Removal of Particulate Matter and NOx from Boiler Exhaust Gas in Electrostatic Water Spraying Scrubber

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Abstract : Boiler exhaust gas consists of many components that cause air pollution. These pollutants normally are mixed. To eliminate them, a scrubber is currently used, depending on a coal fuel used for combustion source in the boiler. In this study, experiments were performed with combination using emulsion oil and an electrostatic water spraying scrubber to evaluate effectiveness for simultaneous removal of NO_x and particulate matter (PM) emissions in marine exhaust gas. The combustion of coal oil and its emulsions was investigated in experiments. Two comparisons between coal oil and oil-water emulsion flames are presented that, due to the different initial conditions of the spray, provide complementary information. The combustion efficiency is improved when water is emulsified with coal oil. The electrostatic water spraying scrubber, studied in this paper, combines advantages of electrostatic precipitators and inertial wet scrubbers, and removes many shortcomings inherent to both of these systems operating independent. Total PM removal efficiency was higher than 99% by electrostatic water spraying scrubber. As the results the electrostatic water spraying scrubber appears to be a promising alternative method for control of mass-based as well as number-based PM emissions.

Keyword*:* Boiler exhausts gas, scrubber, electrostatic spraying water

1. INTRODUCTIONS

Removal of PM smaller than a few micrometers from marine gases presents a serious problem. PM of this size, such as smoke, fine powders, or oil mist, which are usually hazardous to human health, are not easy to remove by conventional methods. Therefore, an effective control of PM in the size range from 0.1 to 2μm is still a great challenge for engineers. To solve these problems, electrostatic water spraying scrubber which combines advantages of dry and irrigated electrostatic precipitators, and conventional inertial scrubbers [1]. In electrostatic water spraying scrubber, PM and scrubbing droplets are electrically charged to opposite polarities. The charged droplets capture the oppositely charged PM due to Coulomb attraction forces. Hereinafter in this paper, the scrubber using electrostatic forces will be referred to as “electrostatic water spraying scrubber” and the precipitation process as “electro scrubbing”. The major objective of this study was to evaluate the potential of electrostatic water spray in controlling pollutant in marine exhaust gas and to improve PM removal efficiency.

Coal oil emulsions have evolved from earlier attempts to reduce combustion temperature for NO_x reduction purposes. Of all the methods proposed to introduce water into the combustion chamber, emulsions appear to be the most appropriate because they require no equipment retrofitting. This type of delivery may also provide advantages due to enhanced droplet evaporation caused by droplet micro-explosion from rapid gasification of the suspended water in the atomised droplets. A reduction in soot formation may be the result of different mechanisms. Some authors [2] explain the decrease in soot concentration as arising from more uniform oxygen distribution as a consequence of the improved mixing caused by the secondary atomization.

2. EXPERIMENTAL WORKS

2.1 Experimental setup

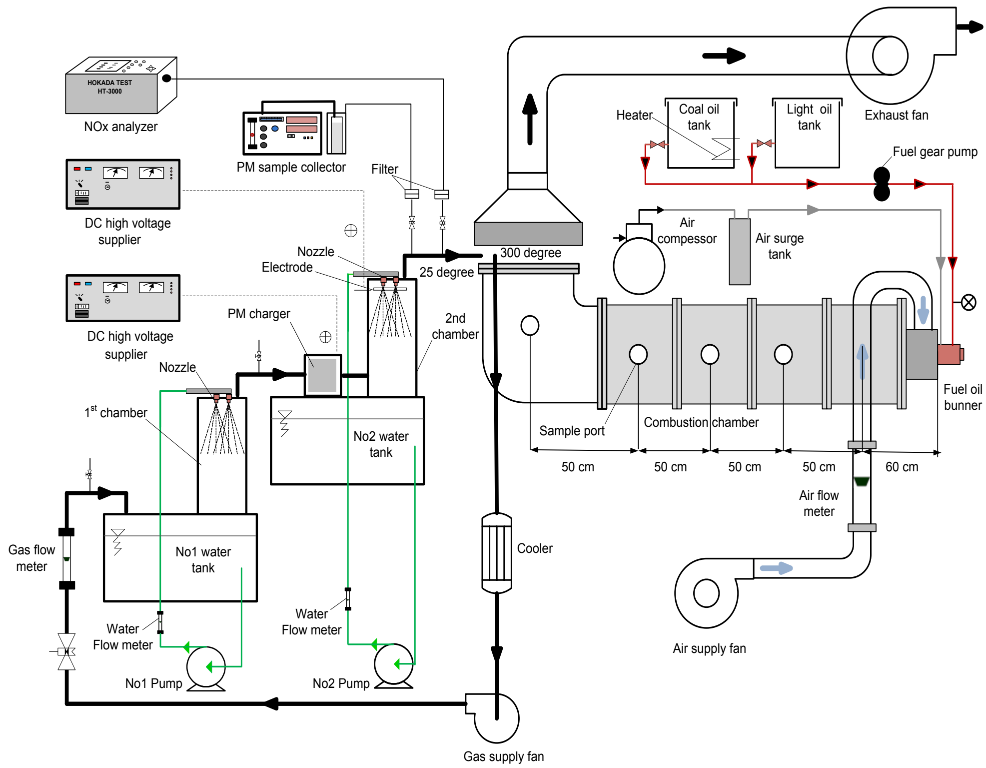

Figure 1. Schematic diagram of experimental setup

Table 1. Oil property

Property	Composition
Density [g/cm^3] 15^{0}C	1.1937
Flash Point [^{0}C]	116
Kinetic viscosity [cSt]	100 (50^{0}C)
Pour Point [^{0}C]	-7.5
Ash [mass%]	0.05
Sulfur [mass%]	0.5
Water [vol%]	0.1
Residual Carbon [mass%]	0.55
Low heating value	38.26 MJ/kJ

Table 2. Aditive

Sodium (Na)	4.86 wt %
Calcium (Ca)	0.001 wt %
Chlorine (Cl)	4.34 wt %
Density (at 20^{0}C)	1.101 g/cm^3
pH (at 20^{0}C)	13.5

Table 3. Working parameters of the equipments

Coal oil consumption for burning	3.2 l/min
Air supply into combustion chamber	4700 l/min
Coal oil supply pressure	0.05 MPa
Atomized air pressure	1 MPa
Coal oil temperature inlet	120 ^{0}C
Gas flow rate enter scrubber	1800 l/hr
Gas temperature inlet scrubber	300 ^{0}C
Gas temperature outlet scrubber	25 ^{0}C

The combustion chamber used in experiment is a horizontal cylinder 2.75 m long and of 0.4 m i.d., with the flow moving upwards. The furnace is formed by four annular segments, a roof and a convergent exit section. All these elements are cooled by separate water jackets, with independent measurements of the flow rate and the exit water temperature. This furnace was used as PM and other pollutant emission source. Coal fuel oil in table 1 was mixed 10% water and additive (table 2) using throughout these experiments. An electrostatic water spraying scrubber used to collect mainly PM in exhaust gas, it shown schematically in Figure 1. The scrubber consists of two chambers. In the first chamber, the water from tank No1 was pumped through two nozzles (orifice diameter 1mm) with flow rate 3.4 l/min. A mount of larger course PM are removed in this chamber. Ultra fine and condensable PM which could not be collected by water are grown to a few tenths of a micron in preparation for removal, and then remain PM were charged by a PM charger. The charger was made of stainless steel saws (4 pcs) as positive electrodes that connect to high voltage supplier adjusted to various voltages range from 1.0kV to 10kV to charge PM positive. These saws were mounted between 5 steel plates which connected to earth. In the second chamber, the water was pumped from tank No2 by centrifugal pump and discharged through two nozzles (orifice diameter 0.5 mm) with flow rate 0.8 l/min. They created droplets with 190-198 µm in diameter measured by Phase Droppler Particle Analyzer Aerometric. A stainless electrode (induction electrode) of inner diameter 15 mm is placed around upper edge of spraying head of nozzle. The induction electrode was connected electrically to a high DC voltage power supply adjusted to various voltages range from 1kV to 5kV to charged water droplets. This arrangement can provide a strong charging field with a relatively low voltage. Thus under stable operating conditions, a nagative charged water droplet cloud is formed to collect charged PM and fall down to the tank, then relatively clean water from the top of the tank is re-circulated by pump to the charging electro, where it is recharged, completing the cycle.

2.2 Measurement of PM mass concentration

The raw and after-treated PM were directly sampled by the filters, and the PM mass on each filter was determined gravimetrically by the difference in mass before and after each test PM mass concentrations in treated or untreated exhaust gas were determined by isokinetic sampling using EPA Method 5 ‘‘Sampling Method for Stationary Sources’’. At least six tests were conducted at each engine load condition and water scrubbing performance such as no spray water (NS); after first chamber (1^{st}); neutral droplet-neutral PM (ND-NP); charged droplet-neutral PM (CD-NP); charged PM-neutral droplet (CP-ND); charged PM-charged droplet (CP-CD). In this method, the PM was collected on a 60-mm glass microfiber. The total PM mass was determined by the gravimetric method.

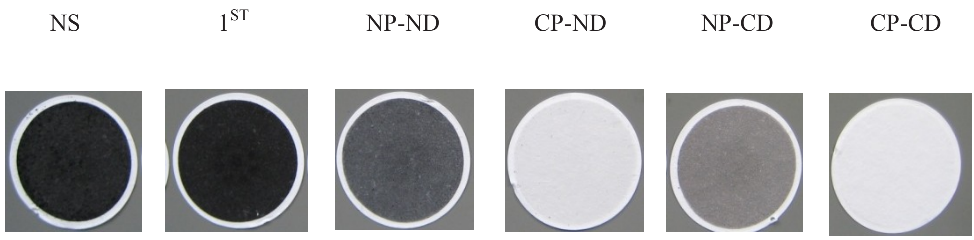

Figure 2. PM mass collected on the filters at various scrubbing performance of water droplet

3. RESULTS AND DISCUSSION

3.1 Reductions of NOx using emulsion oil

Figure 3 shows the measured NO and NOx concentrations for coal oil and emulsion along axial length of the combustion chamber. The NO and NOx emissions display a remarkable difference between the coal oil and emulsion combustion tests. The addition 10 % of water has a dramatic effect on the flame. The presence of water in coal oil brings about a considerable reduction in NOx emission. The results indicated that 10% water in the coal can give a reduction in NO and NOx emission of up to 28-48% and 18-42%, respectively. As a result from the coal oil combustion process about 90% of the NOx is NO. The NO is primarily formed by the oxidation of atmospheric nitrogen (N2). Water added to the fuel lowers the combustion temperature due to water evaporation. When the water in the coal-water emulsion evaporates, the surrounding fuel is vaporized, too. This increases the surface area of the coal oil. The lower temperature and the better coal oil distribution are leading to a lower formation of NO and NOx. The flame temperatures are reduced by

65 K. The heat absorbed by the water injected in the emulsion and enhanced radiative heat transfer due to the higher particle number density. The distribution of NOx indicates that a significant reduction is obtained in the final part of the flame; this may be attributed to a decrease in the rate of thermal-NO formation as a consequence of lower gas temperatures.

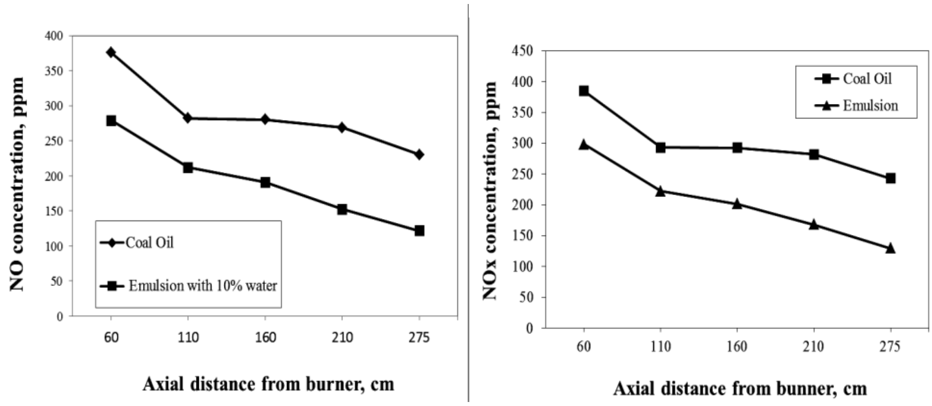

Figure 3. NO and NOx concentration at different positions of furnace

3.2 Reduction of PM by using electrostatic water spraying scrubber

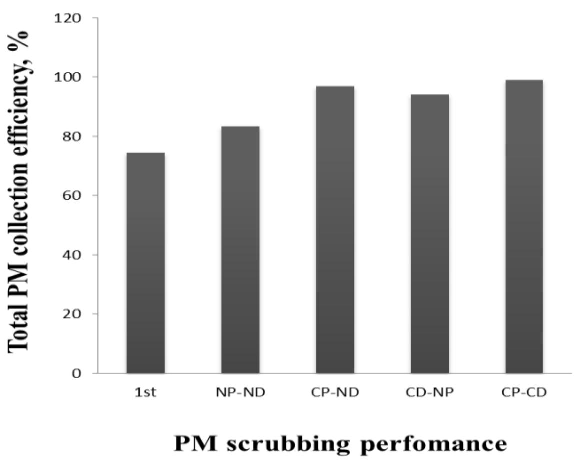

Figure 4. PM mass concentration at various scrubbing performances of the scrubber

In Figure 4 shows PM collection efficiency of the scrubber. Comparison of the results of water performances such as no spray water, neutral water and neutral PM, charged water and neutral PM, spray neutral water and charged PM, both charge PM and water droplets. When the scrubber using neutral water to remove neutral PM, it only collects coarse PM by simple impaction mechanism as conventionally. But these is not affect on fine particulate matter, because of their very lightweight, fine PM are pushed out of the part of the water droplets and are forced to follow the streamlines; therefore, PM was removed with low efficiency at various engine loads. The highest PM collection efficiency only reaches to 72% for first chamber and 80 % for both chambers. It can be note that the same amount of spraying water, in cases using charged droplet-neutral PM or neutral droplet-charged PM result in more effective collection of PM than using neutral droplet-neutral PM. Because an image charge of opposite sign is induce on neutral objects, generating a force of attraction. These forces lead to the PM-water droplet attracted each other that stronger than impaction and interception mechanism causing an increase in the efficiency of PM collection up to 97%.

The better results were obtained when both PM and water droplets were oppositely charged. The collection efficiency was gained in this case as high as 99%, corresponding to positive PM and negative droplets more many time upper than using neutral droplets-neutral PM 20% . The collection efficiency was highly increased due to there are Coulomb force between charged droplet and charged PM [3], these forces form a strong mechanism to drive charged PM to charged droplet. It was demonstrated experimentally that the electrical charging of droplets and PM allows an increase of the collection efficiency of PM that compare with conventional scrubber at the same amount of using water

4. CONCLUSIONS

1. The spatial distribution of NOx inside the combustion chamber indicates that the generation of NOx over the final part of the flame is reduced by the addition of water. The main source of NOx in that region is considered to be the thermal mechanism, and the observed reduction in NOx formation is in accord with the decrease in flame temperatures. Reduction in NO and NO_x emission of up to 28-48% and 18-42%, respectively.
2. The addition of water to heavy oil in emulsion form can significantly accelerate the evaporation and combustion processes in the flame. These effects are very important if the fuel spray is of relatively poor quality (coal oil and emulsion), while the changes are much weaker when fine atomization of the heavy oil is achieved (coal oil and emulsion). Among the possible effects of water addition, the micro-explosion phenomenon is considered responsible for the significant changes in the flame. The consequence is higher burnout of the cenospheres initially generated in the flame, so that the unburnt carbon when firing emulsions is reduced by from 5-36 %.
3. The electrostatic water spraying scrubber was found to remove the fine PM effectively. It was demonstrated experimentally that the electrical charging of droplets and particulate matter allows an increase of the collection efficiency of PM from diesel exhaust gas. The total collection efficiency of PM as high as 99%. Pressure drop of exhaust gas is very low when it is crossing the system. All soluble acid and caustic gases are removed at the same levels as conventional scrubbers. Further improvement of the removal efficiency is obtained by charging sprays utilizing electrical forces can effectively operate for small sizes of PM.

5. REFERENCES

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