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CONTENTS

THEORETICAL DETERMINATION OF THE EFFECTIVE POWER OF A TRACTOR ENGINE USING COMPRESSED NATURAL GAS AS ALTERNATIVE FUEL

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ABSTRACT

The determination of the effective power of a tractor engine using Compressed Natural Gas (CNG) as alternative fuel was carried out by following the procedure for the design of Internal Combustion Engine (I.C.E.). The indicated parameters i.e. pressure, temperature and volume at the completion of intake, compression, combustion and the expansion processes were determined to be 0.144 MPa, 6.211 MPa, 11.801 MPa and 0.442 MPa; 336.44K, 967.35K, 2189.04K and 1159K; 6.705×10^4 m^3, 4.47×10^{-5} m^3 and 6.705×10^4 m^3 respectively. The indicated diagram was constructed (P-V graph) and the indicated diagram area was determined to be $3254 mm^2$, length of diagram 155mm and the scale µ on the pressure scale was 0.05 MPa to 1mm, hence the mean effective pressure was determined to be 0.83 MPa. With the engine displacement capacity of $2.5 \times 10^{-3} m^3$, the effective power of the tractor CNG engine was determined to be 41.5KW. This power falls within the third category of tractor power rating classification (30-70kW) i.e. general-purpose tractor.

KEYWORDS: Effective power, tractor engine, compressed natural gas (CNG), alternative fuel.

1. INTRODUCTION

A tractor is a self-propelled machine that can be used to power farm implements or equipment attached to it. The farm tractor has an internal combustion engine that uses either of the traditional fuels (petrol or diesel) as fuel. Alternative fuels can be used in place to power automobile other than petrol or diesel. The alternative fuels are much more environment friendly. (Peter, 2001)

They are relatively cheaper to obtain than the traditional fuels in terms of fuel economy indices. These alternative fuels include Natural Gas (CNG, LNG), LPG, Alcohols (M85, E85), Bio diesel, Vegetable Oil (B20), P-series fuel, Hydrogen fuel, etc. The use of these fuels gives rise to, Low Emission Vehicles (LEVs), Zero Emission Vehicles (ZEVs) and Flexible Fuel Vehicles (FFHs) (Bechtold, 1997).

Compressed Natural Gas is an alternative fuel that is currently in use in developed and developing countries to power automobiles including tractors.

In Nigeria and other developing countries, where Natural Gas is flared in large quantities, running to billion of liters, appropriate technologies are required to convert or process these natural gas into LNG, CNG and LPG that can be used to power automobiles, generate electricity and also for space heating. Compressed Natural Gas comprises chiefly methane (about 95%). CNG is assumed to contain only carbon and hydrogen (CH_4).

According to (Indiamart, 2002), Compressed Natural Gas can be used in tractor engines as a mono fuel, bi-fuel (i.e. a combination of CNG and either petrol or diesel) and as a dual engine system (where two fuels will be used concurrently).

The use of CNG as an alternative mono fuel for tractor engines requires the determination of the effective power generated by the engine.

The conversion kits for a CNG mono fuel engine system are as follows: CNG cylinder with valves and vapour box, the vapour bag assembly, TNI electronic regulator, on-off refueling electric valve, Mixer i.e. a special air valve diaphragm carburetor, a gaseous metering system, ignition system and ignition trigger, fuel electronic gauge.

The Effective Power of an engine is the power that is delivered at the flywheel of the crankshaft of the engine. Indicated power is the actual power produced inside the engine cylinder as a result of the combustion of fuel. The effective power of an engine is 10-12% less than its indicated power because some power is lost in overcoming frictional forces in the mechanism and in driving ancillary equipment (pumbs, fans, generator etc.) (Heywood, 1996).

The effective power $N_e = \frac{P_e V_1 n}{60\tau}$

Where Ű = 2 for four-stroke engine, 1 for two stroke engine.
V_I = engine displacement capacity in m^3, P_e = mean effective pressure, MPa

New engines correspond essentially to current models but contain changes or modifications made possible by improvement in design, ñfuelò, lubricant or materials. The first step of any engine design problem is to select the speed, type, number and size of cylinder and the arrangement of the cylinders for the required output, (Liljedahi, *et al*., 1989).

Countries like Nigeria and other oil producing countries are seen as ideal for gas power generating set and heavy-duty engines (tractor engine inclusive) as good quality natural gas are readily available, cheaper than diesel power (African review, 2002). Hence, the objective of this research is to determine the effective power of a tractor engine using Compressed Natural Gas as alternative fuel from the Mean-effects-pressure developed by the engine.

2. METHODOLOGY

2.1 Design of Engine

A tractor diesel engine was used as the prototype (existing) engine, whose engine parameters served as a basis for the tractor CNG engine design. The basic parameter of the selected tractor engine as provided by the manufacturer are as follows:

Prototype tractor: Steyr 8077a
Engine type: WD411.45
Effective power: 47kW
Rated Engine Speed $n^{Ű}$: 2,400rpm
Compression ration, Ů= 16.2:1
No and type of cylinder: i = 4p
Stroke to bore ration, (S/D): 110mm/100mm
Maximum torque at engine speed, Nm = 229 at 1400rpm
Mean piston speed = 8.8m/s
Injection sequence: 1-3-4-2
(Source: Steyr Daimer Puch: Aktiengesellschaft) Steyr, Wein Graz Austria.

2.2 Design Assumptions

ə = R/L (between 0.21 to 0.30) (Adgidzi, 1988), for this design, ə = 0.25 $\Rightarrow$ R = 0.25L (Heywood, 1996)
$n^{Ű}$ CNG = 2400rpm, S/D = 110mm/100mm. The CNG engine operates on the principle of Spark ignition engine, hence, the compression ratio is reduced to 15, Ů= 15.0:1
ɖ$_m$ of CNG engine = 0.85
ɕ = 0.89 for CNG

2.3 Determination of Parameters for Indicated Diagram

For absolute pressure, P, and absolute temperature, T, the pressure and temperature for points at a- completion of intake, c- completion of compression, z- completion of combustion and b- completion of expansion processes are required in the construction of the indicated curves for the CNG engine.

2.3.1 Pressure, (Pa), and Temperature, (Ta) after Intake

$$P_a = \frac{\eta_v p_o (\varepsilon - 1) T_o + p_r T_o}{\varepsilon T_o} \text{ (Adgidzi, 1988)} \qquad (1)$$

d_v = 0.78 (Heywood, 1996), P_o = 101.325 KPa, Ů= 15.2, T_o = 300K P_r = 1.06 MPa

$$\Rightarrow P_o = \frac{0.78x101.325x10^{-3}(15-1)x300 + 1.06x300}{15x300}$$

$$T_a = \frac{\varepsilon P_a T_o}{\eta_v (\varepsilon - 1) P_o + \frac{T_o}{T_r} P_r} \qquad (2)$$

$T_o = T_o$ = 300K, T_r = 388K (Richard, 1985)

2.3.2 Pressure, (P_c), and Temperature (T_c) after Compression

$P_c = P_a$ Ů1, MPa (3)

$T_c = T_a$ Ů$^{-1}$, k (4)

2.3.3 Specific Volume at the Completion of Compression, (v_c)

$$V_c = \frac{V_a}{\varepsilon} \qquad (5)$$

$$V_a = \frac{8.314x10^{-3} T_a}{\mu_a p_a} \qquad (6)$$

= 6.705x10^{-4} m^3, we know that Ů= 16.2, therefore;

Quantity of gas (air) in the cylinder at the end of compression (TDC) i.e. (Diesel) with Composition; C, H, O and CNG with Composition; C, H

The theoretical quantity of air required to burn one kilogram of fuel (CNG) with compression C, H

$$L_o = \frac{1}{0.23}\left(\frac{8}{3}C + 8H\right) kg/kg \text{ - (Adgidzi, 1988)} \qquad (7)$$

$$L_o = \frac{L_o^{1}}{16} \qquad (8)$$

C, H weight per element per kg for CNG. C = 0.75, H = 0.25.

$$\therefore L_o^{1} = \frac{1}{0.23}\left(\frac{8}{3}(0.75) + 8(0.25)\right)$$

= 17.39 kg/kg

L_o = 1.087 kmol/kg

Actual quantity of air required for combustion of 1kg of fuel was given as

$L = aL_o$ (9)

Where Ŭ= excess air co-efficient (take Ŭ= 1.9)

Quantity of fresh mixture, M_1 was determined as

$$M_1 = \text{Ŭ}L_o + \frac{1}{\mu_d} \qquad (10)$$

Where ε_d = molar mass of the fuel (CNG) = 16

M_1 = 2.1275

Apart from the in-coming air (mixture) into the cylinder, there are residual gases in the cylinder, therefore, quantity of residual gases in the cylinder was determined as

M_r = ɔ $_r aL_o kmol$ / kg (11)

ɔ$_r$ = co-efficiency of residual gases by equation (12) below:

$$ɔ_r = \frac{P_r T_o}{P_o T_r \eta_v (\varepsilon - 1)} \quad (12)$$

M_r = 1.530

Total quality of mixture in the cylinder at the compression process

$M_1 = M_1 + M_r$ (13)

Quantity of gases in the cylinder at the completion of combustion process, for the combustion of 1kg of fuel with excess air Ŭ> 1. The components of the burnt gases consist of CO_2, water vapour, excess oxygen nitrogen, this quantity was detonated by M_2 and calculated as:

$$M2 = Ŭ L_o + H/4 \quad (14)$$

Taking into consideration, the residual gases, the quantity of gases in the combustion chamber after combustion was given as:

$M_z = M_2 + M_r$ (15)

Co-efficient of molecular change in the mixture was given as:

$$\varepsilon = \frac{M_z}{M_1}. \quad (16)$$

2.3.4 Pressure (P_z), and Temperature (T_z) after Combustion

P_z = ɘ$_p P_c$, MPa (17)

ɘp = 1.90

P_z = 11.801 MPa

T_z = temperature at the completion of combustion process was determined from the combustion equation for 4 ï stroke engine as (Adgidzi, 1988)

$$(\mu_{cv} + 8.28\lambda_p)T_c + \frac{\xi H_u}{\alpha L_o (1 + \gamma_r)} = \mu.\mu_{cp} T_z \quad (18)$$

Where H_u = heat of combustion. For Compressed Natural Gas H_u = 50,175 kj/kg

ɜ =0.89, ε = 1.00, ŬL_o = 2.065, T_c = 967.35K, ɘ$_p$ = 1.9

$\varepsilon_{cv} = 20.16 + 1.738X10^{-3} T_c$ (19)

$$\varepsilon_{cp} = 8.28 + \left(20.1 + 0.921/\alpha\right) + \left(13.82/\alpha + 15.49\right)x10^{-4} T_z \quad (20)$$

= 28.865 + 22.764X10$_4 T_z$ (20*)

Substituting equations 19 and 20* into equation 17 and solving the equation quadratically give Tz = 1677K (low).

Assuming p = 1.06

$$\rho = \frac{\xi . T_z}{\lambda_p T_c} \quad (21)$$

$$T_z = \frac{\rho \lambda_p T_c}{\xi} = 2{,}189.04K$$

The ration of the compression ration to the pre-expansion index, ŭ is used to determine P_b and T_b for both Diesel and CNG.

$$\delta = \frac{\varepsilon}{\rho} \quad (22)$$

2.3.4 Pressure (Pb) and Temperature (Tb) after Expansion

The pressure, P_b after expansion is determined as:

$$P_b = \frac{P_z}{\delta^{n2}} = P_z \left(\rho / \varepsilon \right)^{n2} \quad (23)$$

$$T_b = \frac{T_Z}{\delta^{n2-1}} \quad (24)$$

2.3.6 Volume After Intake (V_a), Volume after Compression (V_c), Volume after Combustion (V_z), and Volume after Expansion (V_b)

Considering equations 25 and 26 below

Polytropic equation for compression $P_x = P_a \left(v_a / v_x \right)^{n1}$ (25)

Polytropic equation for expansion $P_x = P_b \left(v_b / v_x \right)^{n2}$ (26)

$\Rightarrow \frac{V_a}{V_x} = \frac{V_b}{V_x} \Rightarrow V_a = V_b$ (Adgidzi, 1988)

But $V_a = 6.705 \times 10^{-4}$ m^3; $V_a = V_b$ é $V_b = 6,705 \times 10^{-4}$ m^3, $V_c = 4.47 \times 10^{-5}$m^3

$V_z = ȷ\, V_c \Rightarrow V_z = 1.06 \times 4.47 \times 10^{-5}$ m^3

2.4 Procedure Followed in the Construction of Indicated Curves

The various pressure points (P_a), and the volume (V_z) were used for both the polytropic compression and expansion curves. (Fig. 1)

The volume axis, V_z was divided into twenty equal parts from V_c to V_a at indicated intervals and the corresponding values of P_x obtained using Equations 25 and 26 for compression and expansion respectively.

Determination of mean indicated pressure from the indicated diagram (curve), - Fig.1:
The mean indicated pressure was given as:

$P_1 = \frac{\mu F}{l}$ MPa (Adgidzi, 1988) (27)

From Fig. 1 ε = pressure scale = 1mm = 0.05 MPa
F = indicated diagram area, mm^2 = 3254mm^2
l = length of indicated diagram, mm = 155mm
$\Rightarrow P_l = 1.05$ MPa
The value of the mean theoretical pressure by the analytical method was given by the formula

$$P_1(cal) = \frac{P_c}{\varepsilon - 1}[\lambda_p(\rho - 1) + \frac{\lambda_p \rho}{n_2 - 1}(1 - \frac{1}{\delta^{n2-1}}) - 1/n_1 - 1(1 - \frac{1}{\varepsilon^{n1-1}}) \quad \text{(Adgidzi, 1988)} \quad (28)$$

The accuracy of construction of indicated diagram was given by the error co-efficient as

$$\delta_{id} = \frac{P_1^{cal} - P_1}{P_1^{cal}} \text{x100\%} \quad (29)$$

ŭ$_{rd}$ should not be more than 3-4% (Adgidzi, 1988)
The actual or real mean indicated pressure given by
$P_c = P_1$ ɔ (30)
Where ɔ is co-efficient of incomplete indicated diagram, ɔ=0.93

$P_c = P_1\eta_m$ (MPa) (31)
Where η_m is the mechanical efficiency, this indicates the level by which indicated parameters e.g. P_1 can be reduced through losses. η_m = 0.7-0.82 for four-stroke diesel engines, η_m = 0.85-0.90 for four-stroke petrol engines. Assume η_m for CNG engine = 0.85
$\therefore P_c$ = 0.83 MPa
$\Rightarrow$ the mean effective pressure of CNG engine = 0.83 MPa.

2.5 Engine Displacement Capacity

The engine displacement capacity $V_1 = V_{hi}$ where i is the number of cylinders = 4 and was given by the relationship:

$$V_{hi} = V_1 = \frac{60\tau N_e}{P_e n} \qquad (32)$$

But from Fig. 1.0, $V_h = V_a - V_c$
$\therefore V_1 = 4 \text{ x } V_h = 2.50 \text{ X } 10^{-3}\text{m}^3$
From equation 31,

The effective power, $N = Ne = \frac{P_e n V_1}{60\tau}$

3. RESULTS AND DISCUSSION

Table 1. shows the value of the indicated parameters, which were used in the construction of the indicated diagram (Fig. 1.). The indicated diagram area was determined to be 3254 mm^2; length of indicated diagram, 155mm and the pressure scale equals 1mm to 0.05 MPa.

Table 1: Indicated diagram parameters.

Specific points (Processes)	Pressure (MPa)	Volume (m3)	Temperature (K)
Intake, a	0.144	6.705 X10^{-4}	336.44
Compression, c	6.211	4.47 X10^{-5}	967.35
Combustion, z	11.801	4.74 X 10^{-5}	2189.04
Expansion, b	0.442	6.705 X10^{-4}	1159.00

The piston displacement, V_h was 6.258 X 10^{-4}m^3 and the total engine capacity was determined to be 2.5 X 10^{-3}m^3. The effective power was determined to be 41.5kW taking into consideration the engine cycle factor of 2 for four-stroke engines and engine rotational speed of 2400rpm.

The pressure at the completion of intake P_a was 0.144 MPa a little above atmospheric pressure, which is less than the completion of compression, P_c was = 0.621 MPa. This is because the intake volume, V_a has reduced from 6.7055 X 10^{-4}m^3 to 4.47 X 10^{-5}m^3 at the completion of compression, hence, Boyleôs law was obeyed. The pressure at the completion of combustion processes was highest at 11.801 MPa and as a result of scavenging, the pressure during the expansion process was as low as 0.442 MPa just above the atmospheric pressure and it is in line with Liljedahi et al. (1989).

There was an increase in volume during the combustion process and this was due to the release of combustion products (CO_2 and H_2O). The intake volume and volume at the completion of expansion process remained the same. The temperature at intake was the lowest (336.44K) while the temperature during the combustion process was the highest (2189.04K). During the expansion and compression processes, the temperatures were 1159K and 967.35K respectively. The difference was as a result of the effect of residual gas temperature after combustion.

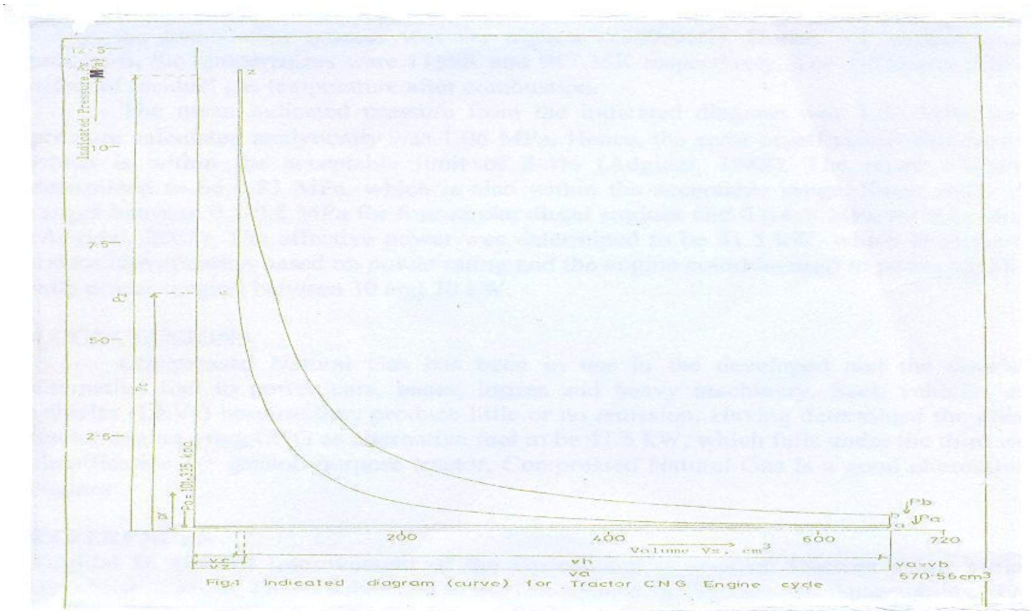

Fig.1 Indicated diagram (curve) for Tractor CNG Engine cycle

The mean indicated pressure from the indicated diagram was 1.05 MPa while the indicated pressure calculated analytically was 1.06 MPa. Hence, the error co-efficient was determined to be 1%, which is within the acceptable limit of 3-4% (Adgidzi, 1988). The mean effective pressure was determined to be 0.83 MPa, which is also within the acceptable range. Since mean effective pressure ranges between 0.5-0.8 MPa for four-stroke diesel engine and 0.6-0.9 MPa for four-stroke petrol engine (Adgidzi, 2002). The effective power was determined to be 41.5kW, which is in the third category of tractor classification based on power rating and the engine could be used in powering all-purpose tractors with power ranging between 30 and 70 kW.

4. CONCLUSION

Compressed Natural Gas has been in use in the developed and the developing nations as alternative fuel to power cars, buses, lorries and heavy machinery. Such vehicles are low emission vehicles (LEVs) because they produce little or no emission. Having determined the effective power of a tractor engine using CNG as alternative fuel to be 41.5 kW, which falls under the third category of tractor classification i.e. general-purpose tractor, Compressed Natural Gas is a good alternative fuel for tractor engines.

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Notation

F ï area of indicated diagram, mm^2
i ï no of cylinders = 4
L ï actual quantity of air for combustion of 1kg of fuel, kmol/kg
M_r ï quantity of residual gases in the cylinder, kmol/kg
M_t ï total quantity of mixture at the end of compression, kmol/kg
P_a ï pressure at completion of intake process, MPa
P_b ï pressure at the completion of expansion process, MPa
P_c ï pressure at completion of compression process, MPa
Pe ï mean effective pressures, MPa
$Pô_1$ ï mean theoretical indicated pressure calculated by the analytical method, MPA
P_1 ï actual mean indicated pressure, MPa
P_o ï atmospheric pressure, MPa
P_r ï residual gas pressure, kPa
P_x ï pressure coordinate for polytropic index curve for compression & expansion, MPa
P_z ï pressure at completion of combustion process, MPa
S/D ï piston stroke to diameter of cylinder ration
T_w T_a T_z T_b are temperature at completion of intake, compression, combustion & expansion processes,
T_o ï temperature of mixture at the point of entry into the combustion chamber, K
T_r ï residual gas temperature, K
V_a V_b V_c V_z are volumes at intake, compression combustion and expansion processes, M_3
V_h ï 1 cylinder engine displacement volume m3
V_p ï piston speed, m/s
V_z ï x-volume coordinates for polytropic index curve for compression and expansion, m^3
V_1 ï total engine displacement volume m^3
$ɖ_v$ ï filling co-efficient /volume efficiency
n_1 ï polytropic index for compression (n_1 -1.39)
Ŭï coefficient of excess gases
ɔ ï coefficient of incompleteness of indicated diagram
$ɔ_r$ ï coefficient residual gases
ɟ ï level (index) of expansion of gases compression
$ɛ_{cp}$ ï mean molar heat capacity of burnt gases under constant pressure, kmol/K
$ɛ_{cv}$ ï mean molar heat capacity of air at constant volume
Ůï compression ration
n_2 ï polytropic index for expansion (n_2 = 1.24)
$ɛ_a$ ï molar mass of air = 28.97
$Ŭ_p$ ï level of pressure increase during combustion
ɚï ration of crank radius to connecting rod length
ŭ ï error in construction of indicated diagram
ɝï co-efficient of heat utilized

DEVELOPMENT AND PERFORMANCE EVALUATION OF A FORAGE CHOPPER

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ABSTRACT

In the dry season, crop residues like maize stovers, millet stovers, sorghum stovers, groundnut haulms, cowpea stems, potatoes stems, rice straws etc are being used to feed ruminant. The crop residues can be fed to the animals directly, as they are collected from the farms or chopped into pieces for easy intake by the animals. The current practice by the small and medium scale livestock farmers to collect and cut the crop residues using machetes and other crude methods is very cumbersome. In this work, a motorized forage chopper was developed and tested. The machine was used to chop crop residues like maize stovers, millet stovers, sorghum stovers, rice straws, gamba grass and elephant grass; in wet and dry conditions. The cutting blade parameters of the machine were: knife edge thickness, ŭ = 80εm, knife thickness = 4mm and sharpening angle (level angle) ϐ = 25^{o}. The moisture content for the wet and dry materials were determined by oven ï dried method before chopping. The average chopping efficiencies for the wet and dry materials were 86 and 92% respectively. The average chopping rate for the dry materials was 24kg/hr and the average chopping rate for the wet materials was 15.6kg/hr. These values indicate that the machine performed better with dry materials than the wet materials. The average length of cut of the materials was 25mm. This length makes it suitable for the preparation of dry season animal feeds with the chopped crop residues as major components and minerals, proteins and vitamins as constituents. The machine is easy to operate and maintain. It requires only one person to operate it and can be used either in the rural or urban areas, using either a diesel or petrol engine of 8.5kW and above.

KEYWORDS: Crop residues, chopper, animal feeds, forage.

1. INTRODUCTION

Animal feedstuff is a very important aspect of livestock husbandry as it is a major limiting factor in the rearing of animals to meet the increasing demand for animal protein, milk, hides, and skin and other products. It is common practice, in Nigeria and other sub-Saharan African Countries for the nomadic Fulanis and Pastoralist to allow the animals graze freely in the fields, in most cases after harvest (Umanna and Agishi, 1988; Agishi 1985). In some cases, the animal rearers collect the crop residues home to feed the animals directly or after chopping into smaller sizes, using matchets or sharp knives. There are well established Fulani settlers with permanent settlements, incorporating both livestock and crop farming systems. The nomadic Fulanis move their cattle to the southern part of the country in the dry season, in search of pasture and water for their animals and move up north in the wet season, to avoid tsetse fly infection (Okorie and Sanda, 1992). The migratory practice of the nomadic Fulanis is usually associated with environmental degradation, incessant bush burning and unpleasant consequences to the communities. A drastic increase in animal body weight in the wet season, when there is abundant fresh grasses and abundant drinking water for the animals, can be noticed. However, in the dry season, when green grasses and water are not sufficient for the animals the resultant consequences is the loss in body weight, hence the little or no availability of milk and other diary products, and high cost of meat in the market, (Umanna and Agishi, 1988). It has been established, (NAERLS, 1989a; Umanna and Agishi, 1988), that the animals can utilize not only the leaves, but also the stovers, if they are reduced into smaller sizes. Cutting the stovers of the crop residues will therefore increase the rate of consumption by animals.

The chopped crop residues can be fed to the animals directly. However, they have very low nutrients, low digestibility because of high fibre content, increase in the energy used by the animals during food intake, and poor voluntary intake by the animals (NAERLS, 1989b).

The chopped crop residues, however, provide sufficient roughages as major components for animal feeds preparation, which can be enriched with protein, vitamins and mineral matters.

Preparation of enriched feedstuffs with the chopped crop residues as roughages and protein, vitamin and mineral constituents provide adequate feeds for the nomadic Fulanis and other pastoralists, especially for the dry season feed management. Using the traditional methods of cutting the crop residues is very cumbersome and risky because of the use of sharp knives.

A motorized forage chopper was therefore developed. The objective of this work was to develop a motorized chopping machine for the cutting of various crop residues and other grasses, and to test the machine on the materials.

2. METHODOLOGY

2.1 Modelling the Crop – Cutting Blade Interactions

Cutting knives are generally sharpened on one side with a sharpening angle ɓ and an edge thickness ŭ. The penetration of a knife into a material causes deformation of the materials and various forces are acting on the surface of the knife, (Fig. 1(a)). The normal force N, acting on the inclined face of the knife is the sum of the horizontal and vertical force component, as given by Sitkei (1986):

$N = P_v$ Sin ɗ + P_h Cos ɗ---(1)

Where Pv and P_h are vertical and horizontal forces, respectively

Tangential forces arising from the action of the knife was expressed as:

$T_2 = \varepsilon N = N$ tan ű-- (2)

Where ε = tan ű (friction coefficient), and ű ï friction angle

The tangential force on vertical side T_1 was given as:

$T_1 - \varepsilon P_h$

and the vertical component of the tangential force was expressed as:

$T_{2V} = T_2$Cos ɓ

= N tan ű Cos ɓ = εN Cos ɓ-- (3)

From equation (1);

$$T_{2v} = \varepsilon \left[\left(\frac{1}{2}\right) P_v \sin 2\beta + P_h Cos^2 \beta\right] \text{------------------------------------ (4)}$$

Where ɓ ï sharpening angle of knife

A force Pc is created at the instant of cutting on the knife edge by the material and was given as:

P_c = ŭ/ů $_B$ (P_c ï is the initial cutting force) ----------------------------- (5)

Where, ŭ ï Thickness of knife edge

l ï length of blade

ů$_B$ ï Yield strength of the material under the edge

The total vertical equation of the forces was expressed as:

$P = P_c + P_v + T_1 + T_{2V}$ --- (6)

The vertical and horizontal forces, P_v and P_h were determined by integrating the elemental force dp_v and dp_h respectively (Fig 1 (b)) and were expressed as:

$P_v = (E/2H).\ h^2$ tan ɓ---(7)

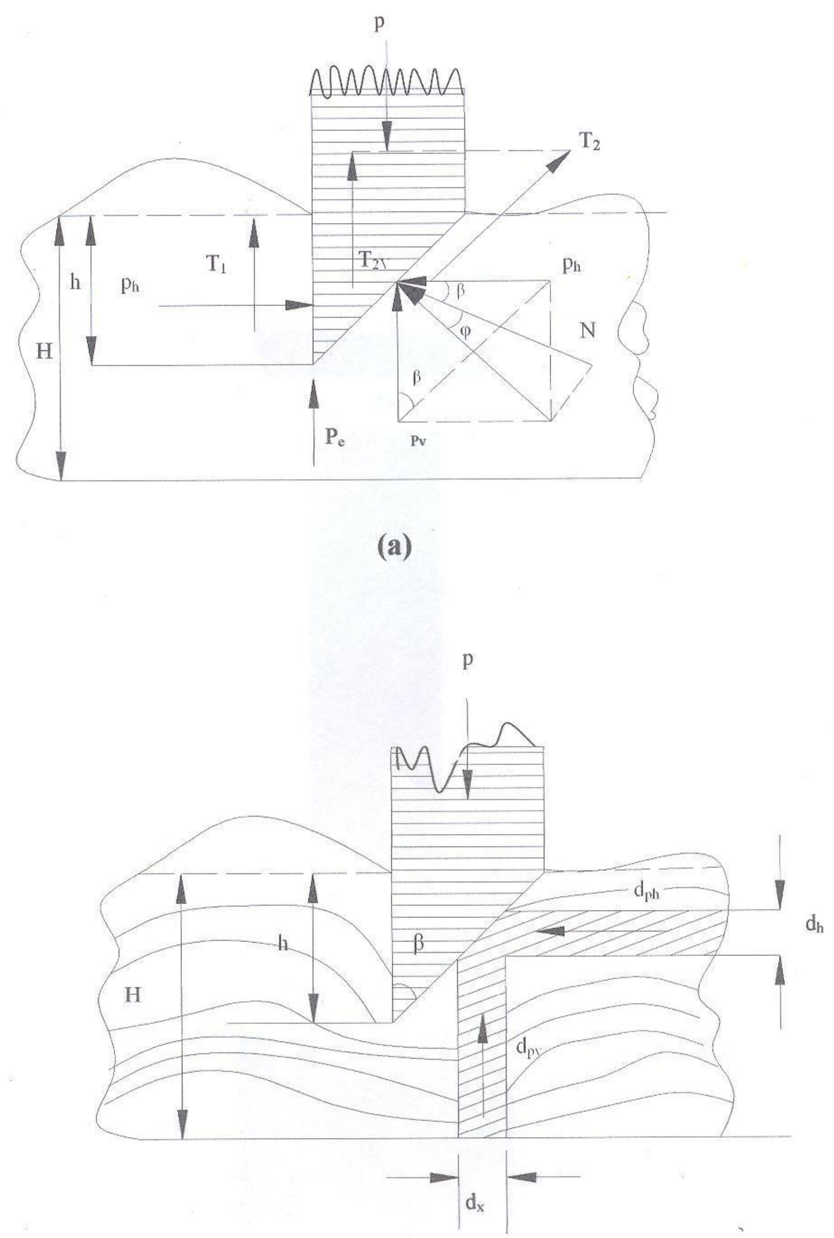

Fig. 1 Crop – Knife interactions: (a) The Vertical, horizontal, and tangential forces (b) the integral forces of dp_v and dp_h

$P_h = (gE/2H)h^2$ --(8)

Where E ï Mean modules of deformation relative to a given loading interval.

g - Poissonôs ratio

h ï Preliminary compaction thickness

H ï Total thickness of the material

Total vertical equilibrium equation (Eqn. 6) was re-written for unit length, with equations 7, 8 and the expression for T_{2v} taken into account, in the form:

$P = ǔů_B + (E/2H)h^2$ [tan б + ε Sin^2 б + g (ε + cos^2 б)]--------------(9)

The first term of equation (9) gives the useful cutting force and the second term expresses the force used to overcome resistant forces. The second term depends on the square of óhô, lasting until the beginning of proper cutting. Its values vary linearly with layer thickness óHô. The additional resistance increases rapidly, with increasing layer thickness and cutting efficiency reduced. Figure 1 shows the interaction of the cutting blade on the material and their related forces.

2.2 Power Requirement

The rotational moment of the shaft carrying the beating/cutting mechanism was determined as given by Grip *et al* (1987):

$$M_1 = M_{cut}^{av} + M_{res} + M_{id} \text{ ----------------------------------- (10)}$$

where M_1 = rotational moment of the shaft carrying the beating/cutting mechanism (Nm)

M_{cut}^{av} = average cutting moment (Nm)

M_{res} = moment developed to overcome resistant forces (Nm)

M_{id} = moment developed to overcome resistances during idle machine running (Nm)

Experimentally, the moments indicated above are given in the ratio: $M_{cut}^{av}:M_{res}:M_{id}$ = 3:1:1 Grip *et al* (1987).

Therefore, the engine required to operate the machine must operate with the rotational shaft moment, M_t, given as:

$$M_1 = M_{eng} = 1\frac{2}{3}M_{cut}^{av} \text{ -- (11)}$$

$$\text{where: } M_{cut}^{av} = \frac{A_{cut}Z}{2\pi} \text{ --(12)}$$

where A_{cut} = total work done, Z ï number of knives (Z =2)

The total work done by the cutting knives comprises the work done by overcoming cutting resistance (A_c) and the work done by effective cutting, (A_v) which was given by Sitkei (1986) as:

$A_{cut} = A_c + A_v$ -- (13)

The total work done per unit area for dry materials A_{cut} = 3 ï 5 kj/m^3 and for wet materials 3 ï 7 kj/m^2 (Grip *et al* 1987).

The total area of materials to be cut using the developed machine determined as 0.0081m^2. Taking the average work done per unit area, for dry and wet materials as 3kjm^2 the total work done for cutting the materials therefore will be:

$$A_{cut} = \frac{3}{0.0081} = 370.37 kj / m^2$$

Substituting values in equation 12, we get:

$$M_{cut}^{av} = \frac{370.37x2}{6.28} = 117.95Nm$$

Putting this value into equation (11) we have;

$$M_{eng} = 1\frac{2}{3} \text{ x } 117.95 = 196.57Nm$$

Therefore the rotational moment of the engine must be taken as 196.57Nm in order to operate both for dry and wet materials.

The power of the engine required to operate the rotating shaft of the machine was given by Grip et al (1987) as:

$$N_{eng} = M_{eng}\omega \text{ --(14)}$$

Where ω = angular speed of the shaft (rad/s)

$$\omega = \frac{2\pi n}{60} = \frac{2\pi\, 400}{60} = 41.87 rad/s$$

Putting these values into equation (14), we have the power required to operate the rotating shaft of the machine as:

196.57x41.87 = 8.23kW

An electric motor of 8.5kW was used to operate the machine. A petrol or diesel engine of the same power rating can also be used, especially during operation in the rural areas, where electrical power may not be available.

2.3 Design of the Hopper

The volume of the hopper was determined as:

$$V = \frac{h}{3}(A_1 + A_2 + \sqrt{(A_1 x A_2)}) \text{ --------------------------------- (15)}$$

Where V = volume of the hopper, m^3

A_1 = area of the top, m^2

A_2 = area of base, m^2

h = height of the hopper = 0.410m

but, A_1 = L x B = 0.360 x 0.360 = 0.1296m^2

and A2 = L x B = 0.160 x 0.160 = 0.0256m^2

therefore $V = \frac{0.410}{3}\left[(0.1296 + 0.0256) + \sqrt{(0.1296 x 0.0256)}\right] = 0.0291 m^3 = 2.91 x 10^{-2} m^3$

2.4 Design of the Cutting/Beating Mechanism

Design of the rods:

The rods are cylindrical, 10mm in diameter and 168mm in length. The rods carry the beater with spaces in between. The rods are six in number.

Volume of rod, V = A x L, M^3

Where A = cross sectional area, m^2

L = length, m

$$A = \frac{\pi d^2}{4} = \frac{\pi(0.01)^2}{4} = 7.85 x 10^{-5} m^2$$

Therefore; V = A x L = 7.85 x 10^{-5} x 0.168

= 1.919 x $10^{-5}m^3$

Total weight of rods $w_r = \rho Vgn$

Where ρ = density of material (for mild steel ρ = 7850kg/m^3)

V = volume of rod = 1.919 x $10^{-5}m^3$

g = acceleration due to gravity, m/s^2

n = number of rods =6

Therefore w_r = 7850 x 1.919 x 10^{-5} x 9.81 x 6

W_r = 6.094N

Design of the beaters:

The beaters are three on each rod and are separated by spaces. The dimension are:

Length = 90mm, width = 50mm and thickness = 5mm

Therefore, the volume was determined as:

V = L x B x t = 0.09 x 0.05 x 0.005 = 2.25 x 10 x $10^{-5}m^3$

The total weight of the beaters was given as:

$w_b = \rho Vgn$

Where, ρ = density of material (ρ = 7850kg/m^3)

V = volume of beater = $2.25 \times 10^{-5} m^3$
g = acceleration due to gravity = $9.81 m/s^2$
n = number of beaters = 3 x 6 = 18

Therefore

$W_b = 7850 \times 2.25 \times 10^{-5} \times 9.81 \times 18 = 31.19N$

Design of the cutting Blade:

The cutting blades are two (2) in number and are firmly attached to the flywheel with bolts and nuts. The dimensions are: Length = 100mm, breadth 60mm and thickness = 4mm

Therefore the volume V = L x B x t =
= 0.1 x 0.06 x 0.004
= $2.4 \times 10^{-5} m^3$

The total weight of knives = ȷ Vgn =
= $7850 \times 2.4 \times 10^{-5} \times 9.81 \times 2 = 3.89N$

2.5 Design of the Chopper Shaft

The diameter of the shaft carrying the beating/cutting mechanism was determined based on the formula proposed by Sharma and Aggarwal (1998) as:

$$d^3 = \frac{16}{\pi\delta,}\sqrt{(M_1K_1)^2 + (M_bK_b)^2} \text{ ------------------------------------- (16)}$$

where, ŭ$_s$ = allowable stress = $40 \times 10^6 N/m^2$

M_t = torsional moment = 196.57Nm

M_b = bending moment = 26.63Nm (from the bending moment diagram, Maduka, (1998)

K_t, K_b = fatigue and shock factor for torsional and bending moments (1.5 and 1.0), respectively.

Therefore $d^3 = \frac{16}{\pi x 40 x 10^6}\sqrt{(196.57x1.5)^2 + (26.63x1.0)^2}$

$d^3 = 1.27 \times 10^{-7} \times 296.10$

$d^3 = 0.000037655m$

d = 0.0335m = 33.5mm

A shaft diameter of 35mm was used to carry the beating/cutting mechanism.

2.6 Design of the Torsional Rigidity of the Shaft

The torsional deflection was determined by using the torsion equation given by Khurmi and Gupta (2004) as:

$$\theta = \frac{TL}{jG} \text{ -- (17)}$$

where ɗ = angle twist in radians

T = torque, (T = 196.57×10^3Nmm)

G = Modulus of rigidity for the shaft material, N/mm^2 (G = $84 \times 10^3 N/mm^2$)

L = Length of the shaft, mm (L = 1000mm)

j = polar moment of inertia of the cross sectional area about the axis of rotation,

$j = \frac{\pi}{32} d^4$ (for solid shaft)

$$j = \frac{\pi}{32} x(35)^4 = 1.47x10^5 mm^4$$

$$\theta = \frac{196.57x10^3 x1000}{1.47x10^{-7} x80x10^3} = 0.0158^o$$

= 0.0158 x ´/180 = 0.00027radains

The permissible amount of twist should not exceed 0.25^o per metre length of shaft, Khurmi and Gupta, (2004). Therefore the calculated twist of 0.0158^o (or 0.00027 radians) for the designed shaft is within the given limit.

2.7 Construction and Principles of Operation of the Machine

The machine performs two major functions namely cutting and beating. Therefore, the construction of the machine was done in such a manner that these functions will be effectively carried out. The machine (Fig. 2 and 3) consists of a hopper, the beating/cutting mechanism, feeding chute (located at one side of the casing), perforated outlet, transport handle, transport wheel and standing support, and is driven by an electric motor. The beating/cutting mechanism consists of two hexagonal flywheels carried by a rotating shaft. One of the flywheels carries two knives, located at the side facing the feeding chute. Six rods are attached to the edges of the two flywheels. Each rod carries three beaters, separated by spacers to prevent free sliding of the beaters along the rods. With the hopper located at the top of the machine, materials are fed through hopper. As the materials fall, they come into contact with the rotating beaters and are either crushed, cracked or shredded, by impact with beaters, as well as the walls of the casing, depending on the nature of the materials fed into the machine. Crop residues like corn, sorghum, millet stovers, rice straws, groundnut haulms; potato stems, cowpea stems are fed through the chute, located at the side of the casing. The materials are held and fed into the chamber manually. The materials come into contact with the cutting blades attached to the rotating flywheels, thus cutting the materials to the required length. Both the materials passing through the hopper and the chute pass through the perforated screen located at the bottom of the casing. The screen can be interchanged, depending on the size of the materials desired. The machine can be powered by an electric motor or petrol engine of 8.5kW and above. The power source is placed on top of the casing, beside the hopper and connected to the shaft by a pulley and belt arrangement. The rotating shaft transmits power to the crushing/cutting mechanism. Figures 2 and 3 show the isometric and orthographic drawings of the machine respectively.

2.8 Performance Evaluation of the Machine

The materials used for testing were maize stover, sorghum stover, millet stover, gamba grass, elephant grass and rice straw both in the wet and dry conditions. The moisture content of the wet and dry materials, collected from the field, were determined by oven ï dried method. Each sample was weighted W_1 and passed through the feeding chute into the chopping chamber, coming into contact with the rotating wheels (carrying the knives), chopped the materials. The chopped materials were collected through the perforated screen below the chopping chamber. The time taken to chop each sample was recorded. The collected materials were weighted as W_2. The materials that did not pass through the screen, after each test were also collected and weighted as W_3. Each test replicated three times. The specific cutting resistance increases with the increase of the stalks fed through the chute, hence the choice of 1.03kg of materials fed per batch, both for dry and wet conditions for the machine (table 1).

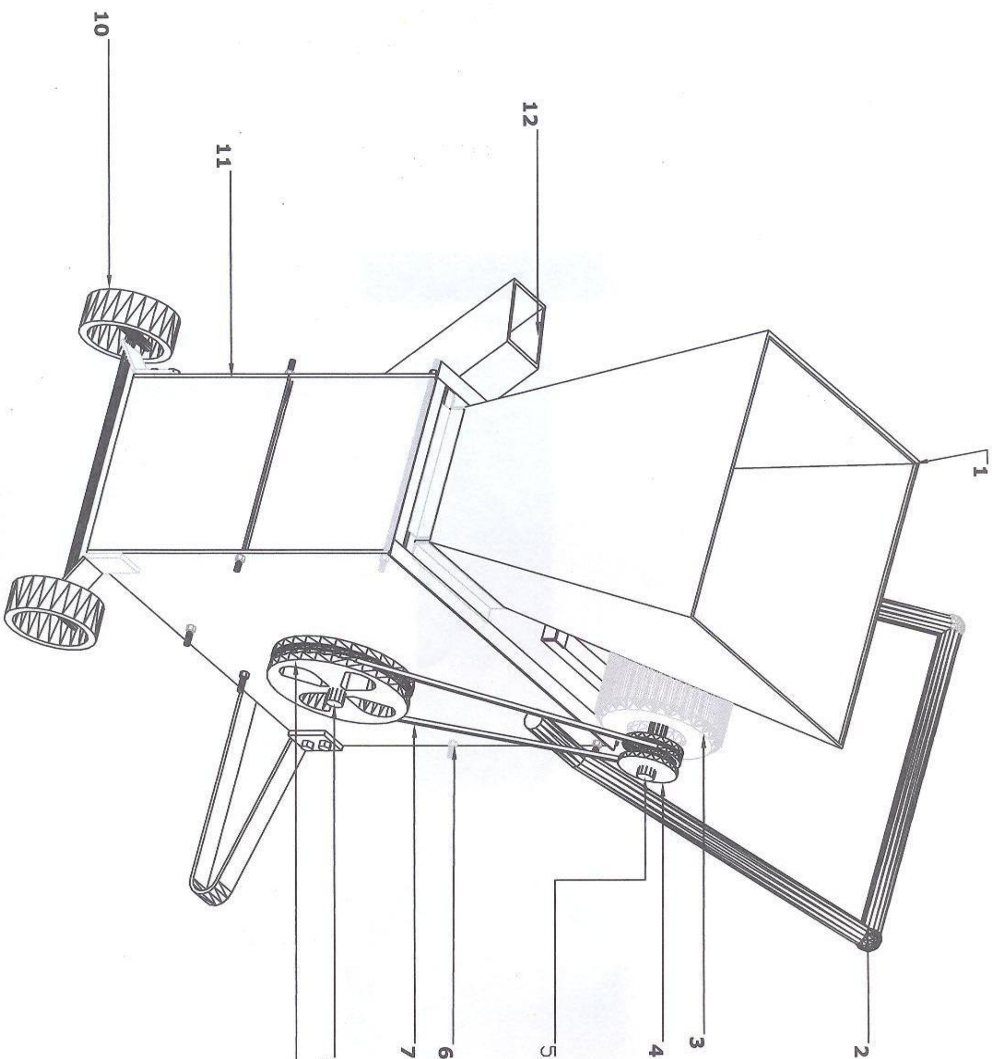

FIG 2: Isometric View Of Forage Chopping Machine SCALE 1:7 ALL DIMESIONS IN (MM)

(1)HOPPER (2) HANDLE (3) ELECTRIC MOTOR (4) MOTOR PULLEY (5) MOTOR SHAFT (6) NUT (7) BELT (8) CHOPPER SHAFT (9) CHOPPER PULLEY (10)WHEELS (11)MAIN HOUSING (12)CHUTTE

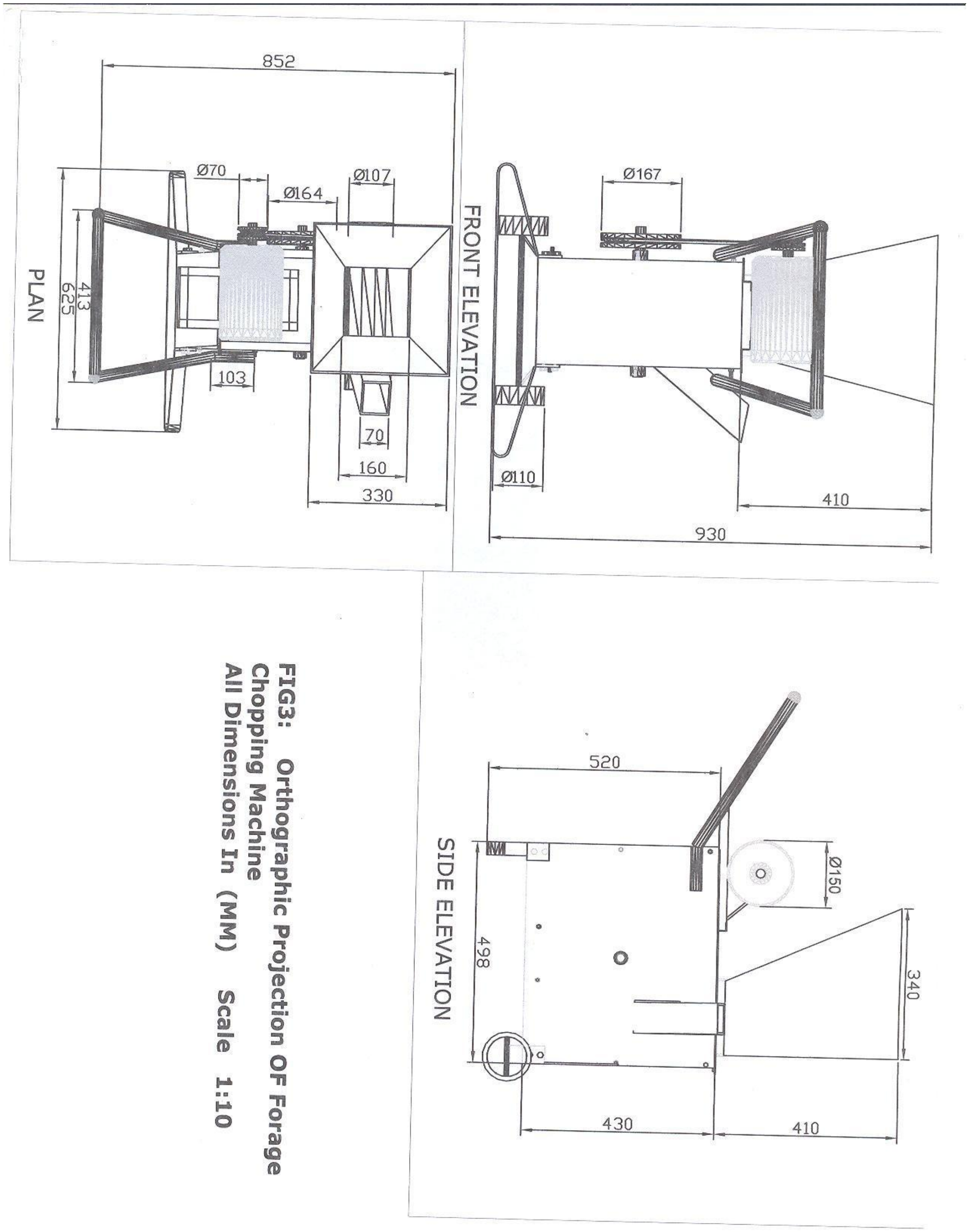

FIG3: Orthographic Projection OF Forage Chopping Machine
All Dimensions In (MM) Scale 1:10

3. RESULTS AND DISCUSSION

3.1 Results

Table 1 shows the results of the performance of the chopper carried out on maize stover, sorghum stover, millet stover, rice straws and some grasses commonly utilized by ruminants, gamba grass and elephants grass. The tests on the materials were carried out both for wet and dry conditions. The table also shows the moisture content of the materials (wb) chopping time, chopping efficiency and the rate of chopping for each of the samples.

3.2 Discussion of Results

In rotating blades, the effect of centrifugal force is prominent and considerable amount of power was lost due to friction energy between the chopped materials and the housing walls (Jekendra and Singh, 1991; Ige and Finner, 1997). The total cutting energy requirement was the sum of the energy required for initial compaction of the material until a pressure was reached at which the material yield, and the energy required for the effective cutting of the material, (equation 9). The cutting energy of crops was mainly affected by the physical and the mechanical properties of the plant, the knife parameters and the moisture content.

The thickness of the cutting edge influenced the cutting resistance in various ways. The force was practically constant for thickness up to 7 - 8εm but for greater thickness it increased significantly (Sitkei, 1986). Consequently it is not advisable to use knife edges that are too thin, since they represent no improvement in terms of energy consumption while they wear rapidly and deform easily. A badly worn, thickened edge consumes much surplus energy. With increasing knife thickness the additional deformation increases, whereby the energy spent in cutting increases.

A knife edge thickness ŭ=80εm was used. This value falls within the recommended value of 50 - 150εm given in Sitkei (1986). The thickness of knife was 4mm and sharpening angle (ɓ) was 25^{o}. According to Sitkei, (1986), for angle above 30^{0}, the energy requirements increase rapidly and for angles less than 20^{0}, the edge will deform easily and thereby reduce the life of the knife. The quantity of stovers fed into the machine through the feeding chute at any particular time affect the cutting of the material. The specific cutting resistance increases with the increase of the stalks fed through the chute, hence the choice of 1.03kg of materials fed per batch, both for dry and wet conditions for the machines, (table 1).

The quantity of dry materials collected after each cutting operation was higher than that of the wet materials. This was as a result of the fact that the beaters helped to further shred the dry materials, make them easier to pass through the perforated screen. This was not so for the wet materials because of their higher moisture content. The efficiency and rate of cutting, therefore, can be related to the mechanical and physical properties of the material, as well as the cutting knife parameters. The mechanical properties depends on the type of material, the stage of growth of the material (that is whether young or old plants), and the moisture content of the material. The cutting resistance of younger plants may be significantly lower than that of older plants (Sitkei, 1986).

Table 1: Test results of the Forage Chopper

S/N	Parameters	Test Materials											
		Maize Stover		Sorghum Stover		Millet Stover		Rice Straw		Gamba grass		Elephant Grass	
		Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
1.	Average weight before chopping W_1,kg	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03
2.	Average weight after chopping W_2, kg	0.90	0.98	0.92	0.96	0.85	0.92	0.90	0.98	0.88	0.95	0.85	0.94
3.	Average weight of materials in the chamber W_3, kg	0.13	0.05	0.11	0.07	0.18	0.11	0.13	0.06	0.15	0.08	0.18	0.09
4.	Time of chopping (secs)	200	146	198	144	201	146	194	141	208	147	210	148
5.	Chopping rate kg/min	0.27	0.40	0.28	0.40	0.25	0.38	0.28	0.41	0.25	0.39	0.24	0.38
6.	Efficiency of chopping %	87	95	89	93	83	89	87	94	85	92	82	91
7.	Moisture Content % (wb)	62.7	18.2	63.5	19.1	58.7	17.3	47.8	16.5	70.9	20.5	80.9	27.5

The average chopping efficiency for the wet materials was 86% and for the dry materials, it was 92%. These generally indicate a very high cutting performance of the machine, especially when the blade parameters were maintained.

The average chopping rate for the dry materials was 24.0kg/hr and the average chopping rate of the wet materials was 15.6kg/hr. This shows that the chopping rate of dry materials is about twice higher than that of the wet materials.

4. CONCLUSION

The forage chopper developed was tested using some crop residues and grasses commonly fed to small and large ruminants. From the test results obtained the chopper has very high cutting performance efficiencies both for wet and dry materials, 85% and 92% respectively. The results of the chopping rate of the machine show that it can produce averagely 15.6kg/hr of wet materials and 24.0kg/hr of dry materials. The chopping length of 25mm makes the chopped material suitable for feeding ruminants directly, or used as major components for animal feeds preparation, with enriched constituents like protein, vitamins and minerals. Preparation of enriched animal feeds with the chopped materials will serve as a major source of feedstuff supplies for both pastoral nomad and livestock farmers, thus improving the countryôs livestock feeding management and leading to increased meat and dairy production. Improvement of livestock feeding management using chopped crop residues will drastically reduce environmental degradation, bush burning and routine clashes caused by the migratory practices of the pastoral nomad. The machine can be operated with either a petrol or a diesel engine of 8.5kW and above. This makes the machine suitable for operation either in the rural or urban communities. The machine is easy to operate and maintain, and requires only one operator to handle.

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BIOGAS PRODUCTION POTENTIAL OF CATTLE PAUNCH MANURE

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ABSTRACT

Abattoir wastes include: animal blood, bones, horns, reject- meat, spent-water and paunch manure. Paunch manure has been found to be the major abattoir waste both volume-wise and because the blood, the bones, and the horns are more readily sold by butchers to buyers who process them for other valuable products. The need to explore the utility of paunch manure so as to enhance its marketability and disposability was established. Consequently, a 40-litre anaerobic digester was designed, constructed and used to investigate the biogas production potential of cattle paunch manure. The paunch manure was found to have biogas production potential**.** A specific gas productivity of 0.07 l gas/gVS ï destroyed was achieved in a single batch process digestion experiment that was performed. The conditions that favoured biogas production from the manure included average mesophilic temperature of 39^0C, pH of 8, volatile acid concentration (VAC) of 278mg/L, NH_3-N of 18.3 and alkalinity of 2800mg/L. The percent stabilization of the waste was 32%. These values were rather low when compared to values found in literature for animal manure. The low values were attributable to the composition of the substrate, ï fibrous vegetable materials usually with low biodegradability. The need for more research was recommended so that the optimum specific gas productivity value for cattle paunch manure could be realized.

KEYWORDS*:* Biogas, paunch manure, cattle, waste, digester.

1. INTRODUCTION

Everyday, in almost all the abattoirs in Nigeria, two or more animals mainly cattle are slaughtered for human consumption. In the process, abattoir wastes are generated as blood, horns, bones, reject meat, spent- water, paunch manure, etc. Quite often, the blood, bones, the horns, and the reject meat are readily disposed off by the butchers for money. Paunch manure (the contents of the rumen in ruminants) was therefore found to be the major abattoir waste that requires proper management. The routine work of the first author of this paper as a former Town Engineer with Nsukka Local Government in Enugu State brought him face ï to ï face with the problem of abattoir waste at Ogige (Nsukka Urban) market.

At the time of conception of this study there existed a pile of decomposing abattoir wastes at the meat section of Ogige (Nsukka Urban) market. Students of Social Work Department from University of Nigeria, Nsukka, who were on industrial attachment with Nsukka Local Government, identified the malodorous waste pile as a social problem in the market environment. It was then that the inspiration came to study the possible benefits derivable from the waste pile for the purpose of recommending appropriate management strategy.

Preliminary investigations showed that cattle paunch manure was different from cattle faeces or ordinary cattle manure. Cattle faeces consist of undigested food, mostly cellulose ï fibre, undigested proteins, excess Nitrogen from digested protein, residue from digestive fluids, waste mineral matter, worn-out cells from intestinal linings, mucus, bacteria, and foreign matter such as dirt consumed, calcium, magnesium, iron and phosphorus, feed and feed additives (Robinson et al, 1971). On the other hand, paunch manure being undigested materials can contain long hairs, whole corn kernels, and large plant fragments of 25 ï 50mm long.

In literature there seemed to be little or no research report on the biogas production potential of paunch manure. The numerous reports found in literature were rather on animal faeces or manure. The objective of this work was therefore to investigate the Biogas production potential of cattle paunch manure in order to promote its utility, marketability, and disposability.

2. MATERIALS AND METHODS

The laboratory ï size biogas plant actually used for this study is shown in Fig. 1 and Fig. 2. The plant consisted of a 40 ï litre anaerobic digester and a biogas collector and measurement unit. The digester was designed, and constructed from a 1.5mm thick galvanized mild steel sheet with a transparent fibre ï glass top for visual inspection of the digester content.

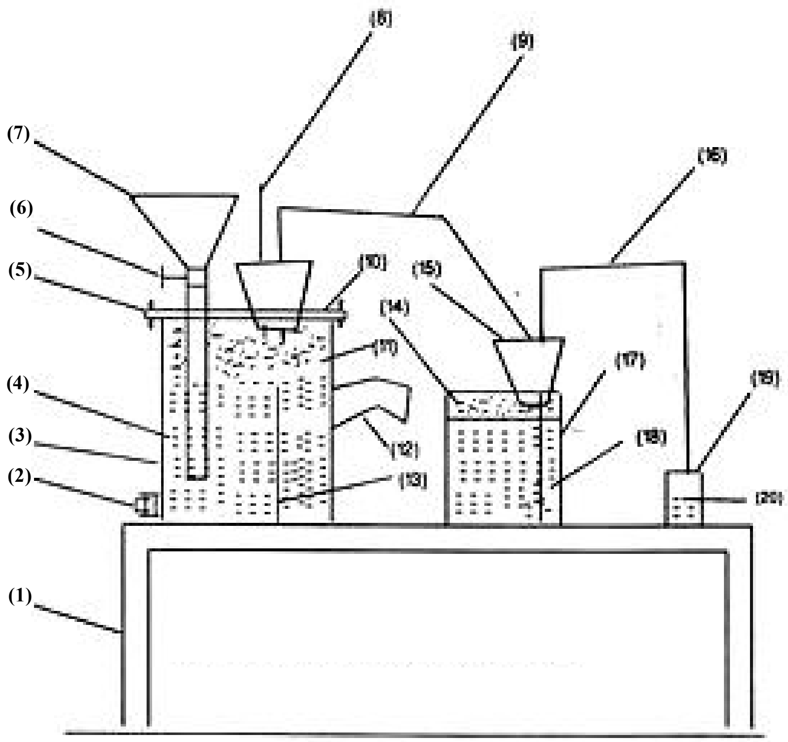

Fig. 1: Sectional Drawing of the Biogas Plant

Legend

1. Lab table
2. Sludge pot and plug
3. Digester
4. Water-waste mixture
5. M-12 bolt and nuts
6. Get valve
7. Inlet funnel and pipe
8. thermometer
9. glass tube and hose
10. fibre glass cover
11. biogas
12. outlet pipe, elbow & plug
13. partition wall
14. biogas
15. hard rubber cork
16. glass tube & hose
17. Jerry can
18. Water
19. water bottle
20. displaced water

The biogas collector and measurement unit used consisted of a 2.5 litre transparent jerry-can and a 225ml bottle, all connected in series to the 8 ï litre digester headspace. Fresh paunch manure collected from the concrete surface of the manure pit of Ogige (Nsukka Urban) abattoir was the organic substrate used for the experiment. Dilution water was obtained from the University of Nigeriaôs public tap.

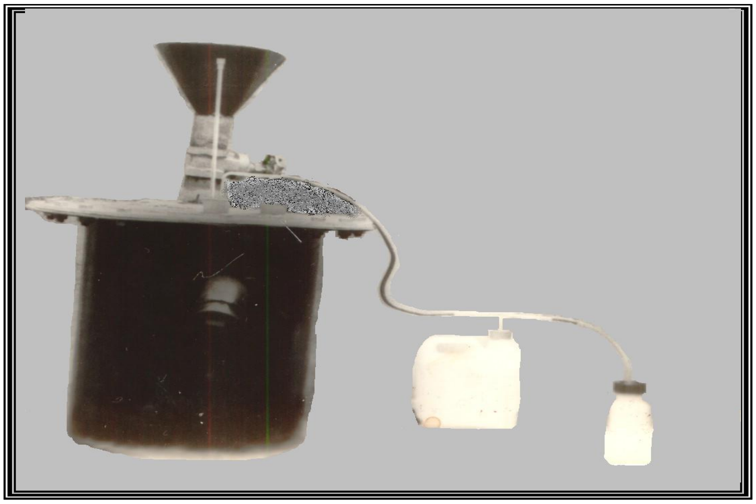

Fig. 2: Photograph of the Biogas Plant

In this study, only one experimental program was performed, namely: the batch process program. The program was performed out-doors with no mixing; 3kg of fresh paunch manure (at 17.8% TS) was diluted with 18 litres of dilution water and was loaded into the digester through the inlet funnel. The whole arrangement was left in place, while both the ambient temperature and the internal temperature of the digester head space were monitored with mercury ï in ï glass thermometers. Biogas production was monitored by downward displacement of water, throughout the 93 day-duration of the experiment.

Three different analytical programs were performed on the paunch manure and the digester effluent. First, a sample of the fresh paunch manure used in the biogas production test was physico-chemically analyzed for TS, VS, COD, C/N ratio, pH, NH_3 ï N, VAC and bulk density.

Secondly, a sample of the digester effluent was collected at the end of the experiment and characterized for TS, VS, COD, pH, alkalinity, VAC, and NH_3 ï N.
And thirdly, while the anaerobic digester was producing gas, a sample of the digester liquor was collected and characterized for pH, VAC, NH_3 ï N and alkalinity.

All the analyses were done in the Public Health laboratory of Civil Engineering Department, University of Nigeria, Nsukka, in accordance with procedures in the Standard methods for the examination of water and waste water (APHA, 1975).

3. RESULTS AND DISCUSSION

3.1 Biogas Production

The minimum and maximum recorded temperature of the digester head space throughout the test duration was 26^0C and 43^0C respectively. The minimum temperature occurred at 6.00a.m in the morning, while the maximum temperature occurred at 3.00p.m in the afternoon. For 77days, gas production was not noticeable, probably, because the 8-litre digester head-space was not gas-filled yet. Biogas production was, however, noticed on the 78th day.

On that day, some quantity of water was displaced from the 2.5 litre biogas collector into the 225ml bottle. The water displacement, indicating biogas production continued for the next thirteen days and then diminished greatly.

Fig.3 and Fig.4 show that within the 13 daysï period, the average temperature was about 39^0C (mesophilic). Also, the average daily biogas production was about 28ml (see Fig. 5).

The Total Daily Biogas Production by the System (G), which is the sum of all daily quantity of Biogas produced by the anaerobic system was 8.37litres. The Specific Biogas Productivity of the waste (SBP), which is the ratio of G to the quantity of volatile solids destroyed by the system, was 0.07 l gas/gVS destroyed.

The Percent Stabilization of the Waste (E_g), which is the ratio of VS content of the waste before stabilization to the VS content of the waste after stabilization, expressed in percentage was 32%.

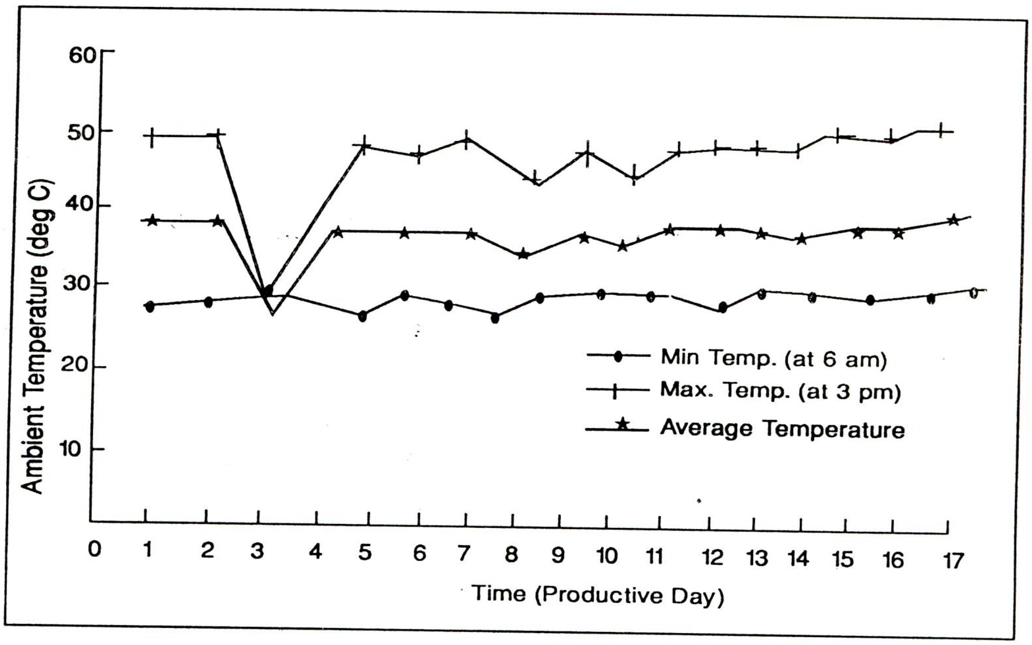

Fig. 3: Graph of Ambient Temperature versus Time

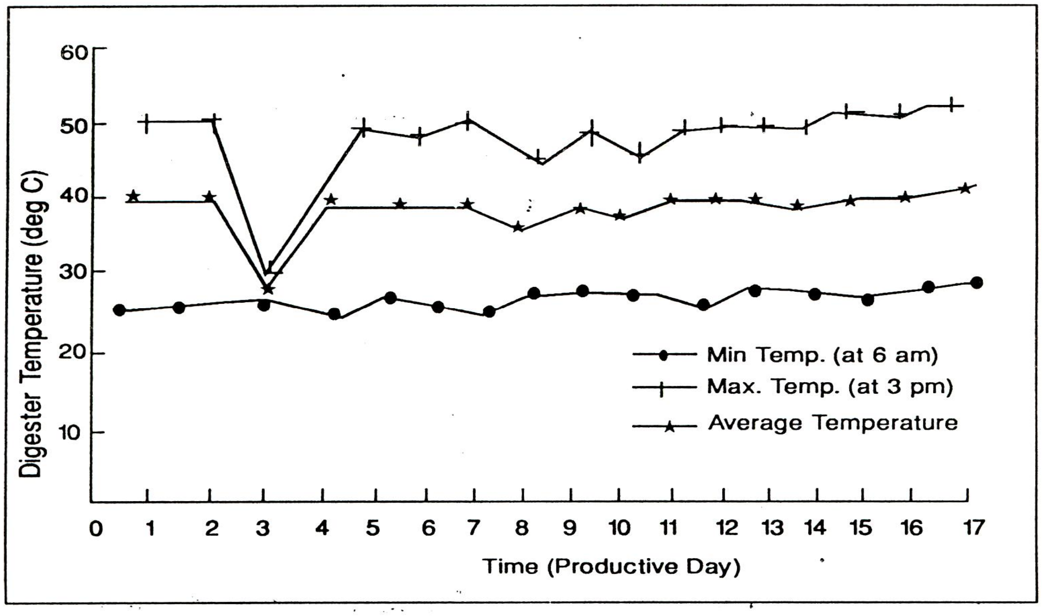

Fig. 4: Graph of Digester Temperature versus Time

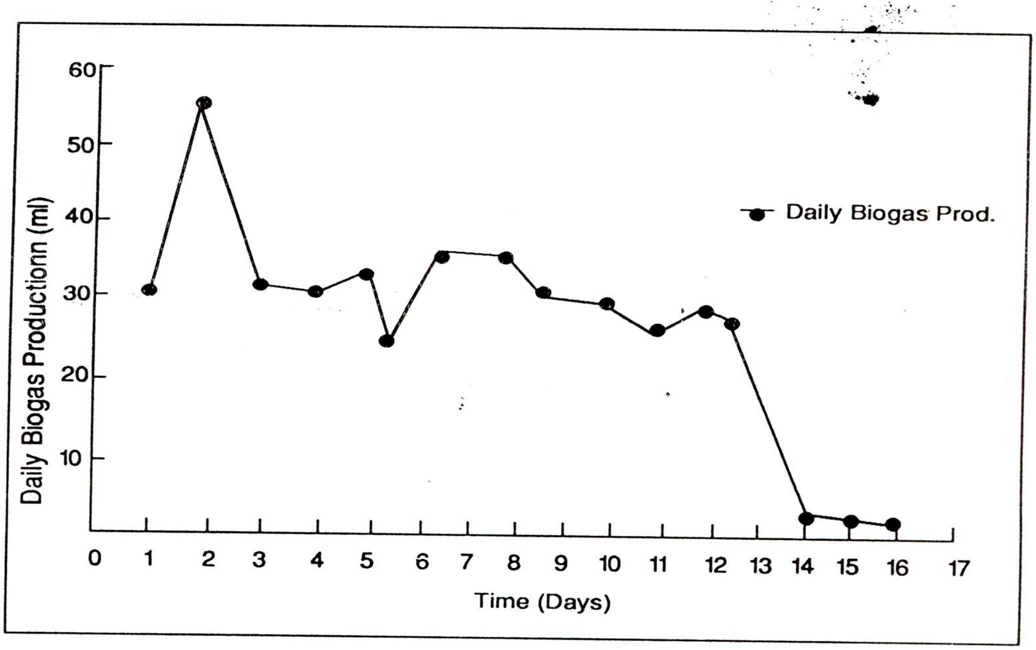

Fig. 5: Graph of Daily Biogas Production versus Time

3.2 Analytical Test Results

The analytical test results for the fresh paunch manure, the digester effluent and the liquor producing gas are presented in Tables 1, 2 and 3 respectively.

3.3 Discussion

The percent stabilization of 32% is rather low when compared to 48% reported in literature for animal manure (Hill, 1982a). Also, the specific biogas productivity of 0.07 l gas per gVS destroyed is much lower than the 0.71 l gas/gVS destroyed, found in literature (Hills, D.J. 1980) for animal manure. These low values are attributable to the composition of the substrate. The paunch manure used as the substrate was mainly of fibrous vegetable materials such as lignin which is known to be unaffected by anaerobic bacteria; and cellulose which is decomposed very slowly, (Loehr, 1974; Morris et al, 1975). The C/N ratio of 70 (Table 1) is also high compared to 8-30 range recommended in literature as being satisfactory for biogas production (Loehr, 1974). The high C/N ratio is indicative of unfavourable substrate composition for effective biodegradation and biogas release.

It could also be observed that the pH of 8.9 (Table 2) is slightly higher than the 6.8 ï 8.0 range reported in literature as being favourable for anaerobic digestion (Loehr, 1974). Little wonder then, that the effluent was no longer producing gas. From Table 3, it could be deduced that the favourable conditions for biogas production include pH of 8, VAC of 27.8 mg/L, NH_3 ï N of 18.3 and alkalinity of 2800mg/L. The fact that the batch experiment took quite a long time to produce Biogas(93days) compared to 7-14days for unseeded cattle manure(feaces) may be indicative of poor biogas production potential of cattle paunch manure.

Table 1: Analytical Test Results for the Fresh Paunch Manure

S/NO	Characteristics	Values
1	pH (Hydrogen ion Concentration)	7.1
2	TS (Total Solids)	17.8%
3	VS (Volatile Solids)	12.5%
4	COD (Chemical Oxygen Demand)	6400mg/L
5	C/N Ratio (Carbon/Nitrogen Ratio)	70
6	NH_3 ï N (Ammonia Nitrogen)	26.8mg/L
7	Volatile Acids Concentration	275mg/L
8	Bulk Density	217kg/m^3

Table 2: Analytical Test Results for the Digester Effluent

S/NO	Characteristics	Values
1	pH	8.9
2	TS	14.6%
3	VS	8.5%
4	COD	4500mg/L
5	NH_3 ï N	8.41mg/L
6	VAC	19.2mg/L
7	Alkalinity (bicarbonate)	2650mg/L

Table 3: Analytical Test Results for the Digester Liquor Producing Gas

S/NO	Characteristics	Values
1	pH	8.0
2	VAC	27.8mg/L
3	NH_3 ï N	18.3mg/L
4	Alkalinity (bicarbonate)	2800mg/L

4. CONCLUSIONS AND RECOMMENDATIONS

Paunch manure (the content of the rumen) is the major disposable constituent of abattoir wastes that possesses pollution potential, since animal bones, horns, and blood find ready market.

This study has shown that cattle paunch manure has biogas production potential. A rather low specific gas productivity of 0.07 l gas/gVS ï destroyed was achieved in a single batch process digestion experiment that was performed (Ezeoha, 2000). If further research shows similar results as obtained in this study, it is recommended that cattle paunch manure should in the mean time be disposed directly on agricultural lands for fertilizer replacement, or dried and used as an ingredient of animal feeds.

ACKNOWLEDGMENT

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DEVELOPMENT OF A DUAL POWERED GARI SIFTER

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ABSTRACT

A dual powered sifter for grated and dewatered cassava mash (*gari*) was designed, fabricated and tested. When manually operated, the machine has a maximum sifting capacity of 84 kg/h and sifting efficiency of 97.3% of grated and de-watered gari mash, requiring 0.015 kW power at 60 rpm. When the machine is powered by an electric motor, the maximum sifting capacity and cleaning efficiency increased to 170 kg/h and 98% respectively requiring a maximum power of 1.815 kW. The machine was further evaluated at three operating speeds of 533 rpm, 355 rpm and 266 rpm. It was observed that increase in speed of operation improved both the sifting capacity and sifting efficiency of the machine. All materials used for fabrication were obtained locally and the estimated cost of producing one unit of the sifting machine (without the electric motor) is seven thousand, five hundred and ninety-five Naira (₦7595.00).

KEYWORDS: Cassava, *gari*, sifter, sifting capacity, sifting efficiency, dual-powered.

1. INTRODUCTION

Since 1990, Nigeria surpassed Brazil as the world's leading producer of cassava with an estimated annual production of 26 million tones from an estimated area of 1.7 million hectares of land (FAO, 1991). Other major producers of cassava are: Zaire, Thailand, Indonesia, China, India, Malaysia, Malawi, Togo and Tanzania. The importance of cassava as a cheap source of calories intake in human diet especially in the tropical areas of Africa, Asia and Latin America, as well as source of carbohydrates in the production of animal feed (chips and pellets) and industrial raw materials such as starch and alcohol has been reported (Odigboh, 1983; Ugwu and Okereke, 1985; Agbetoye, 1995 and 2003; Kawano, 2000; Ali and Ogbu, 2003). Cassava starch is an ingredient in the manufacture of dyes, drugs, chemicals, carpets and in coagulation of rubber latex (Odigboh, 1983). Cassava which has previously been regarded as a poor man's food is increasing in industrial and economic potential (Agbetoye, 1995). Infact, there had been a revenue generation projection of about $100 million for cassava in Nigeria by 2005 (Ali and Ogbu, 2003).

Currently, there is high demand for cassava products both locally and abroad. At the local scene, there is a Federal Government directive that producers of flours for baking bread must include 10% cassava in their product. The Chinese and other Asian countries have also ordered for large quantities of cassava chips. There is no doubt therefore that the cost of *gari,* the most popular food derived from cassava will increase. One solution to the impending scarcity of *gari* is the development of small-scale technologies for increase in *gari* production. Furthermore, for the Federal Government to exploit the opportunity to generate revenue from cassava and to remove over-dependency on oil revenue, urgent attention must be given to the development of machinery for mechanized production and processing of cassava. Most of the cassava produced in Nigeria still comes from peasant farmers who depend on manual tools for their field operations. Increase in production of cassava implies mechanization of its cultivation, harvesting and processing.

Unlike many other foods, such as fruits and vegetables, roots and tubers are rarely eaten raw. These normally undergo some forms of processing before consumption. Even though raw sweet cassava is occasionally eaten in the Congo region, Tanzania and West Africa, cassava is not generally consumed raw. Cassava consists of high percentage of water. Processing it into dry form will therefore reduce the moisture content and convert it into more durable and stable product. *Gari* is very popular in West Africa and is a staple food in Nigeria, Ghana, Benin and Togo. Its ability to store well and its acceptance as a ñconvenience foodò is responsible for its increasing popularity in the urban areas of West and Central Africa (IITA, 1990 and FAO, 1990). It is often consumed as the main meal in the form of dough or a thin porridge. Both are prepared in the household by mixing dry *gari* with hot or cold water and cooking and are served with soup or stew. *Gari* is also eaten as a snack when mixed in cold water with sugar, and sometimes milk.

The processing of *gari* from cassava has been reported by many authors as a labour-demanding operation while women and children are the major producers. Onwueme (1978) stated that, in traditional setting, only very simple hand equipment is employed in the production of *gari*. According to Nweke *et al*. (1994), poor processing quality of *gar*i emanates from the difficulty of processing, such as problems associated with peeling, grating, milling, dewatering, toasting, sifting etc, which are labour-intensive tasks. Francis (1984), in his study of problems involved in traditional processing of cassava into *gari* in Ibadan, highlighted several problems involved in each stage of *gari* processing and concluded that it was energy, time and labour consuming. Likewise, Ikpi and Hahn (1989) reported that cassava processing is almost entirely performed by women at the household level or at a central location such as a village or town market place. They estimated that at least 45% of the labour requirements are for peeling and sifting.

Sifting of cassava mash is important before frying to ensure that particles have uniform size. The uniform size of particles will ensure uniform roasting during garification. Final product must be uniform in size too to attract good market value. Mash cassava is first sifted after de-watering in order to remove the fibre (ungrated cassava pieces). In the final re-sieving, the product is separated into chaffy, fine, coarse and medium size fractions. This is done after the frying operation. It has been identified that one of the ways to achieve better quality of *gari* as well as to reduce time duration for processing *gari*, is to have proper and quicker means of sifting cassava mash. FAO (1998) explained that after pressing, the de-watered cassava mash, it has to be broken up and sieved to remove the large lumps and fibre, in order to obtain a homogenous product.

Traditional method of sifting is still adopted by most of the *gari* processing industries. The mechanical method of *gari* sifting is not widespread among processors. FAO (1998) suggested that perhaps, because sifting operation not difficult or arduous compared to some of the other *gari* processing operations, there is little advancement in sifting equipment at the village level. Traditional sifting is done manually using sieves made from palm leaves, bamboo or raffia cane. IITA (1990) reported that the size of the sieve is between 300 and 400 microns. The cassava cake is pressed and rubbed against the surface of the sieve. After some minutes of rubbing, the fibres and un-grated lump are separated, leaving the granular particles under the sieve.

Francis, (1984) identified the shortcoming of traditional method of sifting as: problem of rubbing onesô hand against palm fibre which can cause injury to operatorôs hand; problem of the operator having backache because of time of sitting down for the operation; and time and energy consumption. IITA (1990) suggested that sifting raw cassava particles is better done by feeding the cassava cake back into the grater after de-watering. But graters cannot sieve the cassava mash to the required particles size for frying, since graters do not have screen that can separate the mash into fine particles. Igoni (2000) constructed a continuous flow rotary sieve for de-watered cassava mash. It sieves *gari* at moisture content of 47.6%. The machine has efficiency of 48.6%. Though the source of power of the machine was not stated, the efficiency of the machine is not enough for effective operation. Jimoh and Oladipo (2000) also developed similar *gari* sifter. It consists of reciprocating screen which is electrically operated with 1.2 kW electric motor. The machine has power requirement of 0.3 kW, sieving capacity of 8.0 kg/h and operating efficiency of 61%.The machine reportedly cost ₦9,057.65.

The objectives of the present work were to design and fabricate a *gari* sifter that could be operated manually or powered by an electric motor and test its performance.

2. MATERIALS AND METHODS

2.1 Design Considerations

The design of this dual-powered operated *gari* sifter was based on the following considerations: the availability of materials locally to reduce the cost of production; the hoper is the open type to allow easy loading of gari mash; the outlet for chaff was installed for proper discharge; the sifted *gari* outlet was inclined at an angle greater than the angle of repose of gari for effective discharge; there is provision for alternative power supply (human power), through hand cranking incase of power failure; it is desired that there should be minimum or no loss of gari during the operation, therefore the pulley was carefully designed to meet the required speed of the sieving unit.

2.2 Description of the Gari Sifter

The major components of the dual-powered *gari* sifter are the frame, sieving unit, cranking assembly, bearing housing, motor frame and collecting chamber (Figs. 1 and 2). The frame is made of angle iron of 2.5 mm thickness. The sieving unit is made of mild steel sheet metal, flat bar and angle iron of 1.5 mm thickness. The cranking assembly is made up of crank handle and shaft. The shaft has 19 mm diameter and is 200 mm long. A bearing was installed in-between the shaft to serve as cam. This cam was bolted to the sieving unit through a flat bar. The crank handle is made of mild steel rod of 200 mm long and a diameter of 10 mm.

The bearing housing is fabricated from mild steel pipe with 20 mm bore, 3 mm thick and three 20 mm diameter ball bearings. The collecting chamber is made of mild steel sheet metal. It is folded below the sieve and projected at angle of 42^0 for easy discharge of the sieved *gari* through the outlet.

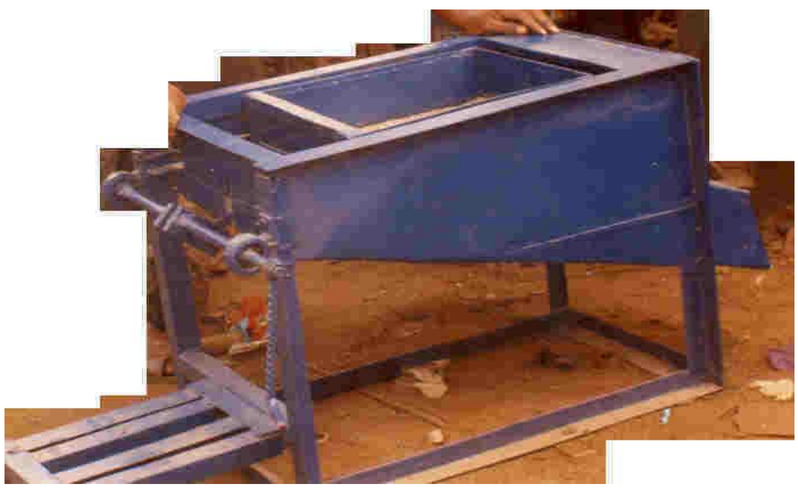

Fig. 1. The gari sifter with handle for manual operation

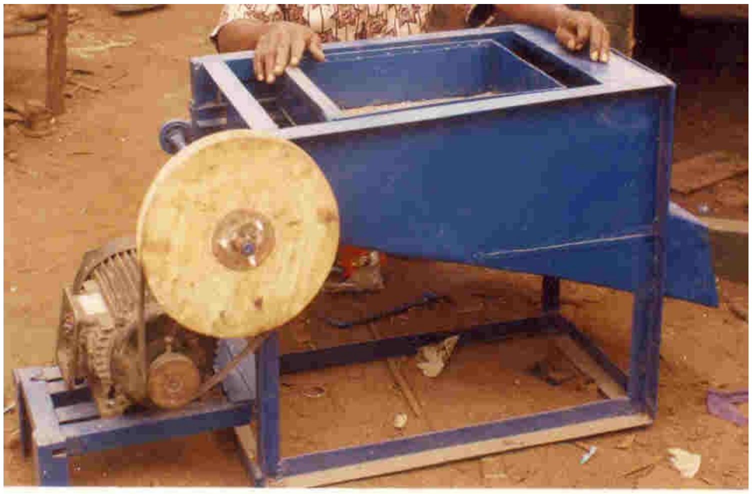

Fig. 2. The gari sifter with electric motor mounted

2.2 Operation of the Machine

Sifted *gari* is achieved by turning the crank handle manually. The shaft transmits the rotary motion through the cam to the sieving unit and this in-turn makes the sieve to reciprocate, which cause sieving. When electric motor-powered, belt and drive system transmit the rotary motion to the shaft and cam. From the cam, the sieving unit receive the power and results in the reciprocating motion that make the *gari* to sieve into the chamber and pass out through the outlet.

2.4 Design Analysis

The power required to sift depends on the weight of the cassava mash; the sieving unit; velocity required to oscillate the machine and the friction at the bearings. The friction produced by the bearings is negligible, because well lubricated ball bearings were used for the oscillation of the screen. Therefore, the power required by this machine is assumed to depend on the weight of the cassava mash and the velocity of oscillation.

From the experiment conducted, the bulk density of cassava mash was found to be 709 kg/m^3. Therefore, the weight of cassava mash that will fill-up the screen is given as:

$$W_g = V_S \vartheta_s g \quad (1)$$

Where; W_g = weight of the *gari,* N; V_s = volume of the screen, = 0.008 m^3; ϑ_g = bulk density of *gari* mash, Kg/m^3; g = acceleration due to gravity, m/s^2

The diameter of the shaft, d_s was determined using standard procedure and equation 2 (Hall *et al*., 1980)

$$d_s^3 = 16/\prod S_s \ \sqrt{(K_b M_b)^2 + (K_t M_t)^2} \quad (2)$$

Where; M_b = maximum bending moment; M_t = maximum twisting moment; K_b = combined shock and fatigue factor applied to bending moment = 1.5; K_t = combined shock and fatigue factor applied to twisting moment =1.0; S_s = Ultimate stress of mild steel = 55 x110^6 N/m^2. The value d_s = 18.79 mm, therefore 19 mm standard diameter shaft was selected.

The power, P (kW) required by the machine is given by the equation;

$$P = M_s V^3 / r \quad (3)$$

Where; M_s = mass of shaft, kg; V = velocity, m/s; and r = radius of the gyration, m;

Using equation 3, the power required to drive the screen, P = 0.089 W; power required by the crank = 0.0197 W; and the power required by the sieving unit (the sieving unit includes the screen and the cassava mash) = 14.3988 W. Therefore, total power required by the manual-cranking was obtained as;

$$P_{max} = 0.0899 + 0.0197 + 14.3988 = 0.015 \text{ kW}$$

Three different pulleys were used because the machine was tested at three different speeds. The three diameters were 200 mm, 300 mm and 400 mm corresponding to rotational speeds of 533 rpm, 355 rpm and 266 rpm respectively. Using equation 2, the respective power requirements were; 816.91 W, 1.23 kW and 1.634 kW. The highest power requirement from the three cases was = 1633.99 W. Therefore the power required by the motorized power source was calculated as;

$$P_{max.} = 1633.99 + 0.0937 + 14.3988 = 1648.4825\text{W} = 1.65 \text{ kW}$$

Taking care of power losses due to friction ($10\,^0/_0$); total power = 1.65 + 0.16 = 1.815 kW. Therefore a 2.25 kW (3 hp) electric motor was selected for driving the machine

2.5 Performance Tests

An experiment was designed such that the sifter was tested under two power sources (manual and motorized). For manual operation, the quantity of cassava mash loaded into the machine per batch included ten levels ranging from 1.5 kg to 5.5 kg at 0.5 kg increments. The operating speed of the sieving unit was determined by the rotation of the crank assembly for manual power source and the driving pulley of shaft for the motor power source. In the motorized tests, three different speeds of 533 rpm, 355 rpm and 266 rpm corresponding to s_1, s_2, and s_3, respectively were used. Three loading levels were utilized i.e. 2.0 kg, 2.5 kg and 3.0 kg.

Each quantity of cassava mash was weighed on the balance. This was poured into the sieving unit and properly spread out. The machine was operated until the cassava mash was completely sieved. The time taken was noted and recorded. The chaff was weighed and recorded. These procedures were repeated for other loading levels.

The performance criteria used were *Sifting Capacity* (SC) and *Sifting Efficiency (SE)*. The sifting capacity is the rate at which the machine sieves the cassava mash and is rated in kilogram per hour. It was calculated with equation 4;

$$SC = m/t \qquad (4)$$

Where; m = mass of cassava mash loaded into the sifter, kg; and t = time for the sifting to be completed, h. The Sifting Efficiency (*SE*) is defined as the percentage mass of clean cassava mash separated after sifting, and is calculated with equation 5;

$$SE = \frac{m - c}{m} X100\% \qquad (5)$$

Where; c = mass of *gari* chaff in kg.

3. RESULTS AND DISCUSSION

The data collected from the tests were analyzed statistically using ANOVA. The summary of results is presented in Figures 3 to 6. For the manually operated machine, the sifting capacity increased from 45 kg/h at 1.5 kg loading to a maximum of 84 kg/h at 3.5 kg loading before reducing again as loading was increased further. The relationship between the loading and the sifting capacity was approximately quadratic (Fig. 3). The sifting efficiency increased slightly from 96% at 1.0 kg loading up to a maximum of 97.3% at 3.0 kg loading before decreasing quadratically to 90.5% at maximum loading. Figures 3 and 4 indicates that for manual operation of the gari sifter, 3.0 kg loading is the maximum loading recommended. The mean rotational speed of shaft driving the sieving unit of the machine is 60 rpm. It was also observed that the *gari* screens sometimes need to be rubbed with hand to break further the lumps of *gari* cake. This probably accounted for the reduced capacity as there were more lumps to be broken as the *gari* increased.

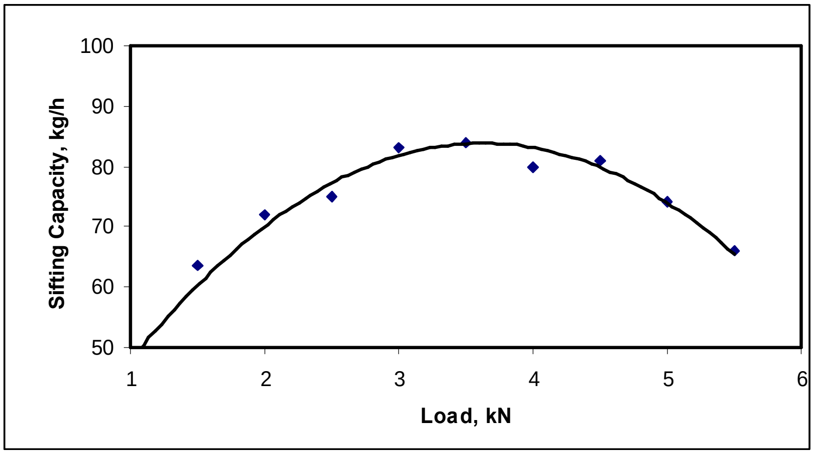

Fig. 3: Effect of Loading on the Sifting Capacity of the Gari Sifter when Manually Powered.

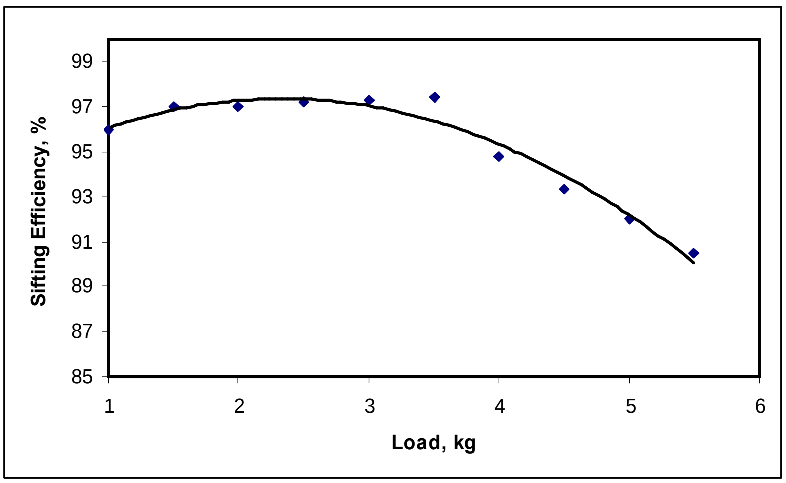

Fig. 4: Effect of Loading on the Sifting Efficiency of the Gari Sifter when Manually Powered.

For motorized operation, both speed of operation and loading had significant effects on the magnitude of sifting capacity and sifting efficiency. Increase in speed increased the magnitude of both sifting capacity and sifting efficiency (Figs. 5 and 6). While loading increased sifting capacity linearly at the three speeds evaluated (S_1 = 533 rpm, S_2 = 355 rpm, S_3 =266 rpm), the sifting efficiency increased with increased loading from 2 kg to 3 kg before decreasing in a quadratic manner similar to the manual case. The increase in sifting capacity with increased loading was due to the fact that increase in speed led to more vibration of the machine, hence the *gari* particles moved faster through the screen apertures.

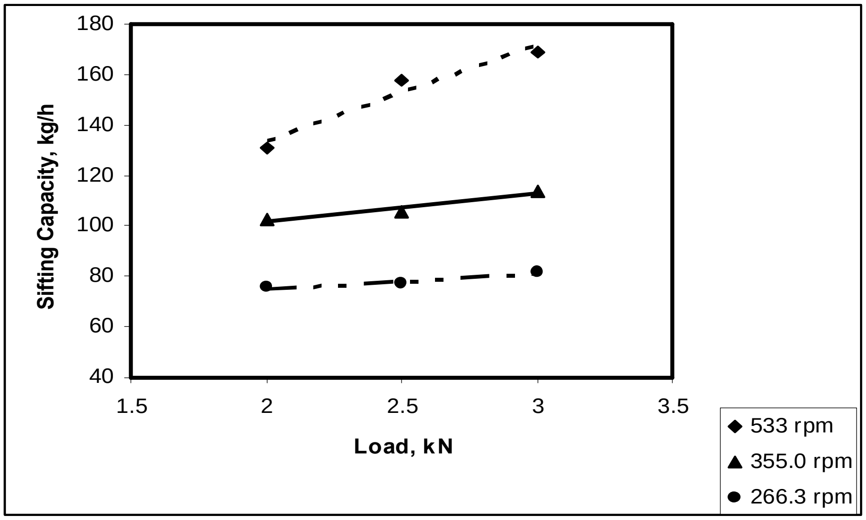

Fig. 5: Effect of loading on the sifting capacity at different operating speeds of sifter when motor-powered

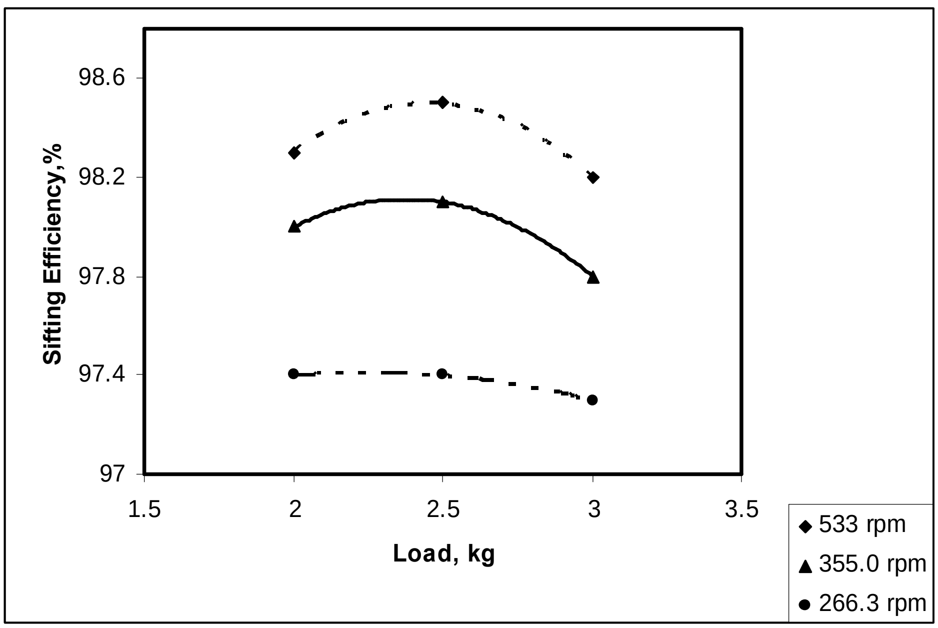

Fig. 6: Effect of loading on the sifting efficiency at different operating speeds of sifter when motor-powered

It was observed from Figure 6 that with increase in load above 3 kg, the cleaning efficiency decreased. This may be due to the fact that there were more lumps of cassava cake present, with increase in cassava mash. The reduction in sifting efficiency at loads beyond 2.5 kg may be due to the fact that the particles gyrated faster than necessary for it to pass through the apertures. At the three speeds, optimum sifting efficiency was obtained with about 2.5 kg loading. The maximum sifting capacity obtained for the motorized powered source was 170 kg/h corresponding to the highest speed of 533 rpm.

4. CONCLUSIONS

A *gari* sifting machine capable of being manually and electric motor-operated was designed, fabricated and tested. Based on the performance evaluation of the machine, it can be concluded that mechanical sieving of cassava mash can be done more conveniently than the traditional sieving done by rubbing cassava mash against weaved sieve. Using the electric motor for operating *gari* sifter is preferred to manually powered operation. In both cases, the sifting capacity and sifting efficiency were greater than those obtained from traditional methods.

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MODIFICATIONS AND PERFORMANCE EVALUATION OF A CASHEW-NUT CRACKER

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ABSTRACT

Modifications were carried out on a cashew-nut cracker which was constructed using locally available materials. The cracker consists of mainframe shaped in the form of an inverted capital letter L (height 300mm on both sides, 130mm on the cut side and 170mm form the base), base attachment (206 x 308mm), lever-hand of length 506mm and cracking assembly (upper and lower cutters, return springs, stopper, main rod and housing). These components parts of the cracker are made of mild steel except for the cutter blades, which are made of galvanized steel.

The cashew nut cracker was tested using small, medium and large nuts (the three sizes of the cashew-nut). Machine efficiencies were obtained as 50.9%, 64.3% and 60.9% for the three sizes respectively. The results also showed that an average of 11%, 4% and 9% of the nuts were uncracked for the three sizes respectively. The cost analysis results showed that, as at the time the cracker was fabricated, the total cost of construction was $66.00 or ₦8,000.00.

KEYWORDS: Cashew-nut, cracker, output capacity, cracking efficiency.

1. INTRODUCTION

Cashew, Anacrdium Occidentale L. belongs to the family of plants called Anacardiaceae and it is widely grown throughout the tropics. The preparation of cashew fruits involves harvesting of the fruit by hand or picking because, generally, ripe fruits fall to the ground. The nuts are detached from the ñappleò, because of its high moisture content, it is exposed to sunlight for 4-5 days, in layers, until the moisture decreases to about 5% (wet basis) before it is stored or further processed, depending on usage (Opeke, 1982).

Manual cracking of roasted nuts began in India in the 1920ôs (Opeke, 1982). The workers protect their hands against any remaining cashew nut shell liquid (C.N.S.L) by smearing them with wood ash, lime linseed oil, castor oil or special pastes. Considerable skill is required for cracking the nuts with a wooden mallet without damaging the kernel. The out turn of whole kernels by experienced workers is about 70-85% (Ohler 1969). Production capacity per 8 ï hour working day in India is about 5-8kg kernels per woman (Hall, 1966), compared to 4ï6kg in countries such as Mozambique and Madagascar, where people are less experienced.

Completely mechanized systems for the processing of cashew-nut were not set up until1960ôs (Oltremare, 1992). Ohler (1969) stated that mechanized decortications process can be divided into three main groups: cracking by pressure-the nuts are raked between two inward turning cylinders of shafts with an opening slightly narrower than the size of the nuts, centrifugal cracking- the nuts are thrown against a rough steel surface to break the shell, cutting or sawing ï the nuts are cut with semi-circular knives that have the same curve as the one on its longitudinal section. They all resulted in varying degrees of whole kernel.

The capacity of a cashew-nut shelling machine has been the bottleneck controlling the capacity of cashew-nut processing plant (Srinivas et. al., 1994). Therefore, any improvement in the capacity of the cracking machine is welcome, as this will greatly improve the capacity of nuts handled at a given time. Also, high cost of imported machines, their complexity and advanced technology involved in the serviceability coupled with poor economic disposition of peasant farmers has necessitated the development of cheap, improved and easily operatable cashew-nut cracking machine.

The objective of the study therefore is to modify and evaluate a cashew-nut cracker for peasant farmers.

2. MATERIALS AND METHODS

2.1 Description of the Cracker and Operation

The cashew-nut cracker was designed for continuous operation and the main modifications carried out on the machine when compared with Ajav (1996) are;

(i) A reduced height was reduced from 700 mm to 300 mm.
(ii) A handle operated cutting mechanism as against foot pedaled.
(iii) A fixed lower cutting blade.
(iv) A reduced cutting platform from 600 mm to 400 mm.
(v) A more portable cracker with less loading volume.

The modifications were also intended to reduce the cost of producing the cashew nut cracker and thereby enhancing its use by small scale farmers from developing countries. The main features of the modified cracker are; main frame, a base and a cracking assembly (Figure 1).

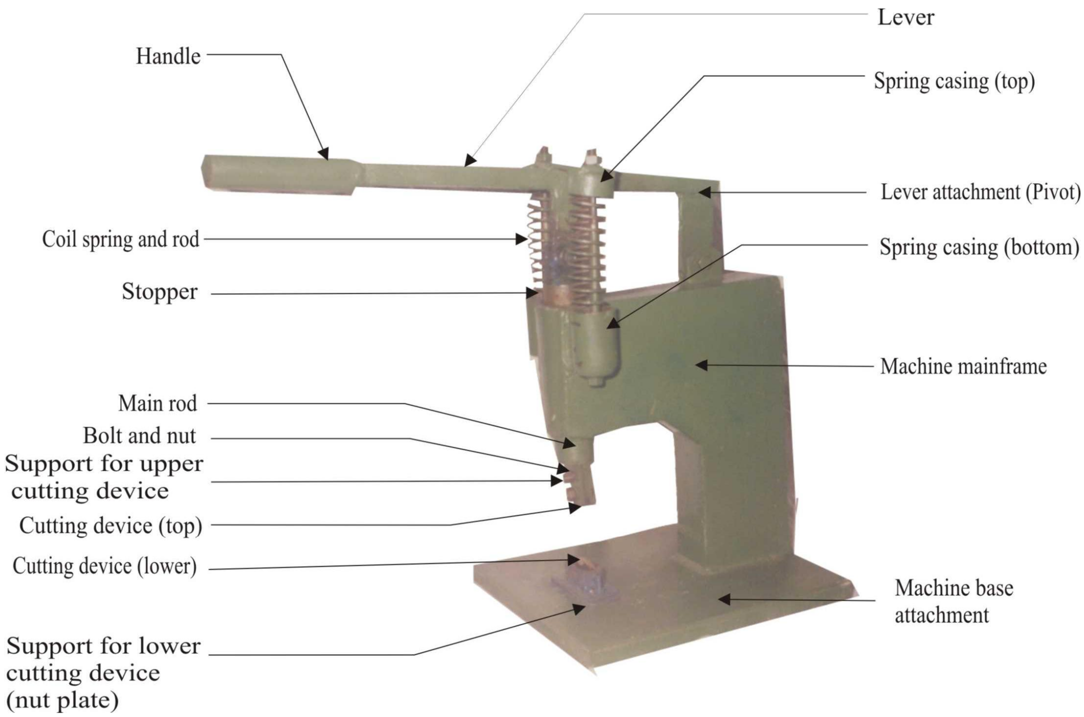

Fig 1: The modified Cashew nut cracker

The mainframe and the base are made of mild steel. These provide support to the cracker. The frame is in the form of inverted capital letter L, with minimum height of 300 mm on both sides separated by a gap of 50 mm. Part of the gap houses the cracking system and flat sheets of metals to which the two sides are welded. The cut side is 130 mm in length and 170 mm from the cracker base.

The lever-hand is made of mild-steel. It has minimum length of 506 mm and is attached to the cracker mainframe through the pivot with bolt and nut. The hand attachment of the lever is fabricated for easy grip.

The cracking assembly is made-up of two return springs for quick return of lever-hand to its original position before actuation. The springs contain two steel rods to prevent severe bending and ease of movement of the lever-hand, the threaded top of the rods contains hexagonal nuts which are used for height adjustment for upper cutter. The springs contain top and bottom casings. The bottom casings are welded to both sides of the cracker frame for stability. The top casings are welded to the lever-hand at minimum distance of 176 mm from the pivot. The lever-hand is joined to the main rod through attachment bolted together.

The lower end of the main rod consists of support for upper cutting device, which holds the cutter which is bolted to the support. The support for the lower cutter is bolted to machine base. The cutting system is in two folds; one consists of lower cutting device welded to a rectangular box of height 26 mm that serves as a seat shaped like a sickle to mimic the convex side of a cashew nut.

Two consists of a stopper which restricts the vertical movement of lever-hand upper cutter thereby preventing violent impact on both blades during downward stroke of the lever-hand. This reduces wear and tear of the blades. The total weight of the cracker is 11.74 kg. The cost analysis for the construction of the cashew nut cracker is as presented in Table 1.

The cashew nut to be cracked is placed on the nut plate. When the lever-hand is activated downward, the upper cutter descends towards the lower cutter. The upper blade cut through the nut concave side while the lower blade cut through the convex side. The nut is removed by hand protected with hand gloves smeared with palm oil. The movement of the upper cutter is adjusted through the thread nuts latching the spring-rods to the lever-hand. The return springs return the upper cutter to its initial position.

2.2 Testing and Evaluation

To evaluate the cashew-nut cracker objectively, the following performance tests were carried out:

(i) Output Capacity

One hundred nuts each of the three sizes of cashew nut (below 22mm, 22-25mm, 26mm and above) were cracked using the cracking machine and the time recorded. The three sizes were the available cashew-nut sizes. The output capacity (kg/hr) for each size was determined as:

$$Oc = \frac{Wc}{t} \quad \text{é é é é é é é é é é é é é é é é é é é .(10)}$$

Where, Oc = Output capacity of the machine; kg/hr, Wc = Weight of 100 nuts kg; t = Time taken to crack, hr.

(ii) Cracking Efficiency

The various sizes of the cracked nuts were collected and hand-separated into whole and broken/split kernels. The weight of the whole and broken/split kernels was taken as M_0 and M_1 respectively. The total weight of the kernel was taken as,

$$M = M_0 + M_1 \text{ --(11)}$$

Efficiency of the cashew-nut cracker (E) is given as

$$E = \frac{M_0}{M} \times 100 \text{ --(12)}$$

Where, E = efficiency of cashew-nut cracker %; M_0 = weight of whole kernel, kg; M_1 = weight of broken/split kernel, (kg) and M = total weight of kernel (whole + broken/split kernel), kg

The tests were replicated three times for each of the three sizes.

Table 1: Cost analysis for construction of cashew-nut cracking machine.

S/No	**Material**	**Quality**	**Unit cost ($)**	**Cost ($)**
1.	Bolt and Nut	8	0.21	1.6
2.	Lever-hand steel rod	1	4.31	4.31
3.	Steel metal sheet	1	21.55	21.55
4.	Return spring	2	2.16	4.32
5.	Spring casing	2	0.86	1.72
6.	Miscellaneous	-	-	8.62
7.	Galvanized steel	1	7.76	7.76
8.	Workmanship	-	-	17.24
Total				**66.00**

3. RESULTS AND DISCUSSION

3.1 Output Capacity for Various Nut Sizes

The output capacity of the cashew-nut cracker is given in Table 2. It shows that, for the three nut sizes (small, medium and large) the highest capacity of 6.51kg/hr was obtained for medium sized nuts followed by large sized nuts with capacity of 5.52kg/hr. The capacity for small sized nuts was very low (2.81kg/hr) due to slow rate at which it was possible to conduct the tests. This was in agreement with the trend reported by Ajav (1996) with the lowest output recorded for small sized nuts. This was due to their smallness in size and extra caution taken during cracking. Generally, the output capacity increased with size of the nut, since the larger the sizes, the more the nuts that could be cracked. This, then implies that for good output of the cracker, a prior grading of the nuts into sizes would be necessary.

Although, the designed capacity of the cracker was assumed to be 8kg/hr, only an over-all average capacity of 6.5kg/hr (81%) was obtained. This is in agreement with the range reported by Hall (1966) for semi-mechanised cashew-nut cracker, and also within the range of output capacity recorded for a low-cost cashew-nut cracker by Ajav (1996). This is due to the following reasons:

(i) The operating speed of the cracker depends on the operator; this is low to allow for experimental accuracies and affects the final output of the machine.

(ii) The initial moisture content of the nuts before boiling affects the cooling time before shelling with the cracker, because the higher the initial moisture content of nuts, the longer the cooling period. This was to prevent water/cashew nut shell liquid (C.N.S.L) from splashing on the operator. The toughening during the cooling period increases nut resistance to cutter blade penetration, which in turn reduced the rate of cracking.

Table 2: Machine capacity determination using three different sized nuts

Sample Test	Small sized nuts (below 22mm)			Medium sized nuts (22 ï 25mm)			Large sized nuts (26mm and above)		
	1st batch	2nd batch	3rd batch	1st batch	2nd batch	3rd batch	1st batch	2nd batch	3rd batch
Number of Nuts	100	100	100	100	100	100	100	100	100
Weight of 100 nut (g)	185	217	214	345	355	366	515	526	509
Time of Operation (min)	4.10	4.90	4.20	3.20	3.20	3.40	5.60	5.70	5.60
Weight of									

100 nuts (kg)	0.185	0.217	0.214	0.345	0.355	0.360	0.515	0.526	0.509
Time of Operation (hr)	0.068	0.082	0.070	0.053	0.053	0.057	0.093	0.095	0.093
Capacity of the machine (kg/hr)	2.72	2.65	3.06	6.59	6.70	6.32	5.54	5.54	5.47
Average capacity of machine (kg/hr)		2.81			6.51			5.52	

3.2 Cracking Efficiency

The cracking efficiency of the cracker for the three sizes of cashew-nut is shown in Table 3. The efficiencies varied from 51% for small sized nuts, 64% for medium sized nuts, 55% for large sized nuts. The average efficiency for the three sizes of nuts is 56.7%, which is higher than what was reported by Hall (1966) for centrifugal cracker. The cracker efficiency agrees with the fact that the output was low for the small sized nuts whereas, it was high for medium sized nuts; this was also reported by Ajav (1996). However, there was marginal difference between the cracking efficiency for the large-sized nuts and the medium-sized-nuts with the medium sized nuts higher, this contradicted what Ajav (1996) reported where the machine efficiency for large-sized nuts were highest. The values of machine efficiency for this experiment vary with human performance. This result compares well with those reported earlier (Hall, 1966, Russel, 1969).

Table 3: Determination of machine cracking efficiency (E) using three different sized nuts

Sample test	Small sized nuts (below 22mm)			Medium sized nuts (22 ï 25mm)			Large sized nuts (26mm and above)		
	1st batch	2nd batch	3rd batch	1st batch	2nd batch	3rd batch	1st batch	2nd batch	3rd batch
Number of Cracked Nuts	82	93	91	96	97	94	92	89	93
Weight of Uncracked nut (g)	18	7	9	4	3	6	8	11	7
Weight of Kernel M (g)	46.0	54.0	50.0	120.0	135.0	125.0	162.0	155.0	160.0
Weight of Whole Kernel M_0 (g)	24.5	28.5	25.5	75.5	90.5	78.5	99.0	95.0	96.5
Weight of Broken/split Kernel M_1 (g)	23.5	25.5	24.5	44.5	44.5	46.5	63.0	60.0	63.5
Cracking Efficiency E (%)	48.9	52.8	51.0	62.9	67.0	62.8	60.9	61.3	60.3
Capacity of Cracking Efficiency (%)		50.9			64.2			60.8	

The cracking efficiency of the cracker for the three sizes of cashew-nuts is shown in Figure 2. This agrees with the fact that the output was low for small-sized nuts, whereas it was higher for medium and large-sized nuts with medium-sized nuts being the highest. The modified cracker was 30 % higher in efficiency when compared with the original design. The cost of production of the modified cracker (Table 1) was 40% lower than the original design.

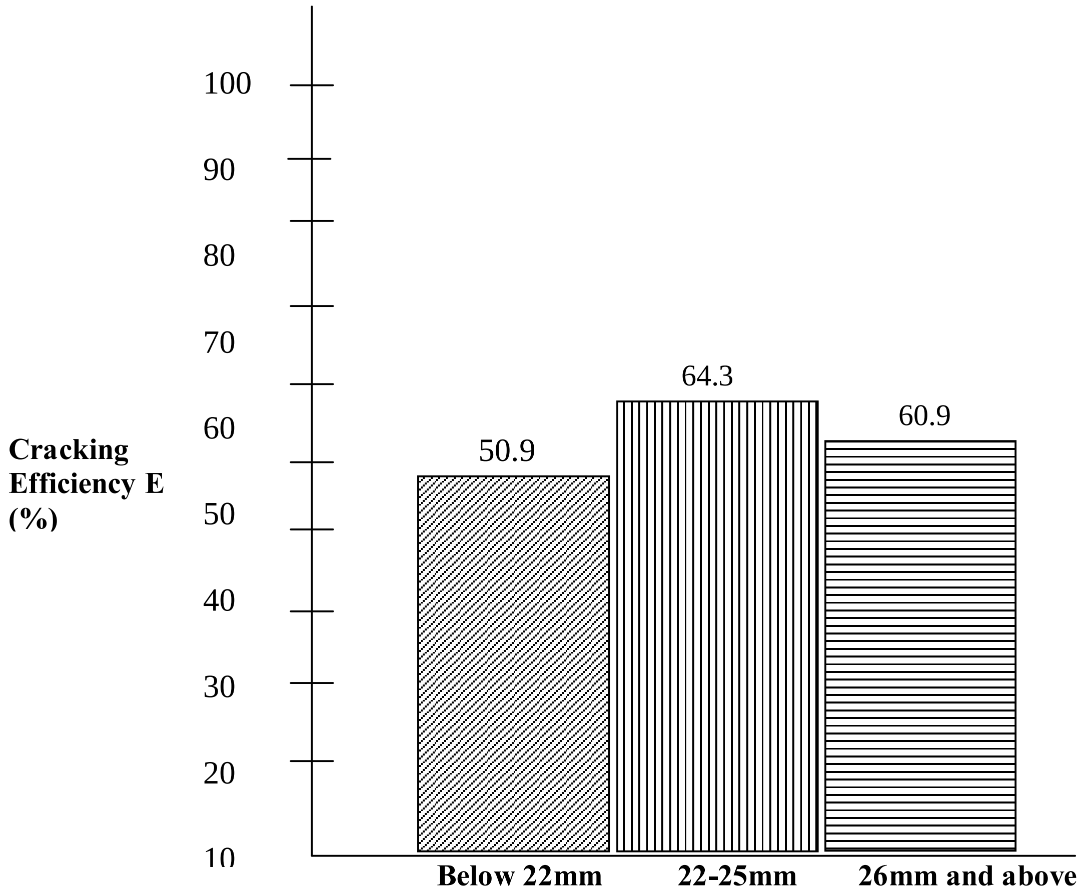

Figure 2. Cracking Efficiency Using Three Different Nut Sizes.

4. CONCLUSIONS

The following conclusions could be drawn:

(i) The capacity of the Cashew nut cracker was 6.51kg/hr for medium size nuts.
(ii) The cracker had the highest cracking efficiency of 64.3% using medium sized nuts while the small and large size nuts had cracking efficiencies of 50.9 and 60.9% respectively.
(iii) The cracker, unshelled an average of 11%, 4% and 9% of small sized, medium and large-sized nuts during shelling respectively.
(iv) A simple device such as the type reported can alleviate the problems of cashew nut processing especially for small scale farmers.

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DEVELOPMENT OF SWEET POTATO – BASED PRODUCTS

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ABSTRACT

An investigation was carried out to develop a new food product from the combination of processed sweet potatoes and cassava tuber. The sweet potatoes and cassava were peeled, washed, grated and fermented at different time intervals. They were grouped into 100 percent sweet potatoes mash; 50 percent sweet potatoes and 50 percent cassava, 30 percent sweet potato and 70 percent cassava mash; and 70 percent sweet potatoes and 30 percent cassava. Each group was further divided into six samples immediately after grating and thorough mixing. Samples from each group were subjected to dewatering, sieving and frying. Thus one for a day 0, 1, 2, 3, 4 and 5 after grinding to undergo fermentation. The results obtained showed that ordinary sweet potatoes mash itch the mouth. Fifty percent sweet potatoes with 50 percent of cassava after frying was tested for ñebaò like an ordinary gari and it forms eba which showed that the mixture of sweet potatoes and cassava can be used to produce eba as food. The results further showed that 50 percent sweet potatoes with 50 percent cassava is the best of the three mixture with two days fermentation. The colour deteriorate as the fermentation period increase to the last day. Also, 30 percent sweet potatoes with 70 percent of cassava after milling was tested for ñAmalaò like an ordinary ñlafunò and after preparation it formed ñAmalaò which indicated that the mixture of sweet potatoes and cassava can be used to produce Amala as food.

KEYWORDS: Sweet potato processing, cassava mash, fermentation, sensory evaluation.

1. INTRODUCTION

Roots and tuber crops such as yam, cassava, cocoyam and sweet potatoes rank in importance to the cereal grains in providing the major part of the daily caloric need of people in the tropics. They are classed with the cereal grains as staple foods because they provide the main item of diet of many people (Abbo et al, 1999).

Sweet potato is one of the worldôs most important food crops. The amount produced is similar to, or slightly higher than, that of cassava but lower than that of Irish potato (Degras, 2003). It is widely cultivated both in small home gardens and farms in the tropics and in much larger areas in the subtropical to temperate zones of the Far East and the USA, making it the worldôs number one crop. However, inadequate research means that the cropôs origins, dissemination and reproductive biology remain some what obscure. This knowledge gap is less strange than can be thought, given the recent decline in the cropôs production.

The sweet potato is a member of the Convolvulaceae family. It is currently referred to as Ipomoca batatas (L) Lam; although some authors still prefer to use the earlier form, Ipomoca batatas L. as its large geographical range suggests, sweet potato is a highly adaptable crop. It grows at latitudes ranging from 40°N to 32°N, at altitudes ranging from 0 to 3000m, in hydromorphic soils in the humid low/and tropics receiving more than 3000mm of rainfall per year and in semi-arid areas receiving barely 500mm per year (Degras, 2003). Of all the cultivated root and tuber crops, sweet potato is probably the best at adapting quickly to new conditions. Nevertheless, its growth and development can be affected by adverse environmental factors such as drought, excessive amount of water, low temperatures (10°C or less), cropping systems, storage systems, soil texture, the symbiotic aspects of mineral nutrition and the physiology of the root system of sweet potato etc.

A very wide range of sweet potato production systems is found in east and south Asia. In Taiwanôs uplands, with little or no irrigation, sweet potato is frequently grown in rotation with groundnut or Soya Bean with vegetables such as cabbage and radish. These systems take various forms. Even more variable are the intercropping of relay cropping systems.

Sweet potato is grown widely in East, Central and West Africa, where it is of major importance as a food crop. The production systems are highly diverse, but different from those in Asia, since there is little irrigation or rice-growing. West Africa has a much smaller area devoted to sweet potato. In eastern Nigeria a system combining cocoyam or taro (Xanthosoma), sweet potato and maize is found on over half of all farms. Maize and cassava are often intercropped or rotated with sweet potato in other areas of West Africa. In Sierra Leone, for example, the crop is frequently alternated with swamp rice, being planted on mounds immediately after the rice has been harvested. In most parts of the region, sweet potato is regarded mainly as a home garden crop and is cultivated mainly by women. Sweet potato originated in tropical America and this is where the most intensive, yet least modernized cropping systems can be found (Degras, 2003).

The earliest archaeological evidence of possible remains of sweet potato tuberous roots were unearthed in Peru and date back to at least 8000 years BC. The cropôs presence has been identified with greater certainty in Central America, where it has been established that the Maya people used it some 2600 ï 1000 years BC (Degras, 2003).

The volume of sweet potato production world-wide has changed little over the past 20 years. The possible exception in Africa, but national statistics here as elsewhere are not accurate (Table 1). Production is some-what unusually, structured. The defining features are farm size, cropping patterns and sequences, the various forms in which the crop is consumed and the length of the period for which products are available.

The objectives of this project use to: find the effect of fermentation on the sweet potato grain, find the effect of mixing cassava mash with the sweet potato grated mash and to develop new food products from the mixture of potato mash and cassava mash.

2. MATERIALS AND METHODS

2.1 Source of Materials

The materials used were potatoes (VRT of sweet potato TIS 8164 code); sacks, water, cassava tubers, stone, sieve, saucer pan, grating machine, weighing machine, plastic bowl, vegetable oil and knives. The raw materials were bought from the following locations:

(i) Potatoes (sweet potato TIS 8164 VRT) were bought at Agricultural Development Project, Ikole-Ekiti, Ekiti State.

(ii) Cassava tubers, sacks, vegetable oil and saucer pan were bought at Ado-Ekiti market.

Table 1. Sweet Potato Production, Area and per Capita Consumption for Selected Regions and Countries

	Product ion (ó000t)							Area (ó000ha)	Per Capita Production (kg)		Per capita Consumption (kg)
Year	1965	1970	1975	1980	1985	1989-91	1995	1992-94	1983-85	1995	1990-92
Global	109690	137227	128000	115713	110842	124294	122034	9199	-	-	-13
Asia	101173	128182	118144	107189	101001	114828	111556	-	-	-	19
Bangladesh	440	852	719	791	683	513	424	46	-	-	4
China	83300	111900	104600	95150	90000	105543	102181	6328	91	84.0	44
India	1098	2397	1658	1313	1523	1265	1300	138	-	1.4	1
Indonesia	2651	2175	2433	2079	1856	2078	2136	217	-	10.7	10
Japan	5025	2670	1418	1317	1527	1346	1264	53	-	10.1	5
North Korea	256	272	332	374	470	502	450	35	-	19.2	17
Philippines	701	657	986	1048	1005	644	710	145	-	10.4	9
South Korea	2997	2136	1953	1103	787	467	347	15	-	7.8	4
Taiwan	3131	3441	2403	2403	1055	485	-	-	-	-	-
Vietnam	1100	1120	920	920	2358	2000	1992	2351	-	31.3	26
Africa	3172	4132	5479	5479	5275	6305	6379	6306	-	-	9
Angola	150	147	160	160	180	180	167	200	-	-18.2	16
Burundi	480	425	450	450	470	520	669	674	112	105	1147
Cameroon	111	149	140	140	130	140	1251	180	-	-13.3	12
Egypt	86	85	75	75	86	100	96	160	-	-2.6	2
Guinea	85	82	69	69	68	70	85	143	-	-21.8	13
Kenya	180	230	280	280	330	280	538	630	-	22.2	21
Madagascar	341	350	270s	270	373	450	484	560	-	-37.8	23
Uganda	600	1200	1953	1953	1200	2000	1712	2235	125	105	84
Rwanda	203	413	675	675	871	900	875	1100	150	183	110
Tanzania	200	245	459	550	530	541	451	201	-	15.8	187
Zaire	192	264	300	303	360	377	407	82	-	-9.2	8
North and Central American	1420	1378	1253	1253	1495	1160	1089	-	-	-	-
Cuba	250	230	248	325	330	253	170	55	20	15.4	19?
Haiti	220	260	295	282	350	220	185	62	-	25.7	34?
USA	702	597	585	497	654	532	584	33	-	22.2	2?

South America	2378	2969	2405	1323	1365	1288	1310	-	-	-	-
Argentina	341	438	418	302	325	297	336	22	-	9.7	8
Brazil	1721	2156	1600	726	750	647	630	60	-	4.0	2
Paraguy	100	99	105	112	102	96	100	12	-	20.4	16
Peru	124	178	162	94	100	165	156	10	-	6.5	6
Pacific	378	428	506	539	566	564	568	-	-	-	79
Papua New Guinea	300	348	420	440	469	463	450	106	136	109	100
Solomon Islands	43	41	43	45	50	57	63	-	193	175	-
Europe	169	139	131	134	110	76	56	-	-	-	-
French Overseas Territories	17	25	21	14	21	11	9	-	-	-	-

Sources: CIP (1996), FAO (1996), Horton (1988), Woolfe (1992) and Degras (2003)

2.2 Methods of Processing Potato

The flow chart in Figure 1 shows the various processing methods commonly used. Cooking at a 85°C by boiling or roasting is always necessary in order to eliminate the acid in the potatoes. This irritate the mouth and throat and make food difficult to digest.

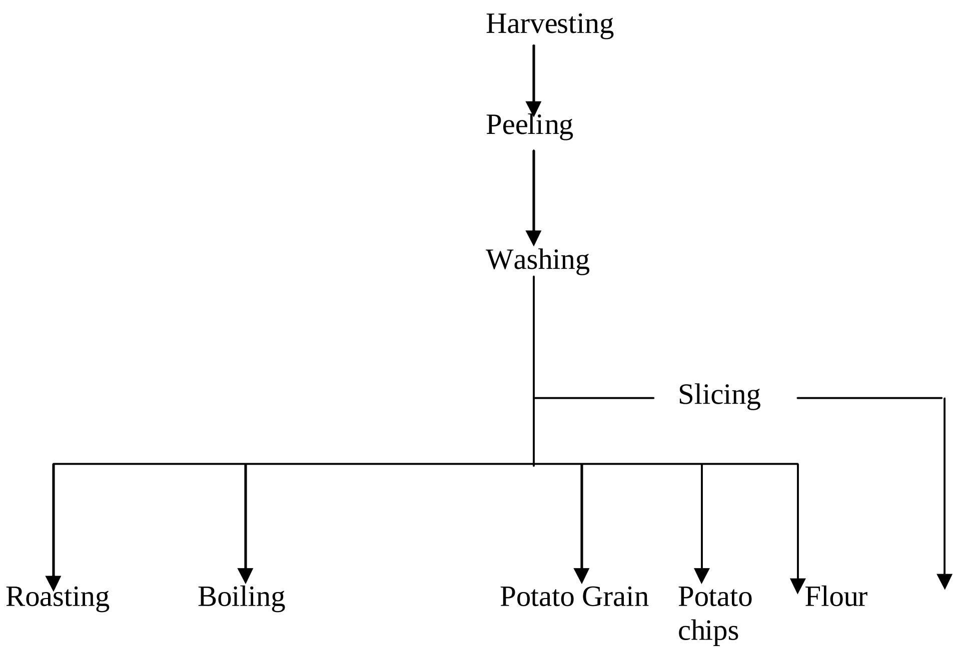

Figure 1: Flow chart for potato gari processing.

The method used by Oloko et al (2002) in the development of cocoyam ï based products was used. Sweet potato were peeled and washed with water. The sweet potato were divided into two groups. The first group was used for ordinary sweet potato test while other groups were for the mixture of sweet potato and cassava.

2.3 100% Sweet Potato Grain Production

The sweet potato were peeled and washed to remove the adhering particles. The peeling was done manually. The grating into mash was done by using grating machine. The mash obtained was divided into six samples. Each sample was bagged and labeled B_0, B_1, B_2, B_3, B_4 and B_5 for day 0 to day five respectively. These samples were subjected to the following processing:

Sample B_0 for Day Zero:
The sample was bagged and dewatered by adding load (wood and rope). During this period, it was detected that dewatering was not achieved because of the hardness of the potato. Consequently, other processes could not be carried out.

Sample B_1 for Day One:
This sample B_1 was fermented for a day and thereafter dewatered. Sieving and frying could not be carried out because it contained water.

Sample B_2 for Day Two:
The sample was fermented for two days. The fermented mash was then dewatered and sieved. After sieving it was then fried using saucer pan. The above procedure was repeated for samples B_3, B_4 and B_5 for day 3, 4 and 5 respectively.

2.4 Mixture of Potato and Cassava (Grain Production)

The mixture of sweet potato and cassava were divided into three samples and weighed.
The samples were:
(i) 70% of sweet potato and 30% of cassava tubers
(ii) 30% of sweet potato and 70% of cassava tubers.
(iii) 50% of sweet potato and 50% of cassava tubers.

These mixtures were separately grated into mash using a grating machine.

The mixtures were labeled C, (for 70% sweet potato and 30% cassava), D (for 30% sweet potato and 70% cassava) and E (for 50% sweet potato and 50% cassava).
These mixtures were grated into mash and mixed properly to make each mixture homogeneous. Each of these mixtures were later divided into six samples and labeled:

C_0, C_1 é é é é é é é é é é é é é to C_5
D_0, D_1 é é é é é é é é é é é é é to D_5
E_0, E_1 é é é é é é é é é é é é é .to E_5

The subscript denotes the number of days after grating. Each of these samples was subjected to dewatering, sieving and frying.

2.5 Sweet Potato Flour

Sweet potato and cassava were peeled and washed with water. The cassava tuber was soaked for four days (96 hours) while the sweet potato was soaked for a day (24 hours) with warm water separately to ferment.

After soaking, they were sun-dried for three weeks. After drying, they were mixed according to the group ratio as indicated below. The first group was used for ordinary sweet potato test while the other group was for the mixture of sweet potato and cassava. The samples are as follows:
(i) 50% of sweet potato and 50% of cassava tubers.
(ii) 70% of sweet potato and 30% of cassava tubers.
(iii) 30% of sweet potato and 70% of cassava tubers.

2.6 Mixture of Sweet Potato and Cassava

There were three mixtures of potato and cassava at various percentages. These mixtures were grated into mash and mixed properly to make each mixture homogenous and sieve properly. Each sample was observed and tested directly under the following heading, Colour, Taste, Flavour and Gelatin formation for 30 minutes interval.

2.7 Potato Chips

The potatoes were sorted manually and cleaned thoroughly by washing. They were peeled manually and sliced. They were divided into two groups; the first group was for salting potato chips while the other were sugar potato chips. They were soaked for over night separately with salt and sugar so that the salt and sugar would penetrate into the potato. The chips were fried in turkey brand vegetable oil for 10 minutes, cooled and packed into 10g sachets using polythene (P.E).

2.8 Sensory Evaluation

Out of the 24 samples, only 16 samples could be subjected to sensory evaluation. This was as a result of non-dewaterbility and non-friability of the remaining samples B_0, B_1, C_0, C_1, D_0, D_1, E_0, E_1.

A panel of 12 testers who were very conversant with gari quality were used for sensory evaluation. These samples were scored for colour, taste, texture, flavour and gelatin formation using a five point hedonic scale as contained in Orimaiye (1998) which are analysed as follows:
5 = Very Good; 4 = Good; 3 = Fine; 2 = Fair; 1 = Poor; 0 = Bad for Gelatin formation: 5 = Full; 4 = Partially full; 3 = Average; 2 = low; 1 = very low.

3. Results and Discussion

The results of the sensory evaluation are as shown in Tables 2 to 6. Tables 6 to 10 show the chemical composition of the edible parts of sweet potato and other root and tuber crops; Vitamin contents of sweet potato and other root and tuber crops; cultivars differences in the chemical composition of different root and tuber crops; some factors explaining variability in the crude protein content of tuberous roots in Taiwan; Amino acid levels in sweet potato and other tuberous roots and approximate composition and crude energy contents of different parts of 49 sweet potato cultivars respectively.

Table 2: 30kg Sweet Potato and 70kg Cassava

Fermentation	Dewatering	Colour	Taste	Texture	Flavour	Gelatin Formation
Two days	5	4	2	2	4	5
Three days	5	2	2	2	3	3
Four days	5	2	1	1	1	3
Five days	5	0	0	0	1	3

From the table, the dewatering was very good for all the days involved while the colour and the flavour was good within two days of fermentation. The Gelatin formation was very good at the two days of fermentation, the colour, taste and texture was bad.

Table 3: 50kg of Sweet Potato and 50kg of Cassava

Fermentation	Dewatering	Colour	Taste	Texture	Flavour	Gelatin Formation
Two days	5	4	4	2	4	5
Three days	5	3	4	2	2	5
Four days	5	3	2	3	2	5
Five days	5	1	0	2	1	4

The dewatering was very good for the whole period of fermentation. The colour, taste and flavour of the mixtures were good during the two days of fermentation. Gelatin formation was very good from the two days to four days of fermentation while it was good on the fifth day of fermentation.

Table 4: Post Grating Activities on 100% Sweet Potato

Fermentation	Dewatering	Colour	Taste	Texture	Flavour	Gelatin Formation
Two days	5	2	2	2	2	4
Three days	5	2	2	2	2	2
Four days	5	2	2	1	2	2
Five days	5	1	0	1	1	1

From the table 3, the dewatering of the 100% sweet potato was very good for the fermentation period while the colour, taste, texture and flavour was at an average for two days to four days and the Gelatin formation was good at the two days of fermentation.

Table 5: 70kg Sweet Potato and 30kg Cassava

Fermentation	Dewatering	Colour	Taste	Texture	Flavour	Gelatin Formation
Two days	5	2	4	3	4	4
Three days	5	2	2	3	2	4
Four days	5	2	2	3	2	3
Five days	5	1	0	1	1	2

Dewatering was very good during all the fermentation period. The taste, texture and Gelatin formation was good during the two days of fermentation while the taste was bad at the fifth day of fermentation.

Table 6: Sweet Potato Four

Mixture	Colour	Taste	Flavour	Odour	Gelatin Formation
50kg Sweet Potato and 50kg Cassava	Brown	3	4	4	5
30kg Sweet Potato and 70kg Cassava	Brown	4	5	5	5
70kg Sweet Potato and 30kg Cassava	Brown	2	3	4	5
100% Sweet Potato	Black	2	2	2	5

From the Table 5, the mixture of 30kg sweet potato and 70kg cassava to obtain sweet potato flour turned black and with very good flavour, odour and Gelatin formation. The 100% sweet potato turned black colour with an average taste, flavour and odour of the mixture but with very good gelatin formation.

Effect of Fermentation on Dewatering Process:

From Tables 2 to 5, it is evident that fermentation encourages dewatering. During the day zero and day one of fermentation process, dewatering of all samples was not possible. The material after loading looked slurry.

During the day two to day five of fermentation, the dewatering was done and free liquid was squeezed. This is due to poor aggregation of the particles.

Effect of Fermentation on Colour:

As shown in Tables 2 to 5, the effect of fermentation is easily noticeable on the colour of the final product. The colour of the product changed in which case some were Greyish ï yellow; Greyish Brown, Black (i.e some were good, some were moderate and some were black. Some that were black could be attributed to long period of fermentation).

Effect of Fermentation on Taste:
Tables 2 to 5 show the effect of fermentation on the taste of sweet potato grains. Long days of fermentation change the taste of the product. As length of fermentation increased, the taste deteriorated. The significance of the fermentation was to reduce the acid to the barest minimum and make the grain produce a pleasant taste like ñEbaò.

Effect of Fermentation on Texture:
From Tables 1 to 5, fermentation contributed to the smoothness and fineness of the end product after processing into grain.

Effect of Fermentation on Flavour:
Fermentation made the grain to give fragrant smell which is very pleasant to the consumers but long fermentation period changes the flavour negatively.

Effect of Fermentation on Gelatin Formation:
From Tables 1 to 5, fermentation made the grain to be compacted very well which is very pleasant to the consumers but long fermentation period changes the gelatin formation negatively.

Table 7: Chemical Composition of the Edible parts of Sweet Potato and other root and tuber crops

				Yam			
	Sweet Potato	Cassava	Taro	D. Alata	Esculenta	Malanga	Irish Potato
Water	70	63	72	76	73	66	78
Protein (%)	1.5	1.0	1.7	1.8	2.4	1.7	2.1
Total Glucosides (%)	26.1	32.4	23.1	21.0	23.4	29.2	18.5
Lipids (%)	0.3	0.3	0.2	0.1	0.1	0.2	0.1
Fibre (%)	3.9	4.4	4.0	2.3	1.2	3.4	2.1
Ca (mg)	32	39	35	11	8	14	9
P (mg)	39	41	65	41	42	52	50
Fe (mg)	0.7	1.1	1.2	0.5	0.8	0.7	0.8
Energy	111	141	103	88	104	125	80

Source: Woolfe (1992), Degras (2003).

Table 8: Vitamin contents of Sweet Potato and other Root and Tuber Crops

	Sweet Potato	Cassava	Irish Potato	Colocasia	Yam	Xanthosoma
Beta-Carotene (μg)	0-20,000	0-120	0-2	43	108	29
B_1 (mg)	0.09	0.05	0.11	0.03	0.05	0.02
B_3 (mg)	0.03	0.04	0.04	0.03	0.03	0.03
Niacine (mg)	0.60	0.60	1.20	0.76	0.41	0.80
B_5 (mg)	0.59	-	0.30	-	0.13	-
B_6 (mg)	0.26	-	0.25	0.08	-	-
Folic acid (μg)	14	-	24	-	-	-
C (mg)	24	20	30	15	20	14
E (mg)	4.6	-	-	-	-	-

Value per 100g fresh weight.

Source: Degras (2003)

Table 9. Cultivars Differences in the Chemical Composition of Different Root and Tuber Crops

			Yam		
	Sweet Potao	Cassava	D. alata	D. rotundata	D. esculenta
Dry matter (%)	22-24	28-45	25-39	21-36	32-43
Starch (% DM)	50-75	56-92	55-91	53-91	58-90
Sugar (% DM)	6.0-15.0	1.0-3.0	1.0-7.1	0.6-4.0	4.8-15.0
Proteins (% DM)	1.7-5.3	1.0-2.3	4.5-6.0	3.4-6.6	4.9-5.9
Fibres (% DM)	0.5-0.9	0.4-0.6	0.3-0.4	0.1-0.4	0.3-0.4
Phenols	0.2-0.5	0.4-0.6	0.4-0.8	-	0.1-0.4

Source: Chalfant et al (1990). Degras (2003).

Table 10. Amino Acid Levels in Sweet Potato and other Tuberous Roots (% DM)

	Cassava	Madeira Vine	Irish Potato	Sweet Potato	Yam	Protein
Arginine	7.7	6.3	5.3	3.4	7.5	-
Cysteine	-	2.3	-	1.6	0.8	2.0
Glycine	-	5.9	3.4	-	1.5	-
Histidine	1.5	6.8	1.8	1.6	2.1	-
Isoleucine	5.3	0.6	4.0	4.0	3.3	4.3
Leucine	5.6	4.3	6.0	5.7	5.2	4.9
Lysine	6.2	7.0	5.6	4.1	3.5	4.3
Methionine	0.6	5.1	-	1.1	0.9	2.3
Phenylalanine	3.5	4.0	4.4	5.4	4.7	2.9
Threonine	3.8	13.6	3.7	3.4	3.4	2.8
Tryptophan	0.5	-	2.0	1.8	-	1.4
Tryosine	-	3.1	4.0	4.5	3.3	2.9
Valine	4.5	5.8	5.2	5.2	4.4	4.3

According to FAO Estimates

Sources: Valetudie (1992), cited in Degras (2003)

Table 11. Approximate Composition and Crude Energy Contents of Different Parts of 49 Sweet Potato Cultivars

	Leaf	Stem	Tuber
Dry matter (% fresh matter)	26.4-36.4	14.9-26.5	17.8-38.2
Crude Protein (% of DM)	5.1-18.3	1.8-8.0	1.4-8.6
Crude firbre (% of DM)	5.9-31.0	22.1-37.5	3.4-5.9
Lipids (% of DM)	0.7-5.9	0.2-2.6	0.3-1.9
Ash (% of DM)	6.3-11.8	9.2-12.9	1.5-6.3
Energy (kcal/g)	1.5-4.6	2.1-4.6	2.9-5.4

Source: Tewe (1994), Degras (2003).

4. CONCLUSIONS

From the sensory evaluation results, it can be concluded that ordinary sweet potato grain can not be consumed like gari because it has some itching effect on the mouth but the mixture of 50% sweet potato with 50% of cassava produces the best result. Sweet potato grain with fine colour, taste, odour, gelatin formation and texture enhances better market value especially when the fermentation is not more than two days.

Also from the sensory evaluation result it can be concluded that ordinary sweet potato cannot be consumed like Amala because of gelatin formation but the mixture of 30% sweet potato with 70% of cassava produces the best result. Sweet potato chips are the best product because it has sweet taste and long shelf life for four days.

According to Oloko et al (2002), the mixture of 30% cocoyam with 70% of cassava produces the best result, hence with the recent results obtained in the mixtures of sweet potato with cassava as reported in this paper, more research should be conducted on how 100 percent of cocoyam or sweet potato without mixing with other crops can be processed like gari, Amala and chips and enlighten both the farmers and the general public on the importance and nutritive values and utilization of sweet potato and cocoyam and how they can be further developed into grains, flour and chips. Also, sweet potato flour can be used as a by-product to be mixed with wheat at the ratio of 10% and 90% respectively to obtain potato bread.

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DEVELOPMENT OF A CUTTING MACHINE FOR FOOD MATERIALS

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ABSTRACT

Cutting is a major operation in food processing. It is time consuming and labour intensive. In Nigeria and most developing countries, it is normally done manually with the exception of a few processing factories where some imported equipment are used. In this study, a low cost motorized, table, rotary cutting machine was designed and fabricated using locally available materials to solve the problems associated with cutting of agricultural and food products in Nigeria. The machine consists of a feeding compartment, cutting compartment, power transmission and outlets. It was designed for cutting vegetables, fruits and confectionaries like chin-chin and salad ingredients. The machine has a throughput of 37.8 g/s. A unit of the machine costs fifteen thousand and four hundred Naira (₦15,400.00). The maintenance of the machine is simple and recommended for small holders, local processors and home use.

KEYWORDS: Food materials, cutting machine, size reduction, machine design.

1. INTRODUCTION

The reduction in size of agricultural products is brought about by mechanical means without change in chemical properties of the materials. They are used to improve the eating quality or suitability of foods for further processing and to increase the range of available products. With the development of a variety of cutting tools for size reduction, a lot of drudgery had been removed from processes which hitherto were tedious to accomplish. The size of agricultural products may be reduced several ways. The main methods used are crushing, impact, shearing and cutting. Size reducing devices include crushers, slicers, grinders, and hammer mills (Fellow, 2003).

Cutting has been described as the continuous process in which penetration of a sharp knife through a material results in a new surface due to failure in shear accompanied by deformation in bending and compression (Lawson, 2004). The method is particularly well adapted to the reduction of sizes of vegetables, fruits, fish, meat, roots and tubers. Cutting operation for large scale processing is used severally today in food processing industries, outdoor catering services, confectionaries, snacks centers and restaurants.

Several types of cutting machine are available. These include knives with one cutting edge, shear with two cutting edges and saw with many cutting edges (Wilson and Kirk, 1982). They may be operated manually or electrically. As reported by Fellow (2003), some cutters consist of rotating or reciprocating blades which cut the food as it passes beneath. In some designs, food is held against the blades by centrifugal forces. In others, such as meat slicers, the food is held on carriage as it travels across the blade. Harder fruits such as apples are simultaneously sliced and decored as they are forced over stationary knives fitted inside a tube. In the hydro cutters, foods are conveyed by water at high speed over fixed blades. Flaking equipment for flaked fish has provision for adjustments of the blade types and spacing used to produce the flakes. Rietz and Schreffler (1976) also reported the existence of dicing and slicing cutters which consist of a disk with a series of radial slots in each of which is mounted a knife blade. These blades are set at an angle and above the surface of the disc. The disc is set in a housing either horizontally or at an angle so that the product to be sliced can fall by gravity. To ensure size reduction, an energy level that will produce a force above the crushing strength is required. The amount of energy that is absorbed by food before it fractures is determined by its hardness and tendency to crack (friability) which in turn depends on the structure of the food. Harder foods absorb more energy and consequently require a greater energy input to create fractures. The more line of weakness in a food, the lower is the energy input needed fracturing. Compression forces are used to fracture friable or crystalline foods, combined impact and shearing forces are necessary for fibrous foods, and shearing forces are used for fine grinding of softer foods. Energy for size reduction of vegetables can be estimated from the relation, (Lewis, 2000).

$$\frac{dEr}{dD} = \frac{-km}{Dn}$$ é (1)

Where, dE_r = energy required to cause a small change in diameter (Joules),
K_m = characteristic constant, depending on the product, D = diameter of the specimen (m),
n= constant (depending on the type of vegetable),
Er can be determined using the Bondôs equation

$$Er = 2km\left(\frac{1}{\sqrt{D2}} - \frac{1}{\sqrt{D1}}\right)$$ é .(2)

Where, E_r = energy required (kWh), D_2 = final diameter (m), D_1 = initial diameter (m)
K_m = Strength characteristic constant.

The benefits that can be obtained through cutting include reduction of the bulk of fibrous materials for easier handling and transportation, attainment of relatively uniform product, product conversion into forms and different varieties of food desired by the consumers for various purposes from basic ingredients. Cutting makes the product more digestible, facilitates accurate mixing of ingredients and it is used as a pre-treatment for raw materials prior to canning, freezing and dehydration. It also helps to increase the rate of diffusion processes which occur in dehydration and solvent extraction (Lewis, 2000).

In Nigerian homes, restaurants, outdoor catering services and snacks centers, cutting operation is usually carried out manually. It is energy and time consuming, tedious, a high risk and back straining operation. Developing a rotary cutter locally will make cooking at home, out door catering and confectionaries easier with good quality products. Also time and energy will be conserved for other useful purpose. The objective of this research is to develop a rotary cutter for cutting fresh/ wet vegetables, confectionary and fruits for small scale food processing.

2. MATERIALS AND METHODS

2.1 Design Consideration

Major design considerations were given to the prime mover, type of product machine frame and blade.

2.1.1 The Prime Mover

To ensure size reduction, an energy level that will produce a force above the crushing strength is required. Using Bondôs equation, the energy and hence the power required was determined to be 0.75 kW. However, a 1 kW, 1,420 rpm electric motor was available; hence there was the need to step down the speed. Maximum speed reduction ratio was used to produce the desired speed. In order to ensure that the motion is transmitted smoothly and without any loss due to friction, the shafts were fixed in bearings as required.

2.1.2 Type of Product

Vegetables e.g. carrots, egg plant, okra, pepper, onions, cabbage, spinach, ammarantus etc are normally processed when fresh, soft, weak and brittle. Hence, the machine is being considered for such food types. Since the machine was being developed for processing of food materials, the materials from which the cutting tool is made must posses certain properties. It should be devoid of contaminants. The materials of the cutting compartment, hopper, cutting blade and the platform must be harder than the materials being cut. When cutting, the edge of a cutting tool operates under intense pressure and will wear due to abrasion by the material being cut. Basically, the harder the material, the better is its resistance to abrasion. Therefore stainless steel blades were used. Also to prevent excessive noise and chipping of metals into food during cutting operation, the cutting platform was made of hardwood.

The sharpness of the blade was considered, the thinner the edge of blade, the finer the material being cut. The cost of the machine should be affordable to local processor. It should be easily disassembled for washing and cleaning. Therefore, bolt and nuts were used for fastening the joints. Also, it should be simple to operate and maintain even by an operator who do not have formal education.. All product contact surfaces must be completely free from crevices which can harbour bacteria. Hence, external surfaces must be smooth and self draining.

2.1.3 The Machine Frame

The frame is the main support of all the components of the machine. Therefore, it should be sufficiently strong and rigid to withstand the arduous nature of the condition which the machine has to withstand. The frame should be sufficiently high to avoid back straining of the operator.

2.1.4 The Blade

The blade is a single cutting rotary element with cutting surface acting as one of the shearing element.

2.2 Machine Description and Design

The electrically operated food cutting machine was design and fabricated. Parameters designed for include shafts, sizes, hopper capacity and dimensions, flat belt conveyor, pulley and belt sizes, belt tension. Figs 1, 2 and 3 show the isometric drawing, the orthographic drawing and the picture of the machine. The components of the machine include the feeding unit, cutting compartment, power transmission unit, frame and outlets.

2.2.1 The Feeding Unit

The hopper is fitted with a slide to control the flow of materials through it. On dropping by gravity from the hopper, the material to be cut is conveyed to the cutting unit through a flat belt conveyor mounted on the frame. The motion of the flat belt conveyor is transmitted from the 1kW electric motor through V-belt and pulley. The center distance of the conveyor was made equal to one revolution of the cutting disk, i.e. 32 cm. A housing made stainless steel sheet is provided for the conveyor to minimize mechanical accident during operation.

2.2.2 The Cutting Unit

The cutting unit comprises of 16 cutting blades held unto a disk with bolt and nuts. The blades are arranged such that they make an angle of 90^0 with the cutting surface. The disk is powered through a cross V- belt and pulley arrangement. The cross belt serves to reverse the direction of cut to that of the conveyor. A guide was provided on the cutting platform that directs the food to be cut towards the blade. The rotating blade cuts the food as it is passed beneath it and thereafter pushes it towards the outlet from where it will be collected. At the point of contact with the material, a clearance of 1mm is provided between the blade and the cutting platform so that the material fails and cut due to the sheared induced by the blade. The size of cut can varied by varying the speed of the cutting disc.

2.2.3 The Transmission System

The transmission system comprising the conveyor shaft, blade shaft, V- belt and pulleys were designed according to PSG TECH (1982).

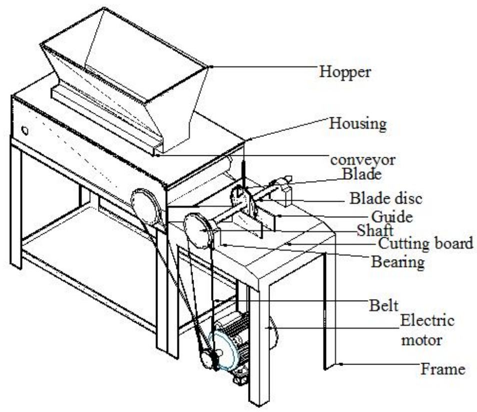

Figure 1. Isometric drawing of the cutting machine

2.3. Performance Evaluation of the Machine

The machine was fabricated and assembled at the Department of Agricultural Engineering Technology, Rufus Giwa Polytechnic, Owo. One major problem encountered during the fabrication of the machine was in fastening of the blades to the disk. The machine was run for 1 hour and tested with a 32cm long, 8g freshly plucked vegetable. About 400 g of the vegetable was collected and run through the machine one after the other. The vegetable was chopped using the machine and manual cutting with a knife for purpose of comparison. The quantity that has passed through after ten seconds was noted while for manual cutting, the quantity that was cut in thirty seconds was noted. This was used to determine the actual throughput. The quantity that was actually collected from the outlet was equally measured. Thereafter, the quality of cut was determined by physically sorting the different ranges of size of cut. Each test was conducted seven times and the average determined. The test parameters include actual time taken to cut, percentage loss during cutting, uniformity of size of cut and efficiency. The following parameters were determined:

- Throughput
- % loss
- Uniformity of size of cut
- Efficiency
- Cost

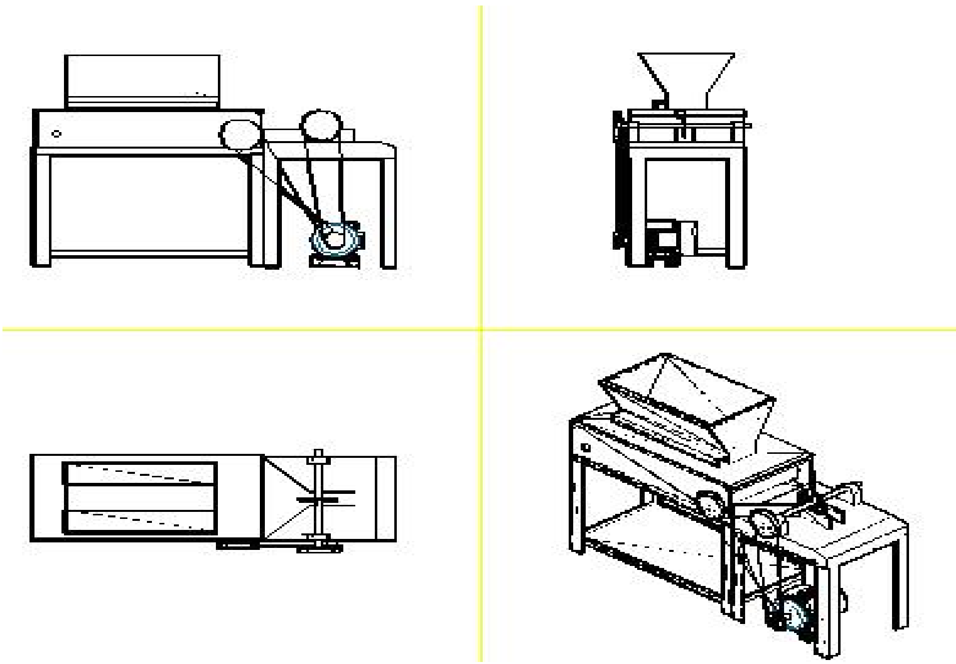

Figure 2. Orthographic drawing of the cutting machine**.**

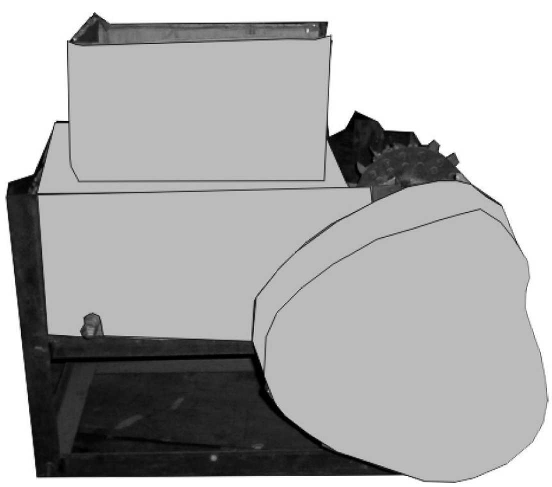

Figure 3. Picture of the cutting machine**.**

2.3.1 Determination of Machine's Throughput

In 1 rev of cutting assembly, since there are 16 blades fitted on the disk, 16 cuts were made; at 16 cuts/rev. Length of 32 cm was cut.

The Diameter of the disc = 10 cm.

Circumference of disc = 32 cm.

Therefore a material/vegetable of minimum length of 32cm was selected.

The cutting machine is designed to be operated by a 1kW, 1,420rpm electric motor, hence there is the need to step down the speed.

Speed ratio = 5:. Speed of cutting disc $=\frac{1420}{5}$ = 284 rpm = 4.73 rev/ s.

In 1 sec. = 4.73rev, But it is expected that in 1 rev, a length of 32cm would be cut $\cong$ 8g.

And in 1 sec (8 × 4.73rev) g of vegetable would be cut
: .The theoretical throughput of machine = 37.8 g/s

2.3.2. The Percentage Loss incurred by Machine

Percentage loss = $\frac{Total\ mass\ of\ sample - mass\ after\ cutting}{Total\ mass}$ é é é é é é é é é é é é é é (3)

2.3.3 Uniformity of Size of Cut

The uniformity of size of cut was determined by sorting out the different size ranges of cut. The uniformity Index (U.I) was computed from the relationship below according to Akande et al, 2008.

$$U.I = \frac{No\ of\ chips\ with\ same\ dimension}{Total\ No\ of\ chips\ collected}$$ é é é é é é é ...é é é é é é é é é é é ...(4)

2.3.4 Determination of Machine's Cutting Efficiency

Efficiency = $\frac{Actual\ throughput}{Theoretical\ throughput} \times 100\%$...(5)

2.3.5 Cost of Production

This comprise the cost of bought out components, cost of materials and parts fabricated and cost of machining and non machining job. The cost of bought out components is presented in Table 1.

Table 1. Bought out Components

Names	Specification	Qty	Cost (₦)
Electric Motor	1 kW, 1420 rpm	1	-
Ball bearing	20 mm ἐ	2	150
Ball Bearing	15 mm ἐ	4	150
Bolt and nuts	M12	84	840
A Type V- belt	1375, 1150 long	2	100
Flat Belt	Reinforced Leather	1.5 m	1200
Electrode	Stainless Steel	10	960
		Total	3400

The cost of materials used is presented in Table 2.

Table 2. Cost of Materials used in fabrication

Material	**Size**	**Unit cost**	**Total Costs(₦)**
Stainless steel sheet SWG 16	600mm x 300mm	2400.00	25000.00
Stainless steel plate (3mm)	100mmἐ	200.00	200.00
Angle Iron (2.54mm)	400mm	100.00	100.00
Spring steel (2mm)	650mm x 30mm	500.00	500.00
Mild Steel pipe (5mmἐ)	100mm	200.00	200.00
Hardwood (20mm thick)	300mm x 180mm	100.00	100.00
Angle Iron (38mm)	1 length	1300.00	1500.00
Mild Steel Plate (30mm)	6000mm x 250mm	100.00	100.00
Mild Steel Rod (20mmἐ)	40mm	100.00	100.00
Mild steel Rod (10mmἐ)	40mm	100.00	100.00
		Total	5100.00

The cost of machining and non machining jobs such as step turning of shafts, drilling, cutting, welding and assembly of machine = ₦ 6,600.

Therefore cost of production excluding electric motor = ₦ (3400 + 5100 + 6600)
= ₦ 15,100.00.

3. RESULTS AND DISCUSSION

Tables 3 shows the results obtained from the tests using the machine and manual cutting while Table 4 shows the distribution of size of cut. The throughput, percentage loss, uniformity index and efficiency of the machine are 25.3 g/s, 12.5 %, 66.7% and 0.7 respectively while the corresponding values for manual cutting are 0.61 g/s, 2%, and 0.31 respectively. The throughput can be increased by increasing the rate of material feeding into the machine, depending on the type and size of the material being cut. Moreover, generally, the cost of cutting operations are charged based on the time spent (Nwokedi, 1995). Therefore, the cost of manual cutting with knife will be by far higher than by use of this cutting machine.

The percentage loss was incurred by the machine because some of the vegetables were shattered during the cutting operation while that incurred during manual cutting were those that dropped from the chopping board. In as much as it is impossible and unavoidable not to incur some losses during cutting operations, this percentage loss in this machine can be reduced by preventing excessive vibration of the machine. A lower uniformity index was obtained with manual cutting when compared with the use of the cutting machine indicating that the manually cut vegetable was uneven in size (Table 4). This observation is normal as a result of human factor. Also, the hands of the person doing the cutting can be injured during cutting.

Table 3. Performance evaluation of the cutting machine compared with manual cutting.

Method / Parameters	Manual Cutting	Cutting Machine
1. Theoretical Throughput, g/s	37.8	ND*
2. Actual Throughput, g/s	25.3	0.61
3. Percentage Loss, %	12.5	2.00
4. Efficiency, %	66.7	ND*
5. Uniformity Index	0.7	0.31

*ND- Not determined

Table 4. Uniformity of size of cut

Method / Size range, mm		Manual Cutting	Cutting Machine
1.	> 20	3	-
2.	14-20	5	11
3.	8-13	6	2
4.	< 8	2	3

The performance of the machine from these records is far better than manual cutting and compares favourably with a slicing machine reported by Aniyi (2006). However, the performance can be improved by fastening the machine on the table to ensure its stability during operation.

4. CONCLUSION

A mechanically operated cutting machine was developed for cutting of agricultural products such as vegetables, fruits, salad ingredients and confectionaries. The efficiency of the machine was 67%, uniformity Index 0.7 and the machineꞌs percentage loss was 12.5%. It is highly recommended for every household in Nigeria.

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DEVELOPMENT OF MODEL EQUATIONS FOR ASSESSING PROFITABILITY OF MECHANIZED MAIZE FARMS IN THE NIGERIA SAVANNA BELT

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ABSTRACT

A linear regression model equation for determining farm profit on a mechanized maize farm within the Savanna belt of Nigeria was developed. The measured effect of farm size and yield per hectare was examined using a 2-factor factorial statistical design and the corresponding response equations due to variations of farm size and yield per hectare was determined using optimization techniques. The results showed that all the model variables had fitted the data well, having correlation coefficients (R^2) of 0.98 and 0.96 on Sebore and Gassol maize farms respectively. Similarly, the models have accounted for most of the variation in the dependent variable $y(x_1, x_2)$ with a significance level of less than 0.05. The models have an accuracy range of ±6.6%.

KEY WORDS: Farm profitability, mechanized maize production system, optimization.

1. INTRODUCTION

Improved and appropriate farm implements/machines are essential inputs in modern agricultural production processes. Thus, mechanization is used to describe the level of application of these inputs. Technological advancement in plant breeding for high yielding varieties and highly pest and disease resistant crop varieties have reached an advanced stage. But, commercialized agricultural production process may not be attained easily without the applications of modern farm machinery. On economic terms the farmers may not break even, talk less of realizing farm profit from their investment.

The appropriate choice and use of these machines for various farm operations have a direct and significant effect on achievable level of agricultural production, the environment and the profitability of the farm production enterprise (Iya, 2005).

The economic management of farm power units and machinery are usually the most significant factors that contribute to farm profit. Farm machinery fixed cost may be the single largest item that almost contributes to the annual farm cost. According to Barboza *et al* (2003) farm machinery operation cost represents about 40% of the total production cost. Kepner *et al.* (1980) reported that, if the capacity of a farm machinery or power unit is too low, then, operating cost may be excessive because of the extra amount of labour required to complete the scheduled operation. Similarly, the resultant untimely operation may cause delays, affecting successive scheduled farm operations ï culminating into timeliness cost. In contrast, if the farm machinery size is too large on comparison to farm size, then, total cost per hectare will be high because of high value of fixed cost. The two phenomena may ultimately affect the farm profit (Kepner *et al.,* 1980). In view of these, there is the need for a concise farm planning operation and economic management on mechanized farms in Nigeria that will ensure optimal selection of farm machinery size, power levels and scheduling of all farm operations at least cost and at the same time maximizing farm profit. The aim of this study to develop a predictive equation using multiple regression technique, to be used for optimal assessment of mechanized maize farm production system in the savanna belt of Nigeria.

2. MATERIALS AND METHODS

2.1 Optimization Techniques

Olayemi (1998) and Ott (1977) as cited in Babatunde (1997) described the method of multiple regression analysis as a response variable $y(x_1, x_2,é\ ,x_n)$ in an event of a unit change of the independent variable x_1, $x_2, .., x_n$. In a 2 ï factor factorial combination experiment, the response variable to any unit change of the independent variables may assume any of the responses in optimizing $y(x_1,x_2)$ as given below;

$$y = b_o + b_1x_1 + b_2 x_2 + b_3 x_1^2 + b_4 x_2^2 + b_5 x_1 x_2 \quad (1)$$

$$y = b_o + b_1x_1 + b_2 x_2 + b_3 x_1^2 + b_4 x_1^2 x_2 + b_5 x_1 x_2 \quad (2)$$

$$y = b_o + b_1x_1 + b_2 x_2 + b_3 x_2^2 + b_4 x_2^2 x_1 + b_5 x_1 x_2 \quad (3)$$

$$y = b_o + b_1x_1 + b_2 x_2 + b_3 x_1^2 + b_4 x_2^2 + b_5 x_1 x_2 + b_6 x_2^2 x_1 + b_7 x_1^2 x_2 + b_8 x_1^2 x_2^2 \quad (4)$$

Where;

b_o is a constant and b_1, b_2,---,b_8 are estimator coefficients, Eqn. 4 is a combination of Eqns. 1 ï 3. The response value of Eqns. 1 ï 4 are determined by the existence of an inverse matrix

$$(x\hat{o}x)^{-1} \quad (5)$$

Where; x is the matrix of coefficient values of the regressor variable x_1, x2, augmented with a unit value 1, at the beginning of each row, first column of the matrix.

The constant and estimator coefficients b_0, b_1, b_2,--, b_8 respectively of Eqns. 1 ï 4 were obtained as the response equations óyô, by multiplying matrix $(x\hat{o}x)^{-1}$ and xôy as given below

$$b_0 = (x\hat{o}x)^{-1}\ x\hat{o} \quad (6)$$

where y is the measured response from experiment matrices x,y, xôx and xôy which are obtained from the experimental data.

The error sum of squares (ESS), regression sum of squares (RSS) and total sum of squares (SST) are determined using the empirical expression below.

$$ESS = y\hat{o}y\ ï\ b\hat{o}xy \quad (7)$$

With a degree of freedom $\left[n - (k + 1)\right]$

Where

k= number of constant coefficient in the regression model.

$$RSS = b\hat{o}(xy) - \left(\sum_{i=1}^{n} y\right)^2 \quad (8)$$

with (k-1) degree of freedom and n = the number of data

$$SST = y\hat{o}y - \left(\sum_{i=1}^{n} y\right)^2 \quad (9)$$

with (n-1) degree of freedom

The regression coefficient is obtained, thus

$$R^2 = \frac{RSS}{SST} \quad (10)$$

Alternatively, a multiple regression relation using a statistical software (SPSS11.0) was used to estimate the error sum of squares (ESS), regression sum of squares (RSS), total sum of squares (SST), as well as the regression coefficient (R^2) as in Eqns. 7 ï 10. Extreme values (turning points) of $y(x_1, x_2)$ are obtained by methods described by Stephenson (1975). The methods involved in solving the partial differential equations of $y(x_1, x_2)$ simultaneously are as follows;

$$\frac{\partial y(x_1, x_2)}{\partial x_1} = 0 \quad (11)$$

$$\frac{\partial y(x_1, x_2)}{\partial x_2} = 0 \quad (12)$$

The nature of the function $y(x_1, x_2)$ is obtained by taking a second derivative of Eqns. 11 and 12 as follows;

$$A = \frac{\partial^2 y(x_1, x_2)}{\partial x_1^2} \quad (13)$$

$$B = \frac{\partial^2 y(x_1, x_2)}{\partial x_2^2} \quad (14)$$

$$C = \frac{\partial^2 y(x_1, x_2)}{\partial x_1 \partial x_2} \quad (15)$$

The criteria below must be fulfilled for the function $y(x_1, x_2)$ to have maximum, minimum or saddle points (values), thus

AC ï B^2 >0; A<0, then (x_1, x_2) are extreme maximum points or values.
AC ï B^2 >0; A>0, then (x_1, x_2) is a minimum value.
AC ï B^2 = 0; then (x_1, x_2) is a saddle point or value.

According to Stroud (1996), in the event the second derivative of Eqns. 11 and 12 are both negative, then the coordinates of (x_1, x_2) is a maximum point. Otherwise, if both are positive, then, the coordinates of (x_1, x_2) is a minimum point. Hence, any function that does not satisfy the above criteria cannot be said to have a maximum, minimum or saddle points.

2.2 Data Collection

An investigative survey approach using structured questionnaires was used to generate data from Sebora and Gassol maize farms in Adamawa and Taraba states, respectively. The data collected include three farm power levels (Streyr 8130, 768 and Fiat 640), five levels of farm sizes (20, 70,100, 150 and 200 ha), six levels of farm yield (0.5, 1,2,3,4 and 5t/ha). Others include; machinery, crop and economic parameters.

2.3 Data Analysis

A 90 x 6 matrix coefficient was formed from Eqns. 1 ï 3. Similarly, Eqn. 4 formed a 90 x 8 matrix. The measured response $y(x_1, x_2)$ formed a 90 x 1 matrix. MS Excel software was used to analyze the matrixes of model Eqns. 1 ï 4 to obtain values of b coefficients in Eqn. 6 and sum of squares in Eqs. 7 ï 9.

3. RESULTS AND DISCUSSION

Tables 1 and 2 show the ANOVA results of the 2-factor factorial analysis on data from Sebore and Gassol maize farms in Adamawa and Taraba States respectively. It can be inferred from both Tables 1 and 2 that, the farm size (area), yields per hectare and their interactions are significant at PÒ 0.05, in contributing to the estimation of farm profit for maize production. Furthermore, the Duncan Multiple Range Test was used to identify homogeneousness of the subset factor means that are not different from each other. Tables 3a and 3b for Sebore farms show that within the subjects of both area (x_1) and yield per hectare (x_2), none has homogeneity means. That is each subset factor contributes differently to the over all farm return (profit). Tables 4a and 4b for Gassol maize farm show that, each subset of area (x_1) had no common homogeneity of means, but yield per hectare (x_2) showed that, 2t/ha and 5t/ha had an entirely different homogeneity of means from the rest of the yields. Whereas, yield 1t/ha and 3t/ha had a common homogeneity of means so also were the results for both yields of 0.5t/ha and 4t/ha.

The result of Eqn. 6 for both Sebore and Gassol maize farms are shown in Tables 5 and 6 respectively. The resulting response equations using the betas (bŝs) in Tables 5 and 6 were further examined for extreme values and the nature of the response at critical point using the methods described by Stephenson (1975).

Table 1: 2 ï Factor Factorial Analysis for Sebore Maize Farm

Source	Type Sum of Squares	df	Mean square	F	Sig.
AREA	27040.344	4	6760.086	23581.970	0.000
YIELD	5357.118	5	1071.424	3737.568	0.000
AREA*YIELD	36961.805	20	1848.090	6446.901	0.000
Error	17.200	60	0.287		
Corrected Total	69376.467	89			

Table 2: 2 ï Factor Factorial Analysis for Gassol Maize Farm

Source	Type Sum of Squares	df	Mean square	F	Sig.
AREA	2213.755	4	3053.439	3602.783	0.000
YIELD	1663.091	5	332.618	392.460	0.000
AREA*YIELD	6871.636	20	343.582	405.396	0.000
Error	50.851	60	0.848		
Corrected Total	20799.333	89			

Table 3a: Duncan Multiple Range Test for Homogeneity of Area Subset Means at Sebore Maize Farm

		Subset				
AREA(ha)	N	1	2	3	4	5
20.00	18	2.5183				
70.00	18		16.4950			
100.00	18			24.8561		
150.00	18				38.5672	
200.00	18					52.5761

Table 3b: Duncan Multiple Range Test for Homogeneity of Yield Subset Means at Sebore Maize Farm

		Subset					
AREA(ha)	N	1	2	3	4	5	6
2.00	15	19.0613					
3.00	15		20.9420				
1.00	15			21.3360			
4.00	15				29.2853		
0.50	15					29.8260	
5.00	15						41.5647

N – number of cases in a category

Table 4a: Duncan Multiple Range Test for Homogeneity of Area Subset Means at Gassol Maize Farm

		Subset				
AREA(ha)	N	1	2	3	4	5
20.00	18	8872				
70.00	18		3.2933			
100.00	18			11.1444		

150.00	18	20.4567	
200.00	18		31.2328

Table 4b: Duncan Multiple Range Test for Homogeneity of Yield Subset Means at Gassol Maize Farm

AREA(ha)	N	Subset			
		1	2	3	4
2.00	15	8.6353			
1.00	15		9.6160		
3.00	15		9.8307		
4.00	15			14.4067	
0.50	15			14.7100	
5.00	15				21.0893

Table 5: Beta Values for the Different Models for Sebore Maize Farm

Betaôs	Model 1	Model 2	Model 3	Model 4
b_0	-3.084217	-3.089136	-3.090159	-3.155887
b_1	-0.002828	-0.003386	-0.003403	-0.001624
b_2	0.002638	0.048057	0.0256	0.099979
b_3	-4.19E-06	-0.002587	-1.59E-06	-7.94E-06
b_4	0.005797	7.76E-05	-1.0E-06	-0.013729
b_5	0.10895	0.10853	0.109173	0.10716
b_6	-	-	-	0.000372
b_7	-	-	-	6.17E-06
b_8	-	-	-	-1.32E-06

Table 6: Beta Values for the Different Models for Gassol Maize Farm

Betaôs	Model 1	Model 2	Model 3	Model 4
b_0	-3.695571	-4.003541	-3.214797	-3.46754
b_1	-0.00442	-0.000213	-0.011279	-0.014358
b_2	0.393623	0.652497	0.043041	0.329049
b_3	9.42E-06	-0.093925	4.03E-05	6.37E-05
b_4	-0.046143	0.000442	-1.2E-05	-0.05279
b_5	0.59077	0.05668	0.061732	0.065216
b_6	-	-	-	-0.000643
b_7	-	-	-	-3.85E-05
b_8	-	-	-	4.89E-06

Table 7 shows the results of the partial differential equations in Eqns. 11 ï 15. The existence and sufficiency of the regression models were examined as shown in the Analysis of variance (ANOVA) in Tables 8 and 9 for Sebore and Gassol maize farms respectively.

The optimal linear regression equations for both farms formed from Eqn. 1 are shown below;

$$y = -3.084217 \text{ ï } 0.002828x_1 + 0.002638x_2 \text{ ï } 4.19E\text{-}06x_1^2 + 0.005797x_2^2 + 0.10895x_1^1 x_2 \quad (16)$$

$$y = -3.696 \text{ ï } 0.004421x_1 + 0.3936x_2 + 9.42E\text{-}06x_1^2 - 0.046143x_2^2 + 0.0908x_1 x_2 \quad (17)$$

Eqns. 16 and 17 represent the optimal linear regression equations for profitable farm return in Sebore and Gassol maize farms. The model variables in Table 8 for Sebore farms fit the data well, since it has a high correlation coefficient (R^2) of 0.98. The high value of the regression sum of squares (RSS) of about 69357.74 as against the low value of the residual sum of squares (ESS) of about 18.73 infers that, the model has accounted for most of the variations in the dependent variable $y(x_1, x_2)$, with significant level of less than 0.05. Similarly the model variables in Table 9 for Gassol maize farm had fitted the data well, since it has a high correlation coefficient (R^2) of 0.96. The high value of regression sum of squares (RSS) of about 20731.80 is more than the low value of residual sum of squares (ESS) of about 67.53, it infers that, the model has accounted for most of the variation in the dependent variable $y(x_1, x_2)$ with a significant level of less than 0.05. The two (2) models (Eqs. 16 and 17) have an accurate range of ± 6.6%.

Table 7. Critical Points of farm Sizes and Yield per Hectare for Optimal Performance using Model 1 Results.

Farm	Variable	Farm Size (ha)	Yield per hectare (t/ha)	Nature of Critical Point Coordinates at
Sebore	Farm Returns	-2.6975E-02	2.8282E-03	Saddle
Gassol	Farm Returns	-5.3152132	0.0765256	Saddle

Table 8. ANOVA Table of Multiple Regression of Farm Return as a Function of Area and Yield per Hectare at Sebore Maize Farm.

Model	Sum of Squares	df	Mean square	F	Sig.	R^2
Regression	69357.737	5	13871.547	62210.246	0.000	0.98
Residual	18.730	84	0.223			
Total	69376.467	89				

Table 9. ANOVA Table of Multiple Regression of Farm Return as a Function of Area and Yield per Hectare at Gassol Maize Farm.

Model	Sum of Squares	df	Mean square	F	Sig.	R^2
Regression	20731.802	5	4146.360	5157.517	0.000	0.96
Residual	67.531	84	0.804			
Total	20799.333	89				

4. CONCLUSION

From the above analysis one can infer that the model equations 16 and 17 can be used within the Nigeriaŝ agricultural production system to predict the possible farm profit for purely mechanized maize production, as a mono-crop plant, assuming that the macroeconomic parameters (interest, fuel price, inflation, machinery among others) are the same throughout the country.

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ABATTOIR WASTE CONTAINMENT USING COMPACTED LATERITIC SOILS AS HYDRAULIC BARRIERS

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ABSTRACT

Qualitative and quantitative (experimental) approaches were used to assess the suitability of three compacted lateritic soil samples as hydraulic barriers for the containment of abattoir liquid waste in waste stabilization ponds. The qualitative approach involved matching the index properties of these lateritic soils with one of the groups of non-lateritic soils already recognized to be suitable for use as liner materials in waste stabilization ponds. The quantitative approach involved using laboratory hydraulic conductivity test results to develop ñacceptable zonesò on compaction planes within which field compaction can be carried out to meet the requirement of a hydraulic conductivity of $1x10^{-7}$ cm/s or less. These lateritic soils have fines contents ranging between 64.057 and 71.524% which are greater than the minimum of 20% fines content and plasticity index in the range of 16.952±2.15 to 17.434±2.76%, which fall within the required range of 16 to 30% for animal waste lagoons. The results of the assessments show clearly that these fine-grained lateritic soils are suitable waste stabilization pond liner materials. Hydraulic conductivities generally ranged between $1.55x10^{-5}$ cm/s and $9.54x10^{-9}$ cm/s for the three soils. The results were used to delineate acceptable zones on compaction planes, which show combinations of dry unit weights (bulk dry densities) and moisture contents that will yield hydraulic conductivities of $1x10^{-7}$ cm/s or less. Proper establishment of the quality assurance to ensure liners of maximum hydraulic conductivity of $1 x 10^{ï 7}$ cm/s can be accomplished by constructing within the acceptable zones developed for each soil sample. A regression model that can be used for the preliminary estimation of the hydraulic conductivity of other candidate lateritic soils was developed.

KEYWORDS: Abattoir wastes, acceptable zones, compacted lateritic soils, hydraulic barriers, hydraulic conductivity, waste stabilization ponds.

1. INTRODUCTION

Agricultural wastes are diverse and include those from post-harvest processes involving cash crops and/or those from livestock (cattle, swine, poultry, etc) farms and abattoirs. Wastes from abattoirs are regarded as animal wastes. Abattoir wastes include animals faeces and waste water (or effluent) resulting from the washing of slaughtered animals and their volumes depend on the number of animals that can be slaughtered daily.

While the faeces could be spread on drying bed or left in open dumps to dry up before being used on agricultural lands as soil conditioners, the wastewater will require some treatment before final disposal. This is necessary because abattoir wastewaters (which contain some meat, animal faeces, and blood) are high-strength wastes rich in organic matter. The waste from large-scale animal operations is often in the form of liquid with suspended solid/organic matter containing high concentrations of nitrogen (Reddi and Davalos, 2000).

Wastewaters from very small abattoirs can be conveniently disposed of on land where this is available, but not those from large abattoirs. Improper disposal of abattoir liquid wastes results in high pollution loadings in water bodies such as rivers or contamination of ground water sources. Apart from nutrients pollution of surface and groundwater, there is also the bacteriological aspect of the pollution by animal (abattoir) wastes (Nwigwe, 1992). The discharge of animal liquid wastes into rivers, for instance leads to the introduction of new micro-organisms into the aquatic system. Whenever there is drainage from animal production units or runoff from agricultural lands into surface waters, a chain for the spread of zoonotic diseases is initiated (Nwigwe, 1992). Moreover, abattoir effluents are unsafe for irrigation purposes. In general, effluent re-use is fraught with many problems, which will militate against its successful and safe use in Nigeria, unlike in the developed countries (Agunwamba, 1993).

Abattoir effluents can be treated to reduce their organic strength before re-use for irrigation or pumping into nearby water bodies. In order to accomplish anaerobic treatment of abattoir effluents, the wastewater can be stored in cement tanks, earthen-lined, anaerobic lagoons or storage basins to form what is known as waste stabilization ponds (WSPs). Ninety-five percent of the nitrogen in lagoon waste is in the form of ammonium (NH_4-N) ranging from 130 to 210 mg/L in cattle and diary lagoons and 100 to 711 mg/L in swine waste lagoons (Reddi and Davalos, 2000). When enclosed in cement tanks as an alternative to lagoons the nitrogen in the ammonium form may range between 2,500 and 3,500 mg/L (Reddi and Davalos, 2000). Thus cement tanks are not a good alternative to lagoons. Unlined excavations will be unsafe as there is possibility of contaminant (or microbial) transport to groundwater sources. Unsaturated conditions in the natural soil can cause a transformation of ammonium to nitrate ($N0_3$ ï N) that could be transported in moving soil water. It is the nitrogen in the nitrate form that is of importance as it poses a human health hazard (causing a condition called methamoglobinemia, also known as blue baby syndrome) (Reddi and Davalos 2000).

Conventional wastewater treatment processes can readily be used for treating abattoir wastes in properly designed stabilization ponds, which can be anaerobic, facultative or aerobic (Nwigwe, 1992). These ponds or lagoons can be operated singularly or in various combinations and are applicable in the tropics. Lagoons for livestock wastes are usually operated anaerobically and require considerable amounts of water to dilute the wastes (Nwigwe, 1992). Odours can be minimized and solids reduced in a waste effluent through this means. When animal wastes are stored in stabilization ponds, natural biological action takes place during storage with resulting oxidation and reduction of organic matter. Waste stabilization ponds provide reliable and inexpensive treatment (Gloyna and Tischer, 1979) and require little attention.

Apart from the obvious function of containment the waste lagoons or ponds are expected to separate the liquid from the solid phase and to reduce the quantity of solids through a digestion process (Reddi and Davalos 2000). A complete waste stabilization pond (WSP) system will consist of an anaerobic pond, a facultative pond and a maturation pond. In facultative ponds, facultative bacteria convert the complex organic compounds into simpler organic compounds, primarily organic acids. The following reaction takes place within the top thin layer exposed to the atmosphere (the aerobic zone):

$$\underset{\text{(wastewater organics)}}{(CH_2O)_X} + O_2 \rightarrow CO_2 + H_2O \quad (1a)$$

$$CO_2 + 2H_2O \xrightarrow{\text{light}} \underset{\text{(algae)}}{CH_2O_X} + O_2 \quad (1b)$$

$$\text{Organic matter} \prec \begin{matrix} CO_2, CH_4 \\ H_2S \end{matrix} \rightarrow \text{Organic acids} \xrightarrow{\text{acid splitting, methane forming bacteria}} CH_4, CO_2, \text{etc.} \quad (2)$$

Mathematically, the reaction is:

$$2CH_2O_X \rightarrow CH_3COOH \rightarrow CO_2 + CH_4 \quad (3)$$

The end product of anaerobic stabilization of organic materials depends on the material being metabolized (Nwigwe, 1992). Gas is usually the end product and methane and carbon dioxide are mostly produced (Hammer, 1975). Stabilization pond systems can be provided at suitable locations but compacted soil liner must be provided in order to prevent excessive seepage from the ponds and limit the contamination of the ground water below the ponds.

Compacted fine-grained, clay-rich soils are used as landfill liners and covers, caps to hazardous waste sites, and liners for surface impoundments and sewage lagoons. The suitability of a soil material for construction of a liner or hydraulic barrier depends, principally, on hydraulic conductivity. To be effective, a compacted soil liner should have low hydraulic conductivity, which in many cases is considered to be less than 1 x 10^{-7} cm/s (Benson et al., 1994). Under most USA State codes a liner's hydraulic conductivity should generally be equal to or less than 1 x 10^{-7} cm/s. Other factors to be considered have been enumerated by Edil et al. (1992) and Benson et al. (1999).

Fine-grained soils can be compacted to yield low hydraulic conductivity lining to excavations that will serve as animal waste stabilization ponds. The objective of this paper is to assess the suitability of lateritic soils as hydraulic barriers (with hydraulic conductivity of less than or equal to 1 x 10^{-7} cm/s) in animal waste stabilization ponds, based on index properties and laboratory measured values of hydraulic conductivity.

2. MATERIALS AND METHODS

Three lateritic soil samples obtained at different points in a large borrow-pit in Shika near Zaria (Lat. 11°15′N and Long. 7°45′E in Northern Nigeria) were used in this investigation. Disturbed, unsaturated soils were collected and designated as LS1, LS2 and LS3, respectively. The index properties, compaction characteristics and hydraulic conductivities were determined in the laboratory. Soils in lateritic deposits are said to vary in engineering properties both vertically and laterally (Gidigasu, 1980a, b; Gidigasu and Kuma, 1987).

2.1 Determination of Index Properties

The natural moisture contents of the soils were determined by oven-drying samples at 105°C for about 24 hours in accordance with specifications outlined in BS 1377 (1990) as well as Head (1992). The specific gravities of air-dried samples were estimated with the use of distilled water in accordance with procedures in Head (1992). Average of nine readings for each soil was recorded. The plasticity characteristics (liquid limit, plastic limit and linear shrinkage) were determined from air-dried samples passing 425μm sieve following procedures in BS 1377 (1990) and Head (1992). Distilled water was used throughout the plasticity tests. The plasticity index values were obtained as the difference between the liquid limit and the plastic limit. Averages of three measurements were recorded for each of the plasticity parameters. The particle size distribution represented by the percentage passing BS No. 200 (75μm) sieve and clay-sized fraction (<2μm) were determined by the mechanical and hydrometer methods (see BS 1377, 1990), respectively. Again, averages of three measurements were obtained for both fines content (percentage less than 75μm) and clay-size fraction. The activity of each soil was estimated from Eq. (4a) while the grading modulus was calculated from Eq. (4b).

$$\text{Activity} = \frac{\text{Plasticity index}}{\text{Percentage of clay} - \text{size fraction}} \tag{4a}$$

$$Grading \ \text{mod}ulus = \frac{300 - (\% < 2.40mm + \% < 425\mu m + \% < 75\mu m)}{100} \tag{4b}$$

2.2 Determination of Compaction Characteristics

Air-dried soil samples were used in the compaction tests to determine values of the maximum dry unit weights (bulk dry densities) and optimum moisture contents. These values were obtained with the use of four compaction energies, namely: reduced BS high compaction (RBSL or RED BSL), BS light compaction (BSL), West African Standard Compaction (WAS) and BS heavy compaction (BSH). Procedures for the BSL (British Standard light) Compaction as well as the BS heavy compaction are outlines in BS 1377 (1990) and Head (1992). The reduced BS light compaction is equivalent to the reduced Proctor compaction defined in Daniel and Benson (1990) as well as Benson and Trast (1995). The procedure for the West African Standard compaction has been described by Ola (1983).

2.3 Hydraulic Conductivity Testing

The three soils were used for the hydraulic conductivity testing. For each soil, clods in the air-dried soil specimens were first mechanically crushed to smaller sizes enough to pass through 4.76mm (BS No. 4) sieve size. The test specimens were mixed with tap water to obtain the desired moulding moisture contents and compacted using one of the compaction energies employed in this investigation. Seven moulding moisture contents ranging between 10% and 25% by dry weight of soil specimens were utilized in preparing the hydraulic conductivity test specimens. Each compacted specimen was soaked for at least 12 hours in distilled/deionized water before the commencement of permeation. Permeation was terminated when the hydraulic conductivity test readings generally were not showing any marked variation or when steady state was reached for the more permeable specimens. Rigid-wall compaction mould permeameter was used throughout the tests. The geometric mean of the last three or four readings was taken as the hydraulic conductivity of each compacted soil specimen.

2.4 Assessment of Suitability of Lateritic Soils as Hydraulic Barriers

Two methods were used here to assess the suitability of lateritic soils as hydraulic barriers in waste stabilization ponds for abattoir effluent containment. The first assessment is based on a comparison of index properties of lateritic soils with those of soils that have been considered suitable for the construction of waste lagoons. The second form of assessment is based on results of laboratory compaction and hydraulic conductivity tests.

2.5 Construction Quality Assurance

Successful design and construction of soil liners for waste stabilization ponds will involve, among other things, the development and execution of a construction quality assurance plan. Construction quality assurance of hydraulic barrier soils are usually based on some compaction control criteria. Benson and Boutwell (1992) identified two compaction control criteria; the common and the modern criteria. Attributes of these two compaction control criteria have been outlined by Benson and Boutwell (1992). Procedures for establishing quality assurance using the modern criterion are described in Daniel and Benson (1990). These procedures were used in constructing hydraulic-based ñacceptable zonesò on compaction planes.

3. RESULTS AND DISCUSSIONS

3.1 Classification and Compaction Characteristics of the Lateritic Soils

The physical properties of the lateritic soils are summarized in Table 1. The plasticity indices fall within a very narrow range of between 16.952 and 17.434. The percentages passing No 200 BS sieve range between 64.057% and 71.524%. Based on the AASHTO classification procedure, the soils could be taken as A-7-6 soils and as inorganic clays of low plasticity (CL) according to the Unified soil Classification System (USCS). The percentage of clay-size particles ranged between 28.662 and 34.135.

The maximum dry unit weights vary from 16.35 kN/m^3 to 18.585 kN/m^3 depending on the compactive effort used. The corresponding optimum moisture contents range between 12.75% and 19.50%. The range of values of the maximum dry unit weight and optimum content are typical of soils used as hydraulic barriers in waste containment systems. For instance, Benson et al (1999) reported maximum dry unit weight values of 13.4 to 20.4 kN/m^3 (17.397±1.773kN/m^3) and optimum moisture content values of 8.5 to 27.4% (17.401±5.069%) for 104 liner soils. Reddi and Davalos (2000) reported corresponding values of maximum dry unit weight of 15.5 to 19.3kN/m^3 and optimum moisture content values of 10 to about 23%.

Table 1 Physical properties of the lateritic soils

Property	Designation of soil samples		
	LS1	LS2	LS3
Natural moisture content (%)	5.24	9.68	7.22
Specific gravity	2.671	2.682	2.686
Liquid limit (%)	40.5	40.267	43.183
Plasticity index (%)	17.434 ±2.76	16.952 ±2.15	17.279 + 0.65
Linear Shrinkage (%)	7.857	8.37	8.535
Percentage pressing BS No. 200 sieve	66.330	71.524	64.057
Percentage of clay-size fraction	34.134	34.045	28.662
Activity	0.5107	0.4979	0.6029
Group index	10	11	10
AASHTO Classification	A-7-6	A-7-6	A-7-6
USCS Classification	CL	CL	CL
Grading modulus	0.5301	0.4484	0.6326

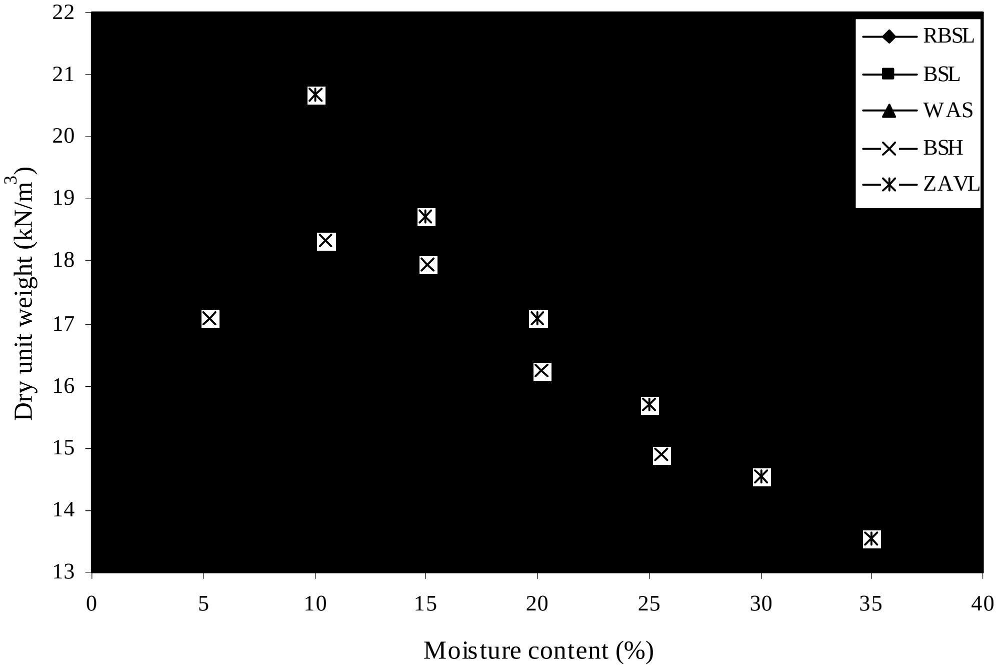


Fig. 1 Compaction curves for lateritic soil sample LS1

Typical compaction curves for the three soils are shown in Figs. 1, 2 and 3. The results of these compaction tests are summarized in Table 2. As would be expected, maximum dry unit weight increased as compaction energy increased for each soil sample. Optimum moisture contents decreased as compaction energies increased. For a given compaction energy, maximum dry unit weight increased while optimum moisture content decreased as grading modulus decreased.

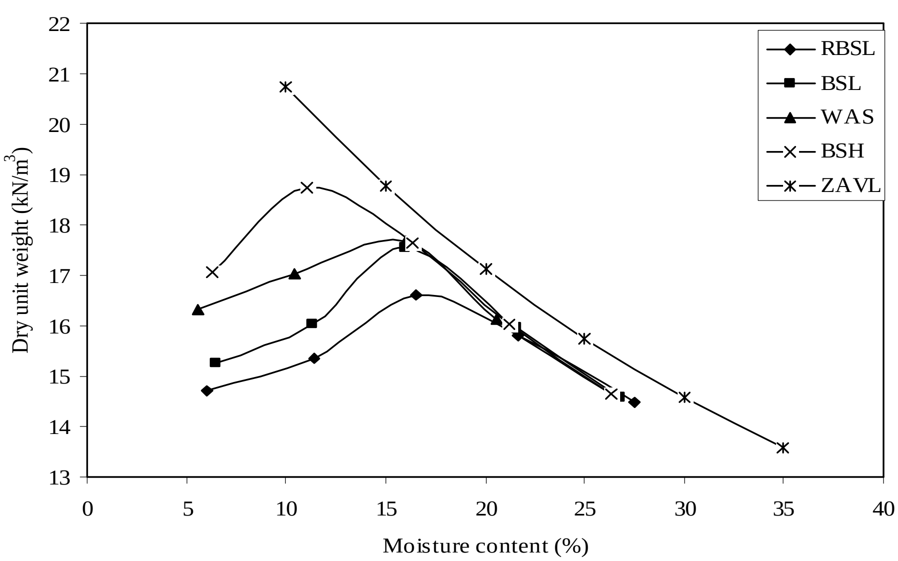


Fig. 2 Compaction curves for lateritic soil sample LS2

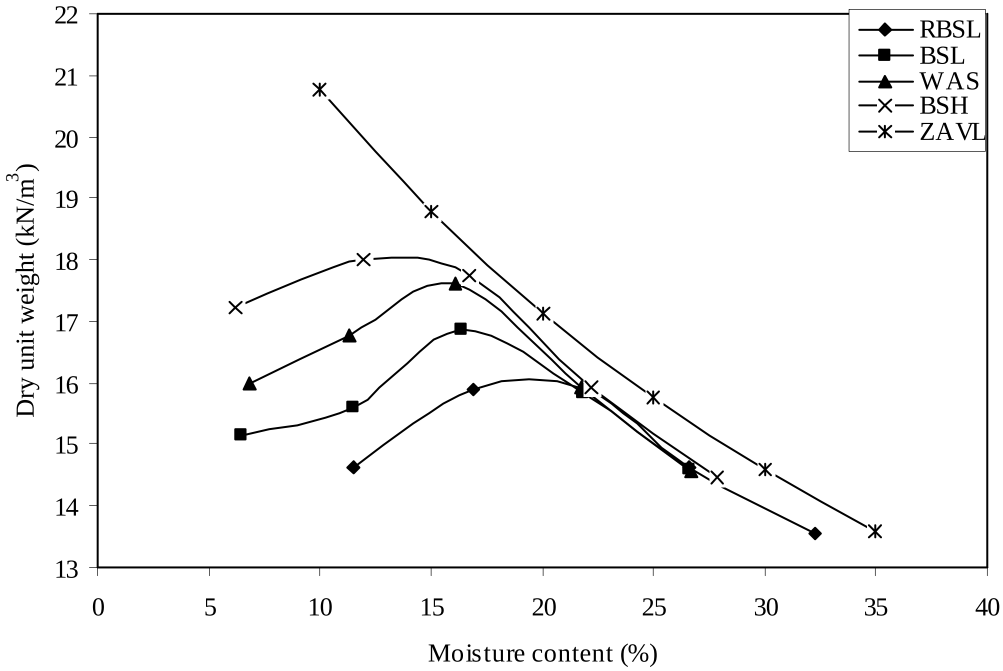


Fig. 3 Compaction curves for lateritic soil sample LS3

Table 2 Compaction characteristics of the soils

Compaction parameter	Designation of soil samples		
	LS1	LS2	LS3
Maximum dry unit weight (kN/m^3)			
Reduced BS light compaction	16.375	16.785	16.35
BS light compaction	16.952	17.34	16.755
West African standard compaction	17.585	17.77	17.415
BS heavy compaction	18.315	18.585	18.105
Optimum moisture content (%)			
Reduced BS light compaction	18.85	17.50	19.50
BS light compaction	16.85	16.25	18.75
West African Standard compaction	15.75	15.00	17.125
BS heavy compaction	12.875	12.75	14.625

3.2 Suitability Assessment

The first part of the objective was achieved by comparing the index properties of fine-grained lateritic soils with those of soils used for animal waste containment in USA. The second part of the objective was fulfilled by developing acceptable zones on compaction planes which show dry unit weights and compaction water contents that yield hydraulic conductivities less than or equal to 1 x 10^{-7} cm/s.

3.2.1 Qualitative Assessment

The National Research Conservation Service (NRCS) of the United States of America (USA) has suggested the grouping of soils to be used as lagoons or stabilization ponds materials into four based on a database of permeability (or hydraulic conductivity) tests performed on over 1100 compacted soil samples. The permeability of the soils in each of these groups was believed to vary in a relatively narrow margin (Reddi and Davalos, 2000). The soilsô groupings are presented in Table 3. The soils are characterized on the basis of their fines contents and Atterberg limits, principally the plasticity index. Soils in Groups I and II may require an additional liner material such as geomembranes while soils falling into Groups III and IV will yield hydraulic conductivities equal to or less than 1x10^{-7} cm/s when properly compacted using appropriate combinations of dry unit weights and compaction water contents. The natural soils classified under Groups III and IV have permeabilities that result in acceptable seepage losses (Reddi and Davalos, 2000).

Table 3: USDA grouping of soil types according to their estimated permeability (USDA, 1997)

Group	Description
I	Soils that have <20% passing No. 200 sieve and have a PI < 5
II	Soils that have 20 ï 100% passing No. 200 sieve and have a PI ≤ 15. Also included in this group are soils with < 20% passing the No. 200 sieve with fines having a PI of ≥ 5
III	Soils that have 20 ï 100% passing No. 200 sieve and have a PI of 16 ï 30.
IV	Soils that have 20 ï 100% passing No. 200 sieve and have a PI of > 30.

The fines contents of these lateritic soil samples fall between 20 and 100%. The plasticity indices of these soils are in the range of 16 to 30%. Thus, these fine-grained lateritic soils fall into soil group III as seen in Table 3. They, therefore qualify as suitable materials for the construction of WSP liners. This is, however, only a qualitative assessment.

3.2.2 Assessment Based on Hydraulic Conductivity

Compacted clay liners are usually provided at sites meant for WSPs to prevent excessive seepage from the WSP and limit ground water contamination below the WSP. In general, regulatory standards in the USA restrict the maximum seepage through the lagoon or WSP; the seepage rate varies from 0.64 cm/day to 0.04 cm/day (that is, 7.407 x $10^{ï6}$ cm/s to 4.62 x 10^{-7} cm/s). The inconsistency in regulations is primarily because some state regulatory agencies (in the USA) accept the notion that particulate and biological clogging eventually seals the liner. Some regulatory agencies support the usage of natural/compacted soils with permeability as high as 1 x 10^{-6} cm/s in anticipation of time ï dependent liner sealing (Reddi and Davalos, 2000).

In the tropics, temperatures are generally higher than in the temperate regions. The use of compacted soils with hydraulic conductivities higher than 1 x 10^{-7} cm/s will be unacceptable because desiccation-induced shrinkage will tend to ensure increase in seepage rates due crack development. Thus, the regulatory maximum hydraulic conductivity of 1 x 10^{-7} cm/s for landfills liners ought to be adopted for animal waste stabilization pond liners.

The hydraulic conductivities obtained from laboratory tests on the three lateritic soil samples are shown in Figs 4, 5 and 6 as well as Figs 7, 8, 9 samples LS1, LS2, and LS3, respectively. These figures show that at certain combinations of dry unit weights and moulding moisture contents the soils, when compacted, can yield hydraulic conductivities less than or equal to 1 x 10^{-7} cm/s. The figures are essentially plots of hydraulic conductivity versus moulding water contents relative to the optimum water contents as well as dry unit weights, respectively. On the basis of Figs 7, 8 and 9, it can be seen that these lateritic soils will have hydraulic conductivities less than or equal to 1 x 10^{-7} cm/s provided that:

i) the initial dry unit weight is greater than or equal to 16.0 kN/m^3
ii) the initial degree of saturation is greater than or equal to 85%, and
iii) compaction is carried out at a compactive effort greater than or equal to that of the BS light compaction.

Soil LS2 which has the lowest grading modulus or highest fines content yielded more points that satisfied these three conditions stated above than soils LS1 and LS3

Figures 10, 11, and 12 show the hydraulic conductivity-based ñacceptable zonesò on the compaction planes of soils LS1, LS2 and LS3, respectively. These acceptable zones show regions on the compaction planes within which compaction can be performed on the lateritic soils to yield hydraulic conductivities less than or equal to 1 x 10^{-7} cm/s. However, in construction practice compaction is expected to be carried out either at optimum moisture content or at any point between optimum moisture content and 2 to 6 % points on the wet side of optimum.

Considering Figs 10, 11 and 12, the bounds of the acceptable zones include the following water content rages; 13.40 - 22.25% for soil LS1; 10.37 (or 12%) ï 23.0% for soil LS 2; and 11.0 (or 12.50%) ï 21.50% for soil LS3. From these figures, it could be concluded that these lateritic soils and other fine-grained lateritic soils having similar characteristics can be used as hydraulic barriers for waste stabilization ponds.

In order to make the results of these tests to be relevant to fine-grained lateritic soils from other locations, a regression model which relates hydraulic conductivity to soil composition and compaction variables was developed. The resulting equation is

$$\ln k = -27.075 - 0.232w - 1.234\gamma_d + 2.232PI - 5.044GM + 0.111EI \qquad (5)$$

where k is hydraulic conductivity in cm/s; w is moulding water content in percentage; γ_d is dry unit weight in kN/m^3; PI is the plasticity index; GM is the grading modulus and EI is compactive efforts index. The PIs are averages of three measurements. EI is an integer categorical value; the values -3, -1 +1 and +3 were assigned to BS heavy, West African Standard, BS light and reduced BS light efforts, respectively. The values of t-statistic for the independent variables were obtained as follows: w = -13.259; γ_d = - 11.808; PI = 4.626; GM = -3.904 and EI = 2.57. These values were found to be significant at 5% level. The value of the coefficient of multiple determination (R^2) was obtained, as 0.8354 while the adjusted R^2 is 0.8249. The overall F value is 79.198 and the standard error of estimate of lnk is 0.7006.

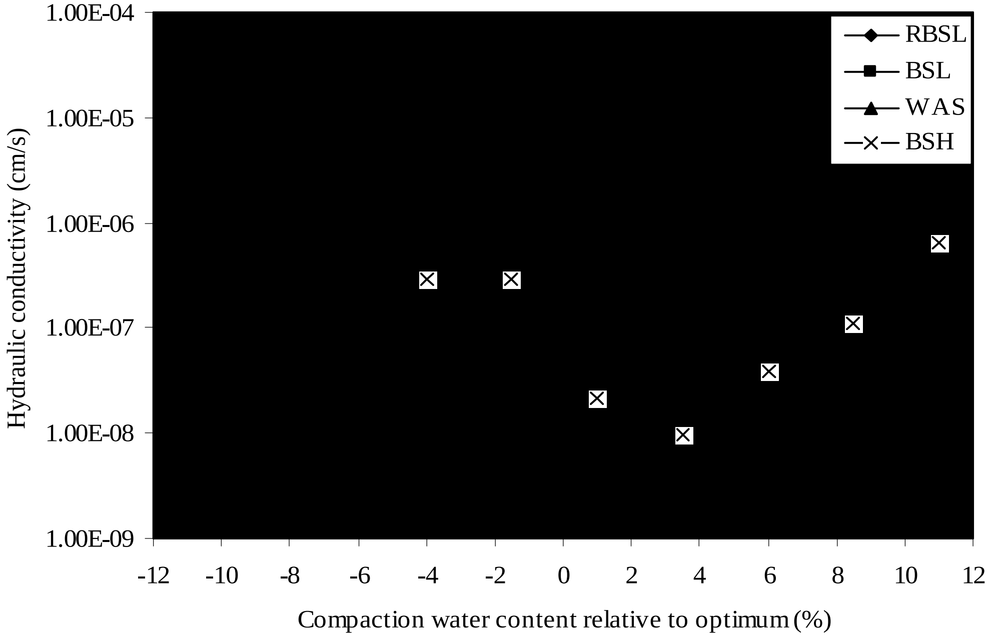


Fig. 4 Hydraulic conductivity versus compaction water content relative to optimum (LS1)

Equation (5) shows that hydraulic conductivity is mostly affected by moulding water content followed by dry unit weight. The least effect is due to the compactive efforts. The values of R^2 and overall F-statistic suggest that reliable predictions of hydraulic conductivity can be made for fine-grained lateritic soils, especially those with plasticity indices ranging from 14.0 to 20.0%, using Eq (5). Once the compaction curves are established for such fine-grained lateritic soils their acceptable zones can be constructed based on hydraulic conductivity only, while preliminary estimates of hydraulic conductivity can be made using eq. (5), laboratory tests on candidate soils is advocated.

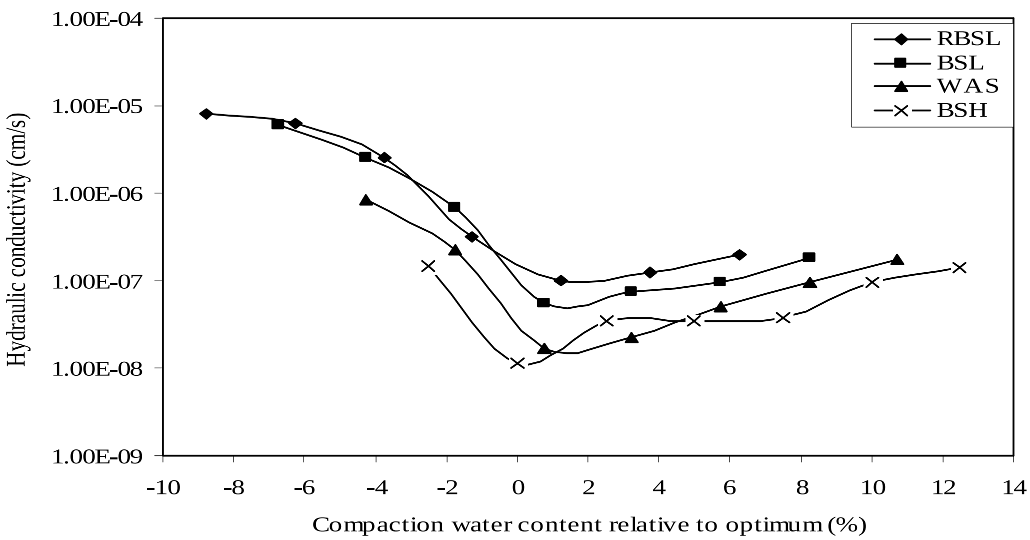


Fig. 5 Hydraulic conductivity versus compaction water content relative to optimum (LS2)

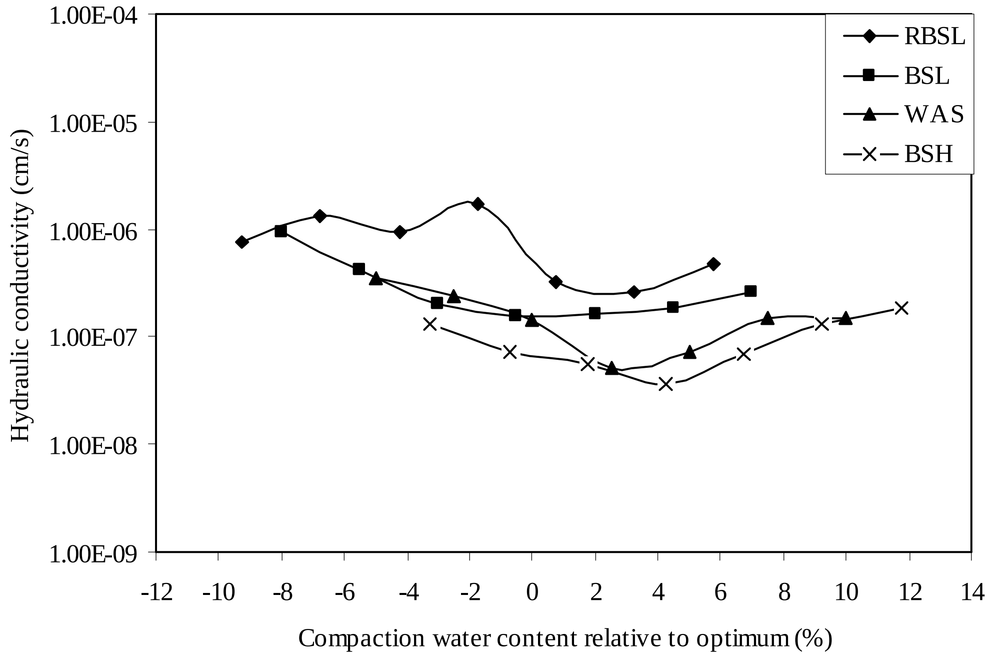


Fig. 6 Hydraulic conductivity versus compaction water content relative to optimum (LS3)

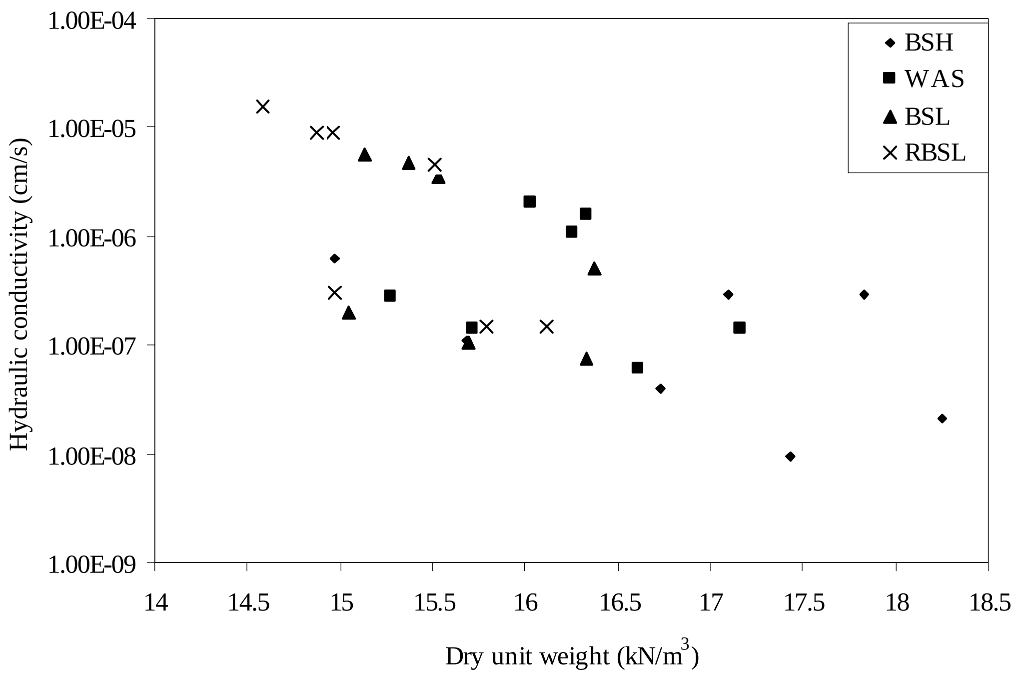


Fig. 7 Hydraulic conductivity versus dry unit weight (LS1)

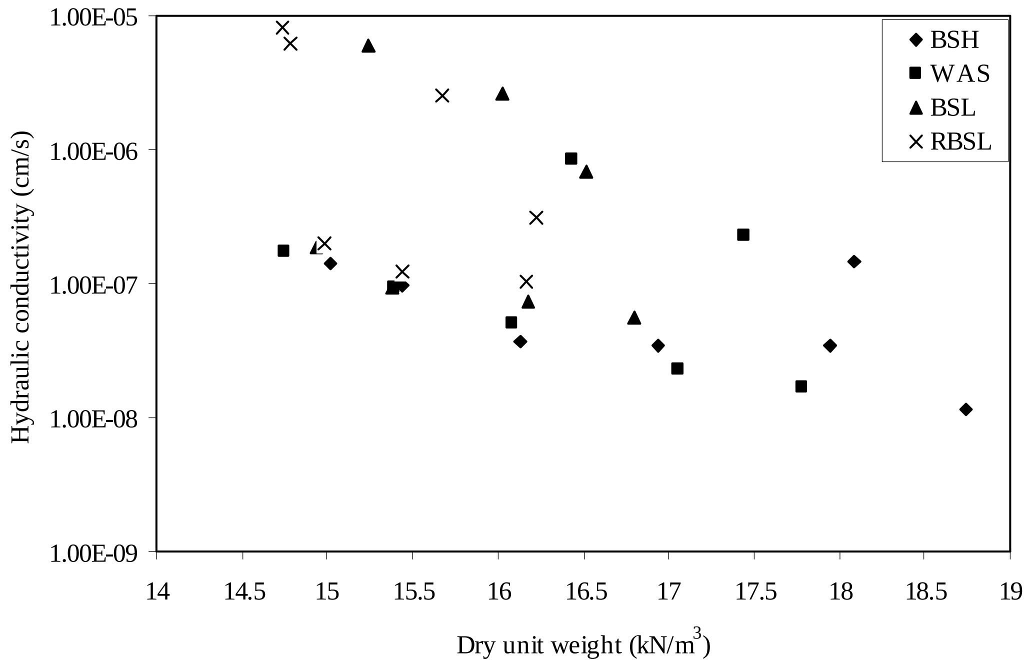


Fig. 8 Hydraulic conductivity versus dry unit weight (LS2)

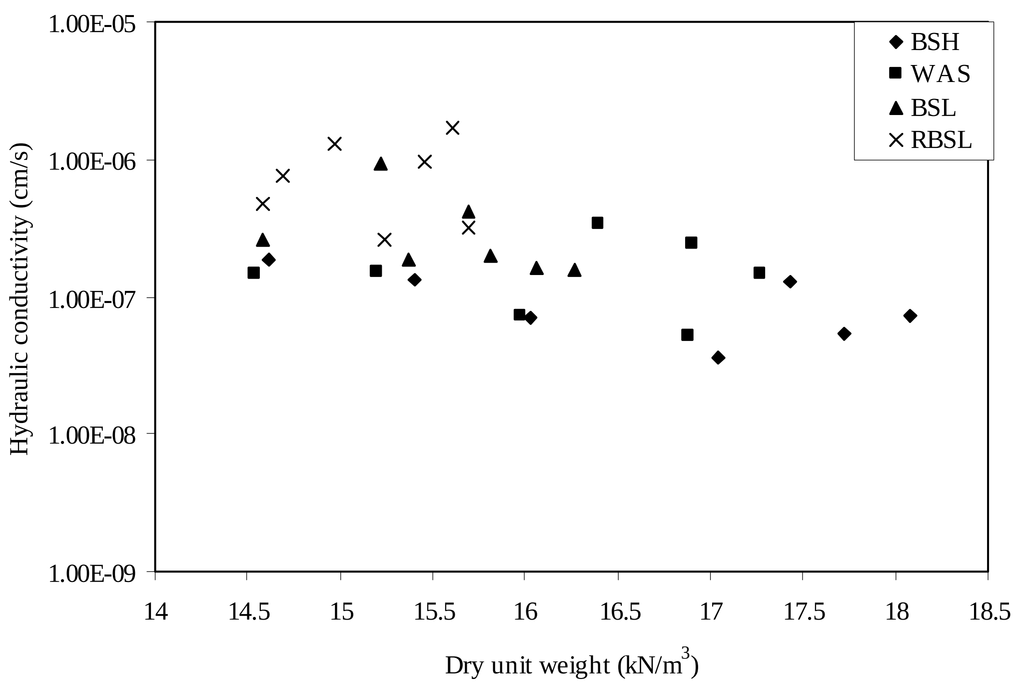


Fig. 9 Hydraulic conductivity versus dry unit weight (LS3)

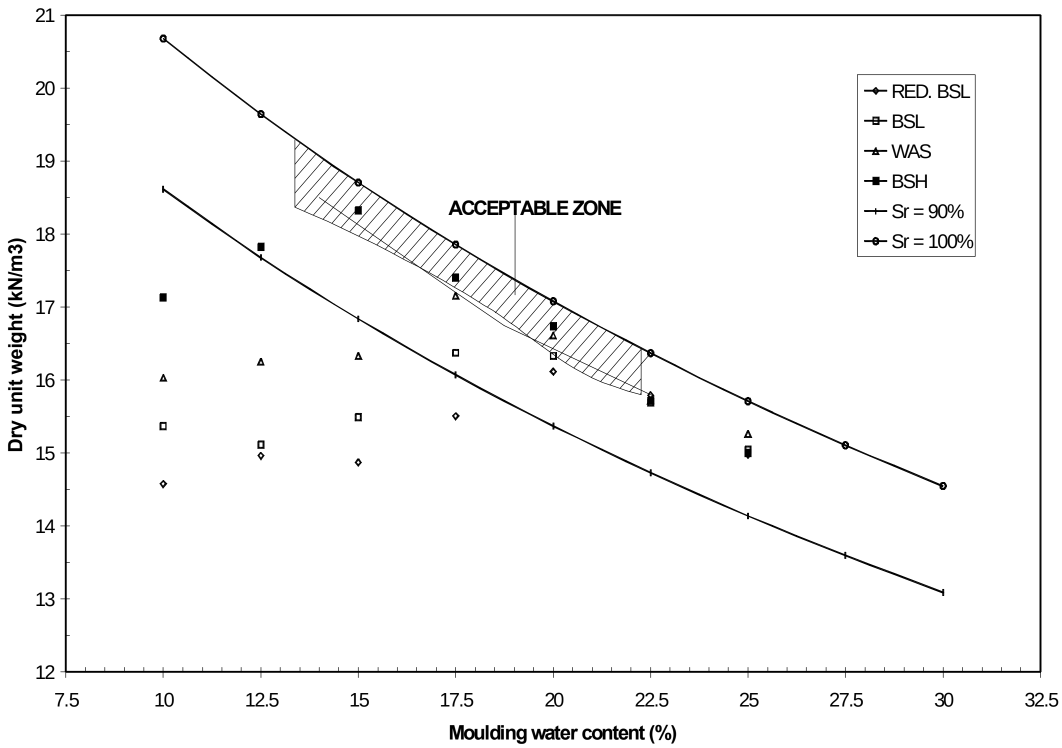
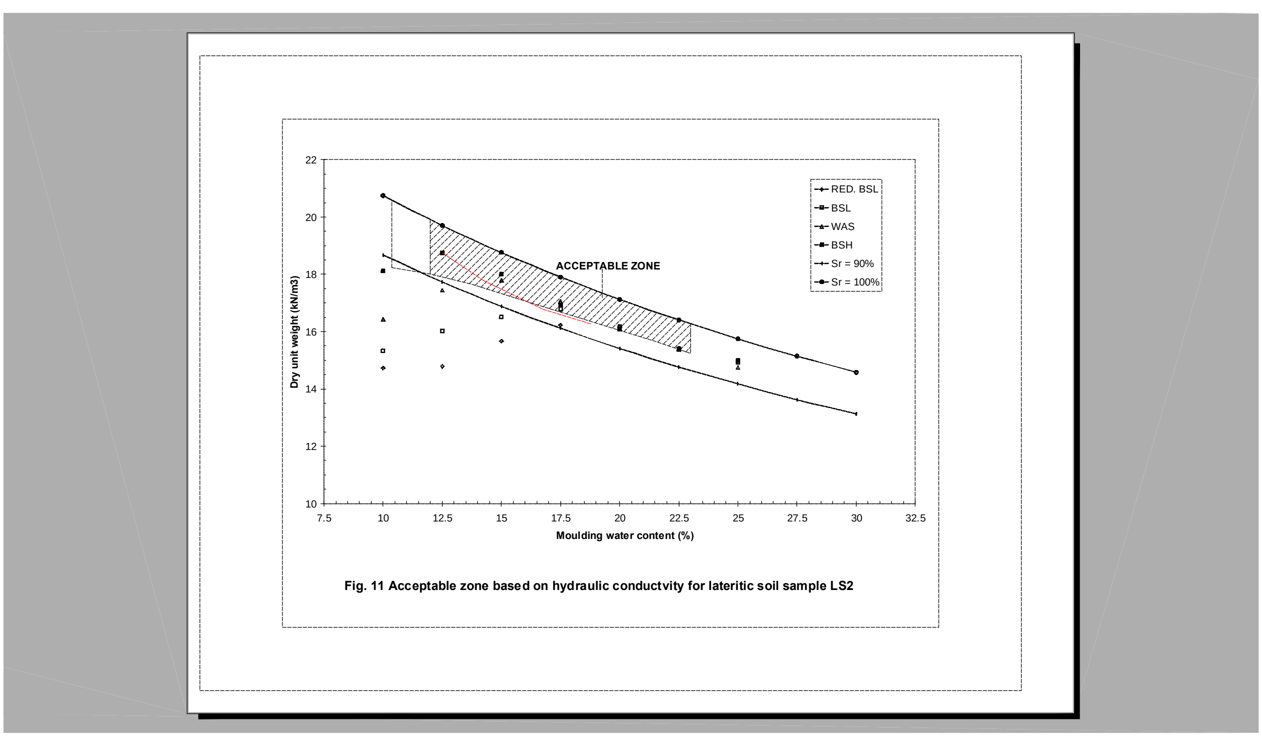


Fig. 10 Acceptable zone based on hydraulic conductvity for soil sample LS1



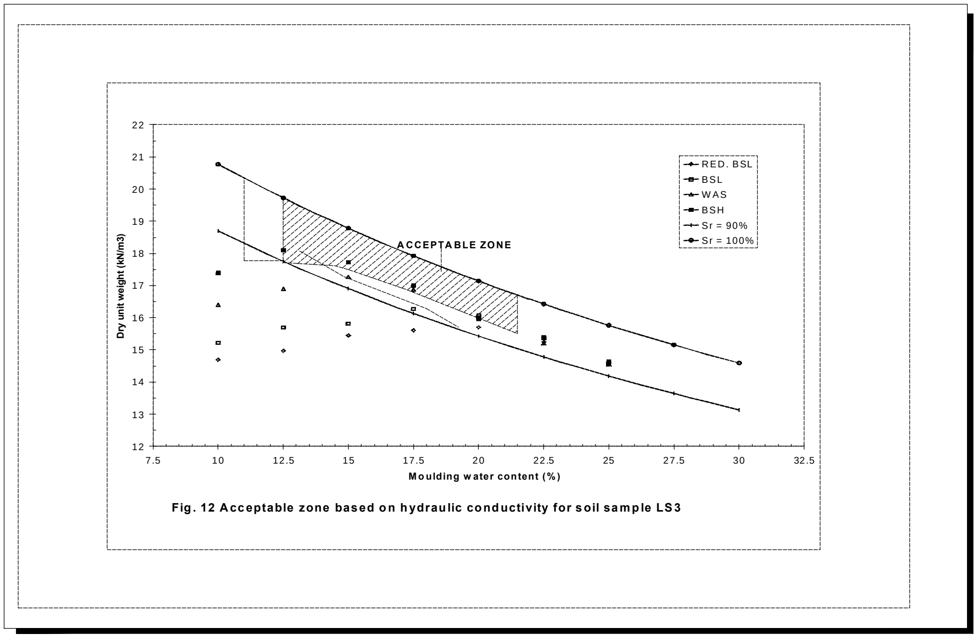


Fig. 12 Acceptable zone based on hydraulic conductivity for soil sample LS3

4. CONCLUSIONS

Suitability assessment of lateritic soils for use as hydraulic barriers in abattoir effluent containment has been performed. Both qualitative and quantitative (experimental) assessments have been made. The two forms of assessment indicate that fine-grained lateritic soils can be used as compacted liners to waste stabilization ponds for the containment of abattoir effluent. In order to ensure proper establishment of a quality assurance that will enable compliance with standard regulations to be made, the acceptable zones on compaction planes were delineated for the three soil samples used. A regression model that was developed could be used for the preliminary estimation of hydraulic conductivity of candidate lateritic soils.

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PROPERTIES OF CEMENT-TREATED SANDY SOILS APPROPRIATE FOR USE IN EARTH DAM CONSTRUCTION

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ABSTRACT

Laboratory investigations of the properties of soil and cement mixtures involving four sandy soils (one granular, A-3, and three fine-grained, A-4, soils) have been carried out. Addition of ordinary Portland cement caused appreciable changes in plasticity, compaction and permeability characteristics of the soils. The results show that the higher dry densities (generally ranging between 1.79 and 2.18 Mg/m^3) and low permeabilities usually required for materials to be used in stabilized earth dam construction were obtained at cement contents of between 2.5 and 10.0%. In general, it was possible to achieve permeabilities less than 1×10^{-6} cm/s at these treatment levels. Statistical analysis, involving two-way analysis of variance at 5% level of significance, showed that the optimum moisture contents and permeability coefficients did not generally respond significantly to variations in compaction energy and cement content but maximum dry density did.

KEYWORDS: Cement-treated soils, dry density, permeability, stabilized-earth dam construction, statistical analysis.

1. INTRODUCTION

Cement stabilized soils have traditionally been used in paving applications. In such cases compressive strength and durability properties, usually reflected by wet-dry and freeze-thaw (for cold regions) behaviour are of primary concern. However, new design approaches require information on tensile and flexural strength, elastic properties, and fatigue behaviour (Mitchell, 1976). On the other hand, the use of cement-treated soils as material for slope protection for earth dams and other hydraulic structures has gained wide acceptance (Holtz and Hansen, 1976) while interest has developed in the use of cement-treated materials for earth dam embankment construction (Raphael, 1976; Mitchell, 1976). This interest is predicated upon the relative advantages including cost of the use of cement-treated soils over natural soil in earth dam construction particularly in the tropical environment.

Cement-stabilized soils can serve as alternative materials for the rapid construction of varying sizes of earth dams using earthmoving machinery. According to Robertson *et al*. (1987) earth dam construction using stabilized soils has the following advantages: (i) reduction in embankment volume of up to 80% giving rise to considerable savings in project cost and construction time compared to conventional embankment dams (ii) resistance to erosion, permitting construction of integral spillways together with a reduced risk of damage due to over-topping during construction and (iii) economical stabilization of dispersive or shrinkable soils to give greatly improved material properties. It is desirable to employ well graded soils with plasticity index of less than 10 and containing less than 10% clay fraction for the production of soil-cements or cement-treated soils although in some cases soils with values above these limits have been successfully utilized (Robertson *et al*., 1987). In order to minimize cement requirement well graded silty sand or sandy gravel soil are preferred for soil- cement production. The presence of some fine fraction is needed in soils in order to achieve high densities and low permeabilities.

Material properties of great relevance in stabilized earth dam construction include high strength and durability, high density, high erosion resistance and low permeability. Compaction characteristics of cement-treated soils are usually established first in the laboratory to enhance field compaction control. While strength, durability, and erodibiltiy properties have been studied by many researchers (e.g. Abboud, 1973), the permeability characteristics of these cement treated soils received very little research attention.

The objectives of this paper were to determine how compaction energy and cement content affect the compaction and permeability characteristics of cement-treated soils and to check the suitability of the materials for earth dam construction.

2. MATERIALS AND METHODS

2.1 Materials Used

Four different soils, a reddish brown granular soil (designated as soil A) and three fine-grained low plasticity soils (a whitish soil designated as soil B, a reddish brown soil designated as soil C and a very light brown soil designated as soil D) were used in this study. Soils A, B and C were collected from burrow pits along Maiduguri ï Biu Road, on the outskirts of Maiduguri (Latitude 11^{0}49ôN and Longitude 13^{0}09ôE) and at depth of between 1.2 and 1.7m. Soil D was collected at a depth of about 2.5m from a burrow pit located within the University of Maiduguri. These soils are sediments of the Quaternary Chad Formation. Ordinary Portland cement was used as the stabilizing agent for the granular as well as the three fine-grained soils. Cement-stabilized soil specimens were subjected to laboratory testing. Distilled water was utilized in these laboratory tests. Distilled water is commonly employed in geotechnical testing in order to avoid any possible ion exchange which could alter the soil properties. However, in the case of sandy soils used, it is unlikely that any ion exchange resulting from the use of clean (or tap) water would produce appreciable soil property changes.

2.2 Methods of Testing and Analysis

The physico-chemical properties of the soils were determined using standard laboratory procedures described in Page *et al*. (1982) for determining chemical properties of soils. The free swell was determined by the procedure suggested by Holtz and Gibbs (1956). Index properties of the natural soils were determined in accordance with specifications in BS 1377 (1990) and Head (1992).

Compaction and permeability tests were carried out on specimens of untreated and cement-treated soils in accordance with specifications in BS 1377 (1990) and Head (1992, 1994). The BS light (BSL) and BS heavy (BSH) compaction procedures were used. In addition, the West African Standard (WAS) compaction procedure (Ola, 1980; Ogunsanwo, 1989; Osinubi, 1998) was also employed to give an intermediate compactive effort. The compactive effort of the West African Standard consists of the energy derived from a 4.5 kg rammer falling through 45 cm unto five layers of soil in a BS or Proctor mould, each receiving 10 blows. The BSL and BSH are the British Standard Institution (BSI) equivalents of the Standard Proctor and Modified Proctor compaction procedures. Specimens for the permeability tests were prepared at or near their respective optimum moisture contents, which were earlier, determined from the various compaction tests. The falling head permeability test method was employed. Air-dried soil specimens were first intimately mixed with appropriate percentages of cement prior to hydration with water and subsequent compaction testing. Dry mixing of soil specimens and cement was to ensure a uniform distribution of cement particles within the soil specimen. Separate soil specimens were mixed, in turn, with the target percentages of cement. Percentages of cement used in cement treatment ranged between 2.5 and 12.5% by weight of dry soil, at increments of 2.5%.

Graphical and statistical methods were used to analyze the results obtained in the study. Graphical plots were used to show the variation of measured parameters with cement content. Graphical methods were used to compare properties of cement-treated and untreated soil specimens. For instance, maximum dry densities obtained for untreated soils were, in turn, used to divide the corresponding values for cement-treated soils. Statistical analysis involved the use of two-way analysis of variance (ANOVA) at 5% level of significance. The spreadsheet QUATTRO PRO version 8 was employed for this purpose.

3. RESULTS AND DISCUSSION

3.1 Properties of the Untreated Soils

3.1.1 Physico-chemical Properties

The physio-chemical as well as index properties of the natural soils are shown in Table 1.

The pH values of the soils ranged between 5.37 and 10.66. Soils A and D with pH values less than 7.0 are slightly acidic while soils B and C with pH values greater than 7.0 are relatively alkaline. The values of loss on ignition ranged between 0.33% and 1.03% and indicate that the soils have low organic carbon content. Electrical conductivity values are low (varying from 0.05 to 0.53 εS/cm) indicating low salt contents and would not add significant amount to the salts that would be produced during hydration of cement (see Neville, 1981). The low free swell percentages (0.0 ï 2.5) suggest the complete absence of swelling minerals and the presence of non-swelling clay minerals especially those of the kaolinite group. The low values of the physcio ï chemical parameters make these soils suitable for cement treatment.

Table 1 Physico-chemical and index properties of the sandy soils

Property	Quantity			
	Soil A	Soil B	Soil C	Soil D
Loss on ignition, %	0.33	1.03	1.01	0.38
pH	5.7	10.66	9.45	5.37
Electrical conductivity, εS/cm	0.006	0.42	0.53	0.05
Free swell, %	1.0	2.0	2.5	0.0
Specific gravity	2.67	2.60	2.50	2.49
Sand, %	73.70	53.70	51.65	43.70
Silt, %	5.00	31.30	28.92	21.30
Clay, %	21.30	15.00	19.43	35.00
Liquid limit, %	-	18.15	22.30	11.00
Plastic limit, %	-	17.87	20.87	4.07
Plasticity index, %	NP	0.28	1.33	6.93
Linear shrinkage, %	0.70	2.50	3.60	0.41
AASHTO classification	A-3	A-4	A-4	A-4

NP-non-plastic

3.1.2 Index Properties

The sand content of the soils are relatively very high, ranging between 43.7 and 73.7% while the clay percents vary from 15.0 to 35.0%. Soil A has the highest sand content as well as the highest specific gravity. The specific gravity values decreased as sand content decreased (Table 1). Soil A is a non-plastic soil and can be classified as an A ï 3 soil while soils B, C and D are classified as A-4 soils based on AASHTO (American Association of State Highway and Transportation Officials) classification system. However, on the basis of the USDA (United States Department of Agriculture) classification system, soil A is a sandy clay loam, soil B is a sandy loam, soil C is loam while soil D is a clay loam (Das, 1998). The particle size distribution curves for these soils are shown in Fig 1. These curves show that the soils are well-graded sandy soils.

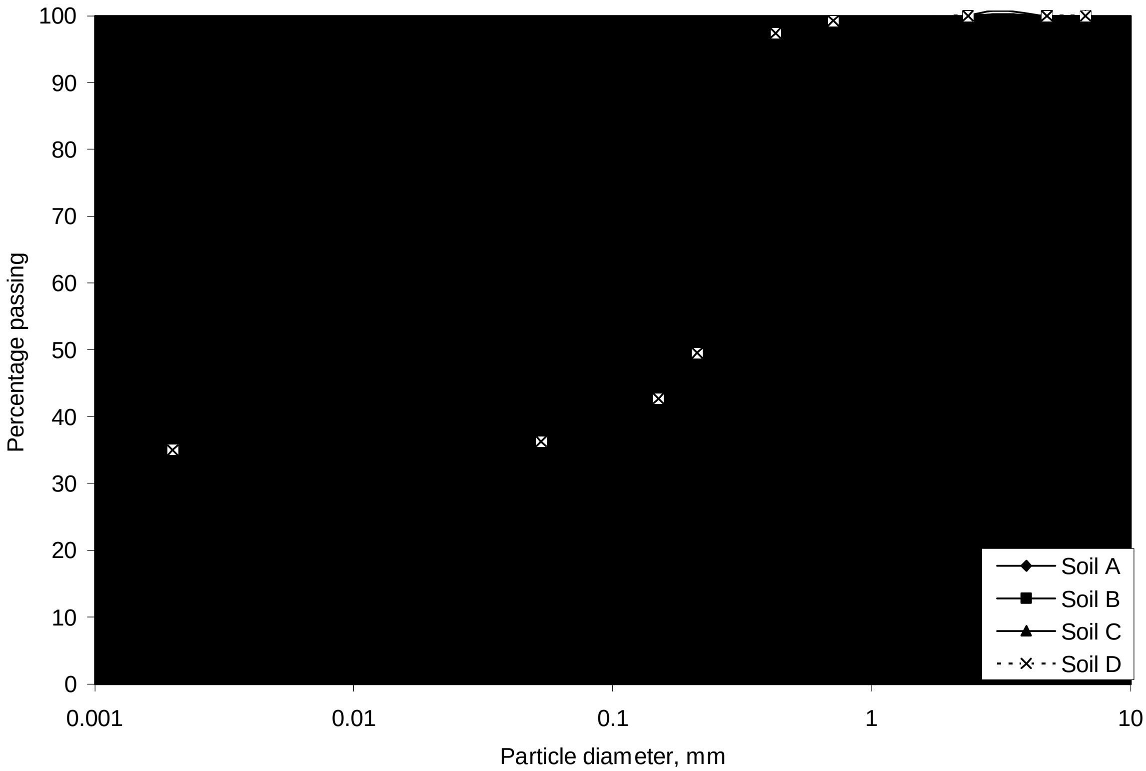

Fig. 1 Particle size distribution of the soils.

3.1.3 Compaction and Permeability Characteristics

The maximum dry densities (MDDs), optimum moisture contents (OMCs) as well as the coefficients of permeability (k) of these soils at the various compaction energies used are shown in Table 2. The MDD values ranged between 1.59 and 1.94 Mg/m^3 and generally increased with increasing compaction energy. Soil D gave the lowest values of MDD at each compactive effort considered. Optimum moisture content values are generally low and range between 8.4 and 14.0% which are typical for non-swelling semi-arid zone soils. The values of the coefficient of permeability generally fell in the range of 7.33 x 10^{-7} cm/s to 1.364 x10^{-6} cm/s indicating that the soils can be compacted for use in the construction of the imperious sections of earth dams and dikes (Holtz and Kovacs, 1981).

Table 2 Compaction and permeability characteristics of the untreated sandy soils

Property	Quantity			
	Soil A	Soil B	Soil C	Soil D
BSL compaction				
MDD, Mg/m^3	1.81	1.705	1.83	1.59
OMC, %	11.00	10.80	14.00	12.80
k, cm/s	$1.056x10^{-6}$	$7.33x10^{-7}$	$1.15x10^{-6}$*	$9.95x10^{-7}$
WAS compaction				
MDD, Mg/m^3	1.925	1.85	1.88	1.755
OMC, %	8.40	10.60	10.80	12.00
k, cm/s	$1.209x10^{-6}$	$8.83x10^{-7}$	$1.482x10^{-6}$	$9.57x10^{-7}$
BSH compaction				
MDD, Mg/m^3	1.91	1.94	1.88	1.86
OMC, %	10.40	8.6	10.80	10.00
k, cm/s	$9.67x10^{-7}$	$1.364x10^{-6}$	$1.037x10^{-6}$	$1.24x10^{-6}$

MDD-maximum dry density; OMC-optimum moisture content; k-coefficient of permeability; *arithmetic mean value

3.2 Properties of Cement-treated Soils

3.2.1 Plasticity Characteristics

The addition of cement to the low plasticity soils induced some changes in their plasticity characteristics. For soil A that is non-plastic as well as for soils B, C and D, the linear shrinkage values decreased as cement content increased (Table 3). The liquid and plastic limits of each of the soils B, C, and D increased non-uniformly as a result of the addition of cement. The plasticity indices of soils B, C and D also changed as a result of the addition of cement but no general trend could be identified (Table 3). However, all the plasticity index values were less than 10. This is desirable for soil-cement mixtures to be used for earth dam construction (see Robertson *et al*., 1987).

Table 3 Plasticity characteristics of the cement-treated sandy soils

Property	Cement content, %	Quantity			
		Soil A	Soil B	Soil C	Soil D
Liquid limit, %	0.0	-	18.15	22.30	11.00
	2.5	-	24.14	23.40	12.00
	5.0	-	22.90	27.40	16.38
	7.5	-	22.12	28.00	16.00
	10.0	-	22.52	26.40	15.50
	12.5	-	26.00	26.53	14.50
Plastic limit, %	0.0	0.0	17.87	20.87	4.07
	2.5	0.0	19.41	20.82	8.22
	5.0	0.0	21.61	25.15	10.56
	7.5	0.0	20.76	24.33	9.90
	10.0	0.0	19.87	25.81	11.60
	12.5	0.0	16.04	23.27	12.39
Plasticity index, %	0.0	NP	0.28	1.33	6.93
	2.5	NP	4.99	2.56	3.75
	5.0	NP	1.29	2.25	5.82
	7.5	NP	1.36	3.67	6.10

	10.0	NP	3.05	0.59	3.84
	12.5	NP	3.96	3.26	2.11
Linear shrinkage, %	0.0	0.71	2.50	3.60	0.41
	2.5	0.36	1.40	2.90	0.41
	5.0	0.14	1.40	1.80	0.21
	7.5	0.14	0.71	1.40	0.21
	10.0	0.14	0.71	1.10	0.07
	12.5	0.07	0.36	0.71	0.07

NP-non-plastic

Soil-cement or cement-treated soils are divided into two groups; granular and fine ï grained. The granular soil-cements are made using the coarse-grained cohesionless soil types, that is, A-1, A-2 and A-3 soils according to the ASSHTO classification while fine grained soil-cements are made using cohesive soils, that is, AASHTO class, A-4, A-5, A-6 and A-7 soils (Mitchell, 1976). Specimens of soil A treated with cement are granular cement-treated soils. Others are fine-grained cement-treated soils.

3.2.2 Compaction Characteristics

The addition of cement to soil generally causes some changes in both the optimum water content and maximum dry density for a given compactive effort (Mitchell, 1976). The response of maximum dry density of the soils to addition of cement are depicted in Figs 2, 3 and 4 for compaction energies of BSL, WAS and BSH, respectively. It can be seen that the addition of cement generally resulted in increase in the MDD values for each compactive effort used. Soil A generally had the highest MDD at 12.5% cement content at each of the compaction energies. The ranges of values of MDD for the percentages for cement contents utilized in this study are shown in Table 4. The highest MDDs were obtained at the BSH compactive effort, and are in the range of 2.15 to 2.18 Mg/m^3. In order to show the improvement in soil properties resulting from cement treatment, all MDD values at different cement contents were divided by the MDD obtained for untreated soils at each compactive effort (see Figs. 5 (a-c).

There is no general trend in the variation of optimum moisture content (OMC) with cement content for each of the compaction energies. However, some slight decreases in OMC values can be observed in Figs. 6, 7, and 8 for increases in cement content. The ranges of values of OMC are shown in Table 4.

Higher densities (>1.6 Mg/m^3) are required for materials to be used in stabilized earth dam construction. For a given cement content, the higher the density the higher the strength for granular soil and cement mixtures (Mitchell, 1976). As both water content at compaction and compaction methods are important for treated cohesive soils, compaction of soils at OMC will tend to yield desirable higher densities.

Table 4. Ranges of values of compaction and permeability characteristics

Parameter		Soil A	Soil B	Soil C	Soil D
BSL	MDD, Mg/m^3	1.81-2.14	1.705-2.01	1.83-2.05	1.59-1.91
	OMC, %	8.4-11	9.6-14.7	9.0-14.4	11.4-18.6
	k ($x10^{-6}$), cm/s	0.462-1.10	0.552-1.55	0.433-1.15	0.667-1.20
WAS	MDD, Mg/m^3	1.925-2.025	1.85-2.0	1.84-2.02	1.755-2.01
	OMC, %	7.8-10.2	9.6-13.2	9.6-14.4	7.2-12.0
	k ($x10^{-6}$), cm/s	0.5-1.50	0.445-1.55	0.521-1.48	0.749-1.38
BSH	MDD, Mg/m^3	1.91-2.15	1.94-2.15	1.88-2.18	1.86-2.16
	OMC, %	9.6-10.6	7.8-10.2	9.0-12.9	9.2-11.4
	k ($x10^{-6}$), cm/s	0.341-1.04	0.6-1.36	0.143-1.04	0.641-1.24

BSL-British Standard light compaction; WAS-West African Standard compaction; BSH-British Standard compaction; MDD-maximum dry density; OMC-optimum moisture content and k-coefficient of permeability

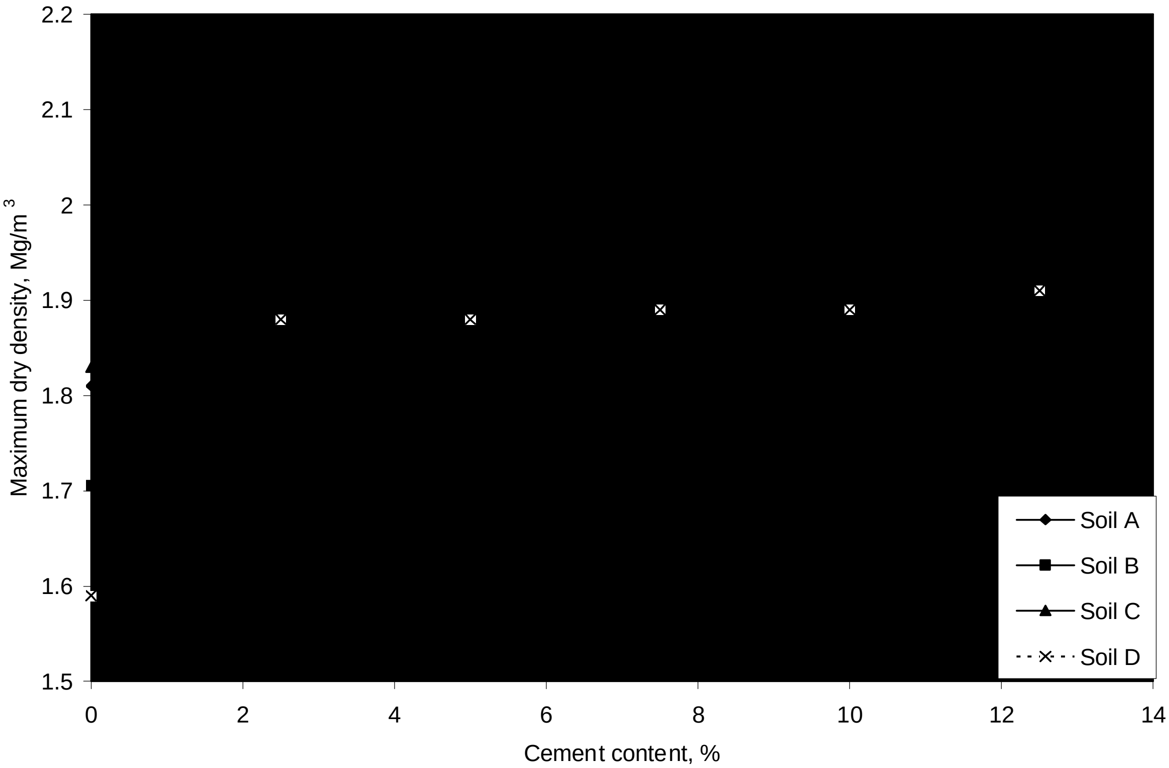

Fig. 2 Maximum dry density versus cement content at BS light compaction energy

3.2.3 Permeability Characteristics

The variation of permeability coefficients with cement treatment levels for both granular (A-3) and fine-grained (A-4) soils are shown in Figs. 9, 10 and 11. The ranges of values of permeability coefficient are shown in Table 4. In general, permeability is seen to decrease as cement content increases. As cement content increases beyond 2.5%, permeability values are generally lower than $1x10^{-6}$ cm/s. According to Mitchell (1976), fine-grained cement-treated soils can be anticipated to have very low permeabilities ($k<1x10^{-6}$ cm/s) at all treatment levels if they are properly compacted. For the fine-grained and granular soils, and in the absence of cracking, permeability decreased non-uniformly as cement content increased up to about 10% (see Figs. 9, 10, and 11). Such very low permeabilities are desired for stabilized soils to be used in earth dam construction.

It is possible to achieve low permeabilities ($<1x10^{-6}$ cm/s) at cement contents greater than 2.5% and less than or equal to 10.0%, with proper compaction control (see Figs. 9, 10, and 11). The ranges of values of MDD and OMC corresponding to these cement contents are 1.81- 2.0 Mg/m^3 and 8.4-14.4% for BSL compaction; 1.79-2.025 Mg/m^3 and 7.2-14.4% for WAS compaction; and 1.91-2.18 Mg/m^3 and 7.8-15.0% for BSH compaction, respectively. These dry densities are much higher than the lower value of 1.6 Mg/m^3 suggested by Mitchell (1976) for granular and fine-grained soils. At higher cement contents (>10.0%), much lower permeabilities can be obtained but this would be uneconomical.

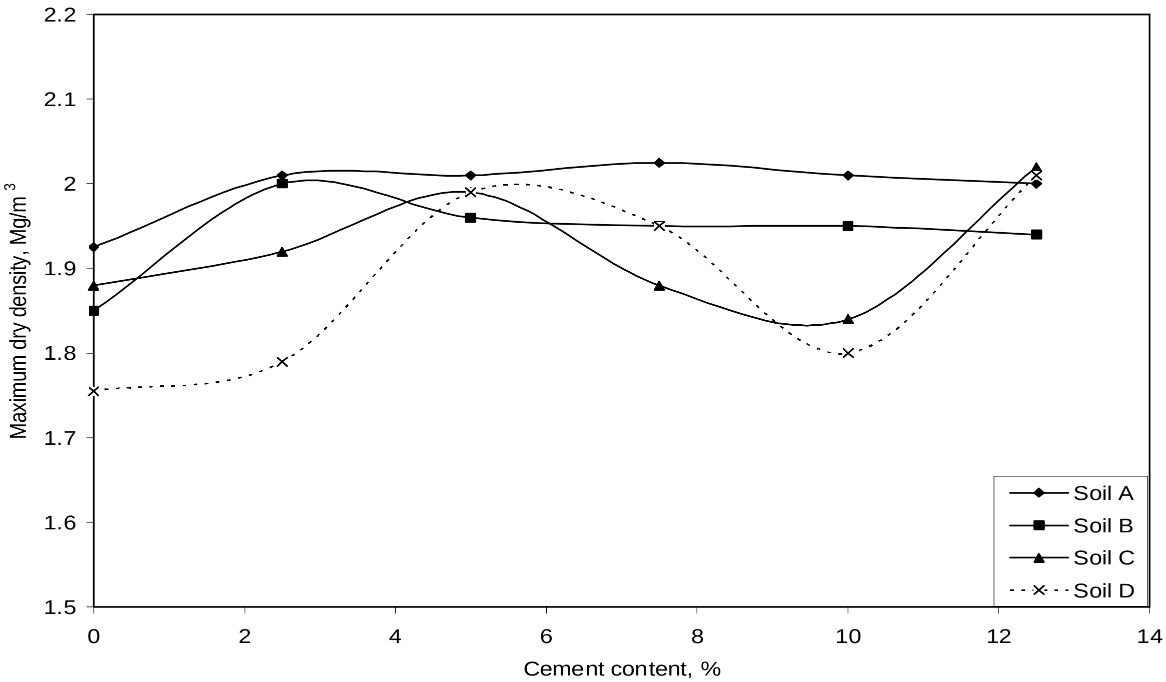

Fig. 3 Maximum dry density versus cement content at WAS compaction energy

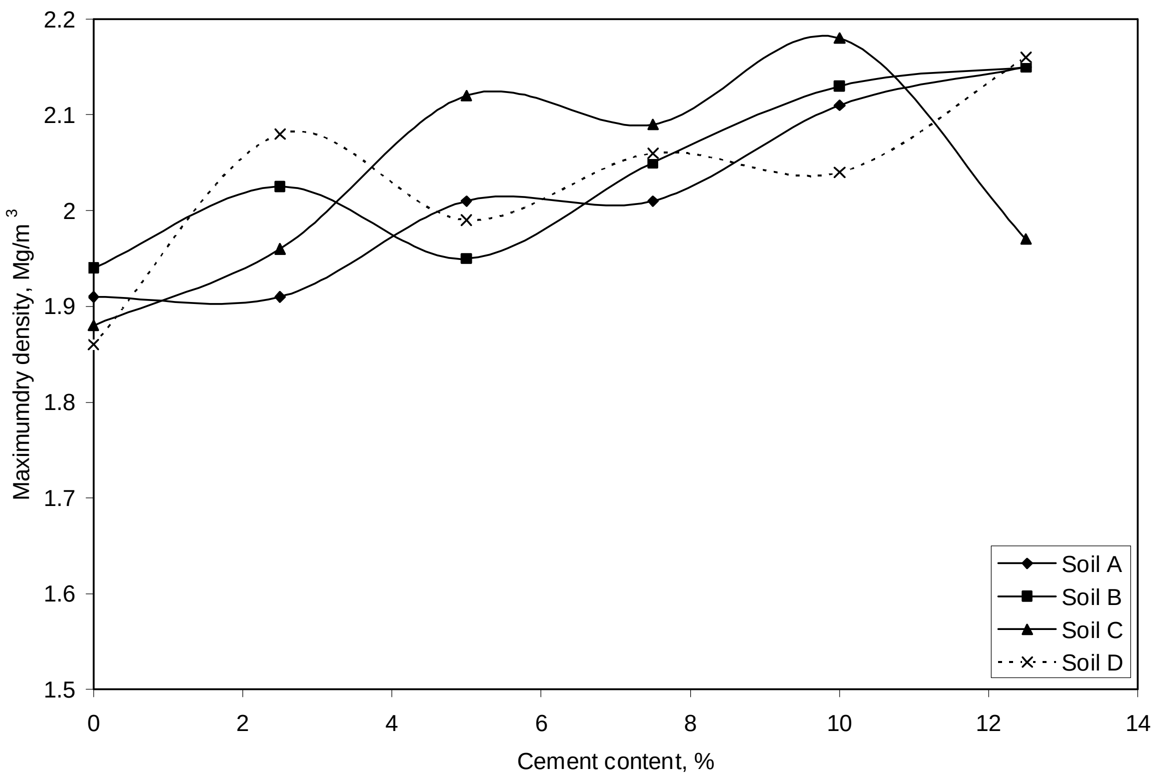

Fig. 4 Maximum dry density versus cement content at BS heavy compaction snergy

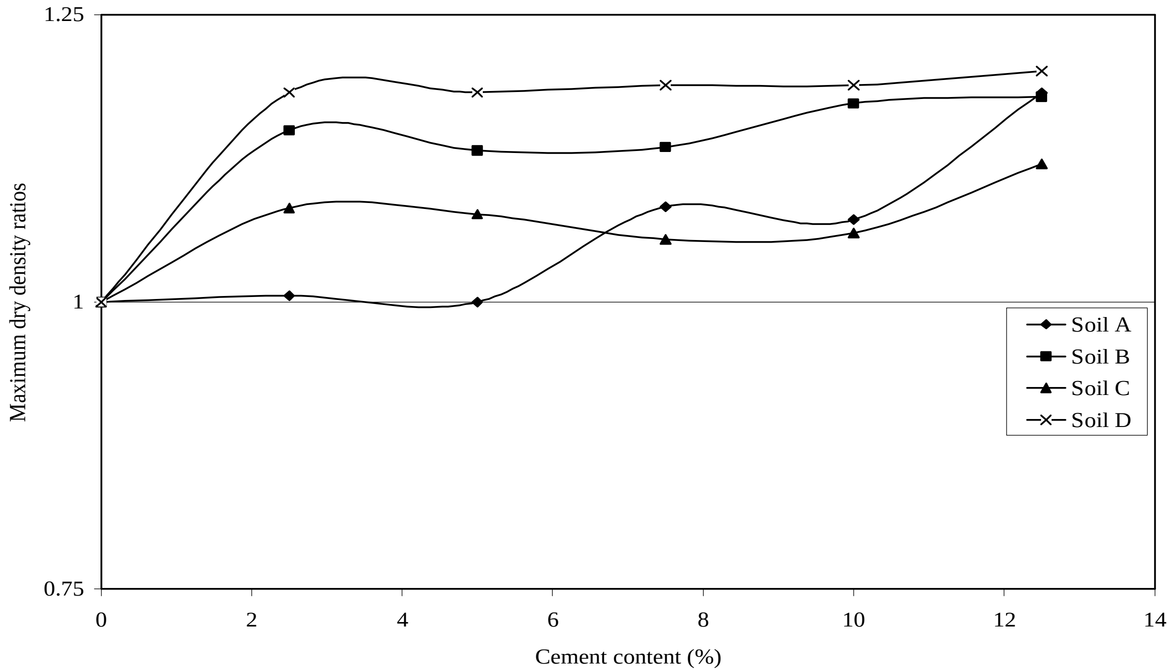

Fig. 5a Maximum dry density ratios versus cement content at British Standard Light compaction (BSL)

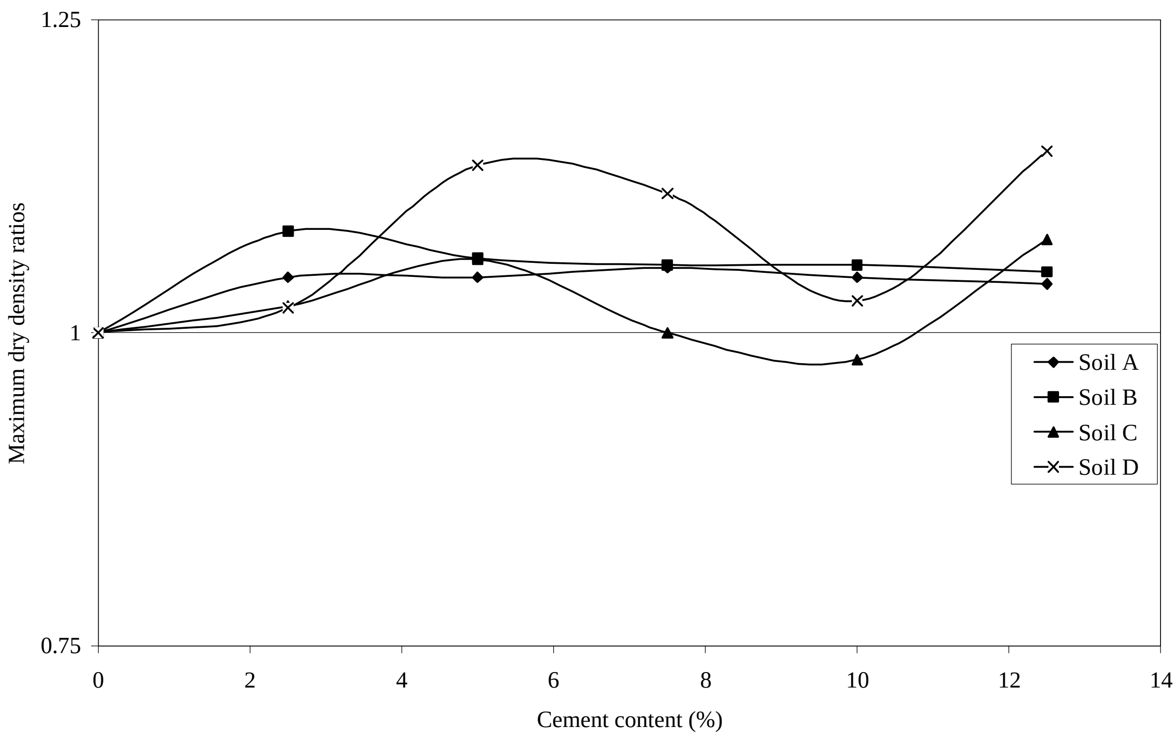

Fig. 5b Maximum dry density ratios versus cement content at West African Standard compaction (WAS)

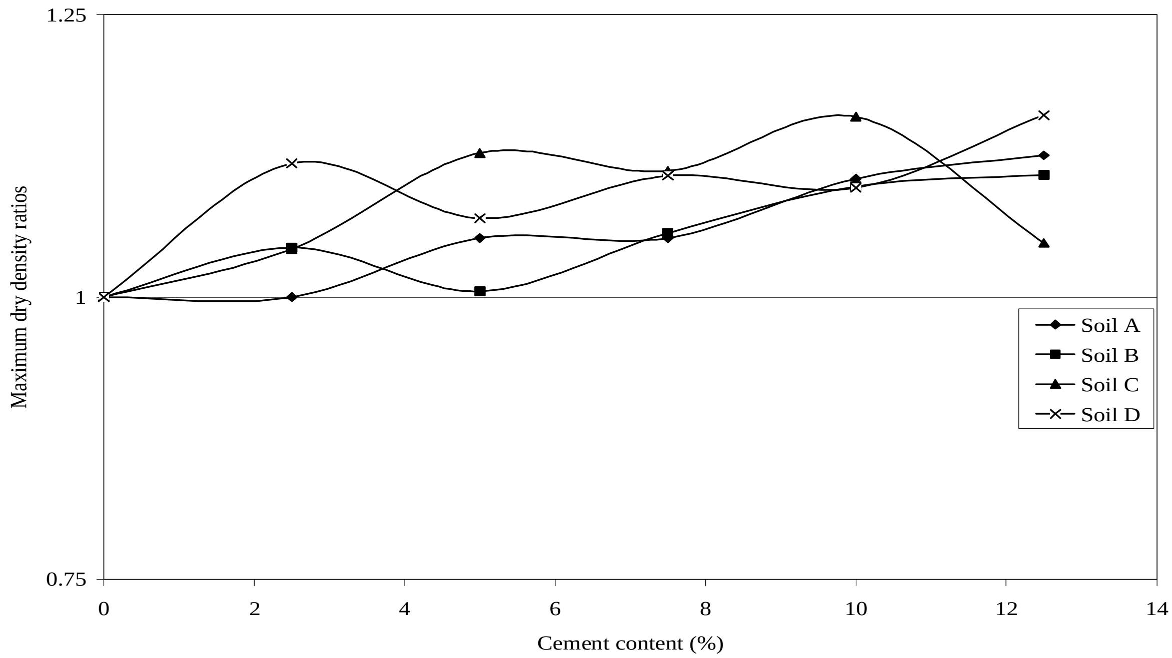

Fig. 5c Maximum dry density ratios versus cement at British Standard Heavy compaction (BSH)

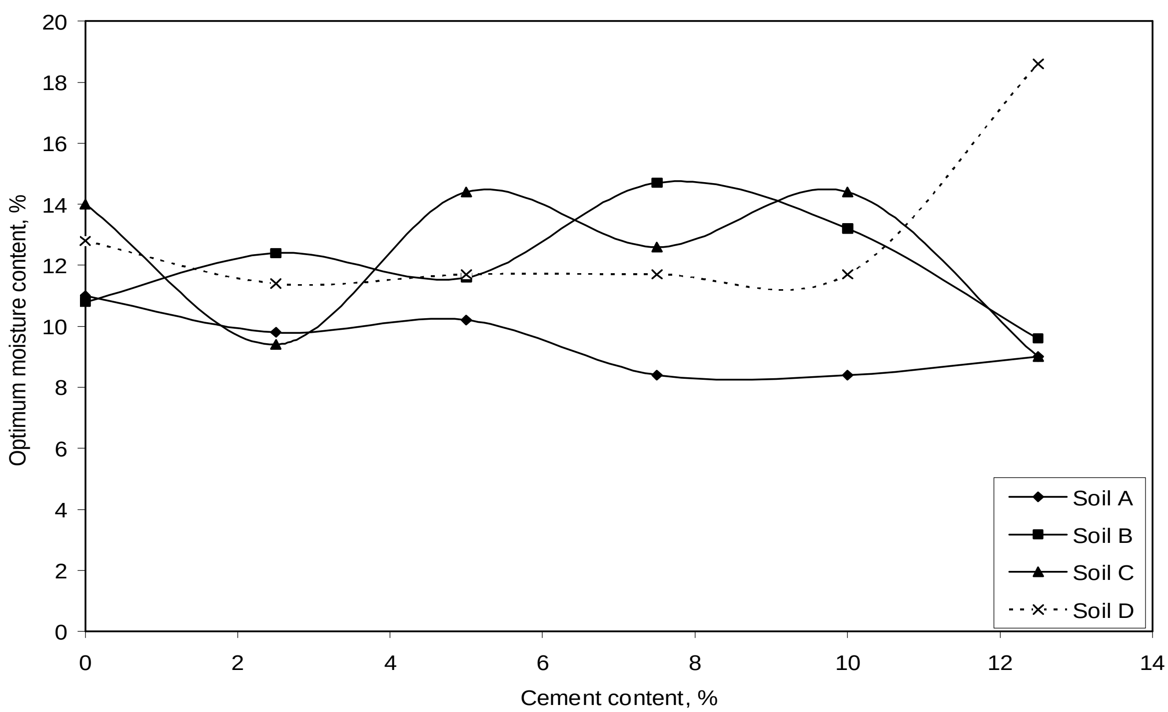

Fig. 6 Optimum moisture content versus cement content at BS light compaction energy

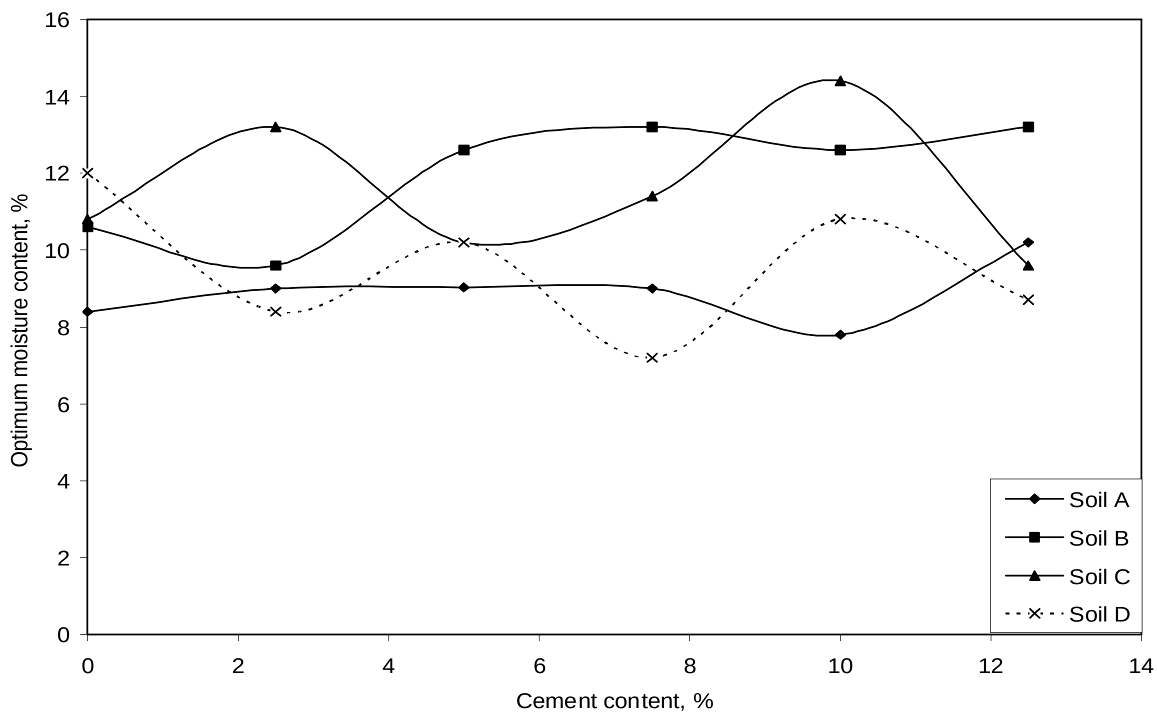

Fig. 7 Optimum moisture content versus cement content at WAS compaction energy

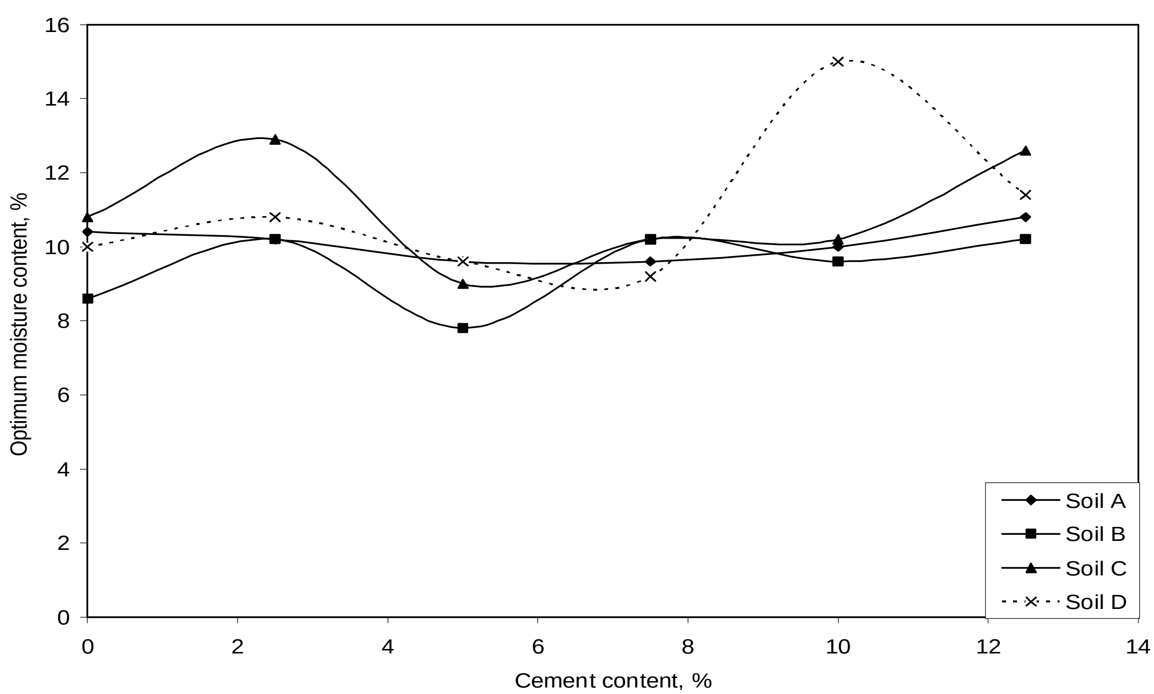

Fig. 8 Optimum moisture content versus cement content at BS heavy compaction energy

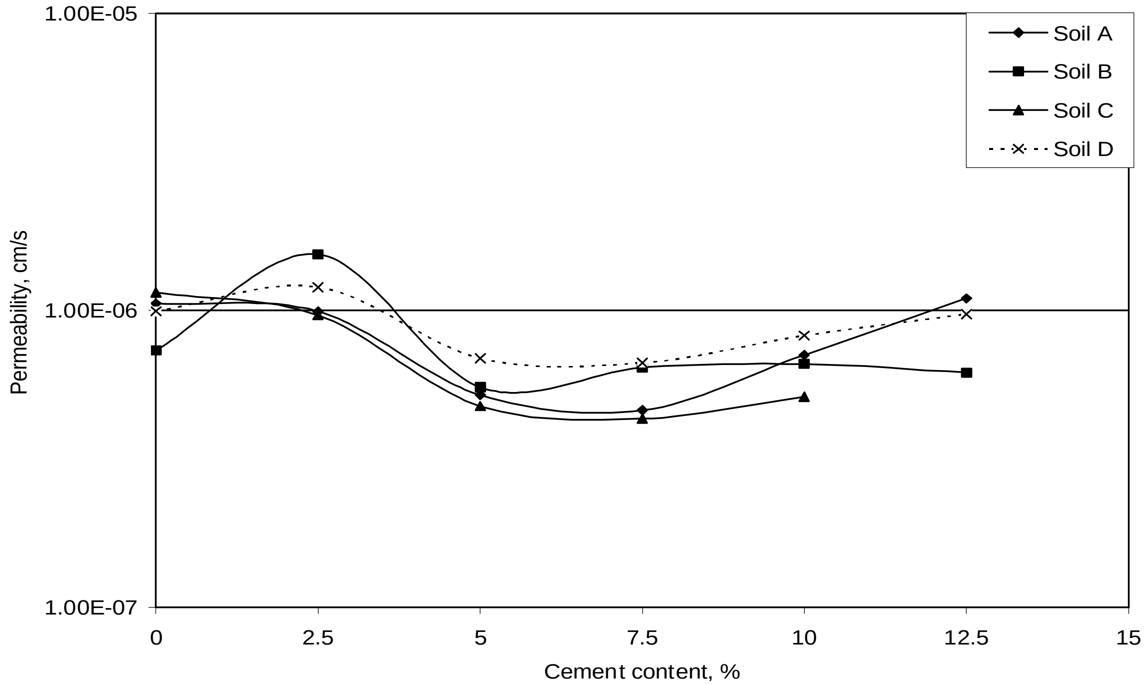

Fig. 9 Permeability versus cement content at BS light compaction energy

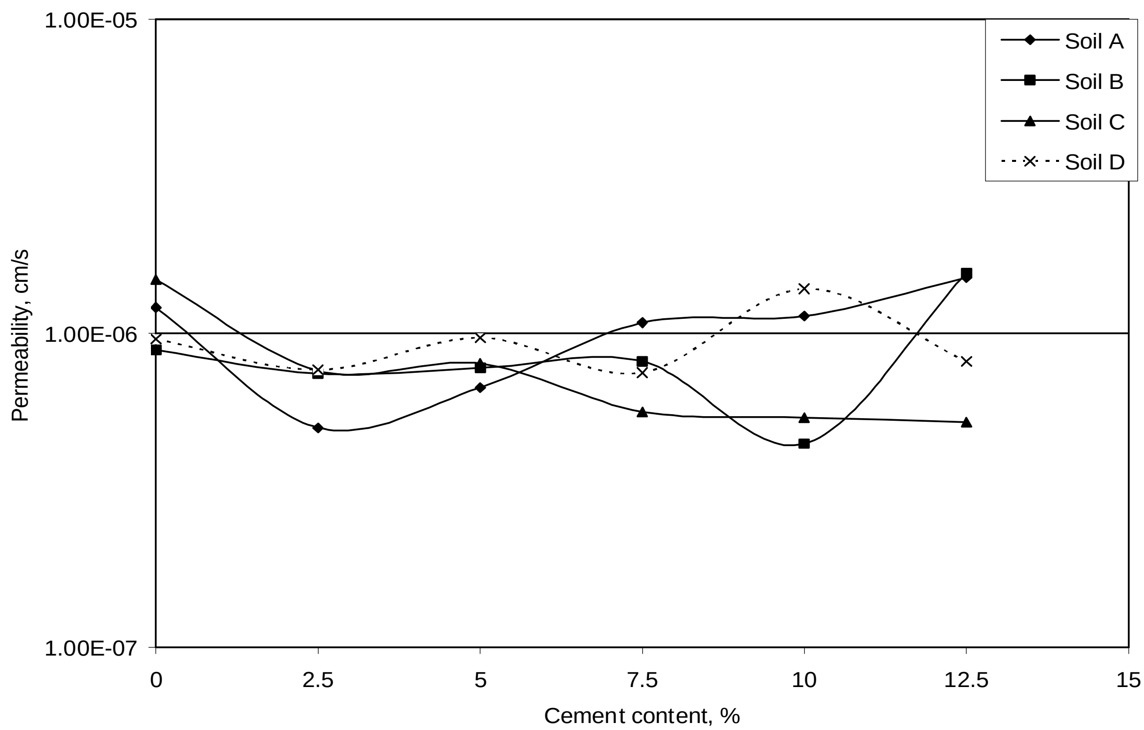

Fig. 10 Permeability versus cement content at WAS compaction energy

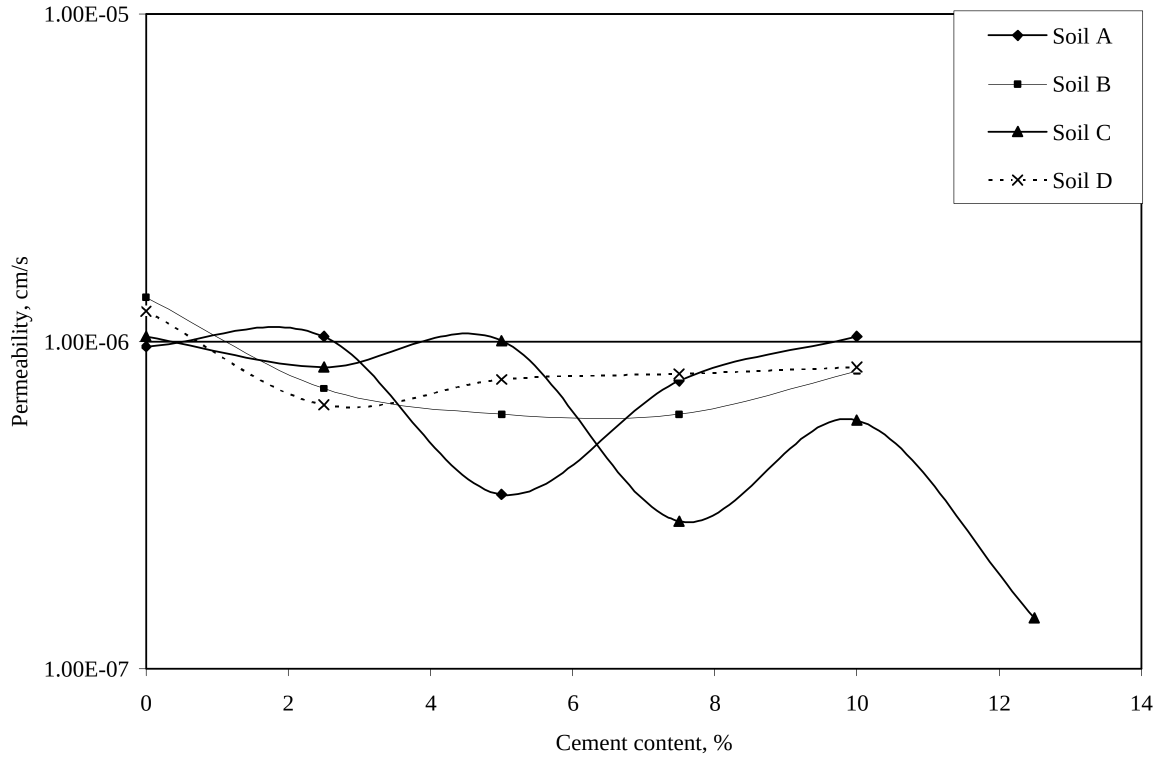

Fig. 11 Permeability versus cement content at BS heavy compaction energy

3.3 Statistical Analysis

3.3.1 Two-way analysis of variance (ANOVA)

Two levels of analysis (at 5% level of significance) were carried out, in order: (1) to determine the relative effects of differences in soil types and cement contents on compaction and permeability characteristics and (2) to determine the combined effects of compaction energy and cement content on the compaction and permeability characteristics of the soil-cement mixtures, for each soil. A sample of ANOVA table is shown in Table 5. The results of these two levels of analysis are summarized in Tables 6 and 7, respectively.

Table 5 Sample of ANOVA table for maximum dry density at BSL compaction

Analysis of Variance (Two-way analysis of variance without replication)						
Source of Variation	SS	df	MS	F	P-value	F-crit
Cement content	0.185471	5	0.037094	8.797615	0.000461	2.901295
Soil class	0.039867	3	0.013289	3.151723	0.056042	3.287382
Error	0.063246	15	0.004216			
Total	0.288583	23				

Differences in natural soil characteristics are only statistically significant for MDD at BSL and WAS compaction, for OMC at WAS compaction (see Table 6). The effects of cement content are only statistically significant for MDD at all the three compactive efforts and for permeability at BSL compaction (Table 6). Thus, the variations in the soil characteristics do not necessarily cause general differences in measured MDD, OMC as well as permeability.

Table 6 Results of two-way analysis of variance (Level 1)

Parameter	Source of variation	Degree of freedom	F value (calculated)	p-value	F value (critical)
MDD ï BSL	Cement content	5	8.7976	0.0005	2.9013*
	Soil class	3	3.1517	0.056	3.2874**
-WAS	Cement content	5	3.4711	0.0278	2.9013*
	Soil class	3	4.0411	0.0262	3.2874*
-BSH	Cement content	5	5.3911	0.0049	2.9013*
	Soil class	3	0.1265	0.9429	3.2874**
OMCï BSL	Cement content	5	0.1765	0.9673	2.9013**
	Soil class	3	2.4612	0.1026	3.2874**
-WAS	Cement content	5	0.3124	0.8978	2.9013**
	Soil class	3	4.7881	0.0156	3.2874*
-BSH	Cement content	5	2.2236	0.1058	2.9013**
	Soil class	3	2.1915	0.1314	3.2874**
k ï BSL	Cement content	4	10.7535	0.0006	3.2592*
	Soil class	3	1.0006	0.426	3.4903**
-WAS	Cement content	5	1.1192	0.3917	2.9013**
	Soil class	3	0.5552	0.6526	3.2874**
-BSH	Cement content	4	3.1498	0.0549	3.2592**
	Soil class	3	0.1915	0.9002	3.4903**

Symbols are as defined in Table 4. *Significant at 5%; **Not significant at 5%.

Table 7 Results of two-way analysis of variance (Level 2)

Parameter	Source of variation	Degree of freedom	F value (calculated)	p-value	F value (critical)
MDD ï Soil A	Cement content	5	3.9024	0.0319	3.3258*
	Compaction energy	2	3.7950	0.0594	4.1028**
-Soil B	Cement content	5	5.386	0.0116	3.3258*
	Compaction energy	2	7.8021	0.0091	4.1028*
-Soil C	Cement content	5	1.5764	0.2523	3.3258**
	Compaction energy	2	3.1215	0.0884	4.1028**
-Soil D	Cement content	5	6.7511	0.0053	3.3258*
	Compaction energy	2	13.9656	0.0013	4.1028*
OMC ï Soil A	Cement content	5	1.352	0.3195	3.3258**
	Compaction energy	2	3.6752	0.0636	4.1028**
-Soil B	Cement content	5	1.4477	0.2887	3.3258**
	Compaction energy	2	6.9961	0.0126	4.1028*
-Soil C	Cement content	5	04612	0.7967	3.3258**
	Compaction energy	2	0.5646	0.5857	4.1028**
-Soil D	Cement content	5	1.1931	0.3784	3.3258**
	Compaction energy	2	3.6965	0.0628	4.1028**
k ï Soil A	Cement content	5	2.3061	0.1462	3.8379**

	Compaction energy	2	0.6096	0.567	4.459**
-Soil B	Cement content	5	1.1325	0.4065	3.8379**
	Compaction energy	2	0.1486	0.8643	4.459**
-Soil C	Cement content	5	8.358	0.0059	3.8379*
	Compaction energy	2	0.5574	0.5935	4.459**
-Soil D	Cement content	5	1.0365	0.4452	3.8379**
	Compaction energy	2	0.3035	0.7463	4.459**

MDD, OMC and k are as defined in Table 4. *Significant at 5%; **Not significant at 5%.

The effects of differences in cement contents and compaction energies are statistically significant for MDD for each of the soils except for Soil C where the cement content did not cause significant differences in MDD (see Table 7). The effects of compaction energy are only statistically significant for the OMC of Soil B while for Soil C only, the differences in cement content caused significant differences in the permeability (Table 7). Both OMC and permeability coefficients do not generally respond to variations in compaction energy and cement content but MDD does.

4 CONCLUSIONS

Laboratory investigations were conducted on cement-treated sandy soils obtained from a semi-arid zone environment in order to check for their suitability for use as materials for stabilized earth dam construction. For the four sandy soils (one granular and three fine-grained soils), cement treatment levels varied from 0.0 to 12.5%. The high dry densities and low permeabilities usually required for materials to be used for stabilized earth dam construction were obtained at cement contents greater than 2.5% but less than 10.0%. In general it was possible to achieve permeabilities less than $1x10^{-6}$ cm/s at these treatment levels. This agrees with the findings of Mitchell (1976). Statistical analysis shows that the OMCs and permeability coefficients do not generally respond significantly to variations in compaction energy and cement content but MDD does. The regression equations developed from test results cannot be used to make reasonable estimates of MDD, OMC or permeability coefficient, k, thus indicating that additional factors contribute to variations in these parameters.

While these cement-treated soils can be used for stabilized earth-dam construction, it is expedient that construction work be completed at minimum cost and in the shortest possible time (during the dry seasons) so that they may be effective when next it rains. This is in line with suggestions by Robertson *et al*. (1987). Moreover, only personnel with adequate knowledge of the earth dam construction technology should be involved in the construction of low cost earth dams. Dispersive or shrinkable soils must not be used in earth-dam construction as such natural soils are susceptible to damage by overtopping caused by flowing water during extreme flood events and to failures resulting from problems associated with construction control.

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SPILLWAY DESIGN FOR A PROPOSED EMBANKMENT IN AN UNGAUGED WATERSHED

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ABSTRACT

Principal and emergency spillways were designed for an embankment to be sited at an ungauged watershed located at the National Centre for Agricultural Mechanization (NCAM); Ilorin. The unit hydrograph was developed using Snyder's method. The 24-hr 25-yr and 100-yr storm hydrographs were developed from the unit hydrograph using convolution procedures. A concrete pipe, drop inlet principal spillway was designed while a grass-lined flood (emergency) spillway was designed using broad-crested weir principles. The spillways were evaluated through reservoir routing and it was observed that at the 25-yr and 100-yr recurrence intervals there was no overtopping which indicated that the spillways were adequate for the embankment.

KEYWORDS: Spillway, embankment, ungauged watershed.

1. INTRODUCTION

Most reservoirs are protected from overtopping by the provision of mechanical (principal) spillways. These types of spillways usually have their entrance opening set at the elevations at which the reservoir is to be maintained. The entrance elevation therefore depends on the level of permanent storage desired. The mechanical spillway may in some instances serve as a drain for cleaning and repairing the reservoir (Barfield *et al*, 1981; Viessman *et al*, 1989; Schwab *et al*., 1993).

The mechanical spillway inlet should be protected with a screening device that prevents floating objects and other foreign objects from entering and clogging the pipe. Such a device should be so designed that after becoming loaded with debris, it will not retard the entrance of water. The spillway outlet should be carried well below the toe of the embankment and protected against scouring. This could be done through the provision of a stilling basin (Schwab *et al*., 1993).

Reservoirs maintained by water harvesting techniques or other means may be provided with flood (emergency) spillways that will safely bypass floods that exceed the temporary storage capacity of the reservoir. In rare cases it is economically possible to store the entire volume of the design flood within the reservoir without overtopping the embankment. The emergency spillway is used to handle flows which exceed the capacity of the drop pipe and floodwater storage. This occurs when the storm exceeds the design storm, when the inlet plugs, or if improper judgment of watershed characteristics occurs. The design capacity of the flood spillway should be the peak runoff rate for a chosen return period depending on the potential damages that could be caused by the storm (Hilborn, 1985).

Design of spillways has a significant effect on the project layout and costs. Many failures of embankments have resulted from improperly designed spillways or spillways of inadequate capacity. If properly designed, structure of adequate capacity may be found to be only moderately higher in cost than a structure of inadequate capacity. In addition to providing sufficient capacity, the spillway must be hydraulically and structurally safe (Barfield *et al*, 1981; Hilborn, 1985; Schwab *et al*., 1993).

Ungauged watersheds abound in Nigeria and other developing nations. A case study is the watershed at the National Centre for Agricultural Mechanization (NCAM), Ilorin, which is being planned for development, to include the construction of an embankment and other facilities. The objective of this work was to design suitable spillways for the embankment in order to help in the safe passage of floods that may exceed the temporary storage capacity of the reservoir.

2. MATERIALS AND METHODS

Project site

The project site is at the National Centre for Agricultural Mechanization (NCAM), Idofian, Ilorin, Nigeria, on Longitude 4^0 $30^/$ E and Latitude 8^0 26/ N. The study watershed has an area of 63 ha, and an average slope of 2 %. The soil consists of 34 ha of sandy loam, 13 ha of loamy sand and 16 ha of clayey loam. The rainfall excess was determined using the Curve number method developed by the United States Soil Conservation Service, SCS (1972, 1986). The soil was estimated as being in Hydrologic Soil Group B (HSG B), with an Antecedent Moisture Condition II (AMC II), being for average conditions. The weighted Curve Number was estimated as 74. The rainfall data for Ilorin were obtained from Ogunlela *et al*. (1995). The unit hydrograph was developed using Snyderôs synthetic hydrograph method. The 24-hr, 25-yr and 100-yr storm hydrographs were developed from the unit hydrograph using convolution procedures (Viessman *et al*,1989; Wanielista, 1990).

2.2 Development of the Spillways

Two spillways were designed namely, principal spillway and flood or emergency spillway.

2.2.1. Sizing of the Principal Spillway

A drop inlet spillway was chosen for the embankment due to the topography of the site and the fact that this spillway has the capacity of discharging water through considerable drop in elevation and dissipating the energy of the falling water.

The stage-discharge curve was developed from the topographic map of the reservoir site. For each elevation (stage), discharges were obtained from the following equations, taking into consideration the three stages of flow involved in the discharge (Barfield *et al*, 1981; Schwab *et al*., 1993).

i) Weir flow

The weir flow was calculated as:

$$Q_w = C_w L H^{3/2} \tag{1}$$

where C_w was assumed to be 3.0.; L = weir length (m).; H = head above spillway inlet(m).

ii) Orifice flow

The orifice flow was calculated using:

$$Q_o = C_o A_o \sqrt{2gh} \tag{2}$$

where C_0 was assumed to be 0.6 and A_0 = area of pipe (m^2)

iii) Pipe flow

The pipe discharge was computed using:

$$Q_p = \frac{a\sqrt{2gh}}{\sqrt{1 + K_e + K_b + K_c L}} \quad (3)$$

Where K_c and K_b are entrance- and bend head- loss coefficients, respectively. For a circular pipe flowing full, K_c is determined from:

$$K_c = \frac{1{,}244{,}522n^2}{D_b^{4/3}} \quad (4)$$

K_c was obtained as 0.036

$$Q = 1.12\sqrt{H_D + H} \quad (5)$$

where H_D = distance from the surface to the point 0.6 diameter above the outlet, m;
H = head above the principal spillway, m; H_D = h ï 0.6D;

D= pipe diameter, m; h = distance between top of inlet pipe and bottom outlet, m.

From the above formulae, for each elevation, the following procedures were followed:

i) Predicted flow rates were calculated for weir, orifice and pipe flows.
ii) The design discharge was obtained by choosing the lowest rate of flow for the three flow conditions.

The values obtained in (ii) above were plotted against the elevation to obtain the stage ï discharge curve (Figure 1). The adequacy of the spillway was checked through reservoir routing. This was done by developing a storage ï indication curve (Figure 2) used in the routing. The reservoir routing results for the 24-hr 25-yr and 100-yr storms are shown in Figures 3 and 4 respectively.

2.2.2 Sizing of the Emergency (Flood) Spillway

The flood spillway was dimensionalized using combined Manningõs and continuity equations:

$$Q = AV = \frac{A}{n} R^{2/3} S^{1/2} \quad (7)$$

where: Q = discharge (m^3/s); A = cross-sectional area of flow (m^2); V = flow velocity (m/s);
n = Manningõs roughness coefficient; R = hydraulic radius (m); S = slope

Various widths and depths were assumed and checked through trial and error methods and the appropriate sizes for the 25-yr and 100-yr return periods are as shown in Table 1. The location of the principal spillway is shown in Figure 5, while the emergency spillway is in shown Figure 6.

3. RESULTS AND DISCUSSION

The evaluation of the spillway through routing showed that the spillway capacity is adequate for the embankment. Using the stage ï discharge curve and storage ïindication curve in Figures 1 and 2 for the routing, the routing curves in Figures 3 and 5 were developed. From these routing, the maximum elevation reached for the 25-yr and 100-yr return periods were 996.94 m and 997.17m respectively. However, the 100-yr return period was chosen for the development of the spillway taking into consideration the potential damages that could be caused to lives and properties at the downstream of the embankment.

For the 100-yr return period, the elevation height reached during routing (997.17 m) was lower than the height of the reservoir embankment of 997.48m (Figure 5). This indicates that the embankment would not be overtopped because the design depth of the spillway was lower and hence can adequately accommodate any impending flood at that return period. Furthermore, the design of the flood spillway was done such that the slope of approach channel would provide adequate drainage and reduce inlet losses (Figure 6).

The design flow was also determined taking into consideration the velocity of flow recommended for grassed waterways (Schwab *et al*., 1993). Table 1 shows the dimensions of the flood spillway and the designed velocities for the 25-yr and 100-yr return periods. It could be seen from the table that the spillway capacity discharge for each return period was higher than the design flow, which reinforces the reservoir routing result that the spillway could adequately evacuate any impending flood above the temporary storage of the reservoir.

Table 1. Emergency spillway dimensions

Return Period (yr)	Width of spillway, b (m)	Depth of spillway, d (m)	Velocity of Flow, v (m/s)	Design flow for a given return period, (m^3/s)	Spillway Discharge, Q (m^3/s)
25	3.0	0.3	1.47	1.794	2.09
100	3.0	0.4	1.58	2.443	2.65

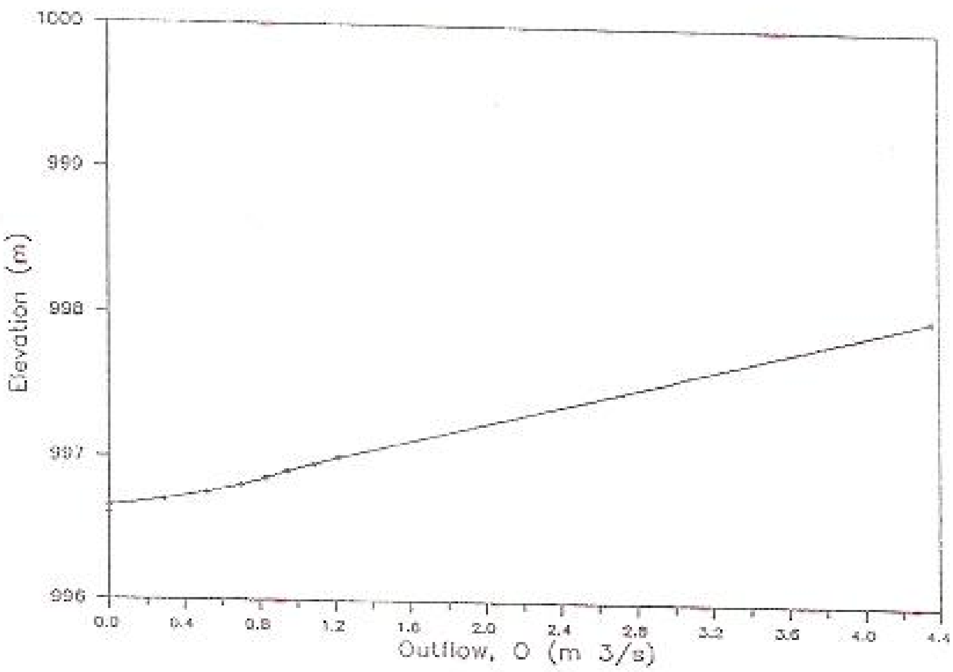

Figure 1. Stage-Discharge Curve.

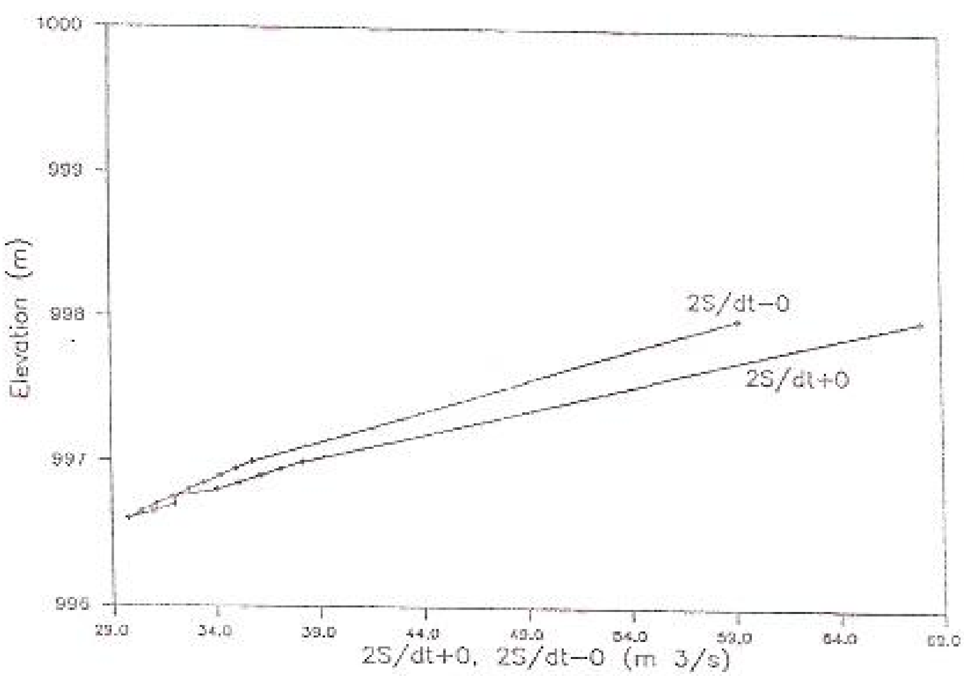

Figure 2. Storage-Indication Curve.

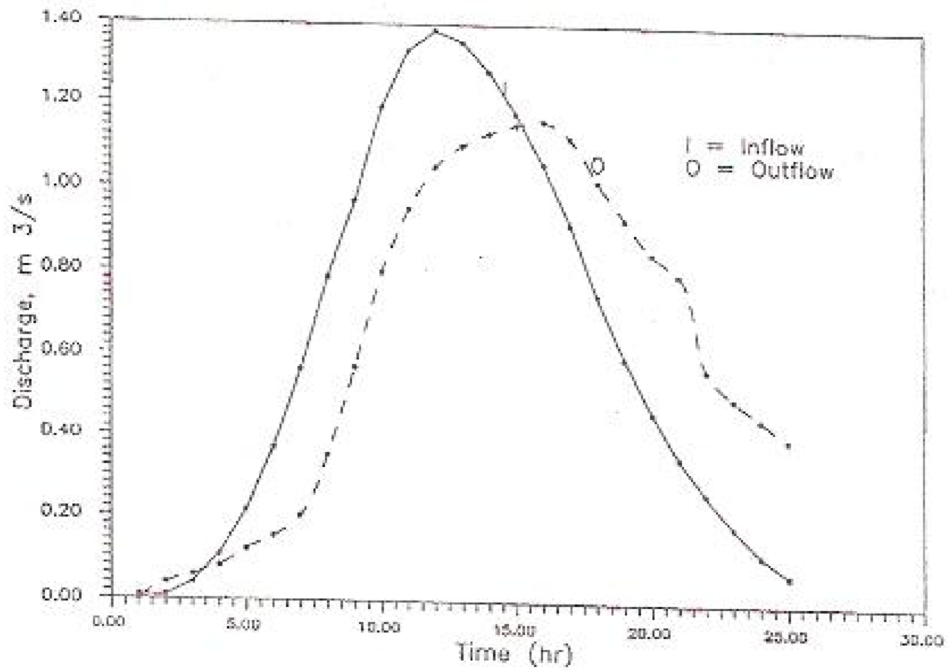

Figure 3. 25-year, 24-hour Storm Routing through the Reservoir

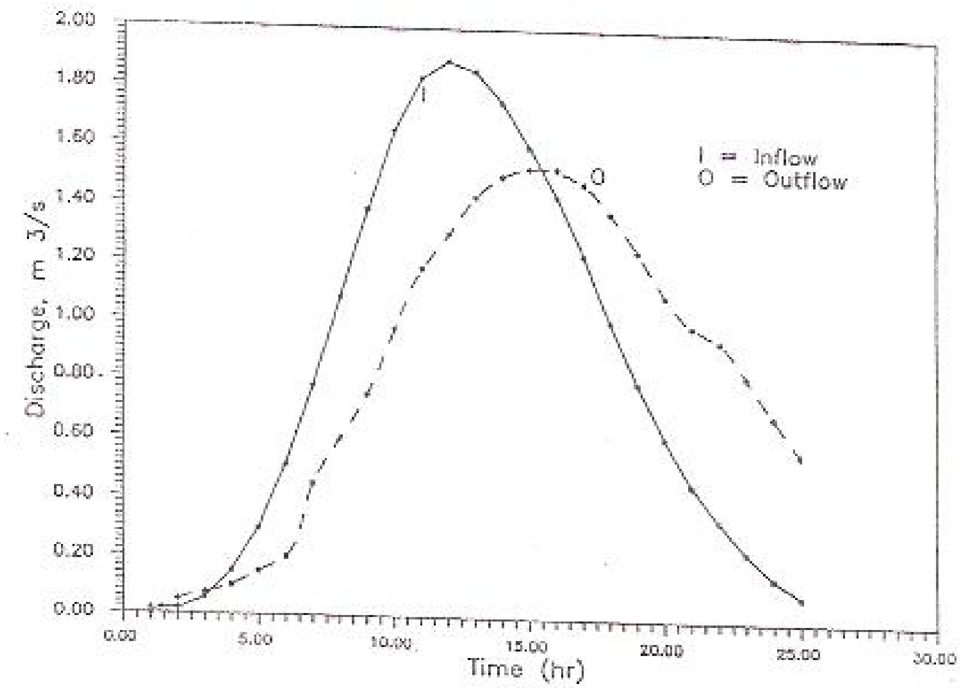

Figure 4. 100-year, 24-hour Storm Routing through the Reservoir.

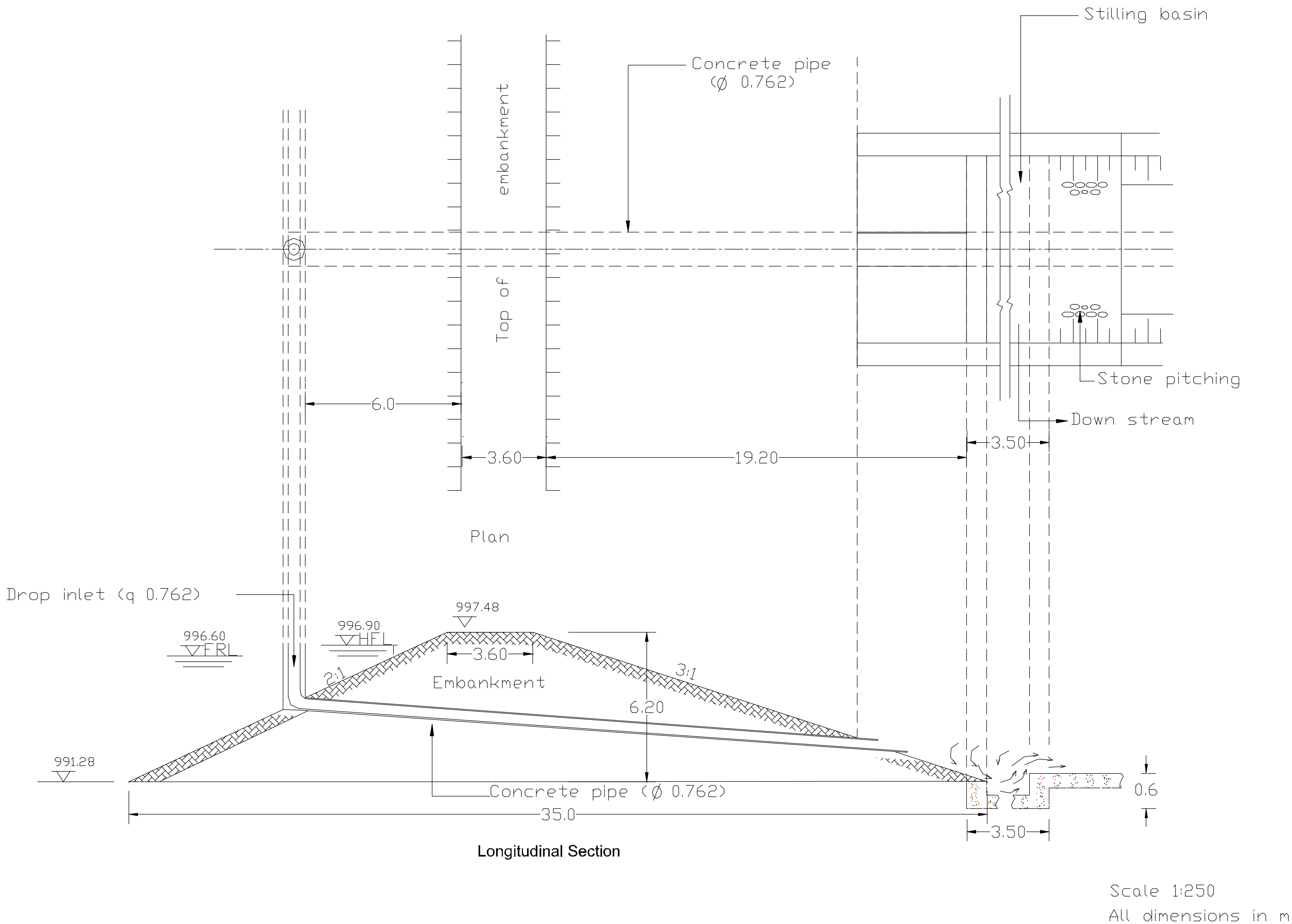

Figure 5. Principal Spillway (HFL-High Flood Level; FRL-Full Reservoir Level).

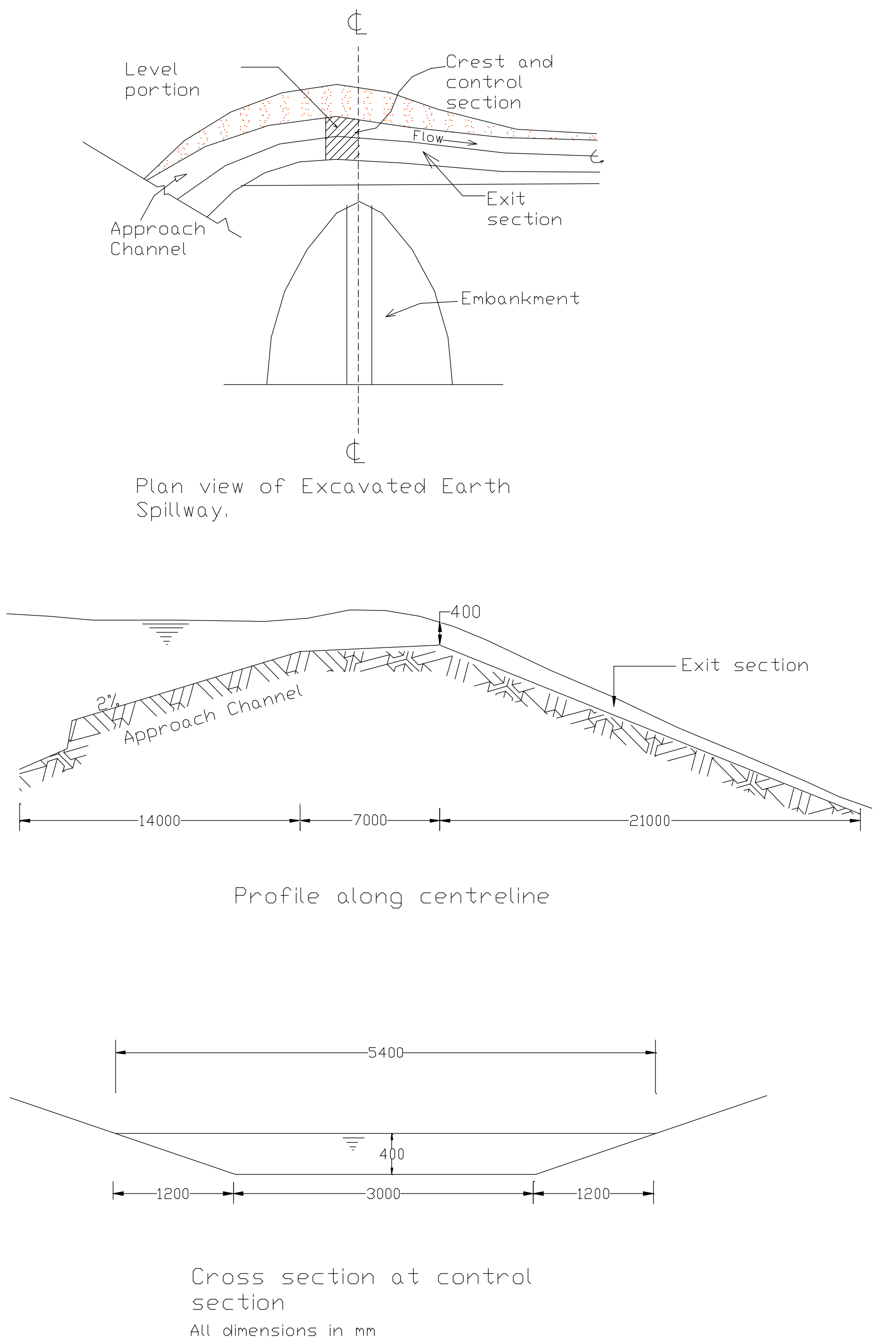

Figure 6. Profile and Cross Section of the Excavated Earth Spillway. (Adapted from Schwab et al., 1993)

4. CONCLUSIONS

An earth embankment for multi-purpose use is to be constructed at the National Centre for Agricultural Mechanization, NCAM, Ilorin. Principal and emergency spillways were designed for the embankment, and evaluated through routing to ascertain its suitability for the proposed structure. Storms of 25-yr and 100-yr 24-hr duration were used in the evaluation. The results indicated that the spillways would not be overtopped, and are thus suitable for the structure-ensuring that lives/properties are protected downstream.

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A CHARACTERIZATION OF WASTES GENERATED FROM PETROLEUM DRILLING ACTIVITIES IN NIGERIA – ITS MANAGEMENT AND IMPACT ON THE ENVIRONMENT

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ABSTRACT

This article discusses the outcome of a one-year survey on the problems of petroleum waste disposal practice in Nigeria, and particularly the Niger Delta area. During the period of the study, 18 oil wells were visited and samples were randomly collected from 10 of these wells for physical and laboratory analysis. Results showed that waste generated by petroleum drilling activities in Nigeria mainly consists of cutting, mud/chemicals, oil spills, lubricants, cement slurry/dust, spent oil, condemned pipes, metal scraps, shaker screens, filter/machinery parts and even high noise levels. Virtually all of these wastes are usually dumped on nearby land, swamp or sea without pretreatment or consideration for the protection of human health and the environment. Consequently, there is a real threat to vegetative, aquatic and human lives from the release of pollutants from petroleum drilling operations in Nigeria as a result of drilling wastes by both national and multinational oil companies.

KEYWORDS: Waste, oil industry, drilling activities.

1. INTRODUCTION

The origin of Petroleum drilling waste is best considered with the history of Petroleum drilling in Nigeria, because at any drilling rig, discharges of foreign materials into the environment, no matter how small, occur by operational routine emissions and also by accidental discharges into the Nigerian environment could be dated back to 1903 when the Nigeria Bitumen Corporation, a German Company, started exploration activities in Nigeria (SPDC, 2003). By 1956, the first commercial oilfield was discovered at Oloibiri in the Niger Delta region of the country (SPDC, 2003). By 1958, Nigeria started exporting oil when production reached 6,000 barrels per day (SPDC, 2003; Nwankwo and Irechukwu, 1988). In recent times with the discovery of more lucrative oilfields, production level is well over two million barrels a day. Association with increased drilling and production operation is the unavoidable release in some cases of large quantities of waste oil into the land, water and air of the surrounding environment. Initially, exploration and production activities were limited to onshore areas of the Niger Delta, but today offshore production constitutes a significant portion of total production, averaging about 40%.

From the early stage of oil exploration, and until recently, all the wells drilled have produced large quantities of drilling wastes which were not taken care of as a result of lack of proper waste control measures. The wastes were merely dumped within the surrounding areas of the immediate well locations. The public awareness of the devastating effect of petroleum waste became evident from poor farm field yields and low fish catch in the areas of exploration. The result of which is the agitation, sometimes violently, in the past years of the people of the Niger Delta region, for compensation of their polluted environment. These agitations have aroused concern among oil companies such as Shell, Elf, Agip, Mobil and other prospecting and servicing companies, government decision makers, the general public and indeed the international community. Therefore, there are concerted efforts, in recent times, to prevent

spills both from drilling and production activities, and from all indications the discharge of petroleum waste into the environment and its disastrous consequences appears to be unabated in Nigeria.
The aim of this paper, therefore, is to identify the various types of petroleum drilling wastes encountered in Nigeria exploration field; to appraise the current handling and disposal methods and its impact on the environment; and recommend appropriate drilling waste management methods, preferably ñstandard best available practicesò applicable in the Nigerian situation.

2. MATERIALS AND METHODS

2.1 Brief Sectoral Characteristic of the Niger Delta

The Niger Delta region is located in the southern part of Nigeria. The region mainly consists of four states, viz: Rivers, Bayelsa, Delta and Edo States. Rivers State with its capital in Port Harcourt is the most prominent of the four states. All oil companies in Nigeria have their headquarters in Port Harcourt. Most of Nigeriaφs oil fields and indeed its oil and gas reserves and production are located in the Niger Delta. At the end of 1992, proven reserves of petroleum stood at 17.9 billion barrels per day) (Dessel, and Omuka, 1994). The oil production alone of the aforesaid 4 states comprises about 70% of the estimated national government revenues in 1992. Confirmed reserves of natural gas amounted to 3.4 trillion m^3 in 1992. At present over 75% of natural gas produced in Nigeria during oil exploitation is flared into the atmosphere (Dessel and Omuka, 1994). Most of the gas flaring occurs in the Niger Delta region. Flaring is gradually being reduced, in recent times, with the development of the Nigerian Liquified Natural Gas Project (NLNG), sited at Bonny, near PortHarcourt, Rivers State.

Since 1979 the Nigerian National Petroleum Corporation (NNPC), the government body in charge of petroleum resources, has operated joint venture equity participation agreements with major oil producers. Shell Petroleum Development Company (SPDC) is the largest producer in the country with about 50% total production (SPDC annual Diary, 2003). The other major onshore producers are Agip and Elf. The principal offshore producers are Chevron and Mobil (Nwankwo and Irrechukwu, 1988).

Agriculture employs the largest proportion of the population in the Niger Delta. The principal crops are cassava, rice, yams, bananas, maize, beans and vegetables. Shifting cultivation is the major form of agriculture. Traditionally, communities manage farm lands as common property resources with areas being communally cut down and burned. Not too long ago, the development of oil exploitation has greatly expanded migration, particularly into Port Harcourt which has significantly disrupted many farming communities.

The average population density of the Niger Delta region is 1.70 people/ha (World Bank, 1995). The region, even with its vast oil resources, is poor. Annual incomes are below the national average of N100,000.00 (about US $900) per person. Unemployment is around 35% in Port Harcourt and is believed to be higher in the rural areas (World Bank, 1995). Rural people commonly fish or practice subsistence agriculture. Within the riverine areas, most people live on the elevated areas to avoid flooding. According to Ayotamuno (1997), new land from the sea is reclaimed and built upon by obtaining chicoco mud from the swamp and spreading it in such a way that the elevation is above sea level. Water related diseases exert an enormous social and economic toll in the Niger Delta. Infact, urban rural infrastructure in the form of electricity, water supply and sanitation levels are generally poor (Ayotamuno and Akor, 1992).

2.2 Survey of Oil Field and Data Collection

A total of 20 fields were visited within the Niger Delta. Out of these, petroleum drilling wastes management practices were observed in 18 wells where drilling operations were in progress onshore or offshore. Ten of these 18 wells were randomly selected and samples collected from them. These number of points were deemed adequate because it was observed that the characteristics of drilling wastes are similar in virtually all the wells. Physical data were collected from wells in clusters of drilling fields. Each of the selected oil wells were visited by using vehicle, or boat and sometimes by helicopter depending on whether the field is located onshore or offshore. The exercise lasted for 1 year. Before the visit, a letter to that effect was dispatched to the necessary company management. In all cases the management cooperated. Physical data was collated through samples from bilge/ballast tanks, cutting, mud from wells, soils around the wells, pools of water and streams around the well locations, and a point discharge of cuttings, daily generated solid waste at rig and within rig locations.

Table 1 shows an inventory of liquid wastes from 4 wells in a particular flow station during the course of drilling operations. Despite the use of water based mud in this flow station, oily waste from lubricants used in the mud system and diesel based pills used during stuck-pipe incidents amounted to as much a 572 barrels. This is in addition to the leaks from rig generator fuel system and all discharges into the waste pit overflows an spread all over the swampy terrain.

Table 1. Example of drilling waste generated in one of the flow station studied

Wells	Hole (Well) section (cm)	Drilling Depth (m)	Drilling Duration (days)	Wastes mud (bbls)	Wastes mud (bbls)	Drills & cutting m^3	Waste oil (bbls)
A	55	914	22	5750	9050	402	118
B	40	2021	20	3200	4700	173	14
C	31	3352	29	2900	5600	81	45
D	22	3568	30	3100	4050	19	350
TOTAL			102	14,900	23,400	645	527

The equipment used for the monitoring exercise consists of gas chromatography, pH meter, Thermometer, audiometer, turbidimeter, spectrophotometer etc. Each information was obtained using standard procedures.

3. RESULTS AND DISCUSSION

In this study, petroleum drilling waste was not limited to the common well bore associated waste such as well blow outs and drilling mud and cutting; but include all related waste generated as a result of petroleum drilling operation in the Niger Delta area of Nigeria. These wastes were classified into solid, liquid and emission waste in this study. The characteristic and the observed disposal of each of these 3 classifications are briefly discussed below.

3.1 Solid Wastes

These include drilling, shaker screens, perforating gun remains and metal scraps, fillers and machinery parts, condemned pipes, glasses and cans, plastics, rubber and papers, and caked fire extinguishers.

Drilling Cutting

In the Petroleum industry a mixture of cutting, mud chemicals, and oil waste are usually discharged from the borehole during the process of drilling. Examples of cuttings include sands and rocks particles which could generally be described as inert. In Nigeria virtually all oil companies dump their cuttings and mud into what is called waste pit. This involves raising a bond wall around a dugout pit. During the raining season some of these pits overflow the bond wall and run into the surrounding lands and nearby farms. Other times, when this waste pit fills up without being emptied quickly, gives a bad odour to the entire environment. It was observed on most offshore locations that cuttings along with mud are flushed into nearby rivers resulting in high oil/grease content of the water. This has had diverse negative consequences on the quality of water (Ayotamuno *et al*, 2002), thus affecting aquatic life and marine vegetation.

Only recently, efforts are being made by Shell and one or two other oil companies to reinject the cuttings back into the ground. This is somewhat a better disposal method for cuttings where it is carried out properly. The process, as shown in Figure 1, involves collecting cuttings in tanks and sending them through a hopper to a grinding machine where they are ground to about 70 microns. These are then slurrified on-line and with the aid of a centrifugal pump, the slurry is pumped at a constant pressure of about 27bar to the selected injected well.

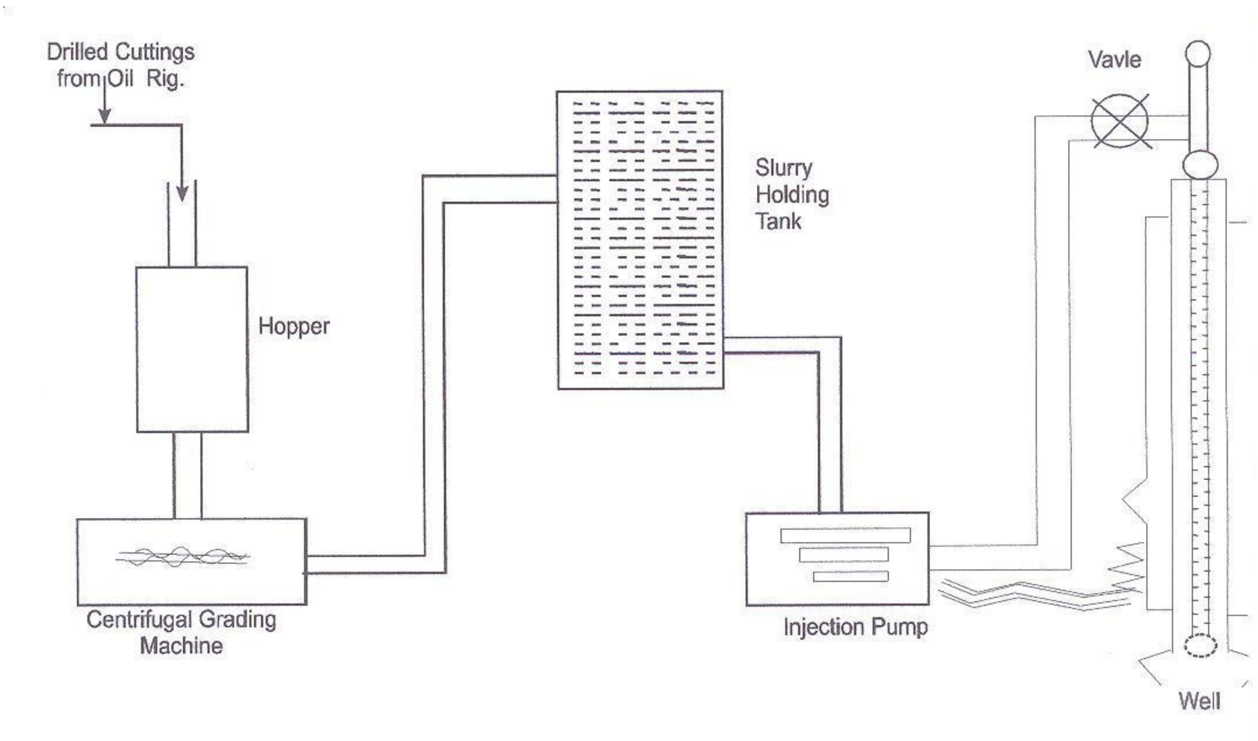

Fig 1. Schematic Representation of cutting re-injection of drilling waste.

Metal scraps

These were observed to be amongst the most predominant wastes in oil field locations in Nigeria. Metal scraps are produced during welding, fabrication or other maintenance processes. Also included in the category of metal scrap are shaker screens and perforating gun remains. Hence metal scrap is not a well-bore related waste. In offshore locations, it was noted that efforts were made by the respective companies to collect the scraps to company dumpsite, but a good percentage were dumped into close-by rivers. On onshore locations, metal scraps could easily be seen heaped close to oil rigs.

Filter and Machinery Parts

In most of the onshore and offshore rig locations, it was observed that oil filets were gathered in trash baskets. The filters are usually burnt whenever the baskets are filled up. Machinery parts are often treated as metal scraps. There were evidences of dumping of machinery parts into nearby waters at offshore rigs. On onshore rigs, these parts could be seen scattered over the entire location.

Condemned Pipes

Condemned pipes could also be seen all over the place. From time to time some are given or sold out to villagers for building support and other uses. At offshore locations condemned pipes are sent to shore base offices where they are used for other purposes including container construction.

Glasses/cans

These were discharged of in offshore location by dumping into the surrounding swamps. On onshore locations, glasses and cans were simply dumped in wastes pits in certain location and in others they are gathered in heaps at different comers of the field.

Plastic, Rubber and Paper

In several locations, plastics bottles, containers and papers were seen littered all over the place. From time to time, they are gathered and burnt openly in the field. In several offshore locations these were seen floating on nearly water surface.

Caked fire extinguisher powders and containers

At least twice a year virtually all oil prospecting companies carry out the servicing of their fire extinguishers. The by-product of this included caked fire extinguisher powders and condemned containers. These are either clustered in the areas where the servicing was carried out or dumped in surrounding waters.

3.2 Liquid Wastes

The liquid wastes obtained during oil drilling operations in the Niger Delta were characterized into mud/chemicals, accidental oil spills, greases, cement slurry, flammable paints, vanishes, spent oil, formation water and acid wastes.

Mud Chemicals

There are two types of mud chemicals, the first which is water based is disposed of directly into the water in swampy or offshore locations. This is done without pretreatment in most cases. On land location, water based mud is disposed of in reserved mud pit. The second is an oil-based mud. These are often collected in tanks or containers for treatment and reuse. However, there are cases where oil based mud is suddenly discharged into surrounding water or land mass as a result of human error or equipment failure.

Accidental oil spills

Accidental oil spills occur mostly where there is a blow out. In other cases leakages through drums of oil could cause an accidental spill especially during transportation, storage or handling. Spills also occur during maintenance of drilling equipment, wherein hydraulic fluid could sometimes be seen spreading across the work area and even reaching nearby surface water. In some locations these spills are scooped or cleaned off using control materials like absorbents, suction machines and agitators.

Cement Slurry and Grease

On offshore locations, cement slurry is commonly flushed into nearby water. On land locations, it is flushed into the surrounding land mass thereby affecting farm vegetation when it hardens. Excess grease is mostly disposed of by cleaning them with rags and the rags later dumped into trash baskets for burning. Many at times, the bodies of the equipment could be seen smeared with grease even after maintenance.

Flammable Paints/Vanishes

Remains of paints, thinners and vanishes are mostly washed into nearby waters and land. In some rigs, paint remains are usually containerized and sent to company dumpsite.

Spent Oil

The disposal of spent oil varies from one company to the other. In some cases spent oil is collected into tanks called ñenviron tanksò and sent to company dumpsite for burning or re-use. In other places, it is simply discarded on land. In some others spent oil is given to the inhabitants of nearby villages who in turn sell it or use it to adulterate good oil.

Formation water and acid waste

This is also called completion water or brine. Formation water is usually dumped into waste pit in land locations and disposed of in water bodies in offshore locations. Acid waste results from acidizing processes during oil exploitation. This waste is either disposed of on land or water depending on the location of the rig site. In some cases the acid waste is collected in tanks and sent to company dump sites for treatment.

3.3 Emission Waste

This category of petroleum drilling waste in Niger Delta consists of gas emissions and high noise cement dust pollution levels.

Gas Fumes

A lot of gaseous fumes are often produced at rig sites during welding and other operations. Generally the welders inhale these fumes or gases without consideration of its harmful effect.

Cement Dust

Once in a while, companies undertake a tank cleaning excise in which the remains of the dry cement in the cement unit are vented into the atmosphere. During such times, the air is usually so cloudy with cement as to impair vision. In fact, in some onshore location, people within nearby villages would collect settled cement from the air into bags for home use.

Noise Pollution

Several noise-producing machines are often used during the process of petroleum drilling. The ones seen operating during this research include; cranes, needle gun or rust removal machine, EMD generator and mud-pumps. Given in Table 2 is the noise value in decibels (db) recorded with the noise meter during the study, for various equipment and locations in one of the flow stations. Virtually all the readings are above the WHO limit. Workers are generally advised to wear earmuffs before entering noise areas, however it was noted that in many instances these earmuffs were not available. Hence workers resort to use their fingers to plug their ears, while walking through these noise areas.

Table 2. Noise level for various equipment and locations in one of the flow stations studied

Equipment/Locations	Noise Level (DB)	WHO
Engine room	142	75
Using needle gun	145	
Draw works	102	
Rig floor	92	
Accommodation (offices)	65	
Main deck	87	
Mud pumps	95	

Mud tank area	75	
BOP area	75	
Warehouse	82	
Crane starting	120	
Crane running	101	
Accommodation (rooms)	63	
During flaring	145	
Shale shaker area	94	

In some rigs, the mud pumps are installed in the same compartment with the EMD engines. During such times the noise level recorded in this research was as high between 145 and 150 decibels. This is especially the situation when the two pumps are running at the same time with the EMD generators. The dangerous effect of such high level noise to the health of the worker and even nearby communities cannot be over emphasized. Rural hunters, in some of these communities complain openly that most of the big animals have been driven far into the forest because of the high noise level of the equipment (Igho, 1998).

4. CONCLUSIONS AND RECOMMENDATIONS

The study examined the various categories of petroleum drilling wastes generation in Nigeria. Their physical properties and the resultant environmental impact on the Niger Delta region of the country from where virtually all the oil fields are located were determined. The research noted that the disposal of drilling wastes as at this twenty-first century is still below appreciable and acceptable level. From the investigations, there were no records of any EIA study in any location before drilling activities were set in motion within the Niger Delta. A great percentage of the untreated petroleum drilling waste is usually discharged into swamps, the sea or land by almost all the multinational oil producing companies. These companies, most often than not, collude with government officials charged with the responsibility of monitoring the environment. The management and disposal for instance, of drilling mud/cuttings, spilled oil, hydraulics and even lube oil, require serious attention and monitoring. All efforts should now be geared towards sanitizing the disposal of petroleum drilling wastes in Nigeria, without which the inhabitants of the oil bearing communities in the Niger Delta would have their fishing and farming activities permanently damaged.

From the study, the following recommendations are made having regard to ñbest available drilling waste management practiceò applicable to the Nigeria situation.

1. All oil companies before the commencement of any drilling operation should be compelled to carry out base line studies of drilling sites. Also effluent monitoring during operations and impact studies at the end of operations be undertaken to develop a data bank for updating or records.
2. Environmental studies and compliance training be put in place by operating companies to include workers awareness.
3. Government establishes a standard monitoring programme throughout the Niger Delta areas. A coastal and estuarine protection unit be established to monitor drilling waste discharge into the water.
4. Waste segregation be encouraged. Government should compel operating companies to submit manifest of wastes generated within every month, both bore-hole and non-bore-hole related waste and how these waste are finally managed.
5. Spent oil should not be disposed of indiscriminately or sold to villagers for adulteration of fuel and lubricants as is currently done. This constitutes health hazard and economic waste to the nation. An appropriate collection centre be encouraged and monitored by government agents.

6. Companies should provide sufficient ear plugs for every worker. High noise machinery should be enclosed in sound barrier compartments.
7. Although the downward injection of liquid waste and slurrified cuttings appears to be best method of permanently containing the waste, steps should be taken to ensure that the well into which the injection is made is appropriate, so as to avoid contamination to producing future well and even fresh water aquifers.

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