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Dynamometer testing of in-service vehicles using biodiesel and ultra low sulphur diesel

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Abstract

A study was conducted to compare the performance of diesel-powered vehicles using biodiesel with ultra low sulphur diesel fuel. The study aimed to provide more information about the tailpipe emissions and engine performance of in-service vehicles using biodiesel with different percentages. Three types of biodiesel fuels were tested with blending ratios of 0, 20 and 100% biodiesel/ULSD fuel. The whole study comprised of two parts, namely, a chassis dynamometer exhaust emission test and a diesel lug down test (adopted by the Environmental Protection Department of the Hong Kong Special Administrative Region Government) for each of the vehicle tested. Totally ten vehicles were tested in this study, covering a wide range of makes, types and models. This paper describes the results of the dynamometer testing focusing on the road power and concentration of the exhaust emissions. The result revealed that whilst there was a slight drop in the maximum road power, a significant reduction in smoke emission was found with the use of biodiesel, even for the 20% blend. Since engine exhaust emissions greatly depend on engine conditions and settings, the effectiveness of biodiesel on reduction of gaseous pollutant varies for different type of vehicles. In average biodiesel blends could reduce the carbon monoxide and unburned hydrocarbon but with small increase in the oxides of nitrogen. The effect of biodiesel on the performance and emissions of

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vehicles increased significantly with an increase in biodiesel content in the fuel.

1 Introduction

Due to the public concern about new energy sources and the needs for resolving air pollution problems, there have been considerable discussions on developing reformulated and alternative fuels for the transportation sector. With great efforts from research scientists and automobile engineers, many green fuels and after-treatment devices have been developed to reduce exhaust emissions and to increase the overall energy efficiency of vehicles (e.g. liquefied petroleum gas, electric vehicle, diesel oxidation catalyst (DOC) etc.). Among those new technologies, biodiesel is regarded as one of the most successful and efficient alternative fuels that is readily available in the market and has been used in many countries for more than a decade.

Biodiesel is an alternative fuel for diesel-powered vehicles produced from renewable resources such as vegetable oils or animal fats. A study by Yusuf et al. [1] found that there was no significant change in power characteristic of diesel engines on fuel blends up to 30% of methyl soyate. Chemical analysis of fuel composition indicated that most vegetable oil fuel has, generally, lower energy content than diesel fuel and this would affect the engine power. Power is one of the important parameters that can affect the performance of vehicles. This parameter is particularly important in Hong Kong due to the presence of many hills and slopes in the Hong Kong's road network. Alt n et al. [2] showed that maximum engine torque using vegetable oil fuel was lower than diesel fuel. Many diesel vehicles are load carrying, therefore a significant drop in power and torque will surely not be welcome by vehicle operators. Regarding the emission of air pollutants, Monyem and Gerpen [3] found that their biodiesel had about 27% and 45% less CO and HC emissions than diesel fuel. The study also pointed out that no significant difference in the emission of NOx for the B20 was found, however, 14% increase in NOx was recorded for the neat biodiesel fuel.

Due to the public interest on the biodiesel fuel, the Environmental Protection Department (EPD) of the Hong Kong Special Administrative Region (HKSAR) Government commissioned the Department of Mechanical Engineering at the University of Hong Kong to carry out a feasibility study of using biodiesel as a motor fuel in Hong Kong in 2001. The study mainly consisted of a comprehensive chassis dynamometer exhaust emission test on ten vehicles, two

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of them were installed with DOC to treat the exhaust gases. Wide ranges of vehicles, from light-duty vehicle (taxi) to heavy-duty vehicle (tractor), were chosen to evaluate the effect of biodiesel fuel on road power, smoke level and the emission of carbon monoxide (CO), unburned hydrocarbon (HC) and oxides of nitrogen (NOx). Both locally produced and imported biodiesel fuels were employed for the testing and they complied with the EPD's proposed specification which was in line with DIN51606. Ultra low sulphur diesel (ULSD), with sulphur content less than 0.005% by weight, was used as baseline fuel and two different biodiesel/ULSD mixing blends, i.e. 20% and 100%, were tested and compared with the baseline fuel.

2 Test procedures

2.1 Equipment

The testing was conducted in an approved vehicle emissions testing centre in Hong Kong. The main instrument of the test was a Clayton Industries ECCT500108 chassis dynamometer which was equipped with an air-cooled eddy current PAU. The maximum power output of the dynamometer was 500hp@50mph. Smoke level was measured by a SPX Dieseltune DX230 smokemeter. A Richard Oliver IGD Toscin310 gas analyser was used to determine the CO and NOx emissions and a Beckman Model 400A flame ionisation detector analyser measured the concentration of HC in the exhaust.

2.2 Test fuels

Three types of biodiesel fuel were tested and they were denoted as Biodiesel A, Biodiesel B and Biodiesel C. Their specifications together with those of ULSD are tabulated in Table 1.

Table 1. Fuel properties of ULSD and biodiesel fuels tested.

Test Fuel	ULSD	Biodiesel A	Biodiesel B	Biodiesel C
Fuel Composition	Petroleum fuel	Rapeseed oil	Wasted frying oil	Waste frying fat
Cetane Number	55 – 60	> 55	> 51	53.3
Flashpoint, °C	> 60	176	177	177
Density @ 15°C, gr./ml	0.813	0.883	0.883	0.880
Viscosity @ 40°C, cSt	2.4 – 3.0	4.5	4.4 – 4.6	4.55
Sulphur, wt.%	< 0.005	---	< 0.001	0.001

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2.3 Test Vehicles

Ten vehicles of different manufacture years, makes, models and engine capacities were selected for the chassis dynamometer emission testing. Details of the test vehicles are provided in Table 2. The Biodiesel C was only available after the first five vehicles had been completed the testing. As a result, the first five vehicles were tested with two types of biodiesel while the last five with three.

Table 2. Test vehicles for the chassis dynamometer emission study.

Vehicle No.	Make & Model	Vehicle Type & Engine Capacity	Year of Manufacture	Biodiesel Tested
M1	Toyota / Crown	Taxi / 2446 cc	1991	A & B
M2	Isuzu / NPR*	Light Goods Vehicle / 4334 cc	1994	A & B
M3	Nissan Diesel / CKB52	Tractor / 16991 cc	1993	A & B
M4	Isuzu / LT132	Single Deck Public Bus / 7127 cc	1999	A & B
M5	Nissan / Civilian	Public Light Bus / 4169 cc	1994	A & B
M6	Mazda / E2200	Van / 2184 cc	1993	A, B & C
M7	Mitsubishi / Canter	Light Goods Vehicle / 3907 cc	1998	A, B & C
M8	Isuzu / FSR	Medium Goods Vehicle / 4334 cc	1991	A, B & C
M9	Scania / 93M	Tractor / 8476 cc	1990	A, B & C
M10	Isuzu / NPR*	Medium Goods Vehicle / 4334 cc	1996	A, B & C

* vehicle equipped with DOC

2.4 Chassis dynamometer emission test

The chassis dynamometer emission test was divided into two sections including a two-power steady speed test and a diesel lug down test. The dynamometer test was repeated within a day and also in three consecutive days to examine sensitivity of the measurement data. The intra-day and inter-day results showed that the test was able to give repeatable measurement.

The two-power steady speed test was designed to study the vehicle exhaust characteristics at different road load conditions, for example, 20% of the rated engine power (low load) and 50% of the rated engine power (high load). The low load and high load conditions were used to simulate the highway and uphill conditions respectively. The vehicle speed was maintained at 50kph, which was the average speed for most goods vehicles, and the tester adjusted the throttle pedal to achieve the desired power set point. Exhaust gas temperature and

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concentration of exhaust emissions were recorded during the sampling period and the test was repeated twice to ensure the results were within a reproducible range.

The diesel lug down test is a fast, efficient and stringent diesel exhaust emissions testing program adopted by the EPD. The test requires a tester to operate the vehicle at wide-open throttle and to drive the vehicle over 70kph by selecting a proper gear. When the vehicle speed achieves its maximum speed, the dynamometer will increase the load gradually to seek the speed at maximum road power. Then the dynamometer controls the vehicle at its maximum power speed for the determination of smoke emission values. This test is designed to measure the smoke levels under a load-simulated condition.

The workflow of the chassis dynamometer emission test is illustrated in Figure 1. The test started from a pre-test inspection which all test vehicles were inspected before commencing the chassis dynamometer emission test. The aim of the inspection was to ensure these vehicles complied with the minimum requirement established for the diesel lug down test (i.e. maximum road power greater than 50% of the engine rated power and all lug down smoke values less than 50 HSU). It then underwent the two-power steady speed test for the air pollutants' concentrations. The diesel lug down test would then follow to measure its maximum engine power and smoke levels. Completing the ULSD baseline emission testing, the fuel (ULSD) was changed to the next biodiesel blend. The test sequence started from the ULSD baseline determination, then a fuel mixture of 20% biodiesel and 80% ULSD (B20) and finally a neat biodiesel (B100). Under the safety concern, the fuel changing was conducted at a fire station under the monitoring of the station officers. An on-road pre-conditioning for about 30 minutes was employed in order to fully warm up the vehicles before repeating the dynamometer test. These procedures were repeated until all biodiesel blends were tested.

The fuel was reverted to ULSD before the vehicle was sent back to the owner. The above procedures were performed again approximate one week after except another biodiesel was used. The entire test was completed after all the biodiesel had been tested and the final baseline testing on the ULSD which was conducted a week after the last biodiesel measurement.

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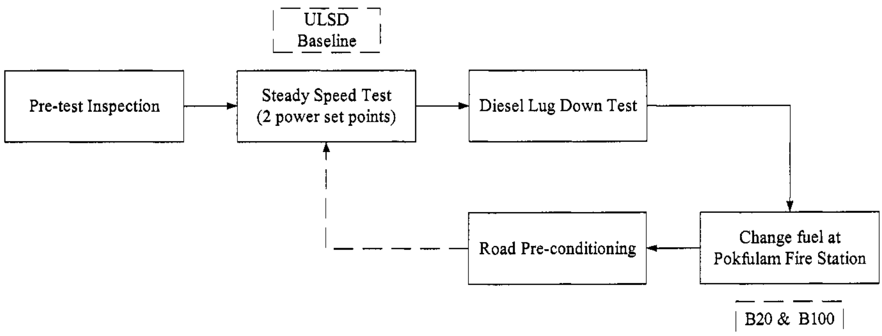

Figure 1. Workflow of the test sequence.

3 Results and discussions

Due to the vast amount of data collected from the measurements, only those pertinent to the present study would be discussed in the following sections and details of the whole study can be found in Leung [4]. Also, as the effects of biodiesel on vehicles would be different for different vehicles, therefore only average performance of the vehicles on biodiesel blends is analysed.

3.1 Road power and smoke level

The results indicated that most of the vehicles experienced only a small change in maximum engine power, the percentage changes varied between -7% and +5%. In Figure 2, the majority of vehicles showed a decrease in maximum road power on both B20 and B100 while the magnitude of the variations was small and not noticeable to the driver.

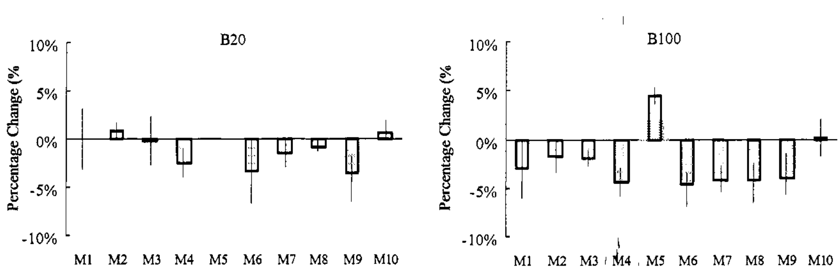

Figure 2. Average and maximum variations in road power for all fuel blends.

An obvious reduction in smoke level, except M6, on biodiesel blends was observed in Figure 3. The magnitude of the reduction increased with increasing biodiesel content. For those eight vehicles that were not equipped with DOC, the

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maximum percentage changes of smoke opacity varied from –40% to +2% with an average of –16% for B20 and from –77% to –35% with an average of –58% for B100. The trends for the two vehicles installed with DOC were similar and the percentage changes of B20 & B100 varied from –27% to +9% with an average of –13% and –76% to –36% with an average of –61% respectively.

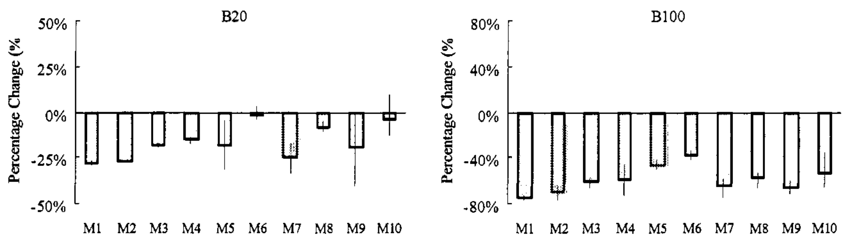

Figure 3. Average and maximum variations in smoke level for all fuel blends.

3.2 Gaseous pollutants

It has been known that engine exhaust emissions greatly depend on engine conditions and setting. Monyem and Gerpen [3] showed that different injection timings, for example standard, 3° advanced and 3° retarded, could result in different levels of NOx and smoke emissions. Thus, the effect of biodiesel on exhaust emissions would be irregular for different vehicles. Individual percentage change of exhaust analysis among the ten vehicles experienced a high degree of variations. In addition, two of the tested vehicles were equipped with DOC which greatly reduced the CO & HC emissions. Such small measurement values resulted in a large fluctuation in the data analysis. In order to minimise the effect of DOC on the average percentage variation, the emission results of these two vehicles were analysed separately.

As shown in Fig. 4, the fuel blends reduced concentration of CO for most of the vehicles and the percentage change increased with increasing the biodiesel blending ratio. The maximum percentage variation in CO for vehicles without DOC were from –74% to +54%. The result of the DOC showed a greater variation and the values were between –76% and +154.5%.

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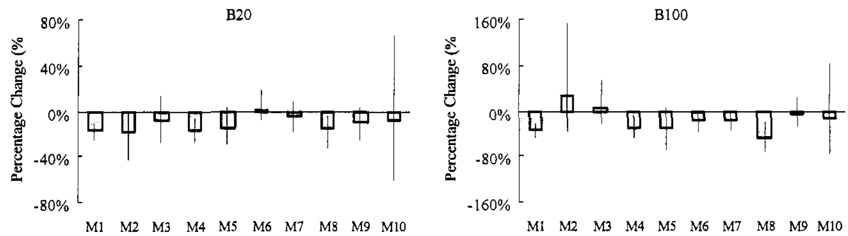

Figure 4. Average and maximum variations in CO for all fuel blends.

The concentration of HC was relatively small for all the vehicles tested and it varied with a range of 2ppm to 71ppm. There were great data variations particularly for those values below 10ppm. The percentage changes varied from –75% to +109% for the vehicles without DOC and –62% to –34% for the vehicle with DOC. The Figure 5 showed that magnitude of the variations increase with increasing the biodiesel content.

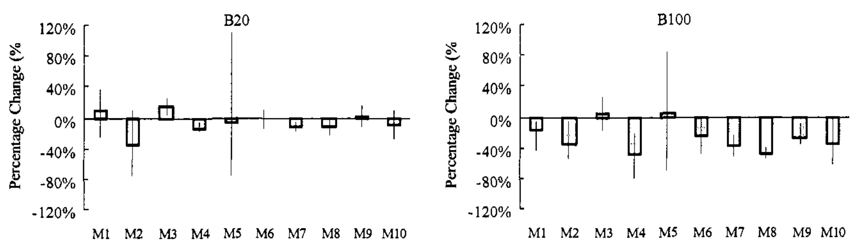

Figure 5. Average and maximum variations in HC for all fuel blends.

The average and maximum variations in NOx for all fuel blends are illustrated in Figure 6. The variation in the NOx emission from B20 was small and the average variation under low load and high load conditions were 0% to +3% respectively. However, an obvious increase in NOx emissions for B100 was observed. The averaged changes were +12% (low load) and +7% (high load).

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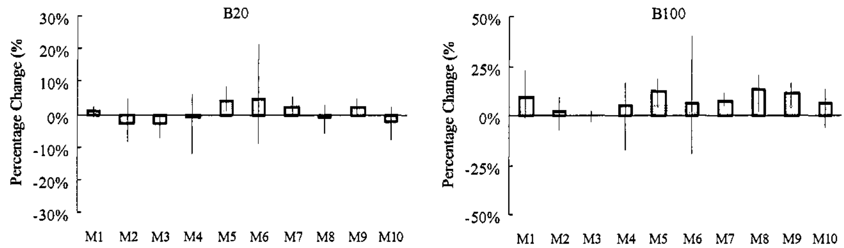

Figure 6. Average and maximum variations in NOx for all fuel blends.

The overall variations in all the testing parameters are tabulated in the Tables 3 and 4 respectively for those vehicles without and with DOC. It should be noted that although the percentage change of individual pollutants among vehicles tested were large, three consecutive measurement had been conducted and the variations in each pollutants were small.

Table 3. Average percentage variation of biodiesel blends – without DOC.

	Power	Smoke	CO	HC	NOx
B20	-2.0%	-16.0%	-10.3%	-4.9%	+1.5%
B100	-3.2%	-58.0%	-24.1%	-29.6%	+9.7%

Table 4. Average percentage variation of biodiesel blends – with DOC.

	Power	Smoke	CO	HC	NOx
B20	+0.9%	-13.2%	+2.7	-28.5	-3.1%
B100	-0.9%	-60.9%	-12.5	-47.8	+5.0%

4 Conclusions

It was difficult to quantify the exact degree of variation in each exhaust pollutant from the in-use vehicles' tailpipe measurement. This study concluded, in general, B20 gave a minimal effect on engine power, HC and NOx emissions but a slight reduction in smoke and CO emissions. The neat biodiesel fuels gave an insignificant engine output loss but an obvious reduction in the smoke, the CO and HC emissions for most of the in-use vehicles. The only shortcoming of using B100 was a small increase in the NOx emission. The emission results also showed that the biodiesel fuels would not affect performance of the DOC and further improvement in emission reduction can be found.

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