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Final Report

Feasibility Study of Using Biodiesel as Motor Fuel in Hong Kong

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Executive Summary

There is a fast growing trend in the use of biodiesel over the past decade, mainly due to its potential of reducing greenhouse gas and air pollutant emissions. Its capability in promoting national agricultural industry and energy security are also the driving forces of its widespread usage. Biodiesel is currently used in more than 20 countries in the world with an annual consumption of about 2 million tonnes. Due to the increased public interest in biodiesel application in Hong Kong, the Environmental Protection Department (EPD) of the HKSAR Government commissioned the Department of Mechanical Engineering at the University of Hong Kong in November 2000 to conduct a feasibility study on the use of biodiesel as an automotive fuel in Hong Kong. The main objective of the study was to investigate the effect of using different percentages of biodiesel fuel on air pollutant emissions, smoke opacity and engine power in diesel vehicles in Hong Kong. The results would serve as a reference for assessing the impact of using biodiesel under Hong Kong diesel vehicle operation environment.

The study consisted of two stages. The first stage included a preliminary test run (to verify the testing protocol and to demonstrate the repeatability of the measurement methods), a main dynamometer test for three diesel vehicles and an on-road emission study (to investigate the vehicle emissions characteristics, in particular the NOx, while travelling inside a tunnel). The second stage of the study involved a main dynamometer test for another seven diesel vehicles and an on-road performance test. Three brands of biodiesel fuels were utilized for the main dynamometer test, one of the fuels was produced from neat rapeseed oil while the other two were derived from waste frying materials. The first stage study was completed in April 2001 and an interim report was submitted to the EPD in May 2001. The initial contractual requirement only involved the main dynamometer test, but during the course of study, it was decided to conduct an on-road performance test for 2 months in order to obtain the on-road performance data on prolong usage of biodiesel fuel. Therefore, two additional vehicles were employed for the on-road performance test, each for one brand of biodiesel fuel.

A monitoring committee, consisting of representatives from various government departments including the Environmental Protection Department, Electrical and Mechanical Services Department, Fire Services Department and Transport Department, trades, oil companies, biodiesel suppliers as well as academia, was established to monitor the progress of the study. The committee members have reviewed this report and endorsed all the findings.

Ten vehicles were successfully tested on the chassis dynamometer with the three available biodiesel fuels. Each biodiesel fuel brand was tested according to three representative biodiesel/ULSD blending ratios, i.e. 0% (ULSD), 20% (B20) and 100% (B100). Lower percentage of biodiesel such as B5 was not included in this trial as the measurement accuracy and variation would not be large enough for any significant analysis. Results of the ten tested vehicles indicated that for an individual vehicle there was no unique answer to whether there was any definite increment or decrement in the engine power, smoke opacity or air pollutants emissions for using biodiesel, particularly for the case of B20. The actual performance of vehicles using biodiesel depends on a number of factors such as engine design, service and running conditions, engine age, etc. Due to the variations in the vehicles tested, the vehicular performance and emission characteristics might be different for different vehicles. A break down of the percentage change under different power and concentration ranges is shown in the table below together with the overall average percentage change with respect to ULSD.

B20					B100				
Engine Power (kW)					Engine Power (kW)				
<30	31–60	61–90	>90	Overall	<30	31–60	61–90	>90	Overall
-3%	0%	-1%	-2%	-1%	-5%	0%	-4%	-4%	-3%
Smoke Opacity (HSU)					Smoke Opacity (HSU)				
<15	16–30	31–45	>45	Overall	<15	16–30	31–45	>45	Overall
-22%	-15%	-16%	-11%	-16%	-60%	-59%	-63%	-50%	-58%
CO Emission (ppm)					CO Emission (ppm)				
<100	101–200	201–300	>300	Overall	<100	101–200	201–300	>300	Overall
-4%	-11%	-19%	-15%	-14%	0%	-9%	-28%	-54%	-23%
HC Emission (ppm)					HC Emission (ppm)				
<10	11–20	21–30	>30	Overall	<10	11–20	21–30	>30	Overall
-75%	-4%	-12%	-14%	-14%	-57%	-36%	-22%	-45%	-40%
NOx Emission (ppm)					NOx Emission (ppm)				
<300	301–600	601–900	>900	Overall	<300	301–600	601–900	>900	Overall
+5%	-4%	-1%	0%	0%	+13%	+8%	+5%	+11%	+9%

From the overall average percentage variations of the ten vehicles shown above, it was found that for B20, there was a slight decrease (-1%) in the engine power; 16% reduction in smoke opacity, 14% reduction in CO and 14% reduction in HC. There was very little change in NOx concentration. For B100, there was a slight decrease (-3%) in engine power; 58% reduction in smoke opacity; 23% reduction in CO and 40% reduction in HC. However, there was a 9% increase in NOx concentration.

The maximum loading applied in the chassis dynamometer test was 50% of the rated engine power, which might not be able to reflect the emission behaviours at high road power conditions. Therefore, an on-road emission study was conducted at two sites to determine the exhaust emissions from a fully loaded van. The first site was at the Tsing Ma Bridge Tunnel that provided a smooth and long flat road of about 2 km for testing. In addition to engine power determination, this site allowed the measurement of vehicle emission inside a tunnel condition. The other site was at the Cotton Tree Drive in Central District that provides a steep slope for the test vehicle travelling up the hill. The emission test results obtained in the Tsing Ma Bridge Tunnel indicated that the test vehicle's engine power utilized was below 20% of the rated engine power. On the other hand, when the same vehicle was driven up the Cotton Tree Drive, the engine power utilized could reach 60% of the rated engine power. The result of the on-road emission measurement indicated that when neat biodiesel fuel was used, there was a reduction of 40-46% (-2 to -9 HSU) in smoke opacity while the NOx concentration was increased by 4 to 12% (with a maximum increase of 40ppm) in both the tunnel and the outdoor running conditions.

Further to the dynamometer and on-road emission testing, an on-road performance test was done to investigate the long-term effects of biodiesel fuels on the vehicle performance. Two goods vehicles had been tested and the results revealed a small reduction in maximum engine power and a decrease in smoke opacity after prolong usage of 100% biodiesel for two to three months. The averaged reduction in maximum engine power and smoke opacity under the Diesel Lug Down Test were 3% (-1kW out of 50kW) and 66% (-12HSU to -17HSU out of 26HSU) respectively, which are comparable to the main dynamometer test result.

In addition, subjective evaluation on the use of biodiesel was also conducted by distributing questionnaires to survey drivers' opinions. Results indicated that about 71% of the responses felt a reduction in road power. Over 85% of the responses commented that there were reductions in smoke emissions and engine noise. As for the fuel consumption, about 24% of the responses felt a slight decrease while 38% opined a slight increase and 14% opined significant increase in fuel consumption.

Issues of concern

Notwithstanding the environmental benefits of using biodiesel, there is considerable concern about roadworthiness and compatibility issues on the use of biodiesel. The following concerns were identified after summarizing all the available information from previous meetings and testing, which need to be addressed before making final decision regarding the use of biodiesel in Hong Kong:

- Fuel line compatibility to biodiesel and roadworthiness for in-service vehicles
- Vehicle warranty and insurance when using biodiesel

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Background

To study the effect of biodiesel on vehicle's power, smoke opacity and air emissions, the Environmental Protection Department (EPD) of the HKSAR Government commissioned Dr. D.Y.C. Leung of the Department of Mechanical Engineering at the University of Hong Kong to conduct a series of test on the use of different biodiesel fuels with three biodiesel/ultra low sulphur diesel (ULSD) blending ratios. The test comprised with two stages. The first stage study included a preliminary run, on-road emission studies (Tsing Ma Bridge Tunnel) and main dynamometer test for three diesel vehicles. The second stage study included the main dynamometer test for seven diesel vehicles, on-road emission studies (Cotton Tree Drive) and an on-road performance test. An interim report (Leung 2001) was submitted to the EPD in May 2001, which reported the result of the stage 1 study. This is the final report summarizing all the results of the stage 1 and stage 2 tests and presenting an overview of the emission test result when comparing the use of biodiesel fuels with ultra low sulphur diesel (ULSD), the normal diesel fuel currently available at refuelling stations.

1. Introduction

Biodiesel is a mono-alkyl ester generally produced from a chemical process "Transestification". The feedstock of the production may come from most vegetable oils, natural fats or even used frying oils. Biodiesel is a renewable diesel substitute that is one of the fastest growing alternative fuels in the US and Europe.

Biodiesel is produced from renewable feedstock such as vegetable oils, natural fats and waste lipids. The advancement of technologies in 80's increased agricultural harvest that resulted in surplus of crop products. Therefore, biodiesel is widely produced from agricultural products such as soybean and rapeseed. Thus, biodiesel production is strongly supported by the agricultural industries. However, the high production cost of biodiesel is a main barrier to its widespread use. Even without any tax imposed on biodiesel, the cost of biodiesel derived from vegetable oils is still higher than petroleum diesel. Another feedstock of biodiesel is the waste lipids that could be collected from food factories and restaurants. This kind of biodiesel feedstock can not only reduce the cost for landfill dumping and wastewater treatment but also reduce the production cost of biodiesel.

Global warming issue and increasing greenhouse gas emissions raise public's concern about the importance of reducing exhaust emissions from motor vehicles. In order to lessen the impact of greenhouse gas emissions, many countries encourage the use of renewable fuels. A lot of research projects have been done to develop cleaner fuels, but not all of them can be applied in commercial scale and some of the technologies are still in development stage. Biodiesel, a CO_2 neutral renewable fuel (IEA 1998), is one of those alternative fuels that have been successfully entered into the auto fuel markets.

In the past decade, the worldwide biodiesel application was in a fast growing trend because of increasing public awareness on environmental protection. A number of pilot tests on biodiesel were conducted in Europe and the USA demonstrating the capability of biodiesel in reducing considerable amount of gaseous pollutants and greenhouse gases. Energy security that biodiesel can bring to a country is another reason of the fast development of the fuel. The government of Austria, France, Germany and Czech Republic are actively promoting the use of biodiesel and its annual consumption increased in a fast pace. Biodiesel is currently used in more than 20 countries in Europe, North America and Asia with an annual consumption of about 1.8 million tonnes, which is predicted to reach 2.8 million tonnes by the end of 2003 (Korbitz 2002). Germany is the largest biodiesel producing countries and there are more than 1400 public pump stations in Germany. Recently, the European Commission proposed a directive that petroleum fuels would be progressively replaced by biofuels from 2% in 2005 to 5.75% in 2010. Except Austria and Germany of which B100 are used, most of the EU countries using biodiesel (including France, the U.K., Switzerland, Norway, Iceland etc.) adopt B5 in their diesel fuel, while B20 has been used in the USA.

According to the worldwide experience and research results, the use of biodiesel in diesel engines can reduce the emissions of unburned hydrocarbons, carbon monoxide, smoke and particulate matter as compared to petro-diesel. Biodiesel contains virtually no sulphur and hence the emission of sulphur dioxide will be eliminated. However, the results on nitrogen oxides are contradictory as there are reports that indicate an increase (Geyer et al. 1984, Chang et al. 1996) or a decrease in the emissions of nitrogen oxides as compared to petro-diesel, according to different engines and testing cycles (Wang et al. 2000), and biodiesel with different cetane numbers (Graboski et al. 2000).

To further study the feasibility of using biodiesel as a motor fuel in Hong Kong, the EPD has commissioned Dr. D.Y.C. Leung of the Dept. of Mechanical Engineering at the University of Hong Kong to launch a trial program for testing 10 diesel vehicles in different categories using different biodiesel fuels and blending ratios. This trial program was later extended due to the extension of the testing items (as described below) during the period of study.

A monitoring committee was set up to monitor the progress of the study. The committee consists of representatives from various government departments (such as the EPD, Transport Department (TD), Electrical & Mechanical Services Department (EMSD), and Fire Services Department (FSD) etc.), relevant trades (such as the Taxi Associations' Federation, Kowloon Truck Merchants Association, and The Hong Kong Union of Light Van Employees etc.), oil companies, biodiesel suppliers as well as academia. A whole list of the monitoring committee members is given in Appendix 1. The chairman of the committee is Mr. W.C. Mok, the Principal Environmental Protection Officer of the Motor Vehicle Emissions Group of the EPD. The committee was formed in November 2000. Since then, five monitoring committee meetings have been conducted. A franchised bus subcommittee meeting and an On-road performance test subcommittee meeting have also been held to discuss more technical issues of the test. In addition, in May 2001, the Motor Services Association (MTA) has commented on the possible risk of using biodiesel in the vehicles in Hong Kong and subsequent meetings have been held to tackle the issue. The notes of the committee and subcommittee meeting are attached in Appendix 2 for reference. A summary of all the works performed during the whole study period was shown in Appendix 3.

2. Objective

The main objective of the study was to investigate the effect of using biodiesel with different blending percentages with ULSD on emissions, smoke opacity and engine power of in-service diesel vehicles in Hong Kong. The results would serve as a reference for assessing the impact of using biodiesel under Hong Kong diesel vehicle operation environment.

It should be mentioned that although different brands of biodiesel fuels were used in the study, they were not identified in this study in order to avoid the comparison of the performance of individual fuel brand.

3. Test fuels

Four biodiesel suppliers, i.e. Sunland Company, Dunwell Engineering Co. Ltd., HednesFord Limited and Bio-clear Energies Limited, all expressed their willingness to join and provide their biodiesel for the tests before the trial commenced. In order to ensure the quality of the biodiesel fuel under test, one pre-requisite of participating in the test was that the biodiesel fuel should comply with the draft biodiesel specifications stipulated by EPD (Appendix 4). The biodiesel from the first three suppliers were accepted for testing after they had provided testing reports (Appendix 5) and showed their compliance with the proposed biodiesel specifications. While the last one, i.e. Bio-clear Energies Limited, could not provide the testing report and the fuel was not tested at all. Also, HednesFord delayed its delivery schedule and its biodiesel was only available for testing in August 2001. Therefore, this fuel was not tested in the early part of the study. Overall, five vehicles were tested with all three qualified biodiesel fuels while the other five vehicles were tested with two biodiesel fuels. The biodiesel fuels supplied by Sunland, Dunwell and HednesFord were produced from neat rapeseed oil, waste frying oil and waste frying fat respectively.

For the baseline testing and for fuel blending, Ultra Low Sulphur Diesel (ULSD) with sulphur < 0.005% was used because it was the only available diesel fuel in fuel refuelling stations in Hong Kong. Therefore, this current study involved the emission performance comparison between biodiesel with the diesel fuel available at pump in Hong Kong. Furthermore it has been agreed in the 1st Monitoring Committee Meeting that symbol, instead of the names of the biodiesel supplier, would appear in all the testing results in order to avoid direct comparison among different biodiesel brands, as it was not the objective of this study.

Each biodiesel fuel brand was tested according to three representative biodiesel/ULSD blending ratios, i.e. 0% (ULSD), 20% (B20) and 100% (B100). Lower percentage of biodiesel such as B5 was not included in this trial as the measurement accuracy and variation would not be large enough for any significant analysis.

4. **Test vehicles**

Ten test vehicles (M1 to M10) ranging from taxis, light buses and goods vehicles of different registration years, brands and engine capacities were selected for the main dynamometer tests. Two additional vehicles (R1 and R2) were employed for the on-road performance test. The details of the test vehicles were as follows:

Vehicle No.	Vehicle Registration No.	Vehicle Make & Model	Type of Vehicle	Registration Year	Biodiesel Tested
Start-up Run					
P1	HT 11XX	Ford Econovan	Van	1998	
P2	HE 24XX	Isuzu FTR	MGV	1997	
P3	HC 49XX	Nissan E24	Van	1997	

On-road Emissions Study					
O1	HT 11XX	Ford Econovan	Van	1998	A, B & C
Main Dynamometer Test					
M1	CL 76XX	Toyota Crown	Taxi	1991	A & B
M2*	GE 83XX	Isuzu NPR	Light Goods Vehicle	1994	A & B
M3	FZ 43XX	Nissan Diesel	Heavy Goods Vehicle	1993	A & B
M4	JA 76XX	Isuzu LT132	Single Deck Public Bus	1999	A & B
M5	GD 78XX	Nissan Civilian	Public Light Bus	1994	A & B
M6	HB 46XX	Mazda E2200	Van	1993	A, B & C
M7	HZ 74XX	Mitsubishi Canter	Light Goods Vehicle	1998	A, B & C
M8	FD 99XX	Isuzu FSR	Medium Goods Vehicle	1991	A, B & C
M9	ET 34XX	Scania 93M	Heavy Goods Vehicle	1990	A, B & C
M10*	GU 61XX	Isuzu NPR	Medium Goods Vehicle	1996	A, B & C
On-road Performance Test					
R1	GC 92XX	Isuzu NPR	Light Goods Vehicle	1994	B
R2	KD 38XX	Mitsubishi Canter	Medium Goods Vehicle	1997	A

* Vehicle installed with a diesel oxidation catalyst (DOC).

5. **Details of Testing**

5.1. Testing methods and procedures

All vehicles participated in the test were required to meet the chassis dynamometer smoke test requirement COP 1.04, i.e. the smoke levels at 3 speed points to be less than 50 HSU and maximum wheel power to be more than 50% of the vehicle rated engine power under the use of ULSD. Each vehicle was checked for the above requirement before accepted for the main dynamometer test. The detailed testing schedule for the main dynamometer test was as follows:

(i) Baseline testing: the test vehicle was first undergone testing using ULSD as baseline in the vehicle testing centre. The testing included measurement of engine power, smoke, and air pollutant concentrations. Details of the measurement items were given in Section 5.2 below.

(ii) B20 testing: Before switched to test B20 (that is, 20% biodiesel and 80% ULSD), the baseline ULSD in the fuel tank of the test vehicle was drained out and refilled with B20.The vehicle was then allowed to run on road for about 30 minutes' for preconditioning before, repeated testing according to item (i) again.

(iii) B100 testing: the procedures in item (ii) were repeated with the use of B100 (100%) Biodiesel.

(iv) After finishing testing with one brand of biodiesel, the vehicle was returned to the owner and reverted to the use of ULSD.

(v) After one week, the vehicle was sent back to the testing centre again and the above procedures (i) to (iv) were repeated using other brands of biodiesel.

(vi) The procedures from item (i) to (v) were repeated for all biodiesel brands qualified for testing.

(vii) After finishing testing with all biodiesel fuels, the vehicles were reverted back to ULSD and returned to their owners.

(viii) Finally, the original base line readings were checked again by testing the vehicle that was reverted to use ULSD after approximately one week of usage.

5.2. Testing items

Photo.1 shows a typical test vehicle ready to be tested on the chassis dynamometer in the testing centre. As mentioned above, all vehicles were undergone the same set of testing and measurement according to the following:

a. Free acceleration smoke test – smoke measurement under no load testing condition.
b. Diesel lug down test – maximum engine power and smoke measurement at 100%, 90% and 80% maximum engine power.
c. Chassis dynamometer test –air pollutants (CO, HC, NOx), engine power and smoke measurement at two steady state loading conditions: 20% and 50% of the vehicle's rated maximum power.

(Detailed descriptions of the testes are provided in Appendix 7)

Exhaust gas temperature and concentration of air pollutants at tailpipe were recorded during the entire steady state test. Concentration of air pollutants was determined when the exhaust gas reached its equilibrium temperature. A sample graph in Figure 5.1 illustrated the criteria for deciding the steady state concentration of pollutants.

In order to minimize variation in vehicle performance and meteorological conditions, the test on each biodiesel fuel would be completed within a normal working day. In addition, the relative humidity (RH) at the testing site was also recorded during the test. NOx correction factor (k_H) for humidity (EEC Council Directive 1970) was applied to correct the influence of humidity on the result of oxides of nitrogen. To ensure the accuracy of the measurements, each set of the testing was repeated twice, so totally three set of readings were obtained for each measurement item. In the results of the main dynamometer test only the average of the three readings were presented in this report

The chassis dynamometer testing was performed in the Vehicle Testing Centre of Dah Chong Hong (Motor Service Centre) Limited (DCH) at Apleichau. Photo 1 showed a typical test vehicle ready to be run on the chassis dynamometer in the testing centre.

Fuel changing was performed at Pokfulam fire Station under the monitoring of the station's officers (Photo 2). Fuel sample was taken during each fuel change and stored for future oil composition analysis.

6. Instrumentation

The following equipment was used for the whole main trial measurements:

Equipment	Make	Model	Accuracy
Chassis dynamometer	Clayton Industries	ECCT500108	Air-cooled eddy current PAU (500hp@50mhp)
Smoke meter	SPX Dieseltune	DX230	± 1% FS (Static)
Combustion analyser for Carbon Monoxide & Nitrogen Oxides measurement	Richard Oliver Ltd.	IGD Tocsin 310	± 1% FSD
Hydrocarbons analyser (non-heated type)	Beckman Industrial	Model 400A	± 1% FSD

The chassis dynamometer and smoke meter (Photos 3 & 4) are provided by Dah Chong Hong Motor Services Centre, which are calibrated periodically by qualified technician/engineer. All other emission analysers (Photos 4 & 5) are calibrated on site before conducting the first set of measurement of the day using standard calibration gases. It was found that equipment drifting was insignificant during the period of the measurement. A sample calibration record was attached in Appendix 6 for reference. The testing was conducted and monitored by the deputy Project Manager and two mechanics, all of them possessed more than five years experience on chassis dynamometer and emission testing.

7. Preliminary tests

As it was not possible to run all of the tests on the same day at the same time, the tests had to be spanned over a whole day and split into separate days for testing each of the biodiesel fuels. This introduces uncertainty of intra-day and day-to-day variability of the engine performance. Therefore, before the main dynamometer test, a series of preliminary tests were conducted to develop the testing protocol and to estimate the degree of data variation of the measurement. Particular concern was paid on the NOx measurement, as most published results indicated that the change in NOx emission is only of the order of a few percents. Therefore, the repeatability of

NOx was of particular concern for this study. The preliminary tests included the following:

Trial	Test vehicle
Start-up run	P1
Fuel change test	P2
Intra-day variation	ULSD: P1 & Biodiesel: P3
Day-to-day variation	ULSD: P1 & Biodiesel: P3

The results of the above tests are tabulated in Table 7.1.

7.1 Start-up run

The objective of this test was to check whether the testing procedures mentioned in Section 5 could be conducted smoothly during actual running and to find out any difficulty during fuel changing at the Pokfulam Fire Station. Since the fuel changing for B20 was more complicated than B100, therefore only B20 was involved in this test run.

The results indicated that in general, the testing procedures in Section 5 could be implemented smoothly except some improvement in the procedure of fuel changing. In addition to that, it was found that the emission testing result at maximum power fluctuated throughout the measurement, probably due to the tyre slippage. Subsequently, it was decided in the 2nd Monitoring Committee meeting that only 20% and 50% of the rated engine power were selected for testing during the main dynamometer test.

Furthermore, even there was a thoroughly cleaned fuel tank, it can also be observed that changing back to ULSD immediately after the biodiesel test could not return to the original vehicle operational condition, probably due to the cleansing effect of biodiesel and residue biodiesel in the fuel line. As indicated from many studies, biodiesel is a good solvent and will clean away the scale and built-up carbon, gum and varnish deposits in the fuel tank as well as in the engine (Monyem & Gerpen 2001). Thus, the vehicle operational characteristics might be changed after using biodiesel.

7.2 Fuel change

The objective of this test was to investigate any adverse effect due to fuel changing, particularly on the NOx emission level. The test was conducted at full throttle condition for two speed settings on two different days. The result indicated that fuel changing would not affect the NOx measurement, as its variation is less than 2% (see Table 7.1). The maximum road power variation was +1% and FAS smoke ranged between -1% and +3%.

7.3 Intra-day variation

The objective of this test was to check the variation of vehicular emissions within a day. Two measurements were conducted, one at the beginning of the day and another was made several hours after the first engine stoppage. ULSD and biodiesel were used consecutively for this test with two different vehicles. The results indicated that in general there was little variation of air pollutant emissions (e.g. maximum NOx variation was 1.9%) within a day even the engine had been stopped for several hours (Table 7.1). However, some tests showed large data variations. For example, it was observed that tyre slippage had occurred during the 50% rated power testing of the Nissan E24 van which caused large variation in CO concentration measurement. As shown in Table 7.1 the CO concentration was 262 ppm which became 383 ppm with tyre slippage. Therefore, tyre slippage, normally occurred for prolong testing at high power, should be avoided during testing.

7.4 Inter-day variation

The objective of the test is to confirm consistency of the result for the measurement conducted over a period. Both ULSD and biodiesel were used in a 3-day test. The results in Table 7.1 showed that the repeatability of the data was generally good and the day-to-day variation was small (e.g. maximum NOx variation was 2.2%).

From the results of the fuel change, intra-day and inter-day variation studying, the repeatability and overall degree of data variation was satisfactory. However, large variation might occur for very small concentration and under tyre slippage condition.

8. Main dynamometer test results

Totally ten vehicles were tested on the chassis dynamometer and the results were shown in Tables 8.1. to 8.10 for the ten vehicles tested. Due to the fact that the baseline test on ULSD had been conducted on each individual testing day, which, as mentioned in Section 7.1, might not be repeatable after switching back from biodiesel to ULSD due to possible cleansing effect. Therefore, analysis on the performance of each biodiesel fuel was conducted for those tests performed on an individual day only, i.e. compared the result of B20 and B100 directly with that of ULSD conducted at the beginning of the test.

The measured absolute changes in maximum engine power, smoke opacity level, CO, HC and

NOx concentration of the ten vehicles were shown in Table 8.11 for B20 and B100. The variations of each of these parameters were discussed below.

8.1 Engine power

Power is one of the important parameters that indicate vehicle performance this parameter is of particular importance in Hong Kong due to the fact that a large portion of our road network consists of uphill and downhill driving conditions. In addition, most of the diesel vehicles are load carrying, therefore if the fuel used will result in a significant drop in engine power it will not likely be welcome by the vehicle operators.

The measured engine power for all the test vehicles using B20 and B100 were shown in Figure 8.1a. The results indicated that most of the test vehicles have shown a very small change in maximum engine power, as shown in Table 8.11. The highest power drop was only 5 kW out of a nominal power of 125 kW. The measured maximum engine power of the ten vehicles varied from 27 kW to 186 kW.

Figure 8.1 b and c show the percentage changes in the maximum engine power for vehicles using B20 and B100 respectively. The overall average for the ten vehicles was given in Figure 8.1d. For B20, the averaged percentage change in maximum road power varied from –6.7% to +3.0% (-8kW to +4kW) with an average of –1.2% for the ten vehicles. Similar trend was observed for vehicles when using B100, but the average maximum power drop was slightly higher, varied from –6.9% to +5.3% (-7kW to +3kW) with an average of –2.6%. Overall, these small drops in engine power would be unnoticeable by drivers when most of these vehicles were operated under light to medium loading conditions.

8.2 Smoke level

Three types of smoke measurements were conducted for all the ten vehicles under dynamometer test. They were free acceleration simulation (FAS) test, diesel lug down test and steady state smoke measurement. Free acceleration test has been adopted by the Transport Department for the quick checking of vehicular smoke on the road. Though convenience, the repeatability and reliability of this measurement is usually not so high as compared with diesel lug down test, which has been adopted by the EPD for checking smoke opacity of diesel vehicle. The diesel lug down test has a better representation of the vehicle's performance as it is run under a load-simulated condition, which can avoid purposely tempering of vehicles. Steady state test, unlike the FAS and diesel lug down test, does not involve any sharp change in fuel injection inside the combustion cylinder, thus the test vehicle usually emits much less smoke than FAS and lug down test. For example, in the present test, all the measured values under steady state were below 10 HSU at 20% rated engine power. Based on the above fact, only the FAS and diesel lug down test results were used for the comparison below.

<u>Free acceleration smoke test (FAS)</u>

The smoke opacity for individual vehicle under FAS condition was shown in Figure 8.2(i)a. for ULSD as well as B20 and B100. The smoke levels obtained from the ULSD's FAS tests varied between 7 HSU and 49 HSU. For B20, vehicles reported a reduction in smoke level but the magnitude of the reduction was small, varying from 0 HSU to 9 HSU (Table 8.11.). One vehicle, i.e. M4 reported an increase in smoke level (+10 HSU). This was a coach fitted with Euro II engine and the increase in smoke opacity occurred in two of the biodiesel fuels tested. For B100, however, all the vehicles reported a reduction in smoke levels varying from 3 HSU to 23 HSU.

The above changes in smoke value were expressed in percentage variation in Figure 8.2(i) b and c. For B20, the percentage change in smoke level varied from –34.8% to +31.9% (-15 HSU to +12 HSU) with a mean variation of –11.4% (Figure 8.2(i)d.). Most of the tested vehicles experienced a reduction in smoke opacity except M2 (slight increase) and M4 (increased by 31.9% or +12HSU). For B100, all vehicles experienced a dramatic reduction in smoke opacity that varied from -1.3% to –73.4% (0 HSU to –27 HSU) with an average change of –43.5 %.

<u>Smoke under diesel lug down test</u>

The smoke opacity under lug down condition for individual vehicle were shown in Figure 8.2(ii)a. for ULSD as well as B20 and B100 with smoke levels obtained from all the lug down tests varied from 3 HSU and 49 HSU. For both B20 and B100, all vehicles shown reduction in smoke levels from 1 HSU to 9 HSU and from 8 HSU to 29 HSU respectively.

The above change in smoke reduction was expressed in terms of percentage in Figure 8.2(ii) b and c. For B20, the percentage change in smoke level varied from –40.0% to +9.1% (-10 HSU to +2 HSU) with an average change of –15.6% (Figure 8.2(ii)d.). All the test vehicles experienced a reduction in the average smoke opacity. For B100, all vehicles experienced a dramatic reduction in smoke opacity that varied from -34.8% to -76.5% (-7 HSU to -30 HSU) with an average of -58.4%.

8.3 Carbon Monoxide (CO)

The CO concentrations of individual vehicle at 20% and 50% rated engine power under steady state condition were shown in Figure 8.3 a and b respectively. The CO concentrations for all the fuels tested lied between 2 ppm and 292 ppm for 20% load, and 10 ppm to 905 ppm for 50% load. As can be seen from Table 8.11, there was no systematic trend in CO concentration variation for low load and high load conditions.

Figure 8.3 c and d showed the percentage variation in CO concentration of individual vehicle at 20% load for B20 and B100 respectively while Figure 8.3 e and f showed the corresponding values at 50%. Figure 8.3 g and h showed the overall percentage variation in CO for 20% and 50% load respectively. As can be seen from all these figures, for B20 most of the vehicles experienced a reduction in CO which varied from –60.0% to +65.4% (-216 ppm to +137 ppm) with an average of -10.3%. For B100, the percentage change in CO varied from -75.6% to +154.5% (-541 ppm to +89 ppm) with an average of -16.5%. It should be noted that large variations in CO occurred in M2 and M10 in which both vehicles were installed with DOC. As can be seen from Fig. 8.3 a and b, the measured absolute CO concentrations for these two vehicles were very small and were much lower than those without DOC. In addition, testing experience indicated that CO emission was very sensitive to the throttle position and it was rather difficult to maintain CO constantly during the measurements. This induced larger error to the results particularly those at small concentration.

8.4 Hydrocarbons (HC)

The HC concentration of individual vehicle at 20% and 50% rated engine power under steady state condition were shown in Figure 8.4 a and b respectively. The HC concentrations lied between 2 ppm and 37 ppm for 20% load and between 2 ppm and 71 ppm for 50% load for all the fuels tested. As can be seen from Table 8.11. the changes in HC concentration were in general, quite low, particularly for B20. However, due to the fact that the measured HC concentrations for several vehicles (e.g. M2, M5 and M10) were also quite low, the percentage change might be very high despite of the small changes in the concentration.

Figure 8.4 c and d showed the change of HC concentration in terms of percentage for individual vehicle at 20% load for B20 and B100 respectively while Figure 8.4 e and f showed the corresponding values at 50%. Figure 8.4 g and h showed the overall percentage variation in HC for 20% and 50% load respectively. For B20, the percentage change in HC varied from –75.3% to +108.5% (-11ppm to +6 ppm) with an average of –6.6%. For B100, the percentage change in HC varied from –81.2% to +83.0% (-32ppm to +6ppm) with an average of –28.2%. As mentioned above the large percentage variation was due to the small HC concentration measured for particular vehicles, especially for those vehicles installed with DOC. The result indicated that the reduction in HC is not obvious for B20 (six out of the ten tested vehicles experienced reduction) but more prominent for B100 (nine out of the ten vehicles showed reduction).

8.5 Nitrogen Oxides (NOx)

The NOx concentration of individual vehicle at 20% and 50% rated engine power under steady state condition were shown in Figure 8.5 a and b respectively. The NOx concentrations lied between 188 ppm and 1046 ppm for 20% load and between 278 ppm to 1920 ppm for 50% load for all the fuels tested. The trend of the NOx concentration for various vehicles was quite similar for 20% and 50% load condition and higher concentrations were obtained at higher load condition due to higher combustion temperature. As shown in Table 8.11. the variation in NOx concentration for individual vehicle was quite low as compared to the magnitude of the NOx concentration measured.

Figure 8.5 c and d showed the percentage variation in NOx concentration of individual vehicle at 20% load for B20 and B100 respectively while Figure 8.5 e and f showed the corresponding values at 50%. Figure 8.5 g and h showed the overall percentage variation in NOx for 20% and 50% load respectively. For B20, the percentage change in NOx varied from –12.1% to +21.1% (-97 ppm to +77 ppm) with an average change of +0.6%. Five of the vehicles showed an increase in NOx concentration while the other five showed a decrease. For B100, the percentage change in NOx varied from –19.6% to +39.4% (-116 ppm to +247 ppm) with an average change of +7.8%. It can be observed that the average increase in NOx concentrations for all vehicles tested under B100 were higher than those of B20. The result indicated that there was an unnoticeable change in NOx for B20 but more prominent change was found for B100.

9. On-road emissions study

During the 2nd Monitoring Committee Meeting, there were some concerns that the 50% maximum rated engine power might be not able to reflect the maximum loading achieved for the vehicles running on road. It was therefore decided to investigate further whether the road power of vehicles could be increased beyond 50% rated engine power for pollutant measurement.

9.1 Tsing Ma Bridge Tunnel

With the permission from Tsing Ma Bridge Management Co. Ltd., a series of test was organized in the Tsing Ma Bridge Tunnel during the period 9th to 24th April 2001. An on-road emissions study was conducted on different road configurations. A light van (Ford Econovan 1998), fully loaded with metal blocks and installed with an exhaust sampling probe at the tailpipe, was used for the study. The van was driven at constant speed of 30 kph and 50 kph inside the Tunnel (Photo 7). Real time smoke opacity and gaseous pollutants from the exhaust were collected and determined. The tests were conducted on three separate days with different fuels: ULSD on the 1st day, neat biodiesel fuel on the 2nd day and ULSD again on the 3rd day.

The results of the tests are summarised in Table 9.1. It can be observed that a large reduction in smoke level (approximate -46%) was obtained with the use of the neat biodiesel. However, due to the small smoke values (less than 5 HSU) recorded during the measurement, larger error may be involved. For NOx, an average of 12% increase in concentration was recorded.

It was not possible to determine the transient road power due to limitation of the equipment for such determination. Oxides of nitrogen emission from a simulated chassis dynamometer test had been used for estimating the road power during the sampling period. It could be noticed that the NOx concentration of the on-road test was lower than that at 20% rated engine power dynamometer tests. The results indicated that though the vehicle was fully loaded, running on a straight road would only require less than 20% of the rated engine power to operate. It was therefore considered that this straight road condition could not generate the desired high power for our emission testing. However, the measurement can be considered as an indication of a vehicle running inside a tunnel using biodiesel.

9.2 Cotton Tree Drive

In order to further determine the emission characteristic of ULSD and biodiesel fuels under high engine power running conditions, several exploratory tests have been conducted at different uphill locations and the results were summarized in Table 9.2. Finally location at the Cotton Tree Drive in Central was selected as the most suitable site for the on-road emission testing. The test started with the use of ULSD as baseline testing, followed by the testing of three biodiesel fuels, namely Biodiesel A, B and C. The comparison of NOx concentration between the on-road and dynamometer measurement showed that the road power output at the test site was approximately 60% of the rated engine power. The test van was driven at 2nd gear and the vehicle speed was maintained at 35 kph, which was approximate 3/4 of the full throttle position. The measurement was started and stopped at two fixed locations of the road and repeated several times (Photo 8). Total travel distance of each journey was 0.6 km and the measurement was conducted for a period of 1 minute.

The results of the test are shown in Table 9.1. Figure 9.1 shows the average and maximum smoke level and air pollutant concentration for ULSD and three other biodiesel fuels, and Figure 9.2 shows their percentage variations. The result indicated that there was a significant reduction in smoke opacity, with maximum reduction from 51 to 61% and average reduction from 30 to 51% (range from –5 HSU to –25 HSU) for the three biodiesel fuels tested. The result was inline with the averaged results of the diesel lug down test (-58% or -17 HSU), and the FAS test (-44% or -13 HSU) present in Section 8.2. For CO emission, the use of biodiesel fuels resulted in a maximum reduction from 52 to 59% (174 ppm to 197 ppm) and averaged reduction from 21 to 32% (38 ppm to 59 ppm). For NOx emission, an increase in concentrations was observed when using biodiesel fuels with maximum increase from 6 to 13% (21 ppm to 50 ppm) and average increase from 2 to 6% (6 ppm to 19 ppm). These results were inline with the chassis dynamometer test result.

10. <u>On-road performance test</u>

Two vehicles, including a light goods vehicle and a medium goods vehicle, participated in this on-road performance test. Each vehicle was tested with one biodiesel fuel at B100 during the testing period. Refilling of biodiesel was carried out at Pokfulam Fire Station under the monitoring of a station officer (Photo 9). Detailed information of the test is given in the table below:

Vehicle no.	Vehicle type	Biodiesel tested	Testing Period (dd/mm/yyyy)	Mileage started (km)	Mileage ended (km)	Approximate fuel consumed (litres)
R1	LGV	B	17/08/2001 to 05/11/2001	310327	318691	1735
R2	MGV	A	24/09/2001 to 18/12/2001	96391	101108	1107

Detailed testing procedures were listed in Appendix 7. In brief, baseline ULSD lug down testing was conducted at the beginning and the end of the trial to study the performance of the vehicles before and after switching to biodiesel. To demonstrate the compatibility of biodiesel with the fuel system and vehicle performance, lug down testing of the vehicles was conducted at a monthly interval to provide the maximum road power and smoke opacity measurement for the vehicles after using biodiesel (Photo 10).

Table 10.1 shows the results of the lug down tests conducted for the LGV (R1) and MGV (R2). It can be observed that for R1, the measured maximum engine power remained fairly constant throughout the measurement period. There was a dramatic drop in smoke opacity after shifting to neat biodiesel (-56%) from 24 HSU dropped to 11 HSU. For R2, the maximum engine power of the vehicle increased slightly (1% or 1 kW) after shifting to 100% biodiesel while the smoke opacity dropped dramatically from 26 HSU to 5 HSU (-81%). It should be noted that for this vehicle, there was a gradual reduction in the smoke opacity with increasing the time of biodiesel usage and also the final ULSD emission test results were much lower than the initial values. This phenomenon was also observed in the case of the LGV tested. This might indicate that the use of both biodiesel fuels produce a cleansing effect on the engines of the two test vehicles, resulting in cleaner exhaust gases.

In addition to the above quantitative measurement, questionnaires were also distributed regularly to collect drivers' opinions on road power, smoke opacity and fuel consumption etc. after using biodiesel on their vehicles. The raw data sheet of the survey was shown in Appendix 8 and the results are tabulated in Table 10.2. The results indicated that about 71% of the responses felt a slight reduction in road power and over 86% of the responses commented that there were reductions in smoke emissions and engine noise. The driver's comments on fuel consumption were quite diversified. About 24% of the responses opined slightly decrease in fuel consumption while 38% opined slightly increase and 14% felt significant increase in fuel consumption. No other adverse comments were reported.

Due to the comments of MTA on the possibility of fuel leakage caused by using biodiesel, all the test vehicles were inspected visually when they returned to the testing centre for lug down testing. However, no fuel leakage on the fuel system was observed during the testing period.

11. Data analysis and discussions

In Table 8.11 the average change in maximum engine power, smoke level, CO, HC and NOx concentration for all the ten vehicles was shown. The results were calculated from all the 20% load, 50% load and from all the ULSD and biodiesel fuels tested. The result indicated that variations do exist between ULSD and biodiesel with 20% and 100% blending. However, due to the presence of experimental errors, not all the variations are significant statistically. A t-test at the 95% confidence interval has therefore been conducted on all the tests to see if the variations in concentration were meaningful or not. The results were shown in Appendix 9. Only those data with significance variations were extracted for analysis. This represented a more realistic result taking into account of the statistical variation of data.

For those significant variations, the average percentage change in maximum engine power, FAS smoke, Lug down smoke, CO, HC and NOx concentrations from vehicles were plotted in Figure 11.1 a to f. A break down of the percentage change under different power and concentration ranges is shown in the table below together with the overall average percentage change with respect to ULSD.

B20					B100				
Road Power (kW)					Road Power (kW)				
<30	31–60	61–90	>90	Overall	<30	31–60	61–90	>90	Overall
-3%	0%	-1%	-2%	-1%	-5%	0%	-4%	-4%	-3%
Smoke Opacity (HSU)					Smoke Opacity (HSU)				
<15	16–30	31–45	>45	Overall	<15	16–30	31–45	>45	Overall
-22%	-15%	-16%	-11%	-16%	-60%	-59%	-63%	-50%	-58%
CO Emission (ppm)					CO Emission (ppm)				
<100	101–200	201–300	>300	Overall	<100	101–200	201–300	>300	Overall
-4%	-11%	-19%	-15%	-14%	0%	-9%	-28%	-54%	-23%
HC Emission (ppm)					HC Emission (ppm)				
<10	11–20	21–30	>30	Overall	<10	11–20	21–30	>30	Overall
-75%	-4%	-12%	-14%	-14%	-57%	-36%	-22%	-45%	-40%
NOx Emission (ppm)					NOx Emission (ppm)				
<300	301–600	601–900	>900	Overall	<300	301–600	601–900	>900	Overall
+5%	-4%	-1%	0%	0%	+13%	+8%	+5%	+11%	+9%

From the table above, it was found that for B20, there was on average a slight decrease in the power (-1%) and no noticeable change in NOx concentration (0%), a slight to moderate reduction in HC (-14%), CO (-14%), and smoke opacity (-16%). For B100, the trends were similar to B20 except for larger magnitude. There was an average of 9% increase in NOx concentration and 3% drop in maximum engine power, 23% drop in CO, 40% drop in HC, and 58% drop in smoke opacity.

It is interesting to note that in the results of the on-road performance test, the smoke level and road power immediately after changing to neat biodiesel were close to those measurements conducted after the end of the testing period. This was a good evidence showing the preconditioning after each fuel change was capable to allow the vehicle to achieve stable conditions. At the end of the trial, a ULSD baseline measurement was also conducted and a slight drop in smoke level was observed indicating the possible cleansing effect of the biodiesel.

The main dynamometer tests involved a large amount of practical work that could not be completed on one day. It could be observed that the ULSD baseline testing conducted before each biodiesel testing varied slightly for most of the test vehicles, and within acceptable range. Also, the findings from the on-road performance test indicated that biodiesel might produce a cleansing effect that affected the short-term vehicle performance. Therefore, the ULSD baseline test employed at the beginning of each test day likely to be suitable to eliminate the vehicle and system variations.

12. Area of concerns and outstanding issues regarding the use of biodiesel

During the course of the present study, the EPD had arranged two special meetings with the TD, MTA and biodiesel suppliers to collect their comments on using biodiesel as motor fuel in Hong Kong. In the meetings, some participants expressed their concerns about the potential hazards that might be caused by using biodiesel and information on the latest technologies on motor vehicles using biodiesel was exchanged.

Summarizing the comments of various parties from previous meetings, the following issues were identified that need to be addressed before a decision can be made regarding the use of biodiesel as a motor fuel in Hong Kong:

- Fuel line compatibility

  During review meetings biodiesel suppliers indicated that biodiesel would attack natural rubber in the fuel system but emphasised that the latest engine design uses synthetic rubber instead of natural rubber. It is therefore generally believed that biodiesel should be applicable to newer vehicle models but modifications may be required for aged vehicles (e.g. vehicle older than 10 years).

  In May 2002 the MTA has warned that vehicle using biodiesel might cause serious problem, such as roadworthiness, but agreed that it would not cause immediate danger to road users. They recommended that those vehicles using biodiesel should be inspected regularly. The MTA was requested to provide more information to substantiate their claim, particularly on the parts/components that can/cannot withstand the attack of biodiesel. However, the MTA replied that they did not have such data.

In order to obtain more information about the attack rate of biodiesel on various elastomers, HKU has initiated a study to investigate the compatibility of fuel hoses using biodiesel. Four types of hoses, which could be obtained from the local market, were used for the test. Two of them (i.e. Isuzu and Iveco) were original parts acquired from vehicle manufacturers while the remaining two (i.e. Dayco and Gates) were purchased from local garages. Each type of hose was tested with two biodiesel fuels and with three blending ratios, namely B0 (ULSD), B20 and B100. A tailor-made system was employed to simulate two operation modes (immersion and circulation) and specimens were collected at the time interval of 200, 600, 1200, 1800 and 2400 hours. Size variation measurement, tension and bursting tests were performed to assess the change in physical properties of the hoses at different time intervals after testing with the biodiesel.

Size variation test demonstrated that there were systematic patterns of swelling of fuel hoses (i.e. decrease in inner diameter and increased in outer diameter) for all biodiesel blends. Tension test showed that load capacity decreased with increasing biodiesel percentage and time period of usage. B20 gave similar size and physical properties changes as ULSD. However, obvious swelling effect and greater reduction in tension strength were observed for B100. In the B100 circulation test, oil droplets were found on the surface of the hoses after about 300 hours and the surface became sticky afterward. It could be noted that the outer layer of some hoses, especially for the Isuzu, were partly dissolved under the B100 immersion environment and after about 1200 hours. Fuel hoses supplied from Iveco, which is produced from biodiesel-resisted material, did not show any swelling effect and no oil seepage was observed for the whole test even under B100 operations. The bursting test result also showed a reduced bursting strength of fuel hoses (except Iveco) for all biodiesel blends.

The results suggested that cautious should be taken for vehicle using B100, particular for older vehicle and it is highly recommended to change the fuel line to biodiesel compatible material. Using 20% biodiesel (B20) or less seems to produce fewer problems but the real impact needs further investigation. It is recognized that the result obtained so far cannot be representative of the whole spectra as only a few types of fuel hoses have been tested while there are more than 10 different types of fuel hose currently used in Hong Kong. Further test is recommended to establish a more comprehensive picture on the influence of biodiesel on fuel hoses with different materials.

- Warranty

  The MTA has emphasised several times that they would not accept any blend of biodiesel without principals' authorization and those vehicles using biodiesel would have their warranty voided. Although these mainly affect those newer vehicles, the issue of warranty needs to be tackled as this will affect the confidence of biodiesel users. One solution is that biodiesel suppliers can provide additional insurance to biodiesel users to increase their confidence of using the fuel.

  It is recognized that warranty policy of engine manufacturers did not match with alternative/clean fuel policy of some overseas governments. For instant, biodiesel has been used in the U.S.A. and Europe for several years with the support of local governments for reducing greenhouse gases, promoting energy diversity and exploiting agricultural produce etc. However, there are still a number of vehicle manufacturers not fully endorse its usage, though this number is decreasing. It has also been recommended by some members during the Monitoring Committee meeting that the government should impose legislative measure so that all new imported diesel vehicles be biodiesel compatible. This can be a proactive movement of the government for encouraging use of biofuels in Hong Kong to demonstrate its commitment to protect the environment.

13. Conclusions

The feasibility study of using biodiesel as an automotive fuel in Hong Kong was completed. Ten vehicles, of different types, brands, engine capacities and years of service, were tested on a chassis dynamometer to measure the gaseous pollutant concentrations, smoke opacity and maximum engine power. Two additional vehicles were selected to run on road with neat biodiesel for testing their on-road performance. Before commencing all the testing, a testing protocol was developed which was further validated through a series of preliminary tests.

For the main dynamometer test, there was no unique answer to whether there is any change in the engine power, smoke opacity or air pollutants emissions for all the vehicles, particularly at low biodiesel percentage. For example, almost all vehicles tested showed a dramatic reduction in smoke opacity, but still there were one or two cases with smoke increase. Therefore, there was no absolute performance data of biodiesel on different types of vehicles, it all depended on the design of the engine, its service conditions and the percentage of biodiesel present in the fuel mixture.

From the average performance of the ten vehicles, it was found that for B20, there was a slight decrease (-1%) in the engine power; 16% reduction in smoke opacity, 14% reduction in CO and 14% reduction in HC. There was very little change in NOx concentration. For B100, there was a slight decrease (-3%) in engine power; 58% reduction in smoke opacity; 23% reduction in CO and 40% reduction in HC. However, there was a 9% increase in NOx concentration. Testing was also conducted in the Tsing Ma Bridge Tunnel and Cotton Tree Drive in Central to study the feasibility of obtaining higher engine power for pollutant measurement. It was found that in the Tsing Ma Bridge Tunnel, the power with a fully loaded vehicle under constant speed was about 20% of the maximum rated engine power while a maximum power of about 60% of the rated engine power could be achieved for the fully loaded vehicle running up the Cotton Tree Drive. Experimental results of the Tsing Ma Bridge Tunnel test showed that there was a reduction in smoke emission (average -46% or -2 HSU) and an increase in NOx concentration (average +12% or +34 ppm). The result at Cotton Tree Drive was similar to that of the Tsing Ma Bridge Tunnel. Over 40% (-7 HSU) of smoke emission was reduced while a small change in NOx was determined (average +4% or +12 ppm).

To obtain more data on the day-to-day operation of diesel vehicles using biodiesel fuels, an on-road performance test was conducted on two vehicles, one LGV and one MGV, each using one type of biodiesel throughout the period. The results of the monthly Lug Down test revealed that there was an unnoticeable change in the maximum engine power but a significant improvement in smoke opacity after shifting to use 100% biodiesel. The smoke opacity of the Diesel Lug Down Test reduced 56% (13 HSU) and 81% (21 HSU) for the two vehicles R1 and R2 respectively. In addition to the above quantitative measurement, questionnaires survey on drivers' opinions indicated that about 71% of the responses felt a reduction in engine power. Over 86% of the responses commented that there were reductions in smoke emissions and engine noise. As for the fuel consumption, about 24% of the responses felt a slightly decrease while 38% opined a slight increase and 14% opined significant increase in fuel consumption. Apart from that no adverse comments from drivers was received. Due to the comments from MTA on the possibility of fuel leakage, all the test vehicles were inspected visually when they returned to the testing centre for lug down testing. No fuel leakage from the fuel hose was observed during the testing period.

The emission testing results indicated that using B100 could reduce a considerable amount of air pollutants but a slight increase in NOx emission and a small drop in fuel economy would be encountered. Its ability in reducing air pollutant emissions diminishes with decreasing biodiesel percentage. Nevertheless, prominent effects could still be achieved even at B20. However, some important issues, such as the fuel line compatibility, roadworthiness and warranty, would be arisen due to the use of biodiesel. Unless these issues could be fully resolved, its attractiveness to our transportation system would be limited.

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Photographs

Photo 1. Chassis dynamometer vehicle exhaust emission test (Main dynamometer test)

Photo 2. Change fuel at Pokfulam Fire Station (Main dynamometer test)

Photo 3. SPX Dieseltune DX230 Smokemeter

Photo 4. AVL 490 Tachometer

Photo 5. Richard Oliver Tocsin 310 Combustion analyser

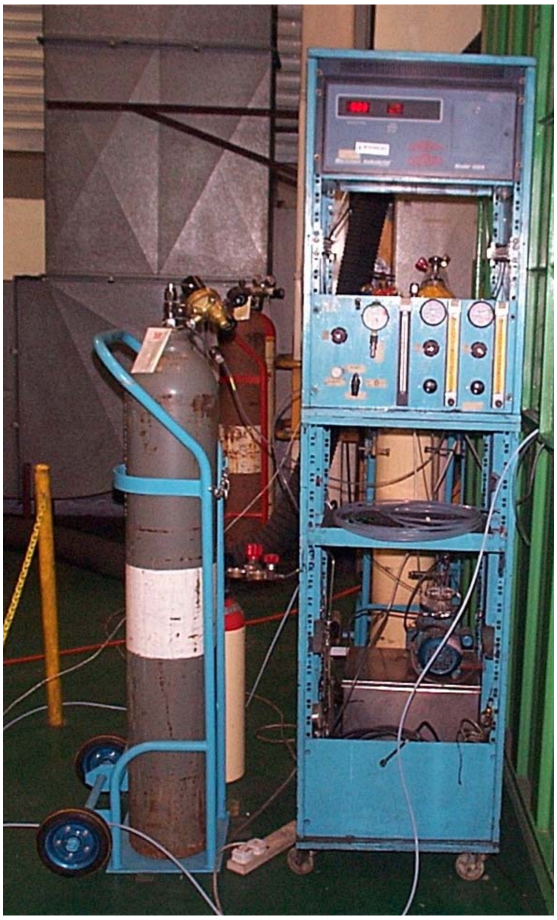


Photo 6. Beckman Industrial Model 400A Hydrocarbons analyser

Photo 7. On-road emissions study at lower deck of the Tsing Ma Bridge (On-road emissions test)

Photo 8. On-road emissions study at Cotton Tree Drive (On-road emissions test)

Photo 9. Refuelling at Pokfulam Fire Station (On-road performance test)

Photo 10. A test vehicle on the chassis dynamometer under the diesel lug down test (On-road performance test)

Tables

	Preliminary Run			Fuel Change				Intra-day								Day-to-day						
Test Vehicle	S1			S2				S1				S3				S1			S3			
Test Date	06-1-01			19-1-01		09-2-01		01-2-01 am		01-2-01 pm		20-3-01 am		20-3-01 pm		30-1-01	31-1-01	01-2-01	19-3-01	19-3-01	20-3-01	21-3-01
Test Fuel	ULSD	B20	ULSD	ULSD (Before)	ULSD (After)	ULSD (Before)	ULSD (After)	ULSD				B100				ULSD			ULSD	B100		
	Free Acceleration Smoke Test																					
Smoke Level (HSU)	12	8	11	17	16	16	16					20		20					33	19	20	20
Percentage variation *	-	-31%	-6%	-	-1%	-	3%					0		0					-	-3%	+2%	+2%
	Diesel Lug Down Test																					
Maximum Power (kW)	34	31	33	101	102	104	105					33		30					29	32	33	32
Percentage variation *	-	-9%	-3%	-	+1%	-	+1%					+4.8%		-4.8%					-	-1%	+2%	-1%
Maximum Smoke Level (HSU)	9	4	9	7	4	5	2					3		5					19	8	3	5
Percentage variation *	-	-56%	0%	-	-43%	-	-60%					-25.0%		+25.0%					-	+50%	-44%	-6%
	Steady Speed Test																					
Vehicle Speed (kph)	Full Throttle @ Maximum Power Speed							50														
Road Power (kW)	32	30	31	102	102	105	104	10	20	10	20	11	28	11	28	10	10	10	11	11	11	11
HC Concentration (ppm)												11	4	15	5				16	10	11	14
Percentage variation *												-18%	-13%	+18%	+13%				-	-14%	-6%	+20%
CO Concentration (ppm)	166	137	141	73	68	66	60	132	108	131	107	166	383#	166	262	131	132	132	174	136	166	156
Percentage variation *	-	-17%	-15%	-	-7%	-	-10%	0%	+1%	-0%	-1%	0%	+19%	0%	-19%	-1%	+0%	+0%	-	-11%	+9%	+2%
NOx Concentration (ppm)	475	431	436	544	539	581	573	293	494	297	496	409	786	408	766	299	302	293	381	401	409	410
Percentage variation *	-	-9%	-8%	-	-1%	-	-1%	-1%	0%	+1%	0%	0%	+1%	0%	-1%	0%	+1%	-2%	-	-1%	+1%	+1%
Relative Humidity (%)	62	62	62	49	52	63	63	64	64	68	68	71	71	74	71	64	68	64	70	71	71	74
	Steady Speed Test																					
Vehicle Speed	Full Throttle @ 45kph			Full Throttle @ 35kph															Part Load @ 50kph			
Road Power (kW)	27	26	27	37	38	37	36												28	28	28	28
HC concentration (ppm)																			5	5	4	4
Percentage variation *																			-	+15%	-8%	-8%
CO concentration (ppm)	102	102	95	52	44	48	48												359	155	383#	165
Percentage variation *	-	-1%	-7%	-	-15%	-	-1%												-	-34%	+63%	-30%
NOx concentration (ppm)	464	455	451	816	814	883	864												793	794	786	816
Percentage variation *	-	-2%	-3%	-	0%	-	-2%												-	-1%	-2%	+2%
Relative Humidity (%)	62	62	62	49	52	63	63												70	71	71	74

* Percentage variation of Intra-day and day-to-day test was devised from mean value

\# Tyre slipping occurred

Table 7.1. Start-up run result

生化柴油試驗計劃 **Feasibility study of using Biodiesel as Motor Fuel in Hong Kong** 車輛廢氣測試結果 **Test Result**							
車輛登記號碼 **Vehicle Registration Mark:**	**CL76XX**		車廠及型號 **Make & Model:**		**Toyota Crown**		
車輛製造年份 **Vehicle Manufacture Year:**	**1991**		車輛種類 **Vehicle Type:**		**Taxi**		
測試日期 **Test Date:**	14-Mar-01	14-Mar-01	14-Mar-01	7-Mar-01	7-Mar-01	7-Mar-01	4-Apr-01
測試燃油 **Fuel**	**ULSD**	**B20-Bio A**	**B100-Bio A**	**ULSD**	**B20-Bio B**	**B100-Bio B**	**ULSD**
空擋加速煙度測試 (踩三腳) **Free Acceleration Smoke Test (HSU)**							
平均煙度 Averaged smoke level (HSU)	33	26	17	42	32	18	37
底盤馬力煙度測試 (跑步機煙度測試) **Lug Down Test:**							
經修正量度所得的最大馬力 Corrected Measured Maximum Power (kW)	33	34	33	33	32	31	31
100% 最大馬力速度時所量度所得的煙度 Smoke level at 100% maximum power speed (HSU)	18	14	6	26	17	7	20
90% 最大馬力速度時所量度所得的煙度 Smoke level at 90 % of maximum power speed (HSU)	15	17	6	20	21	7	17
80% 最大馬力速度時所量度所得的煙度 Smoke level at 80 % of maximum power speed (HSU)	30	22	8	34	24	8	28
固定車速測試 **Steady State Speed Control Test:**							
20% Load:							
車輛速度 Vehicle Speed (kph)	50	50	50	50	50	50	50
固定車速度時所量度所得的馬力 Road Power (kW)	11.4	11.4	11.4	11.4	11.4	11.4	11.4
固定車速度時所量度得的煙度 Smoke level at steady state speed (HSU)	5	1	0	7	6	1	7
固定車速度時所量度得的碳氫化合物濃度 HC concentration at steady state speed (ppm)	19	24	17	25	19	14	15
固定車速度時所量度得的一氧化碳濃度 CO concentration at steady state speed (ppm)	199	176	126	229	169	119	208
固定車速度時所得的修正後氮化物濃度 Corrected NOx concentration at steady state speed (ppm)	561	572	620	537	544	658	603
固定車速度時所量度得的排放氣溫度 Exhaust Gas Temperature at steady state speed (℃)	311	276	260	266	261	252	259
相對濕度 Relative Humidity (%)	69	67	67	74	74	74	74
50% Load:							
車輛速度 Vehicle Speed (kph)	50	50	50	50	50	50	50
固定車速度時所量度所得的馬力 Road Power (kW)	28.5	28.5	28.5	28.5	28.5	28.5	28.5
固定車速度時所量度得的煙度 Smoke level at steady state speed (HSU)	9	3	1	16	10	4	19
固定車速度時所量度得的碳氫化合物濃度 HC concentration at steady state speed (ppm)	15	20	14	13	12	11	10
固定車速度時所量度得的一氧化碳濃度 CO concentration at steady state speed (ppm)	205	172	139	248	212	195	447
固定車速度時所得的修正後氮化物濃度 Corrected NOx concentration at steady state speed (ppm)	868	862	864	847	848	885	855
固定車速度時所量度得的排放氣溫度 Exhaust Gas Temperature at steady state speed (℃)	522	451	432	456	446	438	472
相對濕度 Relative Humidity (%)	69	64	66	74	74	74	74

Table 8.1. Main dynamometer test result – M1

生化柴油試驗計劃 **Feasibility study of using Biodiesel as Motor Fuel in Hong Kong** 車輛廢氣測試結果 **Test Result**							
車輛登記號碼 Vehicle Registration Mark:	**GE 83XX**		**車廠及型號 Make & Model:**		**ISUZU NPR**		
車輛製造年份 Vehicle Manufacture Year:	**1994**		**車輛種類 Vehicle Type:**		**LGV**		
測試日期 Test Date:	26-Feb-01	26-Feb-01	26-Feb-01	12-Mar-01	12-Mar-01	12-Mar-01	4-Apr-01
測試燃油 Fuel	**ULSD**	**B20-Bio A**	**B100-Bio A**	**ULSD**	**B20-Bio B**	**B100-Bio B**	**ULSD**
空擋加速煙度測試 (踩三腳) Free Acceleration Smoke Test (HSU)							
平均煙度 Averaged smoke level (HSU)	24	24	19	22	23	13	31
底盤馬力煙度測試 (跑步機煙度測試) Lug Down Test:							
經修正量度所得的最大馬力 Corrected Measured Maximum Power (kW)	57	58	57	58	58	56	57
100% 最大馬力速度時所量度所得的煙度 Smoke level at 100% maximum power speed (HSU)	33	24	8	29	25	10	32
90% 最大馬力速度時所量度所得的煙度 Smoke level at 90 % of maximum power speed (HSU)	24	19	6	23	20	10	24
80% 最大馬力速度時所量度所得的煙度 Smoke level at 80 % of maximum power speed (HSU)	26	21	8	34	24	12	28
固定車速測試 Steady State Speed Control Test:							
20% Load:							
車輛速度 Vehicle Speed (kph)	50	50	50	50	50	50	50
固定車速度時所量度所得的馬力 Road Power (kW)	16.4	16.4	16.4	16.4	16.4	16.4	16.4
固定車速度時所量度得的煙度 Smoke level at steady state speed (HSU)	4	3	1	4	3	3	3
固定車速度時所量度得的碳氫化合物濃度 HC concentration at steady state speed (ppm)	6	7	6	13	4	7	6
固定車速度時所量度得的一氧化碳濃度 CO concentration at steady state speed (ppm)	4	4	9	5	3	3	0
固定車速度時所得的修正後氮化物濃度 Corrected NOx concentration at steady state speed (ppm)	738	725	801	743	680	712	755
固定車速度時所量度得的排放氣溫度 Exhaust Gas Temperature at steady state speed (℃)	254	235	229	258	242	238	218
相對濕度 Relative Humidity (%)	61	66	71	64	55	51	74
50% Load:							
車輛速度 Vehicle Speed (kph)	50	50	50	50	50	50	50
固定車速度時所量度所得的馬力 Road Power (kW)	41	41	41	41	41	41	41
固定車速度時所量度得的煙度 Smoke level at steady state speed (HSU)	15	15	5	18	18	10	20
固定車速度時所量度得的碳氫化合物濃度 HC concentration at steady state speed (ppm)	5	4	3	11	3	5	5
固定車速度時所量度得的一氧化碳濃度 CO concentration at steady state speed (ppm)	15	13	16	18	16	14	8
固定車速度時所得的修正後氮化物濃度 Corrected NOx concentration at steady state speed (ppm)	1470	1536	1605	1492	1416	1409	1516
固定車速度時所量度得的排放氣溫度 Exhaust Gas Temperature at steady state speed (℃)	378	380	376	409	393	386	361
相對濕度 Relative Humidity (%)	61	71	70	64	52	51	74

Table 8.2. Main dynamometer test result – M2

生化柴油試驗計劃 **Feasibility study of using Biodiesel as Motor Fuel in Hong Kong** 車輛廢氣測試結果 **Test Result**							
車輛登記號碼 **Vehicle Registration Mark:**	**FZ43XX**		車廠及型號 **Make & Model:**		**Nissan Diesel CKB520**		
車輛製造年份 **Vehicle Manufacture Year:**	**1993**		車輛種類 **Vehicle Type:**		**MGV**		
測試日期 **Test Date:**	27-Feb-01	27-Feb-01	27-Feb-01	6-Mar-01	6-Mar-01	6-Mar-01	4-Apr-01
測試燃油 **Fuel**	**ULSD**	**B20-Bio A**	**B100-Bio A**	**ULSD**	**B20-Bio B**	**B100-Bio B**	**ULSD**
空擋加速煙度測試 **(踩三腳) Free Acceleration Smoke Test (HSU)**							
平均煙度 Averaged smoke level (HSU)	42	27	15	34	32	20	47
底盤馬力煙度測試 **(跑步機煙度測試) Lug Down Test:**							
經修正量度所得的最大馬力 Corrected Measured Maximum Power (kW)	178	182	176	186	181	181	180
100% 最大馬力速度時所量度所得的煙度 Smoke level at 100% maximum power speed (HSU)	43	38	16	47	38	18	49
90% 最大馬力速度時所量度所得的煙度 Smoke level at 90 % of maximum power speed (HSU)	46	34	15	44	35	19	44
80% 最大馬力速度時所量度所得的煙度 Smoke level at 80 % of maximum power speed (HSU)	46	34	16	44	38	20	49
固定車速測試 **Steady State Speed Control Test:**							
20% Load:							
車輛速度 Vehicle Speed (kph)	50	50	50	50	50	50	50
固定車速度時所量度所得的馬力 Road Power (kW)	45	45	45	45	45	45	45
固定車速度時所量度得的煙度 Smoke level at steady state speed (HSU)	0	0	0	4	1	2	1
固定車速度時所量度得的碳氫化合物濃度 HC concentration at steady state speed (ppm)	24	26	30	18	23	18	11
固定車速度時所量度得的一氧化碳濃度 CO concentration at steady state speed (ppm)	165	187	254	208	150	159	191
固定車速度時所得的修正後氮化物濃度 Corrected NOx concentration at steady state speed (ppm)	1019	949	1036	993	973	967	1126
固定車速度時所量度得的排放氣溫度 Exhaust Gas Temperature at steady state speed (℃)	208	200	205	210	221	203	210
相對濕度 Relative Humidity (%)	69	62	63	63	64	64	74
50% Load:							
車輛速度 Vehicle Speed (kph)	50	50	50	50	50	50	50
固定車速度時所量度所得的馬力 Road Power (kW)	112.5	112.5	112.5	112.5	112.5	112.5	112.5
固定車速度時所量度得的煙度 Smoke level at steady state speed (HSU)	6	1	1	8	5	3	6
固定車速度時所量度得的碳氫化合物濃度 HC concentration at steady state speed (ppm)	25	26	27	20	24	17	14
固定車速度時所量度得的一氧化碳濃度 CO concentration at steady state speed (ppm)	98	98	109	100	84	76	99
固定車速度時所得的修正後氮化物濃度 Corrected NOx concentration at steady state speed (ppm)	1605	1582	1639	1560	1561	1550	1639
固定車速度時所量度得的排放氣溫度 Exhaust Gas Temperature at steady state speed (℃)	351	341	351	358	352	334	337
相對濕度 Relative Humidity (%)	69	63	62	64	64	62	74

Table 8.3. Main dynamometer test result – M3

生化柴油試驗計劃 **Feasibility study of using Biodiesel as Motor Fuel in Hong Kong** 車輛廢氣測試結果 **Test Result**							
車輛登記號碼 **Vehicle Registration Mark:**	**JA76XX**		車廠及型號 **Make & Model:**		**Isuzu LT 132L**		
車輛製造年份 **Vehicle Manufacture Year:**	**1999**		車輛種類 **Vehicle Type:**		**Coach**		
測試日期 **Test Date:**	26-May-01	26-May-01	26-May-01	14-Jul-01	14-Jul-01	14-Jul-01	21-Jul-01
測試燃油 **Fuel**	**ULSD**	**B20-Bio A**	**B100-Bio A**	**ULSD**	**B20-Bio B**	**B100-Bio B**	**ULSD**
空擋加速煙度測試 **(踩三腳) Free Acceleration Smoke Test (HSU)**							
平均煙度 Averaged smoke level (HSU)	38	46	19	37	49	26	45
底盤馬力煙度測試 **(跑步機煙度測試) Lug Down Test:**							
經修正量度所得的最大馬力 Corrected Measured Maximum Power (kW)	102	98	99	102	101	96	101
100% 最大馬力速度時所量度所得的煙度 Smoke level at 100% maximum power speed (HSU)	10	6	2	7	8	3	7
90% 最大馬力速度時所量度所得的煙度 Smoke level at 90 % of maximum power speed (HSU)	10	7	2	7	7	4	7
80% 最大馬力速度時所量度所得的煙度 Smoke level at 80 % of maximum power speed (HSU)	18	15	5	15	13	8	14
固定車速測試 **Steady State Speed Control Test:**							
20% Load:							
車輛速度 Vehicle Speed (kph)	50	50	50	50	50	50	50
固定車速度時所量度所得的馬力 Road Power (kW)	29.4	29.4	29.4	29.4	29.4	29.4	29.4
固定車速度時所量度得的煙度 Smoke level at steady state speed (HSU)	1	0	1	4	0	0	3
固定車速度時所量度得的碳氫化合物濃度 HC concentration at steady state speed (ppm)	25	20	19	20	17	4	10
固定車速度時所量度得的一氧化碳濃度 CO concentration at steady state speed (ppm)	251	183	144	262	197	137	169
固定車速度時所得的修正後氮化物濃度 Corrected NOx concentration at steady state speed (ppm)	271	286	302	283	249	233	244
固定車速度時所量度得的排放氣溫度 Exhaust Gas Temperature at steady state speed (℃)	282	279	282	287	262	263	291
相對濕度 Relative Humidity (%)	69	65	65	77	77	77	71
50% Load:							
車輛速度 Vehicle Speed (kph)	50	50	50	50	50	50	50
固定車速度時所量度所得的馬力 Road Power (kW)	73.5	73.5	73.5	73.5	73.5	73.5	73.5
固定車速度時所量度得的煙度 Smoke level at steady state speed (HSU)	9	2	5	14	11	5	9
固定車速度時所量度得的碳氫化合物濃度 HC concentration at steady state speed (ppm)	20	17	15	11	11	4	7
固定車速度時所量度得的一氧化碳濃度 CO concentration at steady state speed (ppm)	121	114	109	159	142	123	163
固定車速度時所得的修正後氮化物濃度 Corrected NOx concentration at steady state speed (ppm)	364	372	422	365	368	402	400
固定車速度時所量度得的排放氣溫度 Exhaust Gas Temperature at steady state speed (℃)	390	378	370	400	372	373	395
相對濕度 Relative Humidity (%)	69	65	65	77	77	77	71

Table 8.4. Main dynamometer test result – M4

生化柴油試驗計劃 **Feasibility study of using Biodiesel as Motor Fuel in Hong Kong** 車輛廢氣測試結果 **Test Result**							
車輛登記號碼 Vehicle Registration Mark:	**GD78XX**		**車廠及型號 Make & Model:**		**Nissan Civilian**		
車輛製造年份 Vehicle Manufacture Year:	**1994**		**車輛種類 Vehicle Type:**		**PLB**		
測試日期 Test Date:	20-Jul-01	20-Jul-01	20-Jul-01	5-Jul-01	5-Jul-01	5-Jul-01	2-Aug-01
測試燃油 Fuel	**ULSD**	**B20-Bio A**	**B100-Bio A**	**ULSD**	**B20-Bio B**	**B100-Bio B**	**ULSD**
空擋加速煙度測試 (踩三腳) **Free Acceleration Smoke Test (HSU)**							
平均煙度 Averaged smoke level (HSU)	15	12	15	18	13	12	18
底盤馬力煙度測試 (跑步機煙度測試) **Lug Down Test:**							
經修正量度所得的最大馬力 Corrected Measured Maximum Power (kW)	57	57	60	57	57	59	57
100% 最大馬力速度時所量度所得的煙度 Smoke level at 100% maximum power speed (HSU)	19	17	11	24	17	12	25
90% 最大馬力速度時所量度所得的煙度 Smoke level at 90 % of maximum power speed (HSU)	18	15	11	23	14	9	24
80% 最大馬力速度時所量度所得的煙度 Smoke level at 80 % of maximum power speed (HSU)	19	18	10	26	18	13	22
固定車速測試 **Steady State Speed Control Test:**							
20% Load:							
車輛速度 Vehicle Speed (kph)	50	50	50	50	50	50	50
固定車速度時所量度所得的馬力 Road Power (kW)	17.6	17.6	17.6	17.6	17.6	17.6	17.6
固定車速度時所量度得的煙度 Smoke level at steady state speed (HSU)	4	3	1	3	0	0	3
固定車速度時所量度得的碳氫化合物濃度 HC concentration at steady state speed (ppm)	7	2	2	4	2	4	4
固定車速度時所量度得的一氧化碳濃度 CO concentration at steady state speed (ppm)	81	79	82	57	58	59	76
固定車速度時所得的修正後氮化物濃度 Corrected NOx concentration at steady state speed (ppm)	204	222	238	206	215	245	206
固定車速度時所量度得的排放氣溫度 Exhaust Gas Temperature at steady state speed (℃)	194	198	183	192	219	193	193
相對濕度 Relative Humidity (%)	73	69	71	58	63	63	71
50% Load:							
車輛速度 Vehicle Speed (kph)	50	50	50	50	50	50	50
固定車速度時所量度所得的馬力 Road Power (kW)	44	44	44	44	44	44	44
固定車速度時所量度得的煙度 Smoke level at steady state speed (HSU)	49	22	14	47	30	17	45
固定車速度時所量度得的碳氫化合物濃度 HC concentration at steady state speed (ppm)	3	7	3	2	2	4	3
固定車速度時所量度得的一氧化碳濃度 CO concentration at steady state speed (ppm)	647	466	241	754	539	241	716
固定車速度時所得的修正後氮化物濃度 Corrected NOx concentration at steady state speed (ppm)	295	298	308	279	281	304	293
固定車速度時所量度得的排放氣溫度 Exhaust Gas Temperature at steady state speed (℃)	415	395	368	423	408	399	427
相對濕度 Relative Humidity (%)	73	71	69	58	63	63	71

Table 8.5. Main dynamometer test result – M5

生化柴油試驗計劃
Feasibility study of using Biodiesel as Motor Fuel in Hong Kong
車輛廢氣測試結果
Test Result

車輛登記號碼 **Vehicle Registration Mark:**	**HB46XX**			車廠及型號 **Make & Model:**			**Mazda E2200**			
車輛製造年份 **Vehicle Manufacture Year:**	**1993**			車輛種類 **Vehicle Type:**			**Van**			
測試日期 **Test Date:**	10-Oct-01	10-Oct-01	10-Oct-01	30-Oct-01	30-Oct-01	30-Oct-01	7-Nov-01	7-Nov-01	7-Nov-01	12-Nov-01
測試燃油 **Fuel**	**ULSD**	**B20-Bio A**	**B100-Bio A**	**ULSD**	**B20-Bio B**	**B100-Bio B**	**ULSD**	**B20-Bio C**	**B100-Bio C**	**ULSD**
空擋加速煙度測試 (踩三腳) **Free Acceleration Smoke Test (HSU)**										
平均煙度 Averaged smoke level (HSU)	26	24	17	28	27	18	34	32	18	35
底盤馬力煙度測試 (跑步機煙度測試) **Lug Down Test:**										
經修正量度所得的最大馬力 Corrected Measured Maximum Power (kW)	29	29	28	29	28	27	30	28	29	30
100% 最大馬力速度時所量度所得的煙度 Smoke level at 100% maximum power speed (HSU)	46	44	30	49	47	29	42	43	26	40
90% 最大馬力速度時所量度所得的煙度 Smoke level at 90 % of maximum power speed (HSU)	43	42	26	45	46	26	40	40	25	38
80% 最大馬力速度時所量度所得的煙度 Smoke level at 80 % of maximum power speed (HSU)	38	38	24	41	39	22	37	38	22	39
固定車速測試 **Steady State Speed Control Test:**										
20% Load:										
車輛速度 Vehicle Speed (kph)	50	50	50	50	50	50	50	50	50	50
固定車速度時所量度所得的馬力 Road Power (kW)	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8
固定車速度時所量度得的煙度 Smoke level at steady state speed (HSU)	5	6	3	7	6	4	6	5	2	8
固定車速度時所量度得的碳氫化合物濃度 HC concentration at steady state speed (ppm)	15	14	11	15	16	13	14	14	14	14
固定車速度時所量度得的一氧化碳濃度 CO concentration at steady state speed (ppm)	228	233	197	215	212	190	223	206	180	230
固定車速度時所得的修正後氮化物濃度 Corrected NOx concentration at steady state speed (ppm)	188	228	263	202	208	233	213	218	234	226
固定車速度時所量度得的排放氣溫度 Exhaust Gas Temperature at steady state speed (℃)	203	193	193	149	160	187	190	173	169	216
相對濕度 Relative Humidity (%)	52	49	46	60	57	54	53	54	43	47
50% Load:										
車輛速度 Vehicle Speed (kph)	50	50	50	50	50	50	50	50	50	50
固定車速度時所量度所得的馬力 Road Power (kW)	22	22	22	22	22	22	22	22	22	22
固定車速度時所量度得的煙度 Smoke level at steady state speed (HSU)	31	31	17	32	30	20	33	28	15	32
固定車速度時所量度得的碳氫化合物濃度 HC concentration at steady state speed (ppm)	62	68	44	71	65	49	65	56	34	69
固定車速度時所量度得的一氧化碳濃度 CO concentration at steady state speed (ppm)	768	905	760	757	745	674	783	723	492	763
固定車速度時所得的修正後氮化物濃度 Corrected NOx concentration at steady state speed (ppm)	527	566	520	576	537	474	596	614	557	615
固定車速度時所量度得的排放氣溫度 Exhaust Gas Temperature at steady state speed (℃)	299	296	305	212	242	300	280	230	258	296
相對濕度 Relative Humidity (%)	52	46	49	60	57	54	53	54	43	47

Table 8.6. Main dynamometer test result – M6

生化柴油試驗計劃 **Feasibility study of using Biodiesel as Motor Fuel in Hong Kong** 車輛廢氣測試結果 **Test Result**										
車輛登記號碼 Vehicle Registration Mark:	**HZ74XX**			**車廠及型號 Make & Model:**			**Mitsubishi Canter**			
車輛製造年份 Vehicle Manufacture Year:	**1998**			**車輛種類 Vehicle Type:**			**LGV**			
測試日期 Test Date:	6-Oct-01	6-Oct-01	6-Oct-01	20-Oct-01	20-Oct-01	20-Oct-01	27-Oct-01	27-Oct-01	27-Oct-01	10-Nov-01
測試燃油 Fuel	**ULSD**	**B20-Bio A**	**B100-Bio A**	**ULSD**	**B20-Bio B**	**B100-Bio B**	**ULSD**	**B20-Bio C**	**B100-Bio C**	**ULSD**
空擋加速煙度測試 (踩三腳) Free Acceleration Smoke Test (HSU)										
平均煙度 Averaged smoke level (HSU)	19	16	8	20	18	9	18	15	8	18
底盤馬力煙度測試 (跑步機煙度測試) Lug Down Test:										
經修正量度所得的最大馬力 Corrected Measured Maximum Power (kW)	73	72	69	70	70	68	71	69	68	70
100% 最大馬力速度時所量度所得的煙度 Smoke level at 100% maximum power speed (HSU)	12	9	5	12	10	5	12	8	3	11
90% 最大馬力速度時所量度所得的煙度 Smoke level at 90 % of maximum power speed (HSU)	10	8	4	10	8	3	9	7	3	9
80% 最大馬力速度時所量度所得的煙度 Smoke level at 80 % of maximum power speed (HSU)	10	7	3	8	7	1	8	6	2	8
固定車速測試 Steady State Speed Control Test:										
20% Load:										
車輛速度 Vehicle Speed (kph)	50	50	50	50	50	50	50	50	50	50
固定車速度時所量度所得的馬力 Road Power (kW)	22	22	22	22	22	22	22	22	22	22
固定車速度時所量度得的煙度 Smoke level at steady state speed (HSU)	2	1	0	1	1	0	1	1	0	1
固定車速度時所量度得的碳氫化合物濃度 HC concentration at steady state speed (ppm)	28	26	21	26	22	19	18	15	10	18
固定車速度時所量度得的一氧化碳濃度 CO concentration at steady state speed (ppm)	157	142	135	132	109	86	137	123	115	131
固定車速度時所得的修正後氮化物濃度 Corrected NOx concentration at steady state speed (ppm)	354	364	378	375	375	396	362	380	380	369
固定車速度時所量度得的排放氣溫度 Exhaust Gas Temperature at steady state speed (℃)	233	223	221	218	215	194	189	184	195	197
相對濕度 Relative Humidity (%)	62	55	58	49	52	54	66	72	67	42
50% Load:										
車輛速度 Vehicle Speed (kph)	50	50	50	50	50	50	50	50	50	50
固定車速度時所量度所得的馬力 Road Power (kW)	55	55	55	55	55	55	55	55	55	55
固定車速度時所量度得的煙度 Smoke level at steady state speed (HSU)	5	4	2	5	4	0	5	4	1	6
固定車速度時所量度得的碳氫化合物濃度 HC concentration at steady state speed (ppm)	36	33	21	33	30	16	32	27	19	24
固定車速度時所量度得的一氧化碳濃度 CO concentration at steady state speed (ppm)	115	123	102	106	102	93	110	115	106	106
固定車速度時所得的修正後氮化物濃度 Corrected NOx concentration at steady state speed (ppm)	527	531	585	547	556	593	547	556	573	546
固定車速度時所量度得的排放氣溫度 Exhaust Gas Temperature at steady state speed (℃)	361	355	361	357	345	308	287	313	301	310
相對濕度 Relative Humidity (%)	62	58	55	49	52	54	66	72	67	42

Table 8.7. Main dynamometer test result – M7

生化柴油試驗計劃 **Feasibility study of using Biodiesel as Motor Fuel in Hong Kong** 車輛廢氣測試結果 **Test Result**										
車輛登記號碼 **Vehicle Registration Mark:**	**FD99X**			車廠及型號 **Make & Model:**			**Isuzu**			
車輛製造年份 **Vehicle Manufacture Year:**	**1991**			車輛種類 **Vehicle Type:**			**MGV**			
測試日期 Test Date:	19-Sep-01	19-Sep-01	19-Sep-01	3-Oct-01	3-Oct-01	3-Oct-01	17-Oct-01	17-Oct-01	17-Oct-01	31-Oct-01
測試燃油 Fuel	**ULSD**	**B20-Bio A**	**B100-Bio A**	**ULSD**	**B20-Bio B**	**B100-Bio B**	**ULSD**	**B20-Bio C**	**B100-Bio C**	**ULSD**
空擋加速煙度測試 (踩三腳) Free Acceleration Smoke Test (HSU)										
平均煙度 Averaged smoke level (HSU)	44	43	35	49	47	41	47	44	39	45
底盤馬力煙度測試 (跑步機煙度測試) **Lug Down Test:**										
經修正量度所得的最大馬力 Corrected Measured Maximum Power (kW)	77	76	74	78	77	73	75	75	73	76
100% 最大馬力速度時所量度所得的煙度 Smoke level at 100% maximum power speed (HSU)	37	35	13	33	32	15	28	25	13	30
90% 最大馬力速度時所量度所得的煙度 Smoke level at 90 % of maximum power speed (HSU)	35	36	12	33	29	15	26	25	12	28
80% 最大馬力速度時所量度所得的煙度 Smoke level at 80 % of maximum power speed (HSU)	38	36	13	35	31	16	28	25	12	27
固定車速測試 **Steady State Speed Control Test:**										
20% Load:										
車輛速度 Vehicle Speed (kph)	50	50	50	50	50	50	50	50	50	50
固定車速度時所量度所得的馬力 Road Power (kW)	22	22	22	22	22	22	22	22	22	22
固定車速度時所量度得的煙度 Smoke level at steady state speed (HSU)	7	6	3	9	8	5	7	7	1	5
固定車速度時所量度得的碳氫化合物濃度 HC concentration at steady state speed (ppm)	37	35	17	37	31	16	30	28	18	30
固定車速度時所量度得的一氧化碳濃度 CO concentration at steady state speed (ppm)	286	272	233	292	264	169	258	228	205	274
固定車速度時所得的修正後氮化物濃度 Corrected NOx concentration at steady state speed (ppm)	482	477	549	495	467	504	456	455	529	467
固定車速度時所量度得的排放氣溫度 Exhaust Gas Temperature at steady state speed (℃)	322	326	319	328	324	316	327	318	313	322
相對濕度 Relative Humidity (%)	64	61	63	60	62	62	51	51	52	61
50% Load:										
車輛速度 Vehicle Speed (kph)	50	50	50	50	50	50	50	50	50	50
固定車速度時所量度所得的馬力 Road Power (kW)	55	55	55	55	55	55	55	55	55	55
固定車速度時所量度得的煙度 Smoke level at steady state speed (HSU)	22	15	5	21	14	8	9	9	5	11
固定車速度時所量度得的碳氫化合物濃度 HC concentration at steady state speed (ppm)	52	47	25	51	40	25	49	42	28	48
固定車速度時所量度得的一氧化碳濃度 CO concentration at steady state speed (ppm)	724	634	254	734	622	193	557	373	216	584
固定車速度時所得的修正後氮化物濃度 Corrected NOx concentration at steady state speed (ppm)	948	947	1137	940	959	1102	985	982	1102	987
固定車速度時所量度得的排放氣溫度 Exhaust Gas Temperature at steady state speed (℃)	489	497	482	477	484	469	475	478	472	490
相對濕度 Relative Humidity (%)	64	63	61	60	62	62	51	51	52	61

Table 8.8. Main dynamometer test result – M8

生化柴油試驗計劃 **Feasibility study of using Biodiesel as Motor Fuel in Hong Kong** 車輛廢氣測試結果 **Test Result**										
車輛登記號碼 **Vehicle Registration Mark:**	**ET34XX**			車廠及型號 **Make & Model:**				**SCANIA**		
車輛製造年份 **Vehicle Manufacture Year:**	**1990**			車輛種類 **Vehicle Type:**				HGV		
測試日期 Test Date:	3-Dec-01	3-Dec-01	3-Dec-01	27-Nov-01	27-Nov-01	27-Nov-01	20-Nov-01	20-Nov-01	20-Nov-01	10-Dec-01
測試燃油 Fuel	**ULSD**	**B20-Bio A**	**B100-Bio A**	**ULSD**	**B20-Bio B**	**B100-Bio B**	**ULSD**	**B20-Bio C**	**B100-Bio C**	**ULSD**
空擋加速煙度測試 (踩三腳) Free Acceleration Smoke Test (HSU)										
平均煙度 Averaged smoke level (HSU)	38	33	14	38	30	19	35	24	9	38
底盤馬力煙度測試 (跑步機煙度測試) Lug Down Test:										
經修正量度所得的最大馬力 Corrected Measured Maximum Power (kW)	125	122	119	127	125	125	123	115	116	123
100% 最大馬力速度時所量度所得的煙度 Smoke level at 100% maximum power speed (HSU)	16	17	8	20	7	6	21	16	9	17
90% 最大馬力速度時所量度所得的煙度 Smoke level at 90 % of maximum power speed (HSU)	19	19	8	20	11	6	23	19	9	21
80% 最大馬力速度時所量度所得的煙度 Smoke level at 80 % of maximum power speed (HSU)	23	23	9	25	15	7	26	21	9	28
固定車速測試 Steady State Speed Control Test:										
20% Load:										
車輛速度 Vehicle Speed (kph)	50	50	50	50	50	50	50	50	50	50
固定車速度時所量度所得的馬力 Road Power (kW)	37	37	37	37	37	37	37	37	37	37
固定車速度時所量度得的煙度 Smoke level at steady state speed (HSU)	2	1	0	1	1	0	3	1	0	1
固定車速度時所量度得的碳氫化合物濃度 HC concentration at steady state speed (ppm)	13	12	9	12	14	8	13	12	9	11
固定車速度時所量度得的一氧化碳濃度 CO concentration at steady state speed (ppm)	102	104	125	109	81	79	97	96	112	112
固定車速度時所得的修正後氮化物濃度 Corrected NOx concentration at steady state speed (ppm)	854	854	889	801	834	932	730	748	836	746
固定車速度時所量度得的排放氣溫度 Exhaust Gas Temperature at steady state speed (℃)	249	249	262	253	235	230	220	241	251	236
相對濕度 Relative Humidity (%)	70	67	67	50	47	50	31	30	36	62
50% Load:										
車輛速度 Vehicle Speed (kph)	50	50	50	50	50	50	50	50	50	50
固定車速度時所量度所得的馬力 Road Power (kW)	92.5	92.5	92.5	92.5	92.5	92.5	92.5	92.5	92.5	92.5
固定車速度時所量度得的煙度 Smoke level at steady state speed (HSU)	5	3	1	3	2	0	5	2	1	4
固定車速度時所量度得的碳氫化合物濃度 HC concentration at steady state speed (ppm)	17	18	11	18	19	16	19	18	14	19
固定車速度時所量度得的一氧化碳濃度 CO concentration at steady state speed (ppm)	221	196	201	188	166	160	189	176	172	234
固定車速度時所得的修正後氮化物濃度 Corrected NOx concentration at steady state speed (ppm)	1674	1751	1920	1724	1736	1810	1609	1626	1799	1712
固定車速度時所量度得的排放氣溫度 Exhaust Gas Temperature at steady state speed (℃)	378	359	345	369	359	345	282	351	361	397
相對濕度 Relative Humidity (%)	62	65	62	50	47	50	31	30	36	65

Table 8.9. Main dynamometer test result – M9

生化柴油試驗計劃 **Feasibility study of using Biodiesel as Motor Fuel in Hong Kong** 車輛廢氣測試結果 **Test Result**										
車輛登記號碼 **Vehicle Registration Mark:**	**GU61XX**			車廠及型號 **Make & Model:**			**Isuzu NPR**			
車輛製造年份 **Vehicle Manufacture Year:**	**1996**			車輛種類 **Vehicle Type:**			**MGV**			
測試日期 Test Date:	6-Dec-01	6-Dec-01	6-Dec-01	30-Nov-01	30-Nov-01	30-Nov-01	23-Nov-01	23-Nov-01	23-Nov-01	0-Jan-00
測試燃油 Fuel	**ULSD**	**B20-Bio A**	**B100-Bio A**	**ULSD**	**B20-Bio B**	**B100-Bio B**	**ULSD**	**B20-Bio C**	**B100-Bio C**	**ULSD**
空擋加速煙度測試 (踩三腳) Free Acceleration Smoke Test (HSU)										
平均煙度 Averaged smoke level (HSU)	18	14	8	23	16	11	18	16	7	19
底盤馬力煙度測試 (跑步機煙度測試) Lug Down Test:										
經修正量度所得的最大馬力 Corrected Measured Maximum Power (kW)	53	53	54	54	54	54	54	55	53	54
100% 最大馬力速度時所量度所得的煙度 Smoke level at 100% maximum power speed (HSU)	24	22	10	22	23	14	23	20	8	21
90% 最大馬力速度時所量度所得的煙度 Smoke level at 90 % of maximum power speed (HSU)	24	22	9	21	24	14	23	19	7	22
80% 最大馬力速度時所量度所得的煙度 Smoke level at 80 % of maximum power speed (HSU)	22	19	10	19	21	14	20	18	7	19
固定車速測試 Steady State Speed Control Test:										
20% Load:										
車輛速度 Vehicle Speed (kph)	50	50	50	50	50	50	50	50	50	50
固定車速度時所量度所得的馬力 Road Power (kW)	16.4	16.4	16.4	16.4	16.4	16.4	16.4	16.4	16.4	16.4
固定車速度時所量度得的煙度 Smoke level at steady state speed (HSU)	9	7	1	8	9	4	8	6	2	8
固定車速度時所量度得的碳氫化合物濃度 HC concentration at steady state speed (ppm)	6	5	2	13	9	8	7	7	4	4
固定車速度時所量度得的一氧化碳濃度 CO concentration at steady state speed (ppm)	2	2	4	15	6	4	6	7	7	7
固定車速度時所得的修正後氮化物濃度 Corrected NOx concentration at steady state speed (ppm)	322	330	365	337	310	317	344	333	373	334
固定車速度時所量度得的排放氣溫度 Exhaust Gas Temperature at steady state speed (℃)	270	262	264	257	254	252	278	258	259	267
相對濕度 Relative Humidity (%)	64	64	55	71	71	71	49	50	52	52
50% Load:										
車輛速度 Vehicle Speed (kph)	50	50	50	50	50	50	50	50	50	50
固定車速度時所量度所得的馬力 Road Power (kW)	41	41	41	41	41	41	41	41	41	41
固定車速度時所量度得的煙度 Smoke level at steady state speed (HSU)	15	12	5	18	17	8	18	14	5	17
固定車速度時所量度得的碳氫化合物濃度 HC concentration at steady state speed (ppm)	7	6	4	11	12	10	7	8	6	6
固定車速度時所量度得的一氧化碳濃度 CO concentration at steady state speed (ppm)	14	10	11	35	22	12	17	29	14	27
固定車速度時所得的修正後氮化物濃度 Corrected NOx concentration at steady state speed (ppm)	540	544	599	524	504	539	541	533	597	541
固定車速度時所量度得的排放氣溫度 Exhaust Gas Temperature at steady state speed (℃)	403	378	386	364	351	323	349	369	367	370
相對濕度 Relative Humidity (%)	64	55	64	71	71	71	49	50	52	52

Table 8.10. Main dynamometer test result – M10

Vehicle No.	Change in Maximum Engine Power (kW)		Change in Smoke Level – FAS (HSU)		Change in Smoke Level – Diesel Lug Down (HSU)	
	B20	B100	B20	B100	B20	B100
M1	0	-1	-9	-20	-9	-24
M2	1	-1	0	-7	-9	-24
M3	-1	-4	-8	-20	-9	-29
M4	-3	-5	10	-15	-3	-10
M5	0	3	-4	-3	-5	-11
M6	-1	-1	-2	-12	-1	-17
M7	-1	-3	-3	-11	-3	-8
M8	-1	-3	-2	-8	-3	-20
M9	-4	-5	-8	-23	-5	-16
M10	0	0	-4	-11	-1	-12

	20% Load						50%Load					
Vehicle No.	Change in CO (ppm)		Change in HC (ppm)		Change in NOx (ppm)		Change in CO (ppm)		Change in HC (ppm)		Change in NOx (ppm)	
	B20	B100	B20	B100	B20	B100	B20	B100	B20	B100	B20	B100
M1	-42	-92	0	-6	9	90	-34	-60	2	-1	-3	17
M2	-1	2	-4	-3	-38	16	-2	-2	-4	-4	-16	16
M3	-18	20	3	3	-45	-5	-8	-6	3	-1	-12	11
M4	-67	-116	-4	-11	-9	-9	-12	-24	-2	-6	6	48
M5	0	2	-4	-2	13	36	-198	-460	2	1	3	19
M6	-5	-33	0	-2	17	42	21	-127	-3	-24	1	-54
M7	-18	-30	-3	-7	9	21	3	-10	-4	-15	8	44
M8	-24	-76	-3	-18	-11	49	-129	-451	-8	-24	7	159
M9	-9	-3	0	-4	17	90	-20	-22	1	-4	37	176
M10	-3	-3	-2	-4	-10	17	-2	-10	0	-2	-9	42

Table 8.11. Change in engine power, smoke level and gaseous pollutant concentration – Biodiesel blends Vs ULSD

Location	Tsing Ma Tunnel												Cotton Tree Drive				
Test Date	9/4/01				17/4/01				24/4/01				3/4/02	4/4/02	18/4/02	13/4/02	20/4/02
Test Fuel	ULSD				B100				ULSD				ULSD	B100-A	B100-B	B100-C	ULSD
	Average of the whole journey																
	Kowloon to Lantau Island		Lantau Island Kowloon		Kowloon to Lantau Island		Lantau Island Kowloon		Kowloon to Lantau Island		Lantau Island Kowloon		Cotton Tree Drive				
Vehicle Speed (kph)	50	30	50	30	50	30	50	30	50	30	50	30	35				
Smoke Level (HSU)	4	3	4	4	2	1	3	2					18	11	9	12	16
CO Concentration (ppm)	196	162	192	165	200	174	200	171	193	157	189	165	183	138	124	145	222
NOx Concentration (ppm)	291	257	320	281	322	297	346	321	260	234	275	270	293	304	312	299	283
Relative Humidity (%)	81	81	81	81	78	78	78	78	74	78	74	78	78	78	81	72	81
	Maximum of the whole journey																
Vehicle Speed (kph)													35				
Smoke level (HSU)													41	20	16	18	35
CO Concentration (ppm)													336	160	139	162	382
NOx Concentration (ppm)													369	390	419	398	374
Relative Humidity (%)													78	78	81	72	81

Table 9.1. On-road emission study result

Location	Cotton Tree Drive	Pokfulam Road I	Pokfulam Road II	Clear Water Bay I	Clear Water Bay II	Clear Water Bay III
Test Date	4-Sept-01	20-Aug-01	20-Aug-01	21-Aug-01	21-Aug-01	21-Aug-01
Test Fuel	ULSD					
Vehicle Speed (kph)	35					
CO Concentration (ppm)	141	144	148	226	153	170
NOx Concentration (ppm)	280	150	213	248	211	268
Relative Humidity (%)	52	52	52	52	52	52

Table 9.2. On-road emission study – evalutation of emissions at different roads

	R1					R2				
Test Date	17-Aug-01	17-Aug-01	18-Sept-01	18-Oct-01	5-Nov-01	24-Sept-01	24-Sept-01	24-Oct-01	11-Dec-01	18-Dec-01
Test Fuel	ULSD	B100			ULSD	ULSD	B100			ULSD
	Free acceleration Smoke Test									
Smoke Level (HSU)	26	11	12	13	44	28	8	5	4	13
	Diesel Lug Down Test									
Corrected Maximum Power (kW)	45	44	43	45	45	46	45	46	48	50
Maximum Smoke Level (HSU)	24	11	11	10	21	26	6	5	4	18

Table 10.1. On-road performance test result

	Survey Statistics				
	Large reduction	**Slight reduction**	**No change**	**Slight increase**	**Large increase**
KD38xx (B100 Vs ULSD)					
Road Power		8	4		
Smoke Opacity	1	9	2		
Fuel Consumption		5	3	3	
Lubricant Loss		1	10	1	
Engine Noise		9	3		
Lubricant Property		1	11		
Overall Performance (B100 Vs ULSD)	1		10		1
GC92xx (B100 Vs ULSD)					
Road Power		7	2		
Smoke Opacity	9	1			
Fuel Consumption			2	5	3
Lubricant Loss			10		
Engine Noise	5	5			
Lubricant Property			10		
Overall Performance (B100 Vs ULSD)	2		7		
Overall Averaged (B100 Vs ULDS)					
Road Power	0	15	6	0	0
Smoke Opacity	10	10	2	0	0
Fuel Consumption	0	5	5	8	3
Lubricant Loss	0	1	20	1	0
Engine Noise	5	14	3	0	0
Lubricant Property	0	1	21	0	0
Overall Performance (B100 Vs ULSD)	3	0	17	0	1
% Population (B100 Vs ULSD)					
Road Power		71.4%	28.6%		
Smoke Opacity	45.5%	45.5%	9.1%		
Fuel Consumption		23.8%	23.8%	38.1%	14.3%
Lubricant Loss		4.5%	90.9%	4.5%	
Engine Noise	22.7%	63.6%	13.6%		
Lubricant Property		4.5%	95.5%		
Overall Performance (B100 Vs ULSD)	14.3%		81.0%		4.8%

Table 10.2. Summary of the questionnaire survey results

	Maximum Engine Power	Smoke (FAS)	Smoke (Lug down)	CO	HC	NOx
B20	-1%	-11%	-16%	-14%	-14%	0%
B100	-3%	-44%	-58%	-23%	-40%	+9%

Table 11.1 Average percentage change for all vehicles tested

Figures

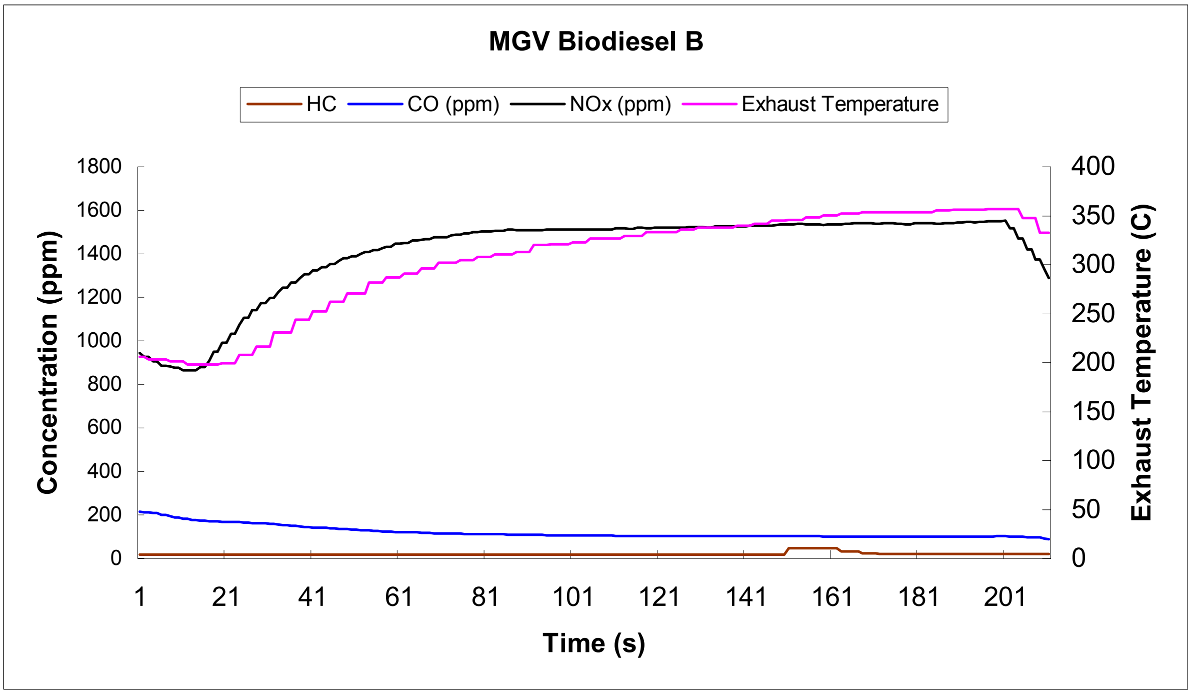


Figure 5.1. Vehicle exhaust temperature and pollutant concentration of steady state test

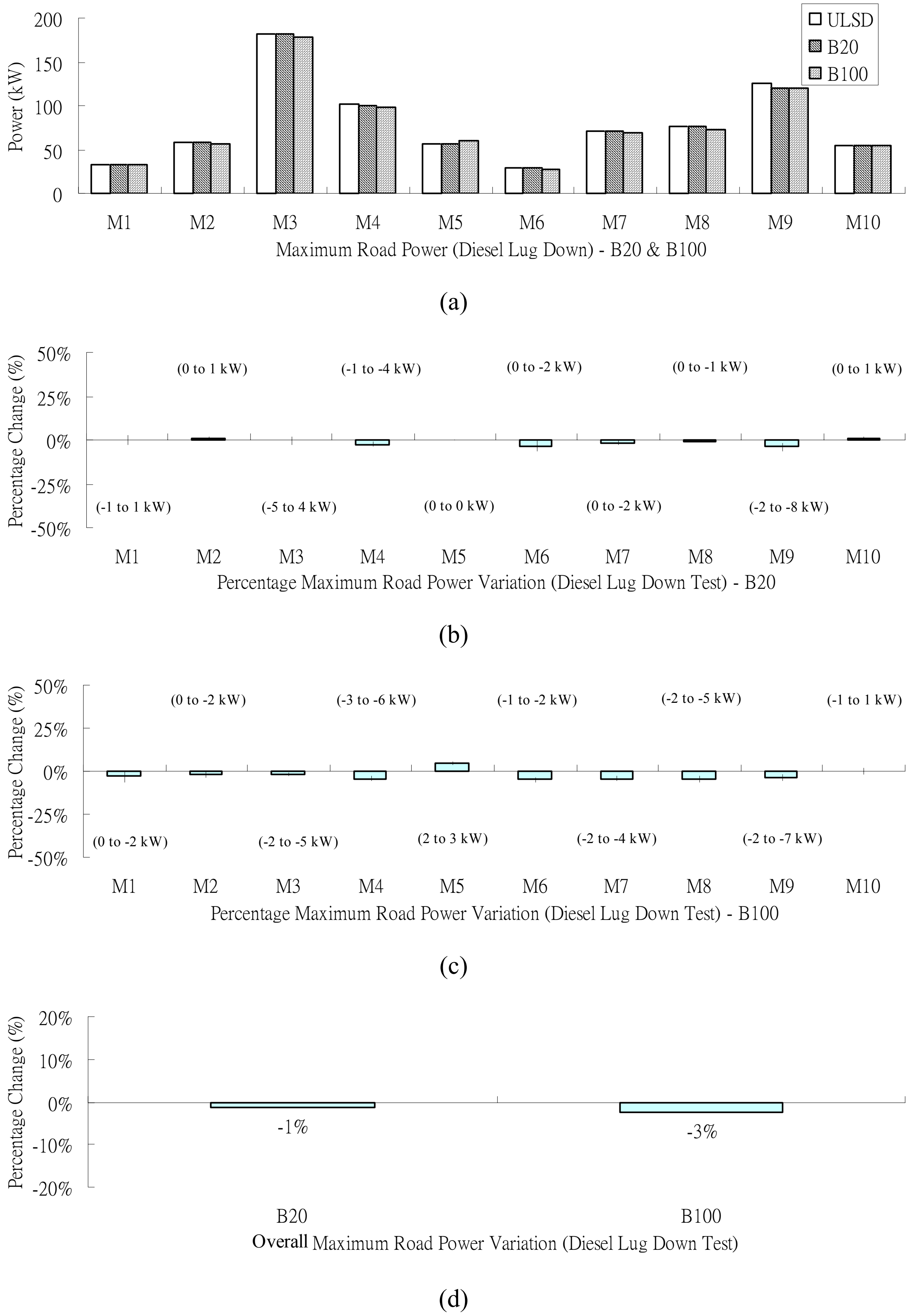
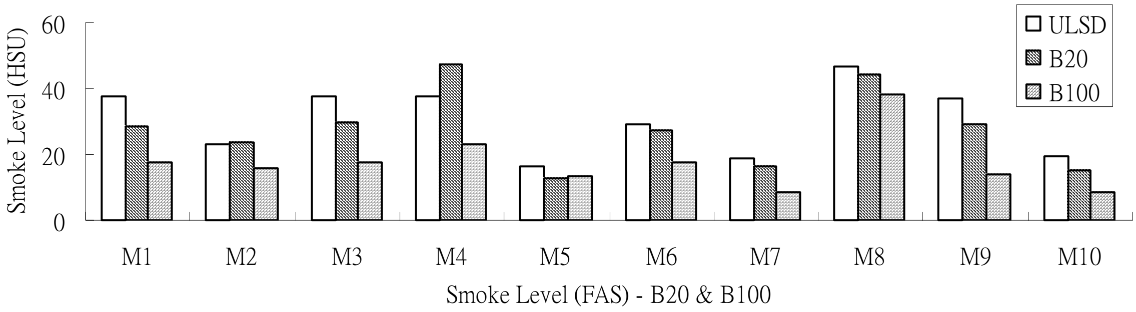
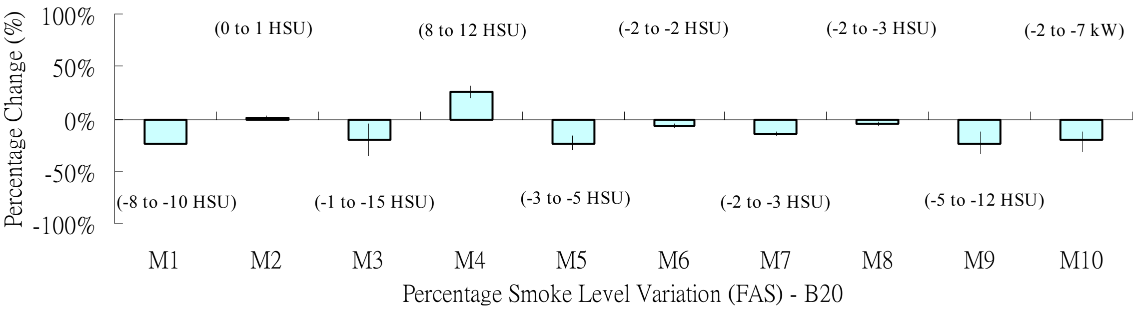


Figure 8.1. Maximum road power and its percentage variation of all vehicles

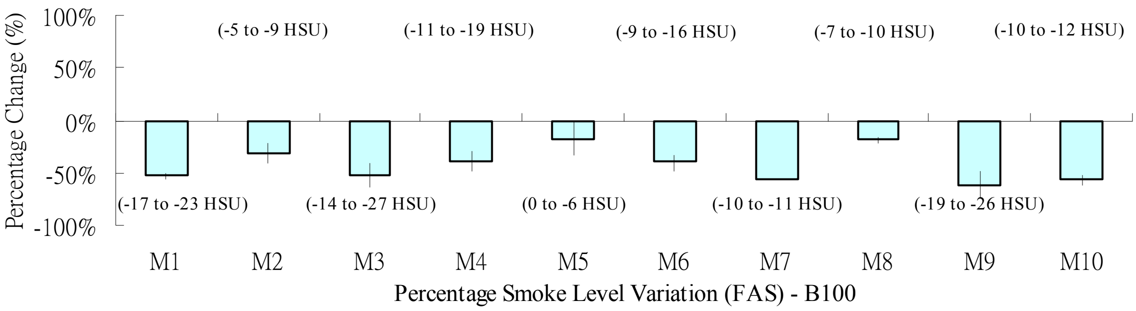
Note: The numbers inside the brackets represent the range of variation in actual engineering unit for individual vehicle



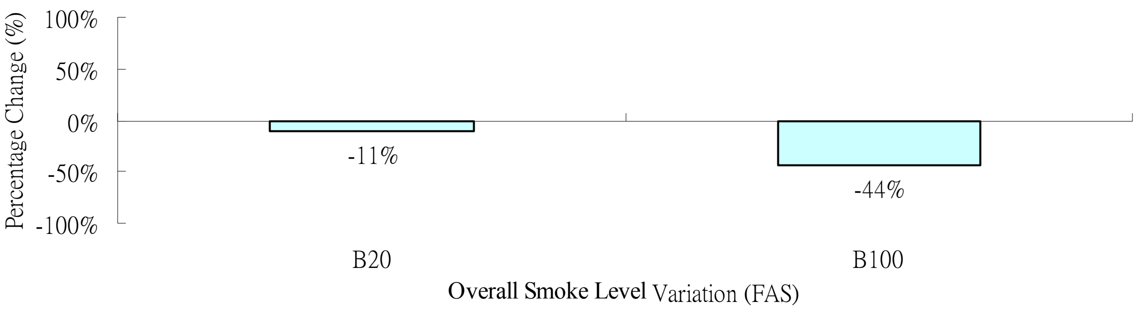
(a)



(b)



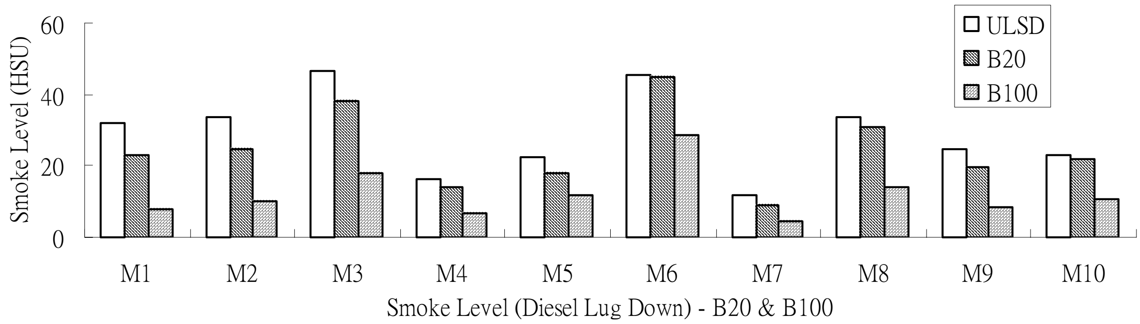
(c)



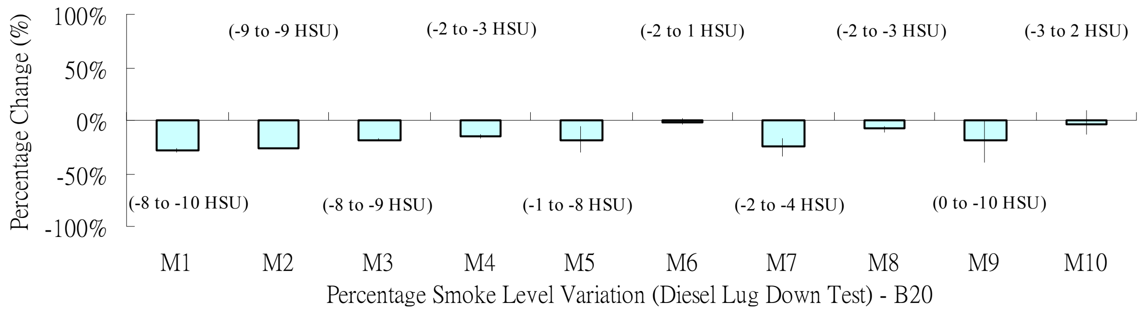
(d)

Figure 8.2(i). FAS smoke opacity and its percentage variation of all vehicles

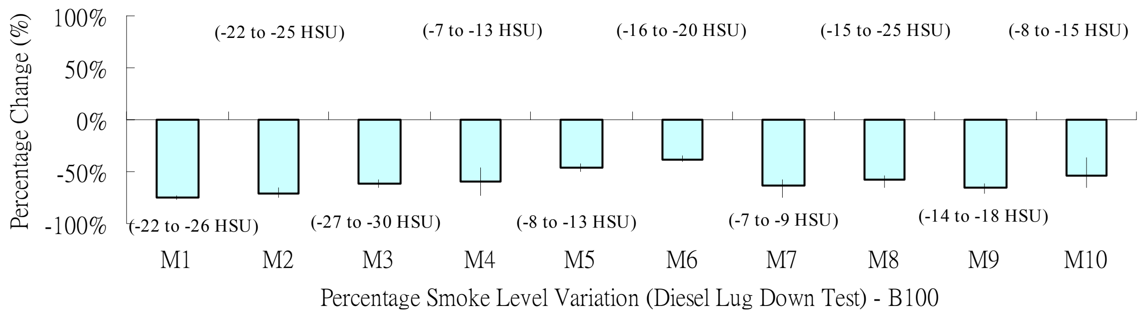
Note: The numbers inside the brackets represent the range of variation in actual engineering unit for individual vehicle



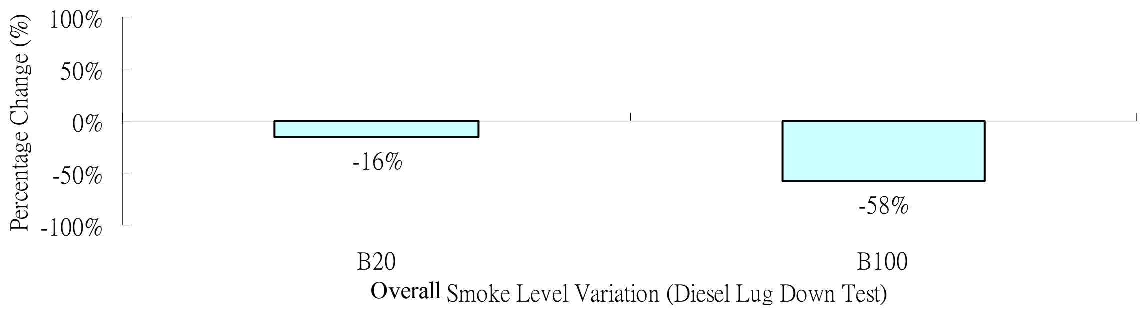
(a)



(b)



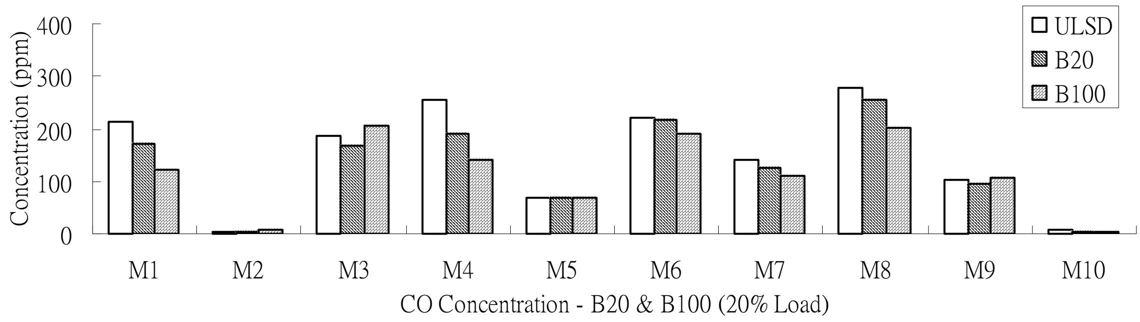
(c)



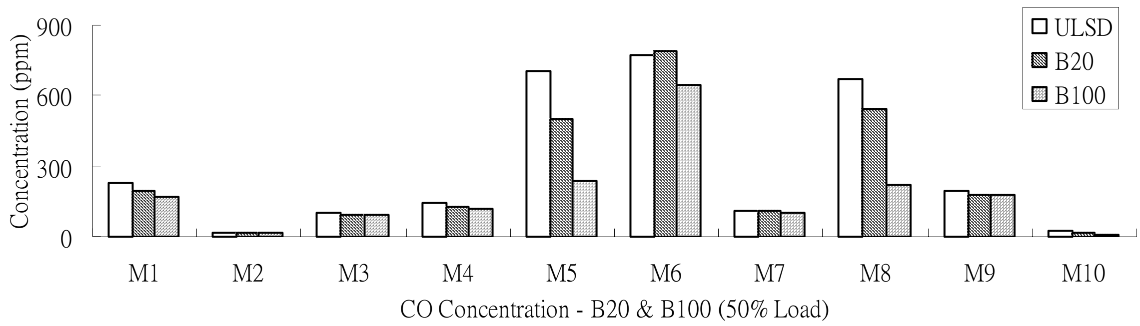
(d)

Figure 8.2(ii). Diesel lug down smoke opacity and its percentage variation of all vehicles

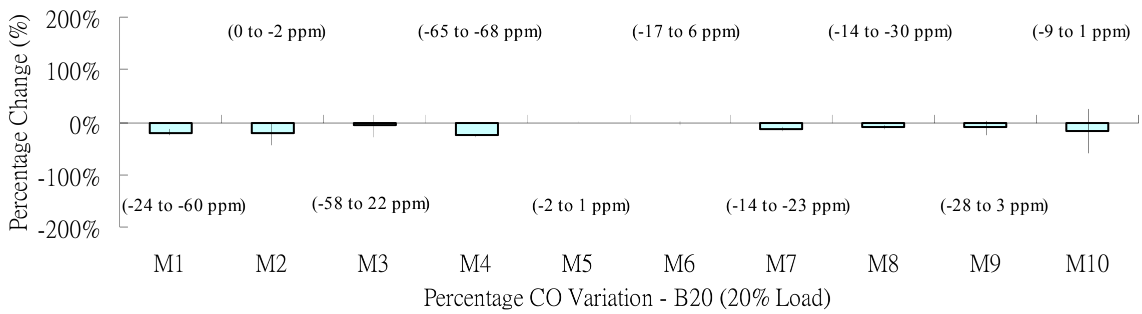
Note: The numbers inside the brackets represent the range of variation in actual engineering unit for individual vehicle


Concentration (ppm)
400
300
200
100
0
ULSD
B20
B100
M1 M2 M3 M4 M5 M6 M7 M8 M9 M10
CO Concentration - B20 & B100 (20% Load)

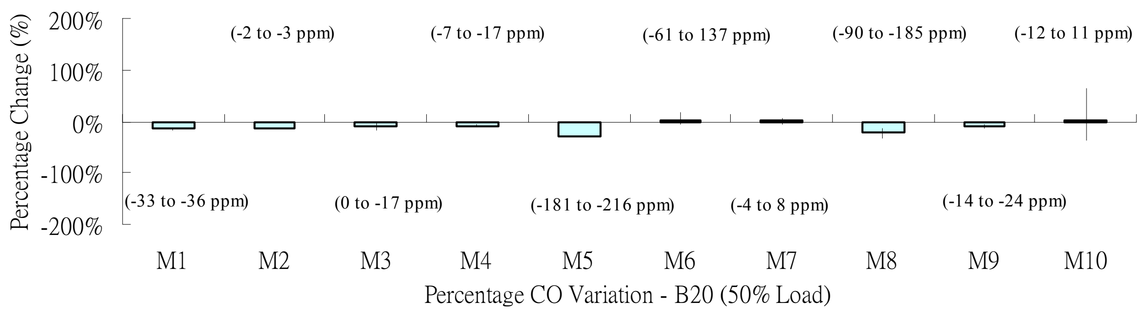
(a)


Concentration (ppm)
900
600
300
0
ULSD
B20
B100
M1 M2 M3 M4 M5 M6 M7 M8 M9 M10
CO Concentration - B20 & B100 (50% Load)

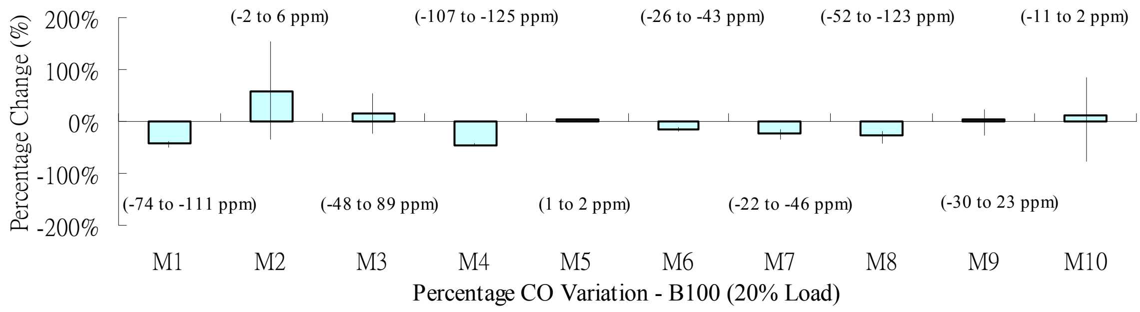
(b)


Percentage Change (%)
200%
100%
0%
-100%
-200%
(0 to -2 ppm)
(-65 to -68 ppm)
(-17 to 6 ppm)
(-14 to -30 ppm)
(-9 to 1 ppm)
(-24 to -60 ppm)
(-58 to 22 ppm)
(-2 to 1 ppm)
(-14 to -23 ppm)
(-28 to 3 ppm)
M1 M2 M3 M4 M5 M6 M7 M8 M9 M10
Percentage CO Variation - B20 (20% Load)

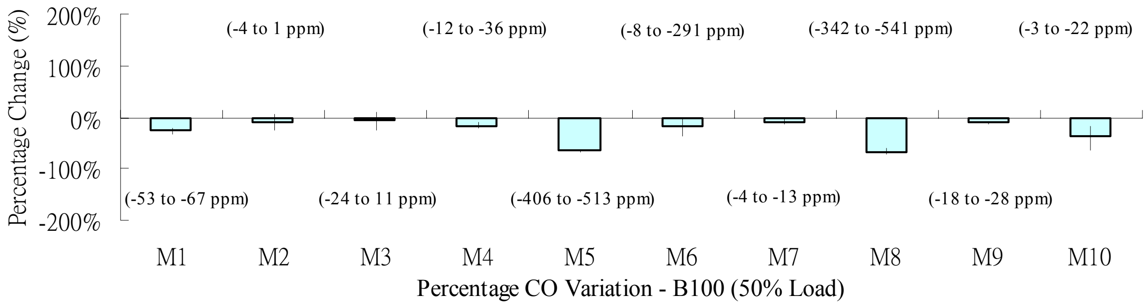
(c)


Percentage Change (%)
200%
100%
0%
-100%
-200%
(-2 to -3 ppm)
(-7 to -17 ppm)
(-61 to 137 ppm)
(-90 to -185 ppm)
(-12 to 11 ppm)
(-33 to -36 ppm)
(0 to -17 ppm)
(-181 to -216 ppm)
(-4 to 8 ppm)
(-14 to -24 ppm)
M1 M2 M3 M4 M5 M6 M7 M8 M9 M10
Percentage CO Variation - B20 (50% Load)

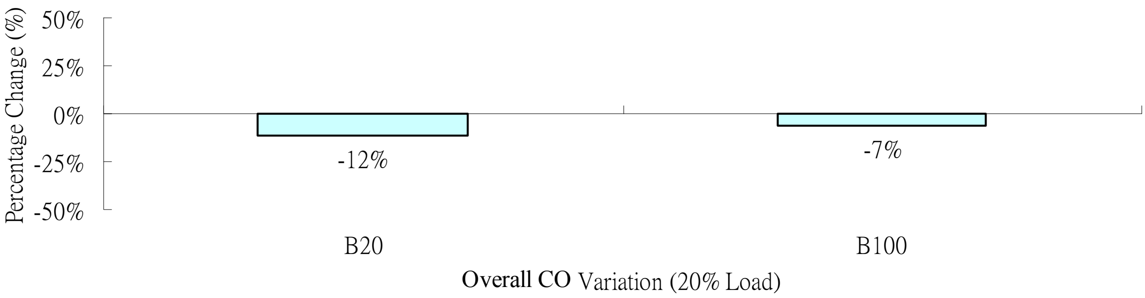
(d)



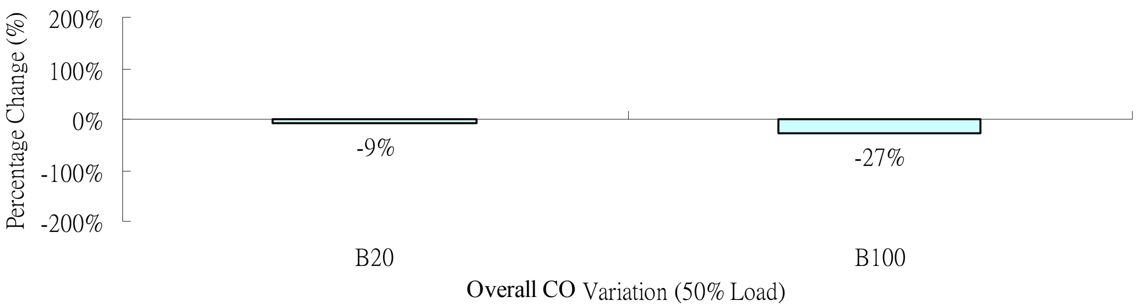
(e)



(f)



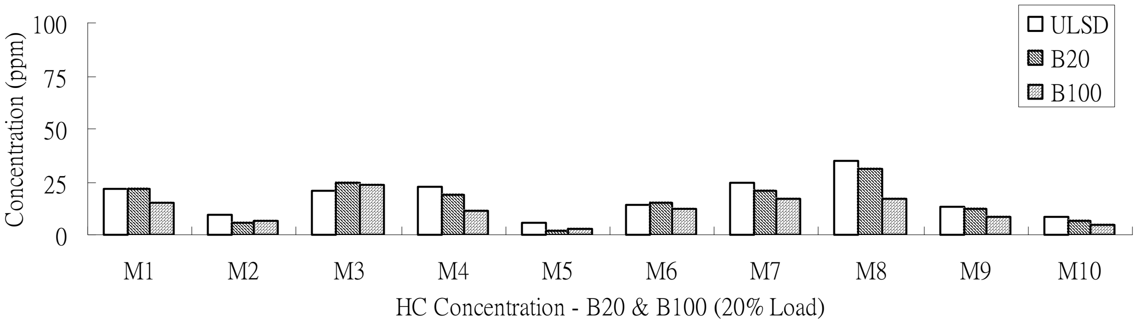
(g)



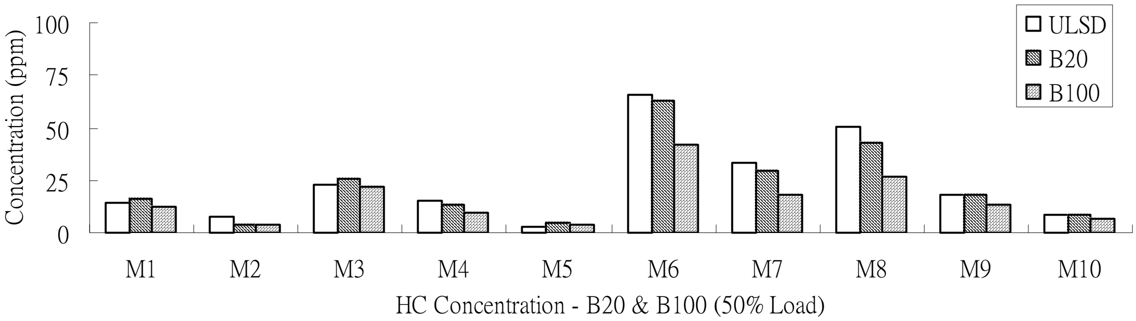
(h)

Figure 8.3. CO concentration and its average percentage variation of all vehicles

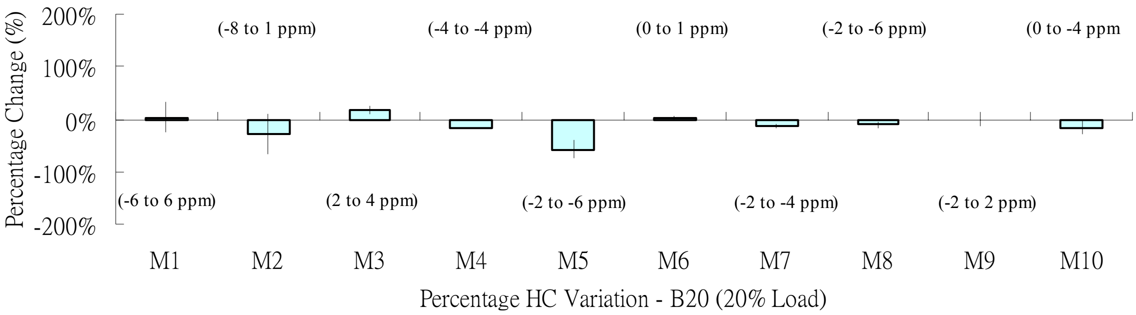
Note: The numbers inside the brackets represent the range of variation in actual engineering unit for individual vehicle


Concentration (ppm)
100
75
50
25
0
ULSD
B20
B100
M1
M2
M3
M4
M5
M6
M7
M8
M9
M10
HC Concentration - B20 & B100 (20% Load)

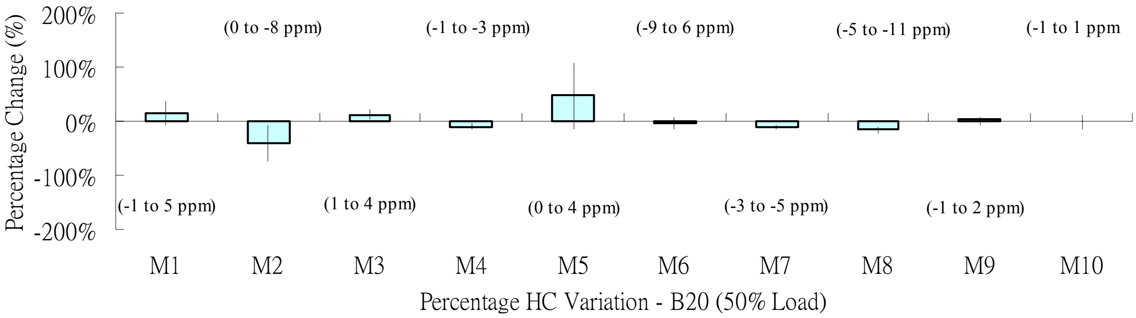
(a)


Concentration (ppm)
100
75
50
25
0
ULSD
B20
B100
M1
M2
M3
M4
M5
M6
M7
M8
M9
M10
HC Concentration - B20 & B100 (50% Load)

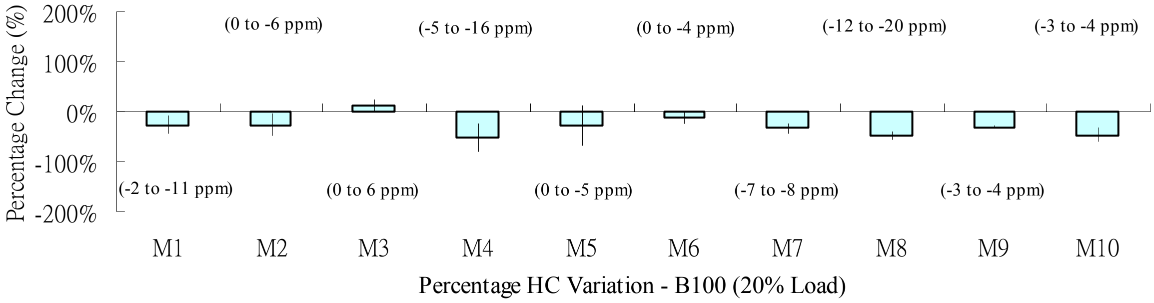
(b)


Percentage Change (%)
200%
100%
0%
-100%
-200%
(-8 to 1 ppm)
(-4 to -4 ppm)
(0 to 1 ppm)
(-2 to -6 ppm)
(0 to -4 ppm
(-6 to 6 ppm)
(2 to 4 ppm)
(-2 to -6 ppm)
(-2 to -4 ppm)
(-2 to 2 ppm)
M1
M2
M3
M4
M5
M6
M7
M8
M9
M10
Percentage HC Variation - B20 (20% Load)

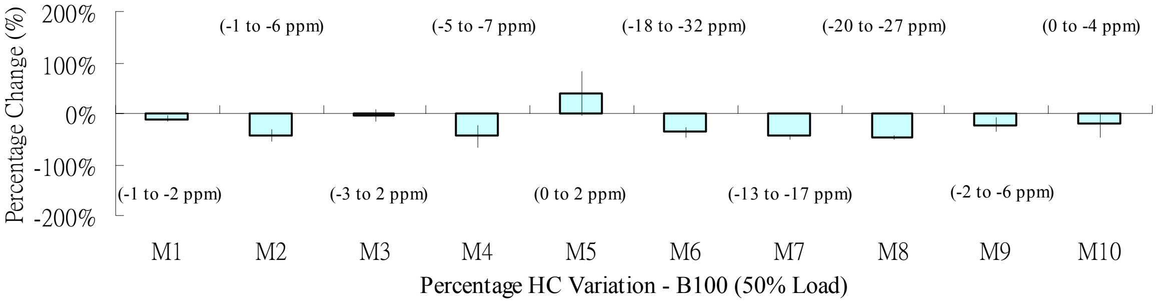
(c)


Percentage Change (%)
200%
100%
0%
-100%
-200%
(0 to -8 ppm)
(-1 to -3 ppm)
(-9 to 6 ppm)
(-5 to -11 ppm)
(-1 to 1 ppm
(-1 to 5 ppm)
(1 to 4 ppm)
(0 to 4 ppm)
(-3 to -5 ppm)
(-1 to 2 ppm)
M1
M2
M3
M4
M5
M6
M7
M8
M9
M10
Percentage HC Variation - B20 (50% Load)

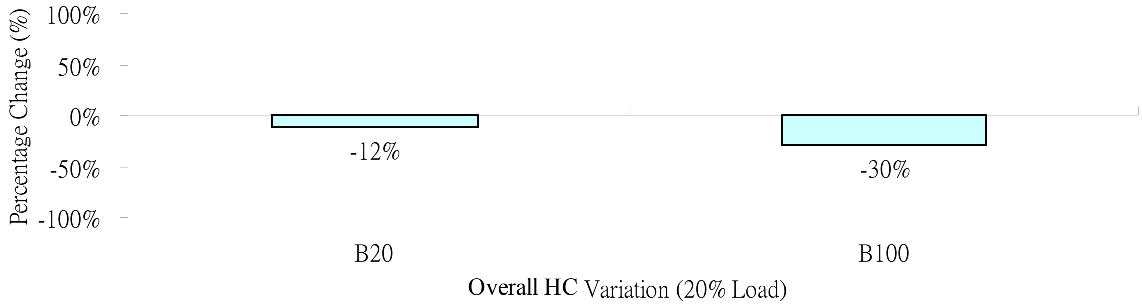
(d)



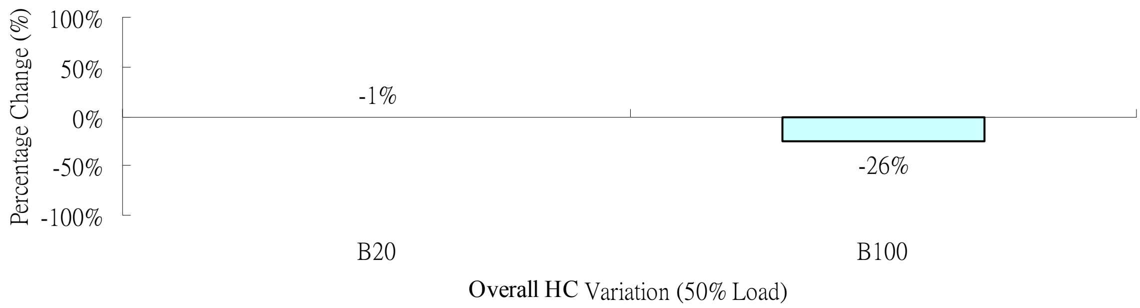
(e)



(f)



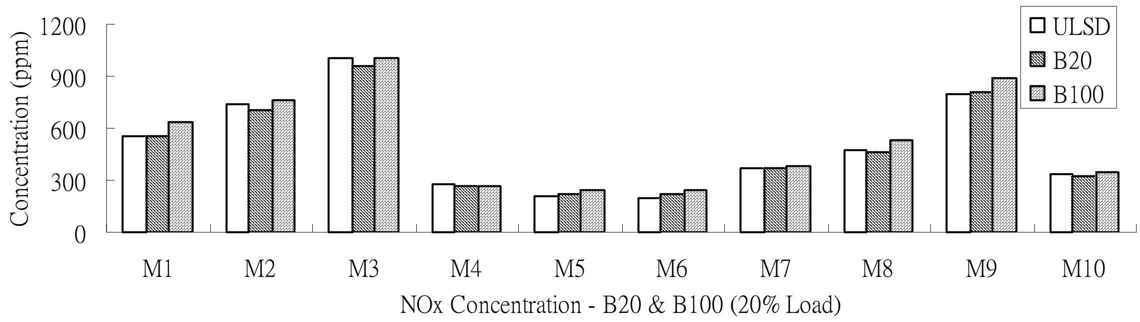
(g)



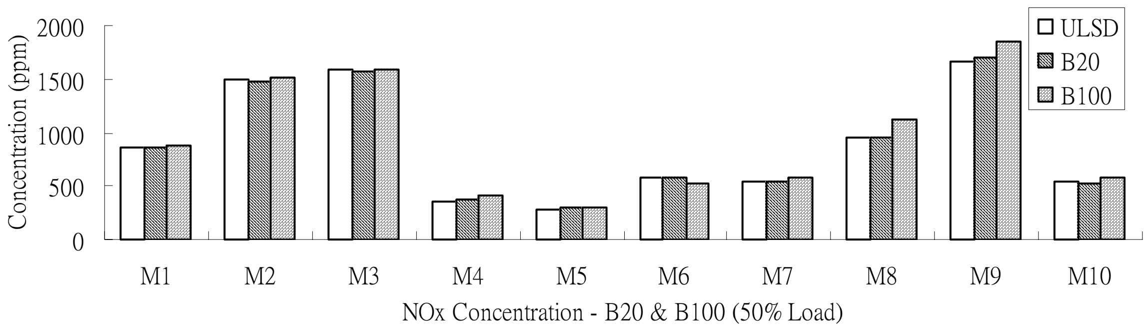
(h)

Figure 8.4. HC concentration and its average percentage variation of all vehicles

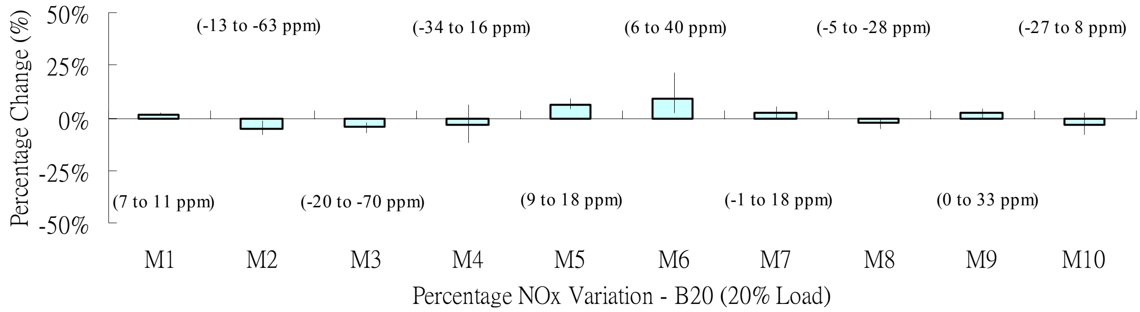
Note: The numbers inside the brackets represent the range of variation in actual engineering unit for individual vehicle


Concentration (ppm)
1200
900
600
300
0
ULSD
B20
B100
M1
M2
M3
M4
M5
M6
M7
M8
M9
M10
NOx Concentration - B20 & B100 (20% Load)

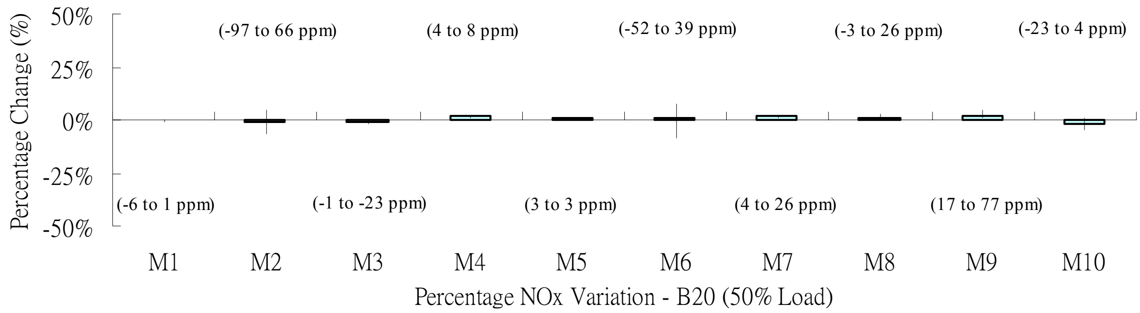
(a)


Concentration (ppm)
2000
1500
1000
500
0
ULSD
B20
B100
M1
M2
M3
M4
M5
M6
M7
M8
M9
M10
NOx Concentration - B20 & B100 (50% Load)

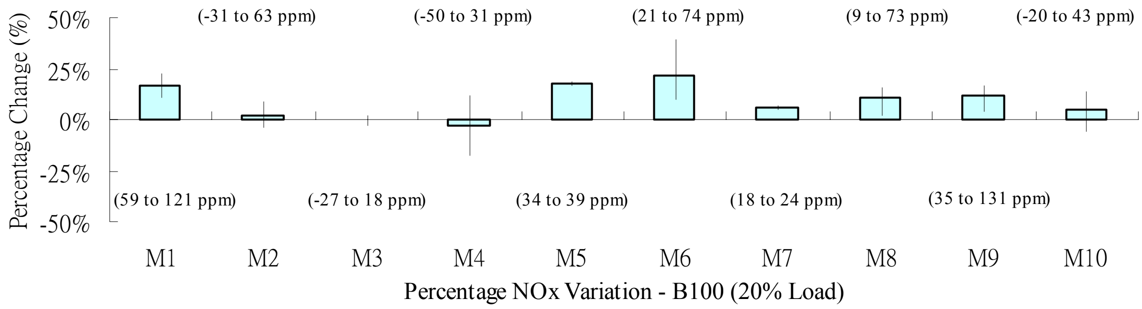
(b)


Percentage Change (%)
50%
25%
0%
-25%
-50%
(7 to 11 ppm)
(-13 to -63 ppm)
(-20 to -70 ppm)
(-34 to 16 ppm)
(9 to 18 ppm)
(6 to 40 ppm)
(-1 to 18 ppm)
(-5 to -28 ppm)
(0 to 33 ppm)
(-27 to 8 ppm)
M1
M2
M3
M4
M5
M6
M7
M8
M9
M10
Percentage NOx Variation - B20 (20% Load)

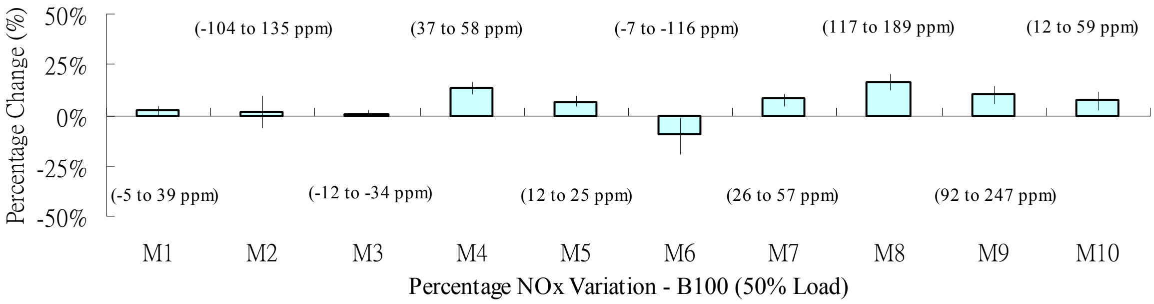
(c)


Percentage Change (%)
50%
25%
0%
-25%
-50%
(-6 to 1 ppm)
(-97 to 66 ppm)
(-1 to -23 ppm)
(4 to 8 ppm)
(3 to 3 ppm)
(-52 to 39 ppm)
(4 to 26 ppm)
(-3 to 26 ppm)
(17 to 77 ppm)
(-23 to 4 ppm)
M1
M2
M3
M4
M5
M6
M7
M8
M9
M10
Percentage NOx Variation - B20 (50% Load)

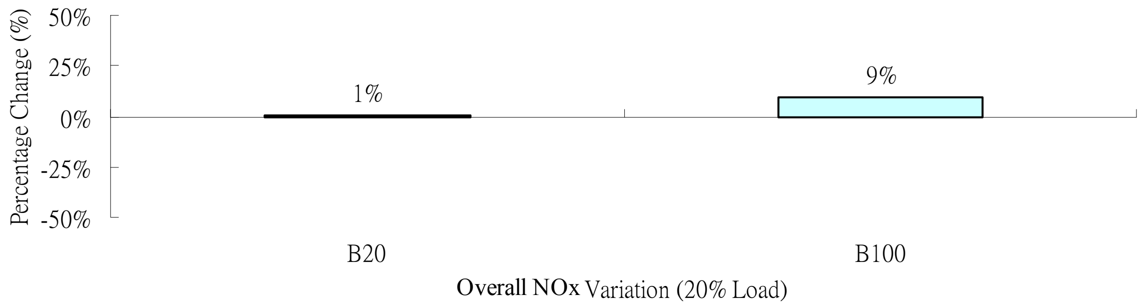
(d)



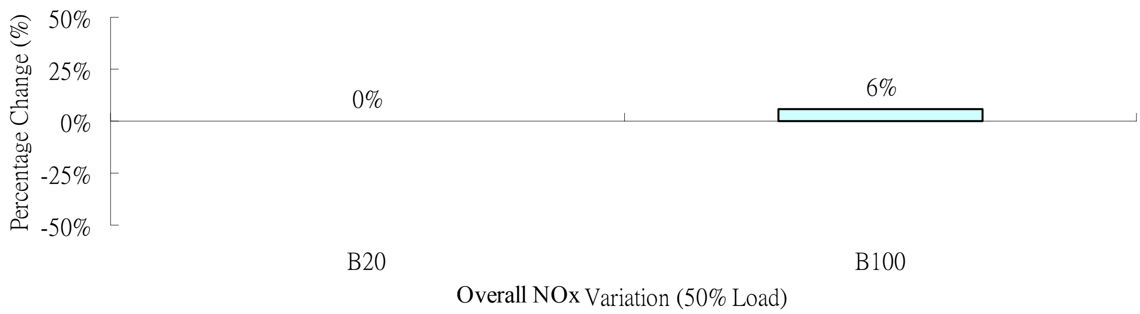
(e)



(f)



(g)



(h)

Figure 8.5. NOx concentration and its average percentage variation of all vehicles

Note: The numbers inside the brackets represent the range of variation in actual engineering unit for individual vehicle

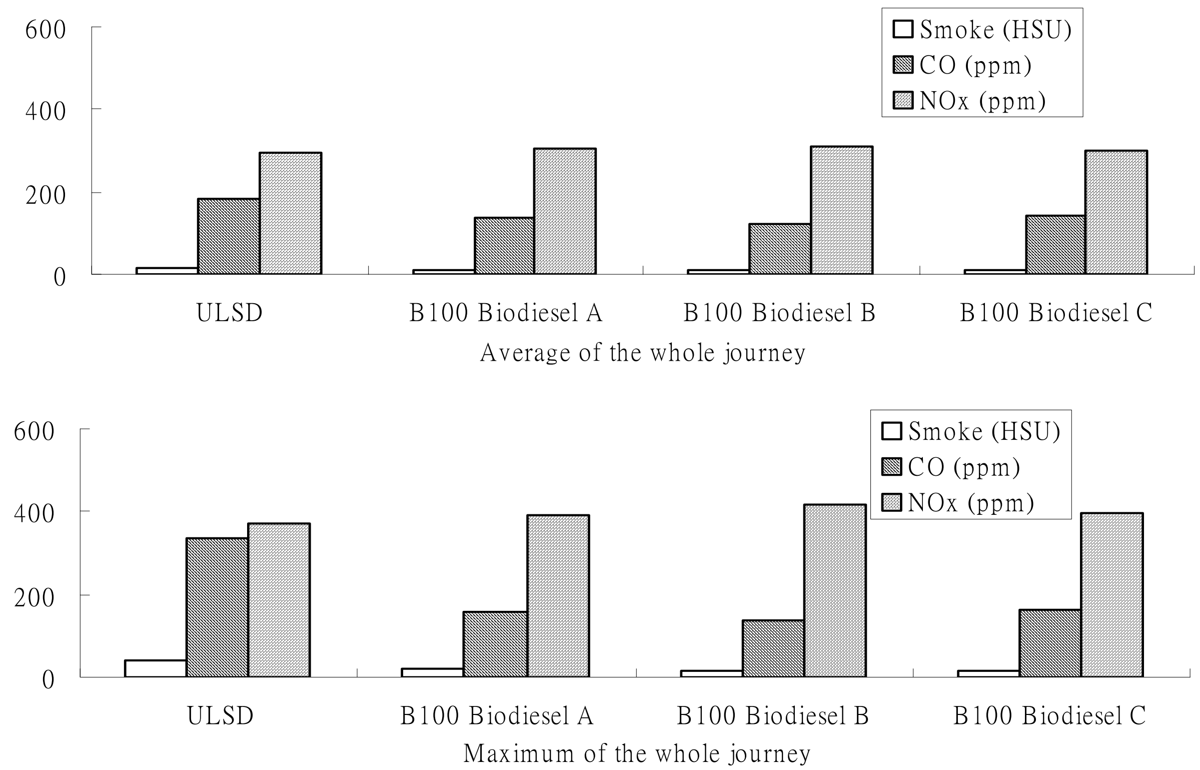
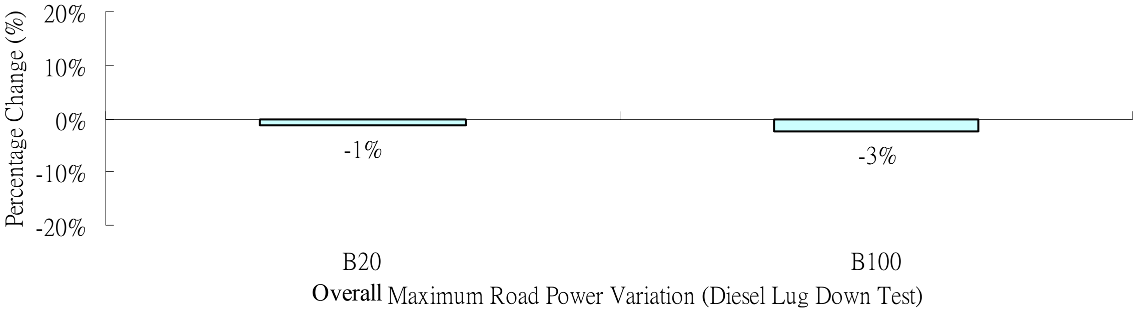
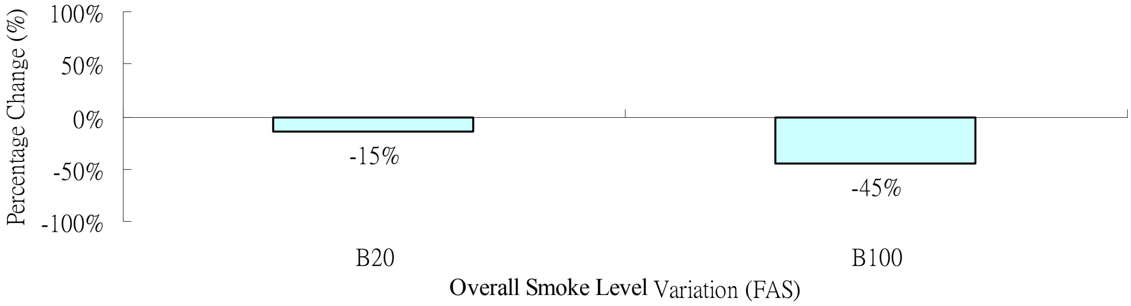


Figure 9.1. Average and maximum smoke level and air pollutant concentration for On-road emission test at Cotton Tree Drive – Neat biodiesel Vs ULSD

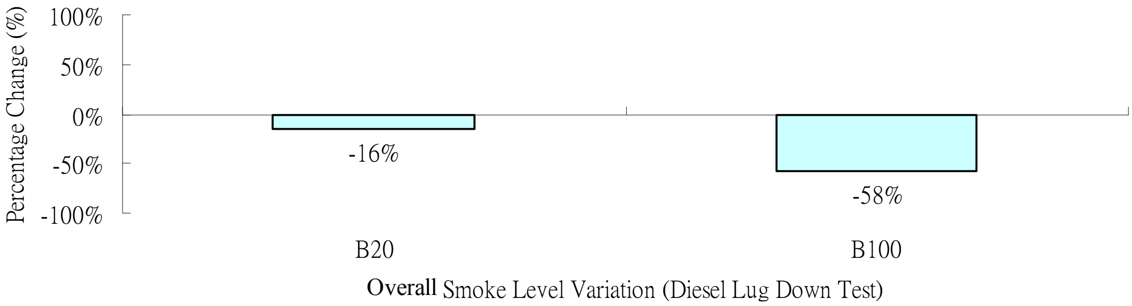
Figure 9.2. Percentage variation of smoke level and air pollutant concentration for On-road emission test at Cotton Tree Drive – Neat biodiesel Vs ULSD


Percentage Change (%)
20%
10%
0%
-10%
-20%
-1%
-3%
B20
B100
Overall Maximum Road Power Variation (Diesel Lug Down Test)

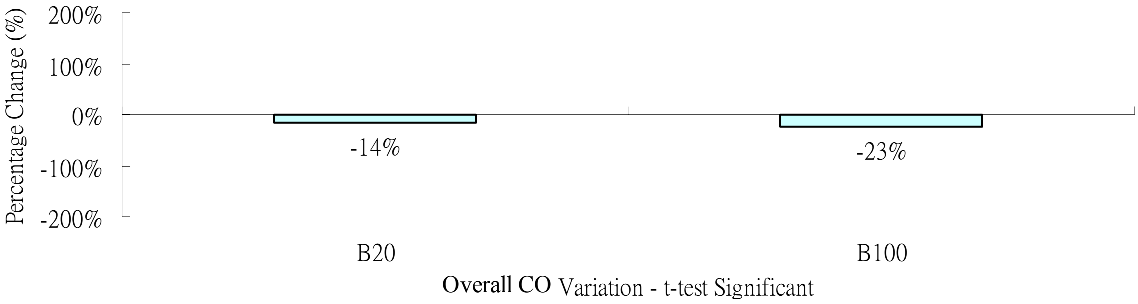
(a)


Percentage Change (%)
100%
50%
0%
-50%
-100%
-15%
-45%
B20
B100
Overall Smoke Level Variation (FAS)

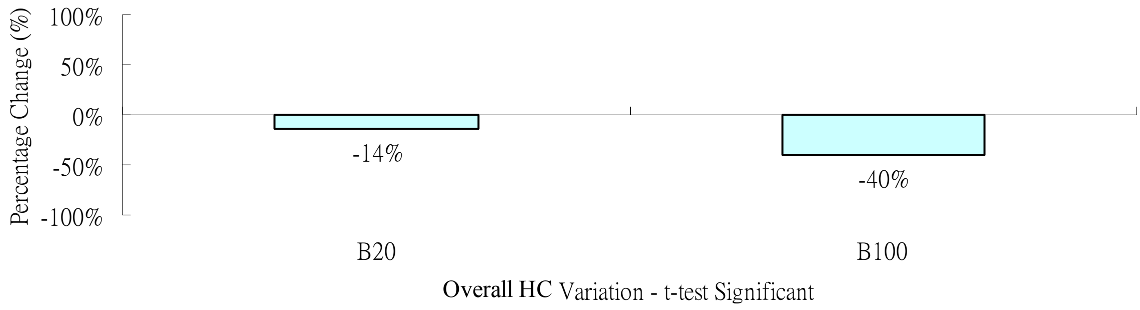
(b)


Percentage Change (%)
100%
50%
0%
-50%
-100%
-16%
-58%
B20
B100
Overall Smoke Level Variation (Diesel Lug Down Test)

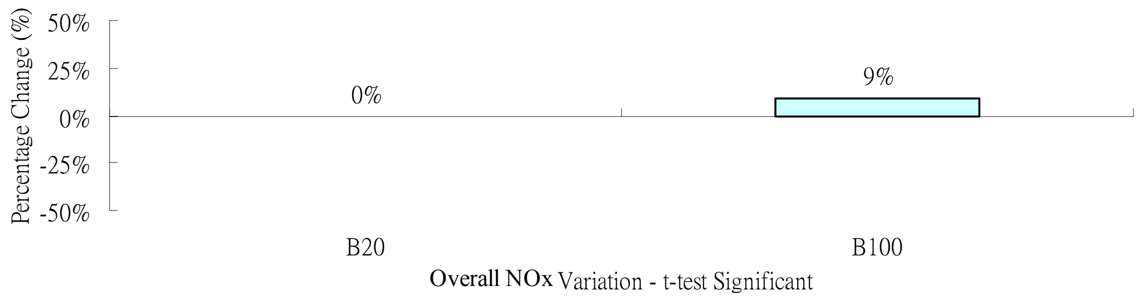
(c)


Percentage Change (%)
200%
100%
0%
-100%
-200%
-14%
-23%
B20
B100
Overall CO Variation - t-test Significant

(d)



(e)



(f)

Figure 11.1. Percentage variation of maximum road power and air pollutant concentration (significant) for all vehicles