Experimental Investigation of the Fuel Properties of Glidfuel, Palm Oil Mill Effluent Biodiesel and Blends

Abul Hossain*, Junior Nyah, Ako Ahmad, Abdelnasir Omran, Philip Davies

Sustainable Environment Research Group (SERG), Aston University, Birmingham B4 7ET, UK
a.k.hossain@aston.ac.uk

Biofuels derived from industry waste have potential to substitute fossil fuels (Diesel and Gasoline) in internal combustion (IC) engines. Use of waste streams as fuels would help to reduce considerably life-cycle greenhouse gas emissions and minimise waste processing costs. In this study an investigation into the fuel properties of two waste derived biofuels were carried out, they are: (i) Glidfuel (GF) biofuel - a waste stream from paper industry, and (ii) Palm Oil Mill Effluent (POME) biodiesel – biodiesel produced from palm oil industry effluent through various treatment and transesterification process. GF and POME was mixed together at various proportions and separately with fossil diesel (FD) to assess the miscibility and various physical and chemical properties of the blends. Fuel properties such as kinematic viscosity, higher heating value, water content, acid number, density, flash point temperature, CHNO content, sulphur content, ash content, oxidation stability, cetane number and copper corrosion ratings of all the fuels were measured. The properties of GF, POME and various blends were compared with the corresponding properties of the standard FD. Significance of the fuel properties and their expected effects on combustion and exhaust emission characteristics of the IC engine were discussed. Results showed that most properties of both GF and POME biodiesel were comparable to FD. Both GF and POME were miscible with each other, and also separately with the FD. Flash point temperatures of GF and POME biodiesel were 40.7^{o}C and 158.7^{o}C respectively. The flash point temperature of GF was about 36% lower than corresponding FD. The water content in GF and FD were 0.74 (% wt) and 0.01 (% wt) respectively. Acidity values and corrosion ratings of both GF and POME biodiesel were low compared to corresponding value for FD. The study concluded that optimum GF-POME biofuel blends can substitute fossil diesel use in IC engines.

1. Introduction

In 2012, about 10% of the total world greenhouse gas emission came from the European Union (EU, 2014b). The EU parliament has set a 2030 target of at least 40% emission reduction compared to 1990 level, and 27% energy share from renewables (EU, 2014a). Fossil fuels are being used for heat and power generation, farming, construction and in automobile sectors. A very large reduction in greenhouse gas (GHG) emission is possible by substitution of fossil fuels used in the internal combustion engines with renewable alternatives such as biofuels produced from waste resources (Baral, 2014). Nevertheless, not all biofuels are suitable for use in the internal combustion engines. Poor quality biofuels may degrade engine performance and emit harmful gases in the environment. Researchers investigated the use of various 2nd generation biofuels and associated techno-economic challenges (Mahmood, 2015, Namchot, 2015, Nigam and Singh, 2011, Agarwal, 2007, Hossain, 2010b, Hossain, 2013, Meher et al., 2013, Naik et al., 2010, Swain et al., 2011). Improved thermal efficiency, increased fuel consumption and reduced pollution than fossil diesel were reported when biodiesel was used in the diesel engine either as a blended form with diesel or as pure (B100) (Schumacher et al., 1996, Lapuerta et al., 2008, Murugesan et al., 2009). However, degrading of seals, filter clogging, cold starting, injector coking and high NOx emissions are some of the problems associated with biodiesel use in the engine (Fazal et al., 2011, Haseeb et al., 2011). On the other hand, engine manufacturers only permit 5-10% biodiesel use as blended with fossil diesel. The viscosities of vegetable oils are much higher than fossil diesel and hence affects injection and combustion characteristics (Hossain, 2010b). Oils produced by pyrolysis of biomass are generally acidic and have high solids content, which limits the quantity of pyrolysis oil

use in the engine (Hossain, 2013, Hossain et al., 2013). Wood derived turpenes were investigated as a potential fuels for gasoline and diesel engines (Hellier et al., 2013, Knuuttila, 2013, Karthikeyan and Mahalakshmi, 2007, Anand et al., 2010, Vallinayagam et al., 2013, Vallinayagam et al., 2014). Pure pine oil was used in a diesel engine and an improvement in the thermal efficiency and heat release was observed (Vallinayagam et al., 2013). Turpentine oil produced by pyrolysis mechanism (pyrolysing resin from pine tree) was blended with the fossil diesel and tested successfully in a diesel engine (Anand et al., 2010). Knuuttila (2013) reported that crude sulphate turpentine can be converted to a hydrocarbon mixture which boils in the range of gasoline boiling point using sulphided desulfurization or dewaxing catalyst. In this study, fuel quality of Glidfuel (GF) and palm oil mill effluent (POME) biodiesel will be assessed for potential replacement of fossil diesel use in the diesel engine. Glidfuel is a waste stream from pulp paper industry, and palm oil effluent is a waste product available in the palm oil processing mills. The aim of the current study is to assess the technical feasibility of glidfuel and palm oil mill effluent biodiesel as potential substitute for fossil diesel to use in the internal combustion engines. The specific objectives of the study are to: (i) characterise the physical and chemical properties of glidfuel and palm oil mill effluent biodiesel, (ii) investigate the miscibility of GF and POME, and also separately with fossil diesel, (iii) characterise the properties of various blends, (iv) compare the properties of GF, POME and their blends with fossil diesel (FD), and (v) asses the fuel quality value of these biofuels and blends, and expected effects on engine performance, exhaust emission and on engine components.

2. Materials and Methods

The glidfuel (GF) and palm oil mill effluent (POME) was supplied by a UK supplier Green Frog Fuels Ltd as part of a collaboration funded by the European Regional Development Fund (ERDF). Glidfuel is a waste stream collected from US paper industry, and POME biodiesel was derived from palm oil mill effluent through pre-treatment and transesterification. Physical and chemical properties of pure GF and pure POME biodiesel and pure fossil diesel (FD) were determined. The GF and POME were mixed together at various proportions and miscibility of these blends were assessed. Additionally, GF and POME was also mixed separately with FD to assess the blending potential with fossil diesel (FD). The blends created were (in vol. %): 20% GF + 80% POME, 30% GF + 70% POME, 40% GF + 60% POME, 50% GF + 50% FD, and 50% POME + 50% FD. The mixing was done manually without using any mechanical or ultrasonic methods. The properties of GF, POME biodiesel, and blends were then compared with the properties of the standard fossil diesel. Fossil diesel used in the study was collected from a local filling station. The names of properties, equipment and associated standards, and accuracy (or standard deviation of measurements) of the equipment is shown in Table 1. In order to ensure repeatability of the results, more than one readings were taken for each measurement and the average values were used for analysis. Measurements of CHNO and S content, ash content, cetane number and ignition delay were conducted externally using an accredited laboratory.

Table 1: Fuel properties and equipment used

Name of properties	Name of the equipment and model	Standard of measurement	Accuracy/standard deviation
Calorific value	Parr 6100 Bomb Calorimeter	ASTM-D240	± 0.1%
Flash point temperature	Setaflash series 3 plus closed cup flash point tester (model 33000-0)	ASTM-D3278	-
Density	Hydrometer	ASTM-D4052	± 0.5^0 C
Viscosity	Cannon Fenski u-tube viscosity meter and a thermostatic water bath (± 0.1° C)	ASTM-D130	± 0.16% to 0.22% STDEV: 0.03 to 0.17
Acid Number	Mettler Toledo G20 compact titrator (internal). Potentiometric Titration (ext. lab)	ASTM-664-04 ASTM D3339	-
Water Content	Mettler Toledo V20 compact volumetric Karl-Fischer titration	ASTM-E203	-
Copper corrosion	Stanhope-SETA cooper corrosion	ASTM D130	-
Cetane number	-	IP 498	-
CHNO analysis	Combustion furnace- Exeter Analytical 440 Analyser	-	-
Oxidation stability	-	ASTM D4625	-
Ash content	Filtration/high temperature combustion		

3. Results and Discussion

Both GF and POME biodiesel were mixed well together and also mixed separately with FD. Samples were left at room temperature to assess the miscibility, no phase separation was observed after 1 week (Figure 1). Table 2 and Table 3 shows various physical and chemical properties results.
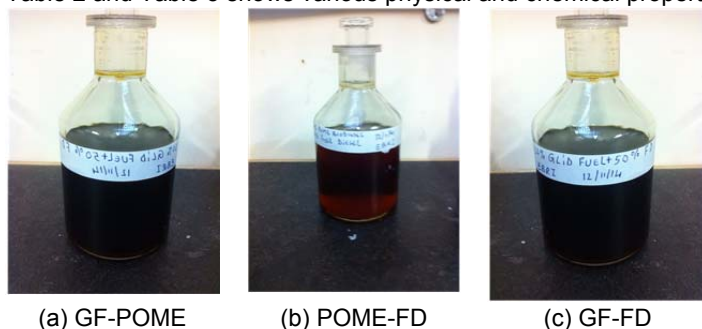

(a) GF-POME   (b) POME-FD   (c) GF-FD

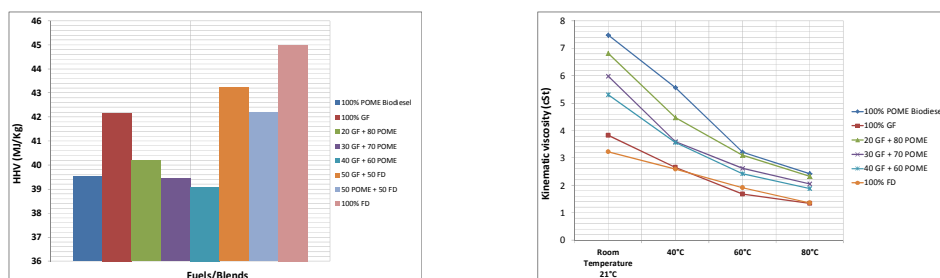*Figure 1: Miscibility and stability tests of various blends*

Heating Value and Density: Heating value is important as this is directly related to the power output of the engine – higher the heating value the higher will be the power output and hence would give improved thermal efficiency. Results showed that heating values of GF and POME biodiesel were slightly lower than that of the corresponding FD value (Table 2). Higher oxygen content in GF and POME biodiesel (Table 3) caused this. Heating value of GF and POME biodiesel were 7% and 2.5% lower than that of FD; interestingly, heating value of 50 GF + 50 FD blend was only about 4.5% lower than FD (Figure 2a). Density of fuel affects storage, fuel supply system to the engine, and injection parameters. High density might cause high ignition delay and hence affects combustion characteristics inside the cylinder. On the other hand, high density of fuel can compensate engine power if a low heating value fuel is used in the engine. Results showed that the density of GF was slightly higher by about 7% than the corresponding FD value (Figure 3a). Among all blends, the density of 50 POME + 50 FD blend was close to FD (Table 2).

Table 2: Properties of GF, POME and various blends

Fuels/ Blends	Higher Heating Values (MJ/kg)	Density (kg/m^3)	Viscosity at 21^{0}C (cSt)	Viscosity at 40^{0}C (cSt)	Viscosity at 60^{0}C (cSt)	Viscosity at 80^{0}C (cSt)	Flash Point Temp (^{0}C)	Water content (% wt)	Copper corrosion [@60^{0}C for 72 hours]
POME Biodiesel	39.51	875.33	7.47	5.57	3.21	2.42	158.5	0.09	1b
100% GF	42.16	893.00	3.83	2.66	1.68	1.35	40.7	0.74	1b
20 GF + 80 POME	40.18	878.67	6.81	4.47	3.11	2.33	64.3	0.24	-
30 GF + 70 POME	39.45	878.33	5.98	3.59	2.62	2.05	53.7	0.40	-
40 GF + 60 POME	39.75	883.00	5.3	3.56	2.43	1.88	43.3	0.34	-
50 GF + 50 FD	43.22	864.17	-	2.14	-	-	45.0	-	-
50 POME + 50 FD	42.19	855.67	-	2.89	-	-	68.7	-	-
100% FD	45.29	835	3.22	3.01	1.91	1.37	64.3	0.01	1b

Viscosity and Flash Point Temperature: Viscosity is an important property of fuels. The high viscosity of fuels would affect atomisation quality such as droplets sizes, spray penetration length and spray angle. Poor atomisation mean poor combustion inside the cylinder and might result in increased CO emission and smoke. High viscosity might help to lubricate the moving parts of the engine, but on the other hand, this may cause
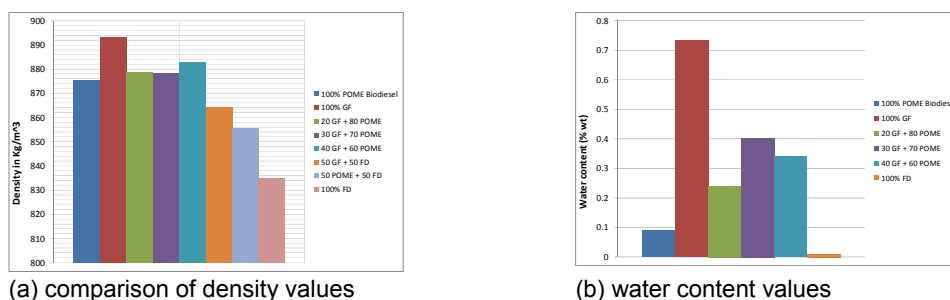
problems in the fuel supply systems by clogging the filters and coking injector nozzle. Kinematic viscosities were measured at various temperatures to see the effect of temperature on viscosity. At 40^0C, the viscosity of GF and FD were close to each other, but the viscosity of POME biodiesel was about two times higher than that of FD. The viscosity of 50 POME + 50 FD blend was similar to FD value. It was observed that for all fuels the viscosity decreases with the increase of temperature (Figure 2b). The flash point temperature plays an important role, generally low flash point fuels are suitable for spark ignition type engine. Furthermore, flash point temperature is a safety parameter, which is used for transportation and storing of fuels. The flash point temperature of POME biodiesel was about 2.5 time higher than FD, and on the other hand, the flash point temperature of pure GF was about 38% lower than FD (Table 2). Both 50 GF + 50 FD and 50 POME + 50 FD blends showed reasonable flash point temperatures.

(a) comparison of the HHV values

(b) viscosity at various temperature

Figure 2: Comparison of HHV and Viscosities

(a) comparison of density values

(b) water content values

Figure 3: Comparison of density and water content values

Water content and copper corrosion: Small amount of water present in the fuel might help to reduce the combustion temperature and as a result the NOx emission would decrease. On the other hand, high water content would lead to decreased heating value and might cause problems to igniting the fuels inside the piston-cylinder. The results showed that both GF and POME biodiesel contain small amount water. Water content was decreased when blended with FD (Figure 3b). The copper corrosion ratings gives an indication of the corrosion levels on copper strips. The copper corrosion ratings were almost same for all fuels (Table 2 and Figure 4).

CHNOS analysis, acid number, oxidation stability and ash content: C, H, N, O and S content analysis showed that carbon and hydrogen content in all 3 fuels (GF, POME biodiesel and FD) were almost similar (Table 3). On the other hand, the oxygen content was higher than FD in both GF and POME biodiesel fuels – oxygen in POME biodiesel was about 2.5 times higher than FD. Higher oxygen content may help to improve the combustion inside the cylinder. The sulphur content in pure GF was about 3 times is higher than the sulphur present in the FD.

High sulphur content in the fuel is not desirable as this may lead to acid rain. Oxidation stability of GF and POME biodiesel were same, which proved that both GF and POME biodiesel were stable products. CHNOS and oxidation stability analysis were not carried out for blends. Acid number measurement is important to assess the possible corrosion of engine components and fuel supply systems. Acid number results showed that none of these fuels were acidic. High ash content would create clogging problems inside the piston-cylinder and intake/exhaust valves. It was observed that the ash content in the GF and POME biodiesel were similar to that of FD (Table 3).

Table 3: Cetane number, acidity and CHNO analysis of the GF, POME biodiesel and FD

Fuels/Blends	C (%wt)	H (% wt)	N (% wt)	S (% wt)	O* (% wt)	Ash content (% wt)	Acid number (mg KOH/g)	Oxidation stability (hours)	Cetane number
POME	86.7	9.9	<0.1	<0.1	3.4	<0.1	<0.1	>9	-
100% GF	87.8	10.1	<0.1	0.3	1.8	<0.1	<0.1	>9	24.2
100% FD	84.73	13.20	<0.1	<0.1	1.40	<0.01	0.023	-	-

*Oxygen calculated by difference = 100- (CHN) - Water (as appropriate)

(a) 100% POME biodiesel   (b) 100% GF

Figure 4: Copper corrosion ratings (after 72 hours)

Cetane number and ignition quality: Cetain number represents the ignition delay and combustion behaviour of the diesel type fuels when used in compression ignition engines. In this study, only cetane number of pure GF (100%) was measured. The cetane number of FD is 50.2 (Hossain, 2012), and on the other hand, cetane number of biodiesel is in the range of 40-45 (Hossain, 2010a). Results showed that the cetane number of GF was 24.2 (table 3) – about half of the corresponding fossil diesel value. The lower the cetane number, the higher would be the ignition delay period. Longer ignition delay would generally decrease the total combustion duration in the engine and as a result engine would consume more fuel to get the same engine output power like FD. The cetane number can be increased either by blending with FD or by using additives. Additives are generally expensive which would eventually increase the operating cost of the engine.

4. Conclusions

A comparative analysis was carried out to assess the fuel quality value of the GF, POME biodiesel and blends. The results were compared with the standard fossil diesel values. Effects of each properties on combustion and emission characteristics of a compression ignition engine were discussed. It was observed that both GF and POME biodiesel were miscible with each other, and also separately with the FD. The oxidation stability of the GF and POME biodiesel was greater than 9 hours. At 40^0C, the viscosity of POME biodiesel was about two times higher than the corresponding value of FD. The viscosity of 50 POME + 50 FD blend was similar to FD value. Flash point temperatures of GF and POME biodiesel were 40.7^0C and 158.7^0C respectively. The flash point temperature of GF was about 36% lower than corresponding value of FD. The water content in GF and FD are 0.74 (% wt) and 0.01 (% wt) respectively. Acidity values and copper corrosion ratings of both GF and POME biodiesel are low. The sulphur content in pure GF was about 3 times is higher than FD. The cetane number of GF was about half of that FD value. Considering the physical and chemical properties of these biofuels and expected effects on the engine performance, 50 GF + 50 FD and 50 POME + 50 FD blends are recommended for diesel engine application. Engine testing using the proposed blends are recommended. The GF and POME biodiesel can be mixed with gasoline and is recommended as further study.

References

Agarwal A.K., 2007, Biofuels (alcohols and biodiesel) applications as fuels for internal combustion engines. Progress in Energy and Combustion Science, 33, 233-271.

Anand B.P., Saaravanan C.G., Srinivasan C.A., 2010, Performance and exhaust emission of turpentine oil powered direct injection diesel engine. Renewable Energy, 35, 1179-1184.

Baral A., Malins C., 2014, White Paper - Assessing the Climate mitigation potential of biofuels derrived from residues and wastes in the European context. icct (The International Council of Clean Transoportation).

EU., 2014a, 2030 framework for climate and energy policies. <ec.europa.eu/clima/news/articles/news_2014102801_en.htm>accessed 04.04.2015.

EU., 2014b, Climate Action - EU greenhouse gas emissions and targets. <ec.europa.eu/clima/policies/g-gas/index_en.htm>accessed 04.04.2015.

Fazal M.A., Haseeb A.S.M.A., Masjuki H.H., 2011, Biodiesel feasibility study: An evaluation of material compatibility; performance; emission and engine durability. Renewable and Sustainable Energy Reviews, 15, 1314-1324.

Haseeb A.S.M.A., Fazal M.A., Jahirul M.I., Masjuki H.H., 2011, Compatibility of automotive materials in biodiesel: A review. Fuel, 90, 922-931.

Hellier P., Al-haj L., Talibi M., Purton S., Ladommatos N., 2013, Combustion and emissions characterization of terpenes with a view to their biological production in cyanobacteria. Fuel, 111, 670-688.

Hossain A., Davies P.A., 2010a, Plant oils as fuels for compression ignition engines: A technical review and life-cycle analysis. Renewable Energy, 35, 1-13.

Hossain A., Davies P.A., 2012, Performance, emission and combustion characteristics of an indirect injection (IDI) multi-cylinder compression ignition (CI) engine operating on neat jatropha and karanj oils preheated by jacket water. Biomass and Bioenergy, 46, 332-342.

Hossain A.K., Davies, P.A., 2010b, Plant oils as fuels for compression ignition engines: A technical review and life-cycle analysis. Renewable Energy, 35, 1-13.

Hossain A.K., Davies P.A., 2013, Pyrolysis liquids and gases as alternative fuels in internal combustion engines – A review. Renewable and Sustainable Energy Reviews, 21, 165-189.

Hossain A.K., Ouadi M., Siddiqui S.U., Yang Y., Brammer J., Hornung A., Kay M., Davies P.A., 2013, Experimental investigation of performance, emission and combustion characteristics of an indirect injection multi-cylinder CI engine fuelled by blends of de-inking sludge pyrolysis oil with biodiesel. Fuel, 105, 135-142.

Kartthikeyan R., Mhahalakshmi N.V., 2007, Performance and emission characteristics of a turpentine–diesel dual fuel engine. Energy, 32, 1202-1209.

Knuuttila P., 2013, Wood sulphate turpentine as a gasoline bio-component. Fuel, 104, 101-108.

Lapuerta M., Armas O., Rodriguez-Fernandez J., 2008, Effect of biodiesel fuels on diesel engine emissions. Progress in Energy and Combustion Science, 34, 198-223.

Mahmood N.A., Thonga L.K., Ibrahimb K.A., Chyanc J.B., Ghazali N.F., 2015, Power Generation From Pre-treated Empty Fruit Bunch Using Single Chamber Microbial Fuel Cell. Chemical Engineering Transactions, 45, 79-84.

Meher, L.C., Churamani, C.P., Arif M., Ahmed Z., Naik S.N., 2013, Jatropha curcas as a renewable source for bio-fuels - A review. Renewable and Sustainable Energy Reviews, 26, 397-407.

Murugesan A., Umarani C., Subramanian R., Nedunchezhian N., 2009, Bio-diesel as an alternative fuel for diesel engines - A review. Renewable and Sustainable Energy Reviews, 13, 653-662.

Naik S.N., Goud V.V., Rout P.K., Dalai A.K., 2010, Production of first and second generation biofuels: A comprehensive review. Renewable and Sustainable Energy Reviews, 14, 578-597.

Namchot W., Jitkarnka S., 2015, Upgrading of waste tyre-derived oil from waste tyre pyrolysis over ni catalyst supported on hzsm-5 zeolite. Chemical Engineering Transactions, 45, 775-780.

Nigam P.S., Singh A, 2011, Production of liquid biofuels from renewable resources. Progress in Energy and Combustion Science, 37, 52-68.

Schumacher L.G., Borgelt S.C., Fosseen D., Goetz W., Hires W.G., 1996, Heavy-duty engine exhaust emission tests using methyl ester soybean oil/diesel fuel blends. Bioresource Technology, 57, 31-36.

Swain P.K., Das L.M., Naik S.N., 2011, Biomass to liquid: A prospective challenge to research and development in 21st century. Renewable and Sustainable Energy Reviews, 15, 4917-4933.

Vallinayagam R., Vedharaj S., Yang W.M., Lee P.S., Chua K.J.E., Chou S.K., 2013, Combustion performance and emission characteristics study of pine oil in a diesel engine. Energy, 57, 344-351.

Vallinayagam R., Vedharaj S., Yang W.M., Saravanan C.G., Lee P.S., Chua K.J.E., Chou S.K., 2014, Impact of ignition promoting additives on the characteristics of a diesel engine powered by pine oil–diesel blend. Fuel, 117, Part A, 278-285.