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A Study on Diesel Engine NOx and Soot Emission Characteristics using Different Fuel Oils

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Abstract : This paper addresses some concerns faced by the shipping industry nowadays. Initially, the environmental issues were resolved and stricter regulations are now being implemented with regards to the exhaust gas, specifically nitrogen oxides (NOx) and sulfur oxides (SOx), emitted from ships. Secondly, with the increasing and unstable cost of fuel oils in the world market, it has become almost a necessity to explore on a new alternative fuel. Hence, this study was conducted.

An experiment was carried-out on a fishing survey vessel with the main engine (M/E) and generator engine (G/E) operated on expensive marine gas oil (MGO). During the experiment, two pre-refinery systems were installed and different fuel oil samples were employed for the M/E and the G/E. Furthermore, the NOx emission and soot concentration were monitored and verified. The results confirmed the compatibility of some fuel oil types to the engines and meeting the emission standards. MDO, MF15 and Bunker A can be used in place of MGO for the engines(M/E, G/E).

Key words : MGO (Marine Gas Oil), Pre-refinery systems, NOx emission, Soot concentration. MCH (Mixing clean heater), C (Ceramic ball), FSN (Filter Smoke Number)

1. Introduction

Sulfur Oxides (SOx), Nitrogen Oxides (NOx), Carbon Dioxides (CO_2) and particulate matters (PM) are the main air pollutants emitted from ships. The increasing trend in ship number and total tonnage can be attributed to the steady increase of these pollutants. The NOx emission has been regulated by the 2000 NOx Technical Code and maybe further reinforced from its present level in 2008[1], [2]. In view of SOx control, the sulphur content of fuels are restricted to 1.5% in Sulphur Emissions Control Areas (SECAs) from 2006[3], [4]. Moreover, the fishing industry is equally faced by the increasing cost of fuel oils nowadays.

Previous studies have been made using an alternative fuel mixture MF30 and

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have also shown positive results. A comparative analysis between MGO and MF30 mixture was compiled based on oil composition and soot level. As a result, MF30 class meets the international standard for NOx emissions and sulfur hexafluoride levels were confirmed. In addition, the analysis showed that it is acceptable to use the MF30 class on condition of proper engine running operation and pre-refinery treatment.

In addition to these results, it is necessary to continue developing this research work to optimize the system towards more economical but lower quality blended oil compared to MF30 with a goal of expanding into inshore and coast-to-coast shipping [5].

Thus, it is a necessity for this industry to explore on some alternative fuels and at the same time, comply with the different emission regulations. In this study, five different fuel mixtures (MDO, Bunker A, MF15, MF60, MF100) were prepared for the experiment as an alternate for MGO. In addition, the study confirmed the possibility of using lower grade blended oil and the limitation by measuring the engine's NOx and soot emission.

2. Apparatus and method

2.1 Apparatus

Table 1 shows the specification for main engine while the generator engine used in the experiment is a Daewoo D236T engine with an idling and mcr of 470 rpm and 2.070 rpm respectively. Table 2 enumerates the mixing ratio of heavy oil (cSt380) and marine gas oil (cSt3) used in this experiment. Figure 1 shows the probe location for soot value and NOx concentration measurement (a, b) and the measuring equipment AVL smoke meter and Horiba NOx analyzer (c, d).

Table 1 Main engine specification

Model	Ssangyong 6L23/30-K
Type/B x S (mm)	6 In -line 225 x 300
Engine speed(rpm)	MCR : 825, Idling : 450
Pmax	133 kg/cm^2
MEPC	16.8 kg/cm^2

Table 2 Blended oil mixing ratio

Fuel	Mixing ratio		Remarks
	cSt 380 (%)	MGO (%)	
MF15	47.6	52.4	
MF30	63.0	37.0	
MF60	73.0	27.0	
MF100	81.2	18.8	
MF150	87.1	12.9	
MF180	89.6	10.4	
MF380	100	0	

Abbreviations used in paper equivalent:
P : Purifier , M : Mixing clean heater
C : Ceramic ball, B/A : Bunker A
FSN : Filter smoke number, F : Filtering

(a) Probe position for G/E NOx and smoke measurement

Fig. 1 Probe positions and analyzers for smoke & NOx measurement

(b) Probe position for M/E NOx and smoke measurement

(c) AVL smoke meter

(d) Horiba NOx analyzer

Fig. 1 To be continued

2.2 Experimental method

The experiment was conducted onboard a fishing research vessel Mu-Gunghwa 24 with the main engine and generator normally operated on MGO. Five different fuel mixtures were prepared for the experiment as an alternative for MGO. Further, Mixing Clean Heater and Ceramic Ball were developed and installed as pre treatment equipment for the fuel. In addition to the two pre-treatment equipments, half of each sample mixture was purified. Each fuel mixture was made to pass through M, C, and M+C.

NOx and soot emissions were analyzed at different loads (no load, 25 % load, 50 % load, 75 % load and full load), according to the different fuel samples for both the main and generator engine.

3. Results and discussion

3.1 Engine FSN measurement

3.1.1 Generator engine FSN measurement

Figures 2, 3 and 4 compare the soot volume generated by the ship's generator using three fuel mixtures (MDO, MF15, B/A) against MGO. The blended fuel were pre-treated by P, P+M, P+C, M, C, and P+M+C. and the soot volume were measured at engine loads of 15kW to 65kW.

Figure 2 shows the comparison of smoke value for MDO on seven (7) different pre-treatment methods against plain MGO smoke value. At 25kW, it indicated an almost identical smoke value for MDO as well as the MGO. However, as the load increases notably from 40kW, the smoke value for all MDO with pre-treatment method are lower than plain MGO. At common point 55kW, MGO FSN is about 2.85 whereas MDO on a mixing clean heater has a smoke number around 1.4. For Figure 3, it represents the comparison of smoke value for blended fuel MF15 on five (5) pre-treatment methods with that of MGO. At 25 kW, FSN value for all MF15 fuel is a little bit higher than MGO. With the load increasing and at around 45 kW, the MGO smoke value exceeded that of the MF15. At 55 kW, MF15(C) has an FSN value of about 1.0 while MF15 (P) and MGO have a smoke value of 1.8 and 2.6 respectively. This graph indicated better soot reduction possibility using either a ceramic ball or a mixing clean heater only while the effect using the said pre-treatment method with a purifier has yielded higher soot volume quantity. Figure 4 is the comparison of soot quantity volume between MGO and Bunker A on different pre-treatment method. Although the result showed almost similar soot volume over the whole range of load for the Bunker A, it can be noted it is lower than the soot generated by MGO.

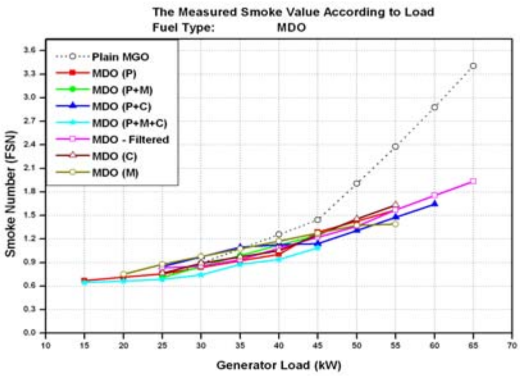

Fig. 2 FSN for generator engine using MDO

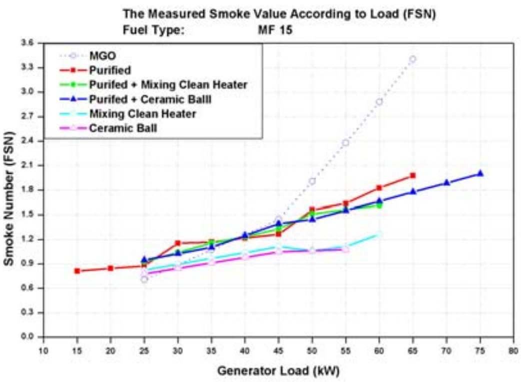

Fig. 3 FSN for generator engine using MF15

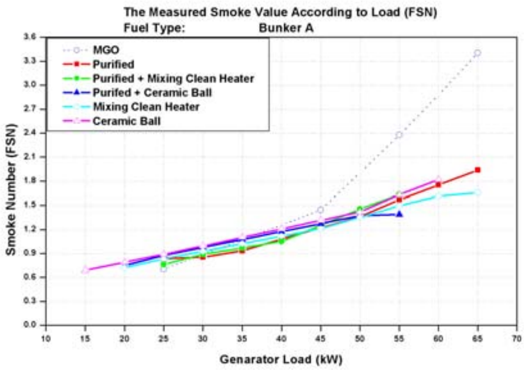

Fig. 4 FSN for generator engine using Bunker A

3.1.2 Main engine FSN measurement

Figures 5 and 6 are the comparison of MGO smoke value against different blended fuels. Fuels sample (MDO+ Bunker A, MF15, Bunker A, MF60, MF100) were used on the engine and the smoke generated value FSN at different loads (no load, 25 % load, 50 % load, 75 % load and full load) were graphed and compared.

Figure 5 shows the smoke value of main engine using different blended fuel pre-treated by purifier and mixing clean heater. For main engine idling speed and no load condition, MGO smoke value is around 0.6 while MF100 is about 2.1 and MDO+BA mixture at 1.3 which is the highest and the lowest among the blended fuels respectively. At 25 % load, while the MGO smoke value continue to increase, the FSN for blended fuels are now decreasing. Then at 100 % load, the FSN for all fuels are almost identical with the MDO+BA mixture showing the lowest smoke value of around 0.4.

In Figure 6, another pre-treatment method using the P + C was investigated. At idling condition, it can be noted the once again the MF100 has the highest smoke value at about 2.1. Then, at 25 to 100 % load, the MF15 fuel shows a remarkable reduction of its smoke value. MF15 FSN is about 1.2, 0.4, and 0.3 for 50, 75, and 100 % load respectively.

Figure 7 is the comparison of main engine smoke value running with MF15 blended fuel but treated with two different methods. Pre-treatment with P + C indicated a lower FSN value over the whole range of engine load compared to the P + M. At 100 % load, smoke value for P+C is about 0.3 while for P+M is around 0.4.

In Figure 8, Bunker A is likewise pre-treated with the same method of MF15. Comparatively, Bunker A on P+C has shown a bit lower FSN value over the Bunker A treated with P+M at all engine loads.

At figure 9, blended fuel MF60 on different pre-treatment methods was used on main engine. The lowest smoke value at zero load condition was shown at less than 1.5 FSN for MF60 (P) whereas the highest was at 2.4 FSN obtained from MF60 (C). Subsequently, from 25 too 100 % load condition; MF60 (P+M), MF60 (P+C), and MF60 (P) have indicated an almost identical smoke value. For MF60 (M) and MF60 (C), a higher smoke value was seen from 25 to 75 % load condition compared to the three other pre-treated MF60 blended fuel. However, at 100 % load there was not much deviation on FSN value for all MF60 mixture.

The soot quantity for MF100 (P, P+M, P+C, M, and C) shown in Figure 10 has somewhat shown the same soot quantity as that of MF60 at all engine load. However, at no load (idling speed), it has indicated a higher soot concentration value for MF100 (M) at about 1.8 FSN compared to MF60 (P) which is around 1.45 FSN. Both mixture, MF60 (P) and MF100 (M), have yielded the lowest smoke number in their respective category.

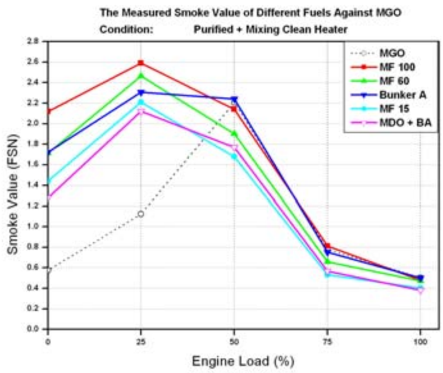

Fig. 5 FSN for main engine using blending fuel by P and M

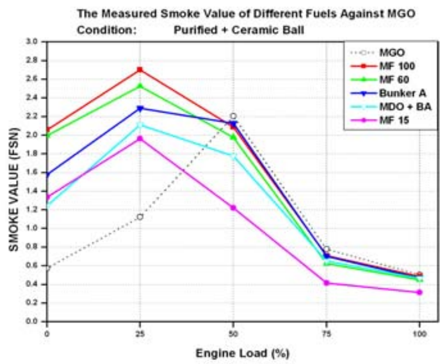

Fig. 6 FSN for main engine using blending fuel by P and C

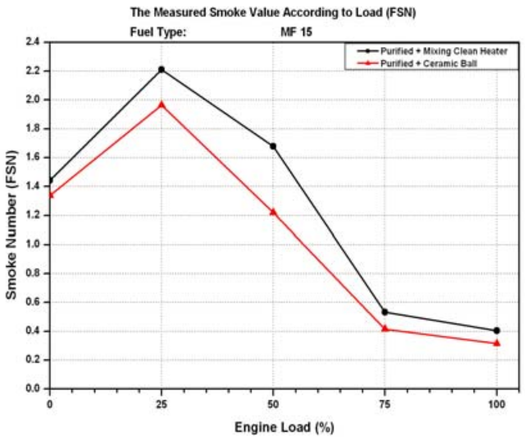

Fig. 7 FSN for main engine using MF15 by M and C

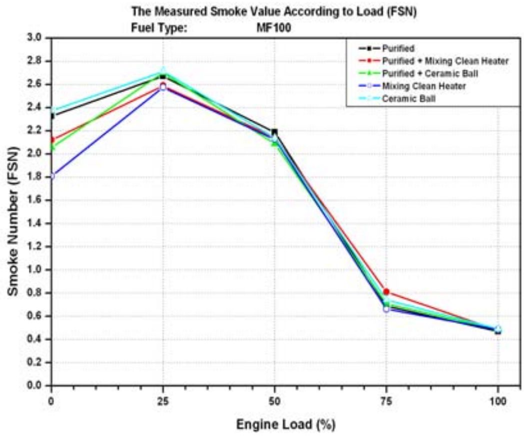

Fig. 10 FSN for main engine using MF100

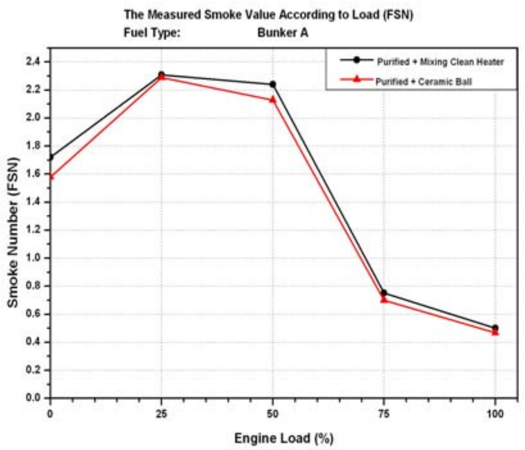

Fig. 8 FSN for main engine using B/A by M and C

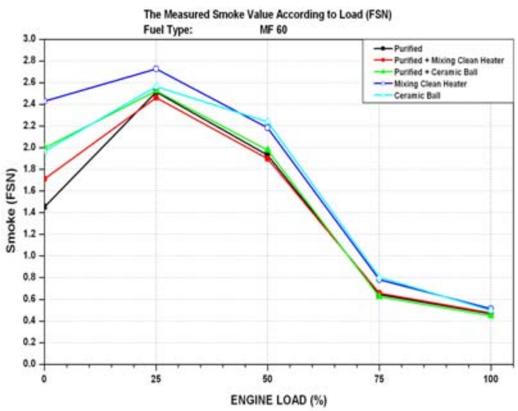

Fig. 9 FSN for main engine using MF60

3.2 Engine NOx emission measurement

3.2.1 Generator engine NOx emission quantity measurement

Figure 11 shows the NOx emission level for generator engine using MF15 on different pre-treatment process. At common point 25 kW load, MF15 on mixing clean heater has shown the lowest level. However the MF15 on P+C treatment has shown a reducing NOX emission value as the load increases and at common point 50 kW, it has the lowest emission level at around 100 ppm. In Figure 12, Bunker A fuel emission level was investigated. Whereas almost all pre-treatment method with Bunker A fuel has indicated an increasing NOx emission level, Bunker A on P+C has otherwise a decreasing level as the load increases. At 50 kW, Bunker A on P+C emission level is about 40 ppm while Bunker A on P has the highest level of more than 250 ppm. Likewise, Bunker A on MCH emission level deviation at 50 kW can be attributed to failure during data gathering and should be confirmed in future studies.

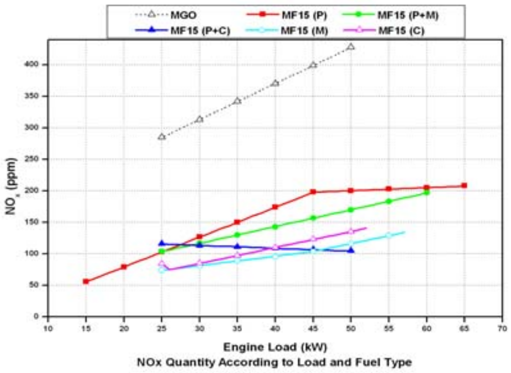

Fig. 11 NOx emission for generator engine using MF15

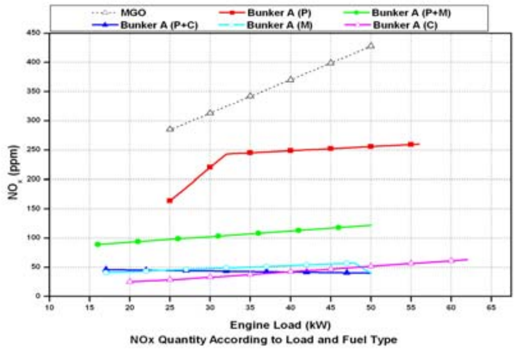

Fig. 12 NOx emission for generator engine using B/A

3.2.2 Main engine NOx emission quantity measurement

Figure 13 compares the NOx emission level of MGO and five (5) blended fuels pre-treated on P+M for main engine. At 25 % load, MGO (C) revealed the highest NOx emission level whereas MF60 (P+M) has the emission level around 75 ppm. At 100 % load, MF60 (P+M) has its emission level at around 100 ppm and almost stable at all engine load. On the other hand, the mixture MDO+BA have indicated an increase in emission level as the load increases. Similarly, pre-treatment method P+C NOx emission on different blended fuels was investigated as given in Figure 14. Indicating almost the same pattern as that of the P+M treatment method, however, NOx emission level for P+C has shown higher values yet again MF60 has the lowest emission level at almost 200 ppm.

Figure 15 compares the main engine's NOx emission level running on MF15 on P+C and P+M pre-treatment method. From zero to 25 % load, NOx emission level for both conditions is almost identical. However at 25 to 100 % load, emission level for MF15 (P+C) at 625 ppm is a little bit higher than MF15 (P+M)'s 580 ppm. Figure 16 indicated the NOx emission volume for Bunker A (P+M, P+C) against the more expensive MGO. Although the Bunker A NOx emission value is almost the same on both pre-treatment method, it can be seen that it is lower than the more expensive MGO preprocessed with a Ceramic ball.

Figure 17 is the result of MF60 mixture NOx emission volume. MF60 was preprocessed on different treatment method (P, P+M, P+C, M, and C). MF60 (P) and MF60 (P+M) has shown a significant reduction in NOx volume and are lower than MGO (Plain) over the whole load range (no load to full load). Further, at 75 % load, all MF60 preparation have shown a lower level of emission compared to the more expensive MGO with MF60 (P+M) showing the most potential result. Additionally for Figure 18, MF100 (P, P+M, P+C, M) NOx emission volume from no load to 50 % load is a little higher than the MGO emissions. However, at 75 % load MF100 (P, P+M, P+C) have shown a lower emission volume specifically for MF100 (P). MF100 (M), although its emission quantity is a little higher than MGO at all engine load range, it has exhibited an almost constant emission volume from 25 % to 100 % load.

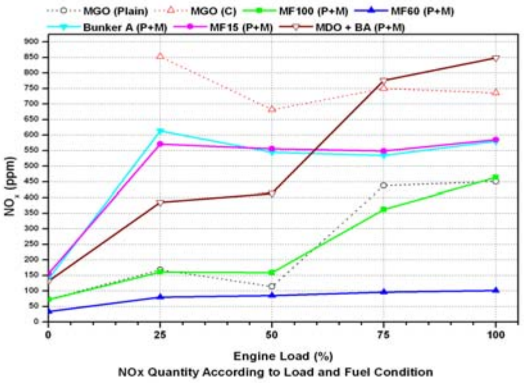

Fig. 13 NOx emission for main engine by fuel with P and M

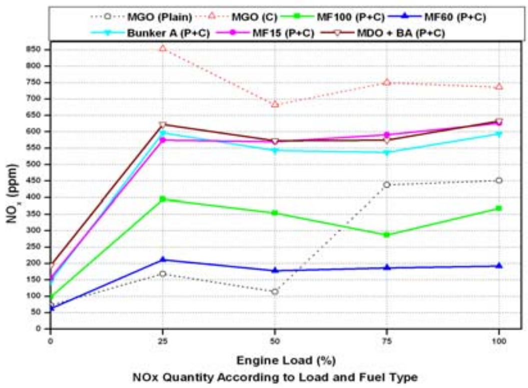

Fig. 14 NOx emission for main engine by fuel with P and C

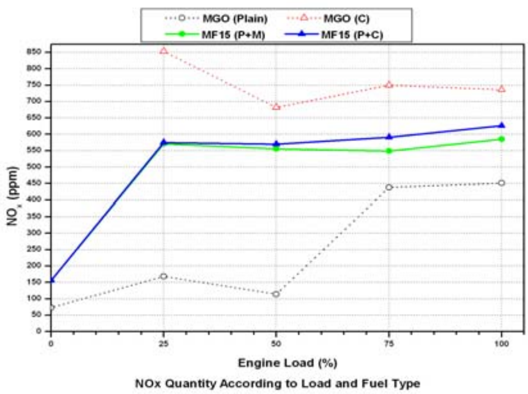

Fig. 15 NOx emission for main engine using MF15

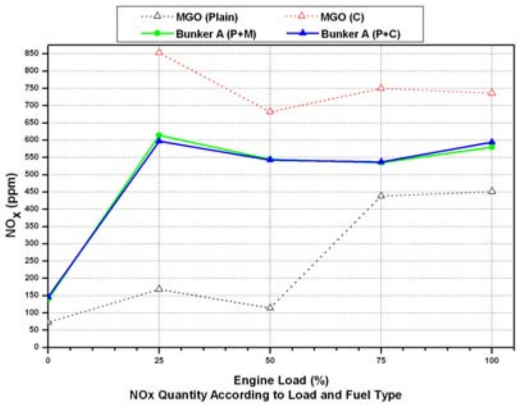

Fig. 16 NOx emission for main engine using Bunker A

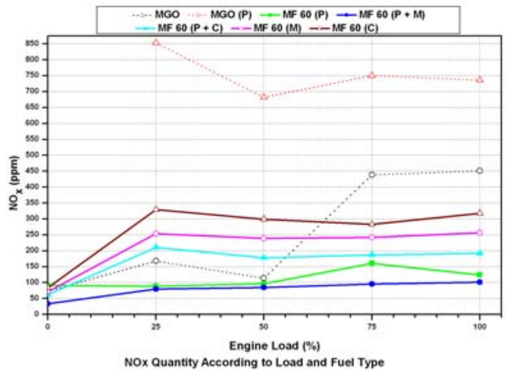

Fig. 17 NOx emission for main engine using MF60

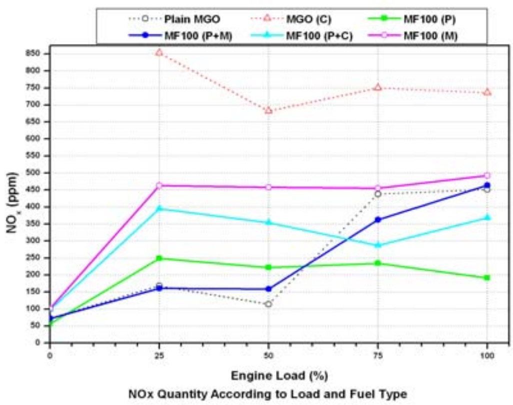

Fig. 18 NOx emission for main engine using MF100

4. Conclusions

This study was conducted with the aim

of seeking alternative fuel to address environmental issues and the rising cost of conventional fuel oils. Different fuel mixtures were prepared and pre-treatment equipment installed onboard a fishing survey vessel. Each fuel sample was used to confirm its compatibility to the main engine and generator engine. The experiment yielded the following results:

1) MDO, MF15 and Bunker A can be used in place of MGO and showed compatibility with the engines. Likewise, it has met the emission standards (NOx and soot).

2) Crude blended oils (MF60, MF100) are “heavier” than MF30. Results showed that these fuel mixtures can not be used on the engines below the fifty (50) percent load and particularly at quarter load due to high soot concentration value. Although at seventy-five (75) percent load to full load, considerations can be made for these fuel mixtures and can be utilized as an alternative fuel.

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