FACULTY OF ENGINEERING
AHMADU BELLO UNIVERSITY, ZARIA
National Engineering Conference 2018

ABU NEC2018 085

ECONOMIC VIABILITY OF USING BIOETHANOL AS AN ADDITIVE TO TARGET HIGH QUALITY UNLEADED MOTOR GASOLINE PRODUCTION IN A NIGERIA REFINERY

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Abstract: The study was aimed at estimating the optimum production rate of gasoline (quality and quantity). This was achieved by formulating and minimizing an objective function for the minimum cost of blend using linear programming technique on MATLAB R2015a. The objective function was explored in three areas; effects of bioethanol price changes, changing the percentage of bioethanol added to the gasoline, and possible production rate that can be obtained from the same pool. The Prices (N/bbl), amounts (bbl/day), RON and RVP of all the gasoline pool components (FCC Gasoline, Reformate and Light Naphtha) for the blend to produce 15000 bbl/d of Gasoline with RON of 90 and RVP of 9 psi max were obtained from KRPC. These data were simulated and gave an optimum cost of 23,783N/bbl. To obtain 15000 bbl/d of unleaded Premium Gasoline with RON of 93 and RVP of (8 min-9 max) psi, these data were simulated with Bioethanol (RON 109, RVP 2 and 5% min -10% max) as an additive and it gave 25,796 N/bbl as the optimum cost. The effect of bioethanol price changes revealed that lower prices of bioethanol below actual price of 55,650 N/bbl gave optimum costs below 25,796 N/bbl, while the higher prices above the actual price gave optimum costs above 25,796 N/bbl. The study of bioethanol percentage changes between 3% and 15% showed that 3% and 4% gave lower optimum cost below 25,796 N/bbl, while 6 to 10% gave higher cost above 25,796 N/bbl. The study of production rate of 11000 bbl/d to 17000 bbl/d gave the same optimum cost of 25,796 N/bbl. Bioethanol addition of 12% to 15% and Production rate of 18000 bbl/d to 20000 bbl/d could not be achieved due to unavailability of FCC Gasoline.

Keywords: FCC Gasoline, Bioethanol, Reformate, Light Naphtha Simulation, MATLAB

1. INTRODUCTION

Crude petroleum in its natural state has little or use, but it is an essential energy source that affects nearly every aspect of our modern lifestyle. It has to be refined into different useful products in the refinery. The refining process aims to maximize the value added by separating the crude oil using different physical and chemical processes into both intermediate products, which can serve as feedstock to other downstream processes and finished products, including transportation fuels (Oduola and Iyaomolere, 2015). The most important crude oil product is Gasoline (PMS) because it is used as fuel for most automotive engines which has increased rapidly due to the advancement in technology (Oduola and Iyaomolere, 2015). Gasoline is one of the most essential products in the oil refining industry due to its widespread usage as a main source of energy all over the world (Kulkarni, 2009., Soheil *et al*., 2012). With the emergence of the internal combustion engine, production of gasoline has dominated the refining processes. This is because the amount of gasoline gotten from distillation alone were not enough to satisfy consumers demand. Therefore, to meet the gasoline demand, some petroleum fractions must be converted to gasoline by processes like cracking, hydro processing, alkylation and catalytic reforming (Faruq *et al*., 2012). This gasoline is called Fluid Catalytic Cracked Gasoline (FCCG) and it normally has octane number greater than Light Straight Run Gasoline (LSR). The LSR gasoline gotten from crude oil processing normally comes with a low octane and would not run very well in cars, which can lead to engine knock. Gasoline additives typically increase gasoline octane rating, displaces gasoline aromatic components such as benzene and sulphur, reduces emission of HC and CO, act as corrosion inhibitors or lubricants (Patil *et al*., 2016; EPA, 2017). The octane rating is a measure of a fuel's ability to avoid knock. Octane is a gasoline additive that is needed for the proper functioning of modern engines (Demirbas *et al*., 2015; EESI, 2016*)*. Since the phase out of lead in the Nigerian Refineries, Reformate has been used as a main octane booster due to the large amount used during the blend. Reformate contains aromatics such as benzene which is dangerous to the environment and human health when discharged in large proportion. These aromatics are responsible for disproportionate amounts of CO and HC exhaust emissions. The presence of benzene in gasoline sold in Nigeria was confirmed in an analysis by Onyinye and Nkechi, (2015). Also, lack of octane enhancers such as oxygenates or additives may result in low RON which increases the gasoline tendency to knock. The fluctuation of RON in gasoline sold in Nigeria was confirmed in the analysis carried out by Onojake *et al.* (2012) and Onyinye and Nkechi, (2015). Bioethanol is an additive, gasoline improver and octane enhancer that will not only boost the octane rating of gasoline, but also reduce the aromatic contents in the fuel thereby minimizing the emission of CO and HC. Bioethanol offers several advantages over gasoline such as higher octane number 108, limits, higher flame speeds broader flammability and increased heats of vaporization. Unlike petroleum fuel, bioethanol is less toxic, readily biodegradable and produces lesser air-borne pollutants (Azhar *et al.*, 2017). The aim of this research is to estimate the optimum production rates (quality and quantity) and was achieved by formulating an objective function and minimizing it for the minimum cost of blend from which the final product is made. The objective function was explored in three areas which include effect of bioethanol price changes, effect of changing percentage of bioethanol added to the gasoline and Possible production rates that can be obtained from the same pool. Production of high quality unleaded gasoline using bioethanol as an additive is of immense importance because they reduce the emission of contaminating gases produced from combustion of gasoline mainly, carbon monoxide (CO) and gaseous hydrocarbons (HC). It also improves the octane rating by decreasing the gasoline tendency to knock.

2. MATERIALS AND METHOD

2.1 Procedure

2.1.1 Collection of Data

The amounts available per day, RON and RVP of Gasoline pool components (FCC Gasoline, Reformate and Light Naphtha) were gotten from Kaduna Refinery and Petrochemical Company (KRPC).

2.1.2 Gasoline Blending Process description with bioethanol addition

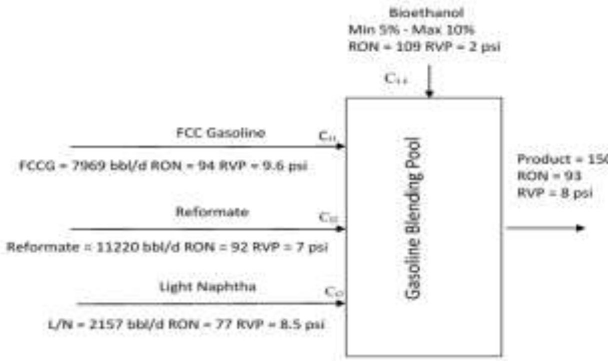

Figure 1: Blending process (gasoline pool) with Bioethanol

2.1.3 Computer Simulation

Linear programming (LP) is one of the easiest ways to carry out optimization. It helps in solving some very complex optimization problems by making few simplifying assumptions. LP software used for analysis in this thesis is MATLAB R2015a Linprog

2.2 Objective Function

It is necessary to identify an objective function must be identified. Maximum profit cannot practically be used in the objective function since the refinery sales are substantially subsidized by government. As an objective function the best possible one to represent this case is the minimization of the cost of "the gasoline blend" from which the product is made.
The prices of gasoline input streams are shown in Table 1 below

TABLE 1. PRICES OF GASOLINE INPUT STREAMS

Components	Price (N/bbl)
FCC Gasoline	25,653
Reformate	22,986
Light Naphtha	22,435

The objective function for the production of 15000 bbl/d premium gasoline is given as:

$$Y = 25{,}653C_{11} + 22{,}986C_{12} + 22{,}435C_{13} + 55{,}650C_{14} \quad N/day \tag{1}$$

Or

$$Y' = \frac{1}{15000}\, x\, (25{,}653C_{11} + 22{,}986C_{12} + 22{,}435C_{13} + 55{,}650C_{14}) \quad N/bbl \tag{2}$$

(Al-Shaia, 2004)

The following conditions and constraints are set for the final product

2.2 Specifications Requirements

The premium gasoline is produced by blending the gasoline components to meet DPR specifications.
Figure 1 shows the blending components with stream rates and properties

(a) Octane Requirement is met by the formula below

$$V_{blend}(ON)_{blend} = \Sigma V_i(ON)_i \tag{3}$$

where,
V_{blend} = Total volume of gasoline blended (barrel).
V_i = Volume of blending component i (barrel).
$(ON)_{blend}$ = Desired true octane of blend.
$(ON)_i$ = Octane number of component i.
(Albahri, 2018)

From which octane constraints can be formulated from Figure 1 as;

$$94C_{11} + 92C_{12} + 77C_{13} + 109C_{14} = 93(C_{11} + C_{12} + C_{13} + C_{14})$$

$$94C_{11} + 92C_{12} + 77C_{13} + 109C_{14} = 93C_{11} + 93C_{12} + 93C_{13} + 93C_{14}$$

By equating to 0, we have

$$C_{11} - C_{12} - 16C_{13} + 16C_{14} = 0 \tag{4}$$

(b) RVP constraints are formulated from Figure 1
For (RVP min)

$$9.6C_{11} + 7C_{12} + 8.5C_{13} + 2C_{14} \geq 8(C_{11} + C_{12} + C_{13} + C_{14})$$

$$9.6C_{11} + 7C_{12} + 8.5C_{13} + 2C_{14} \geq 8C_{11} + 8C_{12} + 8C_{13} + 8C_{14}$$

By rearranging, we have

$$1.6C_{11} - C_{12} + 0.5C_{13} - 6C_{14} \geq 0$$

Or

$$-1.6C_{11} + C_{12} - 0.5C_{13} + 6C_{14} \leq 0 \tag{5}$$

For (RVP max)

$$10.6C_{11} + 8C_{12} + 9.5C_{13} + 3C_{14} \geq 9(C_{11} + C_{12} + C_{13} + C_{14})$$

$$10.6C_{11} + 8C_{12} + 9.5C_{13} + 3C_{14} \geq 9C_{11} + 9C_{12} + 9C_{13} + 9C_{14}$$

By rearranging, we have

$$1.6C_{11} - C_{12} + 0.5C_{13} - 6C_{14} \geq 0$$

Or

$$-1.6C_{11} + C_{12} - 0.5C_{13} + 6C_{14} \leq 0 \tag{6}$$

(c) The Total Production Rate
The total production rate of gasoline is about 15000 bbl/d

$$C_{11} + C_{12} + C_{13} + C_{14} = 15000\ bbl/d \tag{7}$$

2.3 Bioethanol constraints

Bioethanol used (C_{14}) is set as $5\%v$ minimum and $10\%v$ maximum of the product, which gives the following two relationships:

$$0.05(C_{11} + C_{12} + C_{13} + C_{14}) \le C_{14}$$

$$\le 0.10(C_{11} + C_{12} + C_{13} + C_{14})$$

$$C_{14} \ge 0.05(C_{11} + C_{12} + C_{13} + C_{14}) \quad (8)$$

and

$$C_{14} \le 0.10(C_{11} + C_{12} + C_{13} + C_{14}) \quad (9)$$

(9)

from Equation (6), we have

$$0.05C_{11} + 0.05C_{12} + 0.05C_{13} - 0.95C_{14} \le 0 \quad (10)$$

from Equation (7), we have

$$0.10C_{11} + 0.10C_{12} + 0.10C_{13} - 0.90C_{14} \ge 0$$

And putting into the optimization problem format becomes:

$$-0.10C_{11} - 0.10C_{12} - 0.10C_{13} + 0.90C_{14} \le 0 \quad (11)$$

The production model is represented in mathematical form by Equation (4) to (11). The characteristics of the streams before blending and the final product specifications are represented by these equations.

The model was solved and investigated. The software MATLAB R2015a Linprog was used for solution. Many cases and scenarios were looked into.

2.4 Cases

Case (a): Analysis of the situation from KRPC figures and data without Bioethanol
Case (b): Analysis of the situation from KRPC figures and data with Bioethanol
Case (c): Effect of Bioethanol price fluctuations
The current price of imported bioethanol ($ 1000 per MT) which stands at N350 per litre (converted to N/bbl) was used with 5%v minimum and 10%v maximum limits of ethanol in the blend. Prices changes of ± 50 was used.
Case (d): Effect of changing Bioethanol minimum limit
The effect of Bioethanol limits in the range 3% to 15% was investigated
Case (e): Effect of changing gasoline production rate
A range of ±50-100 of the actual production rate was analysed.

3. RESULT AND DISCUSSION

Unleaded Gasoline is made by blending the gasoline pool components: FCC Gasoline, Reformate, Light Naphtha and Ethanol as an additive to replace the undesirable and banned alky lead compounds. The product is to meet the Department of Petroleum Resources (DPR) specifications of unleaded motor gasoline premium grade. For this purpose, an objective function is set and optimized using linear programming. The study is conducted to target high quality unleaded motor gasoline using Ethanol as an additive. Kaduna Refining and Petrochemical Company (KRPC) production rates and data are used as input data.

3.1 Simulation result with and without Bioethanol

The simulation result presented in table 2 and 3 represent the amount of components used to produce 15000 bbl/d of gasoline

TABLE 2: ANALYSIS OF THE SITUATION IN KRPC WITHOUT BIOETHANOL

	FCC Gasoline (bbl/d)	Reformate (bbl/d)	Light Naphtha (bbl/d)	Product (bbl/d)
Amount available	7969	11220	2157	-
Amount used	4821.4	8535.7	1642.9	15000
%age in product	32.1	56.9	11.0	100
%age used	60.5	76.1	76.1	-

Value of the objective function: $Y = 3.5674 \times 10^{8}$
$Y' = 2.3783 \times 10^{4}$

TABLE 3 ANALYSIS OF THE SITUATION WITH BIOETHANOL

	FCC Gasoline (bbl/d)	Reformate (bbl/d)	Light Naphtha (bbl/d)	Bioethanol (bbl/d)	Product (bbl/d)
Amount available	7969	11220	2157	unlimited	-
Amount used	6776.8	6719.6	753.6	750	15000
%age in product	45.2	44.8	5.0	5.0	100
%age used	85.0	59.8	34.8	-	-

Value of the objective function: $Y = 3.8695 \times 10^{8}$
$Y' = 2.5796 \times 10^{4}$

From the analysis of KRPC data, it has been found that 60.5% of FCC Gasoline, 76.1% of Reformate and 76.1% of Light Naphtha from available amounts were used to produce 15000 bb/d of Gasoline. That is, 32.1, 56.2 and 11% are the percentage of FCC Gasoline, Reformate and Light Naphtha in the final product. The minimum cost of blend is found to be 23,783 N/bbl (149 N/L) as shown in Table 2. Reformate is of high-octane content and due to the amount of reformate used, there are presence of Aromatics such as benzene, toluene and xylene in the gasoline. This was confirmed by the analysis carried out by Onyinye and Nkechi, (2015). These aromatics are responsible for disproportionate amounts of CO and HC exhaust emissions. Also, lack of octane enhancers such as oxygenates or additives may result in low RON which increases the gasoline tendency to knock. The fluctuation of RON in gasoline sold in Nigeria was confirmed in the analysis carried out by Onojake *et al*. (2012), Faruq *et al*. (2012), and Onyinye and Nkechi, (2015). These problems above are why Bioethanol is being introduced as an additive to not only increase the octane number of gasoline, but to also reduce the aromatic contents in it. This was confirmed in the analysis done by Atan *et al*, (2015), Singh *et al*., (2016) and Fotouh *et al*., (2017). From the introduction of Bioethanol to the blend, it was discovered that 45.2, 44.8, 5.0 and 5.0% were the percentage of FCC Gasoline, Reformate, Light Naphtha and Bioethanol respectively in the final product. There was increase in the percentage of FCC Gasoline used while there were decrease in the amount of Reformate (aromatics) and Light Naphtha (low RON) used as shown in Table 3. This is because bioethanol reduced the aromatic content in the fuel and increased the octane rating from 90 to 93. The minimum cost was given as 25,796 N/bbl (162 N/L) which is higher due to the high price of imported Bioethanol sold at $ 1000 per MT which is 55,650 N/bbl (350 N/L). This is why effect of bioethanol Price range was considered.

3.2 Effects of Bioethanol Price Changes

According to The Director of Allied Atlantic Distilleries (AADL) Igbesa Ogun State, Mr Rajavelu Rajasekar, a litre of bioethanol is sold between N350 to N400 now as against N160 per litre in 2015. The study of the effect of Bioethanol price changes on the optimum cost of unleaded gasoline blend and the amounts of blend components was carried out using 10 differences prices lower and higher than the actual bioethanol price from 7,950 to 79,500 N/bbl (50 - 500 N/L).

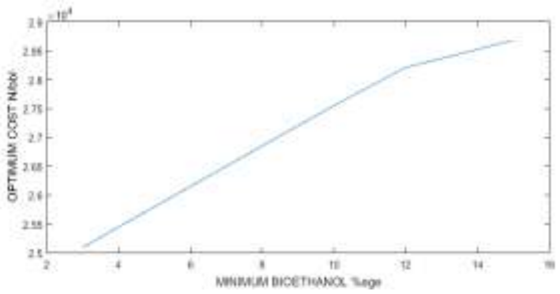

Figure 2a: Effect of bioethanol price changes on optimum cost

From Figure 2a, The minimum cost of blend was 22,781 N/b (143 N/L) and 23,576 N/b (148 N/L) at bioethanol price of 7,950 N/bbl (50 N/L) and 15,900 N/bbl (100 N/L) which is lower in cost and higher in quality when compared to the cost and quality of blending without bioethanol. The amounts of components in the product were 51, 27.5, 11.5 and 10% for FCC Gasoline, Reformate, Light Naphtha and Bioethanol respectively at both prices. This showed that the price of bioethanol determines the amounts of components in the product. At very low bioethanol price, more FCC Gasoline, Light Naphtha and Bioethanol were used with less Reformate but as bioethanol prices increases, there was decrease in the amount of FCC Gasoline, Light Naphtha and Bioethanol used while there was significant increase of Reformate as shown in Figure 2b.

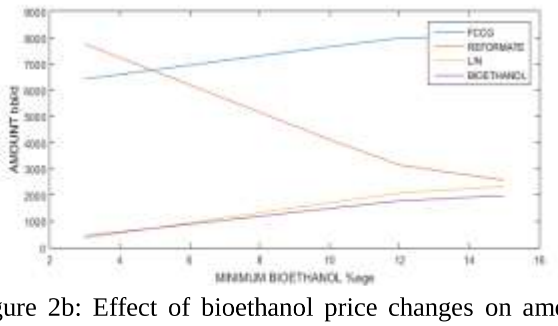

Figure 2b: Effect of bioethanol price changes on amounts of components used

Bioethanol price of 23,850 N/bbl (150 N/L) to 79,500 N/bbl (500 N/L) gave cost of blend to be 24,206 N/bbl (152 N/L) to 26,989 N/bbl (169 N/L) and amounts of components in the product to be 45.2, 44.8, 5.0 and 5.0% for FCC Gasoline, Reformate, Light Naphtha and Bioethanol respectively.

3.3 Effects of changing bioethanol percentage added

The effects of changing Bioethanol percentage in the blend was also addressed and found out that the optimum cost increases with increase in Bioethanol percentage as shown in Figure 3a.

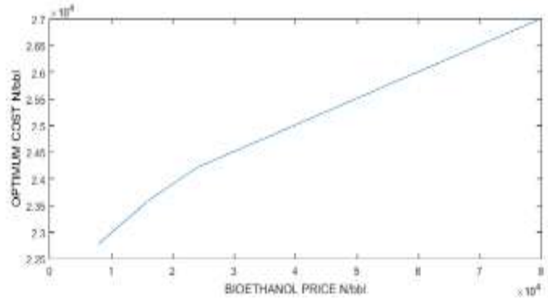

Figure 3a: Effect of changing bioethanol percentage on optimum cost

At bioethanol percentage of 3% and 10%, the optimum cost was 25,095 N/bbl (157 N/L) and 27,551 N/bbl (173 N/L). This is obvious as Bioethanol is the most expensive component of the gasoline pool [55,650 N/bb (350 N/L)]. From the result, it was discovered that at the lowest limit of 3%, the amounts of Gasoline, Reformate, Light Naphtha and Bioethanol in the product were 42.8, 51.7, 2.4 and 3.0%. And at 10%, the amounts of Gasoline, Reformate, Light Naphtha and Bioethanol in the product were 51, 27.5, 11.5 and 10%. This means that at low Bioethanol percentage in the product, more Reformate is used in the blend, FCC gasoline and Light Naphtha were also reduced. As the bioethanol percentage increased, reformate reduced while FCC gasoline and Light Naphtha increased slightly as shown in Figure 3b.

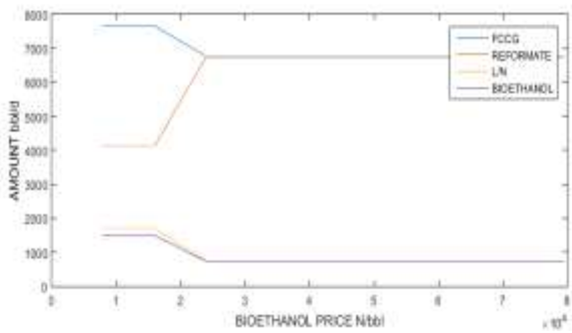

Figure 3b: Effect of changing bioethanol percentage on amounts of components

Bioethanol percentage of 12 and 15% could not be achieved because the FCC Gasoline available is not enough to carry out the operation as more FCC gasoline above 7969 bbl/d will be required. Therefore, the effect of Bioethanol percentage shows that bioethanol percentage is directly proportional to FCC Gasoline and Light Naphtha while inversely proportional to Reformate.

3.4 Effects of Production rates

On the study of Production rate of unleaded gasoline, it was discovered that from 11000 to 17000 bbl/day rates, they gave the same optimum cost of 25,796 N/bbl (162 N/L) as shown in Figure 4a with constant percentages of 45.2, 44.8, 5 and 5% for Gasoline, Reformate, Light Naphtha and Ethanol respectively in the product as shown in Figure 4b.

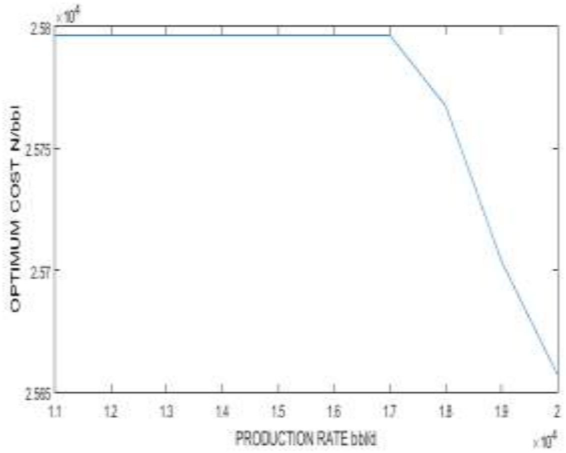

Figure 4a: Effect of production rates on optimum cost

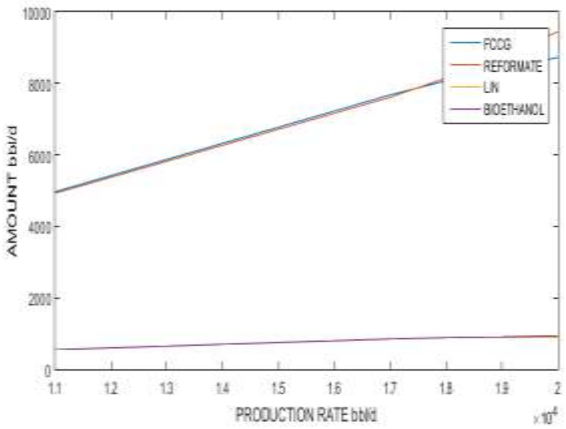

Figure 4b: Effect of production rates on amounts of components used

Production rate above 17000 b/day could not be achieved because the FCC Gasoline available is not enough to carry out the operation as more FCC gasoline above 7969 bbl/d will be required.

According to an article published in Punch on April 28, 2018, the Group Managing Director of NNPC, Dr Maikanti Baru disclosed that as at December 23, 2017, the landing cost of imported Premium Motor Spirit (pms) was 171.40 N/L but NNPC has been subsidizing the cost of petrol as the official price remained at 145 N/L.

CONCLUSION

From the Simulation carried out, it was established that for Bioethanol to worked perfectly as an additive in reducing aromatics and raising the octane rating of Gasoline, certain condition must be met. At low bioethanol prices, the composition of reformate which is the main source of aromatics in gasoline was reduced while more bioethanol was used. Therefore, high prices of bioethanol affect the effectiveness of bioethanol as an additive. Also, the composition of reformate at low bioethanol percentage was high, for ethanol to effectively reduce aromatics and increase the octane rating of gasoline, the percentage of bioethanol should not be less than 5%. Furthermore, the production rate should be maximized to reduce loss since the production rates all gave the same cost of production. Lastly, components of gasoline blend should be readily available for production as a component was exhausted while simulating thereby unable to achieve some results. According to the Director of Allied Atlantic Distilleries Limited in Ogun State, the largest cassava based bioethanol producing company in Africa, Mr Rajavelu Rajasekar, Nigeria spends N160 billion annually to import 400 million litres of Bioethanol. To reduce the high cost of bioethanol, NNPC has signed MOU with Kogi State to build Ethanol biofuel processing plant capable of producing 84 million litres annually. NNPC is also in talks with Ondo, Benue and Kebbi states to produce combined 317 million litres of biofuel annually.

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