Performance evaluation of biodiesel from used domestic waste oils: a review

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Performance evaluation of biodiesel from used domestic waste oils: A review

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1. Introduction

The generation of waste and their significant environmental consequences has been described to have risen in the past decades due to the rapid industrialization and its associated impact upon the world economy (Tsai and Chou, 2004). The proper management of waste not only contributes significantly to reducing the numerous adverse effects on public health (Fabiyi and Skelton, 1999; Winward et al., 2008) but also has a major impact upon lowering global warming effects (Papageorgiou et al., 2009). The latter problem has been identified as the most critical environmental issue currently (Ahmad et al., 2011). Among the detrimental effects of global warming are loss of lives, extinction of species and submerging of islands arising from a rise in sea levels (Ahmad et al., 2011).

Recently, there has been a lot of clamours regarding the environment and its sustainability (Folizaro et al., 2006; Papageorgiou et al., 2009). Thus UDWO should be considered as a source of fuel for effective mitigation of greenhouse gas emissions (GHG) as well as for providing environmental benefits and sustainable development via waste conversion to energy (Papageorgiou et al., 2009). Still on attaining sustainability, and in line with the objective of achieving the 2020 and 2030 goal of substituting approximately 20% and 30% of
petro-diesel with biofuels in US and EU, respectively (González Gómez et al., 2002), a policy of recovering value from waste has been enforced and this includes waste diversion from landfill. The interest of the European Union in the utilization and consumption of biodiesel is based on their greater production of biodiesel, which is estimated at approximately 85% of the world’s total (3.8 billion liters in 2005) (Ahmad et al., 2011).

Energy from waste has been described by Papageorgiou et al. (2009) as a waste management option that could significantly reduce greenhouse gas emissions (GHG). For used domestic waste oil (UDWO), the current world annual figure of UDWO generation is estimated at more than 15 million tons (Kalam et al., 2011). This waste is channeled through the drain with the related implications of energy loss and inhibiting performance of municipal wastewater treatment plants (Felizardo et al., 2006). These reasons among others results in the prohibition of dumping domestic wastes in municipal waste treatment facilities. Thus, these wastes, if effectively treated are a potential source of an environmentally friendly fuel (Cvengros and Cvengrosova, 2004).

The interest of this study is limited to wastes with potentials of being converted to fuels and specifically to methyl esters (MEs) of long fatty acids (biodiesel). The performance of the biofuel is adjudged to be comparable to fossil fuels (Felizardo et al., 2006) and its use in the compression-ignition (CI) engine requires little or no modification of the engines themselves (Çetinkaya et al., 2005). Biodiesel is also an environmentally friendlier form of fuel. Being renewable it offers the merit of reduction in greenhouse gas emissions while the UDWO is available everywhere. Moreover, indicators show that sources of fossil energy are rapidly depleted, and the future forecast is not encouraging. Thus biodiesel could go a long way in attaining the 2020 and 2030 target by several key players in the global market. For instance, the US plans to replace the utilization of both diesel and petrol with biofuels by 30% (2030) and similarly EU member countries have planned a 20% substitution of fossil fuel by 2020 in the transportation sector. This necessitates adopting policies by all of the most active players in the industry, i.e., the European Union, China, Australia and New Zealand, aimed at increasing production. Currently, the annual biofuel production target is approximately 227 billion liters (Blake et al., 2008).

The objectives of this review are to give an overview of potential sources of feedstock for biodiesel production, their merits and demerits, and the environmental incentives for promoting biofuel generation from such sources. The benefit analysis in using UDWO as a fuel source is further discussed. The summary of the findings clearly indicates several merits in the generation of biodiesel from UDWO, an energy source yet to be fully exploited. The research findings further establish the need to harness UDWO for mass-scale biodiesel production.

2. Biodiesel

2.1. Definition

Biodiesel can be defined as a monoalkyl ester of long chain fatty acids derived from a renewable lipid feedstock, such as vegetable oil or animal fat.

2.2. History

A succinct history of biodiesel has been provided in a separate review paper (Lin et al., 2011a). Biodiesel production from vegetable oils was first conducted by Duffy and Patrick in 1853. In 1893 vegetable oils were used for the first time in a CI engine by Rudolf Diesel. By 1920s, due to the relative cost effectiveness, availability and government subsidies, fossil-based diesel application completely over took the vegetable oils. Due to problems arising from poor atomization of the fuel that resulted in deposition of residues and coking of the injectors, combustion chamber and valves, the vegetable oils needed refining by processes such as pyrolysis (Mahfud et al., 2007), blending (Fontaras et al., 2007; Pramanik, 2003) and microemulsification (Srivastava and Prasad, 2000). However, problems were observed to persist especially with carbon deposition and contamination (Gerpen, 2005; Sarin et al., 2007). Hence, conversion of vegetable oils to biodiesel using transesterification grew in popularity.

To ensure proper quality control of the fuel various biodiesel standards, such as EN 14214 (Europe) and ASTM D 6751 (North America), were formulated. Adherence to these standards made it easier for automobile manufacturers to issue engine warranties for the implementation of biodiesel fuel in the engine (Lin et al., 2011b). Continuous revision and updates of the standards became necessary as automobile manufacturers evolved newer engine designs with the passage of time. As a consequence of strict quality control on biodiesel fuel, service outlets started frequenting many parts of Europe and US during the 2000s. However, the cost of biodiesel fuel has limited its widespread commercialization and various research and development programs are ongoing throughout the globe to bring the cost factor down (Chuepeng and Komintarachat, 2009; Lin et al., 2011a). Thus, identifying cheaper and sustainable sources would always be a welcome progress.

3. Potential biodiesel feedstock sources

The need to examine and harness potential feedstock for biodiesel production is hinged on the fact that the petro-diesel sources are associated with plenty of problems. They range from possible depletion of the fossil fuel sources (estimated at 41 years) (Agarwal, 2007) to adverse effects on the environment as a consequence of their utilization (Ahmad et al., 2011). In fact, a major problem that arises from the exploration and consumption of the fossil based fuels is the steady decline in underground-based carbon fuel reserves (Melvin Jose et al., 2011).

There are many potential sources for biodiesel production from biomass. By definition, biomass includes all biodegradable fractions of products, waste and residues from agriculture (vegetable and animal substance), forestry and related industries and the biodegradable components of industrial and municipal waste (Chuepeng and Komintarachat, 2009). Some of these sources would be briefly analyzed in the proceeding sections.

For feedstock of forestry origin, many socio-economic and environmental issues adversely affect the large scale exploitation of this form of resources for biodiesel production. Among others are policies involved in primary forest destruction, issues with non-governmental organizations (NGO),
displacement of natural habitat and conflict with the indigenous population (GFOM, 2007).

The high cost of biodiesel is incurred in the form of feedstock cost, which ranges from 70 to 95% of total operating costs. A limit of 75% for the cost of raw materials has also been reported (Ahmad et al., 2011; Chuvepang and Komintarachat, 2009; Lim and Teong, 2010) and illustrated graphically in Fig. 1. This higher production cost necessitates the search for more economically attractive feedstock which, via their utilization, effectively lowers the production cost (Ahmad et al., 2011).

3.1. Industrial

These categories of waste are known to be the most problematic of all the wastes disposed/generated. This is associated with their great complexity and serious environmental hazards (Fabiyi and Skelton, 1999; Pidou et al., 2009; Tsai, 2010). They are an unattractive source of generating energy as they are known to contain toxic contaminants in quantities sufficient for adversely affecting the environment and quality of life. Equally, non-hazardous waste is generated from sources such as food processing waste, scrap plastics, waste rubber, waste paper, organic/inorganic sludges, coal ash and others (Tsai, 2010). However, most of these wastes are non-biodegradable in nature. Thus, they lack the potentials for biodiesel production as they fail to meet the “biodiesel from biomass” criteria. On the other hand, there are industrial discharges of waste that are non-hazardous in nature and have potentials for biodiesel generation, especially from the palm oil industry. Among such are palm oil fatty distillates (Hayyan et al., 2011), tobacco seed oil (Usta et al., 2011), rubber seed oil (Melvin Jose et al., 2011) and low grade oils such as sludge palm oil (Hayyan et al., 2011). Again, issues of sustainability of some of these sources become their bane.

A sustainable source is the use of waste generated from crude vegetable oil discoloration (bleaching). Reported work in the literature suggests that the utilization of the adsorbed crude vegetable oil on the spent bleaching earth (SBE) is an economical approach. These residual oils recovered from the SBE are a potential biodiesel feedstock source. The SBE oils, mostly generated from soybean, rapeseed and palm oil refinery facilities have similar composition to vegetable oils (Pizarro and Park, 2003; Loh et al., 2006; Huang and Chang, 2010).

As the SBE is directly sourced from edible oil, the sustainability of this form of feedstock is assured. Thus, based on figures reported by Huang and Chang (2010) of 1.2-1.6 kg of SBE generation per metric ton of edible oil production, an average of 1.5-2.0 million tons of biodiesel are generated from the edible oil production of 128.2 million metric tons.

In addition, the percentage yields of residual oils recovered ranges between 20 and 40% of residual oil from SBE (Loh et al., 2006; add). This coupled with the high conversion yield of the extracted oil make its utilization attractive. There are several routes for the methyl esters conversion. The lowest conversion is obtained in the case of methanolysis, such as the use of lipase-catalyzed method as reported by Pizarro and Park (2003) where a conversion of 55% (w/w) is attained. However, as lipase catalyzed transesterification is expensive compared to other methods, it is not very economical to produce biodiesel using this reaction (Marchetti et al., 2005; Boey et al., 2011).

A higher conversion of 75.2% is reported when the in situ transesterification is supplemented by means of ultrasound using petroleum ether (PE) as an organic co-solvent (Boey et al., 2011). The higher yield may be associated with induced asymmetric cavitation bubbles collapse at the oil/alcohol boundary which enhances the mass transfer between the phases thus accelerating the reaction (Boey et al., 2011). A slightly higher conversion of 80% (Table 1) is obtained when solvent and supercritical-fluid (SC-CO2) extraction are employed (Loh et al., 2006). Of the many conversion approaches, the two-step esterification reported by Huang and Chang (2010) gave the highest yield of 85–90%.

The quality of biodiesel derived from residual oil of SBE is in reasonable agreement with both EN 14214 and ASTM D6751 standards and have comparable fuel properties as petroleum diesel. Hence, these methyl esters may be used as a diesel substitute (Huang and Chang, 2010).

Moreover, as disposal of the SBE poses serious environmental hazards associated with fire and pollution (Huang and Chang, 2010; Boey et al., 2011), the oil extraction becomes a sound alternative to its disposal. In addition, the oils extracted exhibit poor qualities in terms of free fatty acids (FFA) content of more than 10% along with high peroxide values (Loh et al., 2006) thus making them suitable for food applications. In addition the de-oiled bleaching earth can be reused as an absorbent in wastewater treatment or as a clay substitute in the brick or tile manufacturing process (Boey et al., 2011).

3.2. Agricultural

Production of biodiesel from agricultural, non-food feedstock sources is another viable option that potentially reduces the utilization of edible oils. Such crops that have been reportedly used includes: rubber seed (Melvin Jose et al., 2011; No, 2011), jatropha ( Jain and Sharma, 2010; Jain et al., 2011; No, 2011), mahua (Saraswani et al., 2010), tobacco seed (Usta et al., 2011), castor (Chakrabarti and Ahmad, 2008), erica sativa (Chakrabarti and Ahmad, 2009) and pongame (Kumar and Sharma, 2011), among others. It could be argued that these sources of biodiesel feedstock have minimal effect on the competition for food and that some species are adaptable to growth on wastelands (Ahmad et al., 2011). However, the viscosity of neat vegetable oil (range of 28–40 mm²/s) is high; its direct use has led to diesel engine problems such as deposits formation and injector coking arising from poor atomization (Knothe, 2010).

Of interest is jatropha curcas oil, as it comprises non-edible oil, coming from a perennial plant, with high oil content in the seed and with good productivity per hectare (Zanette et al., 2011). Most recent experimental studies on this oil have been conducted by Zanette et al. (2011). In their study new
Table 1 - Reaction time and biodiesel yield from various methods utilizing SBE.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Methyl ester yield (%)</th>
<th>Esterification method</th>
<th>Reaction time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Huang and Chang (2010)</td>
<td>90</td>
<td>Two-step esterification</td>
<td>60 min</td>
</tr>
<tr>
<td>Piizarro and Park (2003)</td>
<td>55</td>
<td>Lipase-catalysis methanolysis</td>
<td>96 h</td>
</tr>
<tr>
<td>Leht et al. (2006)</td>
<td>80</td>
<td>Solvent and supercritical-fluid (SC-CO₂)</td>
<td>180 min</td>
</tr>
<tr>
<td>Roe et al. (2011)</td>
<td>72.5</td>
<td>In situ transesterification by the aid of ultrasound and organic co-solvents petroleum ether</td>
<td>120 min</td>
</tr>
</tbody>
</table>

Table 2 - Global distribution of biodiesel feedstock according to countries (Ahmad et al., 2011).

<table>
<thead>
<tr>
<th>Country</th>
<th>Feedstock</th>
<th>Oil yield (l/ha/year)</th>
<th>Land use (m²/year/kbbiodiesel)</th>
<th>Biodiesel productivity (kg/biodiesel/ha/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>Soybeans</td>
<td>636</td>
<td>18</td>
<td>321</td>
</tr>
<tr>
<td>Europe/EU</td>
<td>Rapeseed, Sunflower</td>
<td>1070</td>
<td>11</td>
<td>946</td>
</tr>
<tr>
<td>Western Canada</td>
<td>Canola Oil</td>
<td>974</td>
<td>12</td>
<td>809</td>
</tr>
<tr>
<td>Africa</td>
<td>Jatropha</td>
<td>741</td>
<td>15</td>
<td>656</td>
</tr>
<tr>
<td>India</td>
<td>Jatropha</td>
<td>741</td>
<td>15</td>
<td>656</td>
</tr>
<tr>
<td>Malaysia/Indonesia</td>
<td>Palm</td>
<td>5366</td>
<td>2</td>
<td>4747</td>
</tr>
<tr>
<td>Philippines</td>
<td>Coconut</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>China</td>
<td>Waste Cooking oil</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Spain</td>
<td>Linseed</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Greece</td>
<td>Cotton Seed</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

Experimental data and kinetic modeling of transesterification of Jatropha curcas oil are reported using heterogeneous catalysts. The results show that by using KSF clay and Amberlyst 15 as catalysts around 70 wt.% of FAME yield are obtained at relatively mild conditions and short reaction times. However, catalyst inactivation during re-use has been found to occur. Thus for large-scale production the technical limitations need to be addressed. Moreover, this feedstock availability is more in Africa and India (Table 2). Accordingly, for EU's utilization of Jatropha curcas importation factors come in. From an economic point of view, this is unattractive and contributes to the figures reported by Predojevic (2008) in which vegetable oil derived biodiesel costs amount to about 10–50% higher than that of petroleum-based diesel fuel.

To attain the biodiesel production target using rapeseed (the main European feedstock), about 60% of Europe's arable land has to be utilized. Based on this figure it is clear that the target cannot be met (GFOM, 2007). Even the previous targeted quota (2010 EU's target of replacing 5.75% of diesel fuel with biofuel), which appears small translates to very large scales in practice. Still, on these figures, Skelton (2007), has highlighted the scenario involved in attaining the previous 2010 EU's target of replacing 5.75% of diesel fuel with biofuel to include competition with food crops and the destruction of rain forests at the expense of new plantations. For palm oil, a report raised by Marcel Silvanus (GFOM, 2007) has shown that as a sustainable source the use of palm oil is unattractive from an environmental perspective. This is based on the release of massive amounts of carbon dioxide, and the oil is far from being carbon-neutral. Although, several articles have questioned the credibility of the data generated and subsequent analysis, the fact is that in Europe several calls have been made for banning its use.

3.3. Municipal

The production of biodiesel from municipal sources, which includes animal fat and beef tallow, has been well documented in many referenced literature (Liu et al., 2011; Ma et al., 1999; Nelson and Schock, 2006; Soldi et al., 2009; Zheng and Hanna, 1996). It offers the merit of being a cheap form of alternative renewable energy source to petroleum fuel. Generally, they are classified into mainly edible and inedible types and are generated by the meat packing, poultry, and edible/inedible rendering industries (Nelson and Schock, 2006). Technically, the use of this feedstock as a biodiesel source presents difficulties in terms of production. They contain a high amount of saturated fatty acids (SFA) which leads to a difficult esterification process. A typical example is beef tallow with an average SFA representing approximately 50% of the total FA, thus accounting for high melting point and high viscosity of the final biodiesel. Additionally, biosecurity consideration is another factor limiting the viability of such sources as contaminated animals are not discriminated in the fat application (Ahmad et al., 2011).

3.4. Used domestic waste oils (UDWO)

Literature is replete with studies on UDWO for biodiesel production. Among the several sources are cottonseed oil, soybean oil, sunflower oil, tobacco seed, and palm oil (Dorado et al., 2003; Hamasaki et al., 2001; Phan and Phan, 2008; Tahkounda et al., 2003; Wu et al., 2009). The UDWO is a more attractive low-cost feedstock for biodiesel production in comparison to vegetable oils as they are not affected by land policies as witnessed in some countries, especially the EU (González Gómez et al., 2002), price is half that of vegetable oil and huge amounts are generated (approximately 0.4 Mt from EU countries while estimated amounts stand at 0.7–1.0 Mt) (González Gómez et al., 2002). In a recent review by Zanette et al. (2011), several advantages of UDWO have been highlighted, and these include a decrease in the competition with food items, overcoming problems associated with planting and harvesting, a minimum or negligible land area requirement, minimum use of fertilizers, and other factors, which result in the significant decrease in the price of feedstock. A detailed breakdown of feedstock statistics is given by Ahmad et al. (2011) for each of the major producers of biodiesel.

The detrimental effect in employing UDWO to prepare feeding formulations for domestic animals have resulted in its ban in the EU from 2002 (Ovengros and Ovengrosová, 2004). This provides further justification for the necessity of
Table 3 – Used domestic waste oil generation by countries (Kalam et al., 2011; Thamsirirj and Murphy, 2010).

<table>
<thead>
<tr>
<th>Country</th>
<th>Quantity (million tons/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>4.5</td>
</tr>
<tr>
<td>Malaysia</td>
<td>0.5</td>
</tr>
<tr>
<td>United States</td>
<td>10.0</td>
</tr>
<tr>
<td>Taiwan</td>
<td>0.07</td>
</tr>
<tr>
<td>Europe</td>
<td>0.7-10</td>
</tr>
<tr>
<td>Canada</td>
<td>0.12</td>
</tr>
<tr>
<td>Japan</td>
<td>0.65-0.57</td>
</tr>
<tr>
<td>Ireland</td>
<td>0.153</td>
</tr>
</tbody>
</table>

Intensifying UDWO conversion to biodiesel. In comparison to beef tallow, the UDWO applications are limited whereby the inedible form of the former finds usefulness among others as an additive for animal feed, use in fatty acids and soap manufacture, lubricants and others (Nelson and Schrock, 2006). Moreover, the use of waste oils for biodiesel production saves cost significantly as it is almost free or usually priced at a value that is approximately 60% lower than that of conventional vegetable oils (Prodejovic, 2008).

It should be noted that in choosing a particular biomass source for renewable energy production, the GHG emission generated in due course of its production, transportation and processing should be factored in. A final check of all the mentioned points might indicate the sources as not so attractive. However, an overall assessment of UDWO clearly shows it is not affected by these limitations.

4. Used domestic waste oil (UDWO)

4.1. Generation

These categories of waste oil are mostly generated from edible vegetable matter. Of all the available sources of domestic waste, used domestic waste oils (UDWO) are arguably the most widely generated. This could be associated with the recent proliferation of fast food outlets (on a small and industrial scale) due to the affinity of the young generation to fast food (Cvengros and Cvengrosová, 2004). Morals of these wastes include less separation and purification steps. Here, pretreatment is basically water and gum filtration, followed by hydrogenation and then de-acidification (Kalam et al., 2011).

The frying process exposes the oil during cooking and the food preparation step renders the oil detrimental to further human consumption (Kalam et al., 2011). Moreover, biodiesel production with UDWO is more universal as fast food outlets are abundant in most urban places while the use of refined edible/non edible oils are restricted to certain countries and regions. This is further buttressed by the amount of UDWO generated from some countries (Table 3). Based on Table 3, it is clearly evident that disposal of these large amounts of UDWO through direct discharges into drains or sewers may lead to significant environmental problems as watercourses and wildlife are directly affected (Kalam et al., 2011).

4.2. Process of frying

Basically, the process of frying involves heating of the vegetable oils for varied times in the air at temperatures ranging from 160 to 200°C (Cvengros and Cvengrosová, 2004). This in turn degrades the oils through hydrolytic, oxidation and cracking reactions resulting in increased viscosity and acidity as well as associated unpleasant odor and a darker coloration. The variation of treatment conditions and the fact that the oils are sourced from different vegetable oils results in an increased variability in the compositional characteristics of the biodiesel formed from UDWO and accounts for the changes in the chemical and physical properties (Felizardo et al., 2006). The same has been highlighted by Knothe and Steidle (2009).

The detailed analysis of the transformations steps is reported by Cvengros and Cvengrosová (2004). The process may be summarized as the hydrolytic splitting of triacylglycerols in the presence of water. Although, a portion of the water evaporates, others dissolve in the fat and induce the cleavage to give rise to higher FA and glycerol content. Oxygen dissolves in the fat and initiates the formation of several oxidation products from the reaction of oxygen with unsaturated acylglycerols. The remainder of the fat in the fried oils, constitute the high free fatty acid content that necessitates an additional step – acid pre-treatment, for adequate high-yield conversion to biodiesel (Canakci and Van Gerpen, 2001; Knothe and Steidle, 2009).

4.3. Effect of UDWO properties on the transesterification reaction

Generally, the physical and chemical characteristics of UDWO are associated with contaminants such as water, free fatty acids; these impurities are subject to the fresh cooking oil and are a cause of concern on the quality of UDWO (Gui et al., 2008; Leung and Guo, 2006; Singh and Singh, 2010; Upham et al., 2009). The transesterification process of UDWO is greatly affected by the following parameters: acid value, iodine value and water content. Thus UDWO feedstock needs to be screened for these three parameters (Math et al., 2010). As described by Tsai et al. (2007), the relevance of the analysis is informed by the fact that the free fatty acids content is reflected by the acid value, which can be saponified with caustic catalyst to form saponifiable matter. High water content, on the other hand, manifest negatively on the downstream processing due to the formation of bulk solids in alkali-catalyzed processes. For unsaturated fatty acid measurements, the iodine value is used. This parameter decreases as the deterioration in the edible oil quality increases. For UDWO with low acid value, the transesterification reaction could be performed directly. Similar reports are abundant in the literature, i.e., Canakci et al. (2009) have reported the use of UDWO (palm oil) having an acid value of 0.58 mgKOH/g for biodiesel production. In the literature, reported use of strong acidic ion exchange resins is effective in the esterification reaction of the FFA in UDWO. However, loss of the catalytic activity poses a challenge (Lou et al., 2008; Ozbay et al., 2008).

Despite the potential of UDWO in biodiesel production, they have a limitation of high free fatty acid content of 0.5% (Hayyan et al., 2011; Jiménez-López et al., 2011; Ozbay et al., 2008). This requirement apparently retards the prospects of UDWO as its FFA content is usually more than 2 wt% (Issariyakul et al., 2007; Watanabe et al., 2001; Zhang et al., 2003). Sabudak and Yildiz (2010), attempted to analyze the compliance of several purified biodiesel fuels with the EN 14214 standard; they faced serious challenges in preparing biodiesel from UDWO without acid esterification when FFA values of the UDWO exceeded 2%. This was similar to the
conclusion reported by Kalam et al. (2011), who further reported that for transesterification reaction, the FFA content of the biodiesel should not exceed 1% (Chakrabarti and Ahmad, 2008; Papageorgiou et al., 2009). Although the FFA content from some sources is less than 2%, others are above 5% (Issariyakul et al., 2007). An implication of this is that the homogeneous alkaline transesterification reaction is hindered by the saponification reaction leading to soap formation (Jiménez-López et al., 2011).

Thus, a step can be incorporated to enhance the suitability and viability of these oils. Canalcı and Van Gerpen (2001) demonstrated the feasibility of reducing the high FFA values of a UDWO to less than 1% in a two-step pretreatment process. More recently, Hayyan et al. (2011) reduced the FFA content of a sludge palm oil (SPO) from 23.2% to below 2%. However, such elaborate pretreatment procedures increase the general overhead costs.

The problems can be addressed by employing a strong liquid acid catalyst whereby the transesterification process is not significantly affected since the catalyst has reduced sensitivity towards FFA (Kulkarni and Dalai, 2006). In the literature, Sendzikiene et al. (2004) has nearly 50% conversion of UDWO to biodiesel when using 1% homogeneous acidic catalyst (H₃SO₄) at 50 °C, and a similar result has been reported for A-15 heterogeneous catalyst (Ozbay et al., 2008). However, a higher temperature is required, and a slower reaction rate is observed (Ozbay et al., 2008). Use of solid acid catalyst (ionic exchange resins, zeolites, superacid, etc.) is more attractive, as corrosion is prevented (Viviana Silva and Rodrigues, 2006), a high FFA conversion is attained, and a more effective catalyst separation is achieved (Loterio et al., 2005). On the use of solid acid catalyst, Ozbay et al. (2008) has studied the batch esterification of FFA in UDWO using four different ion-exchange resins (Amberlyst-15 (A-15); Amberlyst-35 (A-35); Amberlyst-16 (A-16) and Dowex HR-2) by varying the amount of catalyst used (1–2 wt.%) and observed an increase in FFA conversion with an increase in both catalyst amount and reaction temperature. However, reaction duration can be reduced using an acid catalyst than an ion exchange process as demonstrated in the work of Sendzikiene et al. (2004) where complete FFA esterification reaction has been attained in 15 min for the homogenous catalyst (H₃SO₄) as against 100 min for Relite CFS (an acidic ion exchange polymeric resin), which was reported by Tesser et al. (2006). It is known that the production route as well as the feedstock affects the biodiesel produced from UDWO (Zhang et al., 2003). More recently, Sabudak and Yildiz (2010), reported that the transesterification of a UDWO having a FFA value of 4.6% by means of an acid base reaction followed by ion-exchange resin purification met the EN 14214 requirements adequately. This research outcome paved the way of utilizing UDWO composing of more than 2% FFA for biodiesel production.

4.4 Quality of fuel

As mentioned by Knothe and Steidley (2009), a major issue with the application of biodiesel is its fuel properties, which inevitably determines its performance. Generally, as with most diesel-range fuels, biodiesel combustion efficiency in an engine is subject to fuel parameters that include viscosity, lubricity, heat of combustion, cetane number (CN), cold flow characteristics, and oxidation stability (Saraf and Thomas, 2007). Biodiesel from UDWO sources have been reported to possess properties similar to fossil fuels. The biodiesel quality is assessed by various agencies in different countries; however, it must comply with either International Biodiesel Standard for Vehicles (EN 14214) or American Society for Testing and Materials (ASTM) standards (ASTM D 6751). The latter standard stipulates 25 parameters but usually a minimum of seven parameters can be used to assess the quality. Based on this, seven parameters (see Table 4) have been used as a basis in this review. Clearly from the results of Table 4, the latter fuel is associated with low viscosity and lower density in comparison to the former. Based on the similarity of the properties, UDWO-fuels are thus more attractive sources of biodiesel feedstock.

Table 4 shows that the UDWO-biodiesel adequately meets the quality indices prescribed by the ASTM and EN-14214 for biodiesel quality. The UDWO based fuels have been shown to have a higher degree of saturation, greater oxidative stability, higher viscosity, higher cetane number as well as higher cloud and pour points than other counterparts (Knothe and Steidley, 2009). However, the latter two properties can adversely affect fuel performance as they can cause poor low-temperature properties. In addition, increased storage time increases the acid and peroxide values, a common phenomenon with biodiesel originating from other sources (Bouaid et al., 2007). Furthermore, the acid value and viscosity are consistently observed to increase with time as established by Knothe and Steidley (2009) due to variation in the extent of oils and fats saturation. It is observed that irrespective of the source and type of the UDWO, the acceptable biodiesel viscosity range of 1.9–6.0 mm²/s (ASTM D 6751) is maintained throughout its storage and performance periods. This is expected as the viscosity of the most viscous methyl ester of common fatty acids (stearic acid methyl ester) is slightly below 6.0 mm²/s (Knothe and Steidley, 2009).

Biodiesel production from UDWO is a continuous one due to increasing production of the waste oils from household and industrial places (Felizardo et al., 2006). A drawback to the use of UDWO is its color (dark-brown or even red), odor (unpleasant), increased viscosity of the fat and acidity due to degradation (Felizardo et al., 2006). Furthermore, increased amounts of free fatty acids, decrease in the iodine number, change in the refraction index and increasing tendency of the fat to foam are all associated with the frying process (Cvengros and Cvengrosová, 2004). These chemical and physical changes, resulting from hydrolytic and oxidative reactions have been discussed by several researchers (Cvengros and Cvengrosová, 2004; Enweremadu and Mbarawa, 2009; Felizardo et al., 2006).

The biodiesel produced from UDWO following transesterification reaction may contain impurities such as soap, monoo-, di-, tri-glycerides, glycerine, methanol and salts. Thus, the post-treatment method becomes vital. Of the several methods, ion-exchange resins have been shown to be particularly useful for high FFA containing feedstock where satisfactory separation of impurities from biodiesel is attained (Berrios and Skelton, 2008; Ozbay et al., 2008).

The high viscosity of the UDWO feedstock necessitates post processing as the transesterification reduces the viscosity but does not meet the required standard at times. On the high viscosity problem, blending about 5% of the UDWO fuel with No. 2 diesel fuel can adequately address carbon deposition, filter plugging, poor atomization of fuel, injector coking and excessive engine wear problems (Kalam et al., 2011). Kalam et al. (2011) used a multi-cylinder diesel engine to compare emission and performance characteristics of palm

Full text is available at :