Chapter 6

Importance of Quality Control and Market Acceptance

Benchmarking of Biodiesel Fuel Standardization in East Asia Working Group

July 2010

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6. IMPORTANCE OF QUALITY CONTROL AND MARKET ACCEPTANCE

6.1 Fuel Quality Control

6.1.1 The fuel quality control method in Europe

In case of European diesel fuel standard (EN590), 7% of the FAME conformed to the neat FAME standard (EN14214) can be blended in diesel fuel. Therefore, it is essential to guarantee the quality of neat FAME for end user acceptance.

In Germany and Austria, Arbeitsgemeinschaft Qualitätsmanagement Biodiesel e.V. (AGQM) was established in 1999. Twenty-three FAME producers, accounting for 90 % of FAME production in both countries, and eight trading companies join the AGQM. Filling stations, which sell neat FAME or FAME-blended diesel fuel, are the AGQM's member, whose logo is shown in Figure 46. The main objectives of the AGQM are as follows;

- Observance of legal and customized requirements of the fuel properties.
- Provision of a consistently high Biodiesel quality.
- Avoidance of technical problems caused by fuel.
- Creation of all user's trust in biodiesel

Figure 46 Logo of European biodiesel fuel quality control scheme AGQM

The AGQM is operated by the membership fee, with quality management of AGQM consisted of the following measures that are not only restricted to production, but also trading.

- Definition of additional requirements
- Independent quality checks by external service providers
- Guidelines for internal quality checks and documentation
- Technical support and counselling
- Round Robin tests

6.1.2 The fuel quality control method in North America

National Biodiesel Board (NBB) has an optional certification system named BQ-9000, whose logo is shown in Figure 47. The objective of BQ-9000 is

- To promote the commercial success and public acceptance of Biodiesel.
- To help assure that Biodiesel fuel is produced to and maintained at the industry standard, ASTM D6751.Definition of additional requirements

Any FAME producers and distributors conforming to BQ-9000 regulation can be certified by NBB. Thirty-six producers and twenty-two marketers of biodiesel has passed rigorous review and inspection of their quality control processes by an independent auditor, and thus are certified as announced on the NBB website [31]. BQ-9000 greatly helps reduce any chance of producing or distributing fuel of inferior quality.

Figure 47 Logo of American biodiesel fuel quality control scheme BQ-9000

6.1.3 The fuel quality control method in Japan

In Japan, the Ministry of Economy Trade and Industry (METI) is responsible for fuel quality in the consumer market, as shown in Figure 48. In accordance with the Japan fuel standards law, METI is obligated to:

- Monitor registration of gas stations, where all gas stations are required to register with METI
- Blenders of Biofuel (ethanol and/or FAME) with petroleum based fuels are required to register with METI.
- Develop fuel quality standards (both mandatory and voluntary)
- Require gas stations to report quality sampling test of gasoline every ten days, or annually if its supply chain is approved by METI
- Monitor fuel quality at the pump, which can be outsourced to four registered testing organizations

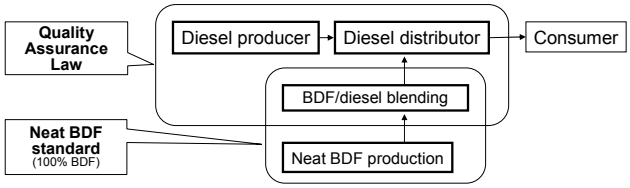


Figure 48 The fuel quality control scheme in Japan

Table 16 shows compulsory FAME blended diesel fuel standard in Japan. The regulated items of FAME blended diesel fuel are obliged to increase due to various concerns on FAME inherit fuel properties. In Japan, FAME conformed to the neat FAME standard (JIS K 2390) can be blended up to 5% in diesel fuel.

The traders, which are not only producers and importers but also distributors of FAME-blended diesel fuel, assume all responsibility by law. There are about 50,000 filling stations in Japan. METI gathers about 200,000 fuel samples/year to investigate their qualities. If METI finds any off-spec fuels, METI instructs fuel suppliers to follow fuel regulations. If they do not follow through, METI orders suspension of business up to 6 months and, in some case, fuel distributors will be charged with criminal penalties. If FAME-bended diesel fuel is made commercially available in Japan, the base fuel has to be modified so that it is fully compatible with the FAME components in the blend.

Table 16 Quality standard items for Gasoline and Diesel Fuel

Items	Level	
Lead	No detection	*
Sulfur	< 10 ppm	*
MTBE	< 7 vol%	*
Oxygen Content	< 1.3 wt%	*
Benzene	< 1 vol%	*
Kerosene	< 4 vol%	*
Methanol	No detection	*
Ethanol	< 3 vol%	*
Existent Gum	< 5 mg/100mL	*
Color	Orange	*
Octane	Regular > 89	
	Premium > 96	
Density	< 0.786 g/cm3	
Distillation Temp.	(specified)	
Copper Corrosion	< 1 max	
RVP	44 - 65 kPa (Summer)	
Oxidation Stability	> 240 min	

Items	Level	
Sulfur	< 10 ppm	*
Cetane Index	> 45	*
90% distillation temp.	< 360 deg.C	*
Flash Point	> 45 deg.C	
Pour Point	Depend on region and month	
CFPP		
10% Carbon Residue	< 0.1%	
Kinematic Viscosity	> 1.7 mm2/s	

Note: * = mandatory

6.2 Quality Control of Biodiesel-Blended Fuels at the Pump in Philippines

Standards are worthless without proper implementation and enforcement. Not all Philippine National Standards (PNS) are mandatory. Unless a regulation is issued by the appropriate government authority, the PNS is voluntary. Thus, PNS for fuels and related products, including biofuels, become mandatory only upon the issuance of a corresponding Circular issued by the Department of Energy (DOE).

The sale of petroleum products at the pump is covered by DOE Circular

DC2003-11-010 “The Rules and Regulations Governing the Business of Retailing Liquid Petroleum Products” or “Retail Rules”. Rule IV of these Circular deals with petroleum product standards, requiring compliance with the PNS. Prohibited acts include adulteration and illegal trading. Adulteration covers products not meeting the PNS. Penalties include fine per act of violation, without prejudice to criminal sanctions.

The DOE is empowered by law to stop operations of oil industry participants that do not conform to the PNS.

6.2.1 Methodology

(1) Inspection and Sampling

The Oil Industry Management Bureau (OIMB) of the DOE conducts inspection and checking of oil industry players’ compliance to DOE standards and regulations, including on fuel quality, at the various supply points, namely: refineries, import terminals, depots, and gasoline stations/retail outlets; and at times from transport vessels such as tankers, barges, tank trucks, lorries and even pipeline. Routine and spot inspections and product sampling are conducted, as well as complaint-related checks.

The OIMB inspectors, among others, take a sample of the various products at the retail outlet/petrol stations. They also check on the quantity delivered by the dispensing pumps, through a calibrating bucket, as well as the compliance of the station to the requirements under the Retail Rules.

Findings of the inspection are recorded in the numbered Inspection Report, which are signed by the inspectors. The dealer or his representative is asked to affix his/her signature on the report to certify that the statements therein are true and correct and filled up in their presence. The dealer gets a copy of the Inspection Report.

The Inspection Report sheet also includes a box wherein the dealer, by authority of the OIMB Director, is directed to institute corrective measures in conformity with the standards prescribed by law, rules and regulations governing the liquid fuels industry, and to cease and desist from selling to the public products which do not meet the prescribed PNS, and products delivered by dispensing pumps that is less than the actual quantity by more than 50 millilitres for every 10 litters. The dealer is further ordered to submit proof of compliance with the above directives and to show cause in writing under oath within 10 days from receipt thereof why no administrative and/or criminal action should be instituted against the him/her for the observed violations. This box effectively shortens the prosecution time by at least one month.

Sample Retention. Regulations require the oil companies and dealers to retain samples which may be needed for referee tests. Recommended samples for retention

include those from their product receipts and from the inspection sample of DOE.

(2) Laboratory Testing and Analysis

The standard procedure is for the inspectors to gather samples and send them to the National Petroleum Testing Laboratory (NPTL) under the DOE Energy Research and Testing Laboratory Service (ERTLS) for testing. Upon completion of testing and analysis, the ERTLS then forwards the result to the OIMB.

(3) Evaluation of Inspection, Testing and Analysis

The OIMB evaluates the result from the laboratory and the ocular inspection vis-a-vis the DOE rules and prepares a report of the inspection.

(4) Prosecution

Cases of violation are forwarded to the Legal Service for due process. The Legal Service issues orders/resolutions to entities found with violations, i.e., the dealer of the off-spec or substandard product, indicating therein the violations and the corresponding penalties. Violators can file a motion for reconsideration.

(5) Feedback

Regardless of the result of the evaluation, the oil company represented by the dealer (entity owning the brand) is formally advised of the results of the inspection. If no violation is observed, the letter may be considered as a Clean Bill of Health. If there is a violation, the company is required to make the necessary corrective actions and inform the DOE-OIMB accordingly. The formal advice makes the company aware of what is going on at the retail outlets, most of which are operated by dealers who are separate entities. With the new Retail Trade Law, though, gasoline stations can now be managed and/or owned by multinational companies, subject to certain conditions.

6.2.2 Quality Control Improvement Initiatives

At present, all samples have to be brought to the single DOE testing facility – the National Petroleum Testing Laboratory (NPTL) at the Energy Center, Merritt Road, Fort Bonifacio, Taguig City, Metro Manila. It usually takes at least 2 weeks from the time the product samples are obtained up to the time the test results are determined and the gasoline station is notified, by which time the product at the subject gasoline station has been disposed of, through further distribution or sale. In this regard, the DOE-OIMB is working for possible use of the following:

(1) Product Marker

Since the 1980's the DOE has required the oil companies to use a marker as a quick-check on adulteration. Added to lower value products is an invisible chemical marker that is detectable by a few drops of extractant into a test tube with the product sample. The DOE inspectors have the portable "test kit – test tube, dropper and extractant" which they use to find out if the required product for marking is properly marked, and if there are products that are not supposed to be marked but have the marker. Such system, however, is not applicable to diesel adulteration vis-a-vis with biodiesel. Moreover, the following are the observed shortcomings of the present system:

- Marker tests are indicative and require laboratory confirmation;
- Marker tests are qualitative; and
- Extractants have short shelf life.

The DOE-OIMB is now in the process of receiving proposals of new marker systems that have the following features:

- Can determine extent of adulteration;
- Can determine source of the product (fingerprint); and
- Applicable to both biofuels and blends.

(2) Portable analytical equipment during field inspection

At the start of this century, the DOE acquired portable fuel analyzers, one each for gasoline and diesel. The infrared-technology equipment has the capability of detecting a wide range of properties in the PNS, including biofuels content. Some test methods have secured ASTM recognition. This means that while most of the tests are preliminary or indicative, some tests are final and need no further confirmatory tests. Such equipment on the field can facilitate the outright closure of pumps dispensing products that do not meet the standards of quality.

Most local oil companies now have the same equipment, correlated with the DOE's analyzer, as well as with the formal laboratory equipment. However, there is generally just one unit for each company/agency, thus the equipment is generally lab-based.

Presently, the OIMB is in the process of setting up its mobile monitoring and testing facilities to be fielded all over the country. The OIMB has received various offers of portable analyzers, which will be evaluated by the inter-agency Technical Committee on Petroleum Products and Additives (TCPPA), inasmuch as most of the TCPPA members may themselves want to have their own portable test facility.

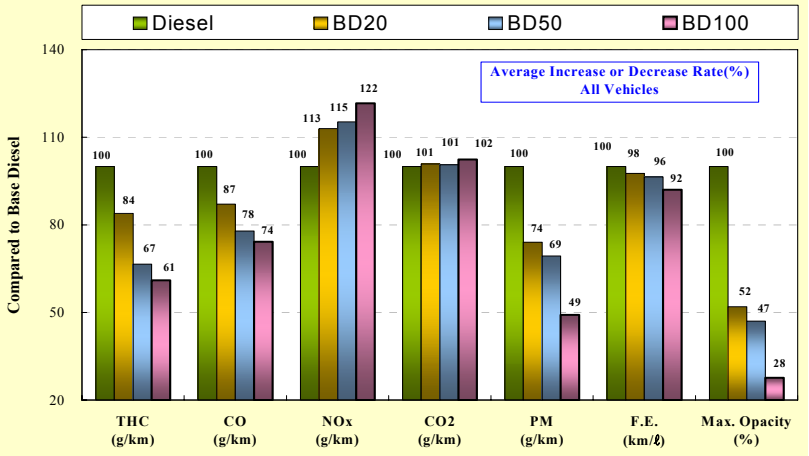
(3) Laboratory/equipment correlation

The ERTLS is also undertaking correlation between laboratories and their equipment among the government, industry players and third party testing facilities to minimize, if not totally avoid inconsistent and contestable test results.

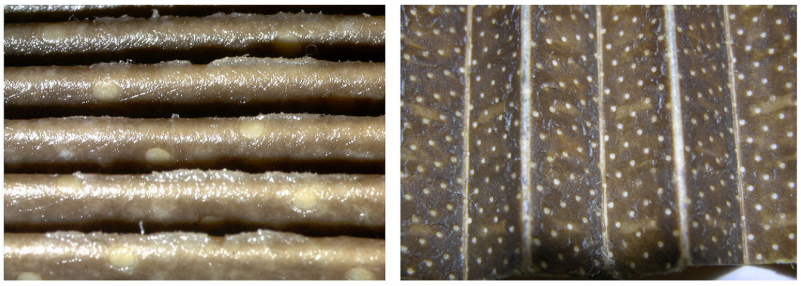
6.3 Field Test of BD5, BD20 and BD100 Powered Diesel Vehicles in Republic of Korea

BD20 demonstration program was officially launched from 25th May 2002 by MOCIE (Ministry of Commerce, Industry and Economy) in Seoul metropolitan area and Jeonbuk provincial area. At this time, mainly transit buses and garbage trucks used BD20 fuel, and ASTM biodiesel standard was adopted.

However, some troubles on cold startability and fuel filter plugging were occurred in winter season occasionally. Then, KIER (Korea Institute of Energy Research) conducted the feasibility study of BD5 and BD20 on diesel vehicles, in which 3 test vehicles, 1 test engines, 2 common rail FIEs were tested and fuel quality was also analyzed, from August 2004 to July 2006 by government sponsored project. This project was also supported by auto makers, FIE (Fuel Injection Equipment) makers, petroleum companies, and biodiesel companies. In this field test as shown in Figure 49(a), there were no troubles found in two passenger RVs tested with BD5 during the first years. However, some running troubles and fuel filter plugging were observed during the second year. For one passenger RV tested with BD20, the plugging problem was quite serious, and it required changing the fuel filters more quickly to solve the problem. From these results, it was concluded that the quality standard of biodiesel is strongly required to strengthen. Therefore, MOCIE changed the BD100 quality standard from ASTM based one to EN based one from the end of 2006, and also BD20 should be used only restricted fleet user which has own oil storage capability and auto repair capability. Figure 49(b) shows some test results of fuel filter plugging by insufficient biodiesel quality.



(a)



Troubled Filter #1, 2004 Troubled Filter #2, 2005

(b)

Figure 49 KIER test results for (a) emission and fuel economy with rice bran biodiesel, and (b) troubled fuel filter due to insufficient biodiesel quality

6.4 Biodiesel Fuel Experience in China

There are three stages for the development of BDF from the eye of stock in China: the first stage (nowadays) is using waste cooking oil, the second and mid-term stage is using remain of vegetable oil and inedible oil, and the third and long-term stock will be algae.

(1) Waste Oil

Statistically, China has about 5 million tons of waste cooking oil, which is considered as a kind of energy waste and also polluting the environment if not used. Several years before, many small private company purchased the waste oil to produce BDF, and they achieved success and gained considerable money. At 2004, the price of waste oil is about 1,400RMB per ton for waste cooking oil and waste pork oil, then many companies set up the BDF produce lines, the sale price of BDF is just as ordinary diesel (about 4,000 RMB per ton). At 2007, the waste oil price is about

2,500-2,800RMB per ton while the Diesel price is about 5,000RMB~5,500RMB.

However, these BDF companies met insurmountable difficulty. At 2008, the diesel price in China increased to about 7,300～7,800RMB per ton while the price of waste oil is as high as nearly 8,000RMB per ton, the result is obviously that many companies has gone bankrupted. Besides the surge in oil prices, the inconvenient truth in China is that if the requirement of waste oil is small, it is really regarded as waste, which results the price of stock being low and hence the bio-diesel company can make money. On the other hand, if the requirement of feed stock, such as waste oil, becomes larger, the waste oil is thought by the collectors as moneybag. Thus, the price increases, and the result is obviously that the BDF companies will be hard to make money.

Besides the price, the volume of production is also a problem for the BDF companies featured by waste oil. The total resource of waste oil in a certain city is limited though most of the Chinese like oily food. The small production scale restricts the BDF quality, thus a vicious circle forms.

(2) Vegetable oil

Vegetable oil is the mid-term stock for BDF in China, but the ordinary edible oil such as rapeseed, soybean, peanut and cotton seed could not be used directed to produce BDF for the reason we have a too large population and are shortage of editable oil. Furthermore, China has determined its principles of developing non-food biomass liquid fuels, that is,

- it should not deprive people of food,
- it should not deprive food of land, and
- it should not deprive cattle of feed.

In China, the way of using vegetable oil seems lying in the remains of oil manufacture. The inedible oils such as Jatropha oil and Chinese pistachio are trying to find their ways of expansion, but still face the obstacles of cost and total yield. Till now, the acidification oil from remains of vegetable oil has been tried by many small companies, but for the obstacles of production scale and the high stock price, their situation is just as hard as the waste oil companies.

(3) Algae

Algae is given great expectations by the BDF companies and the government, but it still needs some technological breakthrough.

(4) BDF problems in China

- Stock is obviously the first obstacle for BDF industry in China.
- Production scale is small. It is statistics that there are more than 2000 BDF companies in China, only 26 companies exceed 10 thousand tons yield, 13 of which is 10-50 thousand tons, 7 of which is between 50~100 thousand tons, 6 of which exceed 100 thousand tons, only one of these company's gross output value is more than 1 billion RMB. In 2008, the total output of biodiesel is less than 300 thousand tons.
- For the above problems, the quality of BDF is not good enough for vehicle use generally speaking.

(5) BDF Vehicle Demo in Shanghai

The performances of many kinds of bio-diesel based on feedstock were measured and the engine performances were measured in China. Based on this, many BDF vehicle demos have been set, such as the BDF demo in Shanghai bus fleets.

In Shanghai, the same nine buses were demoed to verify the BDF vehicle performance. BD5 was used in 3 buses, and BD10 was used in 3 other similar buses, while the rest 3 buses used ordinary diesel. The specification of the buses is in Table 17.

Table 17 Technical specifications of the experiment buses

Type		SWB6100V2
Size (mm)	Length	10490
	Width	2500
	Height	3150
	Wheelbase	5000
Engine Type		C260 20
Power (kW/rpm)		191/2200
Torgue (N.m/rpm)		1025/1400～1500
Displacement (L)		8.3
Emission		Euro II

From the demo, the following conclusions can be made:

(1) The fuel consumption of BD5 is just equal to that of Diesel buses, less than that of BD10 buses, the difference is just less than the calorific value.

(2) The BDF vehicles had better and stable poison emission, especially the smoke emission is much better that of diesel vehicles.

(3) The power of BD5 vehicle is less 2% than that of diesel vehicle, while the BD10 vehicle is less about 4%.

(4) BDF with qualified quality can be used directly as bus fuel.

6.5 Community Biodiesel Standard for Agricultural Machine in Thailand

In Thailand, Department of Energy Business (DOEB) under Ministry of Energy (MOEN), is the governmental authority responsible for issuing the specification for biodiesel. In August 2005, DOEB has announced the FAME biodiesel standard (2005) [32] to allow biodiesel to be blended with diesel as B5 for commercial use in selected area. There are totally 24 items on the properties specification, which derive from either ASTM or EN standards on biodiesel, as shown in Table 18. Note that minor modification on the testing method in FAME biodiesel standard was announced in May 2007 [33], and the increase of oxidation stability from 6 to 10 hours effective in August 2009 [34], which has been used till now.

Table 18 Comparison between FAME and community biodiesel standards in Thailand

No	Specification		Biodiesel B100		
		< or >	FAME	Community	Method
1	Methyl Ester [%wt]	>	96.5		EN 14103
2	Density at 15 °C [kg/m^3]	> <	860 900	860 900	ASTM D 1298
3	Viscosity [cSt] at 40 °C	> <	3.5 5.0	1.9 8.0	ASTM D 445
4	Flash Point [°C]	>	120	120	ASTM D 93
5	Sulphur [%wt]	<	0.0010	0.0015	ASTM D 2622
6	Carbon Residue, on 10% distillation residue [%wt]	<	0.30		ASTM D 4530
7	Cetane number	>	51	47	ASTM D 613
8	Sulfated Ash [%wt]	<	0.02	0.02	ASTM D 874
9	Water [%wt]	<	0.05		EN ISO 12937
	Water and Sediment [%vol]	<		0.2	ASTM D 2709
10	Total Contaminate [%wt]	<	0.0024		EN 12662
11	Copper Strip Corrosion	<	No. 1	No. 3	ASTM D 130
12	Oxidation Stability at 110 °C [hrs]	>	10		EN 14112
13	Acid Value [mg KOH/g]	<	0.5	0.80	ASTM D 664
14	Iodine Value [g Iodine/100 g]	<	120		EN 14111
15	Linolenic Acid Methyl Ester [%wt]	<	12.0		EN 14103
16	Methanol [%wt]	<	0.2		EN 14110
17	Monoglyceride [%wt]	<	0.8		EN 14105
18	Diglyceride [%wt]	<	0.2		EN 14105
19	Triglyceride [%wt]	<	0.2		EN 14105
20	Free glycerin [%wt]	< <	0.02	 0.02	EN 14105 ASTM D 6584
21	Total glycerin [%wt]	< <	0.25	 1.5	EN 14105 ASTM D 6584
22	Group I metals (Na+K) [mg/kg]	<	5		EN 14108 and EN 14109
	Group II metals (Ca+Mg) [mg/kg]	<	5		prEN 14538
23	Phosphorus [%wt]	<	0.001		ASTM D 4951
24	Additive (if any)				
25	Color			Purple	Visual Inspection

With increasing oil price after biodiesel standard was issued, Thai government has promoted the use of biodiesel, especially on the community level, where farmers can process their own biodiesel for agricultural machine without having to paying for fossil diesel. During 2005-2006, Department of Alternative Energy Development and Efficiency (DEDE) under Ministry of Energy (MOEN) has promoted biodiesel utilization in the community level, in accordance with His Majesty the King philosophy on 'Sufficiency Economy'. Many small biodiesel reactors (100 L/batch) were awarded to selected communities with technical training of the local villagers to use the reactor. Even though biodiesel production or transesterification process itself is not complicated, processing biodiesel using the simple reactor in the community within FAME specification, shown in Table 18, has posed a challenge. Hence, DOEB has announced the community biodiesel standard (2006) in July 2006 [35] in order to better regulate community biodiesel production so that the biodiesel production in the community level can practically benchmark with the fuel quality, not greatly harmful to the agricultural engine. As shown in Table 18, the requirement for community biodiesel has reduced from 24 to 13 items with more relax values, compared to the FAME biodiesel standard, with omission of certain properties such as %methyl ester, carbon residue, total contaminate, oxidation stability, iodine value, %methanol, %mono-/di-/tri-glyceride,%-metal and %phosphorous. For easy identification, the standard requires community biodiesel to be purple. This community biodiesel standard is strictly issued for use with agricultural machine, defined as a single four-stroke cylinder (horizontal type & water cool), and is not allowed to be blended with diesel for transportation vehicles.

To further illustrate any damage to the single-cylinder engine when fueled with biodiesel of community grade, DOEB has contracted PTT to investigate such effects via performance, black smoke and durability tests, as well as engine parts rating and lube oil analysis [36]. Community-grade biodiesel was sampled from over 20 communities among those 72 communities awarded from DEDE. Those with high viscosity, but still within the community biodiesel standard, and large enough capacity were selected as sources for durability test. Tested single-cylinder engines were Kubota model RT140ES since Kubota has about 70% market share in Thailand, and this model has a direct-injection technology for upper limit test. Some details of Kubota RT 140ES are shown in Table 19.

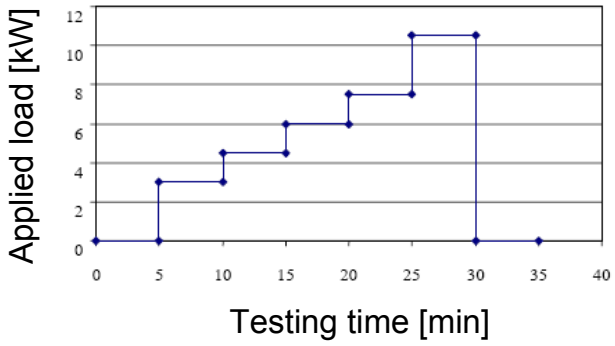
Table 19 Specific information of tested engine

Detail	Specific information
Model	Kubota RT 140ES
Type	Direct-injection, horizontal type, water-cool
No. of cylinder	1
Bore x Stroke (mm x mm)	97 x 96
Displacement (cc)	709
Max power, hp at rpm	14 / 2,400 (10.3 kW / 2,400)
Max torque, Kilogram force at rpm	5.0 / 1,600
Specific fuel consumption (g/kW.h)	231
Compression ratio	18:1
Engine no. 1	Runs on diesel
Engine no. 2 & 3	Runs on community-grade biodiesel

Two Kubota engines were tested with community-grade biodiesel (Engine No.2 & 3) while one Kubota engine (Engine No.1) of the same model was tested with commercially available diesel fuel for comparison. All engines were coupled with electricity generator and subsequently resistance heater coil for boiling the water, as shown in Figure 50. Performance test was conducted before and after 2,000 hrs. durability test at full throttle and applied load of 3, 4.5, 6, 7.5 and 10.5 kW at 5 min interval each. On the other hand, durability test was conducted at full throttle and applied load of 10.5 kW for 5 hours with 1 hour break. Hence, four 5-hours engine-running slots result in 20 hours of durability test each day. Figure 51 shows testing pattern for both performance and durability tests.

(a) (b)

Figure 50 Experimental setup showing (a) Kubota engine coupled with electricity generator and (b) resistance heater coil



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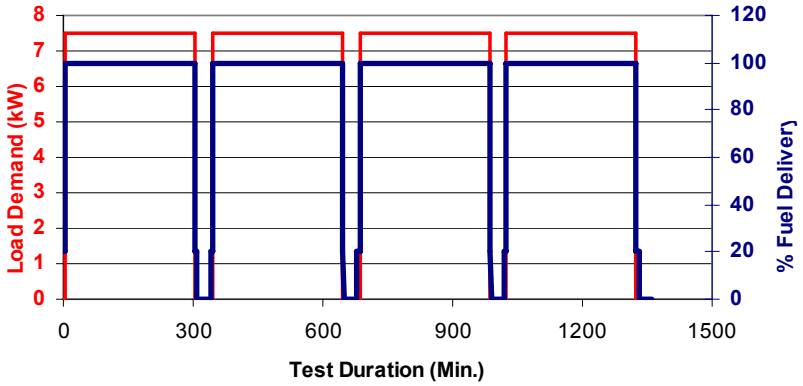


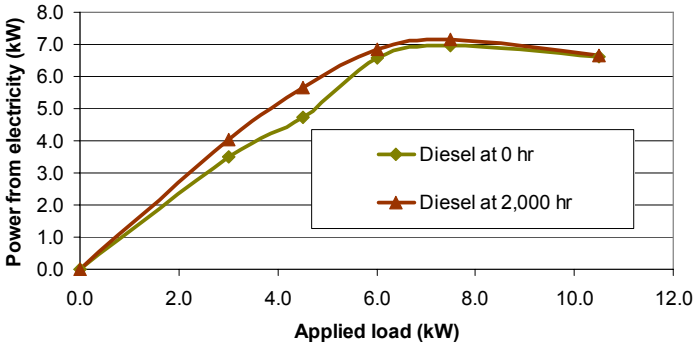
(b)

Figure 51 Applied load pattern of (a) performance test and (b) durability test, both at full throttle

Figure 52 shows performance test results before and after 2,000 hrs durability tests for all three engines. It clearly shows that engine performance is similar for engine no. 1 after 2,000 hrs with diesel while slight drop in performance are shown in both engine no. 2 & 3 after 2,000 hrs with community-grade biodiesel.

For black smoke test, Figure 53 shows that running diesel for 2,000 hrs does not affect black smoke much but running community-grade biodiesel for 2,000 hrs significantly reduces black smoke by 27% for heavy applied load or at least 50% for light applied load.

In term of specific fuel consumption (SFC), Figure 54 shows that slightly higher SFC with SFC increases over running time regardless of whether diesel or community-grade biodiesel is used.



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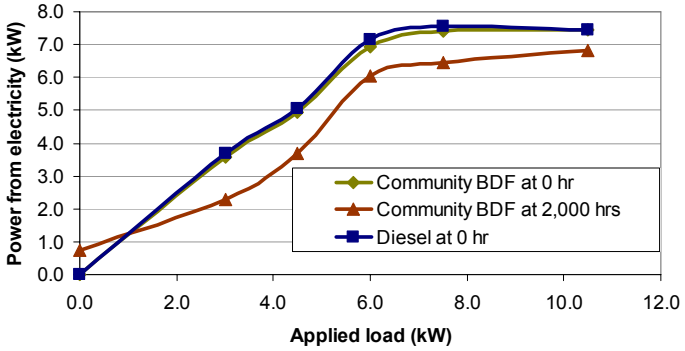

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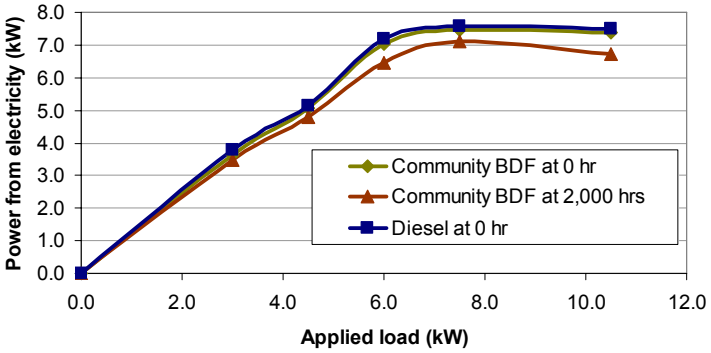
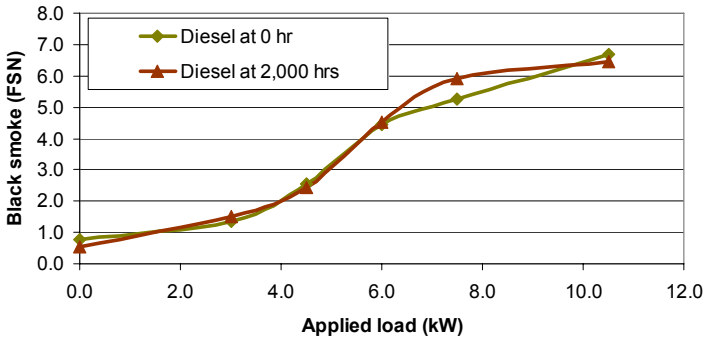
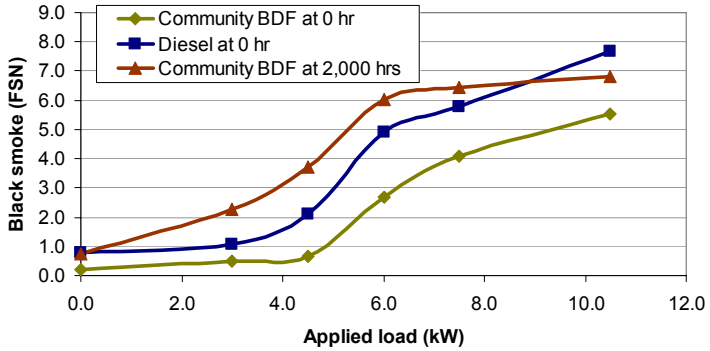


(c)

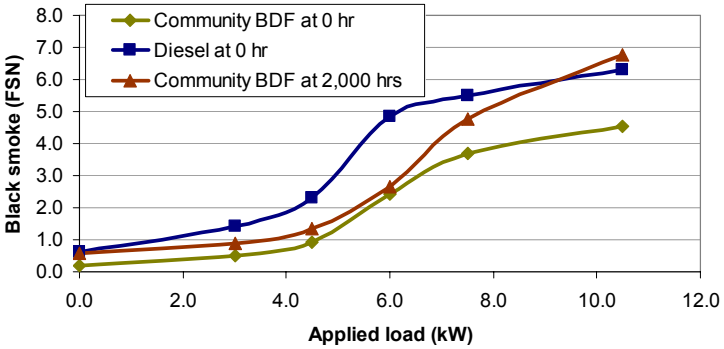
Figure 52 Performance test results of engine before and after running on (a) diesel: engine no. 1, (b) biodiesel: engine no. 2 and (c) biodiesel: engine no. 3 for 2,000 hrs



(a)

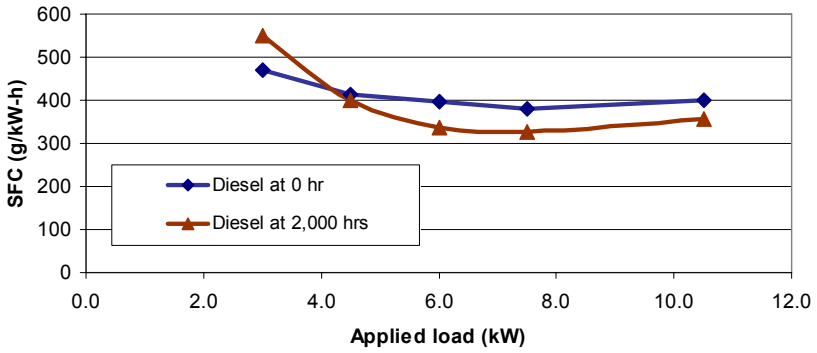


(b)

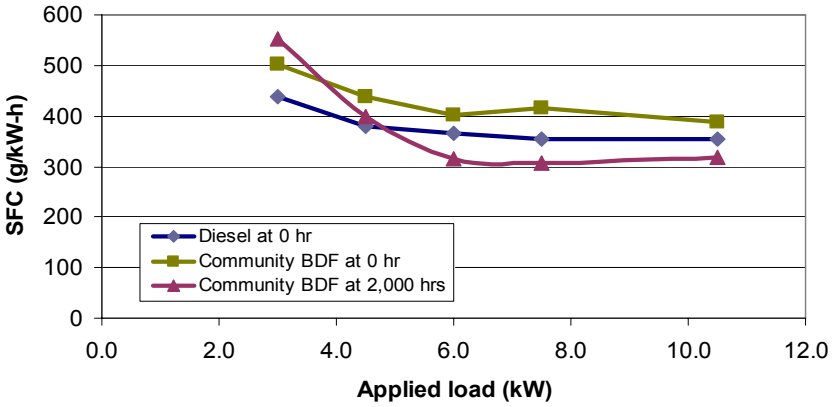


(c)

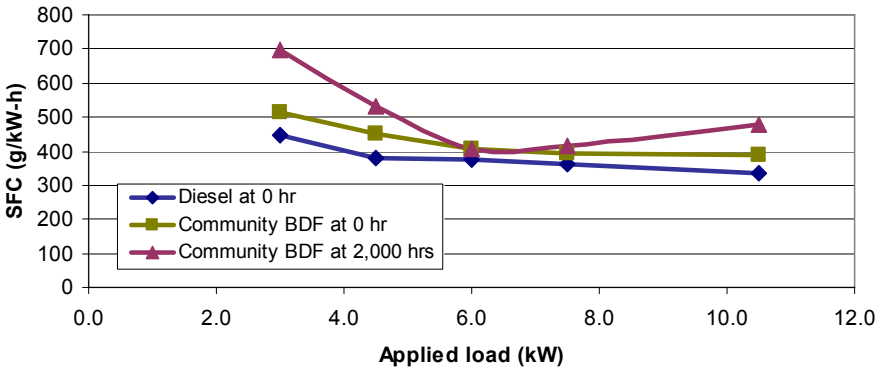
Figure 53 Black smoke test results of engine before and after running on (a) diesel: engine no. 1, (b) biodiesel: engine no. 2 and (c) biodiesel: engine no. 3 for 2,000 hrs



(a)



(b)



(c)

Figure 54 Specific fuel consumption test results of engine before and after running on (a) diesel: engine no. 1, (b) biodiesel: engine no. 2 and (c) biodiesel: engine no. 3 for 2,000 hrs

For engine part inspection after 2,000 hrs durability test, Figure 55 show that the top part of fuel tank shows certain degree of rust in both diesel and community biodiesel

cases, with likely higher amount in the cases with community biodiesel.

(a)

(b)

(c)

Figure 55 Visual inspection of top fuel tank (show inner surface) reveals rusty surface in all cases with highest amount in Engine No. 3

Visual inspections of other engine parts, such as injector tip, injector liner, piston, intake/exhaust valves, gear and bearing, do not significantly show wear or sign of damage in the community biodiesel cases compared to diesel case. However, fuel filter needs to be replaced at 300 hrs, sooner than the recommended 400 hrs from the manufacturer. Analysis of engine lube oil shows acceptable trace levels of Aluminum, Iron, Chromium, Copper, Silicon and Lead in all three engines.

In conclusion, the quality of biodiesel according to community level specification has proved acceptable to be used for single-cylinder agricultural engine without significant drop in performance with acceptable fuel consumption and significantly improve in black smoke. However, proper maintenance must be taken, especially on changing fuel filter sooner than the manufacturer's recommendation and checking for potential rust in the top inner surface of fuel tank.