Engine Performance and Emission study of Waste cooking oil and Sewage sludge derived Biodiesel blend

To cite this article: D Priyadarshi and KK Paul 2018 IOP Conf. Ser.: Earth Environ. Sci. 167 012035

View the article online for updates and enhancements.

Related content
- Chemical states of trace heavy metals in sewage sludge by XAFS spectroscopy
  M Nagoshi, T Kawano, S Fujiwara et al.
- Waste cooking oil as source for renewable fuel in Romania
  F Um Min Allah and G Alexandru
- Investigation on Properties and Leachability of Sewage Sludge from Wastewater Treatment Plant Incorporated in Fired Clay Brick
  N S Abdul Salim, A Abdul Kadir, M A Kamarudin et al.
Engine Performance and Emission study of Waste cooking oil and Sewage sludge derived Biodiesel blend

D Priyadarshi¹ and KK Paul²

¹Research Scholar, Department of Civil Engineering, National Institute of Technology, Rourkela, India, 769008.
²Assistant Professor, Department of Civil Engineering, National Institute of Technology, Rourkela, India, 769008
E-mail: k_karar1@yahoo.co.in

Abstract. Sewage sludge and waste cooking oil based biodiesel (WCOB) recently gaining popularity for a fair amount of lipid content for biodiesel production. In this study, for the first time sewage sludge biodiesel (SSB) based blend was subjected to engine performance analysis. SSB has relatively higher saturated fatty acid content and reduced polyunsaturated fatty acid content. While WCOB has low saturated methyl esters and very high unsaturated methyl ester concentration. Hence, effect of fatty acid structure on performance and emission were also monitored. On the basis of performance WCO30 (30 % v/v WCOB and 70 % v/v diesel blend) found better alternative with low break specific fuel consumption and lesser exhaust gas emission compared to SSB30. However, decent performance was also witnessed for SSB30. It was observed that fatty acid profile has negligible effects on the performance parameters. Whereas, significant variation in NOx, CO and HC emission were noted with change in individual fatty acid methyl ester contents. Utilising SSB30 and WCO30 reduced the CO emission by 12.82% and 10.39% respectively. Saturated fatty acid methyl ester rich SSB30 resulted 9.09% higher NOx emission than petroleum diesel. Hydrocarbon emission were increased by the presence of unsaturated fatty acid methyl esters.

1. Introduction
The growing fuel crisis and limited vegetable oil based biodiesel attracting researchers towards the search of new alternatives. As per World Energy Council (WEC), in 2040 there will be a rise in ratio of the diesel demand to gasoline demand from 1.5 to 3.8 [1]. Among diesel alternative fuels, biodiesel has similar physico-chemical properties to petroleum diesel, high oxygen content, and rich in resources. Therefore, a potential candidate for fossil diesel substitute fuel. Recently, there is a significant increase in biodiesel use in compression ignition engines [2]-[4]. It is reported that 20% biodiesel blend in diesel engine can provide similar performance and emission with that of petroleum diesel [5]. Currently, engine configurations are as such that 100% biodiesel can be used without modification. However, special attention should be paid for transportation and storage of biodiesel. Biodiesel can reduce the emissions of unburnt hydrocarbons (HC), carbon monoxides (CO), sulphates and particulate matter (PM) depending upon methyl esters and engine conditions [6], [7]. Again, biodiesel is renewable. Even if additional energy consumption takes place during production of biodiesel, it is well managed by the very less emission of greenhouse gases during engine operation. It provides clean energy with low particulate emission [8], [9].

For a long time, vegetable oil based biodiesel dominated the biodiesel market worldwide [10]. Whereas, availability of seed for oil extraction is limited. Therefore, less amount of oil production and
high processing cost of vegetable oil biodiesel is a major drawback for its commercialization [11]. This is not sufficient to fulfil a large requirement of biodiesel. The search for low cost raw materials has focused towards alternative feedstocks like animal fat, waste cooking oil [12] and sewage sludge [11], [13].

Recently, biodiesel from waste like sewage sludge and waste cooking oil gaining popularity due to its high fatty acid contents [14]. Worldwide more than 20 million tone of dry sewage sludge are produced every year [15]. For some time, treated sludge were used as fertilizer. However, strict regulations on sludge fertilizer introduced due to its heavy metal contents that might degrade the crop quality and damage the soil fertility [16]. Hence, biodiesel production can be a better alternate for reuse of sewage sludge. SSB production follows lipid extraction and transesterification of lipids. Transesterification may be base catalysed or acid catalysed depending upon the free fatty acid (FFA) concentration in lipid. Sludge based lipid found high in FFA as tested in laboratory. Base catalyst doesn’t hold good for lipid and oil with high FFA. Acid catalyst is a better option but highly time consuming process [17].

Recently, cosolvent based acid catalysed transesterification getting recognition due to its easy and fast conversion of high percentage of FFA into methyl esters [18], [19]. Cosolvents such as methyl tert butyl ether (MTBE), tetrahydrofuran operates well in low temperature transesterification [19].

In this study an attempt was taken to analyse the performance and emission of biodiesel from sewage sludge and waste cooking oil. Previously no study was performed on engine performance of sewage sludge biodiesel (SSB). SSB has taken along with waste cooking oil biodiesel (WCOB) to investigate the effects of fatty acid profile on performance and emission of DI engine.

2. Sample and methodology

2.1. Test sample preparation

Sewage sludge was collected from the primary settling tank outlet of a municipal sewage treatment plant located in panposh, Rourkela. Lipid extraction was performed following methods adopted by Priyadarshi and Paul (2017). Lipid yield of 25.51 % was measured from sewage sludge. Free fatty acid content more than 3 mg/g KOH was observed in lipid sample. Therefore, lipid was subjected to acid catalysed transesterification in presence of cosolvent (MTBE). Transesterification were performed with 5:1 (v/w) MTBE (methyl tert butyl ether), 15:1 (w/v) methanol, and 1 % (wt%) sulfuric acid in lipid. The mixture was subjected to 500 rpm stirring at a constant temperature of 45 °C for 4 hours. After phase separation of FAME and glycerol were collected separately. FAME phase was subjected to wet wash with warm distilled water and finally recovered FAME were analysed with GC-MS and GC-FID.

Waste cooking oil biodiesel fulfilling international standard EN14214 were procured. Both SSB and WCO biodiesel were mixed at ratio 3:7 (30% biodiesel and 70% diesel) with petroleum diesel. After blending SSB30 (30% SSB and 70% diesel v/v) and WCO30 (30% WCO biodiesel and 70% diesel v/v) were kept under scrutiny for 10 days. Sample was then subjected to engine performance and emission analysis. Detailed characterisation of diesel, SSB, SSB30, WCOB and WCO30 biodiesel are summarized in Table 1.

Table 1. Properties of diesel, waste cooking oil methyl ester and sewage sludge biodiesel.

| Properties                  | Diesel | SSB | SSB30 | WCOB | WCO30 |
|-----------------------------|--------|-----|-------|------|-------|
| Density, Kg/m$^3$           | 820-830| 880 | 846   | 874  | 834   |
| Viscosity, cSt              | 2.5-3.2| 4.55| 3.7   | 4.41 | 3.4   |
| Calorific Value, MJ/kg      | 42-45  | 39-42| 43.25 | 38.5-41| 43.5 |
| Flash point, °C             | 50     | 178 | 68    | 170  | 63    |
| Iodine value, g I$_2$ per 100 g | -     | 85-93| -     | 95-102| -     |
| Saturated fatty acid, %     | -      | 30-40| -     | 15-23| -     |
2.2. Engine set up and methodology
Experiments were performed in a single cylinder, four strokes, direct injection air cooled diesel engine with full power of 4.4 kW and maximum speed 1500 rpm. Schematic diagram of the experimental set up was shown in Figure 1. Engine technical specification were given in Table 2. A sensor is fitted to calculate fuel consumption. Air flow intake rate were measured by a U tube manometer. Exhaust gas temperature was measured by a K-type thermocouple. AVL DiGas444 exhaust gas analyser was used to measure exhaust emissions of the engine. Details about the equipment was given in Table 3.

| Mono unsaturated fatty acid (C18:1), % | 35-44 | 38-45 |
|---------------------------------------|-------|-------|
| Poly unsaturated fatty acid, %        | 20-25 | 30-37 |

2.2. Engine set up and methodology
Experiments were performed in a single cylinder, four strokes, direct injection air cooled diesel engine with full power of 4.4 kW and maximum speed 1500 rpm. Schematic diagram of the experimental set up was shown in Figure 1. Engine technical specification were given in Table 2. A sensor is fitted to calculate fuel consumption. Air flow intake rate were measured by a U tube manometer. Exhaust gas temperature was measured by a K-type thermocouple. AVL DiGas444 exhaust gas analyser was used to measure exhaust emissions of the engine. Details about the equipment was given in Table 3.

2.2. Engine set up and methodology
Experiments were performed in a single cylinder, four strokes, direct injection air cooled diesel engine with full power of 4.4 kW and maximum speed 1500 rpm. Schematic diagram of the experimental set up was shown in Figure 1. Engine technical specification were given in Table 2. A sensor is fitted to calculate fuel consumption. Air flow intake rate were measured by a U tube manometer. Exhaust gas temperature was measured by a K-type thermocouple. AVL DiGas444 exhaust gas analyser was used to measure exhaust emissions of the engine. Details about the equipment was given in Table 3.

2.2. Engine set up and methodology
Experiments were performed in a single cylinder, four strokes, direct injection air cooled diesel engine with full power of 4.4 kW and maximum speed 1500 rpm. Schematic diagram of the experimental set up was shown in Figure 1. Engine technical specification were given in Table 2. A sensor is fitted to calculate fuel consumption. Air flow intake rate were measured by a U tube manometer. Exhaust gas temperature was measured by a K-type thermocouple. AVL DiGas444 exhaust gas analyser was used to measure exhaust emissions of the engine. Details about the equipment was given in Table 3.

Figure 1. Schematic layout of experimental setup

Table 2. Engine specifications

| Make/Model          | Kirloskar TAF 1 |
|---------------------|-----------------|
| Rated output        | 4.4 kW          |
| Rated speed         | 1500 rpm        |
| Bore                | 87.5 mm         |
| Stroke              | 110 mm          |
| Piston type         | Bowl-in-piston  |
| Compression ratio   | 17.5:1          |
| Nozzle Opening pressure | 200 bars    |
| Injection timing    | 23° BTDC        |
| Injection type      | Pump-line-nozzle|
| Nozzle type         | Multi-hole      |
| No. of holes        | 3               |

Table 3. Details of gas analyser

| Parameters | Model                  | Range   | Accuracy | Uncertainty |
|------------|------------------------|---------|----------|-------------|
| CO         | AVL 444 di gas analyzer| 0–10%   | 0.06%    | ±0.2        |
3. Result and discussion

3.1. Performance parameter

3.1.1. Brake specific fuel consumption (BSFC)

BSFC is a prime parameter that predicts the engine performance. BSFC is the ratio of fuel consumption and brake power of engine. Figure 2 portrays the variation in BSFC observed for SSB30, WCO30 and diesel at different brake power. It is observed that BSFC reduced with increase in brake power. BSFC of 12.99 and 12.57 MJ/kWhr were observed for SSB30 and WCO30 at full load. In the entire process, BSFC recorded were 58.27 MJ/kWhr, 57.58 MJ/kWhr and 66.82 MJ/kWhr for diesel, SSB30 and WCO30 respectively. WCO30 has a more complete combustion than SSB30 due to higher unsaturation in fatty acid content that helps to reduce the BSFC [20]. SSB has high long chain fatty acid concentration along with high density and viscosity sets barrier for complete burn of fuel leads to high BSFC [4], [21]. Significantly higher BSFC in SSB30 biodiesel blend observed. This is because engine supplies fuel on volumetric basis and SSB30, WCO30 density is more than that of petroleum diesel, which delivers additional biodiesel to counteract the lower calorific value [22]. The higher kinematic viscosity of SSB30 causes poor atomization. Hence poor mixing air-fuel. This was the key reason for larger BSFC during engine analysis of SSB30. The higher oxygen in biodiesel blend developed extra lean combustion environment that degraded the engine efficiency, which led to higher BSFC [7], [23].

3.1.2. Brake thermal efficiency

Brake thermal efficiency of engine is inversely proportional to BSFC. Among the tested fuel i.e., diesel, SSB30 and WCO30 brake thermal efficiency of 29.89%, 27.69% and 28.23% respectively were recorded at full load (Figure 3). High viscosity of SSB30 results power loss as it reduces the combustion efficiency due to bad fuel atomization [24], [22].

3.1.3. Exhaust Gas Temperature (EGT)

Variation in exhaust gas temperature in different loading conditions are shown in Figure 4. Mixed effects were observed for biodiesel blends. At 2.2 and 3.3 kW load WCO30 resulted maximum EGT whereas, at 1.1 kW SSB30 has maximum EGT. Relatively equal EGT recorded at full load condition for WCO30 and SSB30. EGT is the amount of heat loss as exhaust gas during engine operation [5]. Increase in EGT were observed with increasing brake power. The recorded EGT values were 303, 339.55 and 340.5 °C for diesel, SSB30 and WCO30 respectively at full load. An elevated EGT generally observed due to longer combustion duration [25].

3.2. Emission

3.2.1. Nitrogen oxide (NOx) emission

NOx formation takes place by chain reactions of O2 and N2 in suitable temperature condition. Generally, NOx emission depends on injection time, injection pressure and fatty acid profile of biodiesel [9]. It can be observed from Figure 5 NOx emission in g/kWhr decreases with increase in brake power. Biodiesel blends recorded significantly high NOx emission than petroleum diesel. The NOx emission at full load for WCO30 (3.59 g/kWhr) and SSB30 (3.51 g/kWhr) are nearly same as shown in Figure 5. Whereas, in all loading condition SSB30 (17.51 g/kWhr) resulted less NOx emission compared to WCO30 (18.21 g/kWhr). SSB30 recorded 9.09 % and WCO30 13.45 % higher NOx emission than petroleum diesel. Higher unsaturation level and hence, high iodine value in WCO causes higher NOx emission [4], [22]. Short chain saturated fatty acid (methyl palmitate) in SSB
reduced NOx emission. However more of methyl linoleate (C18:2) in WCO30 increased the NOx emission [9], [4].

3.2.2. Carbon monoxide (CO) emission

CO emission in g/kWhr decreases with increase in brake power are shown in Figure 6. Including all loading condition CO emission of 19.34, 16.86, 17.33 g/kWhr were observed for diesel, SSB30 and WCO30 respectively (Figure 6). Significant reduction in emission were observed in biodiesel blends due to high oxygen content that helps in more complete combustion [26]. CO emission reduced by 12.82% for SSB30 and 10.39% for WCO30. Small difference in reduced emission observed due to the close density values of both biodiesel blends. Presence of large amount of palmitic acid methyl ester and less unsaturated fatty acids can reduce CO emission significantly [4], [7]. Therefore, highly saturated SSB with nearly 30% palmitic acid methyl ester has better CO emission than highly unsaturated WCO biodiesel.
Figure 5. Variation in NOx emission with brake power.

Figure 6. Variation in carbon monoxide (CO) emission with brake power.

Figure 7. Variation in hydro carbon emission with brake power.

3.2.3. Hydrocarbon (HC) emission

Total HC emission at all loading conditions were shown in Figure 7. Emission of 0.4 g/kWhr, 0.32 g/kWhr and 0.38 g/kWhr were observed for diesel SSB30 and WCO30 respectively. WCO30 and diesel recorded equal amount of emission i.e., 0.059 g/kWhr at full load. Whereas, SSB30 HC emission lowered by 20% and 15.7% from diesel and WCO30 respectively. HC emission in g/kWhr also decreases with increase in brake power. Large concentration of polyunsaturated fatty acid in WCO resulted higher HC emission. Presence of high concentration of methyl palmitate, methyl stearate and methyl oleate can be attributed to the lowest HC emission [3], [4]. Methyl ester of linoleic acid in large amount is responsible for high HC emission by WCO30.

4. Conclusion
While the entire world is in need of energy source and facing fuel crisis alternate sources like waste cooking oil biodiesel and sewage sludge biodiesel can counter the requirements. On the basis of performance parameters WCO30 is a better replacement of diesel, however the emission characteristics of SSB30 is better than WCO30. Prime finding of the study was given below:

- The BSFC for WCO30 found better than petroleum diesel. This is the most influencing characteristic for the commercialisation of WCO30.
- SSB30 has a satisfying BSFC instead of low immiscibility and higher viscosity.
- Fatty acid profile significantly influenced the emission profile. SSB30 with 30% saturated methyl ester resulted better and cleaner emission than highly unsaturated WCO30 biodiesel blend. Similar monounsaturated methyl ester for both biodiesel blend concluded that the poly unsaturated methyl esters has contributed to higher nitrous oxide, carbon monoxide and hydro carbon emission.
- SSB30 resulted 9.09% hike in NOx emission than diesel and 4.36% lower NOx emission than WCO30. Carbon monoxide emission for SSB30 lowered by 12.86% and 2.48% as compared to diesel and WCO30. SSB30 has a reduced the HC emission of 15.7% and 20% compared to WCO30 and diesel.

5. Notations

SSB – Sewage sludge derived 100% FAME
WCOB – Waste cooking oil derived 100% FAME

6. References

[1] World Energy Council (WEC) 2011 Global transport scenarios 2050 (London: WEC)
[2] Jayaprassanna Kumar D and Binnal P 2012 Performance evaluation of a single cylinder diesel engine fueled with biodiesel produced from pumpkin oil J. Sci. and Ind. Res. 71 75–78
[3] Liu H, Ma X, Li B, Chen L., Wang Z and Wang J 2017 Combustion and emission characteristics of a direct injection diesel engine fueled with biodiesel and PODE / biodiesel fuel blends Fuel 209 62–68 doi:10.1016/j.fuel.2017.07.066.
[4] Pinzi S, Rounce P, Herreros J M, Tsolakis A and Dorado M P 2015 The effect of biodiesel fatty acid composition on combustion and diesel engine exhaust emissions Fuel 104 170–182 doi:10.1016/j.fuel.2012.08.056.
[5] Yu CW, Bari S and Ameena A 2002 Comparison of combustion characteristics of waste cooking oil with diesel as fuel in a direct injection diesel engine J Automobile Eng. 216 237–43
[6] Gnanasekaran S, Saravanan N and Ilangkumaran M 2016 Influence of injection timing on performance , emission and combustion characteristics of a DI diesel engine running on fish oil biodiesel 116 1218–1229 doi:10.1016/j.energy.2016.10.039.
[7] Ruhul A, Abedin J, Rahman S M A, Haji B, Masjuki H, Alabulkarem A, Kalam A and Shancita I 2016 Impact of fatty acid composition and physicochemical properties of Jatropha and Alexandrian laurel biodiesel blends: An analysis of performance and emission characteristics J. clean. prod. 133 1181-1189
[8] Aurélio M, Lagnier B, Ferreira G, Guilherme L, Lamare A, Murta S, Aurelio M and Freitas V De 2017 Comparative study of NOx emissions of biodiesel-diesel blends from soybean, palm and waste frying oils using methyl and ethyl transesterification routes Fuel 194 144–156 doi:10.1016/j.fuel.2016.12.084
[9] Omidvarborna H, Kumar A and Kim D S, 2015 NOx emissions from lowerature combustion of biodiesel made of various feedstocks and blends Fuel Pro. Tech. 140 113–118 doi:10.1016/j.fuproc.2015.08.031
[10] Azeeem M W, Hanif M A, Al-Sabahi J N, Khan A A, Naz S and Ijaz A 2016 Production of biodiesel from low priced, reclaimed and abundant date seed oil Renew. Energy 86 124–132 doi:10.1016/j.renene.2015.08.006.
[11] Olkiewicz M, Torres C M, Jimenez L, Font J and Bengoa C 2016 Scale-up and economic analysis of biodiesel production from municipal primary sewage sludge Bioresour. Techno.214 122–131 doi:10.1016/biortech.2016.04.098.
[12] Tan Y H, Abdullah M O, Nolasco-hipolito C, Syuhada N and Zauzi A, 2017 Application of RSM and Taguchi methods for optimizing the transesterifi cation f i catalyze solid ostrich and chicken-eggshell derived CaO Renew. Energy 114 437–447 doi:10.1016/j.renene.2017.07.024.

[13] Urrutia C, Sangaletti-Gerhard N, Cea M, Suazo A, Aliberti A and Navia R 2016 Two step esterification-transesterification process of wet greasy sewage sludge for biodiesel production Bioresour. Technol. 200 1044–1049 doi:10.1016/j.biortech.2015.10.039.

[14] Olkiewicz M, Caporgno M P, Fortuny A, Stuber F, Fabregat A, Font J and Bengoa C 2014 Direct liquid-liquid extraction of lipid from municipal sewage sludge for biodiesel production Fuel Pro. Tech. 128 331–338 doi:10.1016/j.fuproc.2014.07.041.

[15] Melero J A, Sánchez-Vázquez, Vasiliadou I A, Martinez Castillejo F, Bautista L F, Iglesias J, Morales G, Molina R 2015 Municipal sewage sludge to biodiesel by simultaneous extraction and conversion of lipids Energy Conv. and Manage. 103 111–118 doi:10.1016/j.enconman.2015.06.045.

[16] Usman K, Khan S, Ghulam S, Khan M U, Khan N, Khan M A and Khalil S K 2012 Sewage Sludge: An Important Biological Resource for Sustainable Agriculture and Its Environmental Implications Ame. J. Plant Sci. 3 1708-1721 doi:10.4236/ajps.3.812109.

[17] Priyadarshi, D., Karar, P.K.: 2017 Optimisation of Biodiesel Production Using Taguchi Model Waste biomass valori. In press doi: 10.1007/s12649-017-0158-9

[18] Choi OK, Song JS, Cha DK, Lee JW 2014 Biodiesel production from wet municipal sludge: Evaluation of in situ transesterification using xylene as a cosolvent Bioresour. Technol. 166 51-56 doi:10.1016/j.biortech.2014.05.001.

[19] Roosta A, Sabzpooshan I 2016 Modeling the effects of cosolvents on biodiesel production Fuel 186 779–786

[20] Heywood J B 1988 Internal combustion engines fundamentals (New York: McGraw- Hill)

[21] Hansen K F, Jensen MG 1997 Chemical and biological characteristics of exhaust emissions from a DI diesel engine fuelled with rapeseed oil methyl ester (RME) SAE paper 971689

[22] Jinlin X, Grift Tony E, Hansen Alan C 2011 Effect of Biodiesel on Engine Performances and Emissions Renewable and Sustainable Energy Reviews 15(2) 1098–1116 http://dx.doi.org/10.1016/j.rser.2010.11.016.

[23] Ganapathy T, Murugesan K, Gakkhar RP 2009 Performance optimization of Jatropha biodiesel engine model using Taguchi approach Appl. Energy 86 2476–2486 doi:10.1016/j.apenergy.2009.02.008

[24] Aydin H and Bayindir H 2010 Performance and emission analysis of cottonseed oil methyl ester in a diesel engine Renew Energy 35 588–592

[25] Sharma A and Sivalingam M, 2014 Influence of Fuel Injection Timing on the Performance and Emission Characteristics of a Diesel Engine Fueled with Jatropha Methyl Ester- Tyre Pyrolysis Oil Blend Fuel 594 1627–1631 doi:10.4028/www.scientific.net/AMM.592-594.1627

[26] Chauhan B S, Kumar N and Cho H M 2012 A study on the performance and emission of a diesel engine fuelled with Jatropha biodiesel oil and its blends Energy 37 616-622.