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Production of Smokeless Briquetted Fuel by Co-Carbonization of Local Coals and Bitumen

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***Abstract*— Binary blend of coal-bitumen by weight (10 % bitumen and 90 % preheated coal samples at 150 oC) was developed, followed by partial briquetting and then moulded into cylindrical shape. The moulded briquetted blend was co-carbonized for about 10 hours at a temperature of 550 oC for the production of smokeless fuel. The calorific value and chemical analysis of the smokeless fuel produced were carried out and only the result of volatile matter was found to be above the acceptable range for use in a boiler system. The results of this study revealed that the use of bitumen as a bonding substance has upgraded the weakly coking and the low-grade (non-coking) coals, to a smokeless fuel briquette with high calorific values with an average combustion period of about 2.5 hours.**

***Index Terms*— bitumen, coal, chemical analysis, calorific value, smokeless fuel..**

I. Introduction

Compaction of bulky combustible materials for both domestic and industrial application as energy source (which is a crucial pre-requisite for the development in any nation) has been a technology widely used by many countries. One of the major driving forces behind this technology is the need to address the irreversible environmental degradation and health hazards associated with the use of solid fuels (such as fuel wood and coal) and also an effective means of managing agro wastes. Among the common types of briquettes widely used in some countries are biomass briquettes, coal briquettes and charcoal briquettes, etc.

The availability of energy source is a crucial pre-requisite for the development in any nation. The inadequate energy resources have made many families' household budgets to suffer from domestic expenses and consequently further subjection to poverty. And due to poverty in conjunction with poor management policies and pressures of population growth, deforestation in search for energy source has become a worldwide epidemic with heavy ecological consequences. Since no country is self-sufficient in its natural resources; the ability to harness the available ones is of great economic and social development for the nation. Coal and tar-sand in the energy mix of Nigeria, and the entire world cannot be under-estimated as sustainable sources of fuel are finite in nature [1]. For instance, processing of coal and tar sand into smokeless fuel has a lot of benefits: protects the environment, generates income and employment, saves time, saves energy and saves lives. Therefore, success in smokeless fuel (briquette) depends on understanding its benefits for the community.

Briquetting is a high pressure process which can be done at elevated temperature [2], or at ambient temperature [3] depending on the technology one applies and the end use. In some briquette techniques, the materials are compressed without addition of adhesive substance to improve the properties especially the strength (binder less briquette) while in others, adhesive materials are added to assist in holding the particles of the material together (i.e. binded briquette). The amount of binder required to yield good result in a substance such as coal falls between 5 and 10 % according to its binding efficiency [4], and the thermoplastic properties of the coal.

The objects of briquetting coal are: to convert cheap or waste fine coal into lump fuel; to produce from coal(s) which decrepitates on grate, solid fuel (smokeless fuel) that can behave satisfactorily during combustion. The briquette smokeless fuel can be produced from all rank of coals (except anthracite) of good grade (less ash and sulphur). Briquette can also be prepared by compacting pulverized coal or biomass with addition of binder and sulphur fixation agent [5], made into different shape and size for convenient application. Carbonization of the coal briquette at low and high temperature produces smokeless fuel and industrial coke respectively. At present, owing to obvious limitations in the availability of fossil fuel, research work has shifted from conventional processing of coal, biomass and wastes into more convenient environmentally green solid fuel known as briquette with better burning properties than the formers.

The main purpose of briquetting material is to reduce the volume and thereby increasing the energy density. When densification takes place, there are two quality aspects that need to be considered, firstly, the briquette has to remain in solid form until it has served its purpose (handling characteristics). Secondly, the briquette has to perform well as a fuel (fuel characteristics). The energy characteristics are other important issues when describing and comparing briquettes with other fuels [6]. The energy characteristics describe how the briquette act and what it produces when burned. The calorific value of briquettes is an important measure of the amount of energy released from every briquette when burned. Briquettes are normally priced by weight, but still, the calorific value is the most important factor in determining the competitiveness of the fuel. The calorific value varies with ash content and moisture content. Different ash and moisture contents in briquettes result in different calorific values [7].

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The smokeless fuel in particular is a kind of economical and efficient combustible that can burn averagely for 8 hours with good heat productivity. It burns with azure (deep blue) colour and no or little flue-gases emission [8]. It is ideal or perfectly suitable for use in its customised stove, multi-fuel stove or open fire; and has high efficiency that burns for up to 40 % longer than the raw coal, producing 80 % less smoke and 25 % less carbon dioxide – CO_2 [9] emission during combustion in line with global concern. Generally, smokeless fuel briquette is a kind of fuel that has an extensive use in the average home for cooking meal, warming bathing water and heating residential house during winter; restaurant, hotel and school dining hall for meal preparation; poultry farm for brooding chicken and cottage industry as energy source.

The aim of this paper is to harness the low grade coal and bitumen for the production of smokeless briquette fuel with good thermal properties. The briquette fuel is a logical alternative to firewood and charcoal for use as a 'green' energy source in a boiler system.

II. Materials and Methods

A. *Materials*

The materials used for this study include five different coal samples collected from Garin Maiganga (GMG), Chikila (CHK), Lamza (LMZ), Shankodi-Jangwa (SKJ) and Afuzie (AFZ); all from Nigeria.

B. *Methodology*

Pre-heating, Composition and Carbonization of Binary Blend

The preheating of the samples was carried out by placing coal sample (9 kg) into an oven and heated to a temperature of 150 °C for about 1 hour. The coal sample was then taken out and mixed with 1 kg of bitumen (10 % by weight bitumen binary blend). The blend formed was then briquetted in the machine. A locally fabricated metal mould (Plate 1) was used in moulding the briquetted blend into round shape with perforated holes (for passage of air to aid combustion). In the moulding process, the metal mould was used in picking up the blend mass into the mould cavity as it was continuously stamped on the mass. Using the leg to press the load pedal on the top of the mould, the briquette was then pushed out and dried by atmospheric exposure for 3 days, after which was then co-carbonized at lower temperature of about 550 °C for 10 hours. At the end of the carbonization residence time, the briquette was then taken out and air-cooled at ambient atmosphere. Thereafter, the combustion period test (ignition to quenching point) of each briquette was then carried out in the customized stove.

Plate 1: Locally fabricated metal mould

Domestic Briquette (Smokeless Fuel) Chemical Assessment

The briquettes produced were characterized in order to ascertain their suitability in the envisaged area of application by the following tests.

Determination of moisture content (inherent)

The test was conducted based on [10] – D3173. A porcelain crucible was preheated in an oven at 110 °C for 1 hour. It was removed and allowed to cool in a desiccator. 1.00 g of the coal sample was weighed in to the crucible. It was put in to the oven and subjected to a temperature of 110 °C for 1 hour. There after it was removed and allowed to cool. The difference or loss in weight was taken as the moisture content

$$\%\ \text{moisture} = \frac{W_O - W_F}{W_O} \times 100$$

where: W_O is the original weight of sample before heating
W_F is the final weight of sample after heating

Determination of ash content

This was done based on the [10] – D3174. The crucible was pre-heated in muffle furnace for 1 hour at 825 °C. It was then cooled in a desiccator and re-weighed. Coal sample (1.00 g) was weighed in to the crucible and heated in the muffle furnace (without lid) for 1 hour at 825 °C, after which it was removed and allowed to cool in a desiccator and re-weighed. The incombustible residue constitutes the ash content which was calculated as follows:

$$\%\ \text{ash} = \frac{W_F - W}{W_O} \times 100$$

where: W is the weight of crucible
W_O is the original weight of sample before heating
W_F is the final weight of sample after heating

Determination of volatile matter (VM)

This was based on [10] – D3175. The standard volatile matter crucible was preheated in a muffle furnace at 900 °C for 7 minutes. It was cooled in desiccator and re-weighed. Coal sample (1.00 g) was weighed in to the crucible, followed by the addition of three drops of benzene. The contents were then heated in furnace set at 900 °C for 7 minutes with the lid on. The loss in weight accounts for the volatile matter of the coal sample which was calculated as follows:

$$\% \, VM = \frac{W_O - W_F}{W_O} \times 100$$

where: W_O is the original weight of sample before heating

W_F is the final weight of sample after heating

Fixed carbon determination

Fixed carbon of coal was obtained by subtracting the percentages of ash, volatile matter and moisture from 100 [10].

% fixed carbon = 100 – (moisture + volatile matter + ash) %.

Determination of sulphur in coke by Eschka method [10]

This was done by igniting 1 g of coke sample and Eschka mixture (2 parts of calcium magnesium oxide with 1 part anhydrous sodium carbonate). The sulphur is dissolved in water and then precipated as barium sulphate. The precipitate is then filtered, ashed and weighed. The total sulphur content was calculated using the formula below:

$$\% \, S_t = \frac{A - B}{C} \times 13.74$$

where S_t = total sulphur

A = mass of barium sulphate from sample

B = mass of barium sulphate from blank

C = mass of sample used

Calorific value determination of the smokeless fuel

The heating values of the cokes were determined based on [10] – 3286 using AC-350 calorimeter. In the experiment, 1.00 gram of the ground coke sample was weighed and placed in a crucible with a fuse wire tied across at two ends and carefully put into a bomb. Oxygen gas was introduced into the bomb at a pressure of 450 Psi and then placed in the combustion chamber containing 200 ml of distilled water. On closing the combustion chamber, the stirrer was put on to ensure homogeneous temperature in the chamber. The electronic thermometer measured the difference in water temperature between the prefire and postfire regime during the combustion of the sample in bomb, processed and then displayed the result (calorific value) on the screen.

III. RESULTS AND DISCUSSION

A. Chemical Properties, calorific value and combustion period of the smokeless fuel or coke (briquette)

The result of chemical assessment (proximate analysis) and calorific value of the domestic briquette is shown in Table 1. The moisture contents of the briquette fuel fall within 0.32 and 1.89 %, and all values are within the range for domestic use. The volatile matter contents of the smokeless fuels range from 12.34 – 29.01 %. Among the briquettes, the GMG binary blend has the least ash content of 6.05 % which falls within the required level, while the SKJ has the highest ash content of 16.82 %. The briquette fuels had appreciable fixed carbon ranging from 61.08 – 70.09 %, with good heating values between 5,990.12 – 7,498.45 cal/g above the minimum of value of 5,510 cal/g for optimum energy source. And the sulphur contents are close to each other with the least amount of 0.49 % observed in GMG briquette and the highest value of 1.42 % in SKJ fuel slightly above the maximum recommended level of 1.2 % [11]. The highest combustion time of 162 minutes was recorded in SKJ briquette, while the least of 137 minutes was in CHK briquette. LMZ briquette is the second in term of combustion period with 158 minutes. GMG and AFZ briquette had 150 and 147 minutes respectively.

SD	MC (%)	VMC(%)	AC (%)	FCC (%)	SC (%)	CV (cal/g)	CP (min)
LMZ_B	0.38 ±0.07	22.01 ±2.85	9.24 ±0.05	68.37 ±2.33	0.53 ±0.07	6,389.76±10.38	158
CHK_B	1.89 ±0.25	28.08 ±3.25	8.95 ±0.54	61.08 ±2.91	0.59 ±0.05	5,990.12±11.14	137
GMG_B	1.59 ±0.55	29.01 ±2.93	6.05 ±0.09	63.35 ±2.09	0.49 ±0.03	6,511.90±15.35	150
AFZ_B	1.89 ±0.63	25.91 ±2.85	8.74 ±0.11	63.46 ±2.35	0.61 ±0.03	7,082.98±12.95	147
SKJ_B	0.75 ±0.11	12.34 ±2.77	16.82 ±0.75	70.09 ±2.33	1.42 ±0.11	7,498.45±13.78	162

Table 1: Chemical analysis, calorific value and combustion period of the smokeless fuel

NB: SD = sample detail AC = ash content
MC = moisture content SC = sulphur content
VMC = volatile matter content CV = calorific value
FCC = fixed carbon content CP = combustion period
B = briquette

The most important chemical properties of smokeless coke are generally assessed in terms of volatile matter, moisture ash and sulphur; which are impurities that are unavoidably usually present in coke. Certain levels of these impurities affect the performance of the smokeless coke in the boiler by decreasing its role as a fuel [12]. Their levels are to be kept as low as possible for optimum efficiency in the boiler.

Volatile matter in coke fuel is residual and is usual far less than that in the coal because more than 50 % may have driven off during carbonization. The volatile matter, even though contributes the heating value of the smokeless fuel, its content should between 5 – 10 % [13]. It is widely speculated that high volatile matter in the cokes produced may be as a result of incomplete carbonization of the charge sample [14]. This assertion is in consonant to operational principle of smokeless fuel production, which is the aim of this work. In the study, all briquette fuel cokes produced have values of volatile matter far above the maximum level requirement, with the exception of SKJ briquette fuel which has 12.34 % almost within the limit respectively [11,13]. The high values of the volatile matter content observed in other coke fuels produced may be due to quality of the parent coal which can be confirmed in further study.

The most undesirous and deleterious chemical properties of critical attention are sulphur and ash (content and chemistry). Coke or smokeless fuel with less ash and sulfur content is highly priced on the market. For the ash, the values higher than 10 weight % can be satisfactory but only if the ash chemistry is acceptable [12]. Essentially all inorganic elements remain in the coke; hence the ash content of the coke is directly proportional to the ash or mineral content of the coal. The amount and nature of the ash and its behaviour at high temperatures affect the design and type of ash-handling system employed in coal or coke-utilization plants [15]. It is therefore a very important quality index, which can be regulated easily only by the choice of coal(s) for carbonization [16, 17]; and this justified the use of these coal samples (particularly LMZ, CHK, AFZ and GMG) for the production of the energy source (briquette coke). Even though sulphur contributes to the heating value of the on combustion it produces acids of sulphur dioxide (SO2) and sulphur trioxide (SO3), which corrode the equipment and also cause environmental degradation or pollution. It is possible to desulphurise the coal, but it's a relatively costly operation. The sulphur content of the coke is therefore an important characteristic and it should not exceed 1.2 % for most application [11]. The sulphur content of the smokeless fuels produced in this project is generally low within the acceptable limit for the energy source application, except SKJ briquette with 1.42 %, slightly above the required level for use [11]. The high values recorded in the SKJ briquette fuel correspond to the high value of the sulphur in the parent coal SKJ coal with 1.63 % [18]. In remedy to the problem of high sulphur in coals for smokeless fuel production, sulphur fixation agent otherwise known as desulfurizing agent can be added to convert most of the sulphur into less harmful substance – salt (ash) instead of liberating it as sulphur dioxide (SO_2) into the atmosphere as sulphur dioxide (SO_2) against the ecological comfort. This implies that, by this technology, the pollution problems associated with burning of coal can be solved, and hence less effect on the ecosystem.

In contrast to sulphur and volatile matter, moisture content reduces the heating value (calorific value) of the coke. Moisture also greatly affects the burning characteristics of briquettes [19]. Coke moisture content ranges from 1– 6 weight % maximum, and common values are in the range 3 – 4 weight % [12]. All the cokes produced in this work have satisfactory moisture contents suitable for intended area of application.

B. Smokeless Fuel (Briquette coke)

In recent years, there is an increasing consumer demand for the production of renewable green energy source, gearing towards reduction in net emission of carbon dioxide (principal agent of global warming), nitrous oxide, sulphur dioxide, mercury, and so forth, resulting from mining and utilization of fossil fuel [20]. This assertion forms the basis for the production of briquette fuel in this research work. Briquette fuel is an economical, combustible, compressed organic material that is mostly domestically inclined in application. Its quality depends on the maceral (which determines thermo-plastic properties) and mineral composition of the pre-cursory coal [21].

Compaction, a mechanical process is the key factor in achieving a good briquette as well as a good indication for effective and sufficient binder. This is because well compacted materials burns more efficiently with high energy output (calorific value) and prolong combustion time. The shape of the brick or briquette can also make a difference in the ignition and combustion operation. It has been found that briquette of hollow cylindrical form exhibits optimal energy as well as ease of ignition [5]. Thus the binary blend of this work was efficiently stamped for compaction when moulding the briquette. The briquette produced is cylindrical in shape with 12 holes (Plate ii) for air passage to aid and increases the combustion efficiency. The briquettes weigh between 750 – 1000 g and noticed to depend linearly with the weight of the parent coal. During carbonization, certain quantity of inherent moisture and inorganic substance (ash) such as carbonates, sulphates, nitrates and so forth that reduce heating value of fossil fuel were eliminated in gaseous form; thereby concentrated the carbon content of the resulting coke. Consequently, the briquettes contain calorific values between 5,990.12 and 7,498.45 cal/g higher than that of the parent coal, which is close to the average heating value of 7,565.0 cal/g for quality coal [17]. Moreover, by law of energy conservation, the energy input of bitumen also contributes to the total energy balance of the briquette. Generally, it was also observed that the calorific values of these fuels have a linear relationship with the quality and the heating values of the parent coals. According to [22], the quality of any fuel briquette depends on its ability to produce adequate heat, ignite with less difficulty, generates less flue gas, produces less ash and is strong enough for safe transportation and handling. The smokeless fuels produced from various binary blends in this project are in consonant with this position above, which have favourable characteristics of low moisture, low sulphur content and moderate volatile matter content with high heating values. The combustion period (ignition to quenching point) of each briquette was carried out, and the total of 754 minutes was recorded for the whole briquettes. Thus confirming the briquettes to have a general average combustion period of 150.8 minutes (2.5 hours); and can take its traditional place of application as energy source in average home, restaurant, hotel and poultry farm for brooding chickens. On the whole, it was observed that combustion time of the briquettes do not actually depends on the calorific value, but rather on the parent coal.

Plate ii: Smokeless fuel (briquette)

C. Construction of Customized Briquette Stove

Fuels have different burning characteristics and so for optimal efficiency the stoves need to have a suitable design for each fuel. For example while firewood transfers most of the heat by convection through the flame, briquette like charcoal transfers heat by radiation. When charcoal is used for cooking, it should be placed close to the pot to get the most efficient transfer of heat by radiation. On the other hand, the firewood needs some space above the fuel for the hot flame. Hence the pot needs to be placed at a higher level when firewood is used, comparing to when charcoal is used [23]. Based on this fact, even though briquette can be used on an open-fire barbeque or multi-fuel stove but for convenience and maximum heat output, customized stove was constructed.

Metal sheet was used in making the cylindrical shaped stove with hollow combustion chamber (similar to one made in India). The kaolin clay layer was used round the inner part of the stove to insulate the combustion chamber, against the environment (although some of the heat is absorbed by the material), and hence efficient heat conservation. An opening hole was created at the side of the stove, which can be used for inserting an igniting gel (inside small tin with a handle) to aid easy ignition as well as for adjusting air inlet for combustion (Plate 3).

Plate 3: Customized stove briquette (smokeless fuel)

III. CONCLUSION

The smokeless fuels (coke fuels) produced are generally good because of their high calorific values, strong to some extent for safe handling, ignite easily because of the perforated holes without any danger, generate less smoke and less ash (dust).

The chemical properties with the exception of the volatile matter content that influence the coke fuel behaviour and reaction during heat treatment in a boiler are generally appreciable in the briquette fuels produced.

These briquettes have been confirmed to burn in an average time of 2.5 hours. It is hoped that this study will mobilize local entrepreneurs to invest in the production of smokeless fuel for domestic and industrial use as an addition to energy mix as well as reduction of ecological devastation, ensuring complete briquetting of the raw material(s) into fire susceptible shape for easy ignition. The use of briquettes as energy source can provide jobs for local residents besides of the advantages of the briquette itself.

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