Scalable Biodiesel Reactor Build and Trial

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***Abstract*— There have been concerted efforts to find alternative sources of energy as it has been realised that fossil fuel sources are not only finite but also degrading the environment. For the benefit of the biodiesel "do it yourself enthusiasts", a stainless steel biodiesel reactor has been designed, constructed and satisfactorily trialed. The reactor consists of two vessels one smaller than the other. The alcohol-catalyst mixture is placed in the smaller vessel and the feed-stock in the other. In addition to the catalysts and feedstock, methanol is used as the alcohol. For the choice of material for construction, stainless steel was selected on the basis of its ability to resist chemical attach. The reactor has been used in the transesterification of waste oil using both acid and base catalysts in separate but identical runs. The tests have shown that the biodiesel yield using the base catalyst is usually higher than the yield with the acid catalyst.**

***Index Terms*— feedstock, Transesterification, methoxide, Biofuel, Biodiesel Reactor, glycerin.**

I. INTRODUCTION

Fossil fuel sources are finite and in combustion they degrade the environment. These factors have encouraged the search for alternative sources of energy that are both renewable and environmentally friendly. Moreover globally, current methods employed in the production, conversion and consumption of fossil fuels are not sustainable. The case for renewable sources is further buttressed by the need to keep up with energy demand growth associated with population growth, ameliorate the effect of the continual volatility in regions from where fossil fuels are sourced and finally nation states jealously guard not only their political but also economic independence and the only guarantor of the later is stability in raw material supply The burning of fossil fuel has always been associated with the release and growth of greenhouse gases and particulates. As a result therefore the call for individuals to reduce their carbon footprint responsible for global warming cannot be over emphasised. The alternative energy sources can only be considered environmentally friendly if they are either carbon neutral or the net release to the environment is significantly lower than that of equivalent kilowatt generated from fossil fuel sources [1]. Among others, some of these alternatives include wind turbine, tidal waves, geothermal, solar, hydro and biofuels. Currently, however, fossil fuels still dominate the energy scene but over dependence on them can be reduced by developing alternative energy sources and integrating them into the main energy supply chain. Each of these alternative renewable energy sources may not on itself alone make an appreciable impact but in combination with the others can go a long way in satisfying a significant proportion of the global energy demand. This aggregation of the renewable energy sources can therefore explain, why so many studies are taking place on alternative energy sources.

Edible vegetable oils such as canola, soybean, and corn have been used for biodfuel production and are proven feedstock sources [2]. However, a major obstacle in the commercialization of biodiesel production from edible vegetable oils is the high production cost. This is due to the conflicting demand for human consumption. Reducing the cost of the feedstock is critical for long term commercial viability of the product. One of the ways to achieve this is to use less expensive feedstock such as waste cooking oil and non-edible vegetable oils such as jatropha with low harvesting costs. Waste cooking oil and fats pose a significant disposal problem. They congeal and grow to eventually block the waste drainage pipelines. This environmentally unacceptable and threatening kitchen waste product could be turned into a beneficial product by proper management and further processing. Some countries have set up policies to encourage re-cycling of all sorts of wastes including waste oil from the kitchen. These include the provision of different waste bins for plastics, paper and the provision of banks for broken glass and tanks for waste oil at strategic positions in cities. In this way re-cycling cost is reduced as households carry out the initial sorting of the wastes and the re-cycling companies have only to collect from the strategic position instead of collecting from individual homes. Some other countries have even gone further by introducing penalties such as refusing to clear the waste for households who fail to comply with the re-cycling directives.

The Energy Information Administration (EIA) in the United States (USA) estimated that around 100 million gallons of waste cooking oil is produced per day in USA, and per person about 4 kg of waste cooking oil is generated in a year. The estimated amount of waste cooking oil collected in Europe is about 0.49 - 0.7 million gallons/day [2].

Biodiesel is derived from fats and oils either by chemical or bio-chemical means. There are at least four ways in which oils and fats can be converted into biodiesel and its blends, namely: transesterification, blending, micro emulsions and pyrolysis. Among these, transesterification is the most commonly used method as it reduces the viscosity of the oil. Biodiesel production by transesterification reaction can be facilitated with alkali, acidic or enzymatic catalysts. Alkali and acid transesterification processes require less reaction time with reduced processing costs compared with the enzyme catalyst process [2]. Alkali process yields high quantity and high purity fuels, however, this process is not suitable for feedstock with high free fatty acid (FFA) content.

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It has not been possible to use neat vegetable oils in compression ignition engines because some of these vegetable oils are characterised by properties that make them unsuitable for such application

. Their viscosity and volatility are some of the primary properties to be considered. Most vegetable oils are very viscous with poor atomisation properties and these can clog fuel flow lines, burn poorly, release hydrocarbon particulates to the environment and leave carbon deposits in the cylinder [1]. The volatile component in the fuel has to be significant for the injected fuel spray to be fully atomized within the restricted space of the engine cylinder. The chemical composition of most vegetable oils gives an insight into why it is impossible to use them neat in diesel engines. Lots of these oils consist of three long chain fatty acids on a base of glycerine These long chain fatty acids need to be broken down to simpler components that will make them suitable for use in diesel engines and this is what transesterification is all about. It has been found that biofuel is cleaner and less polluting than fossil fuels and as a result a number of studies are on-going to better understand the kinetics and improve the quality and quantity of yield in the transesterification processes [1]. These studies centre mainly on production and utilisation. Abed et al [3] have carried out experiments on blends of biodiesel made from waste cooking oil to find that the resulting biodiesel and its blends, on the down side, have lower thermal efficiencies, higher specific fuel consumption, higher exhaust gas temperatures, higher CO^2 emission but on the plus side, lower smoke opacity, lower CO and HC emissions compared with the pure petroleum diesel. In their work, Alaa et al [4] optimised at feedstock temperature of 70^oC, the production of biodiesel using date palm pit as the catalyst to obtain a yield of about 98.2% and concluded that the catalyst synthesized from waste date pits has a high potential for biodiesel production. Using E-tericornisis as the feedstock, Hariram et al [5] obtained an optimised yield of 74.18% of biodiesel with improved physiochemical properties. In a laboratory study Anawe et al [6] optimised the production parameters of biodiesel from persea Americana (Avacado) plant oil. In this work some of the factors considered include: alcohol type, alcohol to oil molar ratio, reaction time and various oil and biodiesel properties. With emphasis on parametric optimisation, Balasubramanian et al [7] in a laboratory and a glass pilot scale study, considered the production of biodiesel from activated sludge sourced from a milk processing plant. In a study to emphasise that feedstock sources are numerous, Liang et al [8], not only produced biodiesel from oil extracted from spent coffee grounds but also considered energy content in the biodiesel and the optimisation of parameters. Arguing that the glycerol content in the resulting biodiesel produced is an indication of the level of conversion of the tryglyceride to biodiesel, Thoai [9] used this technique to study biodiesel production and concluded that the molar ratio and catalyst content are the two most important factors that affect the total glycerol content in biodiesel as well as the efficiency of the biodiesel production process. Ashok et al [10] have tested biodiesel blends made from calophyllum inophyllum feedstock to find, in agreement with Alaa et al, slightly reduced brake thermal efficiency and significantly higher NOx emission penalty but reduced hydrocarbon and carbon monoxide emission compared with conventional diesel. In addition, combustion and engine parameters such as ignition delay period, heat release rate and cylinder gas pressure were studied. In their study of brake horse power, brake specific fuel consumption and brake thermal efficiency of a supercharged diesel engine fuelled by blends of biodiesel Mohammed et al [11] concluded that the supercharged operation generally performed better than the natural aspirated engine. Most of the biodiesel production studies found in the literature are laboratory scale based otherwise they are proprietary. Fallon W et al [12] which considered a production design failed to include either the engineering drawing or a plate picture of the built design and its dimensions. These are necessary to enable others repeat the process or modify and use the design for their own purposes. This can explain why the biofuel “do it yourself, DIY” enthusiasts resort to all types of unconventional equipment in biodiesel production. As a result, therefore, the purpose of the study is to construct and test a scalable biodiesel reactor (based slight modification of design [1]) capable of handling both acid and base catalysts.

II. MATERIALS AND EQUIPMENT

Plate 1: The Stainless Steel Biodiesel Reactor

The reactor consists of two main stainless steel vessels as shown in plate.1. The bigger stainless steel vessel that measures 0.23m in diameter and 0.45m in height contains the waste cooking oil. The reactor carries a glass tube for indicating the separation level between the resulting glycerol and biodiesel during the settling stage. The other smaller vessel also made of stainless steel is for mixing the alcohol and acid or base catalyst and it measures 0.17m in diameter and 0.28 in height. There is a one-way, non-return valve inserted in the stainless steel pipe connecting the two vessels. In addition to the alcohol (methanol, CH_3OH), acid and base catalysts, the following were also used: pipette, syringe, glass tube, mesh or sieve, containers for mixing, weight measuring machine, overall jackets, hand gloves and goggles. The last three items are for personnel safety and protection.

III. METHOD

Basically, measured quantity of the alcohol and catalyst are mixed in the smaller reactor vessel. The waste cooking oil which has to be preheated to about 60^0C is placed in the bigger vessel. Opening the valve between the two vessels feeds the mixture of alcohol and catalyst, by gravity, slowly into the vegetable oil vessel. Any fumes are vented outside through a top cover on the feedstock vessel that carries a pipe especially when the operation is carried out in an enclosed place. It is also necessary to stir the big vessel at the processing stage to aid proper mixing and reduce process time.

The reaction takes place and the mixture is allowed to separate with the biodiesel on top and the denser glycerol at the bottom. The separation is observed through glass tube mounted on the side of the feedstock vessel. When the separation is complete, the glycerol is run off by opening the valve at the bottom of the big reactor vessel.

A. Washing

It is necessary to wash the biodiesel in order to protect the engine using the fuel. Settling and filtering will not remove the soap, catalyst, glycerin or excess methanol contaminants. There are three main methods to effect the washing – Mist Washing, Bubble Washing and Stir Washing, [13]. In Mist washing, water is sprayed on the wash tank surface and the water droplets carry the contaminants as they settle at the bottom of the tank. For the bubble wash, air bubbles are allowed to travel from the bottom of the wash tank, entrain water, burst on the surface and the released water droplets carry the contaminants as they sink to the bottom. of the tank. In stir washing, a motor driven impeller is used to mix the wash water and biodiesel thoroughly and the mixture allowed to settle for subsequent separation.

. An ideal washing method maximizes the interaction between the fresh biodiesel and washing water, while minimizing the risk of emulsification. The stir wash achieves this requirement.

IV. RESULTS AND DISCUSSION

The reactor has been successfully built and tested with waste oil from the kitchen as the feedstock. Both sodium hydroxide (base) and sulphuric acid have been used as the catalysts. The tests were carried out with each of the catalysts separately but under similar conditions. The resulting biodiesel sample is shown in plate 2

Plate2: Sample of Biodiesel

The unwashed biodiesel contains impurities such as traces of methanol, monoglycerides, diglycerides and glycerin which with time will foul fuel lines and the engine cylinders.

Well-made biodiesel should separate quickly and cleanly from the wash water when it settles. If the biodiesel is not processed properly traces of monoglycerides and diglycerides will be present. With these traces in the biodiesel, some of the biodiesel will form permanent and stable homogeneous mixture with water and will not separate from the wash water, or if does, not quickly enough. This results to an emulsion problem. In fact, this should form an initial production stage quality test – take a sample of the biodiesel in a glass tube, cork it and shake vigorously if it fails to separate in time consider reprocessing. Properly made biodiesel with reaction to completion will not emulsify. Gentle washing techniques like bubble washing and mist washing will only mask the problem that the biodiesel has not been made properly. Some producers add excess methanol to ensure the absence of the mono and diglycerides. This can add to the processing cost because of the cost of the excess methanol and extra processing to recover the methanol.

A more complicated problem with biodiesel washing is oil oxidation. All oils are not the same, some oils are more saturated than others. Unsaturated oil will polymerise into tough plastic-like insoluble solids and the process is accelerated by high temperatures as found in diesel engines. This will foul injector pumps. Polymerisation occurs when the double bonds in unsaturated oil molecules are broken by oxygen from the air or water. The oil oxidises, to form peroxides (hydroperoxides), and the peroxides polymerise, bonding with carbon to create a long and stable molecule called polymer (plastic). Another effect of oxidation is that the hydroperoxides attack elastomers, such as pump seals. Saturated oils don't polymerise, unsaturated oils do. The level of unsaturation is called the Iodine Value (IV). Highly unsaturated oils have high IV but it should be noted that without oxygen the oil cannot polymerise. Converting unsaturated oils to biodiesel reduces the polymerisation effect but may not completely prevent it.

V. CONCLUSION

The biodiesel reactor has been constructed (based on Achara [1] (design) and successfully tested by transesterification of waste cooking oil using methanol as the alcohol and sodium hydroxide and sulphuric acid as the catalysts. The biodiesel yield using the base catalyst is found to hover around 93% and 96% in all the runs whereas the yield in identical tests with the acid catalyst ranged between 67% and 73% .

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