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Contribution of Liquid Biofuels To Socio-Economic Rural Development

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Abstract

The rural community still lacks access to clean, cost effective and sustainable form of energy that is needed to power their socio-economic activities, particularly for agriculture, water supply and food processing. Understanding that energy has a close link with poverty reduction, economic growth and sustainable development, a study on the process of modifying plant oil (PO) to produce a suitable liquid biofuel that can run diesel engines commonly used in rural areas for various social-economic activities was carried out. The research was part of works by Policy Innovation System for Clean Energy Security (PISCES) research project, which was a five-year initiative project funded by the UK's Department for International Development (DFID). PISCES, which had partners in Kenya, India, Sri Lanka, United Kingdom and Tanzania, intended to provide policy makers with information and approaches that can unlock the potential of bioenergy to improve energy access and livelihoods in rural communities. The PO used was indigenous non-edible oil from Jatropha (Jatropha Curcas L.) seeds. Modified Plant Oil (MPO) presents a potential clean, cost-effective, sustainable and accessible fuel to meet rural basic energy needs. MPO can also power rural agro-processing activities by being used in power tillers, millers, water pumps, etc., and become an important key for socio-economic development of rural population relying on agricultural activities. The use of renewable energy from PO will contribute to sustainable energy source and to reduce CO_2 emission, contributing to reduce climate change problems.

Keywords: *modified plant oil, liquid biofuel, natural gas condensate, diesel engine*

Introduction

The rural world comprises more than 80% of the world's population, and is dominated by poverty (FAO & PISCES, 2009; UN, 2007). The lack of access to modern energy services, or inadequate energy infrastructure, is one of the reasons for the domination of poverty in rural areas. Modern energy

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technologies are often inaccessible to rural communities due to low income, a typical economy of this population. Consequently, the rural population relies on biomass sources such as wood, animal wastes and agricultural residues to meet their basic energy needs (FAO & PISCES, 2009; UN, 2007). Solid biomass sources seem to be simple, manageable and easy to access for rural people. However, the ongoing unsustainable biomass extraction is a major cause of deforestation as the primary effect. The secondary effects include soil erosion, and above all, climate change due to loss of CO_2 sink. Moreover, the use of wood fuel affects negatively the quality of life due to the inherent indoor air pollution and overburdening of women and children as a result of walking long distances to collect wood (UN, 2007).

In Tanzania there is a disparity in wealth between rural and urban areas, whereby 48% of the populations in rural areas lack basic needs compared to 10% of their peers in urban areas (UNICEF, 2009); this being a result of the lack of adequate energy infrastructure in rural areas. Greater levels of access to modern energy services are required, particularly in rural areas. Agriculture mechanisation is one of the means of spearheading economic growth in the rural areas (Basinger et al., 2010). Liquid biofuels have the potential of being alternative fuels that can provide affordable access to energy that rural populations require for poverty reduction and sustainable development. Liquid biofuels are liquid fuels produced from biomass and present proper utilisation of bioenergy that can provide a clean, cost-effective, sustainable and accessible fuel needed to power rural agro-processing activities from small, slow and medium speed diesel engines in order to bring socio-economic development for rural communities (Basinger et al., 2010; Dermibas, 2008).

The use of locally grown non-edible POs has the potential of providing a low cost, sustainable solution. Historically, the idea of using PO as diesel fuel substitute is not new; it started as early as the 1900s. De Almeida (2002) used pure palm oil to fuel a stationary diesel engine to supply energy for a small village in the Amazon basin. Cardillo and Nesta (2008) reported the use of pure Jatropha oil in a stationary diesel engine (generator) for the electrification in rural area in the southern part of Tanzania. The Lister engine types, which are common in rural areas, can run on unmodified PO. The Tanzania Traditional Energy Development Organisation (TATEDO) in Tanzania has been involved in the development of liquid biofuels since 2003, and efforts are directed in supporting small scale farmers to grow and use Jatropha oil for the provision of modern energy services. The organisation has used Lister engines in its various projects, which are fuelled with diesel or biodiesel or Jatropha oil (Sanga & Meena, 2008; Sawe, 2007; UN, 2007). Also FAO and PISCES (2009) present a number of case studies of established initiatives in developing countries that use PO as fuel in running diesel engines.
The interest in liquid biofuels is growing rapidly worldwide today due to recent fossil fuels' crises, rapidly increasing prices and uncertainties on the availability of fossil fuels as they are non-renewable, hence not sustainable; as well as environmental problems associated with their uses due to emission of greenhouse gases (GHGs) from combustion (Addison, 2008; Mittelbach & Remschmidt, 2004; Altin et al., 2001; Srivastava & Prasad, 2000; Ma & Hanna, 1999). The use of diesel leads to the generation of GHG emission amounting to 2.67 kg of CO_2 per litre of diesel used (IPCC, 2006).

Various tests done on using pure POs as fuel in unmodified diesel engines have shown that relatively high viscosity of POs, phospholipids (gums) and FFAs contents in POs are the major parameters that lead to serious problems in engine performance in terms of operation and durability (Mittelbach & Remschmidt, 2004; Srivastava & Prasad, 2000; Ma & Hanna, 1999). Due to these problems, several techniques have been suggested and used to modify POs in order to try to adapt the fuel (PO) to the engine (Mittelbach & Remschmidt, 2004; Srivastava & Prasad, 2000; Ma & Hanna, 1999). However, the focus of the majority of these techniques have been on producing high quality fuels for running in high speed diesel engines like in automobiles, trucks and cars, which are mostly found in urban areas; and not on the quality of fuels for running in low- and medium-speed diesel engines like in farm tractors, fishing boats and stationary electric power generators, which are commonly used in rural areas, and do not necessarily require high quality fuels.

Low- and medium-speed diesel engines are the common engines found in rural areas in food processing, power generation, agriculture and transportation applications (Basinger et al., 2010). Currently, these engines operate on fossil fuels, and very small percentage on electrical energy (Basinger et al., 2010; Janssen, 2006; GTZ, 2005). However, the cost of electrical energy and fossil fuels currently excludes the majority of low income households from such services (Janssen, 2006; GTZ, 2005). It is possible to modify PO into liquid biofuel for low- and medium-speed diesel engines (Mlay et al., 2014; 2010) and bring socio-economic development in rural settings.

Modified Plant Oil (MPO) is an alternative energy source that can be used to reduce dependence on diesel, which is a fossil fuel. MPO is a modified PO for running in low- and medium-speed diesel engines, which is expected to be prepared from plant oil produced by farmers in their localities. The amount of diesel used in tractors and power tillers can be estimated from the amount of tractors and power tillers used in Tanzania. As reported in the Tanzania parliament,[4] the number of tractors and power tillers in Tanzania in 2013 was 9,148 and 5,520, respectively. Based on the average diesel consumption of tractors of 20 litres/h[5] and for power tillers of 1.4l/h (Veerangouda et al., 2011; Ademiluyi & Oladele, 2008) (tillage of about 0.15 ha/h), the amount of diesel consumption can be estimated to be 160m litres per year. If MPO could take up 5% of the diesel fuel needed for agricultural machinery, about 8m litres of MPO will be required. This means PO of the same magnitude will need to be produced, hence a stimulus in the social-economic activities in Tanzania. Substituting 5% of fuel consumption with MPO will reduce the GHG emissions by about 187 tons per year. To attain this, about 40,000 litre of MPO will be required per day.

However, the cost of feedstock is a major component (~75-80% of overall costs) affecting the economic feasibility of liquid biofuels production like biodiesel due to insufficient amount of raw material or feedstock and the relatively high costs of edible oils, which are currently commonly used as feedstock (Mlay et al., 2014; Dermibas, 2009; Balat & Balat, 2008; Motsomane et al., 2007; Haas et al., 2006; Zhang et al., 2003). Therefore, to be able to have MPO at reasonable costs, the cost of oil seeds have to be low, while oil yield of the seeds have to be high. The PISCES study conducted in seven Tanzania regions established that there are more than 20 non-edible oilgenous plant species with potential for biofuel production. Out of these, six species are currently undergoing preliminary evaluation to establish their field performance for large scale cultivation. These species include *Croton megalocarpus, Exocoecaria busssei, Ricinus communis, Telfairia pedata, Legenaria siceraria,* and *Jatropha curcas*. These are very promising raw materials for local energy and fuel production because of their high oil content. The potential of MPO, therefore, will economically become viable if there is sufficient PO in the market. The beauty of this is that, MPO can utilise both edible and non-edible PO. Hence, in areas with excess of edible oil, the surplus can be utilised for the production of MPO; and in other places non-edible PO can be produced from non-edible oilgenous plant species ensuring sustainable supply of PO. This may stimulate the rural agricultural economy to grow sustainably without depending solely on fossil fuel.

Another sensitive parameter affecting the viability of an MPO project would be plant operating costs (Mlay et al., 2014; Dermibas, 2009; Balat & Balat, 2008; Motsomane et al., 2007; Haas et al., 2006; Zhang et al., 2003; Sinnott, 1993). However, it could not portray the effect since it largely depends on trade discounts encountered on the raw materials purchased. This means that for larger plant capacities, raw materials will be purchased in bulk. Costs like transport, packaging and sellers' profit margin can be reduced.

4*Daily News* of June 6, 2013

5Virginia Cooperative Extension Publication 442-073, (2010), www.ext.vt.edu, (accessed July, 2013).

The main questions to answer are: (i) What quality of PO is needed for low- and medium-speed diesel engines; and (ii) What measures are required to improve oil quality for use as fuel in these diesel engine types, which are common in remote rural environment in order to provide energy that rural populations require? This paper provide answers to these questions and presents MPO as the desired liquid biofuel for low- and medium-speed diesel engines that can provide affordable access to energy that rural populations require for socio-economic development. Low- and medium-speed engines can operate on either diesel fuel or heavy fuel oil (HFO). They are capable of utilising lower grade (slower burning) fuels than high speed engines. Lower grade fuels are often heavy distillates, high viscosity fuels and of lower costs (Dermibas, 2009; Balat & Balat, 2008; Dermibas, 2008; Song, 2000; Srivastava & Prasad, 2000; Challen & Baranescu, 1999; Ma & Hanna, 1999; Harker & Backhurst, 1981).

Materials and Methods

Materials

The plant oil (PO) used was indigenous non-edible oil from Jatropha (*Jatropha Curcas L.*) seeds, one of the PO, which has been utilised for some time. In the PISCES study, Jatropha seed oil (JO) was one of the plant oils that were investigated. The modifier used was a natural gas condensate (NGC) supplied by TPDC, which is a by-product of Songosongo gas extraction. NGC had limited utilisation and it has been treated as waste (TPDC, 2011; Rajabu et al., 2009). Others were phosphoric acid that was used for degumming, and sodium hydroxide (NaOH) that was used for the neutralisation for FFAs removal.

Methodology

The main component was the preparation of MPO using JO. The approach was based on modifying JO to lower and/or remove the undesired materials from it. However, the level (limits) of the quality of JO to be used as fuel in diesel engines will depend on the intended service application, i.e., application in what kind of engine in terms of speed and design as indicated by Mlay et al. (2014, 2010), Song (2000), Challen and Baranescu (1999) and Harker and Backhurst (1981). The prepared MPO' fuel properties approximate the specifications for diesel fuel grade 4-D (ASTM D975), and the PO standards (DIN V 51605) as shown in Table 1, for low- and medium-speed diesel engines.

Table 1: Standard Test Methods[a]

Property	Test method adopted	Diesel Fuel Grade 4-D Specifications (ASTM D975)	PO standards (Europe) (DIN V 51605)
Kinematic Viscosity [cSt] @ 40oC	ASTM D2196 (Test Method A)	5.5 – 24 (max.)	36.0 (max.)
Density [g/cm3] @ 15oC	ASTM D1298 or EN ISO 3675	--	0.90-0.93 (max.)
Flash Point [oC]	ASTM D93	55.0 (min.)	220 (max.)
Calorific Value [MJ/kg]	ASTM D4868	--	36.0 (min.)
Water Content [% Volume]	ASTM D95	0.50 (max.)	0.075 (max.)
Sulphur [% mass]	ASTM D4294	2.00 (max.)	10.0 (max.)
Ash [% mass]	ASTM D482 or IP 4	0.10 (max.)	0.01(max.)
Cloud Point [oC]	ASTM D2500	6.0 (max.)	--
Phosphorus Content [mg/kg]	Spectrophotometric method of phosphorus Determinationb	--	12.0 (max.)
Acid Value	ASTM D974 or TZS 674:2006	--	2.0 (max.)
FFA Level	ASTM D974 or TZS 674:2006	--	1.0 (max.)

Note: IP = Institute of Petroleum

[a](Fürstenwerth et al., 2008; Mittelbach and Remschmidt, 2004; Westbrook, 2003; Song, 2000; Challen and Baranescu, 1999; Harker and Backhurst, 1981; APHA, AWWA and WEF, 1998; Tanzania Bureau of Standards, 2006; IS, 1964).

[b](4500-P B.4 and 4500-P E in APHA, AWWA and WEF (1998))

Diesel fuel grade 4-D was chosen since it is a slightly more viscous, low-quality fuel used primarily in low- and medium-speed diesel engines in non-automotive applications, i.e., for applications involving predominantly constant speed and load like in marine auxiliaries, stationary electric power generators, ships, fishing boats, pumping units and farm tractors (Song, 2000; Challen & Baranescu, 1999; Harker & Backhurst, 1981). The physicochemical and fuel properties of the JO were used as baseline in establishing the desired liquid biofuel.

The main problems to address were viscosity, FFAs and gums (phospholipids). Thus, JO was degummed and neutralised to remove gums and FFAs, then the degummed-neutralised JO was blended with NGC modifier to lower the viscosity. The resulting oil was the MPO, the desired liquid biofuel for low- and medium-speed diesel engines. Fig. 1 shows the MPO appearance as compared to crude JO and normal diesel (diesel fuel grade 2-D). The process was as shown in Fig. 2. MPO was then tested to run in low- and medium-speed diesel engines, and this included cereal milling machine, generator, water pump and a power tiller.

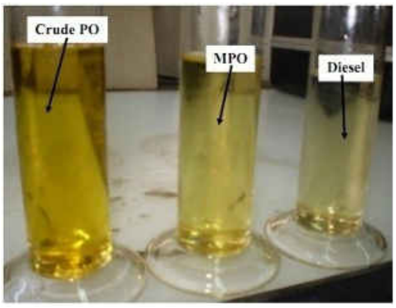

Figure 1: ***MPO Appearance as Compared to Crude JO and Normal Diesel***

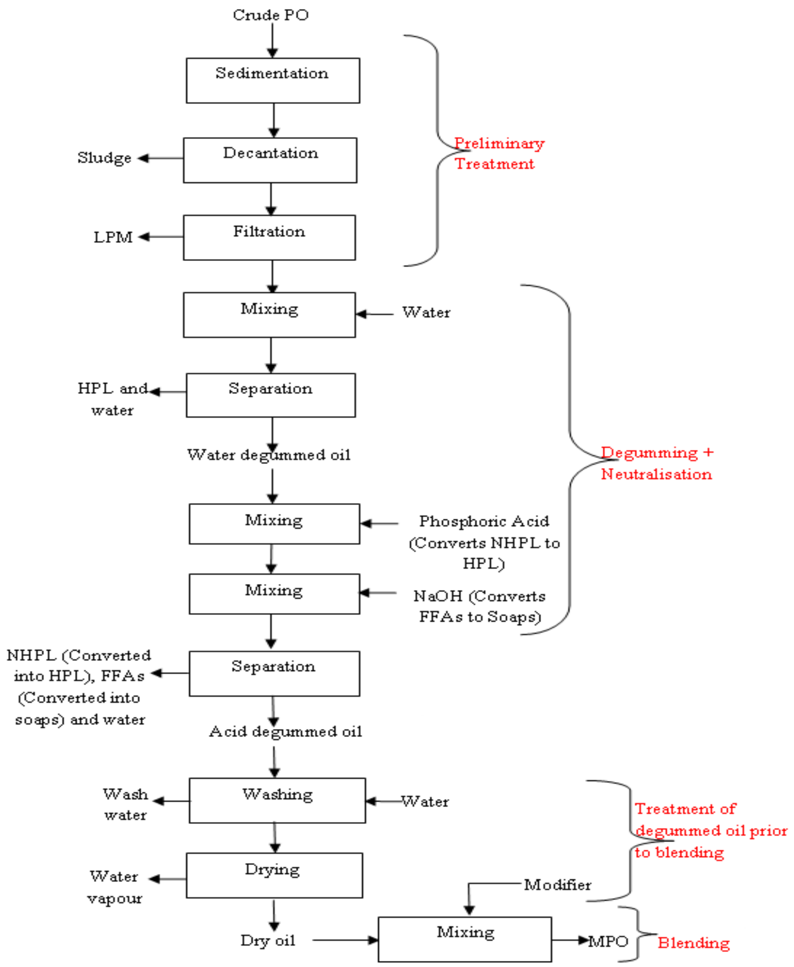

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Figure 2: ***Flow Diagram Producing MPO***

Findings and Discussion

Characterisation of Raw Material and Product - Laboratory Results

About 98% removal of gums and FFAs were achieved after acid-degumming and neutralisation steps. The natural gas condensate (NGC) was able to impart about 50-80% decrease in viscosity. The properties of MPO approximated well to specifications for diesel fuel grade 4-D (ASTM D975) or standards (DIN V 51605) from Table 2.

Table 2: Characteristics of Raw Material and Product

Engine ***Tests*** -

Property	JO	NGC	MPO	Specifications for Diesel Fuel (Grade 4-D)
Kinematic Viscosity [cSt] @ 40°C	37.78	1.27	22.97	5.5 – 24 (max.)
Density [g/cm^3] @ 15°C	0.92	0.800	0.907	–
Flash Point [°C]	282	33	68	55.0 (min.)
Calorific Value [MJ/kg]	44.4	46.00-52.00	44.65	–
Water Content [% Volume]	<0.05	0.00	<0.05	0.50 (max.)
Sulphur [% mass]	0.003	0.011	0.003	2.00 (max.)
Ash [% mass]	0.019	0.001	0.009	0.10 (max.)
Cloud Point [°C]	-3	-27	-9	6.0 (max.)
Phosphorus Content [mg/kg]	41.5	–	1.30	–
Acid Value	12.08	0.01	0.23	–
FFA Level	6.07	0.01	0.115	–

Preliminary Field Results

The UDSM signed a Memorandum of Understanding (MoU) with the TPDC to carry out field tests of the developed MPO. The TPDC provided funds to acquire a tractor, 4 power tillers and 3 water pumps and field costs to test the MPO in running the engines. Test runs which commenced in early 2013 were carried to assess the performance of the engines, bottlenecks, operability as well as developing operational procedures for running the engines with MPO. The tests have shown that it is possible to modify PO using NGC with other additives to obtain suitable MPO for running tractors, power tillers and generators. The main outcome is that PO needs to be free of gums and low cloud point.

Conclusion

Laboratory and preliminary field results have shown that MPO can run in low- and medium-speed diesel engines like cereal milling machines, generators, water pumps and power tillers. This implies that MPO present a potential clean, cost-effective, sustainable and accessible fuel to meet rural basic energy needs. Furthermore, MPO can also power rural agro-processing activities (power tillers, millers, water pumps, etc.) and become an important key for socio-economic development of rural population relying on agricultural activities. The use of renewable energy from MPO will contribute to reduce CO_2 emission, contributing to reduce climate change problems. In this way, MPO will contribute to sustainable energy source since PO is a renewable source. This will not only benefit the rural society, but also will be of global benefit since climate change does not only affect the rural community but is a global challenge. NGC utilisation will make the blending process more economical than using commercial modifiers as it promotes the concept of utilising natural low-cost raw material that adds value to it.

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