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MAIGANGA COAL ANALYSIS AND GASIFICATION SIMULATION FOR POWER GENERATION

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Abstract: Nigeria is faced with energy deficit which led to closure of many industries that contribute immensely to socio- economic development of the country. The nation's electricity sources are natural gas and hydro-power plants respectively but periodic attacks on pipelines supplying gas to power plants have caused serious setback in meeting its rising energy demand. On the other hand, electricity output from hydro-power plants tend to drop during dry season. The use of coal for power generation has been in existence for decades in other countries, however, Nigeria with its abundant deposits is yet to develop its potential. In this work, the potential of Maiganga Coal from Gombe State for power generation was investigated. Proximate, ultimate and sulfanal analyses were carried out which gave the carbon, hydrogen, nitrogen and sulfur contents of the coal. The results of these analyses were used to model and simulate an integrated coal gasification – power generation plant using ASPEN PLUS simulation software. From the analyses, the coal carbon content was found to be 61.85 wt % while total sulfur was 0.38 wt %. From the simulation, it was revealed that power generation from 7200kg/hr of coal was 29 MW with a boiler efficiency of 66% and overall efficiency of 64% based on lower heating value estimate.
Keywords: CHNS analyzer, Gasification, RGIBBS, Power.

1. Introduction

Nigeria depends mainly on natural gas and hydro-power plants for electricity generation whose combined output is insufficient to meet the nation's energy demand. This has been causing major drawback in socio- economic development of the country. Recently, attacks on pipelines supplying gas to power plants has compounded the problem further. This threaten the already ailing power security of the nation.

The Nigerian government has invested a lot in the power sector, especially in building gas power plants, but militancy has make it unrealizable. Nigeria has approximate power generation capacity of 9000 MW, and peak generation capacity fluctuating between 2800 to 5000 MW [1] with projected power demand of 160 GW in 2030 [2], the problem of meeting this projected demand using the current facilities would obviously be difficult.

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Apart from oil and gas, Nigeria is endowed with coal resources. The coal reserve in Nigeria has been estimated to almost 2 billion metric tonnes of which 560million tonnes are proven, spread in over 13 states [3]. Maiganga town alone in Gombe state has proven reserve of 760 million tonnes. The diversification of energy resources via coal exploitation will address the present power shortage in the country [1]. Most of the world powers depend largely on coal in generating power. For instance, 38.4% of United Kingdom power comes from coal. Despite the climatic concern on emissions from coal power generation plants, many countries utilize coal power plants to diversify their power sources, for instance Vietnam has proposed its annual power growth rate at 11-12 % and to achieved 613.2 TWh from coal by the year 2030 [4]. The use of coal for power generation is a well-established technology. The properties and composition of Nigerian coals from various deposits have been studied [5]. Adeleke *et al*. [6] have studied the properties of Lafia-Obi coal. Ryemshak *et al*. [7] studied the mineral matters in Nigerian coal which is one of the components required in simulating coal power plant. Nyakuma [3] have carried out proximate and ultimate analysis of Maiganga coal in Gombe. Usman and Maitera [8] reported that the coal has heating value as high as 5359 kcal/g. However, non of the work presents sulfunal analysis of the coal. Evaluation of coal for power generation requires this parameter. It is imperative to carry out the sulfurnal analysis of the coal. In 2008, United States Energy Information Administration, (EIA) reported the cost of generating electricity from coal is five times less compared with that from natural gas. It has been reported that the range of energy density of Nigerian coal is between 20 to 30 MJ/kg [6].

Gasification is a chemical process that converts carbonaceous materials like biomass into useful convenient gaseous fuels or chemical feedstock.

Gasification converts fossil or non-fossil fuels (solid, liquid, or gaseous) into useful gases and chemicals. It requires a medium for reaction, which can be gas or supercritical water (not to be confused with ordinary water at subcritical condition). Gaseous medium include air, oxygen, subcritical steam, or a mixture of these [9].

The aim of this work is to simulate the coal power generating plant using Maiganga coal as fuel, with the following objectives.

i. To carry out the proximate, ultimate and sulfunal analysis of the coal;

ii. To simulate power generating plant using the coal attributes.

2. Materials and methods

The coal sample was acquired from the Maiganga coal field in the Akko Local Government Area of Gombe State in Nigeria. Major equipment used in the analyses were CHNS analyzer (LECO-932, LECO Corporation, Michigan USA), Sulfur analyzer: LECO SC-144DR, USA, Ultrasonic bath extractor ET460 (Elma, Singen, Germany) and Muffle Furnace in Quality Control Laboratory of Ashaka Cement Plc.

Proximate Analysis

Moisture content

The mass of an empty tray was weighed and recorded as M_1, then 15 g coal to be tested was spread evenly on the tray, weighed and recorded as M_2, the tray was placed into the drying Oven with a temperature of 110 ^oC and then allow it to be dried for a period of 2 hours after which, it was removed and placed in a dust free area to cool for 30 min. The tray and its content, was re-weighed and recorded as M_3. The moisture content was calculated based on weight loss principle as follows

The weight of the sample: $S_1 = M_2 - M_1$ 1

The weight of the dried coal sample: $S_2 = M_3 - M_2$ 2

$$Moisture\ content = \frac{S1-S2}{S1} \text{x } 100 \quad 3$$

Volatile matter

The final dried sample from the moisture content determination was put into oven and heated to a temperature of 650 ^oC for 30 minutes after which final sample was weighed and recorded. The percentage volatile matter was calculated as done for moisture content.

Ash content

The sample from the volatile matter determination charged into a crucible and put into muffle furnace and it was turned on and allowed to burn at 800 ^oC. for 2 hours. The residual ash was weighed and recorded.

Fixed carbon content

Fixed carbon content was obtained by subtracting moisture content, volatile matter and ash content from initial 15 g of the coal sample.

Ultimate analysis

Coal sample weighing 5 g was put into LECO-932 CHNS analyser after calibration with sulfamethazine. The analyser connected to a personal computer was turned on for the analysis and the result which gives the percentage carbon, hydrogen, oxygen, nitrogen and sulfur in the sample displayed on the computer screen was saved.

Sulfunal analysis (Forms of sulfur)

Coal sample weighing 0.25 g was mixed with 10 mL of 5 M HCl into digestion vessel, it was then allowed to settle after which it was decanted. The solid part was spread out uniformly at the bottom of a boat and placed in the sulphur analyser connected to computer. On the keyboard, F4 was press, to select sulphate sulfur from the drop down option and the percentage sulfate in the sample was displayed on the computer screen after the analysis. 50mL of de-ionized water was added to the residue from the sulfate analysis, the procedure was repeated as in sulfate determination, but pyritic sulfur was selected instead of sulfate. The residue from pyrite was mixed with dichloromethane then placed in ultrasonic bath, the machine was on for the extraction after which it was transferred into the boat and placed into the sulfur analyser and the procedure repeated as in above.

3. Simulation Study

The models of the processes considered are developed using ASPEN PLUS V8.8 as the process simulator. The different stages considered in ASPEN PLUS simulation, in order to represent the overall gasification process, are drying of the wet coal, decomposition, volatile reactions, Ash separation, char gasification, and combined power generation.

Assumptions

The following assumptions were considered in the modeling of the gasification:

1. Process is steady state
2. Coal Pyrolysis takes place instantaneously.
3. Char only contains carbon.
4. Saturated steam production at 125 bar.
5. Final condensation to 20°C.
6. Steam turbine operating at ideal reversible conditions.
7. Condensate pump operating at ideal reversible conditions.
8. No extra pressure drop through heat exchangers or piping.

Coal Drying

Drying of coal was deemed the first unit due to the higher percentage of water obtained from the Proxinal analysis result. RStoic block models the drying of coal, although this process is not normally considered a chemical reaction. RStoic block was used to convert a portion of the coal to form water. The following equation was the chemical reaction considered for coal drying:

$$Coal(wet) \rightarrow 0.055\, H_2O + Coal\ (dry) \qquad 4$$

Coal Decomposition

The ASPEN PLUS yield reactor, RYIELD, was used to simulate the decomposition of the feed. In this step, coal is converted into its constituting components including carbon, hydrogen, oxygen, sulfur, nitrogen, and ash, by specifying the yield distribution according to the ultimate analysis [10].

Volatile Reactions

The ASPEN PLUS Gibbs reactor, RGIBBS, was used for volatile combustion, in conformity with the assumption that volatile reactions follow the Gibbs equilibrium, where chemical equilibrium and phase equilibrium are calculated by minimizing Gibbs free energy of the system. Product consist mainly traces of CO and CO2, and some H_2O, CH_4, H_2S and N_3H. Carbon will partly constitute the gas phase, which takes part in devolatilization, and the remaining carbon comprises part of the solid phase (char) and subsequently results in char gasification.

Char Gasification

The ASPEN PLUS stoichiometric reactor, RSTOIC, performs char gasification by specifying the gasification reactions [11]:

$$C + O_2 \rightarrow 2CO \qquad 5$$

$$C + CO_2 \rightarrow 2CO \qquad 6$$

$$C + H_2O \rightarrow CO + H_2 \qquad 7$$

$$C + 2H_2 \rightarrow CH_4 \qquad 8$$

$$CO + H_2O \rightarrow CO_2 + H_2 \qquad 9$$

Power Generation

Power generation blocks model a simple Rankine steam cycle for electricity production. The system consists of steam turbine, steam condenser, condensate pump, and a boiler.

Separation Columns NITR-SEP and ASH-SEP were used before the RYIELD and the RGIBBS reactor respectively. NITR-SEP was used to separate left-over nitrogen gas from coal and ASH-SEP used to separate the volatile materials and solids in order to perform the volatile reactions. The amount of volatile material can be specified from the coal approximate analysis.

Other blocks used in the simulation are described in Table 1 and Table 2 shows the setup parameters used in the simulation.

Table 1: Description of other units used in the Simulation

Unit Name	Unit Type	Description
DRYCONTR	Calculator	Used to control to control the drying
MIX	Mixer	Used To quench the syngas to its dew point.
HEAT	HEATER	To calculate energy balance for previous decomposition
WATER	Calculator	To calculate the slurry water amount required under a given slurry percentage.
PYROCAL	Calculator	To simulate the pyrolysis of coal. The NC coal is separated to elemental form.
SET P	Calculator	Used to feed forward the condenser's pressure to march the turbine's discharge pressure.
ADJ-WFLO.	Design Spec	To make ASPEN PLUS Automatically determine the limited Oxygen required for gasification.

Table 2: Experimental Setup Parameters

	CONDSAT	NITROGEN	OXYGEN	WATER	WET-COAL
Temperature C	10	132.2	480	480	
Pressure bar	0.008	1.013	67.569	72.395	1.013
Mass Flow kg/sec	7.193	13.889	0.962	0.754	4

Source: [10].

Complete process flow diagram of the power generation plant developed is depicted in Figure 1.

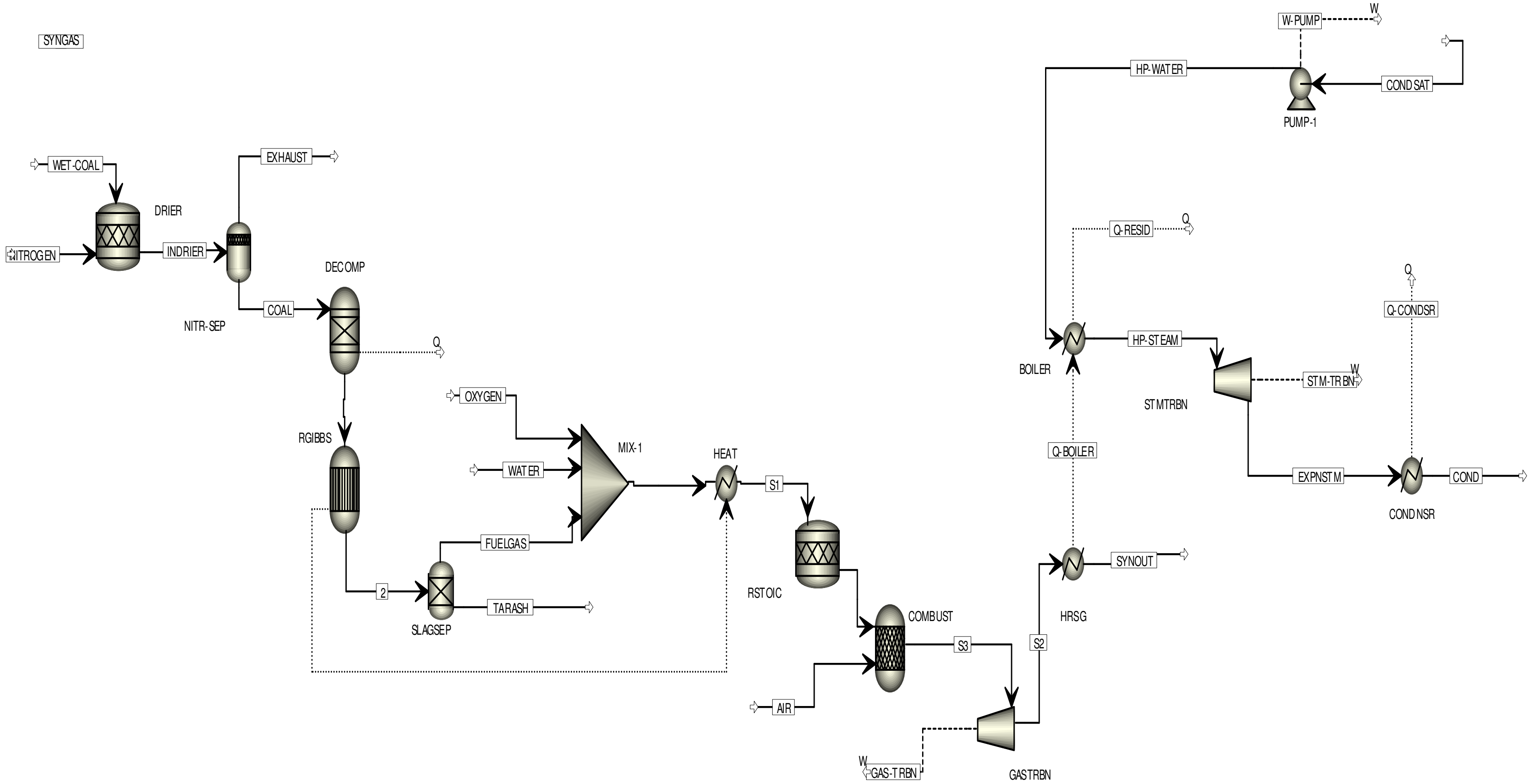

Figure 1: Simulated Flow Sheet of Coal Gasification Process

4. Results and Discussion

From the analyses, the coal attributes obtained were volatile matter, fixed carbon content, ash content, nitrogen content etc. These were summarized and presented in Table 3.

Table 3. Coal Attributes

Proximate Analysis	% weight	Ultimate Analysis	% mass	Sulfunal Analysis	% mass
Moisture	17.24595	C	61.80	Pyritic	0.02
Volatile	31.29758	H	4.43	Sulfate	0.13
Ash	16.50943	N	1.08	Organic	0.23
Fixed C	34.94704	S	0.38		
		O	32.26		

The moisture content of the coal was found to be 17.25 % weight as shown in Table 3 which shows that the coal from the field was wet and requires drying before burning to prevent corrosion of process equipment. The fixed carbon content, 34.95 % weight as shown in the table and the high calorific value, 5359 kcal/g [8] indicated that significant amount of heat capable of generating electricity could be obtained from the coal combustion combustion.

The ultimate analysis revealed that the coal has low sulfur content (0.38 % weight) as shown in Table 3compared to that of Enugu (0.8 % weight) and Lafia (0.7 % weight) respectively [12]. This is an indication of low toxic hydrogen sulfide and oxides of sulfur emission from the coal combustion.

From Figure 1, char gasification will take place in the RSTOIC reactor. The principal product is syngas i.e. H_2 and CO along with the other components like H_2O, N_3H, S_2H, CO_2, and CH_4. This stream is the outlet stream of the RSTOIC i.e. stream SYNGAS. The mass fractions of all these components are shown in the Table 4.

Table 4. Gasifier Outlet; Stream SYNGAS Composition

Mass Frac	%
CO	0.484
H2	0.294
H2O	0.154
CH4	0.044
H2S	0.002
AR	0.003
CO2	0.013
NH3	0.006

The heat content of the product of the combustion, 'stream S3' was used in the gas turbine 'GASTRBN' to produce electricity. The heat recovered from the cooling of 'stream S3' was also used in the steam turbine 'STMTRBN' to produce electricity. The combined quantity of electric power produced from the process is 29MW with a boiler and overall efficiency of 66% and 61.4% respectively.

5. Conclusion

Coal sample from the field was obtained and analyzed. It was deduced that the coal has high fixed carbon, low sulfur content and high moisture content; hence it is suitable for electricity generation. The data obtained from the analyses were used to model and simulate an integrated combined coal gasification and power generation plant using ASPEN PLUS simulation software. From the result of the simulation, it was revealed that power generation from 7200kg/hr of coal was 29 MW with a boiler efficiency of 66% and overall efficiency of 64% based.

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