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Emissions of Marine Heavy Fuel Oil in the Spray Flame

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Abstract : Recently, the International Maritime Organization makes an effort for an effective solution against the emissions from shipping in the international maritime industry. The objective of the study was to quantify the exhaust emissions of marine heavy fuel oil in the combustion process of the spray flame. An experiment was performed to measure CO, CO_2, NOx, SO_2, N_2O, DS, SOF and the other components with the flame temperature. The sampling probe was directly set up in the flame fields at each position of 103, 324, 545, 766 and 987mm vertically apart from the fuel-injected nozzle in the burner furnace. From the results of the study, it was estimated that approximately 270ppm of oxides of nitrogen (NOx), 1000~1400ppm of sulfur dioxide (SO_2), 8ppm of nitrous oxide (N_2O), 2.0~2.5g/m^3 of particulate matter (PM) divided with dry soot (DS) and soluble organic fraction (SOF) and 60~80mg/m^3 of sulfuric acid. With respect to further development of this work, the emission quantification could also be applied to assessing emission reduction from the international shipping.

Key words : Emission, Marine heavy fuel oil, Spray flame

1. Introduction

The standardization of marine heavy fuel oil is difficult as a variety of property all over the world[1]-[2]. The sulfur and the residual carbon contained in fuel oils have a great affect on the formation of NOx, SOx, COx and PM. The formation of N_2O is related to NOx, SOx and H_2O included in the exhaust pipe[3]. The reaction of NOx with SOx of the similar type as responsible for N_2O sampling artifact may play a role for N_2O formation[4]. This study was based on an experimental measurement of the emissions in the fuel-injected flame. The experiment was examined spatially the combustion characteristics such as the temperature, the unburned droplet and analyzed the emission characteristics of NOx, N_2O, SOx, DS, SOF, sulfur acids and the other various metals.

2. Experimental apparatus and procedures

Fig.1 shows the experimental apparatus. The furnace is set up with the industrial-scale that is capable of making large steady spray flames as follows; vertical type, 5 stages composed of internal diameter ϕ 430mm and height 250mm water-cooled steel. This equipment is 5~13kg/hr of the combustion rate and

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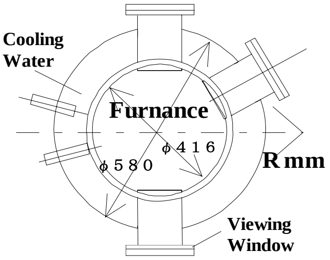
50,000kcal/hr of the calorific power. For using high viscosity of marine heavy fuel oil, there is equipped with heating coils from fuel tank to burner nozzle. Furthermore, Fig.2 illustrates flame funnel cone (D/d=1.05) to make stable flames.

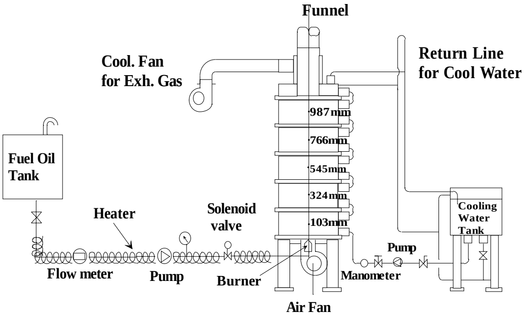
The experiment was thoroughly done by direct sampling methods with water cooling probes shown as Fig.3. Firstly, Fig.3(a) shows stainless steel probe of internal diameter 5mm to sample the combustion products of gas phase and PM. When PM sampling is carried out, another tube (1mm) is equipped to produce a water jet in order to stop rapidly its reaction. And Fig.3(b) shows the probe to collect unburned droplets of flame internal in order to observe the combustion process. The droplets was collected as shutter speed 0.46ms with 5 glasses placed at 20mm interval respectively in the probe head And the glasses was covered MgO on the surface. Table 1 shows the property of testing fuel oil.

Table 1 Property of marine heavy fuel oil

Density (g/cm^3)	0.982
Flash point (℃)	74.0
Kinematics viscosity at 50mm^2/sec(cSt)	177.0
Pour point (℃)	-10.0
Residual carbon (mass%)	12.3
S (mass%)	2.56
H_2O (vol%)	0.50
Ash content (mass%)	0.02
High calorific value (MJ/kg)	42.78
N (mg/kg)	0.25
V (mg/kg)	58.0
Al (mg/kg)	4.0
Mg (mg/kg)	2.0
Si (mg/kg)	13.0
Ca (mg/kg)	18.0
Fe (mg/kg)	36.0
Ni (mg/kg)	20.0



(a) Cross section of furnace



(b) Combustor layout

Fig. 1 Experimental apparatus

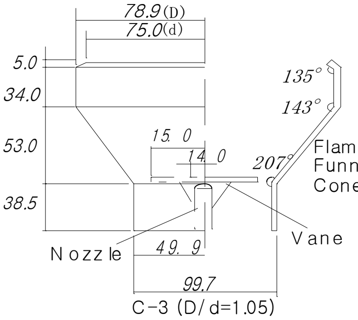
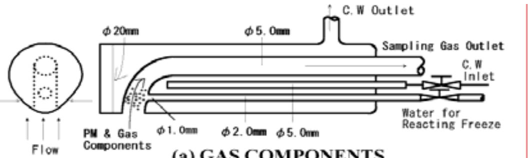
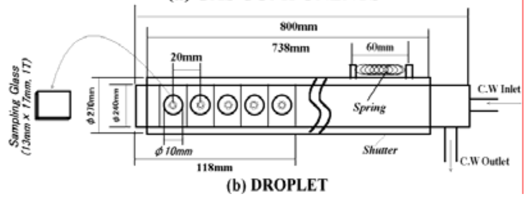


Fig. 2 Flame funnel cone



(a) GAS COMPONENTS



(b) DROPLET

Fig. 3 Sampling probe

3. Results and discussion

3.1 Combustion characteristics

Fig. 4 shows the distribution of unburned droplets. The combustion conditions are as follows ; 12.3ℓ/hr of the flow rate of fuel oil, 22.0kg/cm^2 of the injection pressure of fuel oil, 140℃ of the heating temperature of fuel oil, 120mmAq of the air inlet pressure, 1.1 of the air excess rate. Fig. 5 shows flame temperature distribution versus radial distance at the each central axial direction - Lc=103, 324, 545, 766 and 987mm - apart from nozzle. Firstly, in upstream of Lc=103mm, the values show a slack saddle-like distribution, but it transforms to a slack mountain-like distribution as the flow goes where the temperature increases. At 987mm, where is the top flame front, it shows a flat distribution from 800℃ to 1000℃.

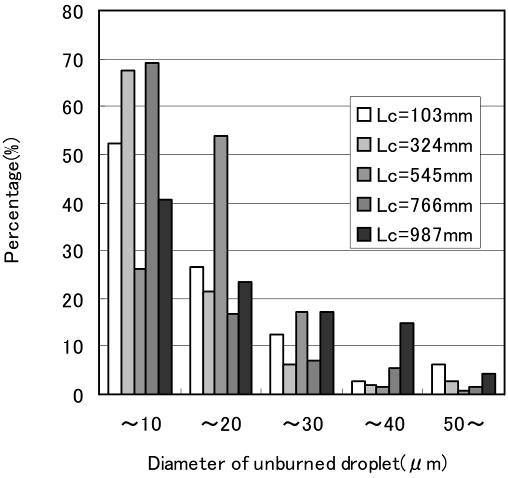


Fig.4 Distribution of unburned droplets

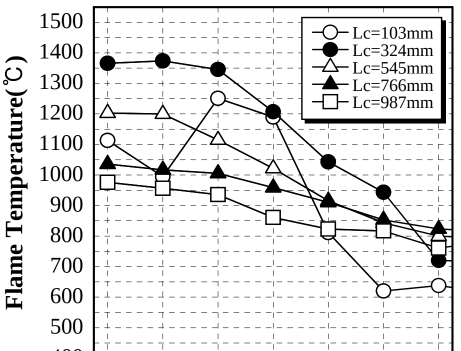


Fig. 5 Radial distribution of flame temperature

Fig. 6 shows the concentration distribution of chemical species in Lc=103mm. The closet location to nozzle (Lc=103mm) illustrates that it is the region of spray droplets lumps for shaping the flame, and can be said to be preliminary phase of combustion process as pyrolysis reaction in the main.

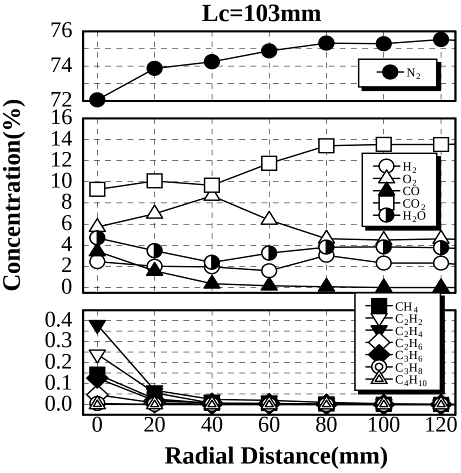


Fig. 6 Concentration of various species

3.2 Formation and decomposition of emissions

Firstly, the NOx concentration versus the radial location at the each axial section is shown in Fig.7. At the upstream of Lc=103, 324mm, NOx is changed roughly together with temperature variation, but uniform distribution can be observed from halfway to downstream where about 270ppm are shown. In Fig.8 and 9, DS and SOF distributions are shown respectively. The data are seemed to be changing a little, but a brief statement can be given as follows. At a little outside region closing to nozzle (R=40~100mm), SOF is more than DS but the latter becomes more than the former at halfway of flame.

Fig.10 shows SO_2 distribution. At the center of nozzle local region, high concentration shows, and then a rough mountain-like distribution is displayed as a whole. The formation decreases accordingly as going forwards downstream, and the

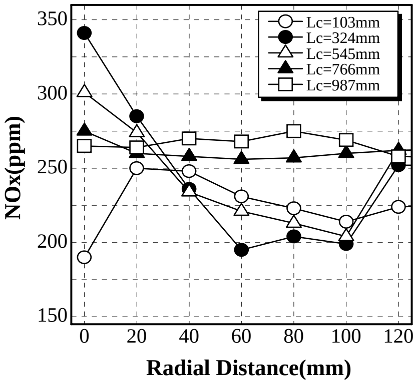


Fig. 7 Radial distribution of NOx concentration

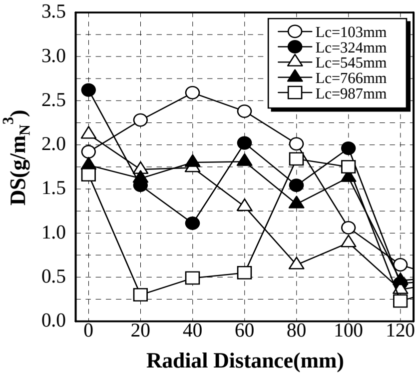


Fig. 8 Radial distribution of DS concentration

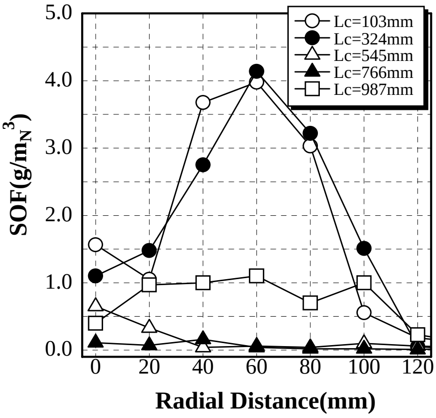


Fig. 9 Radial distribution of SOF concentration

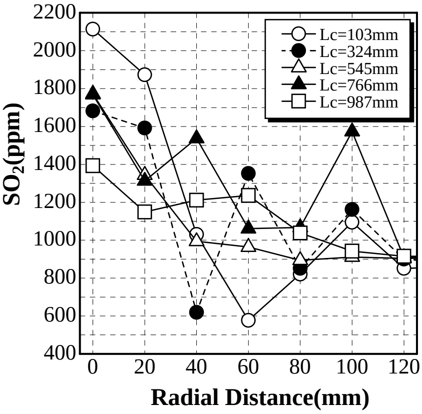


Fig. 10 Radial distribution of SO_2 concentration

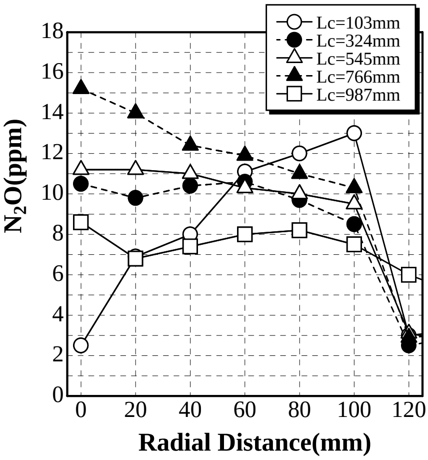


Fig. 11 Radial distribution of N_2O concentration

concentration is about 1200ppm at the last flame stage. Fig.11 shows N_2O distribution. It is about similar to SO_2 distribution except to Lc=103mm. It shows that N_2O formation is affected by unburned hydrocarbon, H_2O, SOx etc. in the sampling tube. And here is discharged about 6~8ppm at flame end.

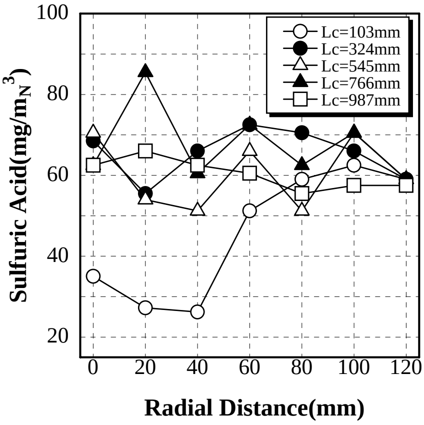


Fig. 12 Profiles of sulfuric acid

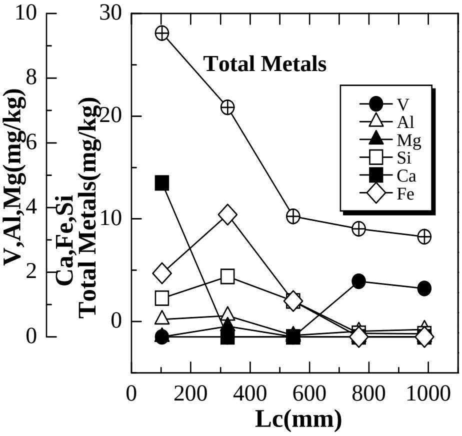


Fig. 13 Profiles of various metals versus central axial distance

Fig.12 shows sulfuric acids distribution. Except to Lc=103mm of axial center location, the value is formed about 60~80mg/m^3. It is supposed to be leaded to SO_3. Finally, the metal distribution in the flame is shown in Fig.13. It shows that the amount of each metal is decreased as going forward downstream.

4. Conclusion

From the results of the experiment, the emissions was indicated on the marine heavy fuel oil as follows;

(1) On 103mm of axial distance(Lc) closing to fuel injection nozzle, the paralysis was mainly leaded by mixing spray droplet lumps and air.

(2) The emissions was approximately 270ppm of oxides of nitrogen (NOx), 1000~1400ppm of sulfur dioxide (SO_2), 8ppm of nitrous oxide (N_2O), 2.0~2.5g/m^3 of particulate matter (PM) divided with dry soot (DS) and soluble organic fraction (SOF) and 60~80mg/m^3 of sulfuric acid.

(3) The total of metal components was about 10~30mg/kg in the spray fuel.

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