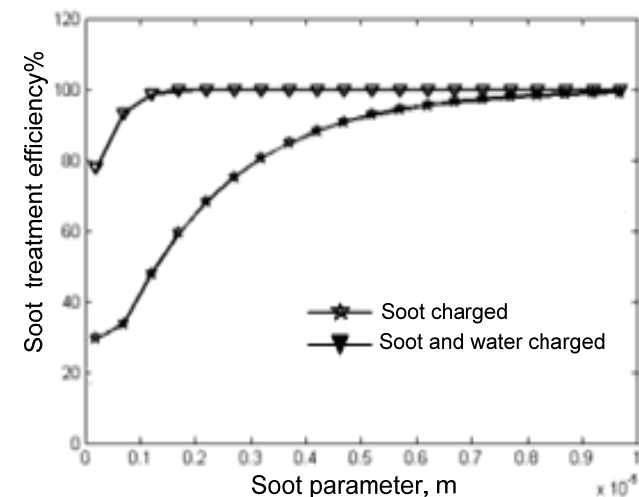
5 RESULTS AND DISCUSSION

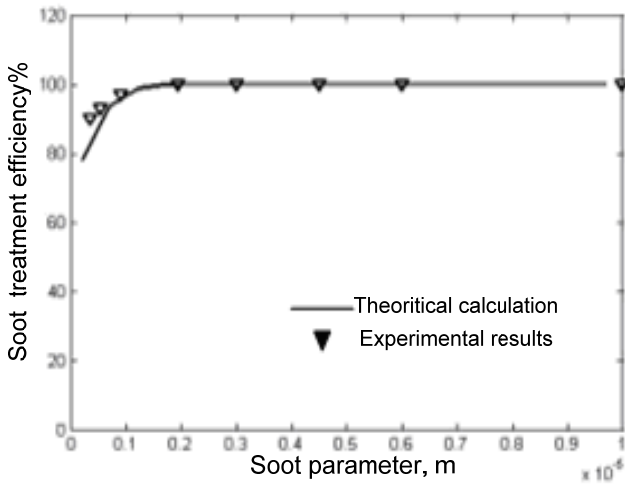Figure 6. Influence of charging mode to treat soot quality

Figure 7. Soot treated quality

Results of theoretical calculations and experiments showed that spraying regimes influence on soot removed efficiency in treated chamber (figure 6). If we employ only neutral water for weeding out soot, effect achieves quite low, at best 65%, the soot particles which are smaller than 1 μm performance is only 20%. When soot particles are charged oppositely or both soot and water are charged, soot removed efficiency significantly increases, reaching 98%.

Results of theoretical calculations and experiments on the soot treatment quality of treatment system with errors negligible are presented in figure 7.

Table 1. NO$_x$ mesurement results before and after the teating equipment

mesurements	After 1 hour	After 3 hours	After 5 hours	After 8 hours
NO$_x$ mesurement results before the treating equipment g/kWh	30	35	35	34
NO$_x$ mesurement results after the treating equipment, g/kWh	7	5	4	3,5
SO$_x$ mesurement results before the treating equipment g/kWh	1,5	1,4	1,5	1,5
SO$_x$ mesurement results after the treating equipment, g/kWh	0,4	0,35	0,35	0,3

NO$_x$ treatment method absorbed by ingestion of urea solution with low treatment cost and investment and high treatment efficiency (efficiency can reach 75%, table 1).

SO$_2$, SO$_3$ treatment method with aqueous lime in treating gets a very high efficiency (can be effective from 70 to 80%, table 1), low treatment and investment cost, simple treatment technology.

Exhaust gas treatment method using treatment system as above can apply to centrilized treatment on ships.

6   CONCLUTION

Exhaust gas treatment system combines NO$_x$, SO$_x$ neitralize and soot treatment that soot and water are opposite charged with very high efficiency. The treatment quality of the system can satisfy standards of IMO and EURO IV emission so that it should be applied for treating exhaust gas on ships.

The cost of treatment and installation is low, very suitble for treating exhaust gas on ships. Ships which are equipped with centrilized exhaust gas treatment system may not have to use fuel with low sulfur content in specific areas of the world. The engines can still use traditional fuels with low cost. These engines need not improve in term of structure.

Exhaust gas treatment system can be focused widely on ships in the future. It offers great benefits to shipowner when installing this system because ships can still use traditional fuels with low cost and it need not use shore exhaust gas treatment system at ports.

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