Investigation of Corrossion Effects of Jatropha Biodiesel on the Injector of an Engine Fuel System

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***Abstract*— This paper presents an investigation into the corrosive behaviour of biodiesel on the injector of the fuel system of a diesel engine. The experimental study was based on the methods of weight loss and scanning electron microscopy. Test specimens prepared from the injector of a diesel engine were exposed to different blends of Jatropha biodiesel for a period of 28 days under ambient conditions. Corrosion rates were determined in accordance with Callister (1997). Jatropha biodiesel blends B100, B50 and B5 exhibited corrosion rates of 0.017 mmpy, 0.013 mmpy and 0 mmpy respectively. Scanning Electron Microscopy (SEM) micrographs revealed some stains on the surfaces of the specimens corresponding to corrosive effects of the media and weight loss within the immersion period. The study has shown that Jatropha biodiesel blends with up to 5% biodiesel content can be used as motor fuel without any modification to the engine fuel system. The findings of the current research can serve as a guide in identifying the blends of Jatropha biodiesel that could suitably be used on a long term basis on a diesel engine without modification. This will surely promote the use of biodiesel as engine fuel and consequently help in protecting our environment.**

***Keywords*—** Biodiesel, Corrosion rate, Weight loss, SEM micrograph, Fuel system

Introduction

Nigeria has an area of 923,768.00 sq. kilometres and lies between latitude 40 and 140 north of the equator and longitudes 30 and 140 east of the Greenwich meridian. This is entirely within the tropical zone. Although Nigeria is wholly within the tropics, its climate varies from the tropical at the coast to sub-tropical further inland. There are two marked seasons: the rainy season, lasting from April to October and the dry season, from November to March. Absolute maximum temperature in the coastal areas of the south is 37°C while the absolute minimum temperature is 10°C. Jatropha Curcas plant grows well in the tropics; its non-edible seeds are attracting attention as a major source of oil for biodiesel. The oil yielding plant is a multipurpose and drought resistant shrub; the geographical position of Nigeria suggests the potential opportunities in terms of seeds production.

Diesel engines are becoming more popular as a result of their high fuel efficiency. This has resulted into a raising demand for fossil diesel. However, the unsustainable nature inherent in the continuous utilization of fossil fuel is made clear by environmental issues and other conflicting factors. The use of biodiesel, an alternative diesel fuel, on conventional fuel system results in coking of injectors and degradation of metal components; which decreases the lifespan of engine parts. Although the impact of biodiesel on the degradation behaviour of fuel system materials has been rarely investigated, biodiesel has been the focus of a considerable amount of recent research as reported in [1]. Researchers in Nigeria have also indicated interest in renewable fuels such as biodiesel. This paper is aimed at investigating the corrosive effects of Jatropha biodiesel produced in Nigeria on injector of an engine fuel system.

2.0 LITERATURE REVIEW

2.1 Biodiesel as transport fuel

Biodiesel is a renewable diesel fuel that can be made from any natural oil or fat. The term "biodiesel" generally refers to "fatty acid methyl ester" (FAME) made by transesterification - a chemical process that reacts a feedstock oil or fat with alcohol (usually methanol) and a base (mostly, potassium hydroxide) catalyst. In technical terms, biodiesel is a diesel engine fuel comprised of monoalkyl esters of long chain fatty acids derived from vegetable oil or animal fat designated as B100. So far, many vegetable oils have been used to produce biodiesel such as sunflower, soya bean, peanut, cotton seed, linseed, palm coconut; and non-edible oils like mahua, neem, karanja and Jatropha as in [2] and [3]. Reference [4] also reported that many vegetable oils, animal fats, and recycled cooking oils can be transformed into biodiesel and there are many different ways to do it. Biodiesel can be used neat or as a diesel additive and is typically used as a fuel additive in 20% blends (B20) with petroleum diesel in compression ignition engines. Other blend levels can be used depending on the cost of the fuel and the desired benefits.

The use of biodiesel started in 1900s when Rudolf Diesel tested his engine on peanut oil at Paris exposition. Diesel believed that the utilization of biofuel was the real future of his engine. In a 1912 speech Diesel said 'The use of vegetable oils as engine fuels may seem insignificant today but such oils may become in the course of time as important as petroleum, as the coal tar products of the present time'.

During the 1920s, diesel engine manufacturers altered their engines to utilize the low viscosity fossil diesel. However, periodic petroleum shortages geared research efforts into vegetable oil as diesel substitute during the 1930's and 1940's. In the 1970's and 1980's straight vegetable oil enjoyed high level of scientific interest.

Research into the use of transesterified sun flower oil was initiated in South Africa in 1979. By 1980 the process for producing fuel quantity engine-tested blends was completed and published internationally. Biodiesel can be used in pure form (B100) or may be blended with petroleum diesel at any concentration in most modern diesel engines [5]. An Austrian company, Gaskoks, obtained the technology from the South African agricultural engineers, created the first biodiesel pilot plant in November, 1987, and established the first industrial-scale biodiesel plant in April, 1989 (with a capacity of 3000 tons of rapeseed per annum). Through the 1990's, plants were established in many European countries, including the Czech Republic, Germany and Sweden. France launched local production of biodiesel fuel (referred to as dieter) from rapeseed oil, which is mixed into regular diesel fuel at a level of 5% and into the diesel fuel used by some automobiles at a level of 30%. Renault, Peugeot and other automobile manufacturers have certified truck engine for use with up to that level of partial biodiesel. Biodiesel's higher lubricity compared to conventional diesel is an advantage that can contribute to longer fuel injector life. Biodiesel is a better solvent than fossil diesel and has been known to break down deposit of residue in the fuel line of vehicles that have previously been run on petro diesel.

Biodiesel has to overcome many challenges to become a feasible substitute for conventional petro diesel. So far biodiesel is commercialized by governments of some countries and enjoyed high subsidies. However, the main hurdle in penetrating the market is high production cost of biodiesel relative to petroleum. The major factor determining biodiesel price is its feedstock price [6]. Biodiesel has a higher cetane number than petroleum diesel, contains no aromatics, and contains 10% to 11% oxygen by weight. These characteristics of the fuel have been seen to reduce the emissions of carbon monoxide (CO), unburned hydrocarbons (HC), and particulate matter (PM) in the exhaust gas. However, studies have also shown that nitrous oxide (NO_X) emissions increase with the use of biodiesel as reported in [7], [8], [9], [10] and [11]

The properties of biodiesel especially its viscosity and ignition properties are similar to the properties of fossil diesel (Table 1). Biodiesel has several advantages, lubricating effects of biodiesel is important in avoiding wear to the engine, the alcohol components of biodiesel contain oxygen which helps to complete combustion of the fuel. Biodiesel is sensitive to cold weather and may require special anti –freezing precautions for temperate countries similar to those taken with standard diesel. Biodiesel has some favorable properties when used, as a fuel component. The US EPA has analyzed B20 blends (20% biodiesel blended with 80% conventional diesel) and has concluded that these blends can reduce VOC emissions by 20%, CO and PM emissions by 10%, NOx emissions were increased by 2% in the EPA study.

Table 1: Properties of Biodiesel in Comparison to Fossil Diesel

Properties	Fuel	
	Diesel	Biodiesel
Density (kg/s)	0.84	0.88
Viscosity (mm^2/s)	5	7
Flash Point (^oC)	80	120
Calorific Value(MJ/kg)	42.7	37.1
Cetane Number	50	56
Fuel Equivalence	1	0.91

Conventional diesel engines operate readily with up to 20% biodiesel blend, but using blend above this limit may require modest modifications to replace some rubber hoses that are sensitive to the solvent characteristics of biodiesel. The World-Wide Fuel Charter (WWFC), a compilation of fuel quality requirements endorsed by the Alliance of Automobile Manufacturers, the European Automobile Manufacturers Association (ACEA), the Engine Manufacturers Association, the Japanese Automobile Manufacturers Association and a number of other automobile manufacturer trade associations around the world, does not endorse fuels that contain more than 5% biodiesel for fuels sold in WWFC defined category 1-3 areas (most of the world). International Truck and Engine Company have stated that the use of biodiesel in their engines at greater than 5% concentration is solely at the discretion and risk of the customer [12].

2.2 Technical Problems Associated With the Use of Biodiesel as Engine Fuel

Engine fuel system is designed to store the fuel and deliver it to the combustion chamber with an appropriate fuel rate and at required velocity, taking into consideration the pressure, viscosity and air fuel mixture ratio [13]. The compression ignition technique of robust diesel engine is fuel economic and emits low pollutants such as CO_2, CO, H. The inventor ran his diesel engine on peanut oil at the Paris exposition in 1900. Its smooth operation on vegetable oil established that diesel engines can run on variety of vegetable oils**.** However, many engine problems may be experienced while using raw vegetable oil as fuel, like coking of injectors; excessive engine carbon deposits on piston head and excessive engine wear [6]. To compensate this shortcoming, most researchers have recommended using transesterification of vegetable oils as a means of reducing viscosity.

Many car manufacturers are now producing flexible-fuel vehicles (FFV's), which can safely run on any combination of biofuel and conventional fuel. They dynamically sense exhaust oxygen content, and adjust the engine's computer systems, spark, and inject fuel accordingly. This adds to initial cost and increases vehicle maintenance expenditure. There are problems associated with biodiesel usage such as diesel engine compatibility in long term operation, severe corrosion, carbon deposition and wear of components of the fuel supply system. Fuel injection equipment (FIE) manufacturers such as Delphy, Stanadyne Densu and Bosch have shown their concern on some properties of biodiesel including: i) corrosion of fuel injection equipment (due to free methanol); ii) reversion of biodiesel to fatty acid and finally results in filter plugging (due to dissolved and free water); iii) corrosion of non-ferrous metals and sedimentation on moving parts which causes filter plugging and injector coking (due to free glycerin); iv) corrosion of zinc, salt of organic acid, organic compounds formed (due to free fatty acid). Fuel pump also suffers badly while operating in biodiesel blends. An identifiable list of fuel pump problems include: A) Corrosion of fuel injection equipment components; B) Elastomeric seal failures; C) Low pressure fuel systems blockage; D) Fuel injector spread hole blockage; E) Increased dilution and polymerization of engine sump oil; F) Pump seizures due to high fuel viscosity at low temperatures; and G) Increased injection pressure as reported in [14]

Corrosion aspect of biodiesel as fuel has been tested by researchers for its viability in CI engines. Reference [15] reported that the absence of sulfur is supposed to reduce the corrosion in the biodiesel fuel container. As reviewed by [16] biodiesel is generally prepared from acid or alkali catalysts that are either homogeneous or heterogeneous. Homogeneous acid catalysts, such as sulfuric acid, which are generally used for acid esterification, impart corrosive nature to biodiesel fuel [17]. However, this problem may be overcome by using solid acid catalysts which are easily separated from biodiesel and hence do not make the fuel corrosive as reported in [18], [19], and [20]. Biodiesel also ought to be of high purity for its compatibility in CI engines. Therefore, incomplete conversion or inadequate purification (by water washing or other means) may result in impurities such as glycerol, free fatty acids, alcohol, and catalyst, causing deposits in the engine, corrosion, and ultimately failure of the fuel [21].

Reference [22] reviewed the effects of corrosion on the engine parts that come in contact with a newly developed biodiesel fuel and its blends. This study reported that copper, aluminum, copper alloys (bronze), and elastomers caused significant levels of corrosion in biodiesel and biodiesel blends as opposed to low corrosion with conventional diesel. Specimens of stainless steel showed significant resistance to corrosion in biodiesel samples as compared to copper, aluminum, and copper alloys. Common methods adopted for measurement of corrosion included weight loss through static emersion tests and electrochemical techniques by electrochemical impedance spectroscopy or on Potentiostat/Galvanostat. The surfaces of the specific metal strips were analyzed by optical, scanning electron, and atomic force microscopy, revealing the nature and extent of corrosion. Fourier Transform Infrared Spectroscopy revealed formation of secondary product due to degradation, and X-ray diffractometer revealed formation of a new phase in the metal strips exposed to biodiesel and its blend with mineral diesel. Biodiesel seemed to degrade due to auto-oxidation and presence of moisture to secondary products that enhanced the corrosion rate. The problem related to the use of non-compatible materials as engine parts for biodiesel-run vehicles is dual in nature. The engine part in contact with the fuel is corroded as a result of fuel degradation.

Reference [23] reported that corrosion also plays little part in engine part degradation due to acidic nature of palm oil diesel (POD). The water content of POD can convert some esters into fatty acids by reverse reaction under favourable conditions and this acid causes corrosive wear to engine parts like piston ring, piston liner, etc. Very few investigations are found on this issue. Moreover vegetable based palm oil contains palmitic and free fatty acids in its composition which reduces wear when palm is contaminated in lube oil. Long duration static immersion test of piston liner and piston metal was conducted. Results found indicated a slight corrosive nature of Jatropha biodiesel which could be caused by presence of linoleic acid in oil (19–41%). Desired anti-corrosive properties were successfully introduced in palm biodiesel blends by using anti-corrosive additives.

3.0 MATERIALS AND METHODS

3.1 Materials

The test specimens were steel coupons prepared from the nozzle of a diesel engine. The specimens were surface grinded on emery paper to 600 grit finish. For the purpose of removing scratch and oxide layer on the specimens, they were then polished with1.0 μm diamond paste, washed with distilled water and rinsed with methyl alcohol. The samples were then dried, weighed in analytical chemical balance and stored in desiccators ready for exposure. The test media for the experiment included: i) Jatropha biodiesel (B100); ii) Blends of jatropha biodiesel with fossil diesel (B85, B50, B25, B15, and B5) and iii) fossil diesel (B0).

3.2 Experimentation

Weighed test pieces of specimens were separately and fully immersed in the following test media: B100, B85, B50, B25, B15, B5 and B0 respectively and allowed to stand for 28 days. The weight loss was determined by finding the difference between the initial weight of the coupon and the final weight after exposure for that period. The corresponding corrosion rates in millimeter per year (mmpy) were calculated according to [24]:

$$\text{The corrosion rate (mmpy)} = \frac{KW}{\rho AT} \quad \ldots\ldots (1)$$

Where: K – a constant, equals to 87,600 hr/yr; W - weight loss (g); ρ - Density of specimen (g/cm^3); A - Area of specimen (cm^2); T - Time of exposure (hours).

3.3 Scanning Electron Microscopy (SEM)

The weighed test specimens were mounted on stage and positioned at a point where a beam of light from secondary electron detector falls on its surface. The image was displayed on a computer monitor connected to the microscope. The high resolution images were downloaded and presented in section 4 of this paper.

4.0 RESULTS AND DISCUSSION

4.1Results

4.1.1 Corrosion rates: The result of corrosion rates of different blends of biodiesel on test specimen within the immersion period is presented in Figure 1.

4.1.2 Scanning electron microscopy: The SEM micrographs of the samples are presented in Plates 1-4. The test specimens were immersed in different blends of biodiesel.

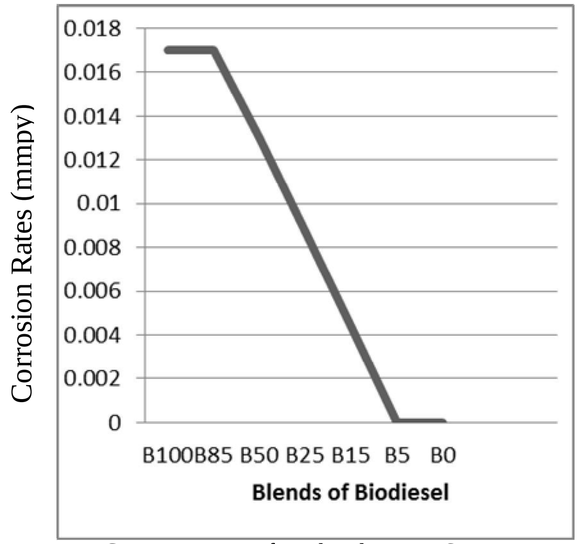

Fig. 1: Corrosion Rates of Biodiesel on Test Specimen.

4.2 Discussion of results

It was observed from Fig. 1 that B85 and B100 showed similar corrosion effect. On the other hand, B5 and B0 (conventional diesel) showed no effect within the immersion period. The weight loss of the samples, which is proportional to the corrosion rates of the nozzle coupons, was negligible when exposed to the fuel blends with just up to 5% Jatropha biodiesel content. Jatropha biodiesel blends with 5% biodiesel content and below can therefore be used on any engine without any modification.

From SEM analysis, Plate 2 shows that the surface of the coupon was oxidized (corroded). As seen in Plates 3 and 4, the effect is higher in blends having higher biodiesel concentration. It was also observed that the corrosion effect of conventional diesel is comparatively low as only small stain was seen on the coupon exposed to B0 (Plate 1).

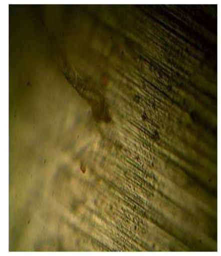

Plate 1: Test specimen in B0 after exposure

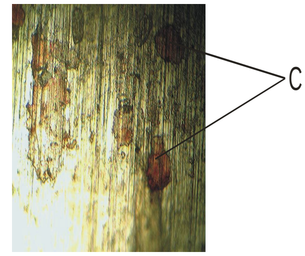

Plate 2: Test specimen in B100 after exposure

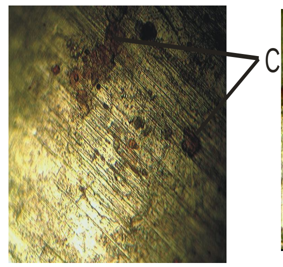

Plate 3: Test specimen in B50 after exposure

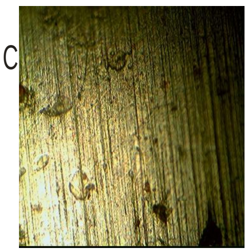

Plate 4: Test specimen in B25 after exposure

5.0 CONCLUSION

The corrosion effect of biodiesel blends of different composition on injector nozzle of a diesel engine has been investigated. Corrosion rate was studied using weight loss method described by Callister (1997). Pure Jatropha biodiesel (B100) and jatropha biodiesel blend B85 were found to exhibit maximum corrosion rate of 0.017 mmpy. Blends with biodiesel concentration of up to 5% (B5) exhibited no effect as the loss in weight was negligible within the immersion period. SEM micrographs of the tested samples complement the experimental results of the studies. Based on study of corrosion phenomenon of the injector nozzle in the Jatropha biodiesel blends, presented in this paper, it could be concluded that up to 5% biodiesel content (B5) may be considered suitable for use as motor fuel in Nigeria.

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