Integrated Geophysical Delineation of the Aquifers in a Part of the Basement Complex of Akure, South Western Nigeria

Abubakar, H. O.1*, Bayode, S.2, Badmus, A.2 Olatunji, S.3, Ajayi, C.A.4, Yusuf M.A.1
1. Department of Geology and Mineral Sciences, University of Ilorin, Ilorin, Nigeria
2. Department of Applied Geophysics, Federal University of Technology, Akure, Nigeria
3. Department of Applied Geophysics, University of Ilorin, Ilorin, Nigeria
4. Department of Geology, Ekiti State University, Ado-Ekiti, Nigeria
Email: abubakar.hussainolanrewaju3@gmail.com

Abstract
Electrical resistivity and Electromagnetic data were acquired using the Schlumberger and VLF techniques to investigate zones of favourable groundwater conditions in the hard rock of the Federal Housing Estate Akure, Ondo state, Nigeria. The static water level of the study area ranges from 0.3 m – 4.2 m. Four prominent lithological series delineated are: topsoil, weathered layer, fractured basement and the fresh basement. The topsoil has resistivity range of 73-267ohm-m and thickness ranges 0.4-5.1 m. The weathered layer has resistivity range of 41-205 ohm-m and thickness range 1.1-8.4m while the fractured basement has resistivity range of 85-2387 ohm-m and its thickness varies from 40 to 122.5 m. The low resistivity in the fractured basement which shows in all the four traverses could indicate presence of conductive matters such as water in there. Fresh basement has highest resistivity of 20614ohm-m, indicating the freshness of the hard rock in the area. A significant highest positive filtered real VLF value of 40% that indicates high conductivity occurs at traverses 2 and 3 while traverse 1 shows as much as 30%. In conclusion, interpretation of results of the stations along four established traverses revealed that the area is generally of a favourable groundwater condition provided the fractured zones are fully penetrated within the basement in other to exploit reasonable quantity of water from the area.

Keywords: Resistivity, VLF, Aquifer, Akure, Schlumberger

Introduction
The use of electrical resistivity method plays a prominent role in the study of earth crust because it is commonly employed for finding detailed information about hydro-geological setting, geological mapping and foundation study (Omosuyi, 2007). It is routinely employed in groundwater exploration to locate zones of relatively high conductivity corresponding to saturated strata, as well as providing structural and lithological information (Olayinka and Olorunfemi 1992). The method has been successfully employed for boreholes sites location in Nigeria Basement Complex (Olorunfemi and Oloruniwo, 1985). This technique have been widely used in groundwater investigations because of its good correlation between electrical properties and fluid content (Frasheri, Lubonja, and Alikaj, 1995; Zohdy, 1969; Fitterman and Stewart, 1986; McNeil, 1990). One of its varieties; VLF-EM methods utilizes Very Low Frequency radio communication signals to determine electrical properties of near surface soils and shallow bedrock, particularly in characterizing fractured zone in a Basement Complex area (Ajayi and Adegoke, 1998; Omosuyi, 2007). This
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Technique can be run quickly and inexpensively to identify anomaly such as faults, fracture zones and areas of mineralization. This method was employed for the geophysical work was carried out in parts of Akure, South-western Nigeria for fracture zone delineation. The aim of this research is to delineate the subsurface ground water zones which will further help to delineate the subsurface geologic sequence to be used in evaluating the hydrogeologic settings of the area. The study area is located within the Federal housing Estate, North Eastern part of Akure and lying within longitudes 7°41′40″ E and 7°43′20″ E (UTM) and latitudes 8°05′00″ N and 8°06′25″ N (UTM) (Fig. 1). The study area is about 2100 km square which is accessible through Owo-Ilesha expressway (Fig. 1). This area is known to be associated with the problems of groundwater aquifer as many of the boreholes drilled including hand-dug wells are either perched or later dried-up during the dry seasons. Therefore there is need to investigate the frequent causes of this aquifer failure in the area.

The study area is relatively populated and can boast of internal road links and fairly distributed social amenities. It lies within the tropical rain forest belt of hot, wet equatorial climate region characterized by wet and dry seasons with mean monthly temperature of about 27°C. Some part of the layout has tick secondary vegetation comprising of several evergreen leaves and trees. The area is characterized by high reliefs consisting of undulating hills and ridges with isolated rock bodies and so exposed to effect of erosion. It has a tropical climate and the natural vegetation is rain forest. Mean annual rainfall is between 1000 m to 1500 m, and mean annual temperature is between 24°C and 27°C (Ileojo, 1980).

Fig. 1: Location Map of the Study Area

Regional Geologic Settings

The study area is the Federal Housing Estate, northeast of Akure. Akure lies within the basement complex of Nigeria. Rocks in the area are classified (Fig. 1) into: The Migmatite Gneiss – Quartzite Complex; Low to medium grained schist belt of supracrustal and Meta – igneous rocks; Pan African Granitoids (Older Granites) and other related rocks – charnockitic rocks and syenites; and Minor felsic and mafic intrusives – intruding the Migmatite-Gneiss-Quartzite Complex (Rahman, 1974; 1976; Adekoya et al., 2003). The rock in the study area are inspected for mineralogical composition, structural and textural features, and mode of occurrence.
Results and Discussion

VLF-EM

VLF data recorded along the four profiles were plotted with distance as shown in figs 3.1a-d. The data showed some anomalies from E-W within each traverse. The 2D tomographic structures of the VLF values shows places of corresponding high/positive peak interpreted to have higher groundwater potentials than the areas with low/negative values. Also, according to Palacky et al., (1981) and Alvin et al., (1997), the high positive filtered real VLF values indicates high conductivity which can be related to water saturated geological layers typical of groundwater aquifers or shallow fracture harbouring conducting fluid. Because, high VLF anomaly may be caused by conductivity in rocks that is due to dissolved mineral, while, the low resistivity may be due to mineralization of soil contamination within the area. Based on VLF results, places corresponding to distances between 100m – 120m, 330m-350m and 610m – 620m along profile AA were interpreted to have high potential for groundwater. Other places with similar interpretations include 40m-50m, 235m – 250m and 295m-305m along profile BB, and 340m-350m along profile CC.

Fig. 2: Geological Map of Ondo State Showing the Major Geological Components

Methodology

For this research work, four profiles were marked for detailed geophysical survey. Geo-electric section study was carried out along the four profiles to know the general trend of rocks resistivity in the area. Station intervals of 15 m and 30 m are used. Subsequently, Very Low Frequency Electromagnetic Profiling was stationed at interval of 10 m along each profile. A number of resistivity meters are in use for measuring the earth’s subsurface apparent resistivity. For this research work, R50 DC Resistivity meters was used for data acquisition along with the metal electrode, connecting cables, hammers, compound/clinometers, measuring tapes and ropes. The current and potential electrodes are maintained at a fixed separation and progressively moved along a profile. Traverse 1 has a total length of 1020m and runs along E-W direction of the study area with the station interval of 10m (Fig. 3.1a). Traverse 2 has a total length of 400m and also runs along E-W direction (Fig. 3.1b).

Fig. 3.1a: VLF-EM Profiles along Traverse 1 (E-W) in the study Area
Inferred Geology from Geo-electric Sections

The interpretation of field resistivity data are in terms of resistivity, depth to the bedrock and the interfaces across which a strong electrical contrast exists. The electrical resistivity varies between different geological materials, depending mainly on variation in water contents and dissolved ions in the water. The analysis and interpretation of the survey data showed different geo-electric layers. To achieve these, resistivity field curves were plotted for all the VES points using ‘WINRESIST’ software. The curves indicated that the area is mostly underlain by 4 geo-electric layers. Samples of such plots are shown in Figs. 3.2a and 3.2b. Thereafter, geo-electric sections equivalent to the identified geologic structures were obtained from the software.

The geo-electric sections generated across the study area are presented in Figs. 3.3a-d. Four subsurface geo-electric units were delineated. These are the topsoil, weathered layer, fractured basement and the fresh basement. The topsoil is the first layer. The resistivity values ranges from 73-267ohm-m. The thickness values ranges from 0.4-5.1m. The topsoil is made up of clay, sandy-clay, clayey-sand and laterite. The second layer is the weathered layer. The resistivity values ranges from 41-205ohm-m. The thickness varies from 1.1-8.4m. The weathered layer is composed of clay, sandy clay and clayey sand. The third layer is the fractured basement. The fractured basement has resistivity range of 85-2387 ohm-m and its thickness varies from 40 to 122.5 m. The last layer is the fresh basement. The resistivity values ranges from 582-20614ohm-m. The weathered and the
fractured basement constitute the aquifer units in the study area.

Fig. 3.3a: Geo-electric Section along Traverse 1 (E-W) in the Study Area

Fig. 3.3b: Geo-electric Section along Traverse 2 (E-W) in the study area.

Fig. 3.3c: Geo-electric Section along Traverse 3 (E-W) in the study area.

Fig. 3.3d: Geo-electric Section along Traverse 4 (E-W) in the study area.
Conclusions
The results of the interpretation of the data obtained from geo-electric exploration for favourable groundwater conditions in hard rock environment of Federal Housing Estate, Akure are presented in this study. VLF-EM was further carried out along the four established traverse stations where fractured on zones were under probe based on zones low resistivity values has been identified by the HP. The correlation of the results of the Geo-electric section and VLF-EM shows that the study area is characterized by low groundwater potential. Also, the north-western part of the study area is of favourable groundwater condition for any hand-dug well as a result of the low depth of water static level.

References


Evaluating Leachate Contamination Potential Using Leachate Pollution Index From Waste Dumpsites in Maiduguri, Borno State

*A.M. Kundiri, B. A. Umdagas and A. S. Muhammed
Department of Civil and Water Resources Engineering, University of Maiduguri, Borno State, Nigeria.
E-mail: alikundiri@yahoo.com

Abstract
This study characterises the leachate contaminants of selected dumpsites in Maiduguri, with a view to determining the physico-chemical composition, leachate pollution potentials and leachate quality based on the leachate pollution index (LPI). The parameters determined include pH (8.19 – 11.32), EC (1445 – 1811), TDS (898 – 7460), BOD (7 – 17), Pb (0.20 – 3.00), Fe (0.30 – 1.47), Zn (0.10 – 1.20), Cu (0.09 – 0.24), Cr (0.10 – 0.62) and Mn (0.01 – 0.15). Results of this study indicates that Ajiganaram dumping site had the highest contamination potential with 21.32 followed by Custom (14.08), Bulabulin (8.14) and Monday market area dumping site (7.11). These values yielded between 0.96 and 2.9 times higher than the standard value of 7.4. Nevertheless, values of EC, TDS, DO and Fe were higher than the maximum limits specified by the federal environmental agency (FEPA) and world health organization (WHO). In order to ameliorate the adverse effect of such environmental hazard, engineered landfills with compacted liners and covers should be encouraged.

Keywords: Contaminants; Leachate Pollution Index, Compacted liners and covers

Introduction
The concept of Municipal Solid Waste disposal in Nigeria just like in most developing nations all over the world is faced with numerous problems due to its uncontrolled, unscientific and poor management. In Borno State, Municipal Solid Waste dispose within the Maiduguri Metropolitan Council (MMC) and Jere Local Government Areas is managed by the Borno State Environmental Protection Agency (BOSEPA). There is no legal framework existing to address the problems of uncontrolled dumping sites which results to adverse environmental hazard on the surrounding ecosystem (Bhalla et al., 2014; Ramaiah et al., 2014; De et al., 2016). Leachate discharge from landfills is the main route for the release of organic and inorganic contaminants commonly encountered in the refuse (Rouholhnejad and Sadrnejad, 2009).

The potential of waste dump leachate contamination can be determined using the Leachate Pollution Index (LPI) as in earlier researches (Kumar and Alappat, 2003; Kale et al., 2010; Zainol et al., 2012; Munir et al., 2014; Hossain et al., 2016). Leachate is a liquid containing decomposed waste, bacteria and other materials that drain out of the landfills (Afsar et al., 2015). Leachate characteristics demonstrate high variations, with range of physical, chemical and biological parameters over several order magnitude (Umar et al., 2010). The LPI ranges from 0 to 100 based on the monitoring of parameters of leachate pollution. Leachate characteristics vary considerably from one landfill to another. The leachate composition is influence by many factors such as the types of wastes deposited in the landfill, composition of wastes, the degree of
compaction, hydrology of the site, moisture content, particle size of the
soil in the sites, climate and age of the
fill (Viraraghavan and Singh, 1997; Kumar and Alappat, 2005; Adewuyi
and Mallam, 2014). This study is aimed
at characterising raw leachate and
ranking of landfill sites based on their
LPI potential in some selected waste
collection centres in Maiduguri
metropolitan council (MMC).

Materials and Methods

Site Description

The four selected waste dumping sites are
Ajiganaram area (lat 11°50’49.54”N and
long13° 10’34.26’’), Bulabulin area (lat
11°49’52.34’’N and long13°09’26.27’’),
Custom area (lat 11° 50’51.23’’N and long
13° 10’38.06’’) and Monday market area
(lat 11°49’55.86’’N and long13°9’14.71’’)

These four waste collection centres
designated as “AA” for Ajiganaram area,
“BB” for Bulabulin area, “CA” for Custom
area and “MM” for Monday market area.
The waste dumping sites have been in use
for over a period of two decades, while
Monday market and Bulabulin areas
dumping sites were being close due to
seasonal stream flow of river (Ngadda)
which passes dumpsites.

Leachate Sampling

Leachate samples were collected from the
selected dumpsites within the study areas.
The leachate samples were collected from
the bottom of the waste dumps where the
leachate was collected and subsequently
transferred to the laboratory for analysis.
The ionic concentration (pH) was
measured using pH 450 portable meter kit,
while sodium; chlorine and calcium were
preserved by acidifying the samples with
concentrated HNO₃ at pH less than 2. It
was also digested, filtered and analyzed
with the UNICAM 969 Atomic
Absorption Spectrophotometer (AAS) to
ascertain the cation concentration.

Leachate Pollution Index

The contamination potential of landfill
dumpsites can be ascertained on a
comparative scale using the leachate
pollution index (LPI). The LPI was
calculated by (Kumar and Alappat, 2003;
Rafizul et al., 2012) using the
concentration of the available leachate
pollutants from multiple chemical and
biological test results of the landfill
leachate from the eqns 1 and 2:

\[
LPI = \frac{\sum_{i=1}^{n} (W_i \times P_i)}{\sum_{i=1}^{n} W_i}
\]  

(1)

Where, \( W_i \) = weight of the \( i \)th pollutant
variable
\( P_i \) = sub index value of the \( i \)th leachate
pollutant variable
\( n \) = number of leachate pollutant
parameters for which data is available, but
in that case \( n \leq 18 \) and
\[ \sum_{i=1}^{n} w_i \leq 1 \]  

(2)

However, the Pollutant variable for all the
parameters were multiplied with the
respective weights assigned to each
parameter as determined from the
aggregate sub-index curves for leachate
pollutant variables in the appendix as
shown in eqn 3.

\[
\left( \sum_{i=1}^{n} W_i \times P_i \right)
\]

(3)

This is divided by the sum of the weights
of the pollutant variables in eqn 4.

\[
\left( \sum_{i=1}^{n} W_i \right)
\]

(4)
Results

Leachate Characterization

The leachate samples used for the characterization were analyzed for twelve general parameters and six heavy metals and the physico-chemical characterization are presented in Table 1.

Table 1: Physico-chemical characteristics of the raw leachate at the different dumping sites

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Dumpingsites</th>
<th>AA</th>
<th>BB</th>
<th>CA</th>
<th>MM</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td></td>
<td>11.32</td>
<td>8.19</td>
<td>10.35</td>
<td>8.54</td>
</tr>
<tr>
<td>EC</td>
<td></td>
<td>1445</td>
<td>1690</td>
<td>1776</td>
<td>1811</td>
</tr>
<tr>
<td>TDS</td>
<td></td>
<td>7460</td>
<td>934</td>
<td>7240</td>
<td>898</td>
</tr>
<tr>
<td>DO</td>
<td></td>
<td>3.21</td>
<td>10.00</td>
<td>4.10</td>
<td>7.00</td>
</tr>
<tr>
<td>BOD</td>
<td></td>
<td>17.00</td>
<td>12.00</td>
<td>7.00</td>
<td>14.60</td>
</tr>
<tr>
<td>Cl</td>
<td></td>
<td>50.80</td>
<td>14.60</td>
<td>61.20</td>
<td>15.60</td>
</tr>
<tr>
<td>Cu</td>
<td></td>
<td>0.24</td>
<td>0.17</td>
<td>0.13</td>
<td>0.09</td>
</tr>
<tr>
<td>Fe</td>
<td></td>
<td>0.42</td>
<td>0.44</td>
<td>0.30</td>
<td>1.47</td>
</tr>
<tr>
<td>Pb</td>
<td></td>
<td>3.00</td>
<td>0.94</td>
<td>0.20</td>
<td>1.20</td>
</tr>
<tr>
<td>Zn</td>
<td></td>
<td>0.96</td>
<td>0.10</td>
<td>1.20</td>
<td>0.48</td>
</tr>
<tr>
<td>Mn</td>
<td></td>
<td>0.01</td>
<td>0.15</td>
<td>0.03</td>
<td>0.11</td>
</tr>
<tr>
<td>Cr</td>
<td></td>
<td>0.62</td>
<td>0.10</td>
<td>0.28</td>
<td>0.12</td>
</tr>
</tbody>
</table>

Ajiganaram area - (AA), Bulabulin area - (BB), Custom area - (CA) and Monday market area –(MM)

Ionic concentration and Electrical conductivity

The value of the ionic concentration (pH) ranges between 8.19 and 11.32, with a mean value of 9.15; while the electrical conductivity ranges between 1445 and 1811mg/l.

Discussion

pH and Total Dissolve Solid

The pH of most leachates increased with time due to the decrease of the concentration of the partially ionized free volatile fatty acids, and could be attributed to the biological stabilization of the organic matter present in the dumpsite which is in conformity with the research by (Agbozu et al., 2015). The pH value of 6.5 is normally considered to be from a new landfill, which is probably less than 5 years; while older or stabilized landfill with over ten years has pH range of 7.5 to 9 as observed by (Oweis and Khera, 1998). When the pH rises above or falls below 8, the water uptake capacity decreases significantly resulting to a decrease in diffuse double layer thickness and therefore, an increase in shrinkage of soil (Oweis and Khera, 1998). Generally, some leachates are found to have pH values between 4.5 and 9.0; which are in agreement with (Christensen et al., 2001).

Total Dissolved Solid (TDS) ranges between 208 and 7460mg/l, indicated high level of TDS. High level of TDS may be responsible for reduction in the palatability of water, and indication of the presence of inorganic materials in the water samples (Gupta and Rani, 2014). However, the heavy metals contents from the raw leachate samples indicates that lead has the highest concentration followed by zinc, chromium, iron, copper and manganese.

BOD is a measure of biodegradable organic mass of leachate and indicates the maturity of the landfill which typically decreases with time (Manimekalai and Vijayalakshmi, 2012). The BOD ranges between 7 and 17mg/l for the four waste dumpsites.

Leachate Pollution Index

The LPI for Ajiganaram dumping site had the highest contamination potential of 21.32, followed by that of Custom area with 14.08, Bulabulin dumping site with 8.14 and the least was the Monday market dumping site having 7.11 as presented in Table 2.
The values of EC, TDS, DO, lead, Fe and Mn were higher than both the Federal Environmental Protection Agency (FEPA) and WHO maximum limit specified by (Ojaowo et al., 2012; Gupta and Rani, 2014). The mean pH value of 9.6 was greater than the maximum limit specified by both FEPA and World Health Organization (WHO, 1997). The presence of the heavy metal such as copper and zinc were considerably lower than both standards. Table 3 shows the comparison of the measured concentration of leachate between the Federal Environmental Protection Agency (FEPA) and WHO standards.

It could be inferred that all the dumping sites except that of Monday market had LPI higher than the standard value of 7.4 as specified in earlier researches (Dsouza and Somashekar, 2013).

The leachate pollution index for the four waste dumpsites in Maiduguri were higher than the standard value of 7.4 by 2.9 times higher at AA, 1.1 times higher at BB, 1.9 times higher at CA and 0.96 times higher at MM.

**Conclusions**

The study of the characterization of the landfill contaminants and LPI was carried out from four different waste dumping
sites at Ajiganaram, Bulabulin, Custom and Monday market areas in Maiduguri. It was clearly indicated that the LPI at Ajiganaram, Bulabulin and Custom waste dumpsites yielded 21.32, 8.14 and 14.08 respectively. High LPI values indicate that the leachates generated from new landfills or dumping sites thus, resulting to high concentration of traces of some heavy metals. All the dumping sites except that of Monday market had LPI higher than the standard value of 7.4 specified by both FEPA and WHO, and were higher than the standard value by almost 2.9 times at AA, 1.1 times at BB, 1.9 times at CA and 0.96 times at MM.

Nevertheless, the significant concentration of EC, TDS, DO, Fe, Pb and Mn which was considered higher than the maximum standard indicated that the influence of such leachate may pose threat to the environment through both surface and groundwater contamination. It could further be recommended that the Borno State Environmental Protection Agency (BOSEPA) should adopt a proper means of waste disposal system like the engineered landfilling or compacted liners and covers.

References


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of Environmental Protection, 3 (1): 28 – 35.


Appendix
Aggregate sub-index curves for leachate pollutant variables

(Source: Kumar and Alappat, 2003)
Influence of Curing Techniques on Strength Development of Black Cotton Soil Stabilized with Lime

Amadi A. A. and Adama E.
Department of Civil Engineering, Federal University of Technology, Minna
E-mail: agapitus.amadi@futminna.edu.ng, agapitusahamefule4@yahoo.com

Abstract
Lime stabilization is one of the techniques used to improve the mechanical properties, particularly the strength of soft clay soils. However the effectiveness of lime depends on curing technique among other factors. This study aims at investigating the effect of different curing techniques on the strength of lime-treated black cotton (BC) soil. Characterization of natural soil and soil mixtures was carried out by Atterberg limits and compaction tests, while the change in the strength of the specimens was evaluated using the unconfined compressive strength (UCS) test. Tests were conducted on remoulded specimens of lime-treated BC soil with lime contents of 0, 3, 6, 9, and 12% (on dry weight basis) and cured using three different methods; namely, moist curing (i.e. specimens were wrapped in air-tight plastic bags and immersion in water bath), air curing (i.e. specimens were wrapped in air-tight plastic bags and exposed to ambient temperature and humidity in the laboratory). Fog room curing (i.e., where specimens were wrapped in air-tight plastic bags and placed in a fog room at 23°C and 100% constant humidity). Curing periods considered were 7, 14, 21 and 28 days. The application of varying percentages of lime lowered the plasticity and maximum dry unit weight of mixtures, while the optimum moisture contents increased slightly following the treatments. For all curing techniques, there is an observed increase in UCS with curing period and lime content with maximum UCS values observed for fog room-cured specimens. On the other hand, the use of the air curing technique, regardless of the lime content or curing periods provided the lowest UCS values when compared with the same type of specimens used in the other two curing techniques.

Keywords: Black cotton soil, Curing techniques, Lime, Strength development

Introduction
Black cotton (BC) soils are expansive soils that are found in many places all over the world especially in the arid and semi-arid regions marked with dry and wet seasons, low rainfall, poor drainage and high temperature (Carter et al., 1963; Ola, 1983; Chen, 1988). Although BC soils are rated less suitable for construction, the growth in population in the last decade and the associated urbanization led to construction in areas dominated by this soil group. This soil group has been problematic for the civil infrastructure including roads and foundations due to their unconventional behaviour. They are normally associated with volumetric changes when subjected to changes in water content due to seasonal water fluctuations and very hard when dry, but losses its strength completely when in wet condition. They also exhibits very low bearing capacity as well as low permeability (NBRRI, 1983; Ola, 1983; Amadi and Osu, 2016). These properties make them unsuitable for construction of embankment, highway, building or any other load bearing engineering structure in their natural state (Nigerian General Specification, 1997). The reason for this behaviour is the presence of montmorillonite and illite clay minerals that possess expanding lattice structure (NBRRI, 1983; Chen, 1988; Nelson and Miller, 1992).
Chemical stabilizers are commonly used to improve the performance of this soil group. Lime, cement or combinations of these and a number of by-product materials used as stabilizers, including lime kiln dust (LKD), cement kiln dust, and fly ash are typically employed for this purpose.

In the present study, lime stabilization which is one of the most practical and cost effective techniques of stabilizing this type of soil was used (Ola, 1977; Osula, 1991; Osinubi, 1995). Treatment of soils using lime involves time-dependent short-term and long-term chemical reactions. The short-term reactions primarily constitute hydration of CaO to Ca(OH)₂ and the agglomeration–flocculation of clay particles as a result of cation exchange. These short-term changes are rapid and are sometimes referred to as modification because they modify the soil to a relatively workable state when compared with its original state. The short-term reactions also result in a high pH environment, which facilitates the dissolution of aluminum and silicon from clay minerals present in the soil. These elements react with calcium to form pozzolanic compounds; namely, calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH) which are cementitious in nature and crystallize to bind the structure together, providing long-term strength (Kedzi, 1979; Amadi and Osu, 2016).

However, the efficiency and effectiveness of stabilization depends on the associated moisture content during compaction as well as the long-term moisture content. Therefore, to achieve optimal strength development and durability of stabilized materials, special attention needs to be given the curing technique to be adopted.

The use of curing methods that provides appropriate conditions such as temperature, moisture conditions significantly contribute to development of the strength and enhancement of durability of stabilized materials on the short and long term. Further, proper curing methods prevent the drying that causes shrinkage and the associated cracking problems as well as the effective retention of moisture in stabilized soils.

**Materials and Method**

**Materials**

*Black cotton soil*

The BC soil used in this study was collected from a site at new Marte, km 44 along Dikwa Gamboru road, Borno state, in the North Eastern part of Nigeria. The location lies within a semi-arid region with long periods of dry weather and short spells of wet weather. The general topography is flat and the vegetation is of the savannah type with scanty tree growth. It was obtained from the upper 0.5 – 1.6 m of the soil profile at the site by method of disturbed sampling. Results of previous work on soil samples within this area had shown montmorillonite to be the predominant clay mineral in the soil (Ola, 1978; Osinubi, 1998; Oriola and Moses, 2011).

*Lime*

Commercially produced (Magnolia brand) finely ground hydrated lime (i.e., calcium hydroxide) with 99% passing 75 μm sieve was obtained from a chemical store in Kaduna and used as the stabilizer. To preserve the lime from carbonation, the bag of lime was double bagged with plastic bags that were securely tied.
Experimental Methods

Index properties

Laboratory tests on the natural and lime-treated BC soil with lime contents of 0, 3, 6, 9, and 12% (on dry weight basis) include particle size analysis, Atterberg limits, moisture – density tests following the relevant British standards (BS 1377, 1990; BS 1924, 1990).

Unconfined Compressive Strength (UCS) Test

Five dosages of lime (0, 3, 6, 9%, and 12% on dry weight basis) were separately mixed with the soil at OMC (as determined in the previous section) and the mixtures were compacted using British standard light (BSL) compactive effort after six hours of mixing to allow for the mellowing period. Upon extrusion, the compacted specimens were cured and subjected to UCS testing at various ages namely 7, 14, 21 and 28 days. The curing methods adopted in this study included: (a) Moist curing (MC) where specimens were wrapped in air-tight plastic bags and immersed in a curing bath (b) Air curing (AC) where specimens wrapped in air-tight plastic bags to prevent moisture loss were exposed to ambient temperature and humidity in the laboratory (c) Fog room curing (FRC) where specimens were wrapped in air-tight plastic bags and placed in a fog room at 23°C and 100% constant humidity. Unconfined compression tests were conducted on a strain-controlled triaxial testing frame at a strain rate of 1 %/min without application of the cell pressure (i.e., \( \sigma_3 = 0 \)) following standard procedure outlined in BS 1377 (1990) and BS 1924 (1990). The maximum load was converted to the unconfined compression strength of the sample.

Results and Discussion

Material Characterization

Table 1 provides the chemical composition of the lime (from the manufacturer) used in this research. Table 2 provides a summary of the engineering properties of the natural soil. The particle size analysis of the soil shows that it is composed of 4.6% sand, 50% silt and 45.4% clay.

Table 1: Chemical composition of lime used in the study

<table>
<thead>
<tr>
<th>Chemical element</th>
<th>Percentage by weight (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>0.6</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>0.4</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>0.3</td>
</tr>
<tr>
<td>CaO</td>
<td>68.6</td>
</tr>
<tr>
<td>MgO</td>
<td>0.7</td>
</tr>
<tr>
<td>SO₃</td>
<td>0.1</td>
</tr>
<tr>
<td>Na₂O+K₂O</td>
<td>0.1</td>
</tr>
<tr>
<td>Loss on ignition</td>
<td>32.0</td>
</tr>
<tr>
<td>pH</td>
<td>12.58</td>
</tr>
</tbody>
</table>

Based on the Unified Soil Classification System (ASTM, 1992), the soil is classified as high plasticity clay (CH) and A-7-6 in accordance with AASHTO soil classification system (AASHTO, 1986). Treatment with varying amounts of lime resulted in only a slight improvement of classification of soil mixtures.

Table 2: Material Properties for the Natural BC soil

<table>
<thead>
<tr>
<th>Soil Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>%Sand</td>
<td>4.5</td>
</tr>
<tr>
<td>%Silt (&lt;0.075mm)</td>
<td>45.5</td>
</tr>
<tr>
<td>Specific gravity</td>
<td>2.5</td>
</tr>
<tr>
<td>USCS Classification</td>
<td>CH</td>
</tr>
<tr>
<td>AASHTO Classification</td>
<td>A-7-6</td>
</tr>
<tr>
<td>Atterberg limits</td>
<td>76</td>
</tr>
<tr>
<td>Liquid limit, LL</td>
<td>52</td>
</tr>
<tr>
<td>Plastic limit, PL</td>
<td>1.15</td>
</tr>
<tr>
<td>Plasticity index, PI</td>
<td>8.20</td>
</tr>
<tr>
<td>pH</td>
<td></td>
</tr>
</tbody>
</table>

Effect of Lime on Plasticity Characteristics of the study Soil

The improvement effects promoted by addition of 0, 3, 6, 9 and 12% of lime on liquid limit and plasticity index are represented in Fig. 1. In general, the addition of 3, 6, 9 and 12% lime promoted reductions of 20, 52, 70 and 110% in liquid limit as well as 24, 50, 86 and 136% in plasticity index. These results are
Influence of Curing Techniques on Strength Development of Black Cotton Soil Stabilized with Lime

consistent with the test results of the lime-stabilized BC soils reported by Ola (1977), Osinubi (1995) as well as Ijimdiya et al. (2009).

The liquid limits of clays are controlled by the shearing resistance at particle level and the thickness of the diffuse double layer (Nelson and Miller, 1992; Amadi and Osu, 2016). The addition of lime reduced the thickness of the diffuse double layer of clay particles by increasing the electrolyte concentration and by exchanging cations. Similarly, reduction in plasticity index (PI) values for lime-stabilized soil specimens are well known and are attributed to chemical reactions between lime and soils including ion exchange and associated flocculation reaction.

Moisture – Density Relationship of Soil Mixtures
The variations in maximum dry density and optimum moisture content with lime content for the various soil mixtures are presented in Fig. 2. The maximum dry density (MDD) when compacted using BSL compactive effort at the optimum moisture content (OMC) for the natural soil are 1.79g/cm³ and 18% respectively. The gradual increase in lime percentage caused a decrease in the maximum dry density (from 1.79 to 1.67 g/cm³) and promoted an increase in the optimum moisture content (from 18 to 20%) which represents a maximum change of -7.2% in MDD and +10% in the case of OMC. These results are in good agreement with the results reported by Osula (1991), Osula (1996) as well as Osinubi and Nwaiwu (2006) who conducted tests on fine grained lateritic soils. The decrease in maximum dry density with the addition of lime was anticipated because lime has a lower density than the soil sample. For reference, the density of lime is determined as 1.63 g/cm³. The increase in the OMC on the other hand is attributed to requirement of more water for hydration reactions of the higher amount of lime.

Fig. 1: Variation of LL and PI with lime content of soil mixtures

**Fig. 2:** Variation of Maximum dry Density and Optimum Moisture content with lime content of soil mixtures

**Effect of Lime Content on UCS of Soil Mixtures**
Experimental results show that the UCS of soil mixtures was significantly increased when compared with strength of the untreated soil. Fig. 3 shows changes in strength promoted by addition of 0, 3, 6, 9 and 12% of lime after 28 days of curing using various curing methods. The strength increased from 103 kN/m² to 171.47 kN/m² for the lime addition of 3% to 12% after 28 days of curing using the air method. Similarly, addition of 3, 6, 9 and 12% of lime provided increments of 70, 75, 80 and 85% respectively when the specimens were cured using the fog room method after 28 days, while specimens with the same sequence of lime treatment
but cured under the moist method produced strength increases of 2.6, 3.3, 3.5 and 4 times the value of untreated soil at similar curing age. Expectedly, in all the cases, 12% lime produced the highest percent increase in UCS values. Strength gain in chemically stabilized soils depends largely on the amount of silica and alumina available from the clay itself; thus, lime stabilization is more effective for montmorillonite soils (Kedzi, 1979; NBRRI, 1983; Osinubi, 2000).

The consistent increase in strength of lime treated specimens may be associated with the increase in pH value, which promotes the alkaline condition. Strong alkaline conditions are assumed to be responsible for the release of silica and alumina from clay mineral. Consequently, cementitious products namely hydrated calcium aluminate (CAH), hydrated calcium silicate (CSH) and hydrated calcium aluminum silicate (CASH) are produced to cause strength increase in the soil mixtures (Kedzi, 1979; Amadi, 2014).

**Effect of Curing Time on UCS of Soil Mixtures**

The role of curing time on the strength development of the lime treated BC soil compacted at optimum moisture content (OMC) and maximum dry density (MDD) is illustrated in Figs. 4 to 6 for the various curing methods. During treatment period, the curing time among other factors affected the strength development of the treated soil. In general, the longer the curing period, the better is the strength development, due to the pozzolanic reactions (Amadi and Osu, 2016). The strength development with time of soil mixtures is evaluated by normalizing the strength at various curing times by the 0 day strength. The strength ratios $q/q_{(0\text{day})}$ of soil mixtures are found in the range 1.3 – 1.98, 1.25 – 1.9 and 1.42 – 1.99 respectively for the moist, air and fog room curing methods. Generally, the UCS increased about 4, 3.8 and 5 times high than of the original untreated strength for moist curing, air method and fog room method respectively after 28 days curing. However, most of the strength gain for compacted soil mixtures occurred within the first 21 days after compaction. Studies on stabilization of highly expansive clay with lime by Osinubi (1977) and Osinubi (1995) indicated similar findings.
Influence of Curing Techniques on Strength Development of Black Cotton Soil Stabilized with Lime

Fig. 6: Variation of Normalized UCS with Curing Duration for Soil Mixtures using Fog room curing method

The significant increases in strength was noted on specimens cured at longer curing time (Amadi and Osu, 2016). This corresponds to the development of cementitious products resulting from pozzolanic reactions as time prolonged.

Effect of Curing Technique on UCS of Soil Mixtures

The role of curing technique in the strength development is now examined and the UCS data is provided in a comparison bar chart shown in Fig. 7 for the various curing methods. For all curing techniques, there is an observed increase in UCS after 28 days of curing, with maximum UCS values observed for fog room-cured specimens.

Fig. 7: Comparison bar chart for the curing methods at varying percentages of lime

The least strength development regardless of lime content was for the case of the air curing method when compared with the same type of specimens used in the other two curing techniques. The UCS value ranged from 103.2 kN/m² to 171.46 kN/m² when the lime content increased from 3% to 12% after 28 days. On the other hand, specimens cured with fog room method produced the highest UCS values at all lime contents proving the strong influence of curing conditions, while the moist curing produced intermediate strength values ranging from 126 kN/m² to 190 kN/m² when treated with 3% to 12% lime after 28 days.

The provision of favourable conditions in the case of fog room method such as temperature, moisture conditions significantly contributed to the creation of high alkaline environment which changed the physico-chemical condition of the mineral surfaces, making pozzolanic reactions to take place for optimal strength development (Kezdi, 1979; Ola, 1978; Amadi, 2014).

Conclusions

This article describes a laboratory study on the effects of various curing techniques adopted for the stabilization of black cotton (BC) soil with varying amounts of lime (0, 3, 6, 9 and 12% on dry weight basis) and the mixtures tested for Atterberg limits and compaction tests as well as Unconfined Compressive Strength (UCS) test to evaluate the change in the strength of the specimens. Specimens for UCS test were cured for 7, 14, 21 and 28 days using three different methods; namely, moist curing (i.e. specimens were wrapped in air-tight plastic bags and immersion in water bath), air curing (i.e. specimens were wrapped in air-tight plastic bags and exposed to ambient temperature and humidity in the laboratory). Fog room curing (i.e., where specimens were wrapped in air-tight plastic bags and...
placed in a fog room at 23°C and 100% constant humidity).
From test results, the liquid limit and plasticity index of mixtures decreased substantially at the 12% lime concentration. The maximum dry unit weight decreased from 1.79g/cm$^3$ for the natural soil to 1.67g/cm$^3$ at 12% lime.
For all curing techniques, there was an observed increase in UCS with curing period and lime content with maximum UCS values observed for fog room-cured specimens. On the other hand, the use of the air curing technique, regardless of the lime content or curing periods provided the lowest UCS values when compared with the same type of specimens used in the other two curing techniques.

References


Influence of Curing Techniques on Strength Development of Black Cotton Soil Stabilized with Lime


Modeling and Optimization of Biogas Production from Anaerobic Digestion of Agricultural Waste: A Factorial Design Analysis

Mohammed Alhassan 1*, Abubakar Garba Isah2 Jibrin Mohammed Jibrin3 and Mohammed Umar Garba4,

1-4Department of Chemical Engineering, Federal University of Technolog, Minna, Niger State, Nigeria
E-mail: moh.alhass@futminna.edu.ng,

Abstract
The aim of this study was to investigate the optimal conditions for biogas production from anaerobic digestion of agricultural waste (namely cow dung, chicken waste and saw dust) using full factorial design of experiments to study the effect of four factors: concentration (A), feed type (B), seeding (C) and time (D) on biogas produced after 28 days of anaerobic digestion. Main effects and interaction effects of these factors were analyzed using statistical techniques. The experimental results showed that the linear model terms of concentration, feed type, seeding and time had significant effect on yield with (p < 0.05). However, there was interactive effect between these variables (p < 0.05), though, concentration and time show no interaction (p> 0.05). The full model equation developed for biogas production is: Y = K-11.5842A+19.9868D constant K for biogas production with seeding = 930.877 for cow dung, 1483.28 for chicken waste and 555.692 for sawdust respectively. While K for biogas production without seeding = 351.309 for cow dung, 903.717 for chicken waste and -23.8759 for sawdust respectively. The highest amount of biogas produced was 1973.33mL at optimum conditions of 20% concentration, chicken waste, seeding and retention time of 28 days.

Keywords: Agricultural Waste, Anaerobic Digestion, Modelling, Optimization, Biogas, Full Factorial Design.

Introduction
Today, the issues of global warming and climate change are strongly receiving public attention and have become a major environmental concern both at national and international level. The increasing concentration of atmospheric greenhouse gases as a result of culpable human activities represents the major cause for this problem (Alhassan et al., 2016). The most important Greenhouse gases from such activities are carbon dioxide, methane, nitrous oxide, and fluorinated gases such as sulfur hexafluoride and hydro fluorocarbon (US EPA, 2007). The atmospheric concentration of such gases importantly influences the earth’s climate and cause global warming. In the context of global warming, carbon dioxide gas currently gains more public attention than other greenhouse gases. However, it is important to also consider other gases. One of these is methane (CH₄) gas which is produced under anaerobic conditions during degradation of organic materials by certain micro-organisms. The major biological sources of methane include natural wetlands, rice paddies, landfills, ruminants, termites, river beds, and lakes (Steven, 2007). Methane is an important greenhouse gas with the ability of global warming 25 times greater than that of carbon dioxide (IPCC, 2007). It is estimated that more than 60% of the global methane release is connected to human activities. Methane emission accounts for 16% of all global greenhouse gas emissions and the current value of global average atmospheric methane concentration is about 1720 ppbv (parts per billion by volume) which is more than double of the concentration during the pre-industrial period 800 ppbv (Mosier et al., 1998). Methane is therefore important greenhouse gas, which needs a serious consideration. With regard to source,
Modelling and Optimization of Biogas Production from Anaerobic Digestion of Agricultural Waste: A Factorial Design Analysis

Agriculture appears to be the major contributor of atmospheric methane. Worldwide, 35% of greenhouse gas emission is from agriculture (IPCC, 1996). According to Mosier et al. (1998) as cited by Olesen et al., (2006) agriculture is a responsible sector for 50% of anthropogenic emission of methane. The major sources of agriculture methane are enteric fermentation and rice paddies.

The rate of energy consumption and waste generation in developing countries necessitates the adoption of technologies that promote renewable energy and the conversion of waste into viable commodity. The biogas technology is one of such systems and has been found to be cost effective and environmentally sound (Brown, 2003). Biogas is a clean, environmental friendly and renewable form of energy generated when microorganisms degrade organic materials in an oxygen free environment. The formation of biogas can occur either in natural environment or controlled conditions in constructed biogas plants, so called anaerobic degradation (AD). Swamps, marshes, river beds, rumen of herbivore animal are some of the areas where biogas is formed naturally (Marchaim, 1992). The same microbial activities are achieved in both natural and controlled conditions. The feedstock for biogas production in constructed plants is more or less any organic fractions from household organic waste to dedicated energy crops like maize (Lantz et al., 2007). The potential feedstock for the production of biogas include; municipal solid waste, industrial organic waste, garden waste, agricultural waste (manure and crop residue), energy crops, cellulose rich biomass, algae and seaweed (water based), by-products of ethanol and bio diesel production (Lantz et al., 2007; Demetriades, 2008; Börjesson and Mattiasson, 2007; SGC, 2007). Several researchers (Adelekan and Bamgboye, 2009; Adeyosoye et al., 2010, Ofoefule, et al. 2011) have reported production of biogas from different substrate such as cassava peels, sweet potato peel, wild cocoyam peel, poultry dropping, maize comb, rice husks and various bulk organic wastes in Nigeria.

The country’s biogas potential has been estimated at 6.8 million m$^3$ per day from animal waste, while from municipal solid waste it was estimated at 1.77 million cubic tonnes per year for biogas Production (Mshandete and Parawira, 2009). Biogas production may therefore be a profitable means of reducing the country’s energy crisis and waste generation. The Energy crisis in Nigeria started far back the 1970s after the advent of the oil boom, since then there has been growing national concern for sustained shortage in energy supply (GueguimKana et al., 2012 Yadolka, 2004). Many scholars (Preston and Murgueitio, 1992; Mattocks, 1984, Feigelson and Babu, 1992) have also envisaged this problem around the globe. In the United States of America for instance, several million gallons of fuel is consumed on daily basis for transportation and other activities to meet their daily needs (Habmigern, 2003). These fuels are obtained from non-renewable sources which are unsustainable due to their impacts on the environment. Sustainability is a current global trend which addresses issues concerning environmental impacts. It first came into play at the World Commission on Environment and Development (Brundtland,1985; Lele, 1991). It was defined as development that meets the needs of the present generation without compromising the ability of future generations to meet their needs (Brundtland, 1985; Lele, 1991)

Materials and methods
The experiments were carried out on batch laboratory scale reactor (1L Tin Digesters). The batch 1 experiment consists of three digesters and was run in triplicate for each of the digester. These digesters were closed with their lids. A puncture hole was bored in the middle of
each lid and a rubber tube of 12 mm diameter was inserted through it, sealed and fixed with araldite. The lid of each digester was further made air tight by melting candle wax all round the edges which on cooling, sealed it up and making it air tight (completely anaerobic). Each digester was connected via a rubber tube, to a 1000 cm$^3$ cylinder. Organic materials or biomasses used were Cow dung, Chicken waste and Sawdust. Digester A$^1$ was charged with 100 g of cow dung and was diluted with 400 mL of water giving the ratio of 1: 4 and concentration of 20% as sample A$^1$. Digester A$^2$ was charged with 100g of cow dung and was diluted with 300 mL of water giving the ratio of 1:3 and concentration of 25% as sample A$^2$. Digester A$^3$ was charged with 100 g of cow dung and was diluted with 100 mL of water giving the ratio of 1:1 and concentration of 50% as sample A$^3$. Each of the three sub-digester was run in triplicate making a total of 9 digesters for batch A. The same procedure was repeated for digester B. Digester B$^1$ was charged with 100 g of Chicken waste and was diluted with 400 mL of water giving the ratio of 1:1 and concentration of 50% as sample A$^3$. Each of the three sub-digester was run in triplicate making a total of 9 digesters for batch A. The same procedure was repeated and 5g of yeast was added to the substrate as seeding for each of the sub-digester A, B and C making a total of 27 digesters for batch 2 experiments. The overall experiment comprised of 54 runs. The solution was thoroughly mixed to ensure the formation of homogenous mixtures. Each digester was connected via a rubber tube, to a 1000 cm$^3$ cylinder which was filled with water, inverted and immersed in a trough containing water. Anaerobic fermentation was carried out at an ambient temperature (30-36°C) for a period of twenty eight days. The effective volume of the reactor was maintained at 0.75 L. Biogas production from the reactors was monitored daily by water displacement method. The volume of water displaced from the digester was equivalent to the volume of gas generated. The reactor was mixed manually by means of shaking and swirling twice daily during the period of fermentation. This aids the discharge of the gas in the digester in to the cylinder and also prevents scum formation. The readings were taken every day at 12:00 pm.

**Design of Experiment**

Minitab16, statistical software was used for the design of experiment and simulation of the results. Design of experiment (DOE) is a well-accepted statistical technique able to design and optimize the experimental process that involves choosing the optimal experimental design and estimate the effect of the several variables independently and also the interactions simultaneously. In a full factorial experiment, responses are measured at all combinations of the experimental factor levels. Each combination of factor levels represents the conditions at which a response measure will be taken. Each experimental condition is called a "run" and each measures an observation. A factorial design of experiments was
applied to find out the effect of concentration, feed type, seeding and time on biogas production. The effect of selected factors was studied by means of a full factorial design. The levels of the factors were selected based on the result of preliminary experiments conducted in Table 1.

**Results and discussion**

Analysis of variance (ANOVA) was used for analysis of regression coefficient, prediction equations, factorial plots (main and interaction effects, surface plot, contour interaction, interval plot and residual plots) and case statistics. Regression first-order polynomial models were developed to describe the relationship between selected factors and the response (Y). The general form of mathematical model used is given in equation (1) (Sajeena et al., 2014).

\[
Y = \beta_0 + \beta_1X_1 + \beta_2X_2 + \beta_{12}X_1X_2
\]  

(1)

where: \( Y \) is the response, \( X_1 \) and \( X_2 \) are the independent variables, \( \beta_0 \) is the intercept of the model, \( \beta_1 \) and \( \beta_2 \) are the linear coefficients in the regression models and \( \beta_{12} \) is the interaction coefficient between factors.

**Table 1: Un coded Values of Independent Variables and Experimental Ranges**

<table>
<thead>
<tr>
<th>Factor</th>
<th>Name</th>
<th>Unit</th>
<th>Type</th>
<th>Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Concentration</td>
<td>%</td>
<td>Numeric</td>
<td>1</td>
</tr>
<tr>
<td>B</td>
<td>Feed type</td>
<td>Ndl</td>
<td>Test</td>
<td>20</td>
</tr>
<tr>
<td>C</td>
<td>Seeding</td>
<td>Ndl</td>
<td>Test</td>
<td>25</td>
</tr>
<tr>
<td>D</td>
<td>Time</td>
<td>Day</td>
<td>Numeric</td>
<td>50</td>
</tr>
</tbody>
</table>

**Table 2: Estimated regression coefficients for production rate**

<table>
<thead>
<tr>
<th>Term</th>
<th>Coef</th>
<th>SE Coef</th>
<th>t</th>
<th>p</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>700.167</td>
<td>74.0913</td>
<td>9.4091</td>
<td>0.000</td>
<td>Very significant</td>
</tr>
<tr>
<td>A</td>
<td>-11.584</td>
<td>1.2924</td>
<td>-9.1248</td>
<td>0.000</td>
<td>Significant</td>
</tr>
<tr>
<td>B1</td>
<td>-59.074</td>
<td>25.243</td>
<td>2.3412</td>
<td>0.0120</td>
<td>Significant</td>
</tr>
<tr>
<td>B2</td>
<td>483.335</td>
<td>25.243</td>
<td>19.1235</td>
<td>0.000</td>
<td>Very significant</td>
</tr>
<tr>
<td>C</td>
<td>299.784</td>
<td>16.4353</td>
<td>18.0318</td>
<td>0.000</td>
<td>Very significant</td>
</tr>
<tr>
<td>D</td>
<td>19.987</td>
<td>2.8756</td>
<td>6.9055</td>
<td>0.000</td>
<td>Very significant</td>
</tr>
</tbody>
</table>

Coef: Coefficient SE Coef: Standard Error of Coefficient t: Student’s t-test P: Probability

\[
S = 209.187, \text{PRESS} = 7339128, \text{R-Sq} = 86.29\% \quad \text{R-Sq(adj)} = 85.85\% \quad \text{R-Sq(pred)} = 85.26\%
\]

The regression coefficients, standard errors, \( t \)-test and \( P \)-values are shown in Table 2. The significance of the regression coefficients was determined by applying a student’s \( t \)-test. The \( P \)-values were used as a tool to check the significance of each of the effect among the variables. The term is very significant as the value of \( t \) is higher and the value of \( P \) is smaller (\( p < 0.05 \)) (Krishna Prasad and Srivastava, 2009).

According to this rule, term A and B1 were significant whereas term B2, C, and D were very significant.

For biogas generated with seeding:

Yield for cow dung (Y) = 700.167 + B1 + C + A + D

Y = 930.877 - 11.5842A + 19.9868D

Yield for chicken waste (Y) = 700.167 + B2 + C + A + D

Y = 1483.28 - 11.5842A + 19.9868D

Yield for sawdust (Y) = 700.167 - B1 - B2 + C + A + D

Y = 555.692 - 11.5842A + 19.9868D

For biogas generated without seeding:

Yield for cow dung (Y) = 700.167 + B1 - C + A + D

Y = 351.309 - 11.5842A + 19.9868D

Yield for chicken waste (Y) = 700.167 + B2 - C + A + D

Y = 903.717 - 11.5842A + 19.9868D

Yield for sawdust (Y) = 700.167 - B1 - B2 - C + A + D

Y = -23.8759 - 11.5842A + 19.9868D

From equation 2-13, a reduced model equation was developed for biogas production as follows:

\[
\text{Production} = K - 11.5842A + 19.9868D
\]  

(14)

The constant \( K \) for biogas production with seeding was 930.877 for cow dung, 1483.28 for chicken waste and 555.692 for sawdust respectively. While \( K \) for biogas production without seeding was 351.309
for cow dung, 903.717 for chicken waste and -23.8759 for sawdust respectively.

The R-sq (adj) of 85.85% explains that about 85.85% of the variable in the response could be captured and explained by the model. The Predicted Residual Sum of Squares (PRESS) is a measure of how well the model fitted each point in the design. The smaller the PRESS statistics, the better would be the model fitting the data points (Box et al., 2005). Here the value of PRESS found from the model summary as 7339128.

**Table 3:** Analysis of Variance for Y(mL) from full model(coded units)

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Seq SS</th>
<th>Sum of squares</th>
<th>Adj SS</th>
<th>Mean square</th>
<th>adj MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression</td>
<td>5</td>
<td>42976157</td>
<td>42976157</td>
<td>8595231</td>
<td>196.42</td>
<td>0.0000000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>1</td>
<td>3744023</td>
<td>3744023</td>
<td>3744023</td>
<td>85.559</td>
<td>0.0000000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>2</td>
<td>23514226</td>
<td>23514226</td>
<td>11757113</td>
<td>268.68</td>
<td>0.0000000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>1</td>
<td>13603908</td>
<td>13603908</td>
<td>13603908</td>
<td>310.880</td>
<td>0.0000000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>1</td>
<td>2114001</td>
<td>2114001</td>
<td>2114001</td>
<td>48.310</td>
<td>0.0000000</td>
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</tr>
<tr>
<td>Error</td>
<td>156</td>
<td>6826455</td>
<td>6826455</td>
<td>43759</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lack of Fit</td>
<td>48</td>
<td>6438222</td>
<td>6438222</td>
<td>134130</td>
<td>37.313</td>
<td>0.0000000</td>
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<tr>
<td>Pure Error</td>
<td>108</td>
<td>388235</td>
<td>388235</td>
<td>3595</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>161</td>
<td>49802612</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

DF= degree of freedom

The statistical significance of model equations was checked by an F-test (ANOVA). All the corresponding data are shown in Table 3. Moreover the model F value of 196.42 (Table 3) implies the model is highly significant ($p < 0.0001$). ANOVA results, presented in Table 3, showed that the term A, B, C and D have very significant effect ($p < 0.0001$) on the response Y (biogas yield). These findings are consistent with that of Sajeena et al., (2014) who studied the effect of three process variables; initial pH, substrate concentration and TOC on biogas production.

“Lack of Fit F-value” of 37.313 implies the Lack of Fit is very significant ($p<0.0001$) (ASA, 1983). There is only a 0.01% chance that a Lack of Fit F-value can occur. A large value for this can occur due to noise (Winer et al, 1991). For biogas production, the value of adjusted square correlation coefficient, R-Sq (adj) of 85.85% was also very high, which indicated the higher significance of the model. The R-Sq (pred) value of 85.26% showed the reasonable agreement with the "Adj R-Sq" value of 85.85%. This indicated a good agreement between the observed and the predicted values (Sajeena et al., 2014).

**Fig. 1:** Main effects plot for Y (Biogas yield)

The main effects plot is used to examine differences between level means for one or more factors. There is a main effect when different levels of a factor affect the response differently. A main effect plot graphs the response mean for each factor level connected by a line (Montgomery, 2004). From Figure 1, the mean response increase slightly with increase in concentration from 20% to 25%. Further increase in concentration decreases the mean response and this confirms the finding of Hilkhia-Igoni (2008) who showed that when the percentage total solids (PTS) concentration of municipal solid waste in an anaerobic continuous digestion process increases. There is a corresponding geometric increase for biogas produced and at some point in the increase of the TS, no further
rise in the volume of the biogas would be obtained. The feed type has the highest effect on the response (biogas yield). The mean response increases mostly with chicken waste followed by cow dung and saw dust (Seadi, et al., 2008). Seeding shows significant effect on the biogas yield as the mean response is higher with seeding (YES) and lower without seeding (NO). This result supports the idea raised by Singh et al. (2001) who reported that using microbial Stimulants could improve biogas production by 55%. As time increases from 14days to 28days, there is gradual increase in mean response. Retention time controls the types of microorganisms that can grow in the process and influences the degree of degradation as well as the gas yield to a great extent (Eder and Schulz, 2006; Grady et al., 1999). These plots show a clear difference in magnitude of the effect on the response among the factors: A, B, C and D. The factor B had the greatest effect on Y, followed by C, D and lastly A. The positive values of the effect show that the increase in the magnitude of parameter increases the response Y. Contrary; negative values reveal that the increase in the magnitude of parameter decreases the response Y (Adrian et al., 2013).

Interaction plot
An interaction plot is used to visualize possible interaction when the effect of one factor depends on the level of other factor. An interaction plot displays the levels of one variable on the X-axis and has a separate line for the means of each level of the other variable on the Y-axis. An interaction is effective when the change in the response from low to high levels of a factor is dependent on the level of second factor. Interaction effects represent the combined effects of factors on the dependent measure. When an interaction effect is present, the impact of one factor depends on the level of the other factor. When an interaction is significant, the slope of the two lines should be different and not necessary for the lines to cross or intersect each other within the range of the data. Parallel lines in an interaction plot indicate no interaction (Winer et al, 1991). From the Figure 2, Concentration and seeding shows significant interaction. The three lines of mean response of concentration for each level of seeding are not parallel. The three lines of concentration have more mean response for the level of seeding (YES) than without seeding (NO). Concentration and time show no interaction because the mean response for the three lines of concentration for each of the three levels of time is almost parallel. There is interaction between the two factors (feed type and seeding); this is because the lines of mean response of feed type are not parallel indicating that the slopes of the lines are different. There is more mean response of feed type for seeding (YES) than without seeding (Shalini sing et al., 2000). There is interaction between the field type and time because the three lines of mean response of feed type for each of the three levels of time are not parallel. The lines with seeding (YES and NO) show difference in mean response for each of the three levels of time. For this reason, there is interaction between seeding and time (Winer et al., 1991).

The Surface plot
The surface plot shows the relationship between three numerical variables. The 3D surface plot for biogas data shows how factor A and D affect the response Y. The surface plot of total biogas yield(Y) produced after 28 days of anaerobic digestion as a function of A and D is shown in Figure 3. The 3D surface plot shows that the maximum total biogas yield, Y (mL) value was found approximately at 25% concentration and at a retention time of 28 days. The minimum total biogas yield value was found at a concentration of 50% and a retention time of 14 days. This indicates that biogas yield increases with additional increase in concentration (Hilkiah, 2008). Further increase in concentration decreases biogas yield. This also shows that increases in retention time increases biogas yield (Eder and Schulz, 2006; Grady et al., 1999).

Contour plot
Contour plot is a graphical representation of the relationships among the three numerical variables in two dimensions. Generally, there are two predictors and one response variable. Contour plots are useful for establishing desirable response values and operating conditions. From Fig. 4, the 3D contour plot shows that the highest total biogas values (1500-2000mL) were found at a concentration of 25% and retention time of 28 days. The lowest total biogas value (0-500mL) was found at a concentration of 50% and a retention time of 14 days. This plot confirms the surface plot of Y in the Fig. 3 that biogas yield increases with additional increases in concentration (Hilkiah-Igoni, 2008). Further increases in concentration decreases biogas yield. This also shows that increases in retention time increases biogas yield (Eder and Schulz, 2006; Grady et al., 1999).

Interval plot
Interval plot is a graphical summary of the distribution of a sample that shows the sample’s central tendency and variability. The mean value is represented by a circle and the interval is represented by a vertical line with horizontal lines at the upper and lower limits. Interval plots are used to display the sample mean along with a range of likely values for the population mean. Interval plots are especially useful
for comparing groups (Montgomery, 2004).

From the Figure 5, the interval plot shows that at 20% concentration and seeding (yes), chicken waste shows the highest biogas yield with an estimated mean values of 1973.33 and 95% confidence interval (1861.32, 2085.35) at time of 21 and 28 days followed by cow dung at 95% confidence interval (918.709, 1117.96) having an estimated mean values of 1018.33. Saw dust shows the least biogas yield at 95% confidence interval (607.739, 1142.26) and mean estimate of 875.

At 25% concentration and seeding (yes), cow dung shows higher biogas yield at 95% confidence interval (1345.57, 1924.43) and mean estimate value of 1635 at time of 28 days followed by chicken waste at 95% confidence interval (1402.44, 1554.22) and an estimated mean value of 1478.33 at time of 21 and 28 days respectively. Saw dust is the least biogas yield at 95% confidence interval (677.697, 888.970) and an estimate mean value of 783.333.

At 50% concentration and seeding (Yes), chicken waste shows high biogas yield at 95% confidence interval (1110.83, 1675.84) and mean estimate value of 1393.33 at time of 28 days followed by cow dung at 95% confidence interval (640.632, 806.034) and an estimated mean value of 723.333 at time of 28 days. Saw dust is the least biogas yield at 95% confidence interval (361.469, 461.864) and mean estimate value of 411.667.

**Residuals**

Residuals are the difference between the observed values and predicted or fitted values. This part of the observation is not explained by the fitted model.

A residual plot is a graph that shows the residuals on the vertical axis and independent variable on the horizontal axis. If the points in a residual plot are randomly dispersed around the horizontal axis, a linear regression is appropriate for the data. Random patterns indicating a good fit for a linear model.

The normal probability plot is a graphical technique for assessing whether or not a data set is approximately normally distributed. The data are plotted against theoretical normal distribution in such a way that the points approximately on straight line. Departures from this straight line indicate departures from normality for the biogas yield data in Fig. 4. Residuals appear to roughly follow a straight line indicating it is normal. This shows no evidence of non normality, outliers, or unidentified variable exists. This result verified the null hypothesis that residuals are normally distributed on a straight line (Feigelson and Babu, 1992).

A histogram is a graphical representation of the distribution of numerical data. It is an estimate of the probability distribution of a continuous variable (quantitative variable). Histogram gives a rough sense of the density of the data. For the biogas yield data, the histogram has a bell shape indicating that the residuals are normal. Because of the appearance of the histogram can change depending on the number of intervals used to group the data, the normal probability plot is used to assess whether the residuals are normal. The normal probability plot in Figure 6 confirmed that the residuals are normal (Feigelson and Babu, 1992).
Residual versus fits plot is a scatter plot with residual on the y axis and fit on the x axis. It is used to verify the assumption or the null hypothesis that the residual have a constant variance. For the biogas data in Figure 6, the errors are randomly scattered about zero. This shows that the residuals are fitted and unbiased. There is evidence of constant variance and no missing terms, outlier or influential points exist. This finding agrees with the null hypothesis that residuals have a constant variance (Minitab User Guide 2, 2000).

Residuals versus order are a scatter plot with residual on the y axis and the order in which the data were collected on the x axis. It is used to verify the assumption that the residual are uncorrelated with each other. It is a way of detecting a particular form of non independence of the error terms, namely serial correlation. It helps to see if there is any correlation between the error terms that are near each other in the sequence. From the residual plot in Figure 6, the residuals appear to be randomly scattered about zero. No evidence exist that the error terms are correlated with one another. Each error is independent of all other errors (Feigelson and Babu, 1992).

Conclusion
The present study focuses on the modelling and optimization of the process parameters such as concentration, feed type, seeding and time for the maximal biogas production. Optimization of those factors was carried out by full factorial design methodology. The factor concentration, feed type, seeding and time had significant individual effects on biogas yield. The interactive effect for all of these factors were found to be significant (p < 0.05) except concentration and time which was insignificant (p > 0.05). The optimum conditions for maximizing the biogas yield were a substrate concentration of 20% and time of 28 days in which maximum biogas yield of 1811.23mL was obtained. The reduced model equations developed for biogas production with seeding is Y = K - 11.5842A + 19.9868D. Where K = 930.877 for cow dung, 1483.28 for chicken waste and 555.692 for sawdust. The maximum generation of biogas found experimentally using the optimized condition is 1973.33mL, which is in correlation with the predicted values 1811.23mL. It can be concluded that the factorial design analysis was a useful technique to optimize the biogas yield from the agricultural waste through anaerobic digestion.

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Kinetic Modeling of Rice Husk Components Pyrolysis Based on Independent Parallel Reactions

Garba, M. U¹, Charise¹, S. G., Bilyaminu, I¹, Alhassan, M¹, Musa U¹, Isah, A. G
¹Chemical Engineering Department Federal University of Technology, P. M. B. 65, Minna, Niger State, Nigeria
Email: umar.garba@futminna.edu.ng

Abstract
This study presents the pyrolysis decomposition mechanism of rice husk in nitrogen atmosphere by thermogravimetric analysis (TGA). The thermal decomposition was carried out in three stages: moisture removal (180-200 °C), main devolatilization (200-400 °C) and continuous slight devolatilization (400 °C). The weight loss of rice husk was modeled based on the assumption that lignocellulose components (cellulose, hemicellulose and lignin) undergo pyrolysis independently in parallel first-order reactions. The kinetic parameters of the three lignocellulose components were determined by means of Microsoft Excel Solver tool using least square algorithm. The result of thermal degradation of rice husk samples shows that the model predictions of the cellulose, hemicellulose and lignin components agreed with the experiments. The activation energy and pre-exponential factors of cellulose, hemicellulose and lignin are 187kJ/mol and $1.2 \times 10^{15}$ min$^{-1}$, 29kJ/mol and $1.6 \times 10^{7}$ min$^{-1}$and 90 kJ/mol and 1.8 $\times 10^{1}$ min$^{-1}$ respectively. The results suggest that thermal decomposition rate of cellulose was found to be higher, whereas that of lignin decomposition rate was lower. The thermal decomposition of hemicellulose decomposition was intermediate.

Keywords: Rice husk, pyrolysis, thermogravimetric analysis, lignocellulose, kinetic model.

Introduction
The depletion of fossil fuel reserves and its associate environmental problems are the major reasons for the shift and focus on sustainable energy resources. Biomass is extensively used as an alternative renewable energy source which is in abundance and in most cases considered to be a waste. It is the world fourth energy resource after oil, natural gas and coal (Vamvuka et al., 2003). Lignocellulose materials are unlike carbohydrate which belong to food that cannot be digested. The use of lignocellulose biomass as a source of chemical, transportation and energy fuels has been growing at a very rapid rate because lignocellulose biomass does not compete with the food supply chain (Basu, 2006).

Nigeria like many other African countries is blessed with abundant biomass because of its huge agricultural resources and this sector has been reported to provide employment to over 60% of the population. Agricultural activities generate huge waste providing a large potential source of lignocellulosic materials. Among the various lignocellulose species, rice husk has potential for chemical energy. Rice husk is used as a source of energy in rice mill, cooking, furnace and boiler (Garba et al., 2006). In Nigeria, about 664,000 tonnes of rice husk is derived from about 3.32 million tons of paddy rice per year (Rainer). Conversion of lignocellulosic material to efficient fuel remains a burden due to their structural complexity which is responsible for the challenges in separating lignocellulose components.
Thermochemical conversion processes such as pyrolysis, combustion, gasification and liquefaction are considered as the alternative means of converting lignocellulose biomass to efficient fuel. However, pyrolysis remains the focal point in all thermochemical conversion processes as in the case of combustion process in which the first step is pyrolysis followed by the reaction of pyrolysis residue with oxygen. The pyrolysis process is the thermal decomposition of biomass in the presence of inert atmosphere to form liquid (bio oil), char (charcoal) and gas. Lignocellulose biomass is composed of hemicellulose, cellulose and lignin (Garba et al., 2012). Experimental results have shown that pyrolysis of organic matter is a complex process involving parallel and series reactions (Garba et al., 2013). The decomposition of biomass has been described by three-component independent reaction, each corresponding to the decomposition of the hemicellulose, cellulose and lignin. The weight loss kinetic model developed for biomass is of two types. The single component overall model (SOM), which considered the biomass as being composed of a single component and uses its char–volatile reaction to describe the weight loss kinetics(Rogers et al., 1980; Cordero et al., 1989; Cordero et al., 1990). The second one is the multi-component overall model (MOM) considering biomass as being composed of hemicellulose, cellulose and lignin (Orfao et al., 1999; Font et al., 19991). In this case, the components are modeled separately and the biomass decomposition is the summation of all the three components. Generally, the weight loss kinetics change as the temperature increases and the weight loss is controlled mainly by cellulose, hemicellulose and lignin. Since the weight loss depends on cellulose, hemicellulose and lignin component, SOM cannot account for the possible change in weight loss kinetics. Contrary, MOM can reveal possible change in weight loss kinetics. Koufopanos et al. (1989) developed a modeling approach which described the overall rate of decomposition as a sum of the corresponding rates of the hemicellulose, cellulose and lignin using nonlinear regression method. In a related work, Rao et al. (1998) developed a kinetic model in which the pyrolysis of lignocellulose components is described by single reaction first order kinetics. In recent years MOM has been used successfully to describe the weight loss processes of bagasse (Liangfeng et al., 2001), jatropha residue (Rajeev et al., 2016), switch grass (Vamvuka et al., 2011) and wood pine and cotton stalk (Wang et al., 2012). The result of almost all the previous studies have shown good agreement between experimental and calculated weight loss pattern. The understanding of biomass pyrolysis is essential for accurate prediction of pyrolysis rates require for optimum design of pyrolyzer. In order to optimize process variable and obtain quality pyrolysis products, there is the need for more profound knowledge of pyrolysis kinetics. In the present work, the pyrolysis of rice husk components is analysed and pyrolysis process is described by independent parallel reactions of first order using nonlinear square methods. The design of equipment for the conversion of biomass through thermochemical processes requires knowledge of pyrolysis kinetic and modeling. Many literatures reported the kinetic investigation however; little
knowledge is available on the modeling aspect. Thermogravimetric curves was used to analysis biomass decomposition, the pyrolysis kinetic model of rice husk based on three-component independent parallel first-order reactions was established by non-linear least squares algorithm. The kinetic parameters obtained for rice components were compared with each other and meaningful results achieved were discussed.

**Methodology**

*Proximate and ultimate analysis*

The rice husk used in this experiment was collected from Minna, Niger State. The experiments were divided into two steps; the first step was to study the pyrolysis characteristics of rice husk by using proximate, ultimate analysis and thermal decomposition. The second step was to study the pyrolysis kinetics of rice husk. The proximate analysis of the rice husk sample was carried out according to ASTM D3172 method and ultimate analysis was done according to ASTM D3176. The thermal degradation was carried out by with the aid of thermogravimetric analysis (TGA). The sample of a ground rice husk was obtained by grinding the rice husk to an average particle size of less than 150 µm. 20 mg of the rice husk sample was used in the experiment. The weight loss of the sample as a function of temperature was measured.

*Kinetic modeling of rice husk pyrolysis*

The approach by most of these kinetic models simulate the chemical reactions that take place during pyrolysis and the chemical reaction scheme is presented in equation (1).

\[ \text{Biomass} \rightarrow \text{volatile} + \text{char} + \text{gas} \quad (1) \]

The kinetic modeling was performed on the pyrolysis profile provided by TGA. The total mass measured by TGA were assumed to be summation of the pyrolyzable materials such as cellulose, hemicelluloses, lignin, charcoal, and ash (Liangfeng et al., 2011).

\[ m = m_p + m_c + m_a \]

where \( m \) is the total mass of biomass by TGA, \( m_p \) is the mass of pyrolyzable (cellulose, hemicelluloses, lignin components) organic materials, \( m_c \) is the mass of produced char, and \( m_a \) is the ash mass.

Assuming the ash is ignored, the mass of biomass is a sum of the pyrolyzable organic chemical and the produced charcoal (Liangfeng et al., 2011):

\[ m_i = m_{ip} + m_{ac} \text{ for } i=1,2,3 \quad (2) \]

the pyrolyzable organic chemicals are mainly cellulose, hemicelluloses, lignin components.

During the pyrolysis process, the degree of conversion and conversion rate for each component in biomass sample are defined as follows:

\[ \alpha_i = \frac{m_{io} - m_{ip}}{m_{ip}} \text{ for } i=1,2,3 \quad (3) \]

Where \( m_{io} \) is the initial weight of biomass and \( \alpha_i \) is the conversion of each lignocellulose components.

For the three lignocellulose components, the overall conversion rate for each reaction can be expressed as

\[ \frac{dm}{dt} = \sum_{i=1}^{3} c_i \frac{d\alpha_i}{dt} \quad (4) \]

Where \( c_1 \), \( c_2 \) and \( c_3 \) are the partial contributions of the overall weight loss; \( c_i \) is defined as

\[ c_i = m_{io} - m_{ichar} \quad (5) \]
The lignicellulose components are presumed to decompose by obeying first-order reaction according to

$$\frac{d\alpha}{dt} = k_{io}e^{-E_i/RT} (1 - \alpha_i)$$  \hspace{1cm} (6)

where $E_i$, $k_{io}$, $T$ and $R$ are the activation energy (kJ/mol), frequency factor (min$^{-1}$), temperature (K) and respectively.

The nonlinear least square algorithm has been used to identify the kinetic parameters that show the lowest values of the objective function (O.F):

$$O.F = \sum [(\frac{dm}{dt})_{exp} - (\frac{dm}{dt})_{sim}]^2$$  \hspace{1cm} (7)

$(\frac{dm}{dt})_{exp}$ is the experiment DTG curve rate of rice husk and $(\frac{dm}{dt})_{sim}$ is the simulated DTG curve rate of rice husk.

**Kinetic constants from modeling**

Equation 4 shows the thermal decomposition rates of the rice husk components during the heating process was a function of temperature and degree of conversion. Equation (5) is a nonlinear ordinary first-order differential equation. The degree of conversion is the dependent variable and absolute temperature is the independent variable. Two kinetic constants for each component, pre-exponential factor $k_{io}$ and activation energy $E_i$, are assumed to be independent of the degree of conversion. The numerical solution could be obtained by solving Equation (6) for the known values of $k_{io}$ and $E_i$ respectively. These constants are determined from the least-square method implemented by the Microsoft Excel Solver tool where the difference between experimental and calculated weight loss were minimized.

**Results and Discussion**

**Characterization of fuel**

The proximate and ultimate analysis results are presented in Table 1. The result show that the rice husk was characterized by high volatiles content of about 66% which makes them desirable for a good regulation of gasification processes. The high percentage of ash in rice husk indicates potential slag or foul formation during combustion. However, the content of sulfur is very low, which means that there will be fewer emissions or corrosion when utilization for power generation (Koufopanos et al., 1989; Rao et al., 1998).

**Table 1. Ultimate and proximate analysis of rice husk**

<table>
<thead>
<tr>
<th>Proximate analysis (wt.%)</th>
<th>Ultimate analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture</td>
<td>C</td>
</tr>
<tr>
<td>3.81</td>
<td>43.83</td>
</tr>
<tr>
<td>Fixed carbon (FC$^a$)</td>
<td>22.01</td>
</tr>
<tr>
<td>Ash</td>
<td>8.18</td>
</tr>
</tbody>
</table>

**Thermal decomposition characteristic**

The thermogram and derivative thermogram (TG/DTG) curves in Fig. 1 were obtained for the pyrolysis of the rice husk at a heating rate of 10 °C/min. The TG/DTG curves represent the weight loss of the tested biomass with respect to temperature. The curves are generally divided into three different stages regardless of what biomass sample is tested. The first stage is drying and release of some light volatiles resulting into slight weight loss at temperature below 200 °C as shown in the TG curve. The second stage is the thermal decomposition of hemicellulose, cellulose and lignin where a significant weight loss was observed at a temperature between 200 and 400 °C. In the third stage, the weight loss occurs...
slowly over wide range of temperature higher than 500 °C mainly due to thermal decomposition of heavy components. In the previous studies (Liangfeng et al., 2011; Vamvuka et al., 2011; Wang et al., 2012), DTG has been reported to qualitatively identifies the components of lignocellulose structures. Generally, hemicellulose decomposition occurs at temperatures between 150 and 350 °C; cellulose decomposition occurs at the temperatures range of 275-350 °C, and lignin is decomposed slowly over a wider temperature range of 250-500 °C (Vamvuka et al., 2011; Wang et al., 2012). The distribution of lignocellulose components in the DTG curve of rice husk is presented in Fig. 1. The DTG curve of rice husk exhibited only one peak. The main peak at temperature of 316 °C stems from cellulose decomposition and its shoulder peak in the DTG curve (which is almost merged to cellulose) is due to hemicellulose decomposition. The curve after the main peak (cellulose) is the decomposition of lignin whose intensity is smaller than that of the hemicellulose and cellulose peaks. It is important to note that one small peaks induced between the temperatures of 800°C and 850°C are due to the fact that rice husk includes another important component which is reactive at a higher temperature. In addition, from DTG curve in Fig. 1 it can be observed that two bumps developed at the temperature between 70 °C and 150°C as a results of moisture removed from the rice husk.

Fig. 1: TG/DTG curves of rice husk at heating rate of 10 °C /min showing the three lignocellulose components.

**Kinetics analysis**

Figure 2 and 3 shows TG and DTG curve of the modeling for the rice husk. Figure 2 shows that the model simulation gives good prediction compared to the experimental data for the TG curve of rice husk sample. The model simulation of the DTG curve (Fig. 3) also shows good prediction compared to the experimental data. Fig. 4 shows the individual contribution of each lignocellulose to the total decomposition rate. With regard to each lignocellulose biomass component, hemicellulose proved to be least stable lignocellulose component and it decomposes first and fast at low temperature. Lignin is more stable lignocellulose component and decomposition takes place over wider temperature range. Finally, the cellulose decomposition started last and that is the reason why kinetic value has high values (Table 2). Among the lignocellulose component, cellulose shows the maximum total decomposition. Generally, the differences between the thermal behaviours of the lignocellulose components are attributed to their different in the intrinsic chemical structures. Hemicellulose is least thermally stable
component due to its amorphous nature and cellulose is the next thermally stable than hemicellulose due its strong intra-molecular bonds. Finally, Lignin is more thermally stable than the other two lignocellulose components and the reason for this is that it has strong cross-linked polymer (Pasangulapati et al., 2012; Xiong et al., 2015). The thermal behavior of each lignocellulose components agreed with other works in the literature (Jeguirim et al., 2001; Vamvuka et al., 2003).

![Fig. 2. Comparison of experimental and simulated TG pyrolysis profile of rice husk.](image)

![Fig. 3. Comparison of experimental and simulated DTG pyrolysis profile of rice husk.](image)

Kinetic parameters are illustrated in Table 2. In the cellulose decomposition, kinetic constants appeared to have higher values than hemicellulose and lignin. Activation energy is the minimum energy required for each decomposition starts. Subsequently, the higher its value is, the higher is the temperature for the initiation of each decomposition. Cellulose requires more energy compared to the other lignocellulose components because of its strong intra-molecular bonds, which prevent its decomposition in lower temperatures (Xiong et al., 2015). Pre-exponential factor is another important kinetic constant indicates indicate molecular collisions that lead to chemical reaction. A higher value of the pre-exponential factor, the more the molecular collisions that can lead to decomposition.

Lignin shows lowest values of activation energy and pre-exponential factor in Table 2. This fact could be observed from the DTG curves (Fig. 4), where the decomposition is seen to have started at lower temperatures and its decomposition rate was lower, compared to that of the other decomposition reactions. In term of thermal stability, lignin is the most stable component, therefore it is not easily decomposed. The observation made herein have been confirmed by previous studies (Xiong et al., 2015; Jeguirim et al., 2009).
The calculated pyrolysis kinetic parameters of rice husk are presented in Tables 2. The activation energy of cellulose decomposition is higher (187 kJ/mol), whereas that of lignin decomposition lower (29 kJ/mol). The activation energy of hemicellulose decomposition is intermediate (90 kJ/mol). The pre-exponential factors of cellulose, hemicellulose and lignin are in the ranges of $1.2 \times 10^{15}$, $1.6 \times 10^{7}$, $1.8 \times 10^{1}$ min$^{-1}$, respectively.

**Table 2. Content of lignocellulose and the kinetic parameters of the pyrolysis process.**

<table>
<thead>
<tr>
<th>Component</th>
<th>C(%)</th>
<th>A(min)</th>
<th>E (kJ/mol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hemicellulose</td>
<td>26.9</td>
<td>$1.6 \times 10^{7}$</td>
<td>90</td>
</tr>
<tr>
<td>Cellulose</td>
<td>48.9</td>
<td>$1.2 \times 10^{15}$</td>
<td>187</td>
</tr>
<tr>
<td>Lignin</td>
<td>24.2</td>
<td>$1.8 \times 10^{1}$</td>
<td>29</td>
</tr>
</tbody>
</table>

**Conclusions**

In this study, the thermal decomposition and pyrolysis kinetics were studied. The thermal decomposition shows that rice husk was divided into moisture removal, main devolatilization and continuous slight devolatilization stages. The mass loss process of rice husk was modeled by assuming cellulose, hemicellulose and lignin undergo pyrolysis independently and in parallel first-order reactions. The kinetic parameters of the three components were determined by means of Microsoft Excel Solver tool using least square algorithm. The simulation rate of thermal decomposition is very close to the experimental data.

**References**


Estimation of Sedimentary Thickness of Maiduguri, Northeastern Nigeria, from Fourier Analysis of Aeromagnetic Data

Nwankwo L.I. 1, Sunday A.J. 2, Lawal T.O. 3, Ige S.O. 3 and Shehu A.T. 4

1Department of Geophysics, University of Ilorin, Ilorin, Nigeria.
2Physics Unit, Department of Science Laboratory Technology, Kwara State Polytechnic, Ilorin, Nigeria.
3Department of Physics, University of Ilorin, Ilorin, Nigeria.
4Physics Unit, Centre for Preliminary and Extra-Mural Studies, Federal University of Technology, Minna, Nigeria.

Abstract
A quantitative interpretation of the aeromagnetic anomalies of Maiduguri (sheet 90) in the north-eastern region of Nigeria has been carried out using Fourier transform method. The study area covers approximately 3,025 square kilometres and forms part of Chad Basin. Regional anomalies were removed from the total magnetic field using 2D least square method and the resulting residual data were used to obtain Fourier spectra of 20 selected profiles. Slopes of high and low frequency portions of each spectrum were utilised to estimate depths to shallow and deeper magnetic sources. The results show that the depths to shallow and deeper magnetic sources vary from 0.20 to 0.84 km with an average of 0.42 km and from 0.85 to 3.27 km with an average of 1.59 km respectively. Depths to deeper magnetic sources are normally inferred as sedimentary thicknesses; therefore the results indicate that the estimated thickness of sedimentary fill in Maiduguri area of Chad basin ranges between 0.85 and 3.27 km.

Keywords: Aeromagnetic, Spectral, Residual, Sedimentary, Maiduguri

Introduction
Airborne geophysical surveying is the process of measuring the regional variation of different physical or geochemical parameters of the earth hidden from direct view such as distribution of magnetic minerals, density, electric conductivity, and radioactive element concentration. The methods used in such measurements are magnetic, gravity, electromagnetic and gamma-ray spectrometry respectively (Mekonnen, 2004).

Aeromagnetic survey measures the variation of the geomagnetic field, which occurs due to the changes in the percentage of magnetite in the underlying rock of an area. It reflects the variations in the distribution and type of magnetic minerals below the earth surface. Magnetic minerals can be mapped from the surface to greater depth in the rock crust depending on their dimension, shape and the magnetic property of the rock. Sedimentary formations are usually non-magnetic and consequently have little effect whereas igneous and metamorphic rocks exhibit greater variation and become useful in exploring bedrock geology concealed below cover formations (Mekonnen, 2004). Variation in magnetic susceptibility combined with other geophysical data and known geology provide important information about the regional geology especially where rock outcrops are scarce or absent and also helps to develop priorities for follow-up in the most prospective areas. For example, mafic dykes usually give rise to magnetic anomalies that are prominent on the aeromagnetic anomaly maps that now
approach universal coverage for the land areas of the world (Dobrin, 1960; Dobrin and Savit, 1988). In regional mapping, mafic dykes give rise to well-defined topographic features and with respect to granitic and most sedimentary host rocks are dark coloured, covered by denser vegetation and more magnetic. Therefore, they could be easily traced from satellite imagery, aerial photographs and aeromagnetic maps (Chavez, 2000). Aeromagnetic data allow fast coverage of large and inaccessible areas for subsurface reconnaissance, which makes magnetic data analysis an essential tool of geophysical exploration (Hinze, 1990; Kasidi and Ndatuwong, 2008). In general, magnetic surveying is used in many different studies targeting all kinds of objects from kimberlite pipes to unexploded military ordnances (Lowrie, 2007; Milsom, 2003; Telford et al, 1990). Magnetic anomaly studies in Nigeria have mainly been interpreting large scale subsurface structures with high magnetic susceptibility such as volcanic intrusions. As long wavelength anomalies are caused by igneous, iron-rich rocks, they can well be resolved and interpreted in magnetic surveys. Numerous magnetic anomaly interpretations have used this characteristic for location and depth estimation of these mostly intrusive bodies. Another achievement of magnetic anomaly studies is the conformation of the theory of geomagnetic polarity reversals and ocean spreading. The observed lineation of magnetic anomalies parallel to ocean spreading zones is caused by the remanent magnetization of oceanic crust. On the other hand, high resolution magnetic surveys are also applicable for short wavelength analysis, which can reveal fault structures in the sediments, though they have a significantly lower susceptibility than basement rocks. In this work, the application of Fourier transform of aeromagnetic anomalies has been used to determine the sedimentary thickness of Maiduguri area of Chad basin, Nigeria.

**Location and Geology**

Maiduguri is situated within the Nigerian sector of Chad basin (Fig. 1). The entire Chad Basin is the largest inland basin in Africa occupying an area of approximately 2,500,000 km² extending over parts of the republic of Niger, Chad, Sudan and the northern portions of Cameroon and Nigeria within latitudes 10°N to 14°N and longitudes 12°E to 15°E. (Nwankwo and Ekine, 2009). The Nigerian sector of the basin constitutes only about 6.5% of the entire basin and extends 152,000 km² of territory in Bornu, Bauchi, Plateau and Kano States. The altitude of the basin ranges from 300 m within the lake to about 530 m at the western margin, along a distance of about 240 km. The Chad basin is an intra-continental rifted basin. It is believed to be genetically related to the Benue trough, which resulted from a failed arm of a triple junction when South American continent separated from the African continent in Early Cretaceous. These two basins are however, separated by the Zambuk Ridge (Burke, 1969; Genik, 1992).
Estimation of Sedimentary Thickness of Maiduguri, Northeastern Nigeria, from Fourier Analysis of Aeromagnetic Data

Fig. 1. Geological Sketch of Nigeria showing the study area (After Nwankwo and Shehu, 2015).

Cratchley (1960) delineated the Nigerian sector of Chad basin into three sub-basins prosperous for hydrocarbons explorations. These sub-basins are centred around Gubio to the southwest, Maiduguri to the South and Lake Chad to the North. Since the late 1970s, the Nigerian sector of Chad basin has been an area of interest in terms of hydrocarbon exploration mainly by the Nigerian National Petroleum Corporation (NNPC). Early exploration works were by Shell-D Arcy in 1938; and later Mobil Exploration Nigeria Limited in 1955. At about 1965, all the oil prospecting companies limited their activities to the Southern Nigeria sedimentary basins, especially the Niger Delta, due to non-discovery of oil in the basin (Okpikoro and Olorunniwo, 2010). However, efforts are been made presently by the NNPC to resume petroleum exploration in Chad basin.

Materials and Methods
Airborne magnetic survey contour map 55 x55 km² of total magnetic field intensity published by the Nigerian Geological Survey Agency (NGSA) on a scale of 1:100,000 was used as the basic data for determining the nature of magnetic anomalies over the area. The survey was carried out in the 1970s along a series of North-South lines with flight spacing of 2 km and an average elevation of 152m above the ground level.

Since one common problem in automated data interpretation is to select digitization spacing and minimum length of data profile in order to minimize aliasing error, selecting a digitization interval of 0.875km is found to solve the problem in this study (Nwankwo et al., 2011). Therefore, the map was carefully digitized using semi-automated method through the following process: the map was scanned, geo-referenced using raster design (AutoCAD) and finally gridded using AutoCAD software at an equal spacing interval of 0.875km to produce a 64x64 data matrix yielding 4,096 data values for the study area. Although hand digitization is the most elementary and least efficient method of digitization, the use of AutoCAD software in gridding the map, made the digitization easier and more efficient. The re-contoured magnetic map drawn with MATLAB software is shown in Figure 2.

Fig. 2: Re-contoured aeromagnetic of the study area. (\( \frac{1}{2} \) x \( \frac{1}{2} \)) degree.

Regional fields were then subtracted from the digitised data yielding residual anomaly (Figure 3), which was implemented using a code developed in
MATLAB for least square polynomial fit for potential field data (Nwankwo, 2006). Then, one dimensional Fourier amplitude spectrum of selected 20 residual anomaly profiles (north–south trend) was implemented, with a Low Hanning pass filter incorporated to smoothen the residual profile data.

The analysis is commonly applied in geophysical studies using Discrete Fourier Transforms (Spector and Grant, 1970; Hahn, 1976; Murthy and Mishra, 1980):

\[ f(n) = F(n)e^{j\phi(n)} \frac{1}{N} \sum_{u=1}^{N} f(u)e^{-j\frac{2\pi nu}{N}} \] (5)

where the given time series are \( f(1), f(2), ..., f(N) \) for \( N \) data points, at equal spacing.

In magnetic analysis, it is useful to have proposed models, such as sphere, cylinders, fault, etc. which cause the anomaly at the surface. For this reason, the total magnetic field anomaly \( \Delta T \), measured in the direction of geomagnetic field is given by (Spector and Grant, 1970; Hahn, 1976; Murthy and Mishra, 1980):

\[
\Delta T = \frac{1}{2} A \ln \left[ \frac{(x - t \cos d) + (h + t)}{x'^{2} + h'^{2}} \right] + B \ln \left[ \frac{\sqrt{(x - t \cos d)} - \tan \frac{\tan i \lambda}{h}}{x'^{2} + h'^{2}} \right] \] (6)

where

\[ A = 2kH_o(1 - \cos^2 i \cos^2 h \lambda) \sin d \cos(d - 2\beta) \] and

\[ B = 2kH_o(1 - \cos^2 i \cos^2 h \lambda) \sin d \cos(d - 2\beta) \] , \( I = \) magnetic inclination, \( d = \) dip of the step, \( t = \) thickness of the step, \( k = \) susceptibility constant, \( H_o = \) geomagnetic field and the angle \( I \) and \( h \) are combined into a single variable defined by \( \tan \beta = \tan i / \sin \lambda \).

The Fourier transform and modified transform of equation (8) is given respectively as:

\[
\Delta T(\omega) = \frac{\pi}{\omega} e^{-\lambda \omega} [(A - A \cos(t \cot d) e^{-t \omega} - B \sin(t \cot d) e^{-t \omega} - j \cos(t \cot d) e^{-t \omega} - j \sin(t \cot d) e^{-t \omega} - B] (7)
\]

\[
\Delta T(\omega) = \pi e^{-\lambda \omega} [A - A \cos(t \cot d) e^{-t \omega} - B \sin(t \cot d) e^{-t \omega} + j \cos(t \cot d) e^{-t \omega} - j \sin(t \cot d) e^{-t \omega} - B] (8)
\]

**Theoretical Considerations**

Fourier analysis is utilized in this work. Fourier theorem explains that a function \( f(t) \) having a fundamental period and satisfying Dirichlet’s condition can be represented by the following infinite Fourier series:

\[ f(t) = a_o + \sum_{n=1}^{\infty} (a_n \cos n\omega t + b_n \sin n\omega t) \] (1)

\[ a_o = \frac{1}{2\pi} \int_{-\pi}^{\pi} f(t) \, dt \] (2)

\[ a_n = \frac{1}{\pi} \int_{-\pi}^{\pi} f(t) \cos n\omega t \, dt \] (3)

\[ b_n = \frac{1}{\pi} \int_{-\pi}^{\pi} f(t) \sin n\omega t \, dt \] (4)

where \( a_o, a_n \) and \( b_n \) are Fourier coefficients and their estimations is referred to as Fourier analysis. \( n = 0, 1, 2, 3, ... \)
Estimation of Sedimentary Thickness of Maiduguri, Northeastern Nigeria, from Fourier Analysis of Aeromagnetic Data

The modified Amplitude Spectrum is consequently given by

\[ A(\omega) = Ce^{-\omega^2}(1 + e^{-2\omega t} - 2 \cos(\omega t) \cos(d) e^{-\omega^2})^{\frac{1}{2}} \] (9)

where \( C = 2\pi KH_o(1 - \cos^2 i \cos^2 \lambda) \sin d \)

Taking the logarithm of equation (9):

\[ \ln A(\omega) = \ln C - m\omega + \frac{1}{2}\ln[1 + e^{-2\omega t} - 2 \cos(\omega t) \cos(d) e^{-\omega^2}] \] (10)

For sufficiently larger value of \( \omega \), equation (10) reduces to:

\[ \ln A(\omega) = \ln C - m\omega \] (11)

where \( \ln A(\omega) \) is modified amplitude and \( \omega \) is frequency (cycle/km).

The depth \( h \) to the causative bodies can subsequently be calculated using the relation (Spector and Grant, 1970):

\[ h = -\frac{m}{4\pi} \] (12)

In this work, the graph of \( \ln A(\omega) \) against frequency \( (\omega) \) was plotted and the gradient \( (m_1) \) for the deeper source and gradient \( (m_2) \) for shallow source were deduced. The depths \( h_1 \) and \( h_2 \) are therefore given by the respective slopes of straight line segments of low and high frequency portions (Spector and Grant, 1970; Hahn, 1976; Murthy and Mishra, 1980):

\[ h_1 = \frac{m_1}{4\pi} \text{ and } h_2 = \frac{m_2}{4\pi} \] (13)

Results and Discussions

Spectral plots of the analysed profiles are shown in Figure 4, while the ensuing quantitative results are shown in Table 1. The table shows that the deeper magnetic sources vary from 0.85 to 3.27 km with an average of 1.59 km, while the shallow sources vary from 0.2 to 0.84 km with an average of 0.43 km. This is found to be fairly consistent with previous results revealing that the depth to deeper magnetic sources in the Maiduguri area of Chad basin ranges between 0.5 and 3 km (Okonkwo et al., 2012) and from 1.5 to 4 km (Lawal et al., 2015). The estimated depth to shallow magnetic sources obtained in this study is also fairly consistent 0.1 – 0.46 km reported by Lawa et al., (2015). Table 1 further show that, while considering the deeper magnetic sources, the central part of the study area is statistically the deepest while both the western and eastern parts are the lowest as elucidated in Fig. 5.
Fig. 4: Amplitude spectrum of selected profiles.

Table 1: Estimates of depth to magnetic sources

<table>
<thead>
<tr>
<th>Profiles</th>
<th>Latitude (°N)*</th>
<th>Longitude (°E)*</th>
<th>Depth to the shallow source (Km)</th>
<th>Depth to the deeper source (Km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>11.75</td>
<td>13.016</td>
<td>0.61</td>
<td>1.31</td>
</tr>
<tr>
<td>2</td>
<td>11.75</td>
<td>13.023</td>
<td>0.56</td>
<td>1.23</td>
</tr>
<tr>
<td>3</td>
<td>11.75</td>
<td>13.031</td>
<td>0.37</td>
<td>1.89</td>
</tr>
<tr>
<td>4</td>
<td>11.75</td>
<td>13.070</td>
<td>0.31</td>
<td>2.05</td>
</tr>
<tr>
<td>5</td>
<td>11.75</td>
<td>13.086</td>
<td>0.42</td>
<td>1.13</td>
</tr>
<tr>
<td>6</td>
<td>11.75</td>
<td>13.094</td>
<td>0.24</td>
<td>0.85</td>
</tr>
<tr>
<td>7</td>
<td>11.75</td>
<td>13.101</td>
<td>0.30</td>
<td>1.68</td>
</tr>
<tr>
<td>8</td>
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<td>13.257</td>
<td>0.52</td>
<td>2.12</td>
</tr>
<tr>
<td>9</td>
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<td>13.265</td>
<td>0.40</td>
<td>2.63</td>
</tr>
<tr>
<td>10</td>
<td>11.75</td>
<td>13.289</td>
<td>0.84</td>
<td>3.27</td>
</tr>
<tr>
<td>11</td>
<td>11.75</td>
<td>13.304</td>
<td>0.58</td>
<td>1.76</td>
</tr>
<tr>
<td>12</td>
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<td>13.312</td>
<td>0.60</td>
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</tr>
<tr>
<td>13</td>
<td>11.75</td>
<td>13.320</td>
<td>0.40</td>
<td>1.60</td>
</tr>
<tr>
<td>14</td>
<td>11.75</td>
<td>13.367</td>
<td>0.36</td>
<td>1.42</td>
</tr>
<tr>
<td>15</td>
<td>11.75</td>
<td>13.382</td>
<td>0.20</td>
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</tr>
<tr>
<td>16</td>
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<td>13.421</td>
<td>0.27</td>
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</tr>
<tr>
<td>17</td>
<td>11.75</td>
<td>13.429</td>
<td>0.44</td>
<td>1.19</td>
</tr>
<tr>
<td>18</td>
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<td>13.452</td>
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<tr>
<td>19</td>
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<td>0.91</td>
</tr>
<tr>
<td>20</td>
<td>11.75</td>
<td>13.500</td>
<td>0.27</td>
<td>1.20</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td>0.42</td>
<td>1.59</td>
</tr>
</tbody>
</table>

* Centre of Profile

Fig. 5: Estimated sedimentary thickness section of the study area.
Deeper magnetic source is generally regarded as a proxy for sedimentary thickness; consequently, Table 1 also reveals that about 80% of the analysed profiles have sedimentary thickness less than 2 km, while only 5% have sedimentary thickness up to 3 km. Such thickness of sedimentary extent may unlikely favour hydrocarbon formation in the Maiduguri area of Chad basin.

The residual aeromagnetic anomaly map (Fig. 3) shows that the study area is dominantly made up of high magnetic anomalies. The rock types associated with positive magnetic anomaly values are usually made up of basic intrusive or rocks rich in ferromagnesian minerals e.g. gabbros, norites, anorthosites, trocolites, dolerites the main minerals in basic rocks are calcicplagioclase, pyroxenes (augite and hypersthenes), olivine etc. It can also be observed that basic rocks are under saturated and therefore do not usually contain free silica (quartz). This is because both remanent and induced magnetism can contribute to the magnetic field produced by basic rocks, and for every old basic intrusive, the remanent magnetization can be a dominant factor contributing to magnetic anomalies. More so basic rocks generally have high iron content and are more magnetic than others, so magnetic methods can be used to map them efficiently. It is also believed that area has some presence of basalt (Onuba et al., 2008). Hydrocarbon prospects in the area could be doubtful because of the likely presence of basalt whose emplacement may have destroyed geological structures that could have served as possible hydrocarbon traps (Onuba et al., 2008).

Conclusions

Depth estimates from Fourier transform analysis of aeromagnetic data of Maiduguri area of Chad basin indicated a two-depth source model. The depth to deeper sources ranges from 0.85 to 3.27 km with an average of 1.59 km, while the shallow source ranges from 0.20 to 0.84 km with an average of 0.42 km. The results of the deeper magnetic source estimation show that the thickness of sedimentary fill in the study area is in the neighbourhood of 0.85 - 3.27 km. However, only 5% of the analysed profiles have sedimentary thickness up to 3 km. Therefore, such thickness of sedimentary extent is unlikely to favour hydrocarbon formation. More so, hydrocarbon prospects are largely doubtful because of the likely presence of basalt in the area whose emplacement may have destroyed geological structures that could have served as hydrocarbon traps (Onuba et al., 2008).

Acknowledgment

The authors are grateful to the Nigerian Geological Survey Agency (NGSA) for the aeromagnetic data used in this work.

References


Paper presented at CCTA Conference on Geology, Kaduna, Northern Nigeria.


Design, Fabrication and Performance Evaluation of a Sweet Potato (Ipomoea Batatas) Peeling Machine
Balami, A. A., Dauda, S. M., Aliyu, M., Tomori, O. O. and Onyeughoh, R. O.
Department of Agricultural and Bioresources Engineering, Federal University of Technology
P.M.B. 65, Minna Niger State
Email: aabalami@futminna.edu.ng

Abstract
Peeling of tubers in Nigeria is normally done by hand which is tedious and time consuming. Therefore, this research work is aimed at designing, fabricating and carrying out performance evaluation of a sweet potato peeling machine, taking into consideration some physical and mechanical properties of the tubers. The machine was evaluated based on the following parameters: speed of the machine, throughput capacity, and peeling efficiency of the machine at speeds of 875 rpm, 933 rpm and 1000 rpm. At the three speeds, the machine has peeling efficiencies of 76 %, 78 %, and 81 % with an average throughput capacity of 82.87 kg/h as against manual of 0.22 kg/h. The machine performed optimally at the speed of 936 rpm with an efficiency of 78.33 % and the percentage peeling weight proportion of 21.67 %. The developed potato peeling machine is 40 % more efficient than the hand method.

Keywords: Sweet potato, spherecity, peeling, compressive strength, abrasive action

Introduction
Sweet potato (Ipomoea batatas) is a dicotyledonous plant that belongs to the family Convolvulaceae. Sweet potato has a large, starchy, sweet-tasting, tuberous roots. The young leaves and shoots are sporadically eaten as greens. The plant is an herbaceous perennial vine, bearing alternate heart-shaped or palatably lobed leaves and medium-sized sympetalous flowers (Janssens, 2001). The edible tuberous root is long and tapered, with a smooth skin whose colour ranges between yellow, orange, red, brown, purple, and beige. Its flesh ranges from beige through white, red, pink, violet, yellow, orange, and purple. Sweet potato varieties with white or pale yellow flesh are less sweet and moist than those with red, pink or orange flesh. Some others are used locally, but many are poisonous. Some cultivars of Ipomoea batatas are grown as ornamental plants; the name “tuberous morning glory” may be used in a horticultural context (Scott, 2000; Udealor et al., 1996; Leon, 1977).

The plant grows best at a standard temperature of 24 °C, surplus sunshine and warm nights. Annual rainfalls of 750 – 1,000 mm are considered most appropriate, with a minimum of 500 mm (20 in) in the growing season (Kwatia, 1986).

Depending on the cultivar and conditions, tuberous roots mature in two to nine months. With care, early-maturing cultivars can be grown as an annual summer crop in temperate areas. They are mostly propagated by stem or root cuttings or by adventitious roots called “slips” that grow out from the tuberous roots during storage. True seeds are used only for breeding (Udealor et al., 1996). Sweet potatoes are grown on a variety of soils, but well-drained, light- and medium-textured soils with a pH range of 4.5 - 7.0
are more favourable for the plant. They can be grown in deprived soils with little fertilizer. In the tropics, the crop can be maintained in the ground and harvested as necessary for market or home utilisation. In temperate regions, sweet potatoes are most frequently developed on larger farms and are harvested before first frosts (Njoku, 2007).

The extremely perishable nature of potato tubers poses a serious difficulty to storage; the deterioration is caused by microbial infections and physiological factors like loss of moisture. Also, processing is to improve sweetness of the food products (Kwatia, 1986). A method that was found competent in hastening the dry rate and improving the quality of product in peeling and drying the tuber.

The works done so far on the development of biomaterial peeling systems revealed five general methods of peeling: use of abrasive action/mechanical peelings, chemical, heat, and manual. The mechanical peeling can be classified into manual and automatic, using abrasive methods. The abrasive method has been used to peel tubers such as potatoes, ginger and yam (Tomori and Onyeugboh, 2014). Over the years traditional methods of peeling sweet potato have evolved which is the use of knife in peeling fresh cornels or hand to peel when cooked. Hand peeling of sweet potato take san hour to peel about 33 kg by hand which is time consuming (Tomori and Onyeugboh, 2014). With the use of a mechanical machine the work will be faster, easier and efficient. Presently in Nigeria, there is no known machine for peeling of sweet potato. This work represents the design, fabrication and performance evaluation of a potato peeling machine.

**Materials and Methods**

**Materials**

The materials used were selected based on their availability, cost, suitability and viability in service among other considerations. In the design of this sweet potato peeling machine, some properties of sweet potato were also considered such as the physical properties (shape, size, sphericity, surface area, and weight of the sweet potato tuber) and the mechanical properties (compressive strength of sweet potato when placed on the horizontal and vertical directions). Also the hardness of the sweet potato was measured so as to know the required force for peeling the periderm of the sweet potato (ASAE, 2003; Balami et al., 2012).

**Methods**

The sweet potato peeling machine shown in Figure 1 has a rotating drum which is eccentrically placed on a shaft and powered by 1 hp electric motor. The sweet potatoes were fed through a feed tray into the peeling chamber where the tubers come across the perforated rotating drum enclosed by a metal case. The peeling of the tubers takes place as a result of the abrasion caused by the perforated drum as the potatoes rotate inside the peeling drum. The peeled periderms are collected through the outlet provided.

**Fig. 1:** The Sweet Potato Peeling Machine
Legend: 1-Hopper, 2-Peeling drum casing, 3-Handle, 4-Lever, 5-Tray outlet, 6-Water outlet 7-frame, 8-Electric motor seat and 9-Electric motor.

Design of the Machine Components

Determination of the volume of the hopper

The volume of the hopper \( V_p \) was calculated using the expression given in equation 1 (Tim, 2009; Tomori and Onyeugboh, 2014):

\[
V_p = \frac{\pi h}{3} (R^2 + Rr + r^2)
\]

Where: \( V_p \) = Volume of the hopper in m\(^3\), \( h \) = Height of cone, \( R \) = Radius of the upper part of circular cone, \( r \) = Radius of the lower part of circular cone

Determination of the volume of the peeling drum

The volume of the peeling drum \( V_d \) was calculated using equation 2 as given by Rajput (2012):

\[
V_d = \pi r^2 h
\]

Where: \( V_d \) = Volume of the peeling drum, \( r \) = Radius of the peeling drum, \( h \) = Height of the peeling drum

Determination of the diameter of the shaft

The required diameter for a solid shaft having combined bending and torsional loads was calculated using the ASME code (Hall et al., 1980) as given in equation 3:

\[
d^3 = \frac{\sqrt{\left(K_b M_b\right)^2 + \left(K_t M_t\right)^2}}{\pi S_s} \cdot \frac{16}{1}
\]

where: \( d \) = Diameter of the shaft in meter, \( S_s \) = allowable combined shear stress for bending and torsion = 40 MPa = 40 x 10\(^6\) \( \frac{N}{mm^2} \) for steel shaft with keyway, \( K_b \) = combined shock and fatigue factor applied to bending moment = 1.5 to 2.0 for minor shock, \( K_t \) = combined shock and fatigue factor applied to torsional moment = 1.0 to 1.5 for minor shock, \( M_b \) = Bending moment; \( M_t \) = Torsional moment

Determination of the torque

The torque was calculated using the expression given in equation 4 (Khurmi and Gupta, 2005):

\[
T = \frac{\pi d^3}{16}
\]

where: \( T \) = transmitted torque, Nm; \( \tau \) = shear stress, MPa; \( d \) = diameter of the peeling shaft, mm

Determination of the torsional deflection of the peeling shaft

The angular deflection of torsion of solid shaft was determined using the expression in equation 5 (Khurmi and Gupta, 2005):

\[
\theta = \frac{32LT}{G\pi D^4}
\]

where: \( L \) = length of shaft = 0.3 m; \( T \) = torque to be transmitted = 5.08 Nm; \( G \) = modulus of rigidity for mild steel = 80 GPa = 80 x 10\(^9\) Pa (Khurmi and Gupta, 2005); \( D \) = diameter of shaft = 0.02 m

Determination of the angle of wrap

In the open belt configuration, the wrap angle of the belt around each of the three pulleys was determined using the expressions given in equation 7 (Khurmi and Gupta, 2005):

\[
\theta_A = \pi - 2\sin\left[\frac{1}{C_1} \left(\theta_B + \frac{R_A}{R_B} \theta_A\right)\right]
\]

\[
\theta_B = \pi + 2\sin\left[\frac{1}{C_1} \left(\theta_A + \frac{R_A}{R_B} \theta_B\right)\right]
\]

where: \( \theta_A \) = wrap angle of pulley A i.e. motor pulley; \( \theta_B \) = wrap angle of pulley B i.e. machine pulley; \( R_A \) = effective radius of pulley A i.e. motor pulley = 50 mm; \( R_B \) = effective radius of pulley B i.e. machine pulley = 75 mm; \( C_1 \) = distance between
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centers of pulley A and B = 170 m; \( \pi = 180^\circ \).

**Determination of the belt size**
The length of the belts between the electric motor and the peeling drum pulley was obtained using equation 8 (Khurmi and Gupta, 2005):

\[
L = 2C_1 + 1.57(D_1 + d) + \frac{(D_1-d)^2}{4C_1} \tag{8}
\]

where: 
- \( C_1 \) = center distance between motor and machine pulley = 170 mm; 
- \( D_1 \) = outer diameter of large sheave = 150 mm; 
- \( d \) = outer diameter of small sheave = 100 mm; 
- \( C_2 = 190 \) m; \( D_2 = 140 \) m

**Determination of the belt tension**
The tensions on the belt were determined using the expression in equation 9 (Khurmi and Gupta, 2005):

\[
\text{Tension ratio} = \frac{T_1}{T_2} \tag{9}
\]

where:
- \( T_1 = \frac{33000(125-F_A) \times Hp}{F_A \times V_b} \) - tension on tight side, (N); 
- \( T_2 = \frac{41250 \times Hp}{F_A \times V_b} \) - tension on slack side, (N); 
- \( Hp = \) horsepower of driving motor = 1 Hp; 
- \( F_A \) = arc of contact correction factor; 
- \( V_b \) = belt speed in rpm

But to find the arc of contact correction factor (\( F_A \)), the coefficient of arc of contact was determined using the expression given in equation 10:

\[
\text{Coefficient of arc of contact} = \frac{D_1 \times d}{C} \tag{10}
\]

where:
- \( D_1 \) = outer diameter of large sheave = 150 mm; 
- \( d \) = outer diameter small sheave = 100 mm; 
- \( C \) = center distance = 170 mm

The belt speed was determined using equation 11:

\[
\text{Belt speed, } V = \frac{\pi d_m n_m}{12} \tag{11}
\]

where:
- \( d_m \) = diameter of motor pulley = 100 mm; 
- \( n_m \) = speed of motor = 1400 rpm

**Power required to operate the machine**
The power required to operate the machine was calculated using equation 8.

\[
P_o = T \omega \tag{12}
\]

where:
- \( P_o \) = Power in Kw, 
- \( T \) = torque in (Nm), 
- \( \omega = \frac{2\pi N}{60} \) - angular speed (rad/s).

\( N_1 \) = speed of the pulley, rpm

**Peeling drum**
This was made of galvanized medium carbon steel sheet, which was punched from one side leaving the spike on the other surface used for the abrasion of the potato periderms. In the selection of the material used, considerations were made based on its resistance to corrosion, weight, and non-toxicity to sweet potato.

**Performance Evaluation**
The machine was evaluated using 100 kg of the white type sweet potato purchased at Kure Ultra-Modern market, Minna, Nigeria. The purchased sweet potatoes was sorted out, cleaned and divided into 3 groups of 30 kg each. The throughput capacity \((T_c)\), peeling weight proportion \((P_w)\) and peeling efficiency \(P_{\text{eff}}\) were determined using equations 13, 14 and 15. The time taken for peeling was determined by a stop watch. The machine was tested at three different speeds of 875, 933 and 1000 rev/min which were used to peel the sweet potato tuber.

**Throughput capacity**
The throughput capacity \((T_c)\) was determined using equation 13 as adopted from Olukunle and Akinnuli (2012):

\[
T_c = \frac{W_h}{\tau} \tag{13}
\]
where: \( W = \) mass of Sweet potato fed into the machine (kg); \( t = \) average time taken for the sweet potato and its peel to completely leave the machine (h)

**Peeling weight proportion**

The peeling weight proportion was calculated using equation 14 (Olukunle and Akinnuli, 2012):

\[
P_w = \frac{M_{pe}}{M_s} \times 100
\]

(14)

where: \( M_{pe} = \) average weight of peelings collected in (kg); \( M_s = \) average mass of the sweet potato (kg)

**Peeling efficiency of a sweet potato peeling machine**

The peeling efficiency of the machine was determined by the expression 15 as given by Agrawal (1987) as:

\[
P_{eff} = \frac{M_{po}}{M_{pr} + M_{ps}} \times 100
\]

(15)

where: \( M_{po} = \) total mass of peeled tubers collected through the peel outlet of the machine, kg; \( M_{pr} = \) total mass of peeled sweet potato, kg

**Results and Discussion**

The technical characteristics of the machine are presented in Table 1.

**Table 1: Technical characteristics of the machine**

<table>
<thead>
<tr>
<th>S/N</th>
<th>Technical characteristics</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Power required to operate machine</td>
<td>0.75 kW (1 hp electric motor selected)</td>
</tr>
<tr>
<td>2</td>
<td>Diameter of peeling drum shaft</td>
<td>20 mm</td>
</tr>
<tr>
<td>3</td>
<td>Speed of operation</td>
<td>1400 rpm</td>
</tr>
<tr>
<td>4</td>
<td>Volume of peeling drum</td>
<td>0.019 m³</td>
</tr>
<tr>
<td>5</td>
<td>Volume of hopper</td>
<td>0.045 m³</td>
</tr>
<tr>
<td>6</td>
<td>Angle of wrap</td>
<td>1st Pulley, ( \theta_1 = 85.34 ) rad; ( \theta_2 = 274.66 ) rad 2nd Pulley, ( \theta_1 = 128.64 ) rad; ( \theta_2 = 205.68 ) rad 3rd Pulley, ( \theta_1 = 101.67 ) rad; ( \theta_2 = 258.33 ) rad</td>
</tr>
<tr>
<td>7</td>
<td>Length of belts</td>
<td>Belt 1 = 740 mm Belt 2 = 700 mm</td>
</tr>
<tr>
<td>8</td>
<td>Arc of contact correction factor</td>
<td>Belt 1, ( F = 0.96 ) when coef. of arc of contact = 0.3 Belt 2, ( F = 0.94 ) when coef. of arc of contact = 0.4</td>
</tr>
<tr>
<td>9</td>
<td>Diameter of camshaft</td>
<td>20 mm</td>
</tr>
<tr>
<td>10</td>
<td>Torsional deflection of shaft</td>
<td>0.1°</td>
</tr>
<tr>
<td>11</td>
<td>Average Peeling efficiency, %</td>
<td>78.33 %</td>
</tr>
<tr>
<td>12</td>
<td>Average machine throughput</td>
<td>82.87 kg/h.</td>
</tr>
<tr>
<td>13</td>
<td>Average manual throughput</td>
<td>33 kg/h.</td>
</tr>
<tr>
<td>14</td>
<td>Average peeling weight proportion</td>
<td>21.67 %</td>
</tr>
</tbody>
</table>

The results of the performance test are shown in Table 2.

**Table 2: Results of performance evaluation of the Machine at the three different Operational Speeds**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Operational Speeds (rpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>875</td>
</tr>
<tr>
<td>Throughput Capacity, (kg/h)</td>
<td>77.12</td>
</tr>
<tr>
<td>Peeling Weight Proportion, (%)</td>
<td>24.00</td>
</tr>
<tr>
<td>Peeling Efficiency, (%)</td>
<td>76.00</td>
</tr>
</tbody>
</table>

Table 1 presents the technical characteristics of the developed machine. The average machine throughput is 82.87 kg as against the average manual throughput of 33 kg. From Table 2 we can notice that at the three operational speeds of the peeling drum of 875 rpm, 933 rpm and 1000 rpm, the average throughput capacities were calculated to be 77.12
kg/h, 81.08 kg/h, and 90.40 kg/h respectively, average percentage peeling weight proportions of 24.00 %, 22.00 %, and 19.00 % were recorded while average peeling efficiencies of 76.00 %, 78.00 %, and 81.00 % respectively were also obtained at the three machine speeds. These values were lower than the value in a research carried out by Tomori and Onyeugboh (2014) and Idris (2015) for yam peeling machine with an average efficiency of 95.97 %.

Conclusions
A sweet potato peeling machine was developed and evaluated at three operational speeds (875 rpm, 933 rpm and 1000 rpm). The developed machine has an average peeling efficiencies of 78.33 % and throughput capacities of 82.87 kg/h respectively. The developed machine is 40 % more efficient than the hand method.

References


Design of A Composite Traffic Control System at Kpakungu Roundabout Minna, Niger State.

Kolo S.S\textsuperscript{1}, Adeleke O. O\textsuperscript{2}, Ayeni S. J\textsuperscript{3}, Akinmade T\textsuperscript{3}, Abubakar M.\textsuperscript{1}, and Yusuf A\textsuperscript{1}.

1. Department of Civil Engineering, Federal University of Technology, Minna
2. Department of Civil Engineering, University of Ilorin, Ilorin

E-mail: s.kolo@futminna.edu.ng

Abstract

A composite traffic control method is proposed to control traffic and ease congestion especially during peak periods at Kpakungu roundabout in Minna, Niger state. Reconnaissance survey of the roundabout was carried out to note predominant directions of traffic flow from each approach to the roundabout; manual counting of traffic for five working days was done between 7:00 am to 12 noon and 3:00 – 7:00 pm daily. The result of the survey shows that congestion occurs at the roundabout between 7:45 - 9:30 am and between 5:00 - 6:30 pm every day. Results also show that the peak hourly traffic flow rate occurs between 8:00 and 9:00 am, and 5:00 to 6:00 pm daily. The result of the traffic count was then forecasted for 2-years using data on annual vehicle registration in Minna for 2011 to 2015 obtained from the Niger State Board of Internal Revenue Service. The Webster method of signal timing was used to design traffic signals that will optimally allocate right of way time to conflicting traffic streams. A 5–phase signalization of 90 and 97 seconds cycle lengths were proposed for morning and evening peak periods, respectively.

Keywords: Congestion, Peak periods, Traffic count, Traffic signals.

Introduction

A road is a thoroughfare, route or way on land between two places that has been paved or otherwise improved to allow travel by means of some conveyance including horse, cart, bicycle or motor vehicle (Gupta and Gupta, 2007). The basic function of a road is the movement of people, goods and services from one place to another (Gurcharan and Jagdish, 1991). A road can be said to be effective only when it performs this function in a manner that is safe, quick and comfortable (F.H.A, 2009; Forbes, 1999).

A highway system consists of different facilities. These facilities include freeway segments, intersections, ramps and other highway elements. Highway and traffic engineers are frequently engaged in evaluating the performance of these various highway facilities and proffering solutions where there are problems, especially at intersections (Martin, 2003). An intersection is an area shared by two or more roads, whose main function is to provide for the change of route directions (Garber and Hoel, 2012). Intersections vary in complexity from a simple intersection, which has only two roads crossing at a right angle to each other, to a more complex intersection, at which three or more roads cross within the same area. Drivers therefore, have to make a quick decision at an intersection on the alternative routes they wish to take (Jaap et al., 2013). This decision, which is not required at non-intersection areas of the highway, is part of the reason why intersections tend to have a high potential for crashes (Bhardmus, 2013). The overall traffic flow on any highway depends to a great extent on the performance of the intersections.

Conflict points are present at intersections, which if not taking care of result in crashes, delays, and congestions. Hence highway engineers usually look for ways of minimizing or removing the conflicts which arise at intersections. Methods usually employed to control traffic, and
hence remove or minimise conflicts at intersections in order of increasing hierarchy are (Maurice, 2005): i.) Basic rule of the road, that is, first come first serve. 
ii.) Use of yield and stop signs usually employed on minor roads. 
iii.) Round-about which eliminates crossing conflicts. 
iv.) Traffic signals or use of traffic wardens. 
v.) Interchange. 

The current method used in controlling traffic at Kpakungu intersection is a roundabout which works on the principle of circulation and entry flows so that motorists yield the right of way to traffic on their left hand. This method of control has proven to be grossly inadequate, especially during peak periods, the need for an improvement. Security and police men are usually deployed to control traffic during peak periods. This is to enhance free flow of traffic at Kpakungu roundabout. As these measures have yielded little dividend, additional measure proposed for traffic control at the roundabout is the introduction of traffic signals. This proposed method, known as a composite traffic control mechanism employs two or more traffic control methods (Backfrieder and Ostermayer, 2014). It involves the use of roundabout with traffic signals. 

The study is aimed at designing a composite traffic control to enhance free flow vehicles at Kpakungu roundabout in Minna, Nigeria. 

The objectives are to determine (i) the peak period (ii) reduce/eliminate the delay experience by motorists and (iii) eliminate conflict at the intersection.

Methodology

The following methods were adopted for the study: 

i.) Traffic flow determination. 

ii.) Geometric measurement.

iii.) Congestion study. 

iv.) Traffic count. 

v.) Signal Timing. 

Traffic flow determination. 

Reconnaissance survey of the Kpakungu roundabout to determine the predominant direction of traffic flow for each of its four approaches. Each approach was divided to lane groups based on the predominant direction of flow for traffic using that lane, shown in Fig. 1 is the lane group A to H. The saturation flow ($S_i$) and start-up lost time ($L_i$) for each lane group was then estimated using the procedure outlined in Highway Capacity Manual (HCM, 2000). The steps followed to determine the saturation flow and start up lost time for each lane group are summarized below:

i.) Queue is allowed to occur at the lane group whose saturation flow is to be determined i.e., vehicles on the lane group whose saturation flow is to be determined are not flowing.

ii.) When the queue in the lane group begins to move, the time taken for each successive car on the queue to cross the yield line of the roundabout at that approach to the roundabout is determined with a stop watch and recorded. This gives the vehicle headway ($h_i$).

iii.) The average of the relatively constant time when successive car cross the yield line as recorded from step (ii) is determined and taken as the saturation headway ($h$).

iv.) Saturation flow for the lane group is calculated using Equation 7-3 of HCM, (2000).

$$S = \frac{3600}{h}$$

(1)

where 

$S$ = saturation flow (pcu/hour) 

$h$ = saturation headway.
v.) The startup lost time for each lane group is calculated using equation 2

\[ L = \sum_{i=1}^{n} h_i - h \]  

Fig. 1: Kpakungu roundabout showing the adopted lane groups.

**Geometric measurement**
The geometric features (approach and exit dimension are measured directly and recorded with the aid of a steel tape as early as 5.30am, in the morning before the heavy flow of traffic for safety reasons.

**Congestion Study**
Congestion study of the roundabout was carried out by physical inspection of the roundabout during peak periods. During the inspection, the approach where the congestion occurred was identified, the time period when the congestion occurred was recorded and the cause of the congestion also noted.

**Traffic Count**
Traffic count was conducted simultaneously on all the four approaches to the roundabout for five consecutive working days as that situation demand. During the count, the continuous and diverging traffic for each approach was counted and recorded for every 15-minute interval. Video camera was mounted on camera stand, employed to video record the traffic flow at two of the approaches to the roundabout (Kure market and Gidan-kwano approach). The video record was later watched to count the continuous and diverging traffic from each of the two approaches. (Grenard and Wei, 2008) Traffic was grouped into seven categories as established by (Salter, 1990). Table 1 shows the seven groups and the type of vehicle belonging to each group and their equivalent passenger car unit conversion factor.

Traffic count for each day was carried out in two sessions namely morning and afternoon sessions. Morning session was from 7am to 12 noon while afternoon session was from 3 to 7 pm (Ayeni, 2015).

**Table 1: Equivalent Passenger Car Unit for Vehicle Groups.**

<table>
<thead>
<tr>
<th>Vehicle Grouping</th>
<th>Type of Vehicle</th>
<th>Conversion Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>One</td>
<td>Cars</td>
<td>1</td>
</tr>
<tr>
<td>Two</td>
<td>Motorcycles</td>
<td>0.5</td>
</tr>
<tr>
<td>Three</td>
<td>Tricycles</td>
<td>0.75</td>
</tr>
<tr>
<td>Four</td>
<td>Pickup and Buses</td>
<td>1.5</td>
</tr>
<tr>
<td>Five</td>
<td>2-3 axle configuration Buses</td>
<td>2.8</td>
</tr>
<tr>
<td>Six</td>
<td>Configuration Tipper and Trucks</td>
<td>2.8</td>
</tr>
<tr>
<td>Seven</td>
<td>3-5 axle combination vehicles</td>
<td>3</td>
</tr>
</tbody>
</table>

**Source:** Salter, 1990

**Signal Timing**
The method adopted for signal timing for this work is the Webster method of signal timing. The sequence of design process is summarized below.

i.) The data obtained from Traffic count for each day was converted to equivalent passenger car unit (PCU) using the conversion factor shown in Table 1 and the average PCU for the five days calculated.

ii.) The data of the annual number of new vehicle registered in Minna for the past five years (2011- 2015) was obtained from the office of the Niger State Board of Internal Revenue Services. The 8 % growth rate in vehicular registration as determined from the obtained data and
was used to forecast the future traffic volume to use the Kpakungu roundabout after fifteen years with proper maintenance which is the design life of the traffic signal (Qu, 2008).

iii.) From the result obtained in step two above, the hourly period having the highest traffic flow for both morning and afternoon session of traffic count was identified and the peak hour factor (PHF) for the peak hours calculated using Equation 3.

\[
P.H.F = \frac{\text{peak hour volume}}{\text{4 x peak 15-minute volume during peak hour}}
\]  

(3)

iv.) The traffic signal design volume of traffic for each lane group is calculated using Equation 4.

Design traffic volume = \[
\frac{\text{forecasted design traffic volume for approach}}{\text{peak hour factor}}
\]  

(4)

v.) A signal phasing sequence for signal timing was developed. The phasing system is such that gives the best possible alternative to achieving the aim and objectives of the system.

vi.) Webster equation (Webster, 1964) of signal timing reproduced as Equation 5 was then used to calculate the optimum cycle length and to allocate effective green time for each phase accordingly.

\[
C_o = \frac{1.5L + 5}{1 - \sum \frac{y_i}{L}}
\]  

(5)

where $C_o$ = Optimum cycle length (seconds)

$L$ = Total lost time per cycle (seconds)

$y_i$ = maximum value of the ratios of approach flows to saturation flows for all lane groups using phase i.

**Results**

*Saturation Flow ($S_i$) and Startup Lost Time ($L_{si}$)*

The saturation flow result for lane groups A, B, C, D, G and H are presented in Table 2. The saturation flow for lane group E and F are not determined using the procedure outlined in signal timing because of low traffic flow from that approach. Instead, the result obtained for lane groups A and B is assumed for lane groups F and E respectively.

**Table 2:** Saturation flow and lost time for each lane group

<table>
<thead>
<tr>
<th>Lane Group</th>
<th>Headway (sec)</th>
<th>Headway (sec)</th>
<th>Headway (sec)</th>
<th>Headway (sec)</th>
<th>Headway (sec)</th>
<th>Headway (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>B</td>
<td>2.50</td>
<td>2.49</td>
<td>2.40</td>
<td>2.35</td>
<td>2.00</td>
<td>2.05</td>
</tr>
<tr>
<td>C</td>
<td>2.38</td>
<td>2.12</td>
<td>2.00</td>
<td>2.01</td>
<td>1.98</td>
<td>1.90</td>
</tr>
<tr>
<td>D</td>
<td>1.98</td>
<td>1.78</td>
<td>1.61</td>
<td>1.59</td>
<td>1.61</td>
<td>1.61</td>
</tr>
<tr>
<td>E</td>
<td>1.75</td>
<td>1.62</td>
<td>1.81</td>
<td>1.70</td>
<td>1.70</td>
<td>1.70</td>
</tr>
<tr>
<td>F</td>
<td>1.61</td>
<td>1.52</td>
<td>1.75</td>
<td>1.60</td>
<td>1.48</td>
<td>1.58</td>
</tr>
<tr>
<td>G</td>
<td>1.59</td>
<td>1.49</td>
<td>1.68</td>
<td>1.55</td>
<td>1.46</td>
<td>1.57</td>
</tr>
<tr>
<td>H</td>
<td>1.46</td>
<td>1.50</td>
<td>1.65</td>
<td>1.50</td>
<td>1.45</td>
<td>1.56</td>
</tr>
</tbody>
</table>

Saturation Flow ($S_i$) and Startup Lost Time ($L_{si}$)

<table>
<thead>
<tr>
<th>Number of lanes</th>
<th>1</th>
<th>1</th>
<th>1</th>
<th>2</th>
<th>2</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S_i$ (pcu/hr)</td>
<td>2264</td>
<td>2400</td>
<td>2130</td>
<td>4646</td>
<td>4900</td>
<td>2293</td>
</tr>
</tbody>
</table>

**Signal Phasing**

The adopted signal phasing sequence for traffic signal design is presented in Fig. 2. Fig. 2 shows the lane groups belonging to each phase.

![Signal Phasing Sequence](image)

**Fig. 2:** Signal Phasing Sequence

**Signal Timing Calculation**

The calculations for allocating the green time for each session morning and afternoon sessions are presented in Table 3.

(i) **Afternoon Session Signal Timing Calculation.** The Peak Hour is between 5:00 – 6:00pm
Table 3: Afternoon session signal timing design data

<table>
<thead>
<tr>
<th>Phase</th>
<th>Max ( y_i )</th>
<th>Max ( L_{1i} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.43</td>
<td>2.5</td>
</tr>
<tr>
<td>2</td>
<td>0.0212</td>
<td>2.5</td>
</tr>
<tr>
<td>3</td>
<td>0.43</td>
<td>3.6</td>
</tr>
<tr>
<td>4</td>
<td>0.355</td>
<td>3.6</td>
</tr>
<tr>
<td>5</td>
<td>0.43</td>
<td>2.6</td>
</tr>
</tbody>
</table>

\[ \sum y_i = 1.644 \quad \sum L_{1i} = 14.40 \]

Optimum Cycle \( c_o \) length from Webster Equation:

\[ c_o = \frac{1.5L + 5}{1 - \frac{5}{2}y_i} \]

Sum of startup lost time \( \sum L_{1i} = 14.40 \) seconds = 14 seconds

Sum of clearance interval between phases \( L_2 = 20 \) seconds
Total lost time per cycle \( L = L_1 + L_2 = 14 + 20 = 34 \) seconds.

\[ C_0 = (1.5 \times 34) + 51 - 1.66 = \frac{56}{0.66} = 84.84 \] seconds

\[ C_o = 89 \text{ seconds} \]

Total Effective green time = \( C_o - L = 85 - 34 = 51 \) secs

Actual Effective green time for each phase \( G_{ai} \) with 3.0 taken as adopted yellow interval for all lane groups

\[ G_{ai} = \frac{Y_i}{2y_i} + L_{1i} - 3.0 \]

\[ G_{ai} = \frac{0.430}{1.660} \times 51 + 2.3 - 3.0 = 12.51 \text{ secs} \]

\[ G_{a2} = \frac{0.812}{1.660} \times 51 + 2.3 - 3.0 = 0.50 \text{ secs} \]

\[ G_{a3} = \frac{0.430}{1.660} \times 51 + 3.6 - 3.0 = 13.81 \text{ secs} \]

\[ G_{a4} = \frac{0.353}{1.660} \times 51 + 3.6 - 3.0 = 11.45 \text{ secs} \]

\[ G_{a5} = \frac{0.430}{1.660} \times 51 + 2.60 - 3.0 = 12.81 \text{ secs} \]

5 seconds of green time is allocated to phase 2. This increases the total effective green time to 56 seconds and cycle length to 90 seconds. The phase diagram is presented in Fig. 3 and 4

Fig. 3: Afternoon session signal phase diagram

Morning Session Signal Timing Calculation

The calculations for the morning session signal timing are presented in Table 4. Peak hour: 8am - 9am.

Table 4: Morning session signal timing design data

<table>
<thead>
<tr>
<th>Period</th>
<th>( A )</th>
<th>( B )</th>
<th>( C )</th>
<th>( D )</th>
<th>( E )</th>
<th>( F )</th>
<th>( G )</th>
<th>( H )</th>
</tr>
</thead>
<tbody>
<tr>
<td>6:00am</td>
<td>172</td>
<td>257</td>
<td>183</td>
<td>296</td>
<td>9</td>
<td>6</td>
<td>278</td>
<td>194</td>
</tr>
<tr>
<td>6:45am</td>
<td>162</td>
<td>257</td>
<td>183</td>
<td>296</td>
<td>11</td>
<td>8</td>
<td>215</td>
<td>217</td>
</tr>
<tr>
<td>7:30am</td>
<td>150</td>
<td>254</td>
<td>180</td>
<td>257</td>
<td>9</td>
<td>6</td>
<td>225</td>
<td>208</td>
</tr>
<tr>
<td>8:15am</td>
<td>140</td>
<td>251</td>
<td>171</td>
<td>289</td>
<td>12</td>
<td>5</td>
<td>239</td>
<td>204</td>
</tr>
<tr>
<td>9:00am</td>
<td>130</td>
<td>248</td>
<td>164</td>
<td>277</td>
<td>11</td>
<td>4</td>
<td>274</td>
<td>204</td>
</tr>
<tr>
<td>Total</td>
<td>580</td>
<td>840</td>
<td>594</td>
<td>834</td>
<td>48</td>
<td>30</td>
<td>580</td>
<td>204</td>
</tr>
</tbody>
</table>

\[ \text{PHF} = \frac{56}{8 \times 0.319} \]

\[ \text{Correlation coefficient} = 0.92 \]

\[ \text{Traffic} = \frac{56}{8 \times 0.319} \]

\[ \text{Signal on lane} = \frac{56}{8 \times 0.319} \]

\[ \text{phases} = 2264 \times 1.081 = 2264 \times 1.081 = 2264 \times 1.081 = 2264 \]
Optimum cycle length \( (C_0) \) = \( \frac{(1.5L) + 5}{1 - \Sigma y_i} \)

Sum of startup lost time \( Li = 14.40 \) seconds

Sum of clearance interval between phases = 20 seconds

\( L = L_1 + L_2 = 14 + 20 = 34 \) seconds

\( C_0 = \frac{(1.5 \times 34) + 5}{0.614} \)

\( = \frac{56}{0.614} \)

\( = 91.21 \) seconds \( C_0 = 92 \) sec

Effective Green time = \( C - L \)

\( G_{te} = 92 - 34 = 58 \) seconds.

Actual green time for each phase with 3.0 sec adopted as the yellow interval for all lane groups.

\( G_{ai} = \frac{y_i}{\Sigma y_i} \times 58 + l_{1i} - 3.0 \)

\( G_{a1} = \frac{0.485}{1.614} \times 58 + 2.30 - 3.0 = 16.73 \) secs

\( G_{a2} = \frac{0.021}{1.614} \times 58 + 2.30 - 3.0 = 0.55 \) secs

\( G_{a3} = \frac{0.378}{1.614} \times 58 + 3.60 - 3.0 = 14.18 \) secs

\( G_{a4} = \frac{0.352}{1.614} \times 58 + 3.60 - 3.0 = 13.25 \) secs

\( G_{a5} = \frac{0.378}{1.614} \times 58 + 2.60 - 3.0 = 13.18 \) secs

The actual green time for phase 2 is put at 5.0 seconds. Hence the total cycle length increases to 97 seconds. The Phase diagram is presented in Fig. 4.

**Fig. 4:** Morning session signal phase diagram

**Discussion of Results**

The traffic survey carried out at the Kpakungu roundabout shows that the Gidan kwano approach to the roundabout experiences more congestion than other approaches. The congestion occurs especially during peak periods (7:45 - 9:00am and 5:00 - 6:30pm). The congestion at the approach was attributed to the following factors.

i.) The approach is not as wide as the other approaches.

ii.) Presence of more pedestrian crossing activities at that approach making drivers to reduce their speed.

iii.) Parking activities of commercial and non-commercial vehicles which reduce the effective space available for traffic which ultimately make drivers to reduce their speed to compensate for the small available space.

iv.) Presence of speed bumps which makes traffic to flow at lower speed.

The above listed factors have caused a significant decrease in the capacity of that road segment thereby making demand to exceed capacity during peak periods ultimately causing congestion.
A five phase traffic signal was designed with phase one having lane groups H, B and A having exclusive right of way simultaneously when the signal lamps for those lane groups will indicate green and that of the other lane groups showing red. Phase two has lane groups E and F having exclusive right of way while lane group A has a permitted right of way (signal lamp shows yellow indicating that traffic going that direction can move if the intersection is clear of conflicting traffic). Phase three has exclusive right of way for lane groups G, D (continuous and right-turn traffic only) and H. Phase four gives exclusive right of way for lane groups C and D while lane group A has a permitted right of way. Phase five gives exclusive right of way to lane groups G and H while lane group D has a permitted right of way.

During the traffic signal design, a clearance interval of 4 seconds each between phases 1 and 2, 2 and 3, 3 and 4, 4 and 5 and 1 is adopted for design for safety reasons so that traffic can clear the roundabout completely before conflicting traffic streams in the next phase are released. A yellow interval of 3 seconds was also adopted for design.

Conclusions

The composite control mechanism provides a method of controlling traffic at the Kpakungu roundabout that is safe, economical and environmentally friendly. Other advantages of the composite traffic intersection include:

i.) The design is relatively cheaper to implement as there will be no need to redesign or reconstruct any new fixed facility at the intersection, just the installation of traffic signals which is relatively cheap.

ii.) It will help to eliminate pollution at the intersection coming from the exhaust of vehicles since there will be no more congestion.

iii.) Also frustrations experienced by drivers during off-peak periods which are experienced in pre-timed traffic intersections could be eliminated by switching off the traffic lights during the off-peak periods and motorist resulting to the normal roundabout rules.

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Statistical Models for Compressive Strength of Concrete with Fly Ash as Sand Replacement Material

M. Abdullahi1, A. U. Raji1, O. James1 and T. Y. Tsado1
1Civil Engineering Department, Federal University of Technology, Minna
Email: m.abdullahi@futminna.edu.ng, abdulapai@yahoo.com

Abstract
Statistical models for the prediction of compressive strength of concrete with fly ash as sand replacement material have been developed in this paper. Secondary data were used for the model development in MINITAB environment. The polynomial models show the relationship between the properties of concrete and its mix compositions. The models were fit with polynomial terms that produced curvilinear effects on the surface plot. These models were developed at 0.05 levels of significance for the terms. The result shows that the models are adequate to predict the underlying relationship with P-values less than 0.05 for each of the variable retained in the model. The adjusted coefficient of determination for the models of compressive strength at 7 and 28 days chosen were 0.9737 and 0.9797 respectively. This shows that the models have the capabilities of explaining 97.37% and 97.97% of variability in the data under consideration. This shows that the models are adequate in predicting the compressive strength of concrete at 7 and 28 days.

Keywords: Models, Compressive strength, Concrete, Fly ash, Replacement materials.

Introduction
Municipal solid wastes and the processes involved in manufacturing and servicing industries produce numerous waste materials. Environmental awareness has contributed immensely to the concerns related with waste disposal. Managing solid waste is among the major problems facing the environment in the world. With the insufficiency of space for land filling and owing to its rising cost, utilization of waste has become a promising alternative to disposal. Several researches have been carried out on the utilisation of waste products as a replacement of natural sand in concrete (Bahoria et al., 2013, Mohammed et al., 2014a, Mohammed et al., 2014b, Mohammed et al., 2013, Mohammed et al., 2011a, Mohammed et al., 2011b, Abdullahi et al., 2009). Ash from coal based power plants is one of such wastes.

Concrete is a mixture of cement, aggregates and water. Other materials added at the mixer are referred to as admixtures (Taylor, 2000). Concrete is a composite construction material that has widely gained acceptance as a viable material in the construction industry and is used extensively in most Civil Engineering projects. Thus, considering environmental sustainability and the conservation of energy and resources, concrete is presumed to be the most preferred construction material. Enormous natural resources is consumed on a daily basis in the production of concrete and it is believed that one day these natural resources will become extinct thus the need to search for a compatible material to replace sand in concrete has become very vital in light of the world facing serious problems due to the decreased availability of river sand (Govndarajan, 2014).

Presently, fine aggregate which is a natural resource is gradually being exploited as a result of the need to meet the high demand of concrete in the construction industry. Here concrete is made by using fly ash to partially replace fine aggregate (sand). This way the natural resources (fine aggregate) can be saved, by using
alternative product. The demand for building materials like fine aggregate, cement and coarse aggregate is increasing in Nigeria due to increase in growth of population, economy and living standards of the people. Based on the Nigeria cement report of 2013; projected cement consumption in the country is estimated to be 23.2 metric tons per annum. The projection show 8.5% Compound Annual Growth Rate (CAGR) in cement consumption in Nigeria from 2012-2015 (Nigeria Cement Sector Report: Emerging Prominence from a Deficit Past, 2013). Cement concrete is the most preferred and most used material of construction because of its wide variety of skills, ease in production and use. Three characteristics are considered in using concrete, namely, its resilience, its cheapness of construction as a result of improvement in design and reduced material cost, and the environmental protection and preservation of energy. These aspects may be satisfied by using fly ash in concrete (Aruna and Kavitha, 2014).

Fly ash (FA) is among the by products resulting from burning of coal which comprises of tiny particles that ascends with flue or vent gases. Fly ash plays the role of a pozzolana when applied as a binder. Pozzolanas are siliceous or siliceous/aluminous materials which forms a cementitious compound when combined with lime and water. The pozzolanas are those materials lacking independent cement properties, but exhibit cementitious properties in its pulverized separated shape when mixed with calcium hydroxide and moisture. Cementitious compounds are formed as a result of chemical reactions between the pozzolana and calcium hydroxide at room temperature. Certain similarities and dissimilarities exist between Ordinary Portland Cement (OPC) and pozzolanas. Pozzolanas also hydrate in water as OPC, though they do not yield the strength required as Ordinary Portland Cement but develops strength over a longer period. Fly ash respond to calcium hydroxide released due to cement hydration and develops numerous calcium aluminum and calcium silicate hydrates. Fly ash is the most popular, suitable and frequently used pozzolanas worldwide (Madhavi et al., 2010).

As by-products of burning of coal in thermal power plants, fly ash is removed as fine molecular residues from the dust collecting system, before releasing it to the atmosphere. Particles of fly ash are normally spherical, with diameters ranging from less than 1mm to 150mm. The dust collection equipment determines to a large extent the range of sizes of the particles of any given fly ash. The type and quantity of inflammable substance present in the coal used, gives an idea of the composition of the fly ash. A large percentage of fly ash comprises of glasses and chemical compound produced from the following elements namely calcium, magnesium and silicon. Incombustible coal remnants gather carbon particles with fly ash. The amount of these carbon particles depend on certain factors which include the air and/or fuel, the rate of combustion of coal, and the level of combustion of the coal. Generally, ash produced as a result of the combustion of sub-bituminous coal has little quantities. Bituminous coals produce unburned carbon in large quantity (Ramezanianpour, 2014).

Studies made on the use of fly ash (FA) show that fly ash improves the structure of Portland cement which eventually enhances its longevity. Numerous building codes approve using fly ash as an admixture in concrete. Several structures have been constructed such as the Petros Tower in Malaysia, Great Belt Bridge and Euro Tunnel in different locations. Both Class C and Class F fly ashes can be conveniently used as partial cement replacements. Class “F” fly ash has unpredictable effects on the concrete’s air
content, resulting in reduction of resistance to the damage caused by freeze/thaw. Most often fly ash can be used to replace cement at levels up to 30% by mass, and most recently it is believed to replace higher dosages in certain applications. To that effect, various methods are established for partially replacing cement with volumes of fly ash as high as 50%. Researchers are optimistic that cement replacement with fly ash will, to a large extent, reduce the greenhouse gas of concrete, as manufacturing a ton of cement produces close to an equal amount of Carbon dioxide (CO$_2$) while no CO$_2$ is generated with fly ash. Although, manufacture of Portland cement has reached nearly four billion metric tons in 2013, replacing huge quota of this quantity with fly ash will reduce to a large extent the carbon emissions associated with construction, in as much as production of fly ash is taken as a waste.

However, very few researches have been carried out on the use of fly ash as a replacement for fine aggregate in concrete. Thus some industrial wastes are effectively utilized in the production of concrete. However, the present rising depletion of fine aggregate in concrete has led to an overwhelming search for possible means for its replacement. Fly ash can generally be used as an admixture in the manufacture of cement, as a replacement for cement and in concrete. Adequate research has been done on the partial replacement of sand in structural concrete. An increase in fly ash content results in higher strength for a given density, as fly ash is of pozzolonic nature. Guidelines for predicting compressive strength of concrete having fly ash as a material partially replacing sand or fine aggregate is not readily available (Rajamane, et al., 2006). It is advantageous to have models for the prediction of compressive strength for fly ash concrete. Previous researchers have developed models for properties of concrete and mixture proportioning (Abdullahi et al., 2009a; Abdullahi et al., 2009b). It would be advantageous to have models for the prediction of compressive strength of fly ash concrete. The research presented here aimed at developing models for predicting the compressive strength of concrete using fly ash as sand replacement material. This was achieved by establishing the graphical relationship between the properties of concrete and its mix composition and obtaining the models relating the properties of concrete and its mix composition using MINITAB.

Materials and Method
The experimental data from secondary source was used for the model development. A scientific approach for carrying out the research was adopted and there were no tests carried out of any sort as secondary data used for the study was extracted from the research work carried out by Rajamane, et al., (2006). The prediction of compressive strength of concrete with fly ash as sand replacement material was studied. Statistical software Minitab 15 was used to develop the model that will predict the strength of the FAC.

Experimental data
The tabular data used was taken from Table 3 in (Rajamane, et al., 2006). For developing models of compressive strength of concrete, certain parameters were considered and extracted from the table. These include the water/binder ratio (w/b), the water/cement ratio (w/c), the fly ash addition factor (m), the sand replacement level (p$_s$), the fly ash fraction in binder (p) and the 7 and 28 days compressive strength determined from the tests carried out under controlled standard laboratory conditions. The aim of the experiment that was carried out is to develop an equation that will predict compressive strength of FACs (fly ash concretes) with FA (fly ash) as Sand Replacement Material (SRM) by considering a cement concrete mix having proportions of cement, sand, coarse
aggregate and water at 1:1:2:0.35; and by preparing fly ash concrete with fly ash at Sand Replacement Levels (SRL) of 20%, 40% and 60% with each sand replacement level having three water cement ratios. A number of 28 mixes were prepared and their compressive strengths determined. An extensive data for analyzing compressive strength in that regard was generated and the same data was used for this research. This data is shown in Table 1.

**Table 1: Comparison between compressive strengths from tests and prediction formulae**

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<th>W&lt;sub&gt;b&lt;/sub&gt;</th>
<th>W&lt;sub&gt;c&lt;/sub&gt;</th>
<th>M</th>
<th>P&lt;sub&gt;s&lt;/sub&gt;</th>
<th>P</th>
<th>f&lt;sub&gt;test&lt;/sub&gt;, N/mm&lt;sup&gt;2&lt;/sup&gt;</th>
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Model development

Models were developed with the data in Table 1 using Minitab15. The model development started by substituting in the data in Table 1 by substituting \( w_b, w_c, m, p_s, \) and \( p \) with \( X_1, X_2, X_3, X_4, \) and \( X_5 \) respectively. This is shown generically below:

- Water / Binder ratio, \( w_b = X_1 \)
- Water / Cement ratio, \( w_c = X_2 \)
- Fly ash addition factor, \( m = X_3 \)
- Sand replacement level, \( p_s = X_4 \)
- Fly ash fraction in binder, \( p = X_5 \)
- 7 Days compressive strength, \( f_{7\text{days}} = Y_1 \)
- 28 Days compressive strength, \( f_{28\text{days}} = Y_2 \)

This was followed by defining the custom response surface design for each column factor and stating the low and high levels for each column. The result of this action is shown in Table 2.

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<th>( X_2 )</th>
<th>( X_3 )</th>
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<td>49.2</td>
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Subsequently, an analysis on the response surface generated by the action above has revealed the possibility of developing four different polynomial models. This includes the linear model, the interaction model, the pure quadratic and the full quadratic model. These models and their expressions are shown as follows:

i. Linear model
\[ Y = a_0 + a_1 x_1 + a_2 x_2 + a_3 x_3 + a_4 x_4 + a_5 x_5 \]  

ii. Interaction model
\[ Y = a_0 + a_1 x_1 + a_2 x_2 + a_3 x_3 + a_4 x_4 + a_5 x_5 + a_6 x_1 x_2 + a_7 x_1 x_3 + a_8 x_1 x_4 + a_9 x_1 x_5 + a_{10} x_2 x_3 + a_{11} x_2 x_4 + a_{12} x_2 x_5 + a_{13} x_3 x_4 + a_{14} x_3 x_5 + a_{15} x_4 x_5 \]  

iii. Pure quadratic model
\[ Y = a_0 + a_1 x_1 + a_2 x_2 + a_3 x_3 + a_4 x_4 + a_5 x_5 + a_6 x_1^2 + a_7 x_2^2 + a_8 x_3^2 + a_9 x_4^2 + a_{10} x_5^2 \]  

iv. Full quadratic model
\[ Y = a_0 + a_1 x_1 + a_2 x_2 + a_3 x_3 + a_4 x_4 + a_5 x_5 + a_6 x_1 x_2 + a_7 x_1 x_3 + a_8 x_1 x_4 + a_9 x_1 x_5 + a_{10} x_2 x_3 + a_{11} x_2 x_4 + a_{12} x_2 x_5 + a_{13} x_3 x_4 + a_{14} x_3 x_5 + a_{15} x_4 x_5 + a_{16} x_1^2 + a_{17} x_2^2 + a_{18} x_3^2 + a_{19} x_4^2 + a_{20} x_5^2 \]  

Where;
- \( Y \) = Response or dependent variable,
- \( x \) = Predictor, and \( x_1, x_2, x_3, x_4, x_5 \) are input variables.
- The term \( x_i \) signifies the result of individual factors, while the product \( x_i x_j \) signifies that of interaction, whereas the term \( x_i^2 \) implies the effect of the square model. The terms \( a_0, a_1, a_2, a_3, a_4, a_5 \ldots a_{20} \) are coefficients.

The number of coefficients in each of the equations above signifies the minimum number of experimental data capable of fitting the polynomial model. A further analysis of the response surface for this experiment revealed that a linear model with a subset of the squares and interaction model will be appropriate for both the 7 and 28 days compressive strengths of the FAC. This was achieved by using backward and forward searching technique. The 7 days compressive strength (denoted as \( Y_1 \)) was selected and a suitable term resulting in an acceptable level of significance (P-value) of less than 5% on successive removal of terms that do not fit in the model from selected terms to available terms of the response surface interface; and including the terms that fit the model from available terms to the selected estimable terms of the response surface design interface of the software. The stated design was carried out using uncoded units and the same process described above was repeated for the 28 days compressive strength (denoted as \( Y_2 \)).

On completing the task above and further analyzing the response surface, graphs were plotted so as to constitute the desired response values and operating conditions. In order to produce a clear picture of the response surface a surface plot was chosen and the option of the software to generate plots for all pairs of factors was selected. This action yielded graphs plotted in three dimensional views.

**Results and Discussion**

The polynomial models developed in this work are presented. The results from the regression analysis and response surface plots are discussed and the graphical models are interpreted.

**Response surface regression for compressive strength at 7 days**

From Table 3, the polynomial model for the compressive strength of concrete at 7 days with fly ash partially replacing sand is as follows:

\[ Y_1 = 94.69 + 97.87 X_1 - 336.13 X_2 - 15.95 X_3 + 216.5 X_4 + 409.34 X_5 + 195.36 X_2^2 - 191.96 X_4^2 - 923.82 X_5^2 + 952.31 X_4 X_5 \]  

(5)
Equation 5 is the model developed for the compressive strength of concrete at 7 days. Table 3 and 4 show the outcome of the response surface regression of the compressive strength at 7 days. The P-values of each of the coefficients are less than 0.05, indicating that the inclusion of those variables in the model will increase its predictive capability and should be retained. The adjusted coefficient of determination, \( R^2 \) (adjusted) is 0.9737. This implies that the model can explain the variability in the data by 97.37%, indicating that the model is adequate. Table 4 shows the analysis of variance for the compressive strength at 7 days. The p-values of linear, square and interaction are all less than 0.05, indicating that all the terms are significant and should be retained in the model.

**Table 3:** Estimated regression coefficients for \( Y_1 \)

<table>
<thead>
<tr>
<th>Term</th>
<th>Coefficient</th>
<th>Std Coefficient</th>
<th>T</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>94.49</td>
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<td>18.963</td>
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<tr>
<td>( X_1 )</td>
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<td>44.776</td>
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<tr>
<td>( X_3 )</td>
<td>-15.95</td>
<td>5.285</td>
<td>-3.018</td>
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<td>( X_4 )</td>
<td>-216.5</td>
<td>65.862</td>
<td>-3.287</td>
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<td>( X_5 )</td>
<td>-409.34</td>
<td>109.812</td>
<td>-3.728</td>
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<tr>
<td>( X_1^2 )</td>
<td>195.36</td>
<td>34.464</td>
<td>5.668</td>
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<tr>
<td>( X_2^2 )</td>
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<td>72.519</td>
<td>-2.647</td>
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<tr>
<td>( X_1X_2 )</td>
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<td>267.094</td>
<td>-3.459</td>
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<tr>
<td>( X_1X_3 )</td>
<td>952.34</td>
<td>270.777</td>
<td>3.416</td>
<td>0.003</td>
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Standard Error of Regression, \( S = 1.49596 \)
Prediction Sum of Squares, \( PRESS = 92.539 \)
Coefficient of Multiple Determination, \( R^2 = 98.25\% \)
\( R^2 \) (predicted) = 95.98% \( R^2 \) (adjusted) = 97.37%

**Table 4:** Analysis of variance for \( Y_1 \)

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<tr>
<th>Source</th>
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<th>Seq SS</th>
<th>Adj SS</th>
<th>Adj MS</th>
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<th>P</th>
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<tr>
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DF= Degree of freedom, Seq SS= sequential sum of squares, Adj SS= Adjusted sum of squares, F = ratio of mean squares, and P = Level of significance.

**Surface plot for compressive strength at 7 days**

The developed model is used to obtain the surface plot. This gives a pictorial view of the model in three dimensions. The pictorial views of the model are shown in Figs. 1 and 2.

**Fig. 1:** Surface plot of \( Y_1 \) vs \( X_5, X_4 \)

Fig. 1, revealed that at seven (7) days the compressive strength decreases as the level of sand replacement increases. A further analysis of the plot revealed an appreciable increase in the compressive strength following an increase in the fraction of fly ash in the binder portion of the concrete. This implies that increasing the fraction of fly ash in the binder portion enhances the seven (7) days compressive strength \( f_{7\text{days}} \) of the concrete.

**Fig. 2:** Surface plot of \( Y_1 \) and \( X_1, X_5 \)

The result of Fig. 2 indicates that the compressive strength at 7 days increases slightly with a gradual increase in the water – binder ratio. A further analysis on the plot shows appreciable increment in compressive strength at the early stage of increasing the fly ash fraction in the binder.
portion of the concrete; but subsequent increase of the fraction of fly ash in the binder has shown a drastic decrease in the compressive strength.

Response surface regression for compressive strength at 28 days
From Table 5, the 28 days compressive strength can be expressed as

$$Y_2 = -65.95 + 215.77X_1 - 296.71X_2 + 276.65X_3 + 330.87X_4 - 326.63X_2^2 + 841.56X_3^2 - 559.55X_1X_3 - 695.97X_1X_4 + 1055.41X_1X_5 + 713.63X_2X_3 + 872.71X_2X_4 - 1328.24X_3X_5 - 442.90X_3X_4 - 551.28X_3X_5$$  

Equation 6 is the reduced full quadratic model developed for the compressive strength of concrete at 28 days. Table 5 and 6 shows the outcome of the response surface regression of the compressive strength at 28 days. The P-values of each of the coefficients are less than 0.05, indicating that the inclusion of those variables in the model will increase its predictive capability and should be retained. The adjusted coefficient of determination, R-Sq (adjusted), is 0.9797.

This implies that the model can explain the variability in the data by 97.97%, indicating that the model is adequate. Table 6 shows the analysis of variance for the compressive strength at 28 days. The p-values of linear, square and interaction are all less than 0.05, indicating that all the terms are significant and should be retained in the model.

Table 5: Estimated regression coefficients for Y₂

<table>
<thead>
<tr>
<th>Term</th>
<th>Coefficient</th>
<th>SE Coefficient</th>
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<tr>
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<td>X₁X₃</td>
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<tr>
<td>X₂X₃</td>
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<tr>
<td>X₄X₅</td>
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<td>194.955</td>
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$$S = 1.81764 \quad \text{PRESS} = 3303.87$$
R-Sq = 99.10% R-Sq (predicted) = 24.81%
R-Sq (adjusted) = 97.97%

Table 6: Analysis of variance for Y₂

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<td>0</td>
<td>0</td>
<td>0</td>
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</table>

Surface plot for compressive strength at 28 days
The developed model for compressive strength at 28 days is used to obtain the surface plot. The three dimensional pictorial views of the model are shown in Figs 3 and 4. Based on the graphical representation of the surface plot above, it can be seen that there is a gradual decrease in the 28 days compressive strength of concrete on successive increase in the water-cement ratio of the concrete. Moreover, increasing the sand replacement level of the mixture reveals an appreciable increase in the compressive strength of the concrete. A thorough analysis of the surface plot of Fig. 4 above shows a gradual increase in the 28 days compressive strength of concrete following an increase in the addition factor of fly ash in the concrete mix. A further look at the plot reveals a significant increase in
compressive strength as the level of partial replacement of sand with fly ash increases.

**Fig. 3:** Surface plot of $Y_2$ vs $X_2$, $X_4$

**Fig. 4:** Surface plot of $Y_2$ versus $X_3$, $X_4$

### Conclusions and Recommendations

**Conclusions**

Based on the results obtained from the experimental design developed and analysis carried out using Minitab statistical, the following are hereby concluded:

1. The reduced full quadratic models have been developed for the prediction of compressive strength of concrete at 7 and 28 days with predictive capabilities of 97.37 and 97.97% respectively.

2. The response surface plots give graphical description of the relationship between compressive strengths at 7 and 28 days, and two variables from the water/binder ration, water/cement ratio, fly ash addition factor, sand replacement level and fly ash fraction in binder keeping other variables constant.

**Recommendations**

Based on the analysis carried out and the results obtained from the statistical models for compressive strength of concrete with fly ash as sand replacement material, the following recommendations are deduced:

1. The models developed herein can be used to predict the seven (7) and twenty eight (28) days compressive strength of concrete.

2. The response surface plots is recommended for use to obtain a pictorial relationship between compressive strength and various input parameters considered in this work.

### References


External Reliability and Quality Control Analysis of Polyvinyl Chloride Pipe Produced Using Job Production Technique

Olugboji, O.A., Ajani, K.C., Kolawole, O.J.
Department of Mechanical Engineering,
Federal University of Technology Minna, Nigeria
E-mail: clemajang@gmail.com

Abstract
The control systems require different information and production management system and this is important to competitive industry. The choice of production technique influences the success or failure of industrial operation. This work seeks study external reliability and quality control analysis of polyvinyl chloride pipe produced using job production technique in Imurat International Limited (IIL) Minna. To validate the quality of the product, several tests, which include Mechanical Testing, Reliability Analysis Using FMEA, Flexural Test, Impact Test and hardness test were conducted. The result after the quality control analysis reveals that reliability of the system was not 100% assured. However the production requirement was above average. The produced pipe was within range of ASTM-D1598 testing standard, except the permissible average elongation that was at 59.8% for the pipe and hardness value (HCR) of 24.5 on average.

Keywords: Design, Polyvinyl chloride, thermosetting, thermoplastic, extrusion

Introduction
Different manufacturing situations require different control systems (Bertrand, 1990). The Production systems are designed and tailored towards specific requirements. There are various kinds of production system and they include customer order, jobbing, batch and mass production. The production for customer order is production planning and control with an order from customer. The jobbing production involves small quantity on routine basis. The batch production is a lot or medium production with outline stages. Mass production involves production in a large scale with continuous process (Sharma, 2003). The identification of defect that occurred in the products, analysing the root cause to minimize the number of future defects is important in industrial production (Gaspersz, 1998; Montgomery, 2009; Laurence, 2011).
Polyvinyl chloride (PVC) is thermoplastics type of polymer that can be softened and re-solidified by adding or removing heat. This is possible through extrusion, injection moulding and processing equipment. The various type of thermoplastics include polymers such as polyethylene (PE), polypropylene (PP), polystyrene (PS), polyvinyl chloride (PVC), polymethyl methacrylate (PMMA or acrylic), acrylonitrile butadiene styrene (ABS), polycarbonate (PC), polyethyleneterephthalate (PET), polybutylene terephthalate (PBT), polyamide (PA or nylon) and polyphenylene sulphide (PPS). The thermoplastic polymers listed are used in extrusion applications (Giles et al, 2005). However, production process in Imurat International Limited Minna, (IIL) is by customer order/jobbing production. The industry produces pipes using production process called plastic extrusion process.

Production is always interchangeable with the word manufacturing, whereas the term ‘manufacturing’ is widely used in USA; the production term is widely accepted in Europe and Japan (Sharma, 2003). The word ‘manufacturing’ is derived from the
Latin words ‘manus’ and ‘factus’ meaning hand and made respectively, that is, the literal meaning is ‘made by hand’. Manufacturing has always been the key to success among nations in the world economy (Cohen, 1987). Production is defined by Telsang (2008) as a step by step approach for converting material to another through chemical or mechanical process to create or enhance the utility of the product for the user.

Plastic extrusion of the pipe involves converting resin to a semi-finished/finished product. The resin is a raw material in form of plastic pellets or powder. The conversion takes place by forming a homogeneous molten mass in the extruder. It requires forcing it under pressure through an extrusion die orifice that gives the shape of the products cross section. The formed material, or extrudate, is cooled and drawn away from the die exit at a controlled rate. The extrudate can then be wound on a spool, cut to a specified length, or directed into another in-line process. Degu and Moorthy (2014), specified that pipe production is carried out in eight distinct stages and they include mixing, helical spring conveyor, extruder, vacuum, cooling, hauling, cutting and belling units.

According to Sahu (2011), use of PVC pipes as electrical conduits, in water supply, irrigation, deep tube well and drainage systems and other industrial activities are well known. It has light weight, non-corrosiveness and high tensile strength that can withstand high fluid pressure.

Effective production management, planning, design and control in thermoplastic industry require a regulatory process or set of procedures to improve productivity like quality control that incorporates reliability analysis into its production. With the application of reliability analysis and quality control of polyvinyl chloride (PVC) pipe production in IIL, Minna there will be effective and continuous production.

Reliability of production processes ensures the stable system operation towards product quality and reduction in production loss. Reliability analysis includes failure modes and effect analysis (FMEA), the network reduction, the decomposition, the delta–star, and Markov methods (Dhillon, 2002).

FMEA is adopted in this study for correcting the mode of failure in the production process. The FMEA process is being used in three areas of product specification and namely design, manufacturing and service. A design FMEA examines potential product failures and the effects of these failures to the end user. Manufacturing or process FMEA examines the variables that can affect the quality of a process. The aim of a service FMEA is to prevent the misuse or misrepresentation of the tools and materials used in servicing a product. Quality control has primary function of controlling the quality of a manufacturing process using sampling techniques and control chart in order of requirement. There must be conformity to the required product design (AbdulKareem, 2001). Quality control helps to generate level of confidence in achieving quality in the design product. Therefore, this study looked into Imurat, Minna production system and examine the causes of machine failure and pipe quality control.

Development of P-chart for pipe production control, determination of acceptable quality level (AQL) of the pipe, development of operating characteristics curve (OCC) for the pipe production, analysing of pipe production failure using FMEA.

This study made use of statistical quality control tool called P-chart to control PVC production process. The study gave the
range of acceptable quality level (AQL) and operating characteristics curve (OCC) of the pipe. The acceptance level developed for risk taking was at 5% and 10% for both producer and consumer. The production process of the pipe was analysed through failure mode and effect analysis (FMEA). The FMEA will include the review of mode, causes and effect of failure during production process.

Materials and Methods

Materials
The research materials for carrying out reliability analysis and quality control of polyvinyl chloride pipe production in Imurat International Limited (IIL) Minna involved the produced pipe itself and testing equipment.

PVC Specification
The PVC pipe product specification was obtained by approval standardisation of ASTM (D-1598) Standard Test Method for Time-to-Failure of Plastics under constant internal pressure for pressure and water transmission pipe.

The following pipes were used to conduct the experiment.
Specimen A: conduit pipe of 20mm diameter by 1.2mm thickness with 1MPa pressure rating.
Specimen B: conduit pipe of 20mm diameter by 1.5mm thickness with 1MPa pressure rating.
Specimen C: conduit pipe of 25mm diameter by 3mm thickness with 1MPa pressure rating.
Specimen D: conduit pipe of 32mm diameter by 3mm thickness with 1.5 MPa pressure rating.
Specimen E: conduit pipe of 32mm diameter by 3mm thickness with 1MPa pressure rating.
Specimen F: sewage pipe of 50mm diameter by 1.5mm thickness with 1.5 MPa pressure rating.
Specimen G: sewage pipe of 50mm diameter by 3mm thickness with 1MPa pressure rating.
Specimen H: sewage pipe of 75mm diameter by 1.5mm thickness with 1.5 MPa pressure rating.
Specimen I: sewage pipe of 75mm diameter by 4mm thickness with 1MPa pressure rating.
Specimen J: sewage pipe of 110mm diameter by 1.5mm thickness with 1.5 MPa pressure rating.
Specimen K: sewage pipe 110mm diameter by 4mm thickness with 1 MPa pressure rating.

Testing Equipment
The equipment used for the test were the Shore-D equipment for hardness test, TIRA test 2810 equipment for flexural test and KARG equipment for impact test. Figs. 1, 2 and 3 show the Shore-D Equipment.

Fig. 1: Shore-D Equipment

Fig. 2: TIRA test 2810
Quality Control Analysis

Quality control analysis refers to the processes of testing, measuring and comparing the PVC pipe with specified standard and then determining whether it should be accepted, rejected, adjusted or reworked. The P-chart was adopted to check for good or bad pipe after production using attribute procedure. Quality control means bringing production variables such as temperature, pressure and extruder speed of the PVC pipe production under control. To check for the quality of the PVC pipe P-chart was adopted for the analysis.

P-chart
Selection of appropriate pipe size under consideration, 100% inspection sampling method was adopted, control limits were developed, satisfactory control limits was for preliminary test, revised control is necessary if preliminary is not satisfied, Plotting the P-chart and taking corrective measure as standard for production process.

The fraction defective (p) is given as (Sharma, 2003):
\[
p = \frac{n}{N} \quad (1)
\]
\[
P = 100p \quad (2)
\]
\[
\sigma_p = \sqrt{\frac{p(1-p)}{n}} \quad (3)
\]
\[
UCL = p + 3\sigma_p \quad (4)
\]
\[
LCL = p - 3\sigma_p \quad (5)
\]
\[
CL = 3\sigma_p \quad (6)
\]

\( UCL = \) Upper control limit, \( LCL = \) Lower control limit, \( CL = \) Center line

\( p = \) Fraction defective, \( P = \) Percent defective, \( n = \) Number of defective in a sample

\( \sigma_p = \) Standard deviation of the sample average of defective,

\( N = \) Total number of sampled data, \( \bar{n} = \) Average number of sampled data

Operating Characteristics Curve (OCC)

The graphical relationship between percentage defective and probability of acceptance of produced pipe is called operation characteristics curve (OCC). Probability of acceptance of defective pipe was determined using Poisson distribution. The following steps was followed: determination of average acceptance number of the pipe, probability of acceptance of defective pipe was determined using Poisson distribution and Plotting of OCC graph.

Acceptable Quality Level (AQL)
The acceptable quality level of the pipe depends on acceptance of risk for defective pipe from both producer and consumer. According to Montgomery (2009), the AQL is the possible lowest level of quality of pipe in which producer is intending to supply and consumer will agree as an acceptable process average of the pipe. The following steps were adopted; determination of probability of acceptance of defective pipe in a continuous process using Binomial distribution, determination of producer risk at 5%, determination of consumer risk at 10%, determination of lot tolerance percentage defective (LTPD)
Bi
where:

\[ n = \text{Number of defective,} \]
\[ q = \text{Possibility of defective occurrence,} \]
\[ p = \text{Possibility of defective is not occurring} \]

**Reliability Analysis Using FMEA**

The steps required and used in this study to analyse the possible failure are as follows (Dhillon, 2006):

1. Identifying the manufacturing process and requirements.
2. Identifying the system components involved in the manufacturing process.
3. Identifying of system components failure modes.
4. Assigning appropriate failure rate to each component.
5. Identifying the effect of failure mode on the system components.
6. Assigning appropriate remarks for each failure modes.
7. Verifying failure mode on each component and the appropriate action that was taken.

In this study, the reliability and availability of the pipe extrusion machine was evaluated and given by (Dhillon, 2006):

**Failure rate,**

\[ \lambda(t) = \frac{f(t)}{R(t)} = \frac{\text{number of failed component (n)}}{\text{testing period in hour (T)}} \]  \hspace{1cm} (9)

**Failure probability function,**

\[ f(t = 1\text{month}) = \lambda e^{-\lambda t} = F(t) \]  \hspace{1cm} (10)

**Reliability,**

\[ R(t) = 1 - F(t) = 1 - \int_{0}^{t} f(t) \, dt \]  \hspace{1cm} (11)

**Mean time between failures (MTBF),**

\[ MTBF = \int_{0}^{\infty} e^{-\lambda t} \, dt = \frac{1}{\lambda(t)} \]  \hspace{1cm} (12)

**Availability**

\[ \frac{\text{MTBF}}{\text{MTBF} + \text{MTTR}} = \frac{\text{uptime}}{\text{uptime} + \text{downtime}} \]  \hspace{1cm} (13)

**Mechanical Testing**

Mechanical testing of the pipe was done using standard test procedure as explained below.

**Flexural Test**

Flexural tests measure bending resistance of the pipe. This was performed on the flexural machine used to measure tensile tests.

**Impact Test**

This is a process in which a load is applied to the pipe surface to determine its resistance. The pipe was struck by a pendulum released from a fixed height and energy absorbed by the pipe was determined. The absorbed energy is the impact value.

**Hardness Test**

Hardness testing is normally used for testing tension or bending analysis in a given specimen. The adopted test method was Brinell Hardness (BH) test in this study. The (BH) uses the area of indentation under load. In this test, a steel ball of about 10mm in diameter was pressed against a chosen surface of the PVC pipe with a load of 50 kg to form indentation on the surface. The indentation diameter produced was then measured to compute the BH number. The BH number is defined as the ratio of the load P to the curved surface area of the indentation.

\[ BH = \frac{2P}{\pi D (D - \sqrt{D^2 - d^2})} \]  \hspace{1cm} (14)
= Load (N), = External diameter of indentation (mm), = Internal diameter of indentation (mm), \( \pi \) = Constant

Table 1: Summary of inspected specimen with defective numbers.

<table>
<thead>
<tr>
<th>Day (D)</th>
<th>Sample size (1000)</th>
<th>Defective number</th>
<th>Defective fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.00</td>
<td>100</td>
<td>0.0385</td>
</tr>
<tr>
<td>2</td>
<td>3.00</td>
<td>102</td>
<td>0.0340</td>
</tr>
<tr>
<td>3</td>
<td>1.00</td>
<td>65</td>
<td>0.0490</td>
</tr>
<tr>
<td>4</td>
<td>2.00</td>
<td>80</td>
<td>0.0400</td>
</tr>
<tr>
<td>5</td>
<td>3.00</td>
<td>92</td>
<td>0.0307</td>
</tr>
<tr>
<td>6</td>
<td>1.00</td>
<td>167</td>
<td>0.1670</td>
</tr>
<tr>
<td>7</td>
<td>2.50</td>
<td>120</td>
<td>0.0480</td>
</tr>
<tr>
<td>8</td>
<td>2.50</td>
<td>130</td>
<td>0.0520</td>
</tr>
<tr>
<td>9</td>
<td>2.90</td>
<td>89</td>
<td>0.0307</td>
</tr>
<tr>
<td>10</td>
<td>2.50</td>
<td>88</td>
<td>0.0352</td>
</tr>
<tr>
<td>11</td>
<td>3.00</td>
<td>87</td>
<td>0.0290</td>
</tr>
<tr>
<td>12</td>
<td>2.50</td>
<td>100</td>
<td>0.0400</td>
</tr>
<tr>
<td>13</td>
<td>1.00</td>
<td>89</td>
<td>0.0890</td>
</tr>
<tr>
<td>14</td>
<td>1.00</td>
<td>168</td>
<td>0.1180</td>
</tr>
<tr>
<td>15</td>
<td>2.50</td>
<td>150</td>
<td>0.0600</td>
</tr>
<tr>
<td>16</td>
<td>1.80</td>
<td>171</td>
<td>0.0950</td>
</tr>
<tr>
<td>17</td>
<td>2.50</td>
<td>98</td>
<td>0.0382</td>
</tr>
<tr>
<td>18</td>
<td>2.20</td>
<td>99</td>
<td>0.0490</td>
</tr>
<tr>
<td>19</td>
<td>1.50</td>
<td>130</td>
<td>0.0887</td>
</tr>
<tr>
<td>20</td>
<td>2.50</td>
<td>76</td>
<td>0.0304</td>
</tr>
<tr>
<td>Total</td>
<td>44.1</td>
<td>2201</td>
<td></td>
</tr>
</tbody>
</table>

Results and Discussion

Results
The analysis of reliability and quality control of produced pipe in Imurat International limited, Minna is presented in this section.

Quality Analysis: The pipe production is controlled using quality control procedure. The eleven different pipes under consideration in 20 days were designated for each different pipes under study. From Control Analysis of Conduit Pipe specimens that were inspected at 100%. However, 1950 pipes found defective among 138760 of the produced pipes which were detected through the three tests and visual inspection. The control has been observed based on the production. However, P-chart plotted in Fig. 1 shows UCL to be the first point on plot at 0.016314 while last point on the plot was LCL at 0.008286 of the conduit pipe. This translated to the process being out of control in all of the days. Based on the trend it is recommended that the conditions for the control be reviewed for greater productivity.

Fig. 4: Fraction defective of conduit pipe

The average allowable production was 6938 pipes per day and at ranges of defective pipes was at 57 to 112 pipes which is allowed according to the control. Sewage Pipe Control Analysis Specimens F, G, H and I were inspected at 100%.

Table 1 shows the number of inspected items with the defective numbers and defective factors. Specimen J and K were inspected. However, 2201 pipes found defective among 44100 of the produced pipes.

Fig. 2 shows UCL to be the first point on plot at 0.0612 while last point on the plot was LCL at 0.0336 of the conduit pipe. The average allowable production was 2400 pipes per day and at maximum defective of 147 pipes and possible minimum defective of 81 pipes.
Acceptable Quality Level

The acceptable quality level (AQL) was plotted in graph of Fig. 4. Only 9 of these pipes are acceptable through LTPD and this is consumer risk while 1 of the pipe is the producer risk at AQL point.

Mechanical Test and Reliability Analysis

Mechanical Test of PVC Pipe

Mechanical test was conducted based on flexural; hardness and impact test for the pipe. Table 2 is stated the result. The produced pipe was within range of ASTM-D1598 testing standard. However, in Table 2 permissible average elongation 59.8% for the pipe. The hardness value (HRC) of 25.4 on average.

Table 2: Mechanical Test of Pipe

<table>
<thead>
<tr>
<th>Specification</th>
<th>ASTM-D1598</th>
<th>Mechanical Test</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure (kPa)</td>
<td>1035±35</td>
<td>1000-1500</td>
<td>Extrusion pressure</td>
</tr>
<tr>
<td>Surge Pressure allowance (m/s)</td>
<td>0.61-6</td>
<td>2.797</td>
<td>Impact test</td>
</tr>
<tr>
<td>Nominal size (water pipe/mm)</td>
<td>100-914±25</td>
<td>50-110</td>
<td>Die setting</td>
</tr>
<tr>
<td>Extrusion temperature (°C)</td>
<td>140-190±2</td>
<td>160-180</td>
<td>Extrusion temperature</td>
</tr>
<tr>
<td>Tensile strength (MPa)</td>
<td>10.3-51.7</td>
<td>7.9±5.3</td>
<td>Flexural test</td>
</tr>
<tr>
<td>Elongation (%)</td>
<td>40-450</td>
<td>59.8</td>
<td>Impact test</td>
</tr>
<tr>
<td>Hardness Rockwell</td>
<td>26-43.5</td>
<td>25.4</td>
<td>Hardness test</td>
</tr>
</tbody>
</table>
Reliability Analysis

Table 3: Effect of Failure Mode of PVC.

<table>
<thead>
<tr>
<th>PVC stages</th>
<th>Product failure</th>
<th>MTBF (hr)</th>
<th>MTTR (hr)</th>
<th>A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mixer and Drier</td>
<td>Product surging, variation in quality and colour contamination</td>
<td>720.0</td>
<td>24</td>
<td>1.00</td>
</tr>
<tr>
<td>Extruder</td>
<td>Product surging, variation in product strength</td>
<td>720.0</td>
<td>24</td>
<td>0.67</td>
</tr>
<tr>
<td>Die</td>
<td>Gauge variation and poor strength</td>
<td>360.0</td>
<td>24</td>
<td>0.66</td>
</tr>
<tr>
<td>Cooling system</td>
<td>Holes in extrudate</td>
<td>720.5</td>
<td>24</td>
<td>0.67</td>
</tr>
<tr>
<td>Puller and cutting system</td>
<td>Gauge and size variation</td>
<td>720.5</td>
<td>24</td>
<td>0.66</td>
</tr>
<tr>
<td>Inspection and packaging</td>
<td>Poor quality and packaging</td>
<td>720.5</td>
<td>24</td>
<td>0.67</td>
</tr>
</tbody>
</table>

The study system was reliable and available for PVC pipe production as at year 2014. The system reliability was at 99.1% and availability was at 83.4%. The occurrence of possible failure (MTTBF) in the production process was at after 5 days (121 hours) continuous production process while the machine needed shut down to check for failure within 24 hours. The shutdown for fixing the failure was the mean time to repair (MTTR).

Table 4 shows each stage of production system based on reliability, availability, corrective measure required for fixing the failure per month. The total component considered was 35 components throughout the system while 6 components failed during study time. The average studying time for this analysis was 30 days (720 hours).

Table 4: Stage of production system based on reliability, availability, and corrective measure.

<table>
<thead>
<tr>
<th>Stages</th>
<th>FC</th>
<th>FR</th>
<th>R</th>
<th>MTBF (hr)</th>
<th>MTTR (hr)</th>
<th>A</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. M</td>
<td>0</td>
<td>0.00000</td>
<td>1.000</td>
<td>720.0</td>
<td>24</td>
<td>1.00</td>
</tr>
<tr>
<td>2. E</td>
<td>1</td>
<td>0.00138</td>
<td>0.998</td>
<td>720.5</td>
<td>24</td>
<td>0.67</td>
</tr>
<tr>
<td>3. D</td>
<td>2</td>
<td>0.00277</td>
<td>0.997</td>
<td>360.0</td>
<td>24</td>
<td>0.66</td>
</tr>
<tr>
<td>4. C</td>
<td>1</td>
<td>0.00138</td>
<td>0.998</td>
<td>720.5</td>
<td>24</td>
<td>0.67</td>
</tr>
<tr>
<td>5. P</td>
<td>1</td>
<td>0.00138</td>
<td>0.998</td>
<td>720.5</td>
<td>24</td>
<td>0.67</td>
</tr>
<tr>
<td>6. Q</td>
<td>1</td>
<td>0.00138</td>
<td>0.998</td>
<td>720.5</td>
<td>24</td>
<td>0.67</td>
</tr>
</tbody>
</table>

Discussion

The defective conduit pipes were 1950 pipes among 138760 of the produced pipes. The average conduit pipe production rate was at 6938 pipes per day. In the first control the production on 1st, 3rd, 6th, 8th, 9th, 13th, 14th and 19th days were not within the range of quality assessing method considered. Hence, revised control was also considered and average pipe production was at 6872 pipes per day. The difference between the two control could be has a result of the control approach, control condition and also the production rate.

OCC in Fig. 3 shows that zero defective pipe will be almost acceptable by the consumers while LTPD shows that 9 defective conduit pipes was consumer risk for buying 6872 pipes. The produced pipe was within range of ASTM-D1598 testing standard, except for the permissible average elongation 59.8% for the pipe and hardness value (HB) of the pipe was at 63.4 on average.

Conclusions

The steps involved in the manufacture of rigid PVC pipes included extrusion, sizing, traction and cutting section. Extrusion of un-compounded PVC resin is not suitable for direct processing therefore it requires additives for processing stability. The downtime of an extrusion system depends on the reliability of each working component and its parts in the system. The reliability of the system may not be 100% assured but to some condition the production requires to be above average under normal condition. The reliability of an automated extrusion machine in IIL,
Minna was the sum of the reliability of its component parts. IIL Minna operates based on installed capacity of 8000 conduit and 3000 sewage pipes per day under normal condition. The pipes were checked using 100% inspection methods. The revised control was considered at average pipe production rate of 6872 conduit pipes per day. The revised control of sewage PVC pipe was at 2400 pipes per day. Operating characteristic shows zero defective pipes is more acceptable. The produced pipe was within range of ASTM-D1598 testing standard. However, the permissible average elongation was at 59.8% for the pipe with hardness value (BHN) of 25.4 was outside the standard range.

References


Performance of a Modified Pulse Sheller Evaluated Under Selected Operation Factors


*Department of Agricultural and Bio-resources Engineering, Ahmadu Bello University, Zaria
**National Agricultural Extension and Research Liaison Services, Ahmadu Bello University, Zaria
E-mail: ibdalha@abu.edu.ng

Abstract
Pulse sheller was designed to shell different varieties of leguminous crops such as groundnut, cowpea, among others. Some components of the machine such as cylinder, cylinder drum, concave grates, feed hopper, and grain delivery chute were modified to enable increase in feed rate for more output. The performance was evaluated using a local groundnut variety; Bahaushiya. A combination of four speed levels; 2.59, 2.79, 2.98 and 3.18 m/s (130, 140, 150 and 160 rpm) and three feed rates (8, 10 and 12 kg/min) were used for the performance evaluation of the modified shelling machine. The effects of some operation factors; cylinder speed and feed rate were assessed statistically in a completely randomized block design. Least Significant Difference (LSD) method was employed to assess the effect of parameter levels. The optimum performance of the modified machine using groundnut was found at a cylinder speed of 3.18 m/s (160 rpm) with a feed rate of 8 kg/min. These gave an output capacity, shelling efficiency, cleaning efficiency, scatter loss and damaged grains of 254.99 kg/h, 94.90, 97.22, 6.29 and 14.00 % respectively. The cylinder speed was found to have positive linear trends with all the performance indices at various feed rates except grain damages. The effects of the selected variables on the performance indices were assessed and revealed that cylinder speeds levels were found to have highly significant effects on all indices except output capacity, similarly those of feed rates were highly significant on all performance indices.

Keywords: Pulses; Operation factors; Shelling efficiency; Cleaning efficiency; Output capacity

Introduction
According to Olaoye (2002) some crop parameters and machine variables are known to influence the performance of threshers, each or combination of these parameters has an impact on threshing ability and grain damage. The author noted that the influence of both threshing ability and grain damage translate to measurable grain losses if not properly managed. To minimize losses in a mechanical shelling, performance of the shelling machine must be evaluated using machine, crop and processing variables such as cylinder speed, moisture content, feed rate, among others. Shelling of grain crop is a unit operation that requires some sets of processing conditions that must be attained for effective shelling action to be accomplished through manual or mechanical operation. Inappropriate shelling conditions in a manual shelling process reduces the grain output with respect to excessive and high energy input (Olaoye, 2002). In a mechanical shelling process the effect of the inappropriate operating conditions does not only affect the effective recovery of the grains from other materials but it also leads to high grain loss. Grain losses are measured in terms of the damage to the grain kernel, loss to the mechanical elements and germination inability of the seeds. Proper adjustment of the operating conditions in a mechanical shelling has been determined as the most critical success factors in grain shelling (Olaoye, 2002; Olaoye, 2004). The key variables of interest are generally classified as the machine parameters, crop characteristics and influencing
environmental or processing conditions, the fundamental and influencing environmental processing conditions with direct bearing on the effective performance of shelling systems are moisture content and feed rate (Olaoye, 2004). Younis et al. (1997) developed a peanut shelling machine. Results of the machine evaluation indicated that breakage was reduced from 57 to 54 %, cleaning efficiency increased from 67 to about 96 %, and separation efficiency increased from 28 to 93 % and total loss was also decreased from 57 to about 4 % in comparison with the initial performance of the shelling machine. Helmy (2001) designed, built and evaluated a reciprocating shelling machine to study the effects of some operating parameters on shelling peanut from the pods. He found that, the peanut shelling efficiency was 95.44 % at about 17.12 % moisture content on dry basis, when the speed, the clearance and feed rate were 1.4 m/s, 18 mm and 80 kg/h respectively. Abubakar and Abdulkadir, (2012) reported that, traditional method of shelling groundnut has proved to be inefficient, time consuming, laborious, and low output. Due to the lack of an efficient motorized machine to shell groundnut, small scale farmers generally depend upon manual shelling. This is time consuming operations and do not match the shelling requirements within a limited period of time. Manual processing is still the norm in Nigeria despite the drudgery and time wastage involved. Drudgery is generally conceived as physical and mental strain, fatigue, monotony and hardships experienced while doing a job (Renuka, 2007). It is certain that, if appropriate drudgery reducing machineries are made available to the rural farmers, it would contribute in drudgery reduction in labour productivity, increased capability, and consequently reduction in greater workload thereby improving labour efficiency. The search for more efficient and cost effective way of shelling raised the demand for the evaluation of pulse shelling machine.

Materials and Methods

Materials
Gauge 16 (A36 mild carbon steel) with a Minimum yield stress of 250 MPa and ultimate tensile strength of 400 – 550 MPa was used for the production of cylinder housing while gauge 18 plate was used for feed hopper and grain delivery chute. The beaters were made from cast iron bars. The materials used for the performance evaluation of the machine were 600 kg of groundnut (Bahauhiya) for preparation of samples, tachometer for the measurement of cylinder speed, weighing balance for quantifying samples, and stop watch for recording the shelling time.

Sample preparation
A local variety known as “Bahauhiya”, used for this study, was procured locally from Dawanau market. The bulk of materials were prepared in to 36 samples of 4, 5 and 6 kg as feed rates for the three replications.

Method

Description of the Modified Machine
The pulse sheller used in this present study, is a modified form of IAR groundnut shelling machine (Plate I). The machine shells and cleans. The two processes are achieved in one operation with the delivery of clean grains at the grains outlet. It consists of the prime mover, shelling unit and cleaning unit. The prime mover is a diesel engine of 6 hp capacity. The components of the machine are; hopper, shelling cylinder, removable concave (Plate II), clearance adjuster (Plate III), blower, chaffs outlet, grains delivery chute and frame.
Plate I: A Pictorial View of the Modified Pulse Shelling Machine

**Operational procedure**
The crops were fed through the hopper to the shelling chamber where shelling is achieved by impact and rubbing action of the cylinder. The shelled materials were pushed through the concave to the cleaning chamber where a stream of air from the blower passed across the falling materials to blown off the chaffs to the chaffs outlet and allow grains to be delivered to the grains outlet.

**Experimental procedure**
The machine performance was evaluated using groundnut sample prepared based on the experimental layout in randomized complete blocked design. The samples were fed into the machine through the hopper and allowed to be shelled while the shelling time was recorded. The materials delivered at the grain outlet and the grains from the chaffs outlet were collected separately and labeled. All the samples collected and labeled were taken to the laboratory in which the foreign materials were separated from the clean grains manually while each was weighed and recorded. Beside, broken grains were sorted out of samples collected from the clean grains then weighed and recorded. The data recorded were used to determine the machine performance indices.

**Components modified**

**Cylinder size**
The cylinder size was increased with the view to increasing its volume to accommodate more quantity (large feed rate) of the crop used. The quest to achieving an increased shelling capacity was the basis for the cylinder size increment. However, the volume of the modified cylinder (0.5 m$^3$), as determined by equation (1), was found to increase by more than 5 times the existing cylinder volume.

$$ V = \pi r^2 h $$  \hspace{1cm} (1)

where: $V$ = cylinder volume (m$^3$), $r$ = cylinder radius (m), and $h$ = cylinder width (m)

**Cylinder drum**
An increased cylinder size called for the modification of the existing cylinder drum to fit the shelling chamber for an improved performance particularly shelling efficiency and capacity. Beside, modification of the cylinder drum was in view to facilitating effective shelling of the required quantity of the crop to be fed, that is the proposed feed rates. The cylinder drum was modified to have 6 bars made of cast iron. A cast iron bars, for the modified drum, are heavier than mild steel flat bars, for the existing drum, of equal size. Using cast iron aimed at increasing the weight of the cylinder drum that would possibly increase the impact force on the streaming crop pods hence, increasing the rate of shelling to counteract the increased quantity of the feed rates. Each cast iron bar, supported by three plates, has 33 conical projections at the bottom face arranged in staggered fashion as a shelling tooth. The existing cylinder drum has a cylindrical tooth type which was modified to conical type with plat end to increase the shearing force required by reducing its contact (surface) area to a narrower shape. Apparently, it was an assertion that the rate of pods shelling could possibly be increased with the increase in shearing force. Equation (2) was used to determine the weight of its components as; Shelling bar 27.50 N, Shelling tooth 0.061 N and Supporting plate 0.357 N. The net weight is 355.23 N

$$ W_f = \delta g v $$  \hspace{1cm} (2)
where: \( W_f \) = Weight of the fan blade (N), \( \delta \) = Density of the fan galvanized steel blade = 7850 kg/m\(^3\), \( g \) = Acceleration due to gravity = 9.81 m/s\(^2\), \( \nu \) = Volume of the fan blades = 8.453x10\(^{-5}\) m\(^3\)

\[
D_g = \left( \frac{6\nu g}{\pi} \right)^{1/3} 
\]

(4)

where: \( D_g \) = Equivalent diameter (mm) and \( V_g \) = Grain volume (mm\(^3\))

The concave size

An increased cylinder size also called for the modification of the existing concave by increasing its size and radius. The concave size was determined in relation to the width of the modified cylinder size. The modified radius of curvature was determined using the expression given by Dangora et al. (2006)

\[
r_c = r_d + h_p + c_c
\]

(3)

where: \( r_c \) = Concave radius (210 mm), \( r_d \) = Radius of cylinder drum (180 mm) \( h_p \) = Peg height above the drum (7 mm), \( c_c \) = Concave clearance (23 mm)

The concave grates (holes)

The concave grates for the existing machine were round in shape but modified to oval shape (Plate III), to better suit groundnut shelling, based on the determined properties of the crops varieties selected. This aimed at improving the rate of passage of the shelled materials out of the chamber in bulk due to increase in feed rate. The grates were arranged in a staggered passion. It was designed to have a length of 40 mm which was determined based on the average length of the groundnut pods (29.12 mm) with a tolerance of 25 % higher than the average length. The grates curved at both ends with 10 mm diameter each based on the average equivalent diameter of the groundnut varieties used. The equivalent diameter of the groundnut pods were determined using equation below:

\[
D_g = \left( \frac{6\nu g}{\pi} \right)^{1/3}
\]

Feed hopper

The existing feed hopper was long and vertically positioned on top of the cylinder cover of the machine which extend beyond average operators’ height that might likely pose ergonomic problems during operation. The feed hopper and its orientation were modified based on the angle of repose of the pods for the selected crops. This was basically for it to accommodate large quantity of the materials to be fed and to ergonomically conform to the operators’ height for reduced stress. It was designed to have an overall height of 300 mm and width of 450 mm. The bottom faces of front and back were inclined at an angle of 38° and 43° respectively. The hopper has a total volume of 3.33x10\(^{-2}\) m\(^3\).

Grain delivery chute

The grain outlet of the existing machine was a perforation directly beneath the shelling chamber for which the shelled materials falls directly on to a tray by gravity. Only a tray could be used to collect the shelled grain which is ergonomically risky. Beside, having increased width of the machine called for a better design that would facilitate easy and ergonomically safe collection of the shelled grains by the side of the machine. In addition, to enable continuous collection of bulk materials delivered due to increase in feed rate. The
Performance of a Modified Pulse Sheller Evaluated Under Selected Operation Factors

A grain outlet was designed and positioned beneath the shelling chamber along its width and inclined downward to the side of the machine. It has a rectangular shape inclined at an angle of 11.98°.

Experimental design and analysis
The experiment was based on Randomized Complete Block Design (RCBD). A moisture content of 11.11% was used during the experiment. Four levels of cylinder speeds; 130, 140, 150 and 160 rpm and three levels of feed rates; 8, 10 and 12 kg/min with three replications were considered for the evaluation of modified machine using groundnut as a test crop. Analysis of Variance (ANOVA) and Least Significant Difference (LSD) were used to assess the effect of the variables, their interactions, their significant differences.

Performance evaluation
The performance of the pulse shelling machine was evaluated based on the following indices; shelling efficiency, cleaning efficiency, damaged grains, scattered loss, and output capacity. These were achieved using the procedure outline by Abubakar and Abdulkadir, (2012).

i) Shelling efficiency, $S_e$ (%):
\[
S_e = \left( \frac{Q_D}{Q_T} \right) \times 100
\]

ii) Cleaning efficiency, $C_e$ (%):
\[
C_e = \left( \frac{Q_C}{Q_T} \right) \times 100
\]

iii) Mechanical damage, $M_d$ (%):
\[
M_d = \left( \frac{Q_D}{Q_T} \right) \times 100
\]

iv) Scattered loss, $S_L$ (%):
\[
S_L = \left( \frac{W_S}{Q_T} \right) \times 100
\]

v) Output capacity, $C_p$ (kg/hr):
\[
C_p = \frac{Q_D}{T}
\]

Where: $Q_D$ = Quantity of damaged groundnut in sample (kg), $Q_T$ = Total quantity of grains collected per unit time (kg), $Q_C$ = Quantity of shelled groundnut (kg), $Q_T$ = Total quantity of groundnut sample (kg), $Q_U$ = Quantity of unshelled groundnut (kg), $T$ = total time of shelling

Results and Discussion

Results
The experimental and calculated results obtained when the modified machine was evaluated using a local groundnut variety; Bahaushiya, are presented in appendix A and B respectively. The summary of the analysis of variance tables for the performance indices and operational parameters ranking based on Fisher’s Least Significant Difference (LSD) method for the evaluation of the modified machine using groundnut are presented in appendix C and D respectively.

Discussion
Effect of cylinder speed and feed rate on the machine Performance
Effects of cylinder speed on shelling efficiency at various feed rates
The shelling efficiency using groundnut ranges from 91.67% to 96.00%. The minimum efficiency was obtained at a speed of 2.98 m/s (150 rpm) and a feed rate of 8 kg/min while the maximum was at a speed of 2.98 m/s (150 rpm) and a feed rate of 12 kg/min (Appendix A). The trend of cylinder speed and shelling efficiency at various feed rates shows a positive linear relationship (Fig. 1). This implies that the shelling efficiency increased with increase in cylinder speed at different feed rates which was due to increased in impact force on the pods. This is similar to the findings of Dalha et al., (2014) in terms of trend and ranges though the shelling efficiencies were found to be a little higher than those of this work at most of the feed rate levels. The differences could be attributed to the quantity of the materials fed and combination of some shelling factors such as tooth and concave grate shapes. The trend at a feed rate of 10 kg/min is more symmetrical compared to other feed rate levels, having the highest coefficient of determination ($R^2 = 0.895$). The feed rate level has the least gradient ($a =$...
1.98) which is indicating the least degree of increased in shelling efficiency with the increased in cylinder speed. However, the degree of increased in shelling efficiency with the increase in cylinder speed is more pronounced with a feed rate of 12 kg/min, having the higher gradient \((a = 4.241)\). The results of the analysis of variance shows that the effect of speeds, feed rates and their interactions were highly significant on shelling efficiency at 1% level of confidence (Appendix B). A further analysis to assess the effects of these variables and their interactions using LSD method indicated that speeds level; 3.18 m/s and 2.98 m/s were statistically at par, likewise 2.98 m/s and 2.79 m/s though the effect of 3.18 m/s was greater than that of 2.79 m/s. Similarly, the feed rates level; 12 kg/min and 10 kg/min were statistically at par, likewise 10 kg/min and 8 kg/min though the effect of 12 kg/min was greater than that of 8 kg/min. A combination of speed level of 3.18 m/s and 12 kg/min feed rate were ranked the best interaction (Appendix C), hence could be the best treatment combination for the shelling process.

Fig. 1: Variation of Groundnut Shelling Efficiency with the Cylinder Speeds at Various Feed Rate

Effect of cylinder speed on cleaning efficiency at various feed rates
The cleaning efficiency for groundnut shelling ranges from 90.94 % to 97.44 %. The minimum efficiency was obtained at a cylinder speed of 2.59 m/s (130 rpm) and a feed rate of 12 kg/min while the maximum was at 3.18 m/s (160 rpm) and 8 kg/min (Appendix A). The trend of cylinder speed and cleaning efficiency at various feed rates shows a positive linear relationship (Fig. 2). This mean, it increased with increase in cylinder speed at different feed rates levels which was due to increase in fan speed. As the fan speed increased there was more stream of air flowing across the fallen objects thereby blowing off the materials other than grains. This is similar to the findings of Dalha et al., (2014) in terms of trend and ranges though the cleaning efficiencies were found to be a little lower than those of this work at most of the feed rate levels. The differences could be attributed to the higher speed levels selected for this experiment. The trend lines for all the feed rate level symmetrically indicated closed coefficient of determination \((R^2 = 0.934 − 0.983)\) with the highest at 10 kg/min while the lowest is at 12 kg/min. The degree of increased in cleaning efficiency with the increase in cylinder speed is more pronounced with a feed rate of 8 kg/min, having the higher gradient \((a = 6.727)\). The results of the analysis of variance shows that the effects of speeds and feed rates were highly significant on cleaning efficiency at 1% level of confidence while the effects of their interactions were not significant at 5% level (Appendix B). When assessing the effects of these variables using LSD method, it was found that the effects of the speed levels were not statistically the same but 3.18 m/s was ranked the best. However, the feed rates levels exhibit otherwise that; 8 kg/min and 10 kg/min were statistically at par, likewise 10 kg/min and 12 kg/min though the effect of 8 kg/min and 12 kg/min was greater than that of 12 kg/min (Appendix C).
Performance of a Modified Pulse Sheller Evaluated Under Selected Operation Factors

Fig. 2: Variation of Groundnut Cleaning Efficiency with the Cylinder Speeds at Various Feed Rates

Effect of cylinder speed on grain damage at various feed rates
A range of 12.00% to 26.67% groundnut grain damage was obtained at the cylinder speed 2.79 m/s (140 rpm) and 2.98 m/s (150 rpm) respectively (Appendix A). The percentages exceeded the expected limit. This could be attributed to the assertion that the shelling teeth were having sharp edges that could easily shear off the grains. In addition, some larger seeds might not be able to pass through the concave opening resulting in more breakage. However, this is not similar to the findings of Dalha et al., (2014). The change in grain damage with increase in cylinder speed at feed rates of 10 and 12 kg/min best fitted a negative polynomial function while that of 8 kg/min gave a positive polynomial function (Fig. 3). The grain damage reaches maximum at a speed of 2.98 m/s and tends to decrease with the cylinder speed. This could be attributed to the fact that when the cylinder speed exceed 2.98 m/s, the centrifugal force due to cylinder rotation increases thereby reducing the grain dwelling time in the cylinder and increasing their tendency to passed out thus reducing the level of breakage. The effects of cylinder speeds, feed rates and their interactions on grains damage were highly significant at 1% level (Appendix B). When these effects were further analysed, the effects of speed levels were not statistically equal while the speed level of 2.98 m/s was ranked the most significant. For the feed rate, the effects of its levels were also not equal and the highest level of 12 kg/min was ranked the most affecting. When assessing the interactions of these variables both levels of 2.98 m/s and 12 kg/min formed the highest combination in terms of grain damage (Appendix C). Hence, the best levels in terms of minimum grain damage are 2.79 m/s and 8 kg/min cylinder speed and feed rate respectively.

Fig. 3: Variation of Groundnut Grains Damage with the Cylinder Speeds at Various Feed Rates

Effect of cylinder speed on scatter loss at various feed rates
For groundnut, a maximum scattered loss of 7.58% was obtained at a speed of 3.18 m/s (160 rpm) with a feed rate of 8 kg/min while a minimum of 0.50% was obtained at a speed of 2.59 m/s (130 rpm) and feed rate of 12 kg/min (Appendix A). The losses indicated higher percentages compared to that of Dalha et al., (2014) which could be due to high grain damage and increase in fan speed. The scattered losses of the machine increased with the increase in cylinder speed at various feed rates but decreased with the increase in feed rates at the higher speed levels (Fig. 4). These were due to the reduction in speed when there were more materials in the shelling chamber resulting in the reduction in the volume of air stream required to blow off the chaffs at the lower speed level. The trend at a feed rate of 12 kg/min is symmetrically better than others, having the higher coefficient of
determination ($R^2 = 0.952$) but least gradient ($a = 8.02$) which is indicating the least degree of increase in scatter loss with the increase in cylinder speed. However, the degree of increase in scatter loss with the increase in cylinder speed is more pronounced with a feed rate of 8 kg/min, having the higher gradient value ($a = 9.124$). The analysis of variance shows that the effects of speeds and feed rates were highly significant at 1% level on the scattered losses but their interactions were not significant at 5% level (Appendix B). Further analysis shows that the effects of the speed levels were not statistically equal while the highest speed level of 3.18 m/s was ranked to have high contribution to scatter loss. However, the effects of feed rates levels were found otherwise that; 8 kg/min and 12 kg/min were statistically having the same effect, likewise 12 kg/min and 10 kg/min (Appendix C). However, this signifies that a speed level of 2.59 m/s and feed rate of 10 kg/min could be the best in terms of minimum scattered losses.

**Fig. 4:** Variation of Groundnut Grains Scatter Loss with the Cylinder Speeds at Various Feed Rates

**Effect of cylinder speed on output capacity at various feed rates**

A maximum output capacity of 254.99 kg/h was obtained at a speed of 3.18 m/s (160 rpm) and a feed rate of 8 kg/min while a minimum of 211.05 kg/hr was obtained at a speed of 2.98 m/s (150 rpm) with a feed rate of 12 kg/min (Appendix A). The output capacity indicated a great improvement in comparison with findings of Dalha et al. (2014). Certainly, the difference was due to increase in the cylinder size and modification of some of its attributing components. The output capacity does not indicate a specific pattern with the increase in cylinder speed at various feed rates but decreased with increase in feed rates which could be attributed to clogging effect when large feed rates were fed (Fig. 5). The output capacity at a feed rate of 8 kg/min indicated a positive trend and is symmetrically better than others having the higher coefficient of determination ($R^2 = 0.989$) but that of 10 kg/min indicated a negative trend with the coefficient of determination of 0.564. However, the trend at a feed rate of 12 kg/min, which is positive, is symmetrically poor having the least and very low coefficient of determination ($R^2 = 0.194$). The effect of cylinder speeds was not significant at 5% level while that of feed rates was highly significant at 1% level and their interactions were also highly significant at 1% level (Appendix B). When these effects were further analyzed, the feed rate levels; 8 and 10 kg/min were statistically equal likewise 10 and 12 kg/min. However, when assessing the interactions of these variables a feed rate level of 8 kg/min and speed of 3.18 m/s gave the best interaction (Appendix C).

**Fig. 5:** Variation of Groundnut Output Capacity with the Cylinder Speeds at Various Feed Rates
Conclusions
The performance of the modified pulse shelling machine was evaluated using groundnut as test crop and the machine was able to satisfactorily shell the crop though with higher grain damage. The cylinder speed was found to have positive linear trends with all the performance indices at various feed rates except grain damages. The effects of the selected variables on the performance indices were assessed and revealed that the cylinder speeds were found to have highly significant effects on all indices except output capacity meanwhile those of feed rates were highly significant on all performance indices. The best performance of the modified machine using groundnut was found at a speed of 3.18 m/s (160 rpm) with a feed rate of 8 kg/min. These gave an output capacity, shelling efficiency, cleaning efficiency, scattered loss and damaged grains of 254.99 kg/h, 94.90, 97.22, 6.29 and 14.00 % respectively.

References:


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Appendices:
Appendix A: Average Experimental Data for the Evaluation of Modified Pulse Sheller using Groundnut

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Additional Data

- S: Sample Number
- C1-C9: Different Operational Parameters
- D1-D3: Different Feed Rates
- E1-E3: Different Cylinder Speeds

Notes:
- Numbers in brackets represent the percentage of performance indices.
- Bold numbers indicate significant differences.
where: $Q_D = \text{Quantity of damaged groundnut in sample} \ (kg)$, $Q_S = \text{Total quantity of grains collected per unit time} \ (kg)$, $Q_{CE} = \text{Quantity of shelled groundnut} \ (kg)$, $Q_{DF} = \text{Quantity of unshelled groundnut} \ (kg)$, $T = \text{total time of shelling (hr)}$, $W_C = \text{Weight of whole materials collected at the outlet} \ (kg)$, $W_S = \text{Weight of scattered groundnut} \ (kg)$, $Q_{CF} = \text{Quantity chaffs collected at the grains outlet} \ (kg)$

**Appendix B:** Average Calculated Data for the Evaluation of Modified Pulse Sheller using Groundnut

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<th>Ce ( %)</th>
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<td>4</td>
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<td>12</td>
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<td>41</td>
<td>02</td>
<td>33</td>
<td>53</td>
<td>05</td>
</tr>
</tbody>
</table>

Where: $S_e = \text{Shelling efficiency}$, $C_e = \text{Cleaning efficiency}$, $M_d = \text{Damaged grains}$, $S_L = \text{Scatter loss}$, $C_P = \text{Output Capacity}$

**Appendix C:** Summary of the Analysis of Variance for the Performance Indices of Groundnut Shelling

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Degree of Freedom</th>
<th>Calculated F Values</th>
<th>Observed F Values</th>
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<tr>
<td></td>
<td></td>
<td>νd</td>
<td>νs</td>
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<tr>
<td>Error</td>
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<tr>
<td>Speed</td>
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<tr>
<td>Friction</td>
<td>F2 (m/s)</td>
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<tr>
<td>Total</td>
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**Appendix D:** Operation Parameters Ranks based on Fisher’s Least Significant Difference (LSD) Method for the Modified Machine using Groundnut

<table>
<thead>
<tr>
<th>Operation parameters</th>
<th>Performance indices</th>
<th>Speed</th>
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<th>Speed</th>
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<td>F1</td>
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<td>S2</td>
<td>S3</td>
<td>F1</td>
<td>F2</td>
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<td>F1</td>
<td>F2</td>
<td>S2</td>
<td>S3</td>
<td>F1</td>
<td>F2</td>
<td>S2</td>
<td>S3</td>
<td>F1</td>
<td>F2</td>
<td>S2</td>
<td>S3</td>
<td>F1</td>
</tr>
<tr>
<td>S1</td>
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<td>F2</td>
<td>S2</td>
<td>S3</td>
<td>F1</td>
<td>F2</td>
<td>S2</td>
<td>S3</td>
<td>F1</td>
<td>F2</td>
<td>S2</td>
<td>S3</td>
<td>F1</td>
</tr>
<tr>
<td>S1</td>
<td>F1</td>
<td>F2</td>
<td>S2</td>
<td>S3</td>
<td>F1</td>
<td>F2</td>
<td>S2</td>
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</tbody>
</table>

Effect of Pulverized Snail (Achantina fulica) Shell Reinforcement on the Mechanical Properties of High Density Polyethylene Composite

A.S. Abdurahman*, A.O. Umeliwu
Department of Materials and Metallurgical Engineering, Federal University of Technology, Minna, Nigeria
E-mail: asipita.salawu@futminna.edu.ng

Abstract
The quest for good environmentally friendly and viable materials have led way to series of intensive research on fibre reinforced polymer. The mechanical properties of high density polyethylene is insufficient to suit the requirement in most automobile, structural and engineering use. It is against these backlashes, the effect of snail shell (Achantina fulica) reinforcement on High Density Polyethylene (HDPE) was investigated in this work. Composites of Achantina fulica (AF) with High Density Polyethylene were produced using compression moulding at 10, 20 and 30 % loading of the filler at 130°C. XRF was used to determine oxide composition of the pulverized AF filler. The XRF of the pulverized AF filler revealed that Ca, Al, Si and Fe were the dominant constituent while Mg, and Ti where seen in traces. The composites were subjected to physical and mechanical tests. The physical tests carried out are density and water absorption while the mechanical tests carried out are tensile strength, flexural strength, hardness and the impact strength. The investigation showed that the density was seen to increase from 0.95 g/cm³ to 1.11 g/cm³ as the filler content increased from 10% to 30%. The water absorption also increased from 0.009 % to 0.011 % while the tensile strength increased from 15.36 MPa to 16.97 MPa from 10 wt% loading and decreased from 16.97MPa to 12MPa at 30wt% loading. The young modulus increased from 46.13 MPa at 0 wt% to 58.32MPa at 10 wt% loading while the percentage elongation was decreasing throughout the loading. Furthermore, the flexural strength increased from 19.91 MPa at 0 wt% loading to 27.47 MPa at 10 wt% was and then decreased consistently to 15.96 MPa at 30 wt% loading. The hardness and impact increased consistently throughout the loading.

Keywords: Composite, Reinforcement, Snail Shell, High Density Polyethylene, Compression Moulding

Introduction
The quest for good environmentally friendly and viable materials have led way to series of intensive research on fibre reinforced polymer. Fibre-reinforced plastics or polymer (FRP) is a composite material usually made of polymer matrix reinforced with fibres. Composites materials are natural or artificial material from multiphase constituent materials with distinct chemical and physical properties which mostly remains separate and significant, in the finished structure. Most composites have strong, stiff fibres in a matrix which is weaker and less stiff (Martin, 2013). The quality and property study of composites material reinforced with fillers for better engineering properties have been on considerable increase. Bio-reinforced composites consist of polymer matrix and reinforcing filler, with the matrix acting as binders for the fillers (Srinivasababu et al., 2010). The importance of low-cost natural fibre reinforced thermoplastics composites are being unveiled in consumer applications such as automobile, building and construction industries because of the
benefit such as renewability, environmental friendliness and biodegradability accrued by their uses (Athijayamani et al., 2009). These benefits qualified the composites as having a replacement potential for glass and currently used reinforcement composites material. In the automobile industry, polymer composite material offers good weight reduction possibilities, thereby increasing the fuel consumption efficiency and reduces the emission of CO$_2$ (Aigbodion et al., 2013).

Polyethylene is a widely used inexpensive thermoplastic that has been researched on extensively in polymer science and engineering, mainly because it is chemically simple and it has an increasing number of applications (Lin et al., 2005). They are generally grouped into high density polyethylene (HDPE) and low density polyethylene (LDPE), depending on the polymerization method applied during synthesis of ethylene. Polyethylene is a synthetic plastic employed in the production of films, sheets, bottles and containers, pipes and tubes, and in wire and cables insulation (Yasim and Daniel, 2004). More of its application in relation to engineering requirement are still being researched and are yet to be discovered. A variation of additive in the form of fillers and reinforcements are added to polyethylene to meet various engineering requirements.

Natural reinforcement is favoured over synthetic reinforcement due to positive environmental benefits such as reutilization of agro waste leading to a sustainable environment (Maleque et al., 2012). They also have an added advantage of being easily available as the source is renewable, cheap and biodegradable. Snail (Achantina fulica) shell is a neglected agricultural waste produced globally in large quantities (Fig. 1), in countries like Nigeria, Spain, Ghana, Cameroon etc. It has good strength which makes it potentially capable of been used as reinforcing fillers. The use of fibers (fillers) results in composites having better mechanical properties which depend on the dispersion and also the content of the filler used. It is expected that there should be a good mix between the filler and matrix interface, this can be achieved when the polymer successfully wet the filler surface. Furthermore, another reason for adding fibres (fillers) are complex, for instant improving may be sought in wear, fracture and toughness etc.(Histon et al., 2004)

![Fig. 1: Snail Shells](image)

There are quite a number of landmarks in the development of polymers. Usually polymer cannot be discussed without the understanding of plastics. The first man-made synthetic plastics accredited to Dr. Leo Hendrik Baekeland (1907) were Bakelite invented in New York and other polymers followed (ASNHCL, 2015).

During the early 20$^{th}$ century, massive organic and physical research led to the understanding of the concept of polymer structures, which consists of long chains of
covalently bonded molecules which Carothers worked with to discover nylon while Hermann standing known as the father of polymer worked on poly-oxy-methylene which is indeed a wonderful contribution (David, 2004). Staudinger used the word micro molecules to describe giant molecules composed in polymers according to his proposed theory. Also the discovery of nylon by Carothers was a mile stone to the nature of polymer he also classified polymers into condensation and addition polymers still in used today. Prof. Karl Ziegler developed a specific stereo-catalyst which enabled alteration of polymer molecular structures which opened the gate for modification of polymer for desired use. Engineering thermoplastics also saw lights in the 1950s, the polycarbonates and acetal, together with nylon, polynide and polysulfone with superb thermal ability, impact strength and physical stability. Thermoplastic polyesters, nitrite resins, polyphenylenesulphide were introduced in the 1960s and 1970s to meet requirements in the aircraft industries of which today are now used in areas requiring high temperature (David, 2014).

Composites are materials said to be composed of strong load bearing materials (reinforcement) usually imbedded in weaker ones (matrix). The strength and rigidity of the reinforcement provides structural support for load. The position and coordination of the reinforcement is maintained by the matrix. Distinctive constituent do not change in their chemical and physical properties but produce formidable quality not possessed individually (Hull and Chyne, 1996). The mechanical properties of high density polyethylene are insufficient to suit the requirement in automobile, structural or other engineering applications. Therefore it is pertinent to look into reinforcing the plastic polymer with cheaply available agro-waste to improve the mechanical strength at low-cost. The purpose of this research therefore, is to investigate the effect of Snail (Achantina fulica) Shell particulate on the mechanical and physical properties of High Density Polyethylene. To achieve this, the XRF, physical and mechanical characterization of the polymer composite was carried out.

Materials and Methods
Materials
The materials used in this research are HDPE which was obtained from Nigerian Institute of Leather and Science Technology (NILEST), Zaria, snail shells collected from a farm in Awka, Anambra State, lime and water for cleaning the AF shells, hammer mill, sieve of 75µm mesh size and digital weighing machine.

Methods
Characterization of the Snail Shell
The XRF analysis was carried out on the Snail (Achantina fulica) shell and its various elemental compositions were determined using Oxford instrument- X Supreme 8000 according to the ASTM D4294 standard.

Fig. 2: Pulverized Snail (Achantina fulica) shell

Preparation of the Snail Shell Particulate
A.S. Abdurahman, A.O. Umeliwu

The snail shells collected were cleaned using lime and water, properly sundried for 2 weeks, pulverized using a hammer mill and then sieved to have a finer grain particle using sieves of different aperture ranging from 75 µm- 425 µm with the particles in the sieve of mesh size 75 µm used.

Cleaning and Shredding of the HDPE

The HDPE obtained was cleaned using water and sun dried for one hour after which it was shredded into smaller sizes for easy feeding into the two roll mill. The shredded HDPE was weighed into different percentages as required and labeled for easy identification.

Mixing

The two roll mill was started and set to the processing temperature of the HDPE (135°C ± 5°C), after a total melt was obtained the filler was then incorporated according to the formulation in Table 1 after which a homogenous mix was obtained and the sample was then sheeted.

<table>
<thead>
<tr>
<th>Table 1: Sample Formulation</th>
</tr>
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<tbody>
<tr>
<td></td>
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<tr>
<td>Control Sample</td>
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<tr>
<td>AF Particulate</td>
</tr>
<tr>
<td>HDPE</td>
</tr>
</tbody>
</table>

Moulding

The compression moulding machine was switched on and the temperature was set to 130°C. The molten composite sample from the two roll mill was placed in the mould to press into a flat sheet. The mould was placed between the platens of the compression moulding machine and was removed after 5 minutes from the mould. The moulded samples are as shown in the Fig. 3.

Fig. 3. Photograph of moulded specimen

Composite Density Determination

The density of the composite specimens was determined using Archimedes principle. The principle is useful for determining the volume and therefore the density of an irregularly shaped object. The mass of the samples in air was measured and recorded and its effective mass when submerged in water was also recorded. The density was calculated using by Equation 1.

\[
\text{Density}(\rho) = \frac{\text{mass}(M)}{\text{volume}(V)} \tag{1}
\]

Composite Water Absorption Test

The specimen was weighed and recorded as initial weight (W1), the specimen was then immersed in water for 24 hours. After which it was brought out and the surface cleaned of water. The specimen was then reweighed and (W2) recorded. The water absorption was calculated in percentage using Equation 2. (use either “sample” or “specimen” and be consistent, see underlined)

\[
\text{Water absorption (Wt %)} = \frac{W2 - W1}{W1} \times 100 \tag{2}
\]

Where W1 is the weight of the specimen before immersion in water and W2 is that after immersion.
Effect of Pulverized Snail (Achantina fulica) Shell Reinforcement on the Mechanical Properties of High Density Polyethylene Composite

Composite Tensile Strength Test
The Monsanto Tensometer machine was used to carry out the tensile test with a capacity of 1.2KN. The standard specimen size was mounted on the clamps of the Tensometer. The Tensometer was devised to measure the applied load and extension simultaneously.

Hardness Test
Hardness test was carried out on the test sample, with ASTM D2240 standard using the Durometer. The sample was placed on the sample holder and the indentor knob was pressed on it. The hardness value was read as displayed on the pointer at three indentations, taken the average value as the hardness value in IRHD (International Rubber Hardness Degree).

Impact Test
The test was achieved using Resil Impactor test instrument, the test sample was positioned on the test machine and firmly held, the total energy absorbed during impact was calculated after the pendulum has swung. The calculation for the impact strength was thus calculated using Equation 3 (Adnan et al., 2015).

\[ \text{impact strength (I.S.)} = \frac{\Delta U}{A \times m^2} \]  \hspace{1cm} [3]

where U denotes the impact value of the specimen as displayed and A represents the area of the specimen.

\[ A = l \times b \]  \hspace{1cm} [4]

L and B depicts the length and breadth of the specimen respectively in Equation 4.

Flexural Strength
The dimension of the specimen used for the flexural strength test analysis was 30x100mm. The test was administered at a constant gauge length of 80mm and the load was applied via a hand pump. Values of the applied load and deflection were recorded from the extensometer digital readout and the load cell digital readout and were used to calculate the flexural strength from the universal testing machine for the flexural strength test with the aid of Equation:

\[ \text{Flexural strength (F.S.)} = \frac{3FL}{2bd^2} \]  \hspace{1cm} [5]

where F denotes the load at a specified point of fracture in newton, L represents the gauge length in millimeters, b is the width of the sample specimen in millimeters, and d connotes the specimen thickness is also measured in millimeters.

Results and Discussion

Results
The results of the HDPE/AF particles Composite are shown below in Figs. 4, 5, 6, 7, 8, 9 and 10 for XRF characterization, Density variation, water absorption, Tensile Strength, Percentage Elongation and Young modulus, Hardness, Impact energy and flexural strength respectively. Also summary of the results is tabulated in Table 2.

Fig. 4. Spectra for Achantina fulica characterization

Fig. 5. Variation of Density of HDPE/AF particles Composite
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Fig. 6: Variation of Water Absorption of HDPE/AF composite Sample

Fig. 7: Variation in Tensile Strength, Percentage Elongation and Young modulus of HDPE/AF Composite Sample

Fig. 8: Variation of Hardness of HDPE/AF Composite sample

Fig. 9: Variation of energy absorbed during impact

Fig. 10: Flexural strength Analysis of the Sample

Table 2: Summary of the Results Obtained

<table>
<thead>
<tr>
<th>AF wt%</th>
<th>Snail shell composition (%)</th>
<th>ρ (g/cm³)</th>
<th>WA (%)</th>
<th>TS (MPa)</th>
<th>E (MPa)</th>
<th>δ (%)</th>
<th>Hardness</th>
<th>Impact Str (kJ/m²)</th>
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<tr>
<td>0</td>
<td>0</td>
<td>0.9</td>
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<td>15.2</td>
<td>46.2</td>
<td>32.6</td>
<td>17.47</td>
<td>46.69</td>
</tr>
</tbody>
</table>

Discussions
The XRF analysis of the AF shell ash in Fig. 4 confirmed that the major elemental composition of AF were CaO, Al₂O₃, Fe₂O₃ and SiO₂. Fe₂O₃ and CaO are part of the hardest substances. Included are other Oxides like MgO, P₂O₅, TiO₂, K₂O, Na₂O which were found in fragments. The existence of hard elements like Fe₂O₃, SiO₂, CaO, and Al₂O₃ suggests that AF shell particle could be used as filler material to improve the mechanical properties of HDPE polymer.

From the result in Fig. 5, the density tends to increase with increase in filler content. This shows an increase in mass as a result
Effect of Pulverized Snail (Achantina fulica) Shell Reinforcement on the Mechanical Properties of High Density Polyethylene Composite

of filler addition at constant volume causing an increase in the density of the sample.

Fig. 5 shows the rate of water absorption as it increases with increase in filler content when the sample is soaked in water for 24hrs. This could be due to the interfacial bonding between the filler and the polymer there by increasing the absorbency of the sample which is a disadvantage to the life span of the composite.

Tensile properties of different levels of loading of the AF shell of the blank HDPE and corresponding composites are in concise summary in the Figure 6. It can be seen that the tensile strength increased by 10 % loading of the Achantina Fulica which shows good phase compatibility and blending (Akanbi et al., 2015)and a decrease in the TS was then seen as the filler loading increases to 20% and 30%. The tensile strength decreases with the addition of filler in account of an increase in the adhesion quality between polymer and filler interface, when an incoherence in stress transfer to polymer-filler interface and the resin rich zones around the boundary of the filler tows surfaces. This is in accordance with the Nielson model (Parvin et al., 2013). The stiffness of the material indicated by the Young Modulus as seen in Figure 7 shows increase with the addition of filler as 10%, 20% and 30% filler addition showed 46.126, 58.316, 46.271 and 162.51MPa respectively. This consequently brought about a decline in the elongation of the samples. This may be attributed to the continuous increase in crystallinity of the sample which indicates better performance than the pure HDPE.

Similar to the water absorption test the hardness was seen to increase with the addition of filler and advances the composites resistance to wear and indentation as shown in Fig.8.

The impact strength of the reinforced matrix and the pure HDPE are shown in Figure 9. The pure HDPE displayed an impact strength of 50.13 kJ/m$^2$, a considerable increase was seen in the 10% filler loading which gave 56.09 kJ/m$^2$. Also 20%, 30% loading showed impact strength of 46.69 and 25.89 kJ/m$^2$ respectively following the same trend as showed by the TS. The impact strength decrease with increase in filler loading could be due to the tendency of filler interaction obstructing the flow of matrix and consequently decreasing the flexibility of polymer chain. Therefore, energy absorption of the composite during force is low (Cui et al., 2008).This is in accordance with Ghani et al (2012).

The flexural strength of the pure and reinforced matrix are shown in Figure 10. There was a corresponding increase in the flexural strength with increase in the filler content (AF) with the peak happening at 20% filler content which tend to show superior property when compared to the pure HDPE (Andradyl and Neal, 2009). The above data shows that the reinforced composite can withstand maximum load before failure. Table 2 gives a summary of the result.

Conclusions

In this research, the effect of Snail (Achantina Fulica) shell on High density polyethylene was investigated alongside the characterization of the pulverized Achantina shell. The produced composite was subjected to some physical and mechanical examinations. From the results
of the investigation, the following conclusions can be drawn:

1. The XRF analysis showed that the major constituent of AF shell include Ca, Al, Si and Fe which are known to be hard elements.
2. The density of the composite increases from 0.95g/Cm$^3$ at 0 wt% to 1.11g/Cm$^3$ at 30 wt%.
3. The water absorption increases from 0.009% at 0 wt% to 0.012% at 20 wt% and then starts decreasing as the loading progresses.
4. The composite has its highest value of tensile strength of 16.97MPa at 10 wt% loading, elongation decreases from 33.3% to 29.1% at 0 wt% and 10 wt% loading respectively while the highest value of the Young Modulus is 58.32MPa at 10 wt% loading.
5. The hardness value of the composite increases consistently throughout the loading from 84 to 97.
6. The impact and flexural strengths have their peak values as 56.09 KJ/m$^2$ and 27.47MPa respectively at 10 wt% loading.

References


Effect of Pulverized Snail (Achantina fulica) Shell Reinforcement on the Mechanical Properties of High Density Polyethylene Composite


Quality Evaluation of Hand Dug Wells Using Water Quality Index

M. Saidu*, D. O. Akuboh and I. O. Jimoh
Department of Civil Engineering, Federal University of Technology,
P. M. B. 65, Minna, Nigeria
Email: mohammed_saidu@futminna.edu.ng

Abstract
This research evaluate water quality from hand dug wells in Kubwa village in Abuja, Nigeria. Water samples were collected from five (5) hand-dug wells within Kubwa Village, and analysed for drinking: Physical, chemical and biological parameter come from the analysis of ground water. Twenty six (26) parameters were analysed in each of the hand well using American Public Health Association (APHA) standard laboratory method. The parameters investigated included Turbidity, Temperature, pH, Total Dissolved Solids (TDS), Sodium (Na), Potassium (K), Calcium (Ca), Magnesium (Mg), Chloride (Cl), Fluoride(F), Zinc (Zn), Nitrite (NO2), Bi-Carbonate (HCO3), Sulphate (SO4), Nitrate (NO3), Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Chromium (Cr), Iron (Fe), Alkalinity, Carbonate, Total Hardness(TH), Electrical Conductivity(EC), E-Coli and Total Coliform (TC). Weighted Arithmetic Water Quality Index method were used to obtain a single value for each well interpreted. An analyses of the results indicates that all water samples (W1, W2, W3, W4 and W5) were found to be unsuitable for drinking purpose using the Nigerian Standard for Drinking Water Quality (NSDWQ) as well as the World Health Organisation (WHO) standards to calculate the WQI as their WQI values were all above 100. The range of percentage difference of water quality index (WQI) determined using NSDWQ and WHO standards for the same water samples were determined to be 159.23% to 313.23%. Therefore, it has been established that apart from laboratory investigation and comparison of values of parameter obtained from laboratory against set water quality standards and weighted arithmetic water quality index is a good tool for summarizing and communicating the overall quality of given water.

Keywords: Groundwater, Water Quality, Water Quality Index, Water Quality Parameters

Introduction
Ground water is an important natural resource to human since it serve as an alternative to surface water for drinking. Groundwater is a source of drinking water, which is used by large population due to unavailable safe surface water. Owamah et al., (2013) revealed that sub-Saharan Africa which constitute about 40% of the world population lack access to portable drinking water. Ground water are usually used for domestic, industrial and agricultural purposes. High demand for water is due to rapid population growth and industrialization (Ramakrishnaiah et al., 2009). Water is an indispensable resources for life support (Sojobi et al., 2014). The provision of potable water to rural and urban population is necessary to prevent water-borne diseases (Okorafor et al. 2012). The quality and quantity of available water have implications on the health status of a community. According to the UN report, more than 5 million people die annually from diseases caused by drinking contaminated water and lack of adequate sanitation. Increase in human population has exerted enormous pressure on the provision of safe drinking water especially in developing countries.
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(Domènech and Saurí, 2011). Hence, the continuous monitoring of groundwater becomes mandatory to minimize and have control on the pollution causing agents. On like surface waters which are easily prone to contamination from diverse sources, ground waters on the other hand are more reliable for domestic and agricultural irrigation needs (Okeola et al., 2010; Haruna et al., 2008; Shymala et al., 2008). The aim of this work is to evaluate water quality of hand dug wells in Kubwa Village Abuja using water quality index.

Materials and Methods

Description of the Study Area

The Kubwa Community is located Abuja the city capital of Nigeria. The Kubwa community has been in existence since 1990 as a satellite town in Abuja. It is part of the Bwari Area Council which is one of the six (6) area councils. It has annual rainfall ranges from 1,100mm to 1,600mm, which is between March to November. Kubwa is underlain by rocks of various types and an undulating terrain. The Gwagi people were the original residents.

The environments of the water sources were surveyed to examine the sanitary condition of the environments to locate wells. Twenty six (26) water quality parameters were analysed according to APHA standard laboratory procedures as provided in the standard methods for the examination of water and waste water, (APHA, 2005). Weighted Arithmetic Water Quality Index (WAWQI) method was adopted for the determination of the water quality index. Water samples were collected from hand dug wells within the study area. New high-density PET screw-capped containers of 1.5 L capacity were used to collect the water samples. The PET containers and stoppers were thoroughly washed with distilled water three times and once with the water to be sampled before collecting the actual sample. At the same time, samples for microbial analysis were collected using autoclave-sterilized sample bottles from the same locations. The water samples were transported to the Laboratory. The water samples were preserved in an ice bag to keep the water content intact until analyses were carried out.

The samples analysed were Total Dissolved Solids (TDS), Sodium (Na), Potassium (K), Calcium (Ca), Magnesium (Mg), Chloride (Cl), Fluoride(F), Zinc (Zn), Nitrite (NO₂), Bi-Carbonate (HCO₃), Sulphate (SO₄), Nitrate (NO₃), Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Chromium (Cr), Iron (Fe), Alkalinity, Carbonate, Total Hardness(TH), Electrical Conductivity(EC), E-Coli and Total Coliform (TC). Detailed Information of the Hand-Dug Wells (Sample Sources) are presented in Table 1.
Table 1: Detailed Information of the Hand-Dug Wells (Sample Sources)

<table>
<thead>
<tr>
<th>Well Water Sample</th>
<th>Lining Material</th>
<th>Well Cover Material</th>
<th>Height Above EGL</th>
<th>Well Diameter</th>
<th>Approximate Depth</th>
<th>Distance of Well Closet Septic Tank/Soak Away Pit</th>
</tr>
</thead>
<tbody>
<tr>
<td>W1</td>
<td>Nil</td>
<td>Wood</td>
<td>0</td>
<td>1350</td>
<td>4830</td>
<td>200</td>
</tr>
<tr>
<td>W2</td>
<td>RC Rings</td>
<td>Flat Steel Sheet and Wood Cover</td>
<td>200</td>
<td>1000</td>
<td>4000</td>
<td>≤ 4000</td>
</tr>
<tr>
<td>W3</td>
<td>RC Rings</td>
<td>RC Slab and Wood Cover</td>
<td>170</td>
<td>900</td>
<td>5000</td>
<td>≤ 2500</td>
</tr>
<tr>
<td>W4</td>
<td>RC Rings</td>
<td>RC Slab and Plastic Cover</td>
<td>245</td>
<td>750</td>
<td>10000</td>
<td>≤ 4000</td>
</tr>
<tr>
<td>W5</td>
<td>RC Rings</td>
<td>RC Floor Slab and Flat Steel Cover</td>
<td>0</td>
<td>700</td>
<td>10000</td>
<td>≤ 4000</td>
</tr>
</tbody>
</table>

NOTE: EGL is Existing Ground Level and RC is Reinforced Concrete

Data Analysis
Microsoft Office Excel 2010 software package was used to statistically analyse the data. The mean values of the parameters analysed were computed for the water samples.

Calculation of Water Quality Index (WQI)
The groundwater samples were analysed for the twenty-six parameters and WQI was calculated using suitable number of parameters out of these twenty-six with both the NSDWQ 2007 and WHO water quality standards for the purpose of comparison. The weighted arithmetic water quality index (WAWQI) was calculated as follows:

1. The five groundwater samples were analysed for twenty-six (26) common parameters namely Na, K, Ca, Mg, Cl, HCO₃, SO₄, NO₃, DO, BOD, COD, Cr, Fe, TH, pH, TDS, EC, E-Coli, TC, Alkalinity, Turbidity, Fluoride, Zn, NO₂, Carbonate and Temperature.
2. The more hazardous a given groundwater pollutant, the lower its drinking water standard, and the unit weight WI for the ith parameter PI is assumed to be inversely proportional to its recommended guideline standard Si (i=1, 2, 3,...n); where n is the number of parameters.
3. Equation 1 shows the relationship between unit weights and the water quality standards

\[ w_i = \frac{K}{S_i} = \frac{1}{S_i} \]  
where,  
\( w_i \) is the unit weight  
k is the constant of proportionality which is equal to unity.

4. Except for pH, equation 2 below shows the relationship between the water quality rating \( (q_i) \) for the ith parameter PI, averages of the
observed data \( (V_i) \) and maximum permissible value in water quality standards \( (S_i) \).

\[
i = 100 \left( \frac{V_i}{S_i} \right)
\]  

(2)

5. For pH and DO, the quality rating \( q_{pH} \) and \( q_{DO} \) can be calculated from equation 3 since \( V_0 = 0 \) except in certain parameters like pH and dissolved oxygen

\[
q_{pH} = 100 \left( \frac{V_pH - 7.0}{8.5 - 7.0} \right)
\]  

(3)

6. Ultimately, the water quality index is calculated by taking the weighted arithmetic mean of the quality ratings \( q_i \) as shown in equation 4

\[
WQI = \left[ \frac{\sum (q_i.w_i)}{\sum w_i} \right]
\]  

(4)

where:

- \( WQI \) = water quality index
- \( \Sigma \) = summation
- \( q_i \) = quality rating for the \( i \)th water quality parameter
- \( w_i \) = unit weight for the \( i \)th parameter

**Note:** Except \( pH \) and DO, unit weights of the other parameters were calculated as the inverse of their guideline values.

7. The WQI obtained are now interpreted in accordance with the Water Quality Rating as per Weight Arithmetic WQI method presented in Table 2.

### Table 2: Weight Arithmetic Water Quality Index Rating

<table>
<thead>
<tr>
<th>WQI Value</th>
<th>Rating of Water Quality</th>
<th>Grading</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-25</td>
<td>Excellent water quality</td>
<td>A</td>
</tr>
<tr>
<td>26-50</td>
<td>Good water quality</td>
<td>B</td>
</tr>
<tr>
<td>51-75</td>
<td>Poor water quality</td>
<td>C</td>
</tr>
<tr>
<td>76-100</td>
<td>Very Poor water quality</td>
<td>D</td>
</tr>
<tr>
<td>Above 100</td>
<td>Unsuitable for drinking purpose</td>
<td>E</td>
</tr>
</tbody>
</table>

**Source:** Neerja *et al.*, (2012)

### Results and Discussion

Table 3 and Table 4 shows all physical parameters for the five (5) water samples, and the results of the laboratory test were within allowable limit of NSDWQ and the WHO Standards. While, Results shown in Table 6 indicate that some parameters exceeds the maximum allowable limits under the NSDWQ standards. The parameters that exceeds the maximum allowable limits under the WHO standards are Iron (Fe) which occurred in wells W1 to W5 and Dissolved Oxygen (DO) also occurred in W1 to W5. All other chemical/inorganic parameters were within acceptable maximum allowable limit for both the NSDWQ and WHO standards as shown in Table 5.
Dissolved Oxygen (DO) Concentration in all the water samples were above the maximum acceptable limit of 5mg/L as prescribed by WHO. The results also shows presence of E.coli bacteria in samples W1, W3 and W4 indicates that the water samples are not safe for drinking. The unsuitability of the well water samples for drinking purposes also agrees with the findings of Odiba et al., (2014), on a research Wukari Town, Taraba State, Nigeria. The differences in the values of the water quality index for the five wells might be attributed to the fact that some of the wells were located close to septic tanks, some without cover and some do not extend above the natural ground or floor level as indicated on Table 6. These findings agree with that of Yisa et al., (2012) who carried out similar study in Maikunkele area of Bosso Local Government Area of Niger State.

Table 3: Mean and Range of parameters for the five hand dug well water Sample

<table>
<thead>
<tr>
<th>S/No</th>
<th>Parameter</th>
<th>Notation</th>
<th>Unit</th>
<th>Groundwater Samples</th>
<th>Mean for Study Area</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>W1</td>
<td>W2</td>
<td>W3</td>
<td>W4</td>
</tr>
<tr>
<td>1</td>
<td>Sodium</td>
<td>Na</td>
<td>Mg/L</td>
<td>65.00</td>
<td>38.00</td>
<td>67.00</td>
</tr>
<tr>
<td>2</td>
<td>Potassium</td>
<td>K</td>
<td>Mg/L</td>
<td>43.00</td>
<td>20.00</td>
<td>22.00</td>
</tr>
<tr>
<td>3</td>
<td>Calcium</td>
<td>Ca</td>
<td>Mg/L</td>
<td>21.00</td>
<td>24.00</td>
<td>18.40</td>
</tr>
<tr>
<td>4</td>
<td>Magnesium</td>
<td>Mg</td>
<td>Mg/L</td>
<td>8.78</td>
<td>2.44</td>
<td>4.88</td>
</tr>
<tr>
<td>5</td>
<td>Chromium</td>
<td>Cr</td>
<td>Mg/L</td>
<td>0.05</td>
<td>0.01</td>
<td>0.03</td>
</tr>
<tr>
<td>6</td>
<td>Iron</td>
<td>Fe</td>
<td>Mg/L</td>
<td>4.5</td>
<td>25</td>
<td>38</td>
</tr>
<tr>
<td>7</td>
<td>Zinc</td>
<td>Zn</td>
<td>Mg/L</td>
<td>39</td>
<td>46</td>
<td>88</td>
</tr>
<tr>
<td>8</td>
<td>Fluoride</td>
<td>F</td>
<td>Mg/L</td>
<td>1.15</td>
<td>1.09</td>
<td>0.98</td>
</tr>
<tr>
<td>9</td>
<td>Chloride</td>
<td>Cl</td>
<td>Mg/L</td>
<td>23.90</td>
<td>13.10</td>
<td>21.20</td>
</tr>
<tr>
<td>10</td>
<td>Bi-Carbonate</td>
<td>HCO₃</td>
<td>Mg/L</td>
<td>30.00</td>
<td>13.00</td>
<td>28.00</td>
</tr>
<tr>
<td>11</td>
<td>Carbonate</td>
<td>CO₂</td>
<td>Mg/L</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>12</td>
<td>Sulphate</td>
<td>SO₄</td>
<td>Mg/L</td>
<td>45.00</td>
<td>21.00</td>
<td>30.00</td>
</tr>
<tr>
<td>13</td>
<td>Nitrate</td>
<td>NO₃</td>
<td>Mg/L</td>
<td>0.19</td>
<td>0.09</td>
<td>0.11</td>
</tr>
<tr>
<td>14</td>
<td>Nitrate</td>
<td>NO₂</td>
<td>Mg/L</td>
<td>0.19</td>
<td>0.09</td>
<td>0.11</td>
</tr>
<tr>
<td>15</td>
<td>Dissolved Oxygen Demand</td>
<td>DO</td>
<td>Mg/L</td>
<td>6.97</td>
<td>6.95</td>
<td>5.25</td>
</tr>
<tr>
<td>16</td>
<td>Biochemical Oxygen Demand</td>
<td>BOD</td>
<td>Mg/L</td>
<td>0.00</td>
<td>0.00</td>
<td>3.00</td>
</tr>
<tr>
<td>17</td>
<td>Chemical Oxygen Demand</td>
<td>COD</td>
<td>Mg/L</td>
<td>0.00</td>
<td>0.00</td>
<td>13.00</td>
</tr>
<tr>
<td>18</td>
<td>Turbidity</td>
<td>Tar</td>
<td>NTU</td>
<td>1.87</td>
<td>1.87</td>
<td>1.78</td>
</tr>
<tr>
<td>19</td>
<td>Temperature</td>
<td>T</td>
<td>°C</td>
<td>23.90</td>
<td>27.56</td>
<td>27.40</td>
</tr>
<tr>
<td>20</td>
<td>Total Alkalinity</td>
<td>Alk</td>
<td>Mg/L</td>
<td>30.00</td>
<td>13.00</td>
<td>28.00</td>
</tr>
<tr>
<td>21</td>
<td>Total Hardness</td>
<td>TH</td>
<td>Mg/L</td>
<td>90.00</td>
<td>64.00</td>
<td>66.00</td>
</tr>
<tr>
<td>22</td>
<td>pH</td>
<td>pH</td>
<td></td>
<td>6.92</td>
<td>6.21</td>
<td>6.53</td>
</tr>
<tr>
<td>23</td>
<td>Total Dissolved Solids</td>
<td>TDS</td>
<td>Mg/L</td>
<td>352.00</td>
<td>160.00</td>
<td>287.00</td>
</tr>
<tr>
<td>24</td>
<td>Electrical Conductivity</td>
<td>EC</td>
<td>mS/cm</td>
<td>525.00</td>
<td>259.00</td>
<td>428.00</td>
</tr>
<tr>
<td>25</td>
<td>Escherichia Coli</td>
<td>E. Coli</td>
<td>CFU/mL</td>
<td>101.00</td>
<td>0.00</td>
<td>126.00</td>
</tr>
<tr>
<td>26</td>
<td>Total Colloid</td>
<td>TC</td>
<td>CFU/100 mL</td>
<td>250.00</td>
<td>110.00</td>
<td>236.00</td>
</tr>
</tbody>
</table>
Quality Evaluation of Hand Dug Wells Using Water Quality Index

Table 4: Results of Physical Parameters for five hand dug well water samples

<table>
<thead>
<tr>
<th>S/N</th>
<th>Parameters</th>
<th>Notation</th>
<th>Unit</th>
<th>Ground water samples</th>
<th>NSDWQ 2007</th>
<th>WHO</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>W1</td>
<td>W2</td>
<td>W3</td>
</tr>
<tr>
<td>1</td>
<td>Turbidity</td>
<td>Tur</td>
<td></td>
<td>1.67</td>
<td>1.85</td>
<td>1.78</td>
</tr>
<tr>
<td>2</td>
<td>Temperature</td>
<td>T °C</td>
<td></td>
<td>27.40</td>
<td>27.50</td>
<td>27.40</td>
</tr>
<tr>
<td>3</td>
<td>pH</td>
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<td>6.92</td>
<td>6.21</td>
<td>6.57</td>
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<tr>
<td>4</td>
<td>Total Dissolve Solid</td>
<td>TDS mg/L</td>
<td>352.00</td>
<td>160.00</td>
<td>287.00</td>
<td>208.00</td>
</tr>
<tr>
<td>5</td>
<td>Electrical Conductivity</td>
<td>EC μS/cm</td>
<td>525.00</td>
<td>259.00</td>
<td>428.00</td>
<td>310.00</td>
</tr>
</tbody>
</table>

Table 5: Results of Chemical/Inorganic Parameters for Water Samples

<table>
<thead>
<tr>
<th>S/No</th>
<th>Parameter</th>
<th>Notation</th>
<th>Unit</th>
<th>Groundwater Samples</th>
<th>NSDWQ 2007</th>
<th>WHO</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>W1</td>
<td>W2</td>
<td>W3</td>
</tr>
<tr>
<td>1</td>
<td>Sodium</td>
<td>Na</td>
<td>Mg/L</td>
<td>82.00</td>
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<td>87.00</td>
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<tr>
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<td>Potassium</td>
<td>K</td>
<td>Mg/L</td>
<td>21.00</td>
<td>20.00</td>
<td>22.00</td>
</tr>
<tr>
<td>3</td>
<td>Calcium</td>
<td>Ca</td>
<td>Mg/L</td>
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<td>21.60</td>
<td>18.40</td>
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<tr>
<td>4</td>
<td>Magnesium</td>
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<td>Mg/L</td>
<td>8.78</td>
<td>2.44</td>
<td>4.88</td>
</tr>
<tr>
<td>5</td>
<td>Chromium</td>
<td>Cr</td>
<td>Mg/L</td>
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<td>0.01</td>
<td>0.05</td>
</tr>
<tr>
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<td>Iron</td>
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<td>Mg/L</td>
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<td>25</td>
<td>38</td>
</tr>
<tr>
<td>7</td>
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<td>Zn</td>
<td>Mg/L</td>
<td>89</td>
<td>46</td>
<td>88</td>
</tr>
<tr>
<td>8</td>
<td>Fluoride</td>
<td>F</td>
<td>Mg/L</td>
<td>1.35</td>
<td>1.09</td>
<td>0.98</td>
</tr>
<tr>
<td>9</td>
<td>Chloride</td>
<td>Cl</td>
<td>Mg/L</td>
<td>22.40</td>
<td>15.10</td>
<td>21.20</td>
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<tr>
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<td>Bi-Carbonate</td>
<td>HCO₃</td>
<td>Mg/L</td>
<td>30.00</td>
<td>13.00</td>
<td>28.00</td>
</tr>
<tr>
<td>11</td>
<td>Carbonate</td>
<td>CO₃⁺</td>
<td>Mg/L</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
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<tr>
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<td>Sulphate</td>
<td>SO₄²⁻</td>
<td>Mg/L</td>
<td>43.00</td>
<td>21.00</td>
<td>80.00</td>
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<tr>
<td>13</td>
<td>Nitrate</td>
<td>NO₃⁻</td>
<td>Mg/L</td>
<td>0.19</td>
<td>0.09</td>
<td>0.11</td>
</tr>
<tr>
<td>14</td>
<td>Nitrite</td>
<td>NO₂⁻</td>
<td>Mg/L</td>
<td>0.19</td>
<td>0.09</td>
<td>0.11</td>
</tr>
<tr>
<td>15</td>
<td>Dissolved Oxygen</td>
<td>DO mg/L</td>
<td>6.97</td>
<td>6.95</td>
<td>5.25</td>
<td>6.14</td>
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<tr>
<td>16</td>
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<td>BOD mg/L</td>
<td>0.00</td>
<td>0.00</td>
<td>3.00</td>
<td>2.00</td>
</tr>
<tr>
<td>17</td>
<td>Chemical Oxygen Demand</td>
<td>COD mg/L</td>
<td>0.00</td>
<td>0.00</td>
<td>17.00</td>
<td>8.00</td>
</tr>
<tr>
<td>18</td>
<td>Total Alkalinity</td>
<td>Mg/L</td>
<td>30.00</td>
<td>13.00</td>
<td>28.00</td>
<td>25.00</td>
</tr>
<tr>
<td>19</td>
<td>Total Hardness</td>
<td>TH</td>
<td>Mg/L</td>
<td>90.00</td>
<td>64.00</td>
<td>66.00</td>
</tr>
</tbody>
</table>

Table 6 indicates that samples W1, W3 and W4 exceed the maximum permissible limits of *Escherichia Coli* as recommended in NSDWQ and WHO standards. It also indicates that all water samples exceed the maximum permissible limits of *Total Coliform* under the NSDWQ as well as the WHO standards. Based on these findings, all the water samples are considered unsuitable for direct domestic consumption (drinking) without appropriate treatment. From the results in Tables 6 and 7 it indicates that calculating the WQI using the NSDWQ and WHO guidelines shows that all water samples (W1 to W5) are unsuitable for drinking purposes as their values exceed 100. The two water quality standards are therefore comparatively said to yield the same results in respect of interpretation of WQI for the given groundwater samples. However, the percentage difference in the WQI obtained using the NSDWQ and WHO guidelines ranges from 159.23% to 313.23%.
Table 7: Classification of Water Samples based on the WQI Rating table for NSDWQ and WHO guidelines.

<table>
<thead>
<tr>
<th>WQI Rating</th>
<th>Rating of Water Quality</th>
<th>Grading</th>
<th>NSDWQ</th>
<th>WHO Guidelines</th>
</tr>
</thead>
<tbody>
<tr>
<td>51 - 75</td>
<td>Poor Water Quality</td>
<td>C</td>
<td>W1, W2, W3, W4, W5</td>
<td>W1, W2, W3, W4, W5</td>
</tr>
<tr>
<td>76 - 100</td>
<td>Very Poor Water Quality</td>
<td>D</td>
<td>W1, W2, W3, W4, W5</td>
<td>W1, W2, W3, W4, W5</td>
</tr>
<tr>
<td>Above 100</td>
<td>Unsuitable for drinking purpose</td>
<td>E</td>
<td>W1, W2, W3, W4, W5</td>
<td>W1, W2, W3, W4, W5</td>
</tr>
</tbody>
</table>

Conclusion

It has been established that Weighted Arithmetic Water Quality Index (WAWQI) is an invaluable tool for summarizing and communicating the overall quality of a given water sample apart from laboratory investigation. It gives a single value for understanding and interpretation to professionals and decision makers. Thus, it can be considered as a confirmatory test of the results of direct comparison of the concentration of parameters in water samples against set maximum permissible limits of various water quality standards in the study area.

References


Okeola, F.O., Kolawole, O.D., and Ameen, O.M (2010). Comparative study of physic-chemical parameters of water from a River and it’s surrounding wells for possible interactive effect. *Advances in*


Case Hardening of Mild Steel Using Animal Bone, Charcoal and Sea Shells as Carburizers

R.A. Muriana , Bori Ige, O.K Abubakre, J.O Abu and C.E Sani

1Materials and Metallurgy Engineering Department, Federal University of Technology, Minna, Nigeria
2Mechanical Engineering Department, Federal University of Technology, Minna, Nigeria
E-mail: mraremu@yahoo.com

Abstract
Samples of Mild steel were treated in carburizing media which included animal bone, wood charcoal and sea shells at varied temperatures. Micro structural analyses, chemical composition tests, and mechanical properties tests were carried out on the carburized samples. Results indicated that the treated samples could be used in local production of some engineering components such as gears in place of imported components where hardness is considered together with toughness. The case hardening of the mild steel with charcoal granules gave the highest carburization of 0.905% on the surface with the highest hardness value of 69.3 HRA.

Keywords: Gears, carbon, energizer, carburization, mild steel.

Introduction
Metals are heat treated to obtain better properties for better engineering performances (Higgins, 2010). Different heat treatment methods including case hardening help in micro structural rearrangement of metal atoms which in turn causes controllable changes in the metals properties. Iron melting made of bloomeries produced two layers of metal: one with a very low carbon content that could be worked into wrought iron, and the rest a high carbon cast iron. Since the high carbon iron is hot short, meaning it fractures and crumbles when forged (Craig, 2006); it always needs further treatment. The wrought iron, with nearly no carbon in it is very malleable and ductile, but not hard. Case hardening involves packing the low-carbon iron within a substance with high carbon, then heating this pack to encourage carbon migration into the surface of the iron. This forms a thin surface layer of higher carbon steel, with the carbon content gradually decreasing deeper from the surface. The resulting product combines much of the toughness of a low-carbon steel core with the hardness and wear resistance of the outer high carbon steel as described by Wellyn (1997).

The traditional method of applying the carbon to the surface of the iron involved packing the iron in a mixture of ground bone and charcoal or a combination of leather, hooves, all inside a well-sealed box (Rajan et al., 2001). This carburizing package is heated to a high temperature for a length of time, usually between 900-920˚C, Sanjibku (2009). The longer the package is held at the high temperature, the deeper the carbon will diffuse into the surface. Different depths of hardening are desirable for different purposes: sharp tools need deep hardening to allow grinding and re-sharpening without exposing the soft core, while machine parts like gears might need only shallow hardening for increased wear resistance. The resulting case hardened part may show distinct surface discolourations, the steel darkens significantly and shows a mottled pattern of black, blue and purple, caused by the various compounds formed from impurities in the carbonaceous materials.

This work investigated case hardening of the locally obtained mild steel using charcoal (Ch), sea shells (Ss) and animal bone (Ab) as carburizers. Machines and automobile parts that are used where high impact
Case Hardening of Mild Steel Using Animal Bone, Charcoal and Sea Shells as Carburizers

Strength is needed often experience fatigue if not well treated before usage (Zamba and Sumansdi, 2004; Rajput, 2008). With the recent Automobile Policy of the Federal Government, the need for sustained and locally manufactured automobile parts such as axles, gears, cam shafts and crank shafts arises. A good way to solve this problem is through case hardening of mild steel used for the needed parts, whereby, carbon is introduced into the surface of the mild steel in which the inner core of the mild steel remains soft and tough.

In carburization, an amount of carburizer is packed into carburizing box and 20% of Barium trioxocarbonat (V) oxide (Ba₂CO₃) is mixed thoroughly with carburizer in the box. The Ba₂CO₃ acts as an energizer and promotes formation of carbon (IV) oxide (CO₂) gas, which in turn reacts with the excess carbon in the media to produce carbon II oxide (CO). The CO then reacts with the low carbon steel surface to form atomic carbon which diffuses into the steel, as shown in equations 1 - 5.

\[ \text{BaCO}_3 (s) \rightarrow \text{BaO} + \text{CO}_2 (g) \]  
\[ \text{CO}_2 (g) + \text{C} (s) \rightarrow 2\text{CO} (g) \]  
\[ \text{Reaction of cementite with carbon monoxide} \]  
\[ 2\text{CO} + 3\text{Fe} \rightarrow \text{Fe}_3\text{C} + \text{CO}_2 \]  
\[ \text{CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2 \]  
\[ \text{C} + \text{CO}_2 \rightarrow 2\text{CO} \]

Methodology

The materials used for this work included formulated carburizers (animal bone, wood charcoal, and sea shells), barium carbonate, mild steel of 0.193% C, stainless steel boxes. Mild steel rod of 32 mm diameter was obtained from Universal Steels Limited, Ogba - Lagos and analysed using a spectrometric analyser to obtain the chemical composition of elements present in the steel, Tables 1 and 2. A total of twenty one (21) samples of this steel were then prepared, while the various carburizing media – animal bone, wood charcoal, and sea shells were obtained and pulverized in a ball milling machine into fine powder of size range -90 µm to increase the surface area. Finally, three stainless steel boxes were fabricated to accommodate the carburizing media.

**Table 1: Characterization of Carbon Materials**

<table>
<thead>
<tr>
<th>S/N</th>
<th>Carburizers</th>
<th>Percentage Fixed Carbon (%)</th>
<th>Moisture Content (%)</th>
<th>Ash Content (%)</th>
<th>Volatile Matter (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ab</td>
<td>85.61</td>
<td>0.07</td>
<td>8.29</td>
<td>6.10</td>
</tr>
<tr>
<td>2</td>
<td>Ch</td>
<td>76.43</td>
<td>0.024</td>
<td>7.20</td>
<td>16.37</td>
</tr>
<tr>
<td>3</td>
<td>Ss</td>
<td>78.86</td>
<td>0.058</td>
<td>7.70</td>
<td>13.44</td>
</tr>
</tbody>
</table>

**Table 2 Chemical Composition of the Mild Steel before Heat Treatment**

<table>
<thead>
<tr>
<th>C</th>
<th>Mn</th>
<th>Cr</th>
<th>Ni</th>
<th>Mo</th>
<th>V</th>
<th>Si</th>
<th>Fe</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.193</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>0.062</td>
<td>98.92</td>
<td></td>
</tr>
</tbody>
</table>

**Sample Preparation**

The mild steel rod was machined to tests sizes of 25 mm diameter and 20 mm thickness for hardness and microstructure tests respectively. The surfaces of the samples were all polished into mirror-like surfaces with progressive grinding on grades of silicon carbide (SiC) impregnated emery paper (240-600grits) sizes. Samples were then pre-polished with 1000grit silicon-carbide powder. A rotating cloth pad impregnated with 1µm size alumina polishing powder (APP) was used in polishing with light pressure. Final polishing was carried out using 0.05µm APP suspended in distilled water (Norman, 2007).

Carburization then followed, whereby carburizers were packed into the stainless steel boxes and 20% of Barium trioxocarbonat (V) oxide (Ba₂CO₃) of mass 140g was mixed thoroughly with each medium in each of the boxes. The Ba₂CO₃ acts as an energizer and promotes formation of carbon (IV) oxide (CO₂) gas, which in turn reacts with the excess carbon in the media to produce carbon II oxide (CO). The CO then reacts with the low carbon steel surface to form atomic carbon which diffuses into the steel. Finally, the prepared mild steel samples were buried completely in the pulverized animal bone, wood charcoal or sea shells inside the boxes.
Pack Carburizing Processes

The mild steel samples were buried completely in the carburizing packages, placed in the three stainless steel boxes in the heat treatment muffle furnace at the foundry shop of Federal Institute of Industrial Research Oshodi- FIIRO, Lagos where they were heated and held at 750 °C up to 950 °C in step of 50 °C, as shown in Table 3 and 4. The furnace was allowed to cool before the samples were removed. The carburized samples were then hardened by quenching in water, followed by tempering at 200°C for one hour. This was done to relieve the internal stresses built up during quenching, and to increase the toughness in the core of the mild steels samples.

Chemical Test

The chemical analysis of the samples was carried out at Universal Steels Limited Ogba, Lagos State, using Spark Test Spectrometry at two different sparks, in order to determine the chemical composition of the steel and to determine specifically, the amount of carbon content present in the steel. This is to classify the steel either as a low-carbon or high carbon-steel. This test showed that the steel contained 0.193 %C, confirming that it is a low carbon steel. After the complete heat treatment of all the samples, the chemical analysis was also carried out at two sparks each, and the results obtained are shown in Table 4.

Characterization of the Carburizers

Proximate analysis of the carbon materials for the case hardening process was carried out to know the carbon percentages, the volatile matter, the ash contents and the moisture contents. The results are shown in Table 1.

Hardness Test

The hardness tests were all carried out using Indentec Universal Hardness Tester, with diamond cone (120°) indentor, Rockwell HRA, minor load 10kg and total load 60kg, in the Metallurgical and Materials Engineering Department of Ahmadu Bello University (ABU) Zaria, at two different indentations. For the untreated As-Received steel sample, 43.7 HRA was obtained, while for the tempered steel samples, the different results obtained were all recorded on a scale of A.

Results and Discussion

The mild steel case hardened with animal bone in the temperature range of 750-850 °C increased in hardness up to 55.3 HRA as against the original value of 43.7 HRA, and then decreased to 48.9 HRA at 950 °C (Table 5). Also, the case hardened steel using charcoal granules, increased in hardness from 46 – 69.3 HRA at temperatures of 750 – 950 °C, and these hardness values lie between the acceptable hardness values of spur gears (50 to 60 HR, ASM standard, 2000.). Case hardened mild steel using sea shells granules, increased in hardness up to 56.5 HRA at 950 °C, and then decreased to 39 HRA at 900 °C. The mixture of animal bone and sea shells granules gave hardness value of 44.5 HRA at 950 °C, charcoal and sea shells granules gave a hardness value of 44.8 HRA, and finally the three mixtures gave a hardness result of 46.4 HRA. It should be noted that the results of the mixtures hardness value were greatest at the three mixtures, Table 5. From Table 6, decarburization of the steel samples was experienced at 750°C in all the three media while a gain in iron was
recorded because at this temperature, penetration of atomic carbon into the intersicles of the iron atoms had not commenced. Manganese content generally decreased below initial 0.7% as carbon diffused into the steels. The case hardened steels increased in toughness and wear resistant properties.

**Table 5: Hardness Values of Steel Samples after Case Hardening**

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Steel Samples</th>
<th>Hardness Results (HRA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>750</td>
<td>Ab</td>
<td>52.1</td>
</tr>
<tr>
<td>800</td>
<td>Ab</td>
<td>54.7</td>
</tr>
<tr>
<td>850</td>
<td>Ab</td>
<td>55.3</td>
</tr>
<tr>
<td>900</td>
<td>Ab</td>
<td>53.5</td>
</tr>
<tr>
<td>950</td>
<td>Ab</td>
<td>48.9</td>
</tr>
<tr>
<td>750</td>
<td>Ch</td>
<td>46.0</td>
</tr>
<tr>
<td>800</td>
<td>Ch</td>
<td>48.4</td>
</tr>
<tr>
<td>850</td>
<td>Ch</td>
<td>61.9</td>
</tr>
</tbody>
</table>

| 900              | Ch            | 58.3                   |
| 950              | Ch            | 69.3                   |
| 750              | Ss            | 45.6                   |
| 800              | Ss            | 40.4                   |
| 850              | Ss            | 40.9                   |
| 900              | Ss            | 39.0                   |
| 950              | Ss            | 56.5                   |
| 950              | 50% Ab + 50% Ss| 44.5               |

| 950              | 50% Ch + 50% Ss | 44.8               |
| 950              | Ab + Ch + Ss(33.3% each) | 46.4               |

**Table 6: Chemical Composition of Steel Samples after Case Hardening**

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Carburizer</th>
<th>C</th>
<th>Mn</th>
<th>Cr</th>
<th>Ni</th>
<th>Mo</th>
<th>V</th>
<th>Si</th>
<th>Fe</th>
</tr>
</thead>
<tbody>
<tr>
<td>750</td>
<td>Untreated</td>
<td>0.193</td>
<td>0.700</td>
<td>&lt;0.0001</td>
<td>0.032</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>0.062</td>
<td>98.92</td>
</tr>
<tr>
<td>750</td>
<td>Ab</td>
<td>0.142</td>
<td>0.697</td>
<td>&lt;0.0001</td>
<td>0.005</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>0.032</td>
<td>99.038</td>
</tr>
<tr>
<td>800</td>
<td>Ab</td>
<td>0.230</td>
<td>0.698</td>
<td>&lt;0.0001</td>
<td>0.013</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>0.035</td>
<td>98.928</td>
</tr>
<tr>
<td>850</td>
<td>Ab</td>
<td>0.211</td>
<td>0.699</td>
<td>&lt;0.0001</td>
<td>0.012</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>0.036</td>
<td>98.831</td>
</tr>
<tr>
<td>900</td>
<td>Ab</td>
<td>0.122</td>
<td>0.701</td>
<td>&lt;0.0001</td>
<td>0.011</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>0.034</td>
<td>99.039</td>
</tr>
<tr>
<td>950</td>
<td>Ab</td>
<td>0.123</td>
<td>0.707</td>
<td>&lt;0.0001</td>
<td>0.009</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>0.033</td>
<td>99.035</td>
</tr>
<tr>
<td>750</td>
<td>Ch</td>
<td>0.013</td>
<td>0.299</td>
<td>0.048</td>
<td>0.018</td>
<td>&lt;0.0001</td>
<td>0.008</td>
<td>0.070</td>
<td>99.443</td>
</tr>
<tr>
<td>800</td>
<td>Ch</td>
<td>0.699</td>
<td>0.294</td>
<td>0.044</td>
<td>0.012</td>
<td>&lt;0.0001</td>
<td>&lt;0.001</td>
<td>0.062</td>
<td>98.758</td>
</tr>
<tr>
<td>850</td>
<td>Ch</td>
<td>0.78</td>
<td>0.255</td>
<td>0.045</td>
<td>0.013</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>0.065</td>
<td>98.70</td>
</tr>
<tr>
<td>900</td>
<td>Ch</td>
<td>0.844</td>
<td>0.069</td>
<td>0.044</td>
<td>0.014</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>0.069</td>
<td>98.662</td>
</tr>
<tr>
<td>950</td>
<td>Ch</td>
<td>0.905</td>
<td>0.332</td>
<td>0.039</td>
<td>0.009</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>0.039</td>
<td>98.572</td>
</tr>
<tr>
<td>750</td>
<td>Ss</td>
<td>0.129</td>
<td>0.689</td>
<td>&lt;0.0001</td>
<td>0.012</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>0.034</td>
<td>99.043</td>
</tr>
<tr>
<td>800</td>
<td>Ss</td>
<td>0.028</td>
<td>0.294</td>
<td>0.046</td>
<td>0.007</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>0.065</td>
<td>99.471</td>
</tr>
<tr>
<td>850</td>
<td>Ss</td>
<td>0.349</td>
<td>0.290</td>
<td>0.041</td>
<td>0.001</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>0.063</td>
<td>99.178</td>
</tr>
<tr>
<td>900</td>
<td>Ss</td>
<td>0.006</td>
<td>0.297</td>
<td>0.044</td>
<td>0.002</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>0.062</td>
<td>99.508</td>
</tr>
<tr>
<td>950</td>
<td>Ss</td>
<td>0.118</td>
<td>0.698</td>
<td>&lt;0.0001</td>
<td>0.021</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>0.041</td>
<td>99.02</td>
</tr>
<tr>
<td>950</td>
<td>Ab + Ss</td>
<td>0.065</td>
<td>0.292</td>
<td>0.047</td>
<td>0.029</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>0.067</td>
<td>99.368</td>
</tr>
<tr>
<td>950</td>
<td>Ch + Ss</td>
<td>0.349</td>
<td>0.290</td>
<td>0.041</td>
<td>0.001</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>0.063</td>
<td>99.178</td>
</tr>
<tr>
<td>950</td>
<td>Ab + Ch + Ss</td>
<td>0.241</td>
<td>0.294</td>
<td>0.048</td>
<td>0.012</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>0.070</td>
<td>99.246</td>
</tr>
</tbody>
</table>
During the carburizing process, carbon was released and subsequently absorbed by the steel samples in different degrees. Highest release and absorption was recorded at 950°C, using charcoal as the carburizing medium. This is in agreement with findings by Panda et al., (2014). Animal bone and sea shells performances were far below charcoal performance as carburizers at all the considered temperatures, except 800°C and 850°C for animal bone. Also, at 850°C, sea shell performed a little bit better than animal bone by raising the carbon level from 0.193 to 0.349. These performances are in agreement with Oyetunji and Adeosun (2012), as well as Fatoba et al., (2013). The mixture of charcoal with sea shell however, gave improved performance as against sea shell alone as a medium at 950°C. Here, the sea shell acted as an energizer (Fatoba et al., 2013), while the carbon from the charcoal diffused into the steel. The silicon content in the untreated sample was 0.062. The uptake of carbon thereby changed the respective percentages of silicon and iron levels in particular. Manganese content remains relatively the same in samples treated with animal bone. This was however different in samples treated with charcoal. As more carbon diffused into the steel, manganese level reduced automatically, relative to iron content. The implication of this at industrial level is that different combinations of the carburizer/energizers can be predesigned to give desired results on the mild steel for specific industrial application.

**Microstructural Analyses**

The samples surface microstructures before and after heat treatment are given in the micrographs (Plates 1-7).

**Plate 1:** Microstructure of the mild steel before heat treatment × 400; Ferrite (Whitish) and iron carbide (Fe₃C) phases clearly shown in an intermixed assemblage.

**Plate 2:** Micrograph after case hardening with animal bone at 950 °C at magnification of 600, and two hours soaking time. Ferrite is still distinctly seen untransformed.

**Plate 3:** Micrograph after case hardening with charcoal at 900 °C at magnification of 600, and three hours soaking time. Transformation of Ferrite to iron carbide was favoured by significant uptake of more carbon from the charcoal.
Plate 4: Micro graphs after case hardening with sea shells at 900 °C ×600, and holding time of three hours. Coarser grains of Ferrite with interstitial iron carbide.

Plate 5: Micro graphs after case hardening with sea shells at 950 °C at magnification of 600, and holding time of two hours. Ferrite grains with interstitial carbide.

Plate 6: Micrographs after case hardening with the mixture of animal bone, charcoal and sea Shells at 950 °C at magnification of 600, and two hours soaking time. Finer grains with few transformation from ferrite to iron carbide favoured by carbon uptake.

Plate 7: Micro graphs after case hardening with the mixture of charcoal and sea shells at 950 °C at magnifications of 600, and two hours soaking time. Ferrite transformation also favoured with finer grains.

Microstructure of the steel in Plate 1 clearly shows the hypoeutectic nature of the low carbon steel. Ferrite (whitish) and iron carbide coexisted. Ferrite dominated the field. Very little carbon penetration was recorded with animal-bone case hardening, Ferrite is still conspicuously seen separated from iron carbide as pearlite (Plate 2). Case structure of Plate 3 presents remarkable carburization efficiency. Good phase transition from ferrite in Plate 1, to pearlite was recorded when charcoal was used as the carburizer (Plate 3), this particular sample gave the highest hardness value of 69.3 HRA in Table 6.

The performance of sea shell alone as carburizer was similar to that of animal bone in terms of poor carbon intake; ferrite is still clearly separated from iron carbide as shown in Plate s 4 and 5, this was also responsible for low hardness values of these samples as presented in Table 5. However, there was improvement in carbon intake when charcoal was mixed with each of animal bone and sea shell. Here, both animal bone and sea shell were considered as energizer, while charcoal acted as the real carburizer, Plates 6 and 7. Systematic intake of carbon was therefore recorded, which also led to improved hardness values. Consequently, the work has confirmed the efficacy of using
charcoal, animal bone and sea shell in mild steel carburization to achieve desired hardness property.

Conclusions
The case hardened mild steel samples showed significant improvement in their mechanical properties, a proof of effectiveness of the carburizers to induce higher hardness values in the steel samples. These samples could then be utilized in different industrial mild steel applications, like gears as alternatives to imported ones. Highest carbon concentration on the surface of the steel was 0.905% C using charcoal granules, with highest hardness value of 69.3 HRA.

Acknowledgement
Supports from Mr Simon Al-hassan and the entire staff of Federal Institute of Industrial Research Oshodi (FIIRO), Lagos, Nigeria, in making this work a success is appreciated.

References


