Road Testings and Evaluations for Waste Collection Vehicles Fueled with Biodiesel

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Abstract Biodiesel as a renewable energy has received considerable attention in recent years. It is reported to be used in its neat form or blended with petroleum-based diesel, and almost without any engine modification. Given the chance of increasing use in biodiesel, however, it is required to quantify its potential emission benefits and effect on power response, especially for those public-serviced diesel vehicles in daily operations. An on-road test for waste collection vehicles using various blending percentage of biodiesel and petroleum-based diesel was evaluated, especially for the particulate matter (PM₁₀) emissions and the dynamometric power responses. Three waste collection vehicles were recruited and operated in their routine routes. The results indicated that the higher the biodiesel blending ratio, the more the power losses, up to 14 % for B100 biodiesel. Heating value of the biodiesel blending is likely to be responsible for this drop of power. Near 68% PM₁₀ reduction is attained for B100 in comparison with the petroleum-based diesel (B0) during testing periods. Both of the reductions in PM₁₀ and power response differed from maker of diesel engine. Based on the testing results, though the biodiesel may abbreviate the environmental loading in PM₁₀ emissions, it is suggested that an engine tune-up and adjustment for fuel supply system be arranged prior to use of biodiesel. Additionally, to make biodiesel a viable alternative fuel for the waste collection vehicles, a long-term assessment together with weather effect is suggested to secure both operational stability and safety on-road.

Keywords Biodiesel, Renewable Energy, PM₁₀, Power Response

1. Introduction

Biodiesel as a renewable energy has received considerable attention in recent years. Due to the decreasing petro-energy availability and increasing environmental concerns, many researchers have suggested that biodiesel holds promising as

a green fuel for diesel engines [1-5]. Biodiesel has several important advantages rendering it an attractive energy supply. First, biodiesel can be produced technically non-specific from either plant oils or animal fats. This advantage also makes the recycling a credit to the waste edible and non-edible oils. Second, biodiesel can be easily miscible in diesel fuel and stays blended. It can be applied in its neat form or petroleum-based biodiesel-blendings to the diesel engines with little or nothing modification. Third, biodiesel can be produced domestically, thereby possibly reducing a country's reliance on crude oil imports.

As biodiesel introduced to the fuel world, standardization of fuel quality was the first consideration [6-7]. Chemically speaking, biodiesel is referred to lower methyl esters of long chain fatty acids, synthesized by transesterification with lower alcohols or by esterification of fatty acids. Partially due to its diversity in feedstocks of the production and scales of plant, however, biodiesel in nature has a wide spectrum in its fuel quality [8-9]. The parameters that define the quality of biodiesel can be divided into two groups. One is the physical group including density, viscosity, flash point, and cold filter plugging point. This group highly influences the fuel supply system, so as to the engines stability and drivability. The other one is the chemical group including the ester content, cetane number, Conradson carbon residue, and total glycerol. This group describes the chemical composition and purity of biodiesel that would affect the combustion efficiencies of diesel engines. These two parameter groups combined together are capable of manipulating the engine performance and exhaust emissions when using biodiesel [10-11].

In recent years Taiwan has increased interest in the development of biodiesel as an alternative fuel [12-13]. Taiwan has limited natural resources for fossil energy supply, and is about 99% dependent on imports. To provide energy independence and improve pollution emissions, the Taiwan's National Council for Sustainable Development (NCSDD) has initiated a Pioneer Program for Biodiesel (PPB) since 2004 [14]. According to the PPB, biodiesel has been firstly promoted and subsidized to those public-owned service vehicles using diesel fuel. Though the target is to

create a biodiesel market nationwide, the humid weather condition in Taiwan has regularly led the microbes to grow and to clog the fuel tanks, resulting in the safety issue and performance reliability. Additionally, many uncertainties still exist regarding the application barrier of biodiesel so far [15-17]. For instance, the operational data are not readily available from the vehicles manufacturers. Moreover, some reported results from the literature are often restricted to the specific analysis of vehicles. In fact, there is limited information available related to the effects of biodiesel and biodiesel blends, especially on the extended engine durability, performance stability, and maintenance cost. Therefore, the local governments in Taiwan have been considered to perform an on-road test for their waste collection vehicles using various blending percentage of biodiesel and petroleum-based diesel.

The Environmental Protection Bureau, Hsin Chu City, Taiwan (EPBHCC) governs a waste collection fleet with more than 200 diesel-engine vehicles. Though all diesel-powered, the daily wastes collection vehicles differ in manufacturers, diesel-engine types, and fuel system. It is optimistic that the usage of biodiesel for these vehicles is of great significance in the promotion of above-mentioned PPB. Nevertheless, collecting the pros and cons of biodiesel before applying to the vehicles is a requirement to prevent from instability of waste collection duty, as well as the loading of air pollution emission. Therefore, the purpose of this study is to evaluate the power response and particulate matter (PM₁₀) emissions from the diesel vehicle using blendings of biodiesel/diesel fuel. The recruited waste collection vehicles worked in their routine schedules and routes, using numerous ratios of biodiesel-diesel blendings. In this arrangement the results of the testings may quantitatively describe the on-road data, with respect to the operational stability and reliability for the waste collection

vehicles. The test results would serve as a base for future justification using biodiesel for the public-served diesel vehicles in Taiwan.

2. Materials and Methods

2.1. Biodiesel Description

A 100% Biodiesel (B100) was purchased from a supplier of the New Japan Chemical Company, ChiaYi County, Taiwan. They used recycled waste cooking oil as feedstock to their biodiesel plant, using the process of alkali-catalyzed trans-esterification reaction. The fuel properties of biodiesel and regular diesel are given in Table 1. Heating values of the biodiesel/diesel blends were determined according to the procedure of ASTM D2015. The biodiesel/diesel blendings were measured on a volume basis. A pre-cleaned, empty 30 liter steel container was placed on a concrete surface to be served as a blender. Biodiesel was added to obtain the required volume, and then mixed with the regular diesel to achieve the blending ratio and total volume required. The biodiesel/diesel blending ratios were repeatedly filled to the gas tank directly from the container as needed.

2.2. Vehicle Recruitment

Three waste collection vehicles with representative model of the fleet were recruited for vehicle testing: one of the Isuzu and two of the International Harvest, as shown in Table 2. These vehicles were all rear-loading packer trucks and were operated on a similar schedule and duty. Each vehicle was inspected before testing to establish and to tune-up to its general condition so as to ensure it was safe before being accepted for testing. The testing vehicles and their characteristics are listed in Table 2.

Table 1. Physical and chemical properties of diesel and biodiesel

Characteristics	Unit	Diesel	Biodiesel
Viscosity @ 40°C	cSt	3.66	4.283
Carbonaceous Residue	wt %	0.012	0.048
Specific Gravity	-	0.834	0.880
Lower Heat Value	cal/g	10937	9487
Cetane Number	-	54.19	48.4
Sulfur Concentration	ppmv	27.2	1.7
Flash Point	°C	77.1	168
Pour Point	°C	-3	6
pH	-	5.63	7.41

Table 2. General descriptions of waste collection vehicles for testing

Vehicle No.	Make	Model Year	Model	GVW (Tonnes)	Engine Size (c.c.)	Fuel, Air System
No. 1	ISUZU	2004	GT125-536	12.0	7790	Direct Injection
No. 2	International	2003	4300SBA 4X2	15.21	7639	Direct Injection
No. 3	International	2004	4300SBA 4X2	15.21	7639	Direct Injection

2.3. Vehicle Dynamometric Testing

The vehicle chassis dynamometric testing was performed using the procedure of Taiwan's National Standard (CNS Code 9845). The testings were done in the EPBHCC Testing Station equipped with Mustang Dynamometer MD1000 (Ohio, USA). Five blending ratios of biodiesel/diesel (B0, B1, B20, B50, B100) were used for testing of power response. The vehicles were coupled with the chassis dynamometer using steel linker and pulley to apply different engine loads. All testing vehicles were warmed-up at low idle to the required working temperature, by increasing engine speed to a designated rate and loading. After engine reaching the stabilized working condition, the intake and exhaust restriction were corrected using rated engine speed and full power. Then the engines were run at the speed at 100%, 60% and 40%, respectively, of full loadings for at least 10 minutes. Then the power responses output data were recorded at the last 2.5 minutes of operation at each rated speed. The power responses were recorded on-line, real-time at 5 seconds intervals in 3 minutes using AVL407 WINSMEX computer interface program.

2.4. PM₁₀ Sampling and Analysis

The sampling procedure was designed to provide a total mass emission rate of particulate matter (PM₁₀). Sampling procedure was employed to collect the PM₁₀ emitted from the exhaust pipe of the testing vehicles [18]. The sampling train is depicted in Figure 1. A steel box was screw-installed on the side frame near the exhaust pipe, housing the sampling pump (SKC Model 224-44XR) and particulate impactor cassette (SKC Model 761-200). A front-seal device with *o*-ring was well capped and fitted to the cassette so that the exhaust will be sucked out from the sampling pump. All samples were collected at a flow rate of 2.0 liters per minutes (lpm). All flow rates were pre-adjusted using a DryCal® Primary FlowMeter (Cat. No.717-03). All 37-mm Teflon membrane filters laminated with PTFE support (Cat. No. 225-1729) were weighted before and after sampling to determine the collected mass using ultra-microbalance (Meter Toledo, Model AX26DR). A high-precision sensitive microbalance is located in an environmental weighing room maintained at a temperature of $24 \pm 0.5^\circ\text{C}$, and a relative humidity of $40 \pm 5\%$. Filter samples were stored in petri dishes, and were preconditioned for 24 hours inside a humidity-controlling box before and after samplings.

3. Results and Discussion

3.1. Power Response

The emphasis of this research is placed on the evaluation of power response and PM₁₀ emission for wastes collection vehicles using biodiesel/diesel blends. Accordingly, a series of biodiesel/diesel blends including B0, B1, B20, B50, B100, have been employed for evaluation. The power response at standard operational loading is evaluated using the diesel chassis dynamometer. The results show that increase of biodiesel percentage in the diesel blend has led to a decrease of power response of the vehicles. The effect of biodiesel blendings on power response at full load is shown in Figure 2.

As can be observed from this Figure 2, the higher the blending percentage, the more the power of vehicle decreases. The trend of decrease is similar to testing vehicles at B1, with increase biodiesel ratio in the diesel blending increases the loss of power. In particular, with B100 there is a power loss up to 14% for the vehicle No. 1. It is noted that, as shown in Figure 2, the testing vehicles No. 2 and No. 3 have a similar loss of power in all biodiesel/diesel blends. This indicates that makers of diesel engines should be taken into consideration when biodiesel is to be used to the waste collection fleet.

Figure 1. Schematic diagram for the PM₁₀ sampling train

Figure 2. Effect of power response on biodiesel blendings.

Figure 3. Lower heating value for the biodiesel blendings.

Previous studies suggested that the reduction in power response may be related to the biodiesel fuel properties [19-20]. As shown in Table 1, the loss of power response can be attributed to the lower heating value of the biodiesel. Two possible explanations are taken into consideration. First, a higher specific gravity may cause a lesser fuel consumption than needed. Without any engine adjustment, the fuel injector can only pump the fuel equally on a volume basis, leading the engine to consume a lesser fuel than normally needed. In general, the stoichiometric air-to-fuel

ratio of an engine is set to a typical value. Therefore, as biodiesel pumping through the injectors decreases, the engine will compensate its air intake and operate as if it is at partial load. This may result in a less power response for vehicles using biodiesel.

Second, a lower heating value may have reduced the volume efficiency of vehicle cylinder. As shown in Figure 3, the heating value decreases with an increase of biodiesel blending ratio. Under normal condition, there is an optimal power response designated by the engine manufacturer that

may specify the heating value of the fuel for use. It is known that the lesser the heating value, the smaller the air intake for the cylinder, leading to a lower combustion temperature. Again without any engine modification, the vehicle cylinder is not working as efficient as it should be. This result is very similar to several previous studies in the literature [21-24]. For example, Cetinkaya *et al.* [21] conducted a road test study using biodiesel. Their experimental results showed a similar fashion that the power output was around 5% less than regular diesel. They also suggested that the lower specific heating value of biodiesel was responsible for this power difference.

3.2. PM₁₀ Emissions

Another aspect in development of biodiesel as an alternative fuel is being driven by the need to reduce the environmental impact on pollution emissions. In order to realize the emissions benefit using biodiesel, it is necessary

to arrange on-road testing for the recruited vehicles. Parameters of the on-road testing for both wastes collection vehicles are listed in the Table 3. These testing vehicles were working under schedule and routes without any difference from their regular timetables and workloads. The effect of biodiesel blendings on PM₁₀ emissions is shown in Figure 4. From Figure 4, the reduction profile of PM₁₀ is clearly systematic and relevant to the percentage of biodiesel added to the diesel fuel. As the ratio of biodiesel blending increases, all testing vehicles showed a high PM₁₀ reduction rate at B100, up to 68% for vehicle No. 1. It is noted that, results of PM₁₀ reduction from vehicle No. 2 and vehicle No. 3 differed to a certain degree, though they were made by the same engine manufacturer. This difference might be related to the collection distances and stops number during each service route, leading to variability in fuel consumption. However, a further research is required to make confirmation if any other factors may exist.

Table 3. Road test parameters for waste collection vehicles

Parameter	Vehicle		
	No. 1	No. 2	No. 3
Testing Trips	5	5	5
Average Road Test Distance (Km) per Trip	68	38	28
Average Road Test Period (minutes) per Trip	195	160	206
Waste Collection Stops per Trip	33	29	25

Figure 4. Effect of PM₁₀ emission on biodiesel blendings

The results presented in Figure 4 are very similar to several previous studies in the literature [21-24]. Those studies suggested that the reduction of PM_{10} is related to the sulfur level and oxygen content in the fuel. For example, sulfur can be first oxidized to sulfate after combustion, then absorbed on soot particle that may increase the PM_{10} emission from diesel engine. As seen from Table 1, biodiesel contains a negligible amount of sulfur. This may partially explain the results of low PM_{10} emission in this study. Another beneficial to biodiesel is that it is an oxygenated fuel made from waste cooking oil. The oxygen content in the fuel may contribute to a complete fuel oxidation, which leads to a significant decrease of PM_{10} emissions. However, comparing these results in conjunction with the power response for each biodiesel blending, balancing both of the energetic and environmental benefits should be taken into account, so as to make biodiesel a viable fuel for waste collection vehicles.

4. Conclusions

This study evaluated the particulate matter (PM_{10}) emissions and the dynamometric power responses using various blending ratios of biodiesel and petroleum-based diesel. Three waste collection vehicles installed with sampling device were recruited for road testing. Testing results indicated that diesel vehicle fueling with biodiesel blending is capable of reducing PM_{10} . Though this is a benefit to the environment, however a trade-off of power response is observed with engine using biodiesel. Based on the testing results, though the biodiesel may reduce the environmental loading in PM_{10} emissions, it is suggested that a suitable diesel engine tune-up and adjustment for fuel supply system be arranged prior to biodiesel use. Additionally, to increase the accountability in biodiesel, a long-term assessment together with weather effect is a must to secure both operational stability and safety issues to waste collection vehicles.

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