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# An Evaluation of the Energy Consumption and $Co_2$ Emission associated with Corn Cob Ash Compared with the Cement Clinker

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**Abstract**

This study compares the energy consumption and the carbon dioxide emission associated with the production of Corn Cob Ash with a view to determining its viability and environmental sustainability as a pozzolan. CCA meeting the requirements of ASTM C618-12 (1994) was produced through two separate processes of open air burning and controlled incineration in an electric muffle furnace. In the first method the quantity of kerosene fuel used in the burning process was measured used in computing the external energy input and the associated $CO_2$ emission, using published World Bank data on heating, thermodynamic property and carbon content of various fuels. In the second method, the energy consumption was computed as a product of the name plate rating (in KW) of the muffle furnace and the time taken (in hours) to turn the measured quantity of corn cob to ash. The result reveals the ash yield of corn cob as an average of 3.6% and 1.7% for open air burning and controlled incineration respectively. Corresponding values for energy consumption were 4.3MJ and 216166MJ per kg of ash respectively. $CO_2$ emission associated with the fuel consumption in open air burning was 0.27Kg per Kg of pozzolanic ash. These compare more favorably with the corresponding data of 5.16MJ and 0.97Kg $CO_2$ established for Portland cement clinker production; in that less energy was consumed and less $CO_2$ was emitted and at the same time found an alternative use for the biomass waste. The paper concludes that CCA is a viable and environmentally sustainable source of pozzolan when it is derived from burning processes that take advantage of corn cob as a fuel, rather than being specially burnt in a furnace. The paper therefore recommends that biomass waste be should be promoted as a clean energy source and the resulting ash harnessed as pozzolan as a way of reducing the consumption of cement; leading to reduced green house gas emissions and contribution to global warming from the construction industry.

**Keywords**: Carbon dioxide emission, Cement, Corn cob ash, energy consumption, global warming, pozzolan

## 1.0 Introduction

A number of biomass residues are increasingly being identified as pozzolans. Utilization of Rice Husk Ash is particularly well developed in the rice producing regions of the United States and Thailand; rice husk is first used as fuel in the rice parboiling plants, with further utilization of the ash residue as pozzolan in making special quality cement concrete (Chungsangunsit et al, 2007). Other biomass residues whose ashes have been identified as having pozzolanic properties include Bamboo Leaf Ash (Dwiveldi et al, 2006), Palm Fruit Ash (Olonode, 2010), Locust Bean Pod Ash (Adama and Jimoh, 2011), and Corn Cob Ash (Adesanya and Raheem, 2009). The interest in the application of biomass ash residues as pozzolan is further propelled by the global concern for the environment, in terms of sustainable development, renewable energy, reduction in energy consumption and green house gas emissions. In the construction industry, the fact that nearly 1kg of $CO_2$ is released to the atmosphere for every kilogram of Portland cement produced (USDoE,

2003) has further emphasized the need to find alternatives to Portland cement if the contribution of the construction industry to global warming is to be reduced. This is presumed on the fact that an economic advantage of certain percentage of savings is possible with application of pozzolans to cement in concrete works. In fact the advocacy for further use of ashes produced from the conversion of vegetation biomass waste as chemical stabilizer for poor and weak road soils (Adama and Jimoh 2012 and Oluremi et al. 2012) is an added motivation of this study.
This paper is focused on the energy consumption and the $CO_2$ emission associated with the production of pozzolan from a typical biomass waste, the corn cob ash in comparison with the benchmark established for Portland cement production. Data from two burning processes (open air burning and incineration in an electric muffle furnace) are compared in terms of pozzolanic quality, ash yield, energy consumption and $CO_2$ emission.

## 2.0 Materials and Methods

2.1 Materials

Corn cobs were obtained from the heaps of waste cobs which abound in *Maya* ($7^o12'$ N) a major corn producing rural community in the *Derived Savannah* Agro-ecological zone of Oyo State in Southwestern Nigeria. Producing at an annual rate of 7.3million tones (FAOSTAT, 2010), Nigeria ranks $13^{th}$ among the corn producing countries of the world, with a corresponding generation of waste cobs across the country.

2.2 Production of Corn Cob Ash Pozzolan with open air burning (Figure 1)

A measured quantity of corn cob was gathered in a heap, sprinkled with a measured quantity of kerosene fuel and set on fire. Mass (weight) measurements were done using *Contech* electronic weighing balance for the kerosene and the *Avery* weighing balance for the corn cob at moisture content earlier determined by the standard methods of soil mechanics BS 1377:2000 (BSI 2000). The temperature of the corn cob was monitored with a *Greisinger* digital pyrometer as it turned from cob to char and to ash to ensure that the temperature was kept below the crystallization temperature of $650^oC$ (Zevenhoven, 2001; Zych, 2008). Maximum temperature attained was $590^oC$. The ash residue was thereafter gathered and weighed on the *Contech* electronic weighing scale. The process was repeated in 4 batches and the results are as presented in Table 1.
The energy consumption $E_c$ and the $CO_2$ emission presented in Table 1 above were derived from equations 1 and 2 respectively which were developed elsewhere (Apampa 2012); and which were also based on World Bank estimates and standard values (World Bank, 1992) for the energy content and $CO_2$ emission for each fuel. By considering the case of kerosene, equation 1 reduces to 2

$$E_c = 50W_k + 31W_c + 16W_w \quad \text{(Apampa, 2012)} \qquad (1)$$

$$Ec = 50W_k \qquad (2)$$

Where $E_c$ = Energy consumption in MJ
$W_k$ = quantity of kerosene consumed in kg
$W_c$ = quantity of charcoal consumed in kg
$W_w$ = quantity of firewood consumed in kg
Where as in this case only kerosene has been used as fuel, equation 1 reduces to:
Likewise, the $CO_2$ emission presented in Table 1 is from Equations 3 and 4 as equally derived from the technical data sheet of the World Bank (World Bank, 1992) which is itself based on the carbon content of each fuel. Equation 3 reduces to 4 for kerosene as the fuel.

$C_f = 3.13W_k + 3.28W_c + 1.74W_w$ (Apampa, 2012) (3)

$C_f = 3.13Wk$ (4)

Where $C_f$ is the quantity of $CO_2$ emission from the burning fuel measured in kg.

2.3 Corn Cob Ash production with a controlled burning in an electric muffle furnace

A measured quantity of corn cob was chopped to maximum size of 12mm put in an electric muffle furnace, *Carbolite Type Elf 11/148* (power rating of 2.6KW and an internal volume of 14 liters) of the Pharmaceutical Technology Department of the Moshood Abiola Polytechnic, Abeokuta, Nigeria, shown in Figure 2.

The temperature of the furnace was to 600oC, which was attained in a period of 15 minutes and maintained for a continuous period of 10hours. After the cob has visibly turned to ash, the residue was recovered and weighed. This was repeated 12 times and the average of the results is as presented in Table 2.

2.4 Physical and Chemical Analysis of the Ash

Sample of ash residue from each of the two burning processes (Figure 4) were separately passed through a 1.18mm sieve and sent for analysis at the analytical laboratory of Lafarge-WAPCO Cement Factory in Ewekoro, Ogun State Nigeria. The result is presented in Table 4 alongside the requirements of ASTM C618-12 (1994) for identification and classification as a pozzolan.

2.5 Corresponding values from Portland cement clinker production

Since one of the major objectives of the study is to compare with the cement production energy and environmental degradation, such as some green house emission, data base for the cement clinker was imported for ease of assessment. A study of energy use for cement clinker production in Canada (OEE, 2001) shows a range of 4.78 – 6.21MJ/kg of clinker and an average of 5.16MJ/Kg, while carbon dioxide emission has been estimated as a total of 0.97kg for every kg of clinker made up of 0.54kg in pyroprocessing and 0.43 kg from the fuels burned (USDoE, 2003). These are summarized together with the foregoing results in Table 3

**3.0 Results and Discussion**

3.1 The ash yield

Corn cob ash yield of 3.6% and 1.7% obtained for open air burning and electric muffle furnace is low when compared with 18-20% reported for rice husk ash (Subbukrishna et al, 2009; Chungangunsit et al, 2009). It is however quite close to the figure of 4% deducible from recent work on locust bean pod ash (Adama and Jimoh, 2012). Ash yield data on palm fruit ash, bamboo leaf ash and other biomass pozzolans have not been reported in existing literature. The low ash content of corn cob does not support its conversion to pozzolan to be economical but however makes it quite suitable as a bio-energy feed stock alone or when co-fired with other fuels (Zych, 2008). The relatively wide disparity in the ash yields from each of the two methods (up to about 50%) is attributable to the different combustion kinetics (Zevenhoven, 2001). While the maximum temperature of 590$^o$C was attained over a 2 hour period in open air burning, the maximum temperature of 600$^o$C was attained in the muffle furnace in 15 minutes.

3.2 Conversion technology

Since one of the objectives of this research effort is to compare burning technology, furnace and open air and possibly recommend an appropriate one, the results clearly show that open air burning and any other technology that takes advantage of the corn cob as a fuel will make the harnessing of the ash residue as pozzolan viable and sustainable. In spite of the apparent inefficiency of the method of open air burning adopted for this work, the distinct advantage of open air burning over electric muffle furnace was demonstrated. This is attributable to the fact that open air burning takes advantage of the characteristic of corn cob as a fuel, whereas electric muffle furnace depends solely on external energy source.

3.3 The gas emissions

The $CO_2$ emission was computed only for the external energy input as 0.27kg per kg ash for open air burning and compared with total emission of 0.97kg for the cement clinker. This is because while all the $CO_2$ released in cement production is from non renewable sources, the $CO_2$ released from the thermal decomposition of corn cob being a biomass is considered carbon neutral (Chungsangunsit et al, 2009). The $CO_2$ emission associated with the production of CCA in a muffle furnace could not be ascertained because in Nigeria, the electricity grid is fed from a mix of thermal and hydropower sources. However, the high energy input of 216166MJ per kg of pozzolanic ash is indicative of the inappropriateness of this method in terms of cost and environmental sustainability.

**4.0 Conclusion and Recommendation**

It can be concluded from these results that:

a) the ash content of corn cob at 3.6% for open air burning but only 1.7% from the controlled furnace burning; which are quite low when compared with rice husk ash which is about 20%.

b) the corn cob is more sustainable as a source of bio-energy whose ash residue can be recovered for use as a pozzolan rather than its being burnt solely for the ash content.

c) Corn cob can be promoted as a fuel source in rural areas, with a view to recovering the for further use as pozzolan class C conforming with ASTM C618-12 (1994).

It is therefore recommended that corn cob be promoted as a non-fossil fuel source and that production of pozzolan should be in the rural and regional zones where its abundant production is more feasible than the urban developed areas with more pronounced competitiveness for land for farming. The further possibility of value addition when the ash residue is recovered as well as the environmental and health benefits of reducing the large stock of biomass waste will ensure a higher quality of life in the rural corn producing regions.

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Figure 1: Open air burning

Figure 3: Corn Cob in Electric Muffle Furnace

Figure 4: Corn Cob Ash

Table 1: Resource Consumption Data from Open Air Burning

| s/n | Dry weight of corn cob (Kg) | Kerosene $W_k$ (kg) | No of hours | Energy Consumed $E_c$ MJ | $CO_2$ emission $C_f$ (Kg) | Ash yield $W_{ash}$ (Kg) | Energy consumption/kg Ash (MJ/Kg) | $CO_2$ emission/kg Ash (Kg/Kg) |
|---|---|---|---|---|---|---|---|---|
| 1 | 8.5 | 0.027 | 8 | 1.35 | 0.085 | 0.304 | 4.441 | 0.280 |
| 2 | 8.3 | 0.026 | 9 | 1.30 | 0.081 | 0.297 | 4.377 | 0.273 |
| 3 | 8.3 | 0.025 | 8 | 1.25 | 0.078 | 0.298 | 4.195 | 0.262 |
| 4 | 8.1 | 0.026 | 8.5 | 1.30 | 0.081 | 0.301 | 4.319 | 0.269 |
| **Ave** | **8.3** | **0.026** | **8.375** | **1.30** | **0.081** | **0.300** | **4.333** | **0.270** |

Table 2: Ash yield data from a 2.6Kw Muffle Furnace

| s/n | Dry weight of corn cob (g) | Ash yield (g) | Ash yield (%) | No of hours | Energy Consumption KwH | Energy Consumption MJ | Energy Consumption/Kg Ash MJ/Kg |
|---|---|---|---|---|---|---|---|
| **ave** | **260.77** | **4.33** | **1.66** | **10** | **260** | **936** | **216166** |

Table 3: Comparison of energy consumption and $CO_2$ emission data, CCA vs Portland cement

| PRODUCT | ENERGY CONSUMPTION MJ/KG PRODUCT | CARBON DIOXIDE EMISSION KG/KG PRODUCT |
|---|---|---|
| CCA (open air burning) | 4.33 | 0.271 |
| CCA (electric muffle furnace) | 216166 | Not computed |
| Portland cement | 5.16 | 0.97 |

Table 4: Chemical Analysis of Corn Cob Ash from Two Processes

| Constituent | Percentage | | |
|---|---|---|---|
| | Open Air | Muffle Furnace | ASTM C618-12 Requirement |
| $SiO_2$ | 63.60 | 65.40 | $SiO_2+Al_2O_3+Fe_2O_3 \geq 70\%$ |
| $Al_2O_3$ | 5.85 | 5.80 | |
| $Fe_2O_3$ | 2.95 | 2.97 | |
| CaO | 3.50 | 3.70 | |
| MgO | 2.11 | 2.3 | |
| $SO_3$ | 1.14 | 1.10 | |
| $K_2O$ | 8.42 | 8.39 | |
| $Na_2O$ | 0.45 | 0.48 | |
| $Mn_2O_3$ | 0.06 | 0.06 | |
| $P_2O_5$ | 2.42 | 2.45 | |
| $TiO_2$ | 0.60 | 0.61 | |
| LOI | 8.55 | 6.49 | 10% max for Classes N and F, 6% max for Class C |
| Total | 99.65 | 99.75 | |
| Residue (45 micron) | 34.32 | 32.45 | 35% max |
| Residue (90 micron) | 11.78 | 9.62 | |