Performance Evaluation of Continuous Oscillatory Baffled Reactor Arrangement on Production of Biodiesel from *Jatropha* Oil Using Heterogeneous Catalyst

*B.K. Highina[1], S. Kiman[1] and I.M. Bugaje[2]

[1]Department of Chemical Engineering, University of Maiduguri, P.M.B.1069, Maiduguri, Borno State - Nigeria.
[2]Department of Chemical Engineering, Ahmadu Bello University Zaria, Kaduna State - Nigeria.
*bkhighina@gmail.com; +2348038514244

Abstract

The purpose of this work was to investigate the performance of the Continuous Oscillatory Baffled Reactor Arrangement on biodiesel yield from *Jatropha* oil using zinc oxide as a catalyst. The effect of various factors of reaction such as catalyst concentration, temperature, oil to alcohol ratio, mean residence time and frequency of oscillation on biodiesel production was studied. The results showed that the optimum catalyst concentration was 15%w/w of oil, optimum temperature was 65^{o}C, oil - methanol ratio of 1:12, best mean residence time was 5minutes and optimum frequency of oscillation was found to be 5Hz.The maximum biodiesel yield obtained from *Jatropha* oil using continuous oscillatory baffled reactor arrangement was 96%.

Keywords: Performance evaluation, COBRA, Biodiesel yield, *Jatropha* oil, Heterogeneous catalyst

INTRODUCTION

Due to the increase in the price of petroleum crude and products as well as environmental concerns about air pollution caused by the combustion of fossil fuels, the search for alternative fuels has been of paramount importance (Alamu *et al.,* 2007). Biodiesel derived from the transesterification of vegetable oils or animal fats with alcohol are potential substitutes for petroleum–based diesel fuels (Bugaje, 2006). Compared with conventional diesel, biodiesel has the advantages of being biodegradable, renewable and non-toxic and have low pollutant emissions (Sharp, 1998). Therefore, it is of utmost importance that the alternatives of petroleum fuels be explored to reduce environmental hazards. The degrading air quality, mainly in urban areas, further warrants the search into alternative clean fuels. With the stock of fossil fuels diminishing throughout the world and demands for energy based comforts and mobility ever increasing, time is ripe that we strike a balance between energy security and energy usage. Studies have shown that Nigeria currently imports about 80% of its petroleum product requirements and has been hard hit by rapidly-increasing cost and uncertainty (Alamu *et al.*, 2007; ECN 2005).

In the Niger Delta region, which is the centre of oil extraction in the country, severe environmental impact that has been ignored, has generated militancy from the local communities, making successful oil prospecting a near impossible task for the multinational companies involved if not for the Amnesty Programme. All these underline the urgency to find alternative renewable forms of energy. There is need to explore the production of biodiesel from non–edible oils such as *Jatropha* seed oil since production of biodiesel from edible oils will lead to high competition for food and biodiesel production (Umar *et al.*, 2006; Bugaje and Mohammed, 2008).

Batch processes have been used for the production of biodiesel but suffered several disadvantages compared to continuous processes. They require larger reactor volume, resulting in higher capital investment (Darnoko and Cheryan, 2000). Based on performances of a pilot plant for biodiesel production using a batch reactor, developed in Ahmadu Bello University, Zaria (ABUZ) and National Research Institute for Chemical Technology Zaria (NARICTZ). The product quality from these pilot plants is not very satisfactory and commercialization is yet to be commenced (Atadashi *et al*., 2007). Subsequently continuous processes in producing biodiesel from vegetable oils have been developed by some researchers to reduce a high procurement cost and to enhance mixing of the reactants in order to improve the reaction rates (Darnoko and Cheryan, 2000). Hence the use of a continuous process tends to be more efficient and is therefore used on a larger scale. However, it is seldom used for long reaction time as conventional continuous reactor designs have certain draw-backs such as long reaction time systems: CSTRs have disadvantages of a broad residence time distribution, plug flow reactors (PFRs) require great lengths of narrow tubing, causing control, operability foot print and pumping problems and continuous stirred tanks in series tend to be expensive. Therefore, the aim of this work was to study the production of biodiesel using continuous oscillatory baffled reactor with the use of heterogeneous catalyst.

EXPERIMENTAL METHOD

The performance evaluation of the COBRA was carried out by determining the biodiesel yield from the transesterification reaction of *Jatropha* oil in the reactor at different factors that affect the reaction such as catalyst concentration, temperature, oil-methanol ratio, mean residence time and frequency of oscillation.

Experimental Materials

Refined *Jatropha* oil (NARICT) with a density and viscosity of 914 kg/m^3 and 31.2mm^2/sat 60^{o}C respectively was used as a source of triglyceride. The methanol and zinc oxide (ZnO) used are of analytical grades (Sigma –Aldrich).

Experimental Equipment

With stirrer for methanol/catalyst and Tank$_2$ for oil) using a twin-headed positive displacement metering pumps of 0.5 hp and the flow rates were monitored by flow meters. Temperatures were maintained in the feed vessels and supply lines by Eurotherm temperature controllers, regulating the output to the hotplates beneath the feed vessels and the tapes around the supply lines respectively. The continuous oscillatory baffled reactor arrangement that was utilized in this work as shown in Figure1 was designed and constructed in the Department of Chemical Engineering University of Maiduguri, Nigeria. The device consisted of two vertically positioned jacketed stainless steel tubes of 1.4 m length and 0.1 m internal diameter, connected at the top by an inverted U-tube, fitted with manually operated purge valve of 0.21 m length. The overall internal volume of the reactor was 2.41x10^{-2} m^3. A series of orifice type stainless steel baffles with a diameter 0.05 m and baffle spacing of 0.15 m were welded to the tube wall. The baffle spacing was 1.5 times the tube diameter as suggested in the literature to achieve effective mixing over broad range of oscillation amplitudes and frequencies (Brunold, 1989). Both ends of the tubes were attached to an oscillation unit that consists of a pair of pistons. Pneumatically driven pistons that work in a push and pull sequence were used to oscillate the fluid within the COBRA at a frequency range of 1.0 to 10 Hz. Reactor temperature was maintained by a Haake F6/B5 heater /circulator unit. The net flow was provided by a liquid pumps from the feed vessels (Tank$_1$)

Fig. 1: Continuous Oscillatory Baffled Reactor Arrangement (COBRA)

RESULTS AND DISCUSSION

Transesterification reactions catalyzed by zinc oxide (ZnO) were conducted at different catalyst concentrations to determine the best catalyst concentration for biodiesel production. ZnO is one of the most commonly used due to its low cost and availability (Amish *et al.*, 2010). Figure 2 shows the different biodiesel yield resulting from the transesterification of the *Jatropha* oil using the heterogeneous base (ZnO) catalyst. It was observed that the optimum catalyst concentration was 15%w/w of oil. This is in accordance with studies on different FAME concentrations resulting from the transesterification of the refined *Jatropha* oil using the different heterogeneous base catalysts concentration (Amish *et al.*, 2010, Leon *et al.*, 2011). The effects of temperatures within the range of 40^{o}C-70^{o}C on transesterification reaction of *Jatropha* oil at oil - methanol ratio of 1:12, with the use of ZnO (15%w/w of oil) at residence time of 5 minutes were investigated and the observed effects are as shown in Figure 3.

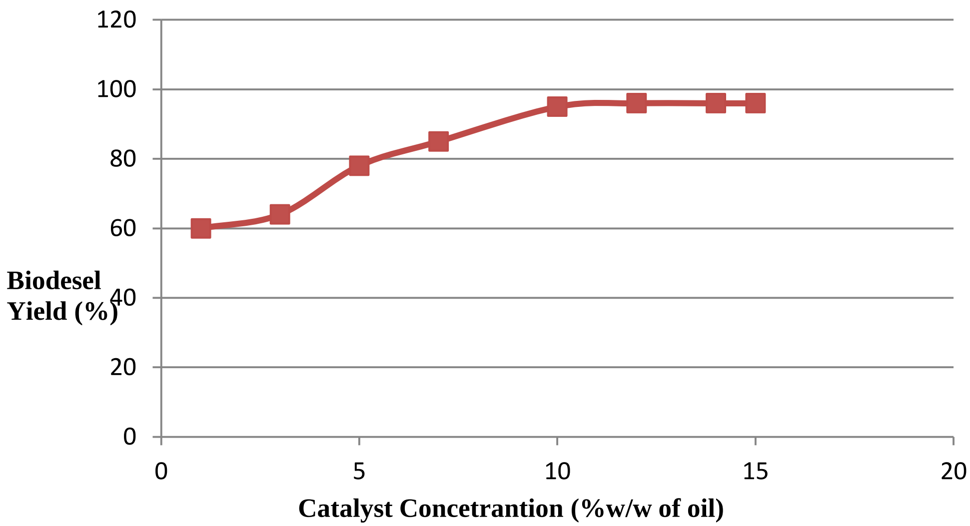

Fig. 2 : Effect of Catalyst concentration on Biodesel Yield

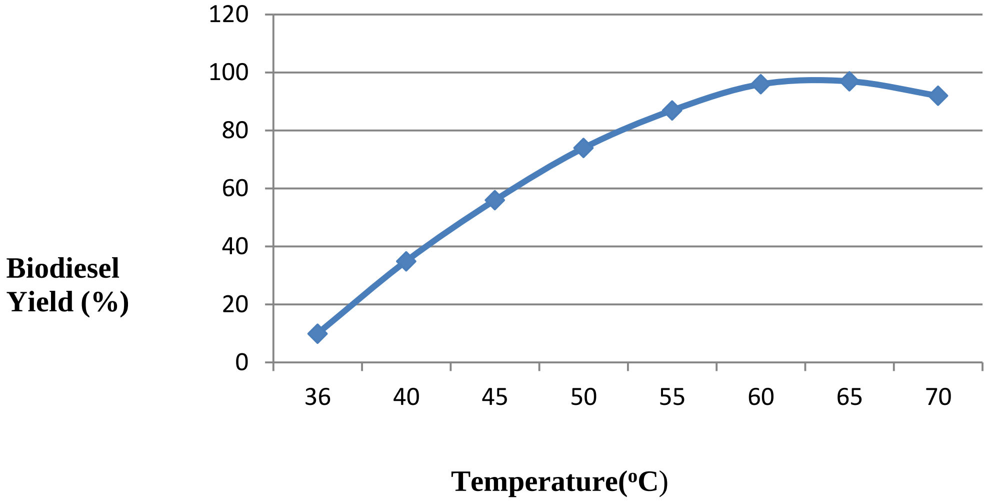

Fig. 3 : Effect of Temperature on Biodiesel Yield from *Jatropha* oil using ZnO (15w/w% oil)

The maximum equilibrium conversion was seen at temperature of 65°C.This study is comparable to the work of Leon et al., obtained 84% conversion of *Jatropha* oil at 60°C and oil-methanol ratio of 1:15 using Zeolite Y (10%w/w of oil) as heterogeneous catalyst [Leon, *et. al*, 2011]. Higher temperature above the boiling point of methanol was used to increase the rate of reaction as solubility of the reactants is increased and there is lower mass transfer resistance. The biodiesel yield generally increased as the reaction temperature was raised until 65°C, which is the optimum temperature. Thus between the temperature range of 40°C to 65°C at every increase in temperature of 5°C there is increase in equilibrium conversion of *Jatropha* oil of approximately 10%-20% At 65°C, highest yield of biodiesel was achieved without having to operate at higher pressure. However, at temperatures above 65°C, a drastic reduction in the biodiesel yield was observed. This can be due to the drastic loss of methanol (B.pt = 64.7°C) that has escaped as vapour.

One of the most important variables affecting the conversion of oil to biodiesel is the molar ratio of Oil to alcohol. The stoichiometric molar ratio for transesterification is three moles of alcohol to one mole of oil, to produce three moles of alkyl esters and one mole of glycerol (Amish *et al.*, 2010). The effect of molar ratio on transesterification reaction is associated with the type of catalyst used. Acid-catalyze transesterification requires a molar ratio of 30:1, while alkali-catalyzed reaction requires only 6:1 molar ratio to achieve the same equilibrium conversions (Canakci and Gerpen, 1999).

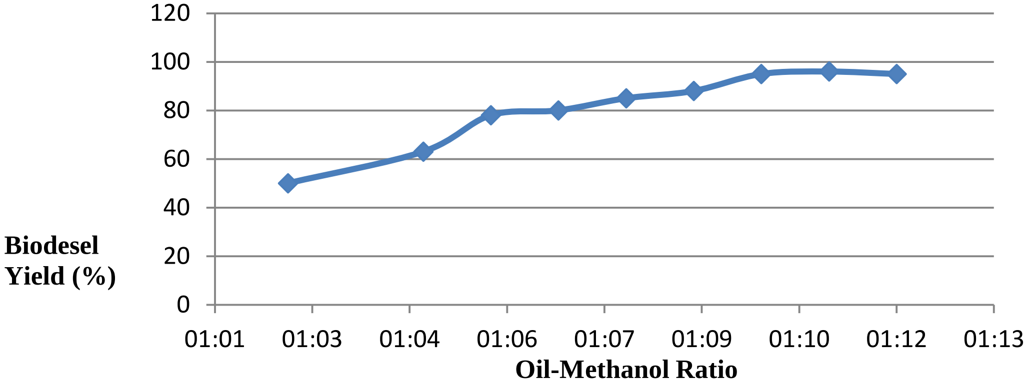

Fig. 4: Effect of Oil-Methanol ratio on Biodesel Yield

As can be seen from Figure 4, by the use of zinc oxide (ZnO) as heterogeneous catalyst maximum conversion of 96% was achieved at oil to methanol molar ratio 1:12 and reaction temperature of 60^{o}C. It is comparable to the work in which 90% conversion was obtained using methanol as an alcohol with triolein oil to alcohol molar ratio of 1:6 and KOH as a catalyst (Hanh *et al.*, 2007). Kumar *et al.*, have obtained above 98% yield using 1:9 *Jatropha* oil - methanol molar ratio and heterogeneous solid catalyst used was sodium silicate (Na/SiO^2) (Kumar *et al.*, 2010). The present study shows that with molar ratio of oil - methanol of 1:12, maximum conversion was achieved in 5 minutes only and after that it remained almost constant over an extended reaction time. Approximately 1-15% increase in equilibrium conversions were observed with an increase in molar ratio from 1:3 to 1:12. At higher molar ratios, the increase in the biodiesel yield was not as high due to the dilution of the reactive species, which in this case was the methoxide anion. Molar ratio of 1:3 and 1:6 were not showing appreciable results may be due to the predominance of esterification reaction at the initial phase, to transesterify the FFA present in the *Jatropha* oil, which can consume methanol present in the reaction mixture and hence, the amount of methanol available for transesterification may not be sufficient to drive the reaction forward for longer time. Figure 5 shows the effect of mean residence time of reaction on biodiesel yield from *Jatropha* oil in a COBRA. It was observed that as the mean residence time increased from 3 to 5 minutes, the equilibrium conversion increased from 64% to 96% though, the conversion was slow during the first and the last minutes due to mixing and dispersion of methanol. The results of this work were compared with the results of the study by Kumar *et al.*, (2010) on the effect of time of reaction on the transesterification reaction of *Jatropha* oil using sodium silicate as the heterogeneous catalyst in a batch reactor where 90% conversion was obtained in 2 hours. It can be seen from Figure 5 that in a continuous oscillatory baffled reactor arrangement, the maximum conversion of 96% of *Jatropha* oil was obtained at maximum reaction time of 5 minutes. This showed that reaction time has been reduced drastically from 2 hours as in the case of batch reactor to 5 minutes in a COBRA. The effect of oscillation conditions of the continuous oscillatory baffled reactor arrangement in the transesterification of *Jatropha* oil was studied. Figure 6 shows that the maximum frequency of oscillation is 5 Hz where the biodiesel yield increased to the maximum of 96%. At a frequency above 5 Hz no significant increase in the biodiesel yields was obtained. This result was in agreement with the result of the study on the biodiesel screening using oscillatory flow meso reactors where the triglyceride conversion in the meso reactor was maximized at the frequency of oscillation of 6 Hz (Zheng *et al.*,2007).

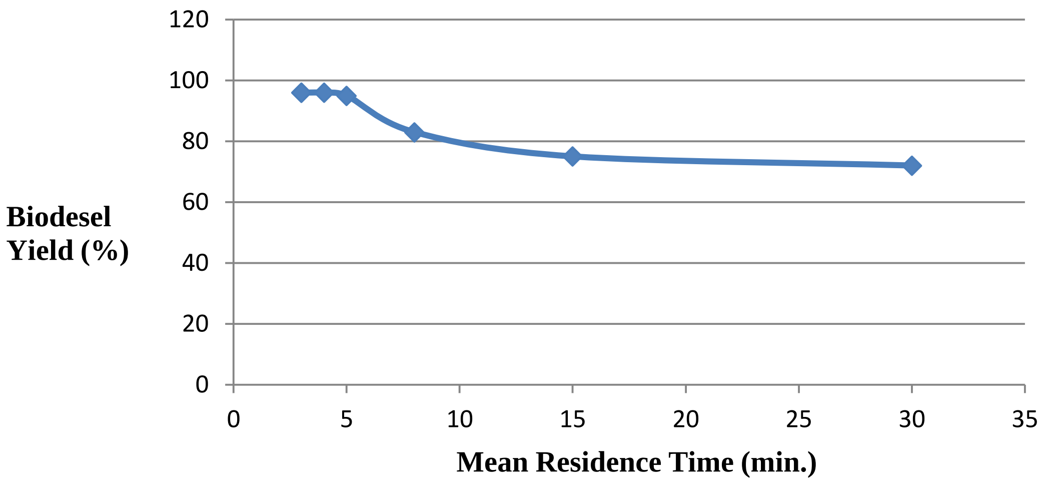

Fig. 5: Effect of Mean Residence Time on Biodiesel Yield

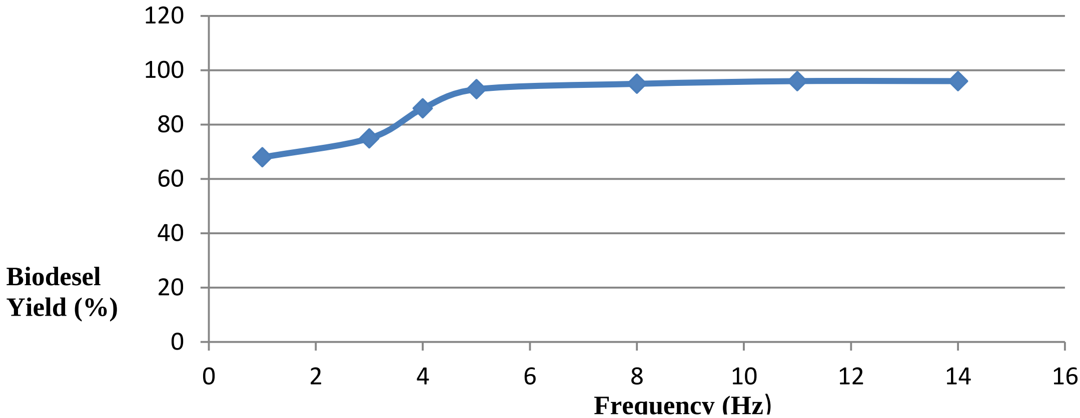

Fig. 6 ; Effect of Frequency of Oscillation on Biodiesel Yield

CONCLUSION

Performance evaluation of the developed COBRA was carried out to determine the biodiesel yield from transesterification reaction of *Jatropha* oil at different factors of reaction. The effect of heterogeneous catalyst (ZnO) concentrations on the production of biodiesel from *Jatropha* oil was analyzed. Effect of temperature on the production of biodiesel using COBRA was analyzed. The result showed that the optimum temperature that gave the highest yield of 97% was 65^{o}C. At temperature of 70^{o}C, there was a drastic decrease in the yield to about 92%. Also, effect of oil-methanol ratio on yield of biodiesel from the COBRA was carried out. It was found that approximately there was 1-15% increase in biodiesel yield with an increase in oil-methanol ratio from 1:3 to 1:12. There was no significant increase in biodiesel yield at higher biodiesel ratios due to dilution of the species such as methoxide anion. The optimum mean residence time of reaction and frequency of oscillation of COBRA were found to be 5 minutes and 5 Hz respectively.

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