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Testing and Analysis of Renewable/Bio/Conventional Diesel Blends for Marine Vessel Applications

- Task 3 Report

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Abstract

Renewable diesel (RD) and biodiesel (BD) are produced from renewable resources. Replacing petroleum diesel by RD and/or BD in power generation has the potential to reduce life-cycle greenhouse gas (GHG) emissions. Therefore, the Canadian Coast Guard (CCG) has been developing a strategy to introduce RD, BD or their blends into its small and large vessel fleet to help reduce net GHG emissions. During this process, immediate questions that need to be addressed are what the optimal RD/BD blend ought to be, how much of the RD/BD blend can be introduced, and how these blends will affect the combustion and emissions performance of the engines powering the vessels.

In this project, the National Research Council (NRC) and CCG work together to characterize and optimize the properties of RD, BD and their blends with petroleum diesel, as well as evaluate the combustion and emissions performance of the RD/BD/ULSD blends when applied to heavy-duty diesel engines.

This report summarizes the findings from the last task (Task 3) of the project, which was designed to evaluate the combustion and emissions performance of an RD/BD/ultra-low-sulfur diesel (ULSD) blend, a RD/BD blend, and a RD with a fuel additive. The findings reveal that switching from ULSD to the three investigated blends containing RD and/or BD does not have significant negative effects on combustion and emissions performance. The engine efficiency and energy consumption rate do not significantly change when switching from ULSD to either of the three investigated blends, but the fuel consumption rate varies due to the change in energy density. Emissions of engine-out carbon dioxide (CO_2), nitrogen oxides (NOx), particulate matter (PM), carbon monoxide (CO) and unburned hydrocarbons also change when switching from ULSD to the three investigated blends due to the changes in fuel properties, such as energy density, ratio of hydrogen to carbon, etc. Most of these variations are positive in terms of reducing emissions.

1. Introduction

In order to reduce greenhouse gas (GHG) emissions, the Canadian Coast Guard (CCG) is developing its own strategies to decarbonize its fleet. One of the strategies is to introduce low-carbon fuels into its in-service fleet. The CCG is increasingly introducing renewable diesel (RD), also known as hydrogenated vegetable oil (HVO), and biodiesel (BD), also known as fatty-acid-methyl-easters (FAME), and their blends to its small and large vessel fleet. During this process, immediate questions that need to be addressed are what the optimal RD/BD blend ought to be and how these low-carbon fuels will affect the combustion and emissions performance of the engines powering the vessels.

National Research Council (NRC) has the capability and experience in characterizing properties of various low/zero-carbon fuels and evaluating the combustion and emissions performance of heavy-duty diesel engines that are widely used in marine vessels.

In this project, the NRC works with the CCG to characterize and optimize the properties of the planned RD/BD and their blends with conventional marine ultra-low-sulfur diesel (ULSD) at different ratios, and evaluate the combustion and emissions performance of the RD/BD/ULSD blends when applied to heavy-duty diesel engines.

The objective is to experimentally test, analyze and optimize the performances of RD/BD/ULSD blends for applications in marine vessels. The performances to be tested and analyzed include lubricity, cloud point, and other critical properties, as well as engine combustion and emissions performance when using RD/BD/ULSD blends. In addition, the effects of two fuel additives produced by SulNOx Group and Katal Energy, respectively, on the ULSD performance will also be evaluated. CCG provided or arranged delivery of all fuels and additives.

The project is divided into three tasks:

(1) Evaluation of combustion and emissions performance of a ULSD, a RD/BD/ULSD blend at the CCG selected ratio of 50/20/30, an ULSD/SulNOx additive blend, and an ULSD/Katal additive blend at the blending ratios suggested by SulNOx group and Katal Energy, respectively. The outcome of this task has been published in the NRC's Publications Archive [1];

(2) Characterization of RD/BD mixtures at various blending ratios. The outcome of this task has also been published in the NRC's Publications Archive [2];

(3) Combustion and emissions performance test of three fuel blends - a RD/BD/ULSD blend, a RD/BD blend, and a RD with the addition of SulNOx additive.

This report summarizes the results of the last task (task 3).

2. Fuel properties of the three investigated blends

Similar to Tasks 1 and 2, the basic fuel properties of the three blends are analyzed first following the test methods required by Canadian General Standards Board (CGSB) [3]. The result of the analysis is listed in table 1. For the sake of comparison, the properties of the ULSD used in Tasks 1 and 2 are also listed in Table 1, in which the three blends are represented as RXX/BXX/UXX, where "XX" after R, B and U are the volume percentages of RD, BD and ULSD in the blends, respectively. U100 represents ULSD, and R100+SulNOx represents RD with the addition of SulNOx additive at the ratio of 1/2000.

Table 1 Fuel properties of the three fuel blends.

Fuel property	U100	R50/B05/U45	R50/B50	R100+SulNOx	Limits [1]	Test method
Flash point (°C)	70.0	75.5	89.5	75.5	>60	ASTM D93
Kinematic viscosity at 40°C (mm^2/s)	2.78	3.06	3.61	3.31	1.7-4.3	ASTM D445
Distillation, 90% recovered (°C)	320.7	318.5	338.6	306.3	<357	ASTM D86
Water and sediment, % by volume	<0.005	<0.025	<0.025	<0.025	<0.02	ASTM D1796
Copper strip corrosion, 3 h at a minimum test temperature of 50°C	1a	1a	1a	1a	-No. 1	ASTM D130
Cetane number (CN)	41.1	58.7	63.4	78.3	>40	ASTM D613
Sulfur content (mg/kg)	13	5.5	<3.2	<3.2	<15	ASTM D7039
Low temperature flow properties: cloud point (°C)	-25.0	-17.2	-6.5	-11.8	-6 (type 11), -18 (type 15)	ASTM D613
Lubricity wear scar diameter, µm)	354.0	186.5	103	464	<520µm	ASTM D6079
Density at 15 °C (kg/m^3)	858.6	829.3	842.6	796.6	800-880 (type 11), 815-880 (type 15)	ASTM D4052
Lower heating value (MJ/kg)	42.366	42.872	40.342	43.828	N/A	ASTM D4809
C (Mass %)	87.17	84.98	79.99	84.45	N/A	GL-103
H (Mass %)	13.33	13.76	13.22	14.82	N/A	GL-103
O (Mass %)	0.17	0.78	6.39	0.04	N/A	SNCUT - Oxygen
H/C	1.822	1.930	1.969	2.091	N/A	Calculated
Stoichiometric A/F ratio	14.41	14.45	13.44	14.81	N/A	Calculated

In Table 1, the fuel properties that do not meet the specifications of the Canadian General Standard for marine diesels are highlighted by red color, and those meet the standard specifications for type 11 (summer) marine diesel but don't meet the specifications for type 15 (winter) marine diesel are highlighted by yellow color. Those that are not highlighted meet the specifications of the Canadian General fuel Standard for marine diesel.

Similar to the findings in Tasks 1 and 2, most properties of the three tested blends and ULSD meet the standard specifications, except

1) Cloud point
   - ✓ All three tested blends meet the standard cloud point specification for type 11 (summer) marine diesel, but do not meet the standard cloud point specification for type 15 (winter) marine diesel. The ULSD meets the standard cloud point specification for both type 11 and type 15 marine diesels.

     As indicated in the report of Task 2 [2], the RD and BD tested in this project were obtained from Province of British Columbia. It is possible that they are not "winter" (i.e. type 15) diesel. This might be one of the reasons that most properties of the tested RD/BD blends meet the standard specifications for type 11 marine diesel, but the cloud point of the tested blends do not meet the standard specification for type 15 marine diesel.
2) Density
   - ✓ The density of R100+SulNOx is 0.4% and 2.4% lower compared to standard density specifications for type 11 and type 15 marine diesels respectively. However, it should be pointed out that the current fuel standard is designed based on petroleum-based diesel whose gravimetric energy density (lower heating vale) is lower than that of the RD. For example, the gravimetric energy density of RD+SulNOx is 43.828MJ/kg, which is 3.5% higher than that of U100 (42.366MJ/kg). This higher gravimetric energy density of RD+SulNOx is more than enough to compensate its slightly lower density compared to the standard specifications for both type 11 and type 15 marine diesels, in terms of volumetric energy density. Therefore, it may be necessary to redefine the standard specification of density when introducing alternative fuels in applications, given that the gravimetric energy density of some alternative fuels may significantly differ from that of petroleum-based diesel.

In addition to those properties analyzed in Tasks 1 and 2, two more fuel properties that are not specified in the Canadian General Standard but may affect the fuel consumption and emissions performance are discussed in this task. They are:

1) Lower heating value
   - ✓ The lower heating value (LHV) of a fuel or blend represents its gravimetric energy density. The higher the LHV, the less fuel will be needed to generate the same power, resulting in lower fuel consumption rate. It is noted from Table 1 that the LHVs of both R100+SulNOx and R50/B05/U45 are higher than that of U100, but that of R50/B50 is lower than that of U100. This difference in LHV will cause the variation in fuel consumption rate, which will be discussed in the section 3.2.
2) H/C
   - ✓ H/C is the ratio of hydrogen atom number to carbon atom number (H/C) in a fuel or blend. The H/Cs of the three tested blends and U100 are also listed in Table 1. The H/C ratio affects the engine-out carbon dioxide (CO_2) emissions. When the LHVs of different fuel blends are similar, the higher the H/C, the lower the engine-out CO_2 emissions, if the engine efficiency does not significantly change. Table 1 suggests that R100+SulNOx has the highest H/C, followed by R50/B50, R50/B05/U45 and U100, respectively.

The combustion and emissions performance of U100, R50/B05/U45, R50/B50 and R100+SulNOx were tested and analyzed in this task.

3. Combustion and emissions performance of the three tested blends and ULSD

3.1 Test engine and procedure

Same as in Task 1, the test was conducted on a 30kilowatt (kW) diesel generator which incorporated an electronically controlled four-stroke, four-cylinder, direct injection, turbocharged diesel engine (Hatz 4H50TIC) coupled to a single-phase, continuous duty alternating current (AC) alternator (Stamford). The engine specifications are shown in Table 2.

Table 2 Engine specifications.

Base engine model	Hatz 4H50TIC
Number of cylinders	4
Bore x stroke	84 mm x 88 mm
Compression ratio	17.5
Displacement	1.952 liter
Number of valves	2
Diesel fuel injection	Common Rail Direct Injection
Maximum generator power output	30 kW

Figure 1 displays the test cell setup. The flow rate of the fuel was measured using a Coriolis type flow meter (Micro Motion CMF010 flow meter and a 1700R transmitter). The flow rate of the fresh air entering the engine was determined by utilizing a thermal gas mass flow meter from Fox Thermal Instruments Inc, specifically the Model FT2A. Temperatures and pressures were also measured at different locations of the test setup, such as the intake and exhaust manifolds.

Figure 1 Test cell setup.

The testing was conducted at three typical generator load conditions, i.e. 25, 50 and 85% of the maximum generator power output, which correspond to about 7.5, 15.0 and 25.5 kW of electrical power output. The performance parameters that were collected and analyzed include engine efficiency, fuel consumption rate, and emissions of carbon dioxide (CO_2), carbon monoxide (CO), particulate matter (PM), nitrogen oxides (NOx), and unburned hydrocarbons (HC).

The concentrations of CO_2, NOx, CO, and HC in the exhaust gas were measured by gas analyzers (California Analytical Instruments – 600 series). Additionally, an AVL 415S smoke meter was utilized to determine the smoke number, which in turn allowed for the calculation of the PM emissions using Equation 1 [4].

$$m_{PM} = \frac{1}{0.405} \times 4.95 \times FSN \times \exp(0.38FSN) \tag{1}$$

where m_{PM} is the PM concentration in exhaust (mg/m^3), FSN is the filter smoke number.

The generator efficiency (%) was defined as the ratio of the generator power-output to the fuel energy input to the engine. The emissions of CO_2, NOx, CO, PM, and HC (brake specific emissions) were expressed as the flow rates of these components in the exhaust (g) divided by the generator power-output, i.e. gram (g)/kilowatt-hour (kW-hr).

Since energy density varies with fuel, conventional fuel consumption rate may not be a reasonable parameter to evaluate the performance of different fuels. Therefore, similar to Task 1, in addition to the performance parameters mentioned above, another parameter called energy consumption rate is used.

The energy consumption rate is defined as the fuel energy consumption per kW-hr of generator power-output, i.e. megajoule (MJ)/kW-hr.

In order to compare the combustion and emissions performance of different fuel blends at the same condition, the key engine operating parameters were kept the same for different blends at a given load, including diesel injection timings, pulse distribution and intake air temperature, although these parameters varied with load change. Therefore, the difference among different tested blends is primarily caused by the variation in fuel properties.

At each generator load condition, the generator was started and warmed up for about two hours, until the intake manifold temperature reached 40, 35 and 35 ^{o}C, respectively, at 85, 50 and 25% of full generator load. Then the combustion and emissions performance data were recorded every 10 minutes over a two-hour period. The average data over the two-hour period are presented in the next section.

For the sake of comparison, the combustion and emissions performance of the ULSD (U100) was also re-tested in Task 3 to avoid the effect of variation in environment condition.

3.2 Engine test results

3.2.1 Engine efficiency, fuel consumption, and energy consumption

The test was conducted at three generator load conditions, as shown in Fig. 2. It is noted that the generator power-output was almost constant at the three load conditions for different fuels. Therefore, the variations in various combustion and emissions performance parameters are caused by the variation in fuel properties.

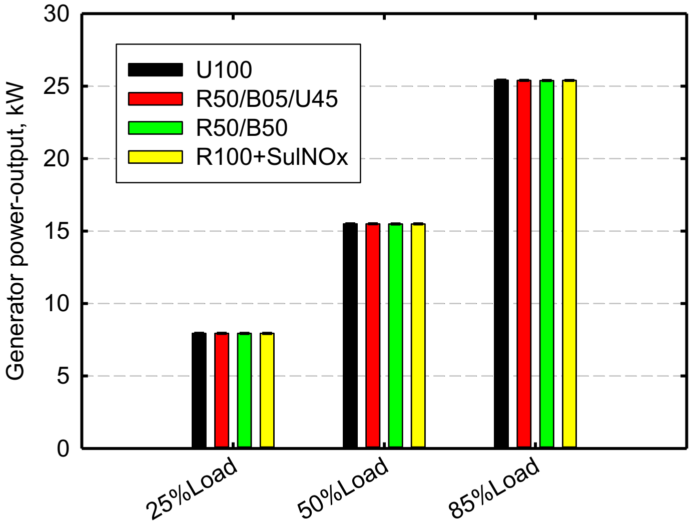

Figure 2 Generator load conditions.

Figure 3 displays the generator efficiency when the three blends and U100 are used. It is noted that although the generator efficiency varies with changing generator load, the variation in efficiency at a constant load is insignificant (within the standard deviation) with changing fuel.

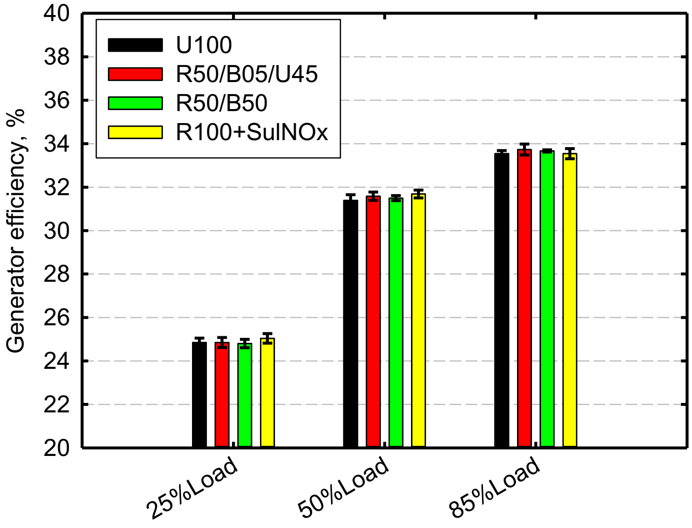

Figure 3 Generator efficiency.

Figure 4 shows the fuel consumption rate for the three blends and U100. It is observed that the fuel consumption rate of R50/B50 is the highest, followed by those of U100, R50/B05/R40 and R100+SulNOx, respectively. The variation trend in fuel consumption rate is almost reversely proportional to the variation in energy density (LHV). This is because the generator efficiency variation is insignificant when fuel changes, and therefore more fuel is needed to keep the generator load constant when energy density is lower.

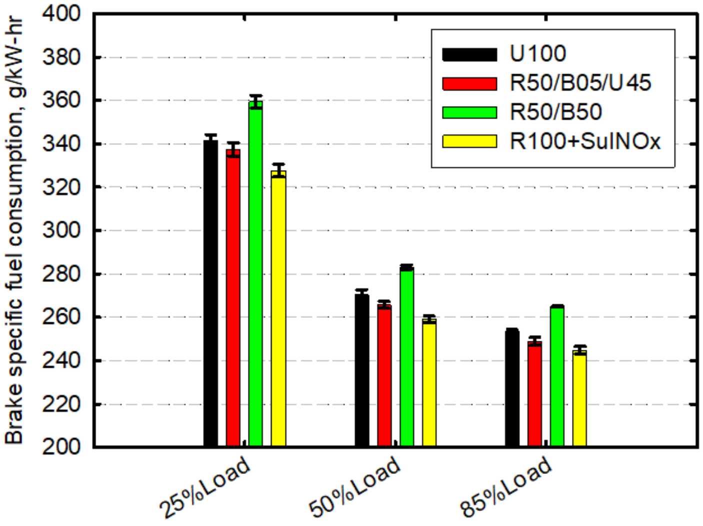

Figure 4 Fuel consumption rate.

Figure 5 depicts the energy consumption rate when the three blends and U100 are used. Similar to engine efficiency, the variation of energy consumption rate is insignificant at a constant load condition.

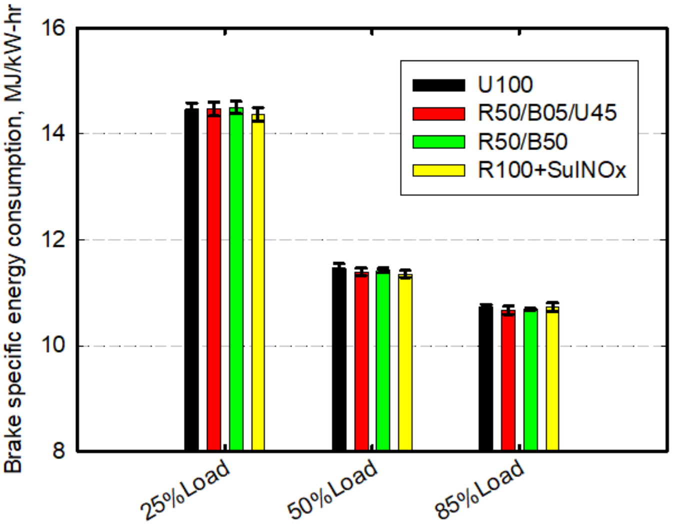

Figure 5 Energy consumption rate.

3.2.2 Measured engine-out CO_2 and the life-cycle GHG emissions

Figure 6 displays the measured engine-out CO_2 emissions when the three tested blends and U100 are used at the three generator load conditions. It is observed that U100 results in the highest engine-out CO_2 emissions, followed by R50/B05/U45, R50/B50 and R100+SulNOx, respectively, at a constant load. This variation trend is caused by the variations in H/C and lower heating value when changing fuel from U100 to R50/B05/U45, R50/B50, and R100+SulNOx, respectively, as shown in Table 1. Both H/C and lower heating value gradually increase with changing fuel from U100 to R50/B05/U45, and R100+SulNOx, leading to gradually reduced engine-out CO_2 emissions. However, R50/B50 has the lowest lower heating value, but leads to the second lowest engine-out CO_2 emissions, suggesting that its higher H/C effect surpasses the lower heating value effect.

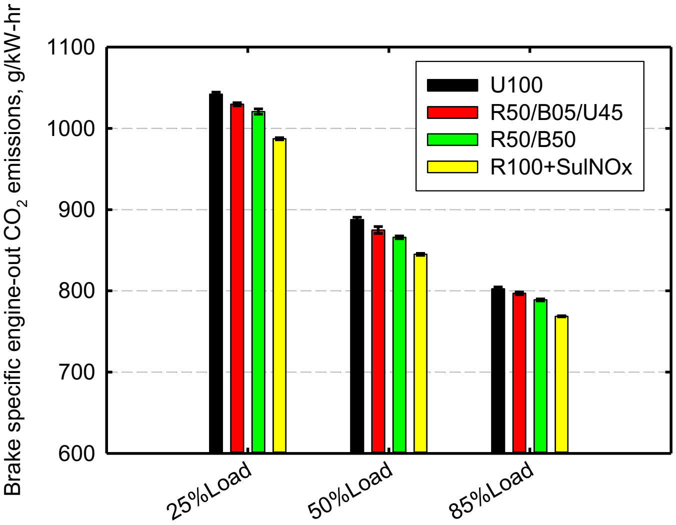

Figure 6 Engine-out CO_2 emissions.

Since the RD and BD are produced from renewable sources, the life-cycle (net) GHG emissions should be lower than the engine-out CO_2 emissions when RD, BD or their blend with other fossil fuels is used. Based on a recent publication [5], the life-cycle GHG emissions of RD or BD reduce by 40~86% per megajoule energy release compared to petroleum diesel, depending on the sources and production process of RD/BD. Based on the density and lower heating values of U100, R50/B05/U45, R50/B50, and R100+SulNOx in Table 1, the energy fraction of the RD and BD in R50/B05/U45 is 48%, and that in R50/B50 and R100+SulNOx is almost 100%. Therefore, compared to U100, the life-cycle GHG emissions are reduced by 19~41% when R50/B05/U45 is used, and 40~86% when R/50/B50 or R100+SulNOx is used.

3.2.3 Pollutant emissions

Figure 7 displays the variation of NOx emissions. It is noted that R50/B05/U45 reduces NOx emissions at all three tested load conditions, compared to U100. This is because BD content (5%) is very small in R50/B05/U45 and RD tends to reduce NOx emissions compared to U100 [6].

R50/B50 slightly increases (by ~2%) NOx emissions at 25% load, but slightly reduces (by about 10%) NOx emissions at 50 and 85% load, compared to U100. This is due to the competition between the effects of RD and BD on NOx emissions. RD tends to reduce but BD tends to increase NOx emissions [7]. At 25% load condition, the effect of BD might be stronger than that of RD, but the situation reverses at 50 and 85% loads.

R100+SulNOx does not affect or slightly reduces NOx emissions, since RD tends to reduce NOx emissions, but SulNOx additive tends to increase NOx emissions, as observed in the Task 1 of this project [1].

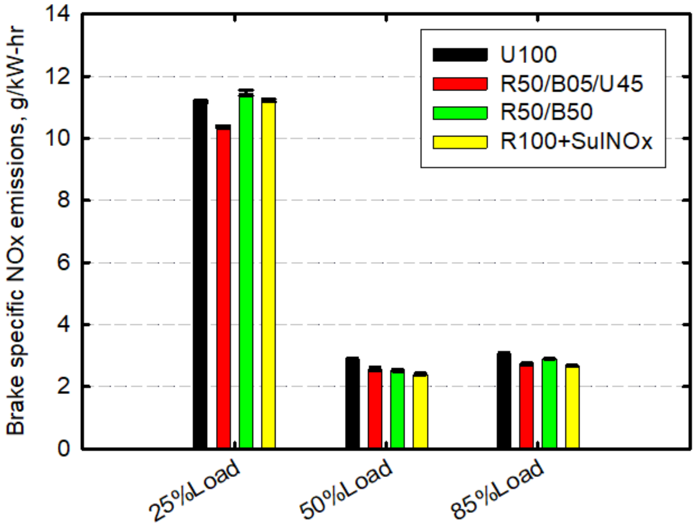

Figure 7 NOx emissions.

Figure 8 shows the variation of PM emissions. It is noted that R50/B50 and R100+SulNOx reduce PM emissions at all test load conditions, with the former being more effective. An early investigation suggested that higher oxygen content and/or lower aromatic compounds in a fuel blend help reduce PM emissions [8]. Both BD and RD almost have no aromatic contents [9] but BD has a certain amount of oxygen, resulting in stronger effect of R50/B50 in reducing PM emissions compared to R100+SulNOx.

R50/B05/U45 either does not significantly change (at 25% load) or slightly reduces (at 50 and 85% loads) PM emissions. This is because it still has aromatic compounds, although the amount is reduced.

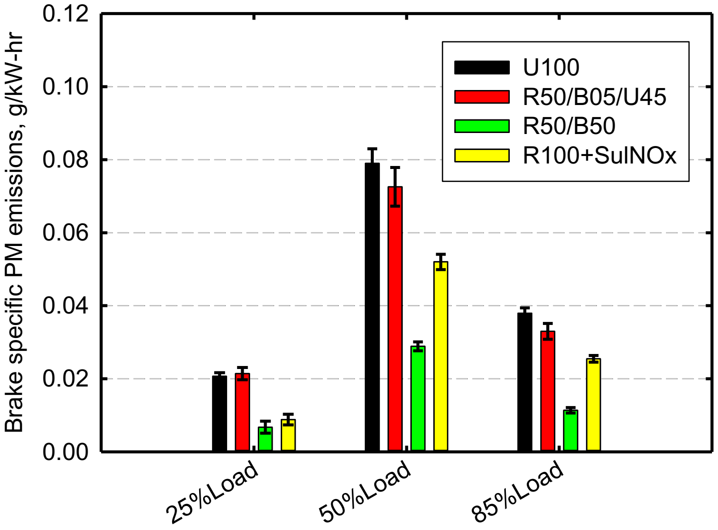

Figure 8 PM emissions.

Figure 9 shows the variation of CO emissions. It is observed that the effects of the three tested blends containing RD or BD on CO emissions vary with changing generator load. At 25% load condition, all three tested blends significantly reduce CO emissions compared to U100. At 50 and 85% load conditions, R50/B50 reduces CO emissions, but R50/B05/U45 and R100+SulNOx either slightly reduce or generate similar CO emissions compared to U100.

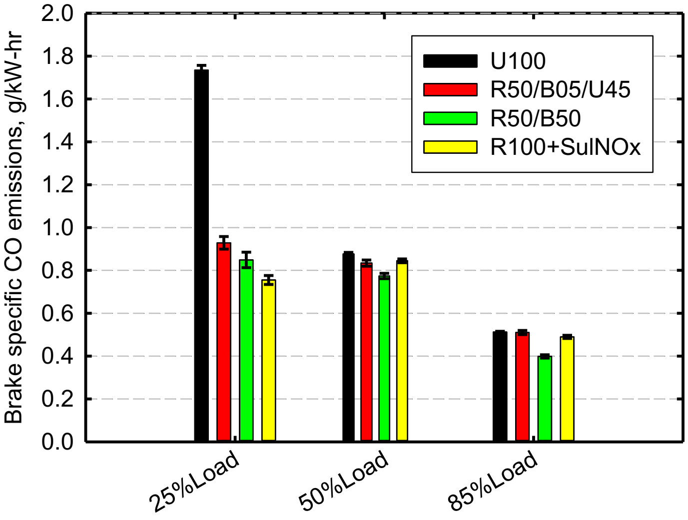

Figure 9 CO emissions.

Figure 10 displays the variation in HC emissions. All three tested blends containing RD and/or BD reduce HC emissions, possibly due to the lack of aromatic compounds. Among the three tested blends containing

RD and/or BD, R50/B50 is most effective in reducing HC emissions. This might be because the oxygen content in BD intensifies the fuel decomposition. R100+SulNOx is second in reducing CO emissions, followed by R50/B05/U45, since R100+SulNOx does not contain any aromatic compounds while R50/B05/U45 still has certain amounts of aromatics.

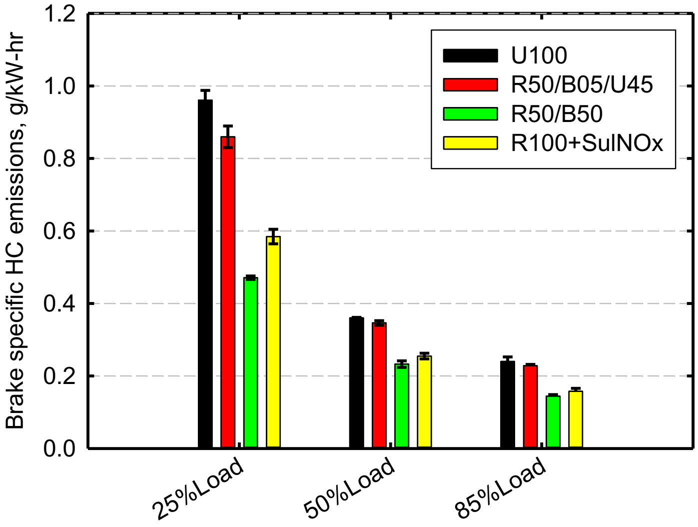

Figure 10 HC emissions.

Overall, compared to U100, all three tested blends containing RD and/or BD do not have significantly negative effect in terms of generator efficiency and emissions performance. Fuel consumption rate varies with changing fuel blend due to the variation in lower heating value.

All combustion and emissions performance data discussed above are summarized in Table 3.

Table 3 Combustion and emissions data.

Parameter	U100			U50/B05/U45			R50/B50			R100+SulNOx		
	25%	50%	85%	25%	50%	85%	25%	50%	85%	25%	50%	85%
Power, kW	7.94±5.8e-4	15.51±1.1e-3	25.41±1.8e-3	7.94±4.6e-4	15.50±3.0e-3	25.40±1.9e-3	7.93±8.3e-4	15.49±1.2e-3	25.39±1.70e-3	7.94±1.30e-3	15.49±2.8e-3	25.40±1.3e-3
Generator efficiency, %	24.85±0.20	31.40±0.26	33.54±0.14	24.85±0.23	31.58±0.19	33.73±0.25	24.80±0.19	31.50±0.12	33.67±0.05	25.04±0.22	31.69±0.18	33.54±0.23
bsFC, g/kW-hr	341.42±2.8	270.44±2.2	253.24±1.1	337.53±3.1	265.66±1.6	248.83±1.8	359.41±2.9	283.11±1.1	264.96±0.4	327.62±3.0	259.02±1.5	244.78±1.7
bsEC, MJ/kW-hr	14.46±0.12	11.46±0.09	10.73±0.05	14.47±0.13	11.39±0.07	10.67±0.08	14.50±0.12	11.42±0.04	10.69±0.02	14.36±0.13	11.35±0.07	10.73±0.08
bsCO$_2$, g/kW-hr	1042±2.64	888±2.77	802±2.30	1030±1.87	875±4.22	797±1.71	1021±3.26	866±1.64	789±1.19	987±1.26	845±1.19	769±0.63
bsNOx, g/kW-hr	11.17±0.04	2.88±0.04	3.07±0.05	10.37±0.04	2.57±0.05	2.73±0.04	11.46±0.09	2.53±0.03	2.90±0.01	11.22±0.04	2.40±0.03	2.6751±0.02
bsPM, g/kW-hr	0.02±1.0e-3	0.08±4.0e-3	0.04±1.5e-3	0.02±1.7e-3	0.07±5.3e-3	0.03±2.2e-3	6.73e-3±1.7e-3	0.03±1.2e-3	0.01±7.4e-4	8.83e-3±1.4e-3	0.05±2.1e-3	0.03±9.3e-4
bsCO, g/kW-hr	1.74±0.02	0.88±7.54e-3	0.51±3.22e-3	0.93±0.03	0.83±0.01	0.51±9.51e-3	0.85±0.04	0.77±0.0123	0.40±7.56e-3	0.76±0.02	0.84±8.74e-3	0.50±7.44e-3
bsHC, g/kW-hr	0.96±0.03	0.36±1.37e-3	0.24±0.01	0.86±0.03	0.35±6.32e-3	0.23±3.55e-3	0.47±4.71e-3	0.84±8.74e-3	0.14±4.04e-3	0.58±0.02	0.25±7.76e-3	0.16±8.13e-3

4. Summary

The basic fuel properties of a ULSD and three fuel blends containing RD, BD and/or SulNOx fuel additive have been tested following the test methods required by Canadian General Standards Board. Then the combustion and emissions performances of the ULSD and the three fuel blends were also tested by using a 30kilowatt (kW) diesel generator and various emission analyzers. Following results have been observed.

- With changing the composition of a blend, the energy density (lower heating value) and the ratio hydrogen to carbon change. This usually causes variations in fuel consumption rate and engine-out CO_2 emissions;
- The generator efficiency varies with changing generator load, but almost does not change with changing fuel at a constant load condition for the tested fuel blends in this project. As a result, energy consumption rate does not significantly change with changing fuel at a fixed generator load condition, but fuel consumption rate is almost reversely proportional to lower heating value;
- Compared to the ULSD (U100), R50/B05/U45 reduces net GHG emissions by 19~41%, and R50/B50 and R100+SulNOx reduce net GHG emissions by 40~86%;
- R50/B05/U45 reduces NOx emissions at all load conditions, but the effects of R50/B50 and R100+SulNO on NOx emissions vary with changing load conditions;
- At 25% load, CO emissions reduce with increasing H/C ratio. However, at 50 and 85% loads, R50/B50 reduces CO emissions, but R50/B05/U45 and R100+SulNOx either slightly reduce or generate similar CO emissions as ULSD (at 85% load);
- All three tested blends containing RD and/or BD reduce HC emissions, with R50/B50 being most effective in reducing HC emissions, followed by R100+SulNOx and R50/B05/U54, respectively;
- R50/B50 and R100+SulNOx reduce PM emissions at all test load conditions, with the former being more effective. R50/B05/U45 either does not significantly change (at 25% load) or slightly reduces (at 50 and 85% loads) PM emissions.

Overall, compared to the ULSD, no significant negative effects were observed during the test for the investigated fuel blends, in terms of efficiency and emissions performance.

We point out that the test of this project was conducted for basic fuel properties and combustion and emissions performance only. It was carried out on a laboratory research engine within limited time. Therefore, there may be some issues that may happen during the applications of biodiesel and renewable diesel, but were not observed by this project.

References

[1]. H. Guo, S. Dev, D. Stevenson, Testing and Analysis of Renewable/Bio/Conventional Diesel Blends for Marine Vessel Applications - Task1 Report, https://doi.org/10.4224/40003268.
[2]. H. Guo, S. Dev, D. Stevenson, Testing and Analysis of Renewable/Bio/Conventional Diesel Blends for Marine Vessel Applications - Task2 Report, https://doi.org/10.4224/40003309.
[3]. Canadian General Standard Board, Naval distillate fuel, CAN/CGSB-3.11-2022.
[4]. Christian, R., Knopf, F., Jaschek, A., Schindler, W., 1993, A New Method f or Measuring Filter Smoke Number with Increased Sensitivity MTZ Motortechnische Zeitschrift, 54 (1), pp. 16-22.

[5]. H. Xu, L. Ou, Y. Li, T. R. Hawkins, M. Wang, Life Cycle Greenhouse Gas Emissions of Biodiesel and Renewable Diesel Production in the United States, Environ. Sci. Technol. 56 (2022) 7512−7521.

[6]. N.,Mizushima, S. Sato, D. Kawano, A. Saito, Y. Takada, A study on NOx emission characteristics when using biomass-derived diesel alternative fuels, SAE Technical Paper Series, SAE2012-01-1316.

[7]. S. K. Hoekman, C. Robbins, Review of the effects of biodiesel on NOx emissions, Fuel Processing Technology 96 (2012) 237-249

[8]. J. Xue, T. E. Grift, A. C. Hansen, Effect of biodiesel on engine performances and emissions, Renewable and Sustainable Energy Reviews 15-2 (2011) 1098-1116.

[9]. H. Guo, W. S. Neill, W. Chippior, R. Gieleciak, Effect of Renewable diesel and jet Blending components on combustion and emissions performance of a HCCI engine, Proceedings of the ASME 2014 Internal Combustion Engine Division Fall Technical Conference, ICEF2014-5472.