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Combustion Characteristics of Heavy Fuel Oil-water Emulsion

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Abstract : This study is intended to check the flame temperature to raise in burning grade C heavy fuel oil and emulsion fuel oil in a boiler and to measure the concentration of Dry Shoot(DS) and Soluble Organic Fraction(SOF) after collecting the Particulate Matters(PM).
The flames temperature in boiler was measured by burning grade C heavy oil and oil-water emulsion (C heavy oil 70% and 30% of water). Combustion characteristics of two fuels was also compared by trapping particulate matters (PM) in exhaust gas and measuring the generated quantities of DS and SOF in fuel gas.

Key words : Marine pollution control, Particulate Matters, Soluble Organic Fraction, Dry Shoot, Hydrocarbon, Soot.

1. Introduction

As a kind of heavy oil, marine fuel oil differs from fuel oils for automobiles and energy-saving plants especially in its properties. As a low-grade fuel oil, it is mainly composed of hydrocarbon and also contains a great quantity of sulfur, nitrogen and residual carbon contents. PM components formed by combustion reaction have not been thoroughly examined. As sea transportation increases, it becomes necessary to grasp the present state of PM's exhausted from vessels as an air-pollutant and to take necessary actions to reduce them. Accordingly, relevant organizations including International Maritime Organization(IMO) continue to consider countermeasures. Roughly classifying low-grade marine fuel oils based upon the PM's solubility by organic solvents, PM's that are generated from combustion of each low-grade marine fuel oil, we can divide them into Soluble Organic Fraction (SOF) and Dry Soot (DS). Component ratio of PM greatly varies according to the combustion process or properties of fuel oil. As Per-Soot, SOF includes PCAH, incompletely combusted droplets of cylinder oil, and sulfides composed of S and N contained in fuel oil. Soot generated from the Polynuclear Aromatic Hydrocarbons (PCAHs) which are formed from polymerized acetylene gas, cenosphere

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(RC) and compounds containing various metal contents are included in DS. Mixing with incompletely combusted hydrocarbons, partial oxides, carbon, a modicum of ash vapor in lubricant additive and a variety of metal contents in fuel oil, PM's are transformed into soot or gas, which causes smog. However, since heavy fuel oil's spray combustion itself is not sufficiently explicated, detailed information of the PM's generation is small.

2. Experimental method and equipment

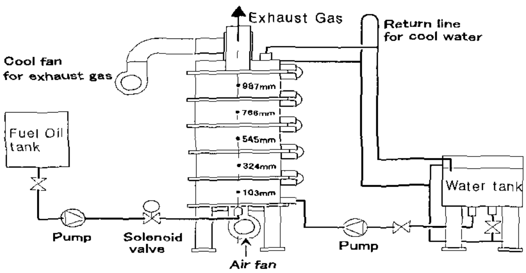


Fig. 1 Arrangement for experiment equipment

2.1 Burner and Fuel Oil

Table 1 shows properties of grade C heavy oil and oil-water emulsion (15.6% of water) used in this study. Viscosity (at 50℃) of two fuels (Grade C heavy oil: 180.0mm^2/sec, oil-water emulsion: 287.0mm^2/sec) show a great difference. It is the case in gross calorific values of two fuels. Both viscosity and gross calorific value have great influence on combustion characteristics of each fuel oil. Two fuels used in this study are mainly composed of carbon and hydrogen and contain more sulfur than other fuel oils. Though small quantities, two fuels contains aluminum, vanadium, etc. Oil-water emulsion is made by adding 30% of water to C heavy oil presented in Table 1. Fig. 1 presents whole experimental equipment.

Table 1 The sacred image of Bunker C Heavy Fuel Oil

	Bunker C Heavy Fuel	Emulsion Fuel
Moisture	0.00[mass%]	15.6[mass%]
Ash powder	0.02[mass%]	0.07[mass%]
Surfur	3.22[mass%]	2.72[mass%]
Carbon	80.92[mass%]	68.55[mass%]
H	9.14[mass%]	9.19[mass%]
N	0.22[mass%]	0.19[mass%]
Cl	4[ppm]	97[ppm]
Na	6[ppm]	200[ppm]
Ca	1 less[ppm]	1[ppm]
Mg	1 less[ppm]	1[ppm]
V	66[ppm]	54[ppm]
Fe	9[ppm]	7[ppm]
Al	1[ppm]	1[ppm]
Ni	25[ppm]	21[ppm]
Si	3[ppm]	5[ppm]
Viscosity	180@50 ℃ mm²/s	287@50 ℃ mm²/s
HHV	42,358 J/g	35,900 J/g

2.2 Experimental Method

In order to burn grade C heavy oil and oil-water emulsion through spray combustion, volume of injected fuel oil (about 12ℓ/h) and air at a constant level were fixed. Measurement system is presented in Fig. 2.

Flames are randomly sampled around center axis. Random sampling points are set at positions of 103, 324, 545, 766, and 987mm vertically apart from the bottom line of burner area. In addition, temperature measurement and PM trapping are carried out at random points at radius direction of each position. PM's trapped there were solved with 20cm^3 of Dichloro Methane for 12 hours to divide them into DS and SOF and, then, their absolute quantity were measured (Semi-micro electronic balance [Shimadzu Corporation, AE−40SM], measurement limit: 0.01 mg).

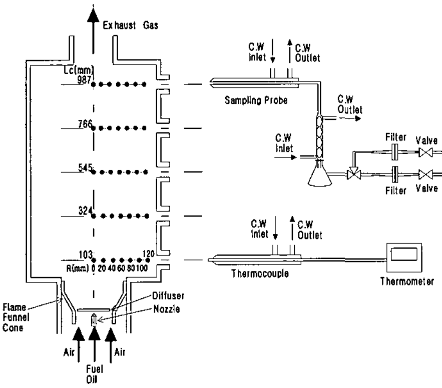


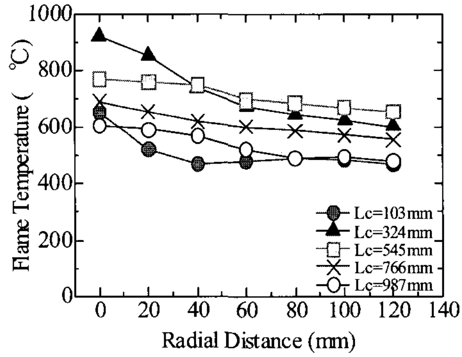
Fig. 2 Measurement system

3. Results and Discussions

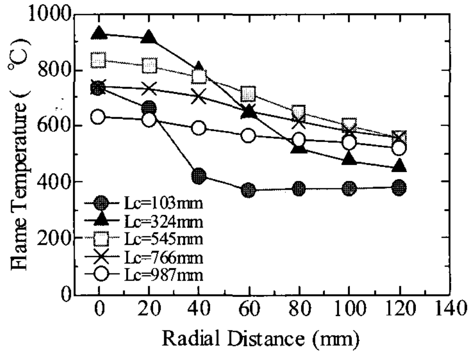
The length of flames of grade C heavy oil and oil-water emulsion were commonly within approximately 1,000mm. As turbulent flames, their color was totally yellowish-orange. Results of temperature measurement at each point at radius direction are presented in Fig. 3. At the center of Lc=324mm, a high temperature area of about 950℃ was observed. As measurement points moved farther away from the center of flame, temperature difference became smaller. As a whole, flames show characteristics in premixed combustion. Fig. 4 present distribution (g/m^{3}N) of DS which is generated when grade C heavy oil and oil-water emulsion are combusted, respectively. Distributional patterns of two fuels' DS are remarkably similar and their quantity also shows similar level. At closer points to nozzle, DS was remarkably increased and had higher concentration. However, as measurement points approached to lower ones, concentration of DS that was decomposed by combustion reaction became lower. At Lc=987mm, its concentration was decreased.

3.2 Component Analysis of Exhaust Gas

Results of analysis on exhaust gas using Portable Gas Analyzer1 (Horiba C o.) are presented in Table 2. Especially, compared components of exhaust gas of C heavy oil and oil-water emulsion are shown in Figure 5.

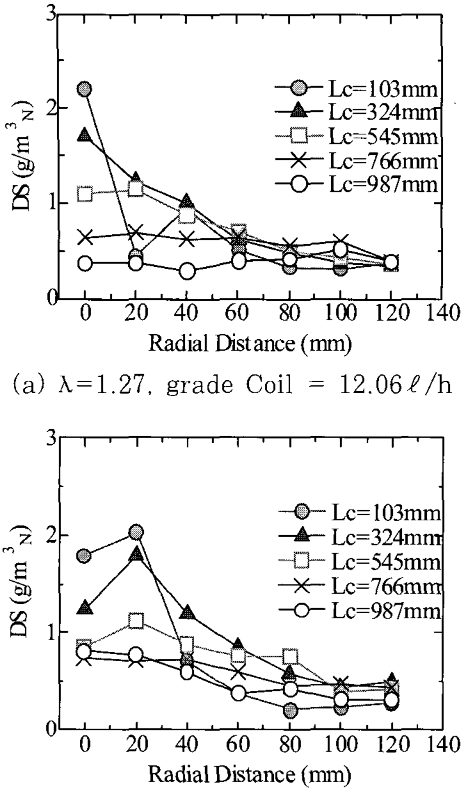


(a) λ=1.27, grade Coil = 12.03ℓ/h



(b) λ=1.76, Oil-water emulsion=12.09ℓ/h

Fig. 3 Flame temperature of Radial distance



(a) λ=1.27, grade Coil = 12.06ℓ/h

(b) λ=1.76, Oil-water emulsion=12.09ℓ/h

Fig. 4 Radial distance of DS

Among exhaust gases in Fig. 5, concentration of O_2 was measure lowered when oil-water emulsion was combusted than when C heavy oil was combusted. This results from the fact that the volume of oil-water emulsion's fuel oil is lower than that of grade C heavy oil.

For oil-water emulsion, combustion temperature was decreased, so concentration of NO was reduced by approximately 16%. By decreasing the volume of combusted fuel oil, concentration of SO_2 and CO_2 were reduced by approximately 25% and 15%.

In this study, water-cooling boiler was used for C heavy oil combustion. Changes in the volume of cooling water and resultant lowering of combustion temperature seemed to lead of NO reduction.

Table 2 Results of analysis on exhaust gas

	Bunker C Heavy Fuel	Emulsion Fuel
Fuel consumption [L/h]	12.06	12.09
Excess air ratio [λ]	1.27	1.76
O_2 [vol.%]	4.46	7.49
NO [ppm]	155.3	130.5
SO_2 [ppm]	966	729
CO_2 [vol.%]	11.85	10.13
Exh. Temp.[℃]	235	223
BLR Burner fuel Temp.[℃]	87.5	88
Wall Temp [℃]	122	120

However, water-cooling boiler used in this study was not able to adjust the volume of cooling water, we could ignore the influence on flames by changes in cooling-water volume. For SO_2, though oil-water emulsion used fuel oil lower than grade C heavy oil, concentration of SO_2 was reduced by 25% only. Presumably, difference of 5% is assumed to result from the fact that sulfur contained in grade C heavy oil transformed into compounds such as SO_2 as well as SO_3. In addition, relatively small number of samples in this study led the difference in concentration of as SO_2. If we increase the number of samples by extending the experimental time, the reduction of as SO_2 concentration in exhaust gas will approach close to 30%. As presented in Table 2, fuel oils contained chlorine (Cl). Thus, dioxin in exhaust gas was predictably generated. However, dioxin was not observed in the separate analysis previously carried out.

4. Conclusions

(1) Temperature distribution when oil-water emulsion was combusted showed similar pattern to distribution when grade C heavy oil was exclusively combusted. For flame temperature, there was no significant difference between grade C heavy oil and oil-water emulsion.

(2) For quantity of generated DS, there was no significant difference between two fuels. For flame temperature, oil-water emulsion was slightly lower since it contained water.

(3) Generation of SOF was decreased when oil-water emulsion was combusted.

(4) In oil-water emulsion, oxygen needed to combustion was decreased by 3%, which led the reduction of CO_2 (15%), NO (16%), and SO_2 (25%).

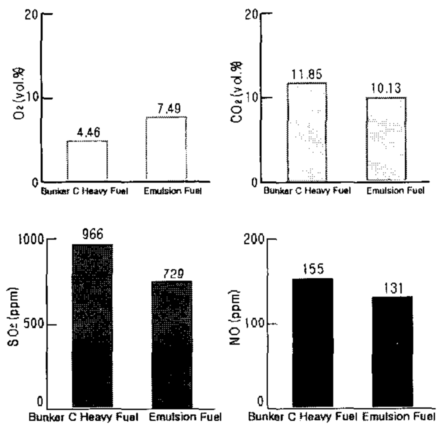


Fig. 5 Exhaust gas components of C heavy oil & emulsion

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Author Profile

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He received B.S. Degree in Engine Department from Mokpo National Maritime Univ. and M.S. degree in Engine Department form Korea Maritime Univ. He is currently in the Ph.D. course in Ocean Mechanical & Energy Engineering from Kobe Univ. in Japan. His research interest are PM Formation-Decomposition and Combustion Characteristics