Selection of Appropriate Clay for Furnace Lining In a Pyrolysis Process

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Abstract
The suitability of some local clay deposits in Ekiti State, for lining the furnace to be used to degrade woody biomass to fuel and chemical products was investigated. Four major sites in Ekiti- State renowned for abundant clay deposits were selected, namely; Ikere Ekiti, Fagbohun Ekiti, Ishan Ekiti and Ara Ekiti. The clay samples were crushed, milled (pulverised) and sieved to produce very fine grains of less than 250 μm particle size distribution for all samples. They were then tested for shrinkage, bulk density, Load on ignition (LOI), cold compression strength, apparent porosity, and thermal shock resistance. Also, their mineralogical composition and fusion temperatures were examined. The densities of the clays were found to be related to their mineralogical composition as shown: Ikere Ekiti clay was found to be less dense, contains more porosity, and possesses low iron content and higher refractoriness with fusion temperature above 1500 °C. Fagbohun clay is also suitable for medium thermal application in furnaces, kilns and stoves, while the rest could be beneficiated to improve on their insulating properties. The kaolin deposit at Ikere Ekiti was found to be the best material suitable for the lining of the furnace for the pyrolysis process as the expected furnace temperature is about 1400 °C.

Keywords: alumino-silicate, apparent porosity, refractoriness, mineralogy, density

INTRODUCTION
Clays are typically anhydrous complex compounds of alumina \((\text{Al}_2\text{O}_3)\) and silica \((\text{SiO}_2)\), that exist in various proportion and contain varied amount of impurities of iron, organic matters and residual minerals (Sanni, 2005). The clays used for furnace linings in metallurgical industries are classified as refractory clays. However, the degree of refractoriness and plasticity of any clay material is often influenced by the amount of the impurities contained in them. Moreover, the ability of selected refractory clay to withstand high temperature and resist physical and chemical corrosion determines the quality and the suitability of such material for use as furnace lining. Clays when fired, lose their chemically bonded water and plasticity at about 500 °C, thus acquiring higher mechanical strength between 950 °C and 1350 °C as the firing temperatures progresses (Al-Amaireh, 2009).

Clay refractoriness refers to its ability to resist melting at high temperature, prevent heat flow across its cross-sectional boundary layer as much as possible, maintain volume stability at high temperature (linear, area and cubical expansivity must be acceptable), withstand unsteady thermal and physical shock, resist abrasion and corrosion and should have higher hot strength and be resistant to hot fluids (gases and liquids). In addition, refractory materials must be dense and porous; hence, insulating refractory clays are high porosity refractory materials with low thermal conductivity and high thermal insulating properties. They have the capability to minimize heat loss in furnaces as much as possible and maximize heat conservation to a great extent. Refractory clays consist mainly of mineral kaolinite \((\text{Al}_2\text{O}_3\cdot 2\text{SiO}_2\cdot 2\text{H}_2\text{O})\) and are broadly classified as fireclays and kaolins, depending on the constituent ratio of alumina to silica. Consequently, refractory clays that are of the kaolinitic type contain ratio 1:2 of alumina to silica, while fire clays that are used as refractories material contain at least 30% alumina \((\text{Al}_2\text{O}_3)\), and less than 1.8% \((\text{Fe}_2\text{O}_3)\). Fire clays are clays with high refractoriness (resistance to high temperature) and possess the capability of maintaining both physical and chemical identity at high temperatures (resistant to fusion and softening at elevated working temperatures) (Sanni, 2005).

Kaolin refractory clays can be distinguished from fire clays by their whiter colour, relatively coarse particles, lower plasticity and much lower impurities. The impurities in fire clays are limonite, pyrites, quartz, calcites, ferrous carbonates and some organic compounds. The organic impurities impart plasticity to the clays while impurities such as quartz and iron reduce their refractoriness. However, refractory clay material obtained from a single site cannot possess all the required properties that will make it a perfect refractory material, hence, it becomes imperative to
Select clays based on the physical, chemical, and thermal analysis of samples. The selected refractory clay will have to be beneficiated with refractory clay material from other sites and be properly blended with other additives to improve their physical, thermal, and chemical properties of the final product (Nahu and Abdullahi, 2008).

Refractory materials could withstand a range of high temperatures from 1,540 °C for products made from fireclay to 2,200 °C for products made from silicon carbide; and are used in flues, stacks, furnaces, and fireplaces. Refractories are produced from natural materials, that consist of the combination of compounds and minerals, such as kaolin (Al₂O₃·2SiO₂·2H₂O). Kaolin is made up of hydrated aluminosilicate that is also the constituent of many plastic and fire clays. Such materials could effectively serve the purpose of being used to build high temperature resistant structures; ranging from simple to sophisticated products; from fireplace brick linings to re-entry heat shields for the space shuttle. In industries, they are used to line boilers and build furnaces of all types, construct reactors, ladles, stills, kilns and chemically inert structures.

Clays are classified according to their relative plasticity or malleability, their strength when moist (green strength), their strength after drying (dry strength), their air shrinkage properties, and their vitrification range. Vitrification refers to the process by which clay molecules begin to fuse when exposed to heat. Clay's vitrification range therefore describes the temperature levels between which the clay begins to fuse and when it achieves its final fusion or hardness. Clays are often mixed or blended to achieve the desired properties dictated by their end use. Thus, whiteware ceramic consists of kaolin, ball clay, feldspar, and ground silica. Kaolin, or china clay, derived its name from the hill where it was first extracted in Kao-Ling, China.

A furnace is a thermal envelope and a device used for heating. It is an apparatus in which heat is liberated and transferred directly or indirectly to a solid or fluid mass place inside its enclosure for the purpose of effecting physical and chemical change on the material (Schutt and Beggs: 1997). The source of heat generation for direct energy supply to furnaces are: fuel combustion as obtainable in the oxidation of fossil fuel, electrical energy due to the flow of electricity in resistance or tubular heaters, atomic fission or fusion in nuclear reactors and solar energy through focusing collectors, as applicable in solar-thermal conversion devices. An industrial furnace is the equipment that is used to provide heat for a process and can serve as a reactor which provides the heat of reaction to objects placed within its enclosure. Furnace designs may vary according to its function, the heating duty performed, heating methods applied or the type of fuel used, controlled thermal environment and the method of introducing air for combustion purposes if required. Insulation property is an essential requirement of furnaces because it prevents excessive heat loss from thermal plants. Refractory materials such as firebricks, castable refractories and ceramic fibres, are used as materials for insulation. The floor of the furnace is normally made of castable type refractories while those on the walls are nailed or glued in place. Ceramic fibre is commonly used for the roof and wall of the furnace and is graded by its density and then its maximum temperature rating. Insulating firebrick is a class of bricks which consist of highly porous fireclay or Kaolin. They possess lightweight, low thermal conductivity and have sufficient resistance to thermal flow that enables them maintain the temperature of a wall’s surface at very high temperature and high heat value while the other is kept at very low temperature and low thermal value. This characteristic enables firebricks to be valuable in permitting rapid changes in temperature with minimal thermal losses and consequently its application in furnaces. Firebricks are actually obtained in a variety of ways, but the most popular route is by forming a mould with a mixture of kaolin, bulk clay and organic matter such as wood sawdust or rice husk in specific ratio and subjecting the mould to high temperature firing when dried. The organic content of the mould burns out when fired to high temperature, to create air voids or pores that further improve the insulating properties of the materials that could now be referred to as firebricks.

Thermal conductivity decreases in refractory materials as its porosity increases with the pores acting as non-heat conducting media. Porous refractories have air entrapped in them. Moreover, the porosity of refractory materials is determined by the amount of air entrapped in its pores and consequently a measure of its insulating quality. Hence, when the porosity of refractory material the high; its thermal conductivity will be low and vise versa. Therefore, the refractories used in melting furnaces, are made to have low thermal conductivities, ensure minimal heat loss and maximum heat retention, and to guarantee large temperature variation within the thermal envelope with maximum energy conversion efficiencies. Conversely, in recuperators where maximum heat transfer is desired to take place, the utilization of refractories with high thermal conductivities is highly desired.

Chesti (1986) defined refractories as materials that are “hard to fuse” and classified them as materials that can withstand high temperatures, resist the action of corrosive liquids and withstand the thermal stresses imposed by dust-laden currents of hot gases or vapours without losing their insulating properties and wall rigidity. Refractory materials are therefore
utilized for the construction of furnaces, crucibles, and other materials that are subject to high temperature operations in order to ensure perfect resistant to heat loss and to overcome the corrosive action of gases and slag that may be present in the plant. High temperature operations are usually involved in almost all operations dealing with the treatment of ores and in the processing of metallurgical, chemical, ceramic, and foundry raw materials; thus making the use of refractories materials inevitable.

Pyrolysis is the technique of applying high heat to organic matter (lignocellulosic materials) in the absence of oxygen or in restricted air supply (Bridgwater, 1999; Diebold and Bridgwater, 1997; Buekens and Schoeters, 1987). The polymeric constituents of the organic matter, such as cellulose, hemicelluloses and lignin structure degrade thermally to produce charcoal, condensable organic liquids (pyrolytic fuel oil), non-condensable gases, acetic acid, acetone, and methanol (Dietrich and Oasmia, 1999). Pyrolysis plant does not produce useful energy directly, but converts original biomass feedstock into a more convenient form of energy products, under regulated heat load and restricted air supply.

The aim of this work therefore, is to investigate the physical and chemical properties of clays from various locations in Ekiti state, Nigeria and select the most appropriate one for the development of a pyrolysis fixed-bed reactor. The objective is to select appropriate refractory clay that meets known physical, chemical, and refractory standards for application in furnace lining and thereby develop an effective pyrolysis plant for converting forest biomass and biological wastes to high dense energy fractions for industrial and domestic utilisation.

MATERIALS AND METHODS

Five kilograms (kg) of clay samples were collected per site from four different locations in Ekiti state, Nigeria, making a total of twenty clays samples weighing twenty kilograms (20kg) in all. The locations have some ample reserve of Kaolin and Ball Clay which could be exploited for economic purposes; as reported by the National Steel Raw Materials Agency Akure, Zonal Office (Oguntade and Dada; 1999). The sites are located in four different towns in Ekiti State and they are: Ikere Ekiti, Fagbohun Ekiti, Ishan Ekiti and Ara Ekiti. The various clay samples were denoted as: (A) for Ikere clay sample, (B) for Fagbohun clay sample, (C) for Ishan clay sample and (D) for Ara clay sample respectively. The clays were subjected to physical, chemical and thermal analysis at the Raw Material’s Laboratory of the “National Metallurgical Development Centre, (NMDC)” Jos, Plateau State; to determine their suitability in lining furnaces. The chemical analysis of the various samples was carried out on an Energy Dispersive (ED), X-ray Fluorescence Spectrometer (XRFs). The physical properties and refractoriness of the clay samples were also determined.

Chemical Analysis of the Refractory Clays

The chemical analysis of the clay samples from Ikere Ekiti, Fagbohun Ekiti, Ishan Ekiti and Ara Ekiti were carried out on an Energy Dispersive (ED), x-ray Fluorescence Spectrometer (XRFs). This technique was used to identify and determine concentrations of elements present in solid, powdered and liquid samples. XRF is capable of measuring all elements from Beryllium (Be) to Uranium (U) and beyond at trace levels often below and part per million (ppm) and up to 100%. The x-ray Fluorescence Spectrometer (XRFs) was used to carry out accurate and reproducible analyses at very high speed.

The clay samples were ground and sieved with a 200 mesh size to produce 75µm particle size of clay specimen. 4grams of the sieved samples was intimately mixed with 1gram of lithium tetraborate binder (Li₂B₄O₇) and pressed to a pellet in a mould, under a pressure of 10-15 tons/in² (15.477 - 23.22 bar). The pressed pellets were dried in an oven at 110 °C for 30 minutes to remove the adsorbed moisture and stored in a dessicator. The Spectrometer was switched on and allowed to warm up in order to stabilize the optics and the x-ray tube. It was then calibrated to determine the expected elements present in the samples. The samples were run using the prepared programs (calibrations) and the elemental concentrations present in the samples were calculated and displayed after applying automatic statistics to the results from the XRF spectrometer. The result of the analysis is as presented in Table 1.

Physical Properties and Refractoriness of the Selected Clay Samples

The physical properties of the clay samples were determined with respect to apparent porosity, cold compression strength (C.C.S) and bulk density. The refractoriness of the samples was equally determined through the following tests: Thermal shock resistance, Pyrometric Cone Equivalent (PCE) or refractoriness/Softening temperature test, Slag resistance test and shrinkage test for all samples. The results of these tests are as presented in Tables 2 and 3.

Determination of Clay Refractoriness

The refractoriness of a clay sample is directly related to its softening temperature and is expressed as its Pyrometric Cone Equivalent (PCE). Pyrometric cone equivalent is the number which represents the softening temperature of a refractory specimen of standard dimension (38 mm vertical height and 19 mm triangular base) and composition. Refractory clays are classified into different grades in respect of
their softening temperatures, typified by the number of the standard pyrometric cone which deform under heat treatment.

Test cones were prepared from the refractory clays, having the same dimensions with segar cones (standard cones). Then the test cone is placed in an electric furnace along with segar cones, and heated. The furnace is heated at a standard heating rate of 10°C per minute during which softening of segar cone occur along with the specimen test cone. The temperature at which the apex of the cone touches the base is the softening temperature. The test cones are then compared with the standard cones and the test material is said to have the pyrometric cone equivalent (PCE) of the standard cone that it resembled most in bending behavior. The minimum PCE for low, intermediate, high, and super duty are 19, 29, 31/32 and 33 respectively; which corresponds to the following fusing temperatures: 1500°C, 1650°C, 1690°C and 1750°C respectively. The result is presented in Table 3 below.

Cold Crushing Strength of Refractory Clays

Cold crushing strength is the amount of load that the refractory clay material could withstand after it has been fired to a temperature of 1200°C. In determining the cold crushing strength (CCS) of the refractory clay samples, cubical specimens were made from the clay samples. The dimensions of the test pieces were taken before they were fired to the required temperature and allowed to cool to the room temperature before the tests were carried out. A cardboard sheet not exceeding 0.63 cm in thickness was then placed between the platens of the hydraulic press and the breaking faces of the test piece which was placed centrally on the platen. Hydraulic load was applied on the test piece, until the test piece failed to support the load. The maximum recorded load was taken as the crushing load. The CCS was calculated using equation (1).

\[ \text{CCS} = \frac{\text{Load}}{\text{Area}} \]  

(1)

Resistance of Refractory Clays to Slag Attack

The refractory material was made into a brick with a hole drilled into it. The hole is packed with the sample of iron slag that it might likely encounter when put to service. The refractory brick was then heated to a standard temperature of about 1300 °C and maintained at this temperature for a period of time, preferably one hour. The brick was the cooled, sectioned and examined to observe the degree of attack and penetration of the slag.

Thermal Shock Resistance

Test pieces of refractory bricks were thoroughly dried and placed in the cold furnace and heated at the rate of 5°C/ min until the furnace temperature read 1200 °C. This temperature was kept for 30 minutes after which the test pieces were removed with a pair of tong previously warmed in the furnace for a short time. The test pieces were then placed on cold fire bricks in the environment free of draught and allowed to cool down for about ten minutes. The test pieces were returned to the furnace for a further 10 minutes. The cycle was repeated 30 times before thermal crack could occur.

Determination of Apparent Porosity of Refractory Clays

The refractory clays were made into bricks in cubical form (2.5 x 2.5 x 2.5 cm) and oven dried at 110±5°C until a constant weight (W_D) is obtained (with an accuracy of 0.1grams). The dried specimen was suspended in 300 ml beaker containing distilled water and boiled for two hours, in this position. It was later allowed to cool down to room temperature and its new weight(s) determined (W_S). The specimen was removed from water, and again reweighed in air to obtain (W_OI).

Apparent Porosity (P) was determined by equation (2):

\[ P = \frac{W_O - W_S}{W_O} \times 100 \]  

(2)

where:

- \( W_O \) = Weight of fired specimen
- \( W_S \) = Weight of fired specimen in water
- \( W_O - W_S \) = Weight of specimen suspended in air

Loss on Ignition of Refractory Clays (LIO)

The loss on ignition (LIO) is the weight reduction on the total weight of the prepared clay samples, in percentage. Hence, the loss in weight by each clay sample was determined to be the difference in their weights before after firing and consequently, the loss on ignition at that temperature is determined as shown in equation (4).

\[ \text{LIO} = \frac{W_I - W_F}{W_I} \times 100 \]  

(4)

where:

- \( W_I \) = Initial Weight of clay sample before firing
- \( W_F \) = Final Weight of clay sample after firing

Shrinkage on Firing

The test pieces of the refractory clay materials were made into rectangular shapes of dimension 13.5 x 2.5 x 2.5 cm in a mould and compacted under a hydraulic pressure of 350 kN/m². A slanted line of length 10 cm was inserted diagonally on each piece and recorded as (L_1). The test pieces were then place inside the furnace and fired up to 1,000 °C and the line drawn across the diagonal axis of the pieces was measured to determine its final length (L_2) after firing. The linear shrinkage of the materials was determined with equation (5).
the aid of sieve analysis and was found to be less than 250 μm for all samples. This is an indication that the clay grains were of finer quality than fine sands in terms of compactness and smoothness. The mean results for the physical and chemical analysis of the samples are presented in Tables (1), (2) and (3).

RESULTS AND DISCUSSION

Five clay samples were taken from each of the four sites for analysis, which brings the total analysed samples to twenty samples in all. The particle size distribution for the clay samples was determined with the aid of sieve analysis and was found to be less than 250 μm for all samples. This is an indication that the clay grains were of finer quality than fine sands in terms of compactness and smoothness. The mean results for the physical and chemical analysis of the samples are presented in Tables (1), (2) and (3).

Table 1: Mean and Standard Deviation of the Chemical composition (wt %) of Select Clay Samples

<table>
<thead>
<tr>
<th>S/No</th>
<th>Clay Samples</th>
<th>Al₂O₃</th>
<th>SiO₂</th>
<th>K₂O</th>
<th>CaO</th>
<th>TiO₂</th>
<th>MnO</th>
<th>Fe₂O₃</th>
<th>MgO</th>
<th>Na₂O</th>
<th>Cr₂O₃</th>
<th>LOI</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A</td>
<td>30.46±</td>
<td>50.92±</td>
<td>0.33±</td>
<td>0.19±</td>
<td>1.88±</td>
<td>0.01±</td>
<td>2.07±</td>
<td>0.13±</td>
<td>0.04±</td>
<td>0.02±</td>
<td>12.18±</td>
</tr>
<tr>
<td>2</td>
<td>B</td>
<td>18.75±</td>
<td>53.90±</td>
<td>3.30±</td>
<td>0.72±</td>
<td>2.29±</td>
<td>0.03±</td>
<td>11.80±</td>
<td>0.13±</td>
<td>0.09±</td>
<td>0.04±</td>
<td>7.85±</td>
</tr>
<tr>
<td>3</td>
<td>C</td>
<td>13.48±</td>
<td>40.68±</td>
<td>2.88±</td>
<td>1.12±</td>
<td>2.68±</td>
<td>0.15±</td>
<td>25.55±</td>
<td>0.10±</td>
<td>0.02±</td>
<td>0.06±</td>
<td>10.78±</td>
</tr>
<tr>
<td>4</td>
<td>D</td>
<td>10.92±</td>
<td>59.90±</td>
<td>3.25±</td>
<td>1.90±</td>
<td>2.76±</td>
<td>0.19±</td>
<td>11.40±</td>
<td>0.19±</td>
<td>0.12±</td>
<td>0.04±</td>
<td>7.98±</td>
</tr>
</tbody>
</table>

A = Ikere-Ekiti, B = Fagbohun - Ekiti, C = Ishan - Ekiti, D = Ara - Ekiti

Values in the same column with different alphabet are significantly different from each other.

It is observed that Ikere Ekiti clay sample as reported in Table 1 is more kaolinitic than all other clay samples obtained from the four different sites in Ekiti State with 30.46% of alumina to 50.92% of silica which could apparently be taken as ratio 1:2 of alumina to silica. This agrees with the standard as reported by Sanni (2005). The clay samples from locations outside Ikere Ekiti probably contain higher proportions of iron oxides and Iron (III) Oxide which makes them more plastic (Ball Clay) than Ikere Clay. Consequently, Table (1) show that Ikere clay contains the least amount iron (III) oxide (Fe₂O₃), which is 2.07% wt/wt as against Ishan clay sample with 25.55%; Fagbohun and Ara with 11.8% and 11.40% of Fe₂O₃ respectively.

Nevertheless, the proportion of elemental composition of iron in clays determines the thermal conductivity potential of such materials; hence Sanni (2005) suggested that any fire clay to be used in refractories should have at least 30% Al₂O₃ and less than 1.8% Fe₂O₃. The proportional increase in the ratio of Al₂O₃ in samples will undoubtedly improve clay refractoriness, whereas a progressive reduction in Fe₂O₃ content of samples will perhaps lower their thermal conductivity in that order. This probably suggests why Ikere clay would be regarded as having better insulating property than the samples from other locations. By implication therefore, thermal conductivity will be highest in Ishan clay, moderate in both Fagbohun and Ara, clay but least in Ikere clay, making Ikere clay the material of choice. Other associated impurities in the various clay samples include K₂O, CaO, TiO₂, MnO, MgO, Na₂O, and Cr₂O₃ which are present in various proportions by weight as shown in Table (1), but the impurities are least in Ikere clay. The Loss on Ignition of Refractory Clays (LOI) was determined as the percentage of moisture loss to ignition on firing the prepared clay samples. This is highest in Ikere clay with 12.18% and moderate in Ishan clay with 10.78% but least in Fagbohun and Ara clay samples with 7.85% and 7.98% respectively (Table 1). This represents the amount of moisture the clay materials could hold or percentage weight reduction of samples which may probably be a reflection of their grain structure and how fine they were. This suggests that Ikere clay is of finer grains than others and more compact than them.

The bulk density of Ikere clay which is 1.7 g/cm³ is least in the four samples while that of Fagbohun and Ishan are both 2 g/cm³ and that of Ara is 1.99 g/cm³. The bulk density of clay (kaolin) commonly plays an important role in its economic value when fired (as a refractory, filler, coat, absorbent, etc.). High-density is commonly desired or demanded for clay refractories because high-fired-density usually confers high physical strength at high service temperatures and high resistance to service corrosion, slag penetration, and abrasion. The high-density clays in the natural, lump state which also are high in P.C.E. (Pyrometric Cone Equivalent, a measurement of fusion) may typically yield refractory material in the high density range, and may necessarily do so (Baumann and Keller, 1975). This property is very vital in the handling and transportation of the refractory materials.

The densities of the materials were considered in this work as a function of the major constituents of the clay samples. Hence, a regression equation was developed that could be used to determine the densities (ρ) of alumino-silicate refractory clays on the basis of its major elemental composition of
Aluminium Oxides (Al₂O₃), Silicon Oxide (SiO₂) and Iron (iii) Oxide (Fe₂O₃) as shown below: since other impurities are in small proportions.

The coefficient of prediction R² is 1. Mean Square (ms) value is 0.022025 while Sum of Squares (ss) is 0.066075 and standard error is zero. The above suggests that the density of a clay sample is a function of its constituent elemental composition (Table 3). The principal elemental contributor to the overall density of the clay materials remain Aluminium Oxides (Al₂O₃), Silicon Oxide (SiO₂) and Iron (iii) Oxide (Fe₂O₃), all other impurities been negligible.

Table 2: Mean and Standard Deviation of the Physical Characteristics of Selected Clays

<table>
<thead>
<tr>
<th>Sample No</th>
<th>Sample Name</th>
<th>Bulk density g.cm⁻³</th>
<th>Porosity %</th>
<th>C.C.S. kg/cm²</th>
<th>Shrinkage Percentage</th>
<th>Slag Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>IKERE</td>
<td>1.74±0.11a</td>
<td>31.44±0.91ac</td>
<td>100±6.21c</td>
<td>5.0±1.23a</td>
<td>Good</td>
</tr>
<tr>
<td>B</td>
<td>FAGBOHUN</td>
<td>2.0±0.15a</td>
<td>20.69±1.01bc</td>
<td>140±6.44b</td>
<td>2.0±0.00b</td>
<td>Good</td>
</tr>
<tr>
<td>C</td>
<td>ISHAN</td>
<td>2.0±0.02ab</td>
<td>19.10±0.19d</td>
<td>227±12.9d</td>
<td>1.50±0.16ed</td>
<td>Poor</td>
</tr>
<tr>
<td>D</td>
<td>ARA</td>
<td>1.99±0.01a</td>
<td>23.31±0.24b</td>
<td>83±3.24d</td>
<td>1.9±0.1bc</td>
<td>Poor</td>
</tr>
</tbody>
</table>

A = Ikere-Ekiti, B = Fagbohun - Ekiti, C = Ishan -Ekiti, D = ARA –Ekiti
Values in the same column with different alphabet are significantly different from each other.

Table 3: Empirical (Regressed Values) and Experimental Clay Densities

<table>
<thead>
<tr>
<th>Sample No</th>
<th>Sample Name</th>
<th>Experimentally Determined Bulk Density (g/cm³)</th>
<th>Empirical Bulk Density (g/cm³) With regression Equation</th>
<th>% Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Ikere</td>
<td>1.7</td>
<td>1.707</td>
<td>+0.42</td>
</tr>
<tr>
<td>B</td>
<td>Fagbohun</td>
<td>2</td>
<td>2.0</td>
<td>0</td>
</tr>
<tr>
<td>C</td>
<td>Ishan</td>
<td>2</td>
<td>2.0</td>
<td>0</td>
</tr>
<tr>
<td>D</td>
<td>ARA</td>
<td>1.99</td>
<td>1.99</td>
<td>0</td>
</tr>
</tbody>
</table>

The value of the porosity of the clay samples in percentages was also determined as shown in Table (2). Ikere clay has the highest porosity of 31.44 % against 20.69 % for Fagbohun, 19.10 % for Ishan and 21.31 % for ARA clays respectively. The porosity of refractory clay material is directly related to the air pockets contained in it, hence, the higher the porosity of the clay material, the higher its insulating properties. In order words Ikere clay which has the fineness grain has a better insulating property than other reference samples. The porosities of the clays were regressed against the clay densities and the relationship between them is established by equation (7)

\[ \text{Porosity} = 45.8066 - 37.4309 \times \text{Bulk Density} \]  \quad (7)

Bulk density is highly significant in predicting the apparent porosity of the clay samples: Coefficient of prediction R² is 0.97889 and standard deviation is 0.996695, sum of squares (ss) is 92.5761, mean square (ms) is 92.5761 and F-value is 93.19098.

The cold compressive strength (C.C.S) of the clay samples were determined as reported in Table (2). Ishan clay specimen has the highest compression strength of 227 kg/cm² and a better advantage over others with respect to rigidity and load bearing capability. Ikere clay also has a load bearing strength of 100 kg/cm², while Fagbohun and ARA clays have the compressive strength of 140 kg/m² and 83 kg/cm² respectively. The shrinkage of the clay samples were considered as indicated on Table 2 and Fig.6. Shrinkage is highest in Ikere clay with 5 % reduction in lateral size, while Fagbohun and ARA shrunk by 5 % and 1.9 % respectively. Consequently, Ishan Clay has the least shrinkage of 1.5%. This indicates that the moisture content of Ikere clay sample is higher than others leading to Ikere clay finer grains than others. The slag resistance of Ikere clay and Fagbohun clay samples are good, but that of Ishan and ARA clays are poor as revealed in (Table 2). Good slag resistance of Ikere and Fagbohun clay samples suggest that they could resists the penetration of corrosive vapours and fumes without deformation if used as furnace lining. Ishan and ARA clay samples have bad slag resistance properties and therefore expected to fail in service if employed as furnace lining materials.

The refractoriness of the clay samples was determined as shown in Table 4. Ikere clay sample has highest Pyrometric Cone Equivalent (PCE) of sger cone 29, as it can withstand the deformation temperature of about 1650 °C before fusing or bend under its own weight. Fagbohun clay has an intermediate Pyrometric Cone Equivalent (PCE) of sger cone 16 as it can only withstand temperatures below 1500 °C. Ishan and ARA clays have low PCE with fusson temperature under 1300 °C. Hence, Ikere clay has the best refractory property among the four samples. It could be used for the lining of furnaces that could operate at temperature well above 1500°C without fear of thermal deformation of the furnace wall.
The test pieces were subjected to several thermal shock resistant cycles of heating and cooling and all the test pieces were able to survive about 30 cycles without any crack. This indicates that the clay samples could withstand abrupt changes in temperature.

CONCLUSION

The kaolin (China) clay obtained from Ikere Ekiti was selected as an appropriate locally sourced refractory material for lining the developed furnace based on the following reasons: In the chemical analysis of the clay samples, the percentage of Iron III oxide (Fe₂O₃) in the clay sample from Ikere Ekiti was the least of all other samples as reported in Table (1) making it a better insulator that others. This is because the percentage of Iron III oxide contained in the refractory clays is a major factor that determines the clays' refractoriness. Hence, the higher the iron content of the clays, the lower the clays’ refractoriness and conversely for clays with lower iron content. The refractory clay sample from Ikere Ekiti is dense and more porous than other insulating refractory clays as reported in Table 2. High porosity in refractory materials translates to increased air pockets and improved thermal insulation particularly in a pyrolysis plant where linings are not exposed to fumes and vapour. This suggests that, Ikere Ekiti clay has better capability to minimize thermal losses in the furnace of a pyrolysis plant than other selected samples.

The slag resistance of Ikere and Fagbohun clays is good as revealed in Table (4), which also suggests that the clays could resists the penetration of corrosive vapours and fumes better than others without deformation. Ikere clay is the only clay sample whose fusion temperature is beyond 1500°C with Pyrometric Cone Equivalent (PCE) of 29 as shown in Table (4). This also implies that it can withstand higher temperature than others because of its higher fusion temperature, which equally suggests it has better refractory property than others.

The thermal conductivity of refractory clays depends on the chemical properties, mineralogical composition, silica content of the refractory and on the application temperature (UNEP, 2006). The foregoing actually suggests that Ikere and Fagbohun clays have good insulating properties than others but Ikere clay is a much better refractory clay, because of its higher porosity (which could trap higher proportion of air into the structure), low iron content and higher refractoriness. Low thermal conductivity is desirable for conservation of heat, as the refractory acts as an insulator. Lightweight refractories of low thermal conductivity find wider applications in low temperature heat treatment furnaces, where the low heat capacity of the refractory structure minimizes the heat stored during the intermittent heating and cooling cycles. Considering the above, the kaolin deposit at Ikere Ekiti is considered suitable for exploitation and would be used to develop the furnace linings for the thermal degradation of selected tropical biomass to fuel and chemical products.

REFERENCES


