Energy Consumption on Pozzolana Production: A Case Study of Pozzolana Production Pilot Plant, NBRRI, Ota

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Abstract

Concrete is considered the most used construction material due to its versatility. Though cost and environmental concerns associated with the production of its major constituent (cement) have led to research into alternatives and admixtures. The Nigerian Building and Road Research Institute (NBRRI) in its attempt to improve housing delivery in a sustainable and affordable manner has built and successfully test run a pilot plant located at Ota, Ogun State, South West, Nigeria for the production of Pozzolana Portland Cement (PPC) as a partial replacement to the Ordinary Portland Cement (OPC). The aim of setting up the pilot plant is to demonstrate the production of pozzolana which will partially replace OPC in the course of buildings, to reduce cost and enhance sustainability levels in the built environment. This present study presents the electrical energy requirement for producing PPC in Nigeria. Electrical energy consumed during test running of the plant was used to establish the energy requirement for the different operations in the production process. The total electrical energy required per tonnage production of PPC was estimated to be 65.282kWh. The percentages of electrical energy utilized for each operation were; 21.94%, 1.44%, 0.32%, 2.45%, 30.20%, 37.78%, and 5%, for palm kernel grinding, clay crushing, nodulizing, nodules conveying into the kiln, blowing, ball milling and metering/bagging respectively. This with other costs of production will enable entrepreneurs that are willing to invest in the area of PPC in Nigeria to establish the unit price of the commodity and determine the break-even point in the business. This report will also give a guide to the appropriate energy back up capacity to run the plant.

Keywords: Concrete, energy, housing, pozzolana, sustainability

1. INTRODUCTION

CONCRETE is a crucial material used in the construction industry because of its flexibility making it superior to materials like wood and steel (Hossain *et al.*, 2011). Its usage in the construction industry is second only to water. Though concrete is superior to other materials used in the construction industry, the production cost of its major constituent which is cement is excessive (Altwair and Kabir, 2010). The global trend is researching into the reduction of the Portland cement contents in the concrete mixtures with cheaper Supplementary Cementitious Materials (SCM) to improve certain properties of concrete. Neuwald (2004) classified SCM as hydraulic and pozzolanic; this classification is based on their reacting mechanisms. He also stated that blended cements are more common in Europe and South America and are generally less expensive than cement.

Pozzolanas are a broad class of siliceous or siliceous and alumnus materials in which in themselves have little or no cementitious property but which will in finely divided form and in the presence of water react chemically with calcium hydroxide at room temperature to form compounds having cementitious properties (Mehta,1987). The measure of capacity of a pozzolana to react with calcium hydroxide and water is given by measuring its Pozzolanic activity (Snellings *et al.*, 2012).

Pozzolanas are classified into two groups: natural and artificial. Natural Pozzolanas are of volcanic origin and are found in areas which have experienced volcanic activities. Artificial Pozzolanas are obtained after some basic materials have undergone some primary production processing. Gourichon (2013) identified eight pozzolanic materials obtained from agricultural bye-products in Nigeria these are; rice husk ash (RHA), Saw Dust Ash (SDA), Oil Palm Bunch Ash (OPBA), Cassava Waste Ash (CWA), Coconut Husk Ash (CHA), Corn Cob Ash (CCA), Plantain leaf Ash (PLA), and Pawpaw Leaf Ash (PPLA). Opeyemi *et al.*, 2018 asserted that there are several pozzolans under study this includes the pulverized clay under study by the Nigerian building and road research institute (NBRRI).

Pozzolans have historical evidences dating back as 500-400 BC. The ancient Greeks deliberately used volcanic materials, such as, volcanic ashes or tuffs (Idorn, 1997). This was uncovered at the ancient city of Kameiros, Rhodes, Greece. Pozzolana was used in Rome which made their concrete structure to withstand weathering (Moore, 1995). In Europe, Asia and America the application of Pozzolanic cements have been established but in Africa, only Ghana has acknowledged the use of Pozzolanic cements where the Building and Road Research Institute, BRRI in Ghana established a Pilot Plant in Ashanti City of Kumasi.

In Nigeria, research works have been carried out on the use of Pozzolana by different researchers. These research reports ranging from undergraduate to Ph.D. degrees are on research shelves. Hence, in other to galvanize these research findings to exploit local resources for economic growth in the construction industry, the Nigerian Building and Road Research Institute, NBRRI in 2011 decided to embark on the first ever Pozzolana pilot plant in Nigeria. The pilot plant was built to meet a demand of 2 tonnes of the product a day. The plant was built to establish capacity for commercialization, such that, investors can build larger plants with much larger production capacity within the country.

In manufacturing, knowing production cost is considered as an important step in creating and maintaining a profitable business. Production cost is defined as a sum total of materials input, direct labor cost and burden incurred during the production process. In production, direct and indirect costs are incurred. Direct costs are raw materials cost and labor required to produce the finished product. Indirect costs include overhead, such as, rent, administrative salaries and utility expenses. Utility expenses are related to the following costs; electricity, water, fuel.

Energy usage is relevant in all aspects of modern society. The international energy outlook IEO, in 2011 asserted that, the industrial sector uses energy for a wide variety of activities, such as, processing, assembling, lightening, etc. The industrial sector uses more energy than any other end user, utilizing about half of the world's total energy delivery (IEO, 2011). According to Fadare *et al.*, (2009), cost of energy constitutes a major component of the overall product cost in manufacturing industries, and according to (Unachukwu, 2003) energy cost attributes to 60.75% of direct manufacturing cost of cement.

In Nigeria approximately 40-50 percent of cement production cost is energy related. The production of cement requires approximately 105kWh of electrical energy depending on the type of method employed. (Unachukwu, 2003). Cement production in Germany is energy intensive (Hoeing *et al.*, 2013). Olayinka *et al.*, (2003) conducted a survey to determine the electrical energy required to produce a tonne of cement in a particular cement manufacturing plant and found out that in 2003, the industry utilized 29408125 MJ. The requirement reduced every year per tonnage until 2010 when 14282744 MJ was utilized. Olayinka *et al.*, (2003) attributed the reduction in energy requirement to proper energy management in the system. Therefore, energy utilization is a major determinant of the profitability of a production outfit. Energy requirement for the production of Pozzolana is classified into three classes, these are: electrical, manual and combustion energy. This paper presents the electrical energy requirement in the production of pozzolana in Pozzolana Production Pilot Plant, NBRRI, Ota, Nigeria.

2. METHODOLOGY

2.1 Raw Material Preparation

Pozzolana production process and equipment

Pozzolana production from calcined clay can be divided into three broad stages. Each of these stages has more than one operation. The first stage is raw material preparation which consists of clay crushing in order to loosen the lumped clay and palm kernel grinding to have powdered form of the palm kernel shells (PKS). The second stage is raw materials processing which involves mixing the crushed clay with the ground PKS at the appropriate proportion, nodulizing, calcining, and ball milling. The third stage is metering and bagging. Figure 1 shows the flow chart for the process.

2.1.1 Clay crushing

Clay from the field comes in form of lumps. Clay crushing is the process of breaking the lumps in the clay to have a loose form of it. Clay crushing is carried out using hammer mill or any other milling machines. This operation utilizes electrical and manual energy

2.1.2 PKS grinding

PKS grinding involves pulverizing the Palm Kernel Shells into a fine powder. PKS here is used as fuel for calcining of the clay. The equipment used for this purpose is a locally fabricated palm kernel shells grinding machine, using electrical energy as the source of power. This process requires manual and electrical energy.

2.2 Raw Material Processing

2.2.1 Clay and palm kernel shell mixing

The crushed clay and the pulverized palm kernel shells are mixed together at a pre-determined proportion on the ground using shovels. This operation requires only manual energy

2.2.2 Nodulizing

The mixed clay and PKS is put in a nodulizer and water is added to form pellets of about 2cm in diameter before discharging off the machine. This process requires both manual and electrical energy.

2.2.3 Drying

The nodulized materials are dried within the workshop bay floor with natural air for about two days depending on the humidity.

2.2.4 Calcining

The dried materials are loaded into the vertical shaft kiln via cup elevator and are heated to a pre-determined temperature for calcining. This requires manual, electrical and thermal energy.

2.2.5 Milling

The calcined materials are loaded into a ball milling machine and milled to get the final product (Pozzolana). This requires manual and electrical energy.

2.3 Metering and Bagging

The milled product is carried by a screw conveyor which loads it into the hopper for bagging and sewing. This process is fully automated and requires only electrical energy.

The process chart for the production process is illustrated in Figure 1

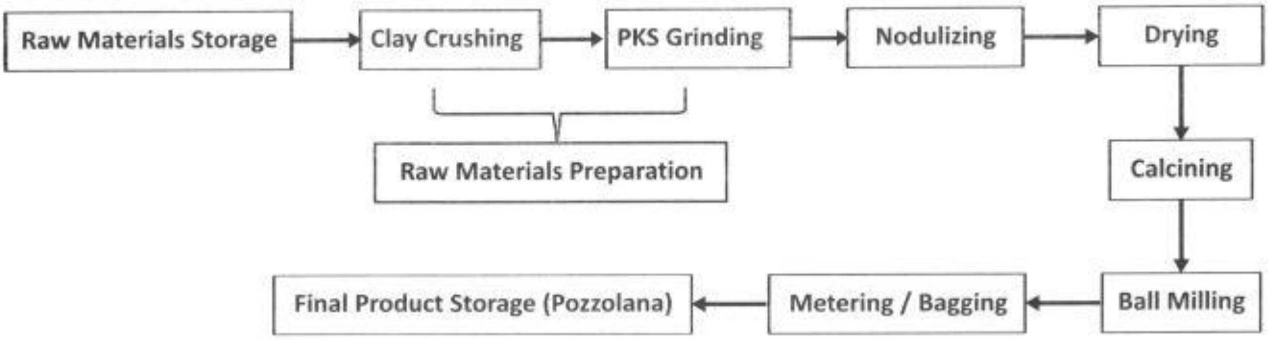

Figure 1. Process chart for the operation

2.3. EXPERIMENT

The study was carried out at the 2 tonnes per day Pozzolana pilot plant in NBRRI laboratory complex in Ota during an intensive test run of the plant. The raw materials for the production of PPC include clay, pulverized palm kernel shell, and water. The sources of energy for processing are manual, electrical and thermal energy. For this work, only electrical energy was considered. Seven distinct operations requiring electrical energy were identified for the production of Pozzolana. These operations were considered for the study and they are; palm kernel grinding, clay crushing, nodulizing, conveying, blowing, ball milling and metering /bagging.

The electrical energy usage for each operation was determined by taking the power rating of the electrical motors used, time required for processing and assuming electric motor efficiency of 80%. The electrical energy for each operation was computed using Eq. (1).

$$p_i = \eta R_i t_i \text{ ---------------------------------- } (1)$$

where, $p1$ is the electrical energy or power consumed for each operation, η is the efficiency of the electric motor, R is the electric motor rating and t is the time in seconds. The total electrical energy requirement was determined as thus; in Eq. (2).

$$\Sigma p_i = \eta \Sigma R_i t_i \text{ ------------------------------- } (2)$$

Power tariff in Nigeria using Ikeja Electrical Distribution Company PLC was used to determine the cost of electricity used in producing a unit of the product. The amount required to produce was determined by the Eq. (3).

$$A_t = 24.56 \Sigma P_i \text{ -------------------------------- } (3)$$

where, At is the total amount of electrical energy required for producing Pozzolana $\sum Pi$, is the total electrical energy requirement of each equipment and 24.56 is the tariff class rate.

Total Amount payable (₦) Ap, is given in Eq. (4) assuming a 5% VAT,

$$A_P = A_t + VAT\ (5\%\ of\, A_t) \text{ ----------------- } (4)$$

A conversion factor from horse power (hp) to electrical energy in watts is given as in Eq. (5)

$$1hp = 746w \text{ -------------------------------- } (5)$$

3. RESULTS AND DISCUSSION

The process chart for the production of Pozzolana is shown in Figure 1. Seven distinct operations were identified in the production process which includes palm kernel shell grinding, clay crushing, nodulizing, conveying, blowing, ball milling and bagging respectively. The electrical energy consumed was obtained by data collected during an intensive test run of the plant.

Table 1 shows the results obtained from the study; the amount column was determined by multiplying the kilowatt hour (Kwh) of each of the equipment by the cost electrical energy per Kwh. The cost of electricity in Kwh varies between electricity distributions companies in Nigeria. For the purpose of this study, Ikeja Electricity Distribution Company PLC rating was used. Tariff code D1 (Heavy Industry) are charged ₦24.56 per Kwh.

Table 1. Time and Electrical Energy Required for Producing 50Kg of Pozzolana

S/No	Item	Power Rating (Kw)	Time (S)	Power Consumed, $P = \eta RT$ (Kwh)	Amount (₦), $A = 24.56P$	Total Amount (₦), $Ap = At + VAT$ (5% of At)
1	Palm Kernel Shell Grinding Machine	55.95	57.60	0.7162	17.5899	
2	Hammer Mill	11.00	19.20	0.0470	1.1542	
3	Nodulizer	4.00	36.00	0.0106	0.2603	
4	Cup Elevator	3.00	119.88	0.0799	1.9623	
5	Blower	37.00	119.88	0.9857	24.2063	
6	Ball Mill	18.50	300.00	1.2333	30.2907	
7	Metering and Bagging	2.872	300.00	0.1915	4.7024	
Total				**3.2641**	**80.1661**	**84.1744**

From the Table 1, in producing 50Kg of Pozzolana, 3.2641Kwh is required, this corresponds 65.282kWh per tonnage of product. Hence, the amount required to produce 50kg of Pozzolana Portland Cement was computed to be ₦80.1661 using Eq. (3) and by using class D1 an energy tariff of Ikeja electricity distribution company PLC as indicated in Table 2.

Factoring in VAT of 5%, the total amount of electrical energy consumption in monetary value for producing 50kg is computed using equation (4) to be ₦84.1744.

Table 3 shows the description for different tariff rates for different categories of customers. These tariffs are subject to changes. This present work uses D1 (industrial consumer) for the period between 2018 and 2022.

The electrical energy of running the ball mill was higher than the rest and this was estimated to be 1.233 kWh. This is due to the fact that, it is a high rated motor equipment of 37 Kw, and with heavy balls. Also, the time for the ball mill to process a unit of the commodity is high. Nodulizing consumed the least energy and cost. This is because, the motor has a low power rating of 4.00Kw and time of operation per unit product is low as well. Compared to the ball mill, the palm kernel shell grinding machine has a higher power rating of the motor but has a lower cost of processing this is due to the fact that the rate of processing is higher than the ball mill. This is further reflected in Figure 2.

Table 2. Ikeja Disco Tariff (₦/Kwh).

Ikeja Disco Tariff – (₦ / Kwh).

Class	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
R1	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
R2SP	13.21	21.30	21.10	18.94	18.45	18.39	18.51	18.34	18.27	18.15
R2TP	13.21	21.80	21.73	21.15	20.59	20.53	20.67	20.47	20.39	20.26
R3	26.25	36.49	35.68	31.62	30.79	30.70	30.90	30.61	30.49	30.30
R4	26.25	36.92	36.11	32.00	31.16	31.07	31.27	30.98	30.86	30.66
C1SP	19.90	27.20	25.56	21.76	21.19	21.13	21.27	21.07	20.99	20.85
C1TP	19.90	28.47	27.59	24.45	23.81	23.74	23.90	23.67	23.58	23.43
C2	24.40	37.74	36.91	32.47	31.62	31.53	31.73	31.43	31.31	31.11
C3	24.40	38.14	37.30	32.81	31.95	31.86	32.07	31.77	31.64	31.44
D1	19.68	28.68	27.93	24.56	23.92	23.85	24.01	23.78	23.69	23.54
D2	25.57	38.38	37.54	33.02	32.15	32.06	32.27	31.96	31.84	31.64
D3	25.57	38.85	37,99	33.42	32.54	32.45	32.66	32.35	32.23	32.02
A1	18.84	26.82	26.23	23.24	22.63	22.57	22.71	22.50	22.41	22.27
A2	18.84	30.20	29.53	26.27	25.49	25.41	25.58	25.34	25.24	25.08
A3	18.84	30.36	29.69	26.31	25.62	25.54	25.71	25.47	25.37	25.21
S1	14.47	19.42	18.99	16.83	16.39	16.34	16.45	16.29	16.23	16.13

Source: Ikeja DISCO, Office.

Table 3: Classification of Electricity Tariff

Tariff Class	Class Name	Description	Sub-Classes
R	Residential	A customer who uses his premises exclusively as a residence, flat or multi storied house.	R1 (life line), R2 (single and three phase), R3 (LV maximum demand), R4 (HV maximum demand)
C	Commercial	A customer who uses his premises for any purpose other than exclusively as a residence, or as a factory for manufacturing of goods.	C1 (single and three phase), C2 (LV maximum demand), C3 (HV maximum demand)
I	Industrial	A customer who uses his premises for manufacturing of goods including welding and ironmongery .	D1 (single and three phase), D2 (LV maximum demand), D3 (HV maximum demand)
A	Special	Customer such as agriculture and agro allied industries, religious houses, government research institutes, teaching hospitals and Schools	A1 (single and three phase), A2 (LV maximum demand), A3 (HV maximum demand)
S	Street Lights	Street Lights	S1 (single and three phase)

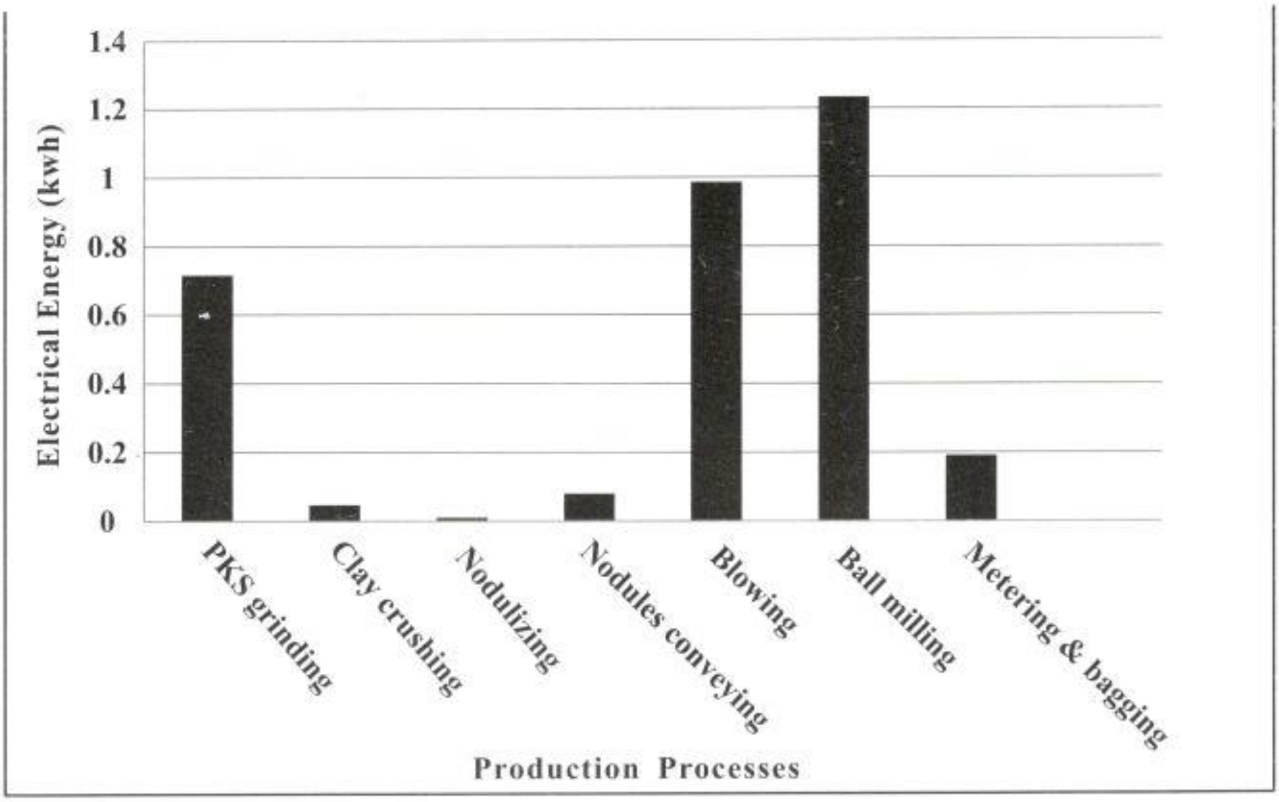

Figure 2: Electrical Energy Requirement for the Different Process

The metering and bagging consists of a series of operations which are screw conveying, packing belt conveying and sewing. Each of these operations consumes very little energy which was accounted for as energy for metering and bagging. Each of these processes required electric motors for their operation, the respective power ratings of the electric motors are 0.37, 0.18, 0.18, 0.37, and 0.18 kW and their operating time per 50kg are 300, 120, 8, 5 and 2 seconds respectively. A 2 hp air compressor is used as auxiliary equipment in the packing and has an approximated running time of 540 seconds to bag a 50kg of Pozzolana. The conversion factor of horse power to watts is as given in Eq. (4).

4. CONCLUSION

The study investigated the electrical energy required for processing Pozzolana cement. The study also identified the production operations, and it was found that, in producing 50kg of PPC, electricity requirement for running the equipment amounted to 3.2641kWh. This corresponds to 65.282kWh per tonnage. Ball milling was the most energy intensive operation constituting 37.78% of the total energy requirement for this study, hence, the need to use energy efficient ball mills to reduce cost. This along with other price fixing determinants will aid investors to establish a unit price of the commodity as well as a break-even point when establishing mass production plant.

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