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ADAPTATION OF IMPACT HAMMER MILL FOR CRUSHING COCOA PODS HUSK AS A LIVESTOCK FEED CONSTITUENT

T. A. Morakinyo¹, B. S. Ogunsina² and A. A. Adebayo³

¹Department of Food Science and Technology, Obafemi Awolowo University, Ile Ife, Nigeria

²Department of Agricultural and Environmental Engineering, Obafemi Awolowo University, Ile Ife, Nigeria

³Department of Agricultural and Environmental Engineering, Federal Polytechnic, Auchi, Nigeria

Author for correspondence: morakzotec@yahoo.com

ABSTRACT

Dried Cocoa Pod Husks (CPH) have been identified as a substitute for maize in livestock feeds production. Conventional hammer mills in which beaters are made of low carbon steel does not provide sufficient impact force to crush dried cocoa pod husks (CPH). The impact hammer mill was adapted for this purpose using locally available materials. Beaters were made of heat-treated high carbon-steel to resist abrasion, distortion and improve overall performance. Crushing efficiency, percentage losses and throughput of the machine were 98.99%, 1% and 239.09 kg/h respectively and it costs One thousand and twenty US Dollars fifty cents only (USD1020.50) to fabricate the machine one-off. This work is a step further in cocoa processing; CPH having hitherto constituted a waste in the industry. It promises additional revenue for primary processors of cocoa especially in tropical Africa where the bulk of world cocoa is produced.

KEYWORD: Cocoa pod husk, hammer mill, crushing, beaters, heat-treated high carbon steel, livestock feed.

1. INTRODUCTION

Cocoa (*Theobroma cacao*), introduced to West Africa in the 16th century by the Spanish, is now largely grown in West Africa, Latin America and Southeast Asia (Owolarafe *et al.*, 2007). Cocoa fruit (pod) contains seeds (also called cocoa beans), which when fermented and dried provide valuable material for beverages, confectionaries and cosmetics. However, cocoa pod husk (CPH) which is over 70% (w/w) of the whole fruit is a grossly under-utilised by-product in cocoa processing. In 2004, cocoa cultivation in the world covered 3.5 - 4.5 million ha of land, yielding over 3.6 million tons of cocoa beans and about 10 million tons of CPH which ended up in the garbage (Owolarafe *et al.*, 2007). The CPH contains a high proportion of potassium and constitutes 52-75% of the pod wet weight (Fagbenro, 1988) and at present it is an undesirable waste product yet to be economically exploited in cocoa processing. Cocoa-pod husk is known to contain sizeable amounts of useful organic nutrients and have been successfully substituted for maize in livestock feed rations (Fagbenro, 1988). Atuahene *et al.*, (1984) and Sobamiwa (1998) established that maize may be replaced with 10% crushed CPH in livestock feeds production without any adverse effect on animal weight gain and carcass quality. It may also be burnt into potash for making soft soap (Adomako, 1995; Spore, 1998; Owolarafe *et al.*, 2007). Previous research efforts on cocoa processing focused on machines for pod breaking and beans extraction (Faborode and Dirinfo, 1994), very little literature exists on the utilization and processing of CPH, the disposal of which constitutes a menace to the industry. Cocoa pod husks processing involve crushing the material in a hammer mill, drying and particle size reduction to enhance proper mixing with other feed components.

In ancient times, milling of cereal grains was carried out by the abrasion generated when rubbing two stones against each other. This later developed into the attrition mill and later hammer mill (Donnel, 1983; Nasir, 2005). There are various types of hammer mill designs mostly based on rotor/beater mechanisms and hopper configuration. In Nigeria and other countries in sub-Sahara Africa where cocoa cultivation is major, hammer mills are locally fabricated using low-carbon steel. However, dried CPH being an excessively hard and abrasive material breaks the rotor/beater mechanisms of the mills incessantly (Adekomaya and Samuel, 2014), resulting in high maintenance costs. From literature review, a design that is capable of crushing CPH

efficiently is hardly found. In this work, the conventional hammer mill was adapted for crushing CPH using beaters made of high-carbon steel with low abrasion rate.

2. METHODOLOGY

2.1 Existing Hammer Mill Designs

Two common types of hammer mill designs were selected as a basis for modification: an imported design in the Department of Chemical Engineering, Obafemi Awolowo University, Ile-Ife (Fig. 1a) and a locally fabricated commercial design in Bodija Market, Ibadan (Fig. 1b) of capacities 0.125 and 0.150 ton/h respectively.

2.2 Design Modifications

The experimental machine was conceived basically as a device that will generate sufficient impact to crush CPH into desired particle sizes as required in livestock feeds production and achieve a milling capacity of 0.25 ton/h. The main components of the modified machine are: Hopper, Milling chamber, Discharge unit and Frame.

2.2.1 Design of the Milling Chamber

The milling chamber of the existing machines has the following components: separator disc, pivot rod, sieve, beater and rotor shaft (Fig. 2) and the following dimensions of the components (Fig. 3) were taken: separator diameter, D_o ; sieve diameter, S_d ; beater length, H_L ; beater width, W_o and beater thickness, T_o ; beater swing length, S_L and pivot rod diameter, P_d . From the foregoing, the relationship between these dimensional indices may be described by the following expressions:



Fig. 1a. An imported hammer mill in the Department of Chemical Engineering, Obafemi Awolowo University, Ile-Ife.



Fig.1b. A locally fabricated commercial hammer mill in Bodija Market, Ibadan

$$S_d = 2D_o \quad (1)$$

$$S_L = 2W_o \quad (2)$$

$$P_d = 2T_o \quad (3)$$

$$H_L = S_L + \left(\frac{P_d}{2} \right) + P_d \quad (4)$$

Based on the foregoing, the relationship between throughput and dimension of components of the milling chamber were calculated as shown in Table 1. It was established that as throughput varied from 0.125 to 0.15 ton/h (at 0.025 ton/h interval), sieve diameter increased from 325 to 350 mm; and that 25 mm increase in sieve diameter translates to 0.025 ton/h increase in throughput. For the experimental machine to develop a throughput of 0.25 ton/h, the separator diameter, sieve diameter, beater length, beater width, beater thickness, swing length and pivot rod diameter of the milling chamber are obtained as: 225, 450, 160, 65, 10, 150, 20 mm respectively. This gave useful information for determining the rotor shaft diameter, power rating of the electric motor and pitch length of the V-belt.

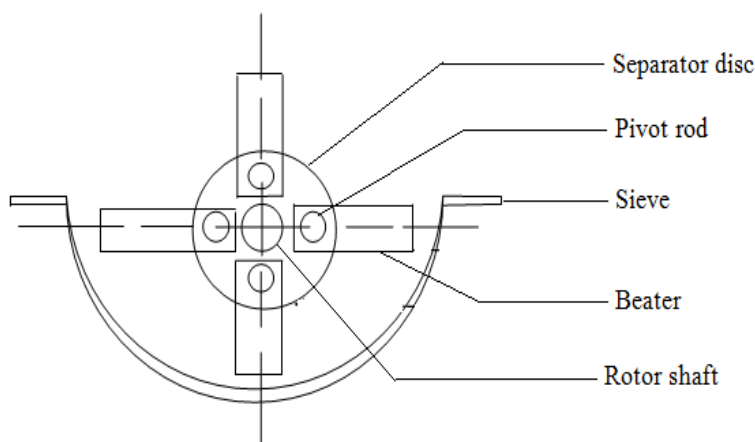


Fig. 2. Schematic drawing showing the internal components of the milling chamber

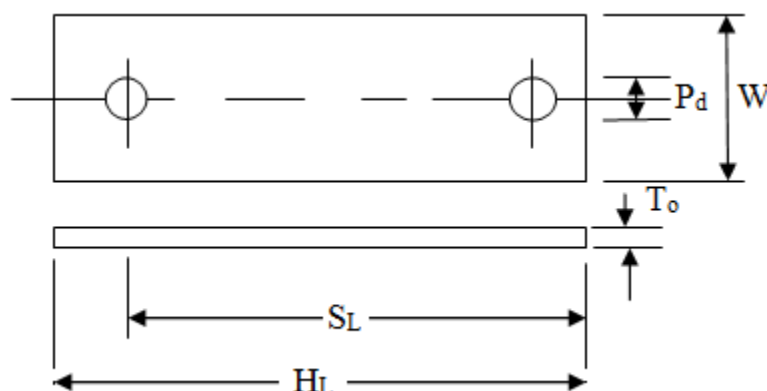


Fig. 3. Schematic drawing showing the dimensions of components of the milling chamber

Table 1. Relationship between throughput and dimension of components in the milling chamber

Throughput Ton/h	Beater Thickness T_o (mm)	Beater Width W_o (mm)	Pivot rod Diameter P_d (mm)	Beater Swing Length S_L (mm)	Beater length H_L (mm)	Sieve Diameter S_d (mm)	Separator Diameter D_o (mm)
0.100	5.00	40.00	10.00	80.00	95.00	300.00	150.00
0.125	5.00	45.00	10.00	90.00	105.00	325.00	162.50
0.150	6.00	50.00	12.00	98.00	117.00	350.00	175.00

0.175	7.00	52.00	14.00	104.00	125.00	375.00	187.5
0.200	8.00	58.00	16.0	116.00	140.00	400.00	200.00
0.225	8.50	60.00	17.0	120.00	145.00	420.00	212.50
0.250	10.00	65.00	20.00	130.00	160.00	450.00	225.00
0.275	10.00	70.00	20.00	138.00	168.00	475.00	237.50
0.300	10.50	70.00	21.0	140.00	172.00	500.00	250.00
0.325	11.00	70.00	22.00	145.00	178.00	525.00	262.50
0.350	12.50	70.00	23.00	166.00	200.00	600.00	300.00

2.2.2 Determination of Rotor Shaft Speed

The rotor shaft speed was obtained from the speed ratio relationship:

$$\left(\frac{d}{D}\right) = \left(\frac{N}{n}\right) \quad (5)$$

where, n = Speed of the driving pulley on the electric motor in rpm; which has diameter “d” mm
N = Speed of the driven pulley (rotor shaft pulley) in rpm which has diameter “D” mm

The speed of a 3-phase, 50 Hz induction electric motor intended for use in this design is taken as 1450 rpm (Enemuoh *et al.*, 2013). If n = 1450 rpm and d = 75 mm, since half of the electric motor speed was desired on the rotor, it follows then that. N= 725 rpm and D = 150 mm.

2.2.3 Pitch length of V-belt on the Rotor Shaft Pulley

The distance ‘C’ between the centres of the two pulleys is assumed as 860 mm being the smallest distance between the rotor and the electric motor pulley. Shigley *et al.* (2004) expressed the pitch length of an open belt drive in mm as:

$$L = 2C + \frac{\pi(D-d)}{2} + \frac{(D-d)^2}{4C} \quad (6)$$

Applying equation (6), L = 2075.1 mm = 81.7 inches. This is equivalent to belt number B-81 using the standard Table for v-belt and load selection (Shigley *et al.*, 2004).

2.2.4 Determination of Belt Tension, Power and Torque Transmitted

For uncrossed belt drives, it is known that the contact angle α_1 and α_2 for the small and large pulley respectively may be expressed as follows:

$$\alpha_1 = 180^\circ - 2\theta = 180^\circ - 2\sin^{-1}\left[\frac{R-r}{C}\right] \quad (7)$$

$$\alpha_2 = 180^\circ + 2\theta = 180^\circ + 2\sin^{-1}\left[\frac{R-r}{C}\right] \quad (8)$$

$$\text{and } \theta = \text{the angle of wrap} = \sin^{-1}\left[\frac{R-r}{C}\right] \quad (9)$$

Substituting the values of “R”, “r” and “C” in equation (5), $\theta = 2.52^\circ$; hence using equations (7) and (8), $\alpha_1 = 3.09$ rad. and $\alpha_2 = 3.23$ rad.

When two pulleys of different diameters are connected by an uncrossed belt, the angle of contact of the small pulley should be considered for determining tensions “ T_1 and T_2 ” of the tight and slack sides of the belt respectively (Khurmi and Gupta, 2006).

$$2.3 \log \frac{T_1}{T_2} = \mu \theta \quad (10)$$

For rubberized v-belts, $\mu = 0.30$; therefore, the ratio $\frac{T_1}{T_2} = 2.02$ (11)

The driven pulley pulls the belt from the tight side and delivers it to the slack side at speed v_1 and v_2 respectively.

where, $v_1 = \frac{\pi d n}{60} = 5.6 \text{ m/s}$, $v_2 = \frac{\pi D N}{60} = 11.39 \text{ m/s}$

According to Khurmi and Gupta (2006), the rubberised Class B type of v-belt material that was selected has the following specifications density, $\rho_{\text{belt}} = 1000 \text{ kg/m}^3$; shear stress, $\sigma_{\text{max}} = 2 \text{ Mpa}$, and belt dimensions, $b = 25 \text{ mm}$ and $t = 15 \text{ mm}$. The belts' pitch length $l = 2075.1 \text{ mm}$. Therefore mass of the belt, $M = b \times t \times l \times \rho_{\text{belt}} = 0.78 \text{ kg}$

However, the maximum tension, T of a belt = $\sigma \times b \times t$
 $= 2 \times 10^6 \times 0.025 \times 0.015 = 750 \text{ N}$.

For greater power transmission, the belt speed, $v_{\text{max}} = \sqrt{\frac{T}{3M}} = 18 \text{ m/s}$

For maximum power to be transmitted, centrifugal tension $T_C = \frac{T}{3} = 250 \text{ N}$

Consequently, belt tension “ T_1 ” on the tight side $T_1 = T - T_C = 750 - 250 = 500 \text{ N}$.

Using equation (11) the tension T_2 on the slack side of the belt, $= 247.5 \text{ N}$

The maximum power that the belt can transmit $P = (T_1 - T_2)v_{\text{max}} = 4.55 \text{ kW}$

Based on the above, the electric motor with the nearest power rating of 5 kW was selected.

Hence, the torque, T_r of the rotor shaft is expressed as $T_r = \frac{P \times 60}{2\pi N} = 65.87 \text{ Nm}$.

2.2.5 Shearing Force and Bending Moment Diagrams

The rotor shaft was considered as been supported at two ends by uniformly distributed load of the beaters gang; the shearing force and bending moment diagrams of which are shown in Fig. 4. The maximum bending moment, M_{max} was taken at point “G” (Khurmi and Gupta, 2006).

$$M_{\text{max}} = 15.3 \times (60 + 180.75) - \left[\frac{0.859(180.75)^2}{2} \right] = 23.36 \text{ Nm}$$

$$\frac{M_{\text{max}}}{I} = \frac{\sigma_b}{y} \quad (12)$$

where $I = \frac{\pi d^4}{64}$, $y = \frac{d}{2}$ and for solid steel shaft the maximum shear stress, $\sigma_b = 100 \text{ N/mm}^2$

Substituting “ I ” and “ y ” in equation (10), $d = \sqrt[3]{\frac{32 \times M_{\text{max}}}{100\pi}} = 13.5 \text{ mm}$

Khurmi & Gupta (2006) recommended a factor of safety of 4 for a steel material under steady load condition. The diameter of the selected rotor shaft = $d \times \text{factor of safety} = 4 \times 14 \text{ mm} = 54 \text{ mm}$, hence a rotor shaft $\phi 50 \text{ mm}$ was selected. The summary of all machine design parameters are shown in Table 2.

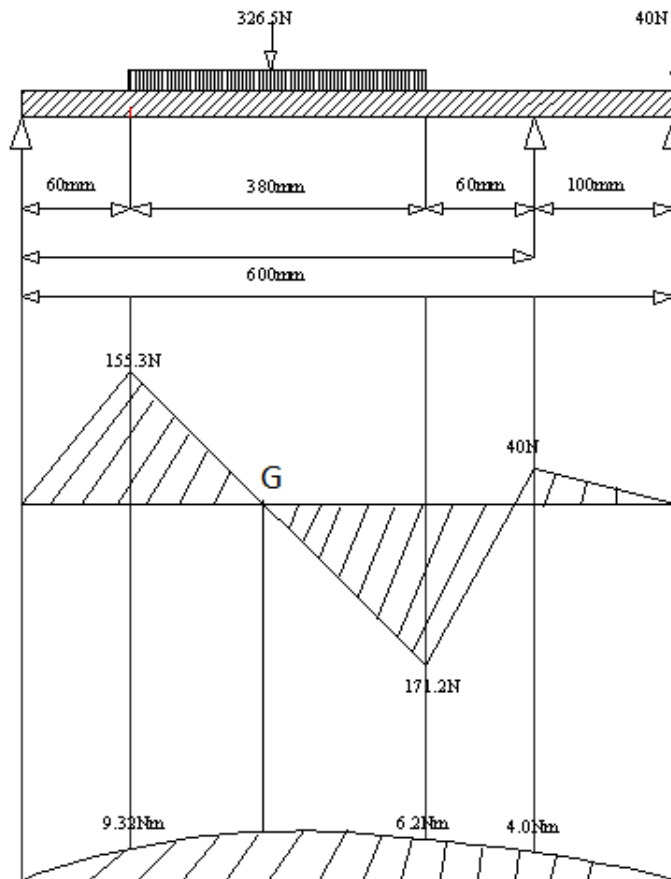


Fig. 4. Bending moment and shear force diagram

Table 2. Summary of machine design parameters

Parameter	Value
V- Belt length, L	2075/81.7 mm/in
Speed of Electric Motor, n	1425 rpm
Speed of Rotor shaft, N	712.5 rpm
Angle of wrap, θ	2.52°
Contact angle for small pulley, α_1	174.96°
Contact angle for big pulley, α_2	185.20°
Tension in the slack side of the belt, T_2	247.5 N
Tension in the tight side of the belt, T_1	500 N
Power transmitted to the shaft, P	5.0 kW
Torque transmitted to the rotor shaft, T_r	67 Nm
Max. velocity of the pulley & belt drive, V_m	18 m/s
Centrifugal force exerted by Beater, F_c	1.1 kW
Weight of Beater, W_b	106 N
Diameter of the rotor shaft, D	50 mm
Weight of the separator plate, W_{sp}	180 N
Weight of the pivoted shaft, W_{ps}	40.5 N

Max bending moment, $M_{\max}$	23.4 Nm
Max shearing force, F_s	171.2 N
Diameter of pivoted shaft, D	24 mm

2.3 Machine Parts Description

Hopper: The hopper is the feeding unit of the mill through which dried CPH is fed into the machine. It is a truncated pyramid made of 6 mm thick mild-steel plate having dimension of 300×400 mm at the top, 160×400 mm basal chute and vertical height of 200 mm. The hopper is inclined at 45° to the horizontal.

The Milling Chamber: The milling chamber is a gang of 27 beaters, swinging on pivoted shafts born by four separator discs which were mounted at 120° space along the circumference and anchored on a rotor shaft. The beaters were held in position by thirty six spacers. The beaters were made of heat-treated high-carbon steel plate of 60 N/mm^2 strength (Juzt and Scharkus, 2003), each having a dimension of $130 \times 55 \times 8$ mm and $\varnothing 25$ mm hole drilled on both ends through which it is pivoted and fixed on the separator disc for easy swinging. Each spacer was a ring, 12 mm in length cut from a seamless steam pipe with inner and outer diameters of $\varnothing 25$ and $\varnothing 35$ mm respectively. Separator discs made of medium-carbon steel plate; 15 mm thickness and cut in circular shapes of $\varnothing 235$ mm each were welded permanently on the rotor shaft. Below these beaters is a half circle-shaped screen of 3.5 mm aperture. The screen is made of a 6 mm thick mild steel plate cut to a size of 420×1320 mm and rolled into a half cylinder. Holes of $\varnothing 3.5$ mm were drilled at 6 mm square distance on the entire plate. This was suspended internally on the bottom of the milling chamber at a radius of 210 mm and 5 mm clearance from the tips of the beater. The rotor shaft, driven by a 7.5 hp, 1450 rpm three phase electric motor; was made of a medium-carbon steel rod of $\varnothing 55 \times 700$ mm, turned to $\varnothing 50 \times 600$ mm and supported by two plummer bearings fixed on the frame. A key-way of $10 \text{ mm} \times 5 \text{ mm}$ was milled on the rotor shaft at a 100 mm distance from one end to fix the driven pulley in place. A transition fit was maintained on both ends for bearing positioning.

The Discharge Unit: The discharge unit is an inclined $200 \times 150 \times 150$ mm chute made of 6 mm thick mild-steel plate welded to the bottom chamber corresponding to the suspended inner plate in which the crushed material flows.

The Frame: The frame is the member which supports the machine. It is made of heavy duty angle-iron cut into 350 mm length and welded to the bottom of the milling chamber at a height of 250 mm to the base. The machine frame occupies a dimension of $1500 \times 1120 \times 600$ mm after assembly.

The orthographic and isometric views of the machine are shown in Fig. 5. The exploded view of the experimental machine and a prototype are shown in Figs. 6 and 7 respectively.

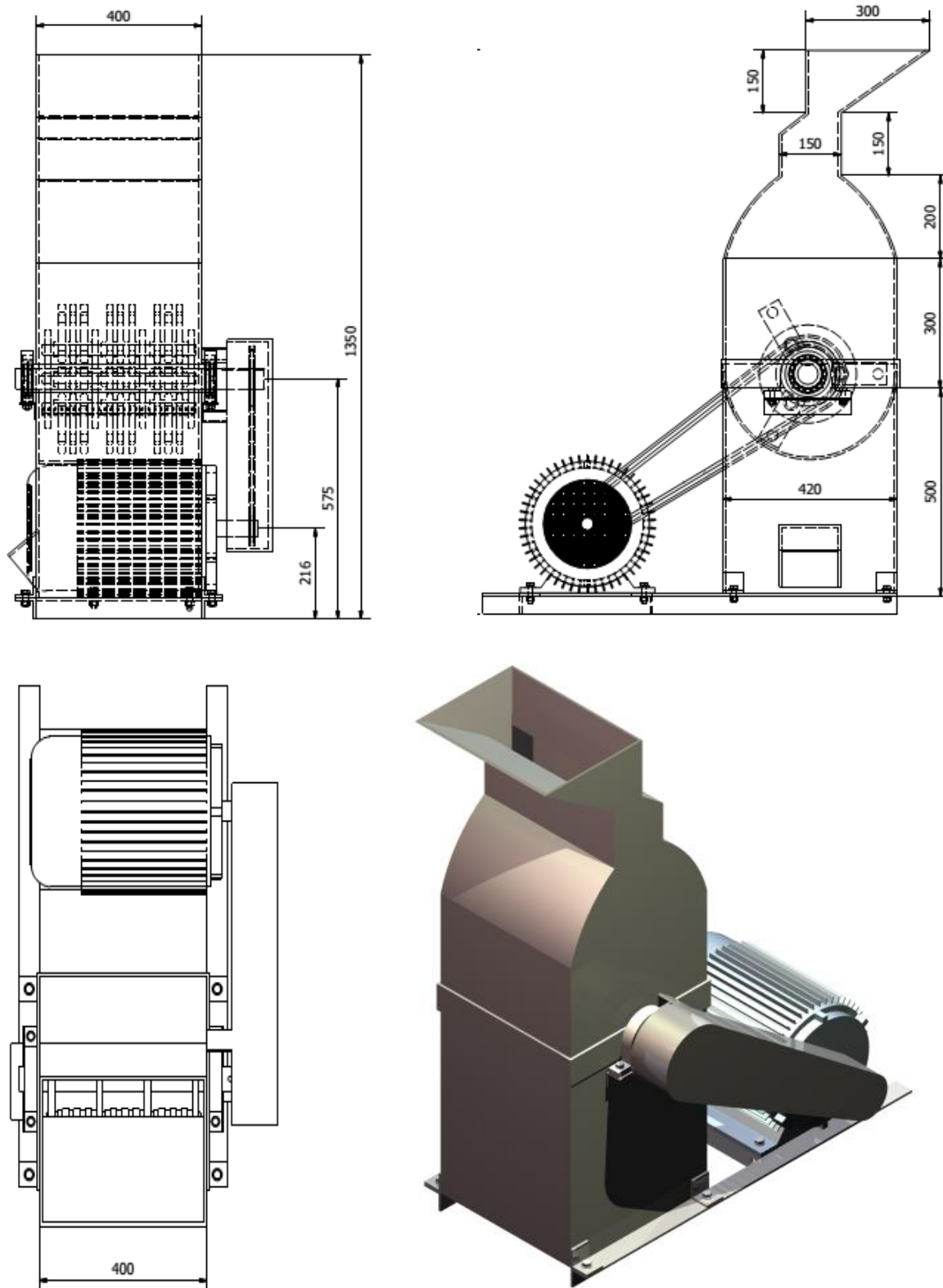


Fig. 5: Orthographic and Isometric Projections of the experimental machine

PARTS LIST			
ITEM	QTY	PART NAME	MATERIAL
1	1	Hopper	Steel, Mild
3	1	Milling Chamber	Steel, Mild
4	1	Rotor, Separator Discs & Beaters Sub-assy	
5	2	Rolling bearing 21310 C GB/T 288-94	Steel, Mild
6	2	Bearing Housing	Steel, Mild
8	8	ISO 7089 - 10 - 140 HV	Stainless Steel
9	4	ANSI B18.2.3.5M - M10 x 1.5 x 35	Steel, Mild
10	4	ISO 4032 - M10	Stainless Steel, 440C
13	1	Sieve	Steel, Carbon
14	1	Discharge Unit	Steel, Carbon
15	1	V-Belt	Rubber
16	1	Grooved Pulley1	Steel
17	1	Grooved Pulley2	Steel
20	1	Frame	Steel, Carbon
23	1	Electric Motor	Steel, Mild
24	1	Belt Guard	Steel, Carbon
25	16	ISO 7089 - 12 - 140 HV	Stainless Steel
26	4	ANSI B18.2.3.5M - M12 x 1.75 x 30	Steel, Mild
27	8	ISO 4032 - M12	Stainless Steel, 440C
28	4	ANSI B18.2.3.5M - M12 x 1.75 x 40	Steel, Mild

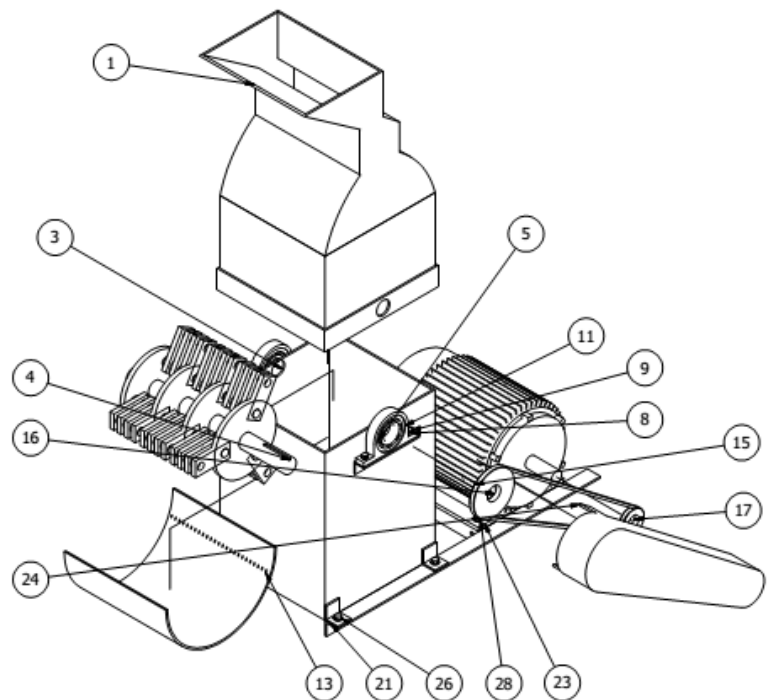


Fig. 6. An exploded view of the experimental machine



Fig. 7. Prototype of the experimental machine

2.4 Performance Evaluation Procedure

The size of pulley on the electric motor was varied in order to test the machine for efficient running speed; the effect of varying speed on machine performance is shown in Table 3. With the same pulley size of 150 mm diameter on both ends, it was observed that the machine vibrated excessively and bulk of input materials (CPH) were thrown out of the hopper. As the pulley size on the electric motor was reduced from 150 to 105 mm, the rotor speed reduced from 1450 to 1015 rpm and there was vibration of machine parts

but no throwing of input materials occurred. As the diameter of pulley on electric motor was reduced further at an interval of 15 mm, there was a corresponding reduction in the rotor speed. However the efficient machine speed was observed when the electric motor pulley diameter was 75 mm; this gave a corresponding rotor speed of 712.5 rpm. At this point, the machine ran smoothly and there was no vibration and material loss was minimal. Further reduction in electric motor pulley diameter below 75 mm resulted in poor machine performance and excessively low output. Therefore the efficient running speed of the machine is 712.5 rpm with an electric motor pulley diameter of 75 mm.

About 950 kg Dried CPH (at 9.56%) obtained from a village near Ipetu-Modu, Osun state, Nigeria were used to test the machine. Machine performance was evaluated on the basis of crushing efficiency, throughput and percent material loss. The electric motor pulley diameter was fixed at 75 mm and the rotor speed at 712.5 rpm during testing. At a feed rate of 4 kg/min, the machine was fed in six successions of 8, 12, 16, 20, 24, 30 and there were three replicates in each run. Crushing efficiency, percentage losses and throughput of the machine were calculated using equations (11), (12) and (13).

$$\text{Crushing efficiency, } \eta = \frac{M_o}{M_i} \times 100\% \quad (11)$$

$$\text{Percentage losses} = \frac{M_i - M_o}{M_i} \times 100\% \quad (12)$$

$$\text{Thoroughput} = \frac{M_o}{\text{Time}} \text{ kg/h} \quad (13)$$

Where M_o = mass of material output and M_i = mass of material input

3. PERFORMANCE EVALUATION RESULTS

The results of the performance evaluation are shown in Table 4. Crushing efficiency, percentage losses and through put obtained are 98.99%, 1% and 239.09% respectively. Percentage loss of 1% may be attributed to particles that flew off out of the hopper and discharge chute during crushing. A thin layer of unrecoverable cocoa pod dust was also noticed on rotor shaft, beaters and the wall of the crushing chamber. Total cost of fabricating the machine is USD 1020.50.

Table 3. Effect of varying speed on machine performance

Diameter of pulley on electric motor, d (mm)	Diameter of pulley on rotor shaft, D (mm)	Electric motor speed, n rpm	Rotor speed N rpm
150	150	1425	1425
105	150	1425	1015
95	150	1425	920
75	150	1425	712.5
60	150	1425	580

Table 4. Test results of machine performance evaluation

Nos of run	Mass of CPH before crushing (kg)	Mass of CPH after crushing (kg)	Time taken (min)	Milling efficiency (%)	% Losses	Throughput (kg/h)
1	8	7.85	2	98.13	1.88	235.50
2	12	11.78	3	98.17	1.83	235.60
3	16	15.81	4	98.81	1.19	237.15

4	22	21.89	5	99.50	0.50	262.68
5	24	23.95	6	99.79	0.21	239.50
6	30	29.88	8	99.60	0.40	224.10
Average						
	18.67	18.53	4.67	98.99	1.00	239.09

4. CONCLUSIONS

A hammer mill for crushing dried cocoa pods into livestock feed has been developed. The machine, which crushes by impact has beaters made of heat-treated high carbon-steel as the major modified component; and was developed from locally available materials. The crushing efficiency, percent losses and throughput were: 98.99%, 1% and 239.09 kg/h respectively. The total cost of producing the machine one-off manufacture was estimated as One thousand and twenty US dollars, fifty cents only (USD1020.50). This work is a significant step in cocoa processing. It offers cocoa processors extra income through value addition to CPH, which hitherto had been a waste in the industry; and lessens competition between man and livestock for maize. Overall, this promises additional source of revenue for cocoa farmers in tropical sub-Saharan Africa where the bulk of world cocoa is produced.

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CAPACITIVE STUDY OF COMBINE FOR HARVESTING RICE IN CHIROMAWA VILLAGE, NIGERIA

A. Akintayo¹, A. E. Adeyemi² and Y. E. Samuel³

¹Department of Agricultural Engineering, Ahmadu Bello University, Zaria, Nigeria
kingafobi@yahoo.com

²Nigerian Stored Products Research Institute, Kano Station PMB 3032, Hadejia Road, Kano, Nigeria
aduadeyemi@gmail.com

³Department of Agricultural and Bio-Environmental Engineering, Nuhu Bamalli Polytechnic, Zaria, Nigeria
elkanahsamuel@gmail.com

ABSTRACT

The capacitive performance of a combine for harvesting paddy rice was investigated in Chiromawa village, northern Nigeria. It was found that the forward speed of the combine during her operation has low value of 0.36 km/h as a result of the roughness of the surface of the rice field caused by the bunks used in making the basins. It was observed that the time for field primary operations of 50% of total field time is low due to the age of the combine. However, the field efficiency of the combine is within the acceptable limit of above 70%. The man-machine productivity and the man-machine performance of the combine in the said location for the investigated harvest season were found to range from 0.15 to 0.38 ha/hr and 0.09 to 0.27 ha/hr respectively. It was also found that there exist a correlation between the forward speed and each of theoretical capacity, actual capacity and field efficiency.

KEYWORD: Combine harvester, theoretical filed capacity, actual field capacity, man-machine productivity, man-machine performance and filed machine-index.

1. INTRODUCTION

Rice (*Oryza Sativa* L) is widely cultivated and consumed as a stable food in many parts of the world. In 1978, the total world rice production was 363 million metric tonnes (De Datta, 1981). While in 2007, world production of rice was 422 million metric tonnes (Kibar *et al*, 2010). This shows 16% increase in the production of rice in the interval of about thirty years. Rice is the second most important cereal after wheat (Kibar *et al*, 2010) and has the immediate lower yield of 2.4 tonnes per hectare after maize which has the highest world average yield of 2.8 tonnes per hectare (De Datta, 1981). Rice is the basic food of two-third of the world population (Kibar *et al*, 2010). Nigeria, with the population of about 170 million, is among the major world consumers of rice. The annum production of rice in Nigeria is 3 million tonnes (Biyi, 2005), this domestic production is augmented by the importation of another 3 million metric tonnes.

The current agricultural transformation agenda of the Federal Government of Nigeria aims at attaining self-sustenance in rice production. For this goal to be achieved there is the need for the mechanization of every stage in the processes of rice production. At the moment in Nigeria, there is a low level of mechanization in the production of rice- from its land preparation to the harvesting stage and even the post harvest stages of threshing and milling of rice (Adu *et al*, 2012). This low level of mechanization has negative effect on the quality and quantity of local rice production in the country. Thus the price of the locally produced rice cannot compete favourably with the imported ones in Nigerian markets.

Almost every process in the production of rice in Nigeria is carried out manually (Adu *et al*, 2012). It must be noted that the harvest of rice in most part of Nigeria is carried out with the aid of handheld sickle, while the threshing is done by flailing handfuls of pinnacles of rice against the body of stationary barrel. Thus the traditional processes of harvesting rice and its threshing are laborious and time-consuming. As a result of drying the harvested crop on farm floors after harvesting and before the threshing, the crop is exposed to contamination from dust, pecking from birds and pilferage (De Datta, 1981).

The traditional methods of harvesting and threshing of rice does not enhance timeliness of the process. Timeliness is an essential factor in the agricultural industry since no other industry is so dependent on season and environmental conditions as agriculture (Hunts, 1983). Hence, there is the need for timeliness in rice production in order to reduce scatter losses on the field. Timeliness would also allow harvesting to be done at the optimum moisture content and as soon as it is deemed fit. For this to be achieved, the manual methods of harvesting and threshing of rice must be replaced with mechanization. The use of combine harvester would allow for the harvesting, threshing, cleaning and even bagging of the product to be carried out at once, which would eliminate the multiple handling of the crop if the processes are to be done separately. These simultaneous operations of harvesting, threshing, cleaning and bagging in one go would also reduce the cost of handling the crop if the operations were to be done differently and lower the losses likely to be incurred in the course of the separate carrying out of the operations. It would also improve on the wholesomeness of the produce for human consumption as the product would be less exposed to contamination from exposure to dust, insects, rodents etc if handled with combine harvester instead of the traditional/manual method.

The objective of this study is to determine the capacitive performance of combine for harvesting rice in Nigeria. It would also determine the man-machine activity and productivity on the use of the combine in Chiromawa village of Chiromawa Local government area of Kano State, Nigeria. It is not in the context of this research to design any experiment for the use of the combine but to rather investigate the capacitive performance of the combine in the way and manner in which the local farmers use the machine on their farms.

2. MATERIALS AND METHOD

The data for this research is gotten by investigating the conventional way the farmers use the combine on their farms. The time used for the primary operation and other support functions were measured and recorded in the 2013 harvest season. There was no modification or any technical advice that was given to the farmers before this study. The farmer were allow to carry out the normal harvesting and threshing of the paddy rice on the field while using the combine in the convectional manner in which they have always done it. The soil type was determined. The moisture content of the harvested crop was also measured. The moisture content was determined using moisture meter. Distances were measured using a tape meter rule. Quartz stopwatch was used to measure the times spent in carrying out each activity. Speed of travelling of the combine was gotten by dividing the distance covered by the time taken to cover the distance.

A special sheet was used to record the time to carry out each activity. The turning time starts when the cutting unit of the combine is lifted to initiate the turning and ends the moment the cutting unit of the combine is lowered again to resume work. Maintenance which took less than 10 minutes was considered as minor repairs and therefore used in this study. But maintenance which took above 10 minutes to carry it out was termed as major and was not used in the study according to Barnes (1960). There were three operators on the combine during its operation. The main operator, the driver, was a man of 43 years of age with about 15 years experience on the job. He also directed the adjustment of all settings and the carried out minor repairs on the combine. The combine was acquired by the farmer 20 years ago and since then it is being used for the harvesting and threshing of rice annually. The field was sectioned into basins and the crop was planted in the traditional way and given the usual agronomic practices commonly used for the planting of rice in the region.

The field was harvested by going round it and not by making a u-turn at the end of the length of the field (Hunts, 1983). Different fields were studied within the same vicinity in the stated harvest reason. The fields have the same weather conditions and have similar soil type and were all owned by the same farmer who also owns the combine and pays for the operations. However, the yields of the fields were slightly different. The fields visited had an average yield of 1.7 tonnes per hectare.

The activity time of the combine on the field was measured using the stopwatch and recorded on the special record sheet. The distance covered by the combine was also measured and recorded. These time and distances were used to determine the speed of the combine while performing its functions on the field. The activities of interest include the performing of the primary function of harvesting and threshing of the crop by the combine which are done simultaneously, the time for other support activities viz; the time for turning, offloading of the paddy, combine maintenance and the private time of the operators. The private time of the operators were the time the combine was stationary for the operators to ease themselves, drink water etc. However, all stoppages which were in excess of ten minutes were not used for the analysis of the capacity performance of the combine. This is according to the recommendation of Barnes (1960). The data were analyzed to determine the theoretical and actual field capacities of the combine, its efficiency, man-machine performance and the field machine index (FMI). Two different methods were used for the determination of the field efficiency of the combine. The first method is the ratio of the actual to theoretical field capacities expressed as a percentage. The second method is the ratio of the time the combine was performing its primary function of harvesting and threshing to total time when the machine engine was actually running.

3. RESULTS AND DISCUSSION

The soil type was tested and found to be sandy loam. The moisture content of the harvested crop was measured using Ohaus MB25 Moisture Meter and it was found to range from 18 to 23% for this study. Table 1 below shows that the speed of operation of the combine is from 0.23 to 0.54 kilometres per hour. The values of the speed of operation of the combine may be said to be low when compared with the results of Alabi (2008) and that of Afolabi *et al* (2012) in their separate capacities study of tractors for tillage operations. While Alabi (2008) got a speed range of 5 to 7 km/h, Afolabi *et al* (2012) had a range of 4.2 to 5.8 km/h. Moreover, the speed is also lower than those of Gwarzo (1975) and Gwarzo (1991) in his field capacitive evaluations of different mobile agricultural machineries. Gwarzo (1975) and Gwarzo (1991) had speed of magnitudes 2.6 to 4.7 km/h and 3 to 12 km/h in his studies respectively. However, this speed range of the combine in this study agrees with those used by Qamar-uz-Zaman *et al* (1992) in their study on a combine for harvesting wheat. The low value of the operational speed of the rice combine harvester may be due to very rough nature of the surface of the field caused by the bunks used in making of basins for the crop.

Table 1: Obtained and Computed Indices for Capacitive Study of Combine

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
0.5	57.8	1.8	11.0	11.0		69.5	0.5	0.3	77.6	0.3	71.8	0.2	96.8	81.7
4	3	9	3	6	1.29	9	1	9	6	8	7	7	4	4
0.3	39.3	1.6			20.0	50.5	0.3	0.2	74.8	0.2	70.9	0.1	95.9	79.8
6	8	6	8.25	8.58	8	2	4	6	4	5	2	8	5	9
0.3	30.0	0.2			32.8	39.9	0.3	0.2	73.4	0.2	71.3	0.1	99.0	78.9
2	7	8	7.72	4.46	4	0	0	2	0	3	6	7	8	9
0.2	30.2	2.8		10.2		53.4	0.2	0.1	70.8	0.1	58.4	0.0	91.4	77.4
3	5	2	5.99	3	7.31	5	2	5	8	5	3	9	7	4

A= forward speed (km/h), B= activity time (min), C= turning time (min), D= personal time of operators (min), E= offloading time (min), F=maintenance time (min), G= percentage time used for primary operation (%), H=Theoretical capacity (ha/hr), I= Actual capacity (ha/hr), J= Capacitive Efficiency I (%), K=Man-machine Productivity (ha/hr), L= Man-machine Activity (%), M=Man-machine Performance (ha/hr), Field-machine Index (%), O= Capacitive Efficiency II (%)

The swath width of 2.6 m was used in this study, which is slightly above the 1.2 to 2.4 m used by Alizadeh and Allameh (2013). Table 1 also shows the times spent for turning, offloading, maintenance and other activities on the field. It is noted that the bulk of the activity time were used for the primary function of harvesting and threshing of the crop (column G of table 1). This shows that an average of fifty percent of the time of the field was spent on the primary function activity. On the third experiment, there was a large

amount of time spent on the maintenance of the combine: this singularly affected the average of the percentage of the time used for the primary functions. The turning time of the combine ranged from 0.30 minutes to 1.89 minutes depending on the available space for manoeuvring at the ends of the field. This turning time range agrees with those obtained by Gwarzo (1975) who got a range of 0.34 to 1.25 minutes for cotton pickers. The other times recorded and shown on the table 1 are the personal time of the operators, offloading and maintenance times.

The offloading time ranged from 6 to 11 minutes depending on the distance of the combine from the point of offloading at the time the combine was to be offloaded and on the volume of threshed material in the tank of the combine at that time. The offloading of the combine was done at the operators' discretion depending on the operator decision and other logistic reasons for offloading. Sometimes, the operators go to offload when the combine's tank is yet to be full just for the operators to have some personal time. Gwarzo (1975) got the ranges of time for dumping and time for travelling to and from dumping point as 0.18 to 6.91 minutes and 0.75 to 5.60 minutes per acre respectively.

The theoretical and actual capacities of the combine are shown on Table 1, columns H and I respectively. The theoretical capacity of the combine was determined from the speed and swath width of the combine. It ranged from 0.22 to 0.51 hectare per hour. While the actual field capacity of range from 0.15 to 0.39 hectare per hour. When converted into hectare per hour, Gwarzo (1975) got 0.4 to 0.7 ha/hr range for the actual field capacity of a cotton picker in Arizona. The low values of the field capacities in this study when compared with Gwarzo (1975) were due to the low forward speed of the combine in this experiment and the difference in the crops. The theoretical and the actual capacity of the combine are plotted against forward speed in the Figures 1 and 2 respectively. The equations and the coefficients of determination of each curve are indicated on the graphs accordingly. The graphs shown linear relationships between each of the theoretical and actual capacities and the forward speed of the combine, the R^2 values are indicative of the co-relationship between the theoretical capacity and the forward speed and between the actual capacity and the operation speed of the combine harvester.

From the actual and theoretical capacities of the combine the field efficiency (column J, Table 1) of the machine was determined. It was found that the field efficiency of the combine harvester is in the range of 73 to 77%. This field efficiency of the combine was found to agree with those of literature (Gwarzo, 1991, Afolabi, *et al*, 2012 and Alabi, 2008). However, the field efficiency of the combine which was found solely from the ratio of activity duration of the combine ranged from 77 to 82%. The results obtained by the two methods are within the range gotten by Gwarzo (1975), who got a range of 54 % to 87.5 % for his study. While Alabi (2008) had 57 to 80% field efficiency and Afolabi *et al*, (2013) had 70.8 to 83.4% for tillage implements mounted on tractors.

The man-machine productivity of the studied combine is also shown in table 1. The range of the value of the man-machine productivity is 0.15 to 0.38 hectare per hour. This result is low when compared with those obtained by Afolabi *et al*, (2012), Alabi (2008), and Gwarzo (1991) for the same parameter. The low value of the man-machine productivity is due to the low value of the forward speed of the combine during the operation. In their studies, Afolabi *et al*, (2012), Alabi (2008), and Gwarzo (1991) got averages of 0.78, 0.90 and 1.23 ha/hr respectively for their man-machine productivities respectively.

The man-machine activity was also computed and tabulated in Table 1. The man-machine activity, in percentage, was found to be about 70%, while higher values have been obtained by other researchers. The low value of the man-machine activity when compared with literature can be put on the age of the studied combine. As a result of the advancement in age of the combine, its components reliabilities have reduced from what they used to be when the combine was first obtained. Therefore, a lot of time has to be spent on the maintenance of the combine as a result of frequent break down. Also, the largeness of the time spent on going to offload and at offloading is another reason for the low value of the man-machine activity value. The man-machine performance, also on Table 1, is low as a result of the low values of the man-machine productivity and activity of the combine.

Figure 1 shows the graph of the theoretical efficiency to the forward speed for the rice combine. The R^2 value is 0.9713, the equation of the relationship is given on the graph. It shows that a correlation exist between the theoretical capacity and forward speed of the combine. Figure 2 is the graph of effective/actual capacity to the forward speed of the combine during its operation. The graph is a linear graph with the R^2 value of 0.9998. The trend also shows that there is high correlation between the effective capacity and the forward speed of the combine. The equation of the relationship is also given on its graph. Figure 3 show the graph of field efficiency against forward speed. This efficiency was calculated as a ratio of actual to the theoretical capacities. The value of the coefficient of determination R^2 is indicative of the correlation between the speed and the field efficiency. Gwarzo (1991) obtained similar graphs in his work where he used a tractor combined with a harrow for harrowing operation. Gwarzo (1975) also had similar trends in his study of cotton picking machines in Arizona, while Alabi (2008) also expressed the same trend.

Figure 4 shows the correlation of two methods used for the determination of field efficiencies of the combine. The first method used the ratio of the actual capacity to effectual capacity express as a percentage. And the second method used the time ration of performing primary activity and total operation time spent working in field. Figure 5 shows the bar chart of the two methods used to determine field efficiency. At all times, the second method gave higher value than the first method. It was found the there existed correction between the two methods and the coefficient of determination (R^2) value was found to be 0.9997. But when the student t-test was used to test if there were significant differences between two methods, the t-test show that there is high significant difference between the two methods used to compute the efficiency.

The field machine index (FMI) on Table 1 is large, ranging from 91.5 to 99%. It indicates that the use of the combine harvester for the harvesting of rice on the field should be encouraged. Figure 6 is the graph of FMI verses turning time: the coefficient of determination and equation of the curve is given on the graph.

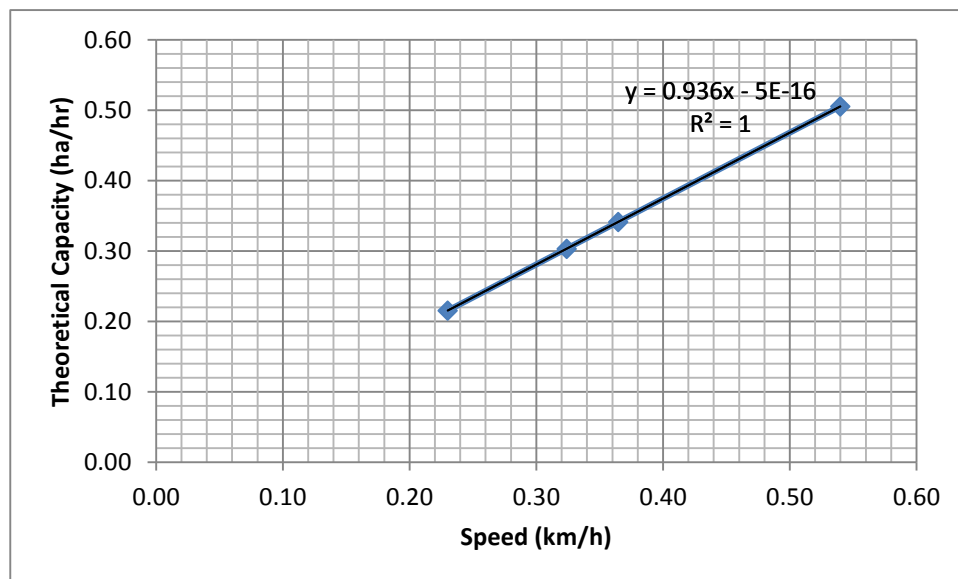


Figure 1: Theoretical Capacity (ha/hr) against speed (km/h)

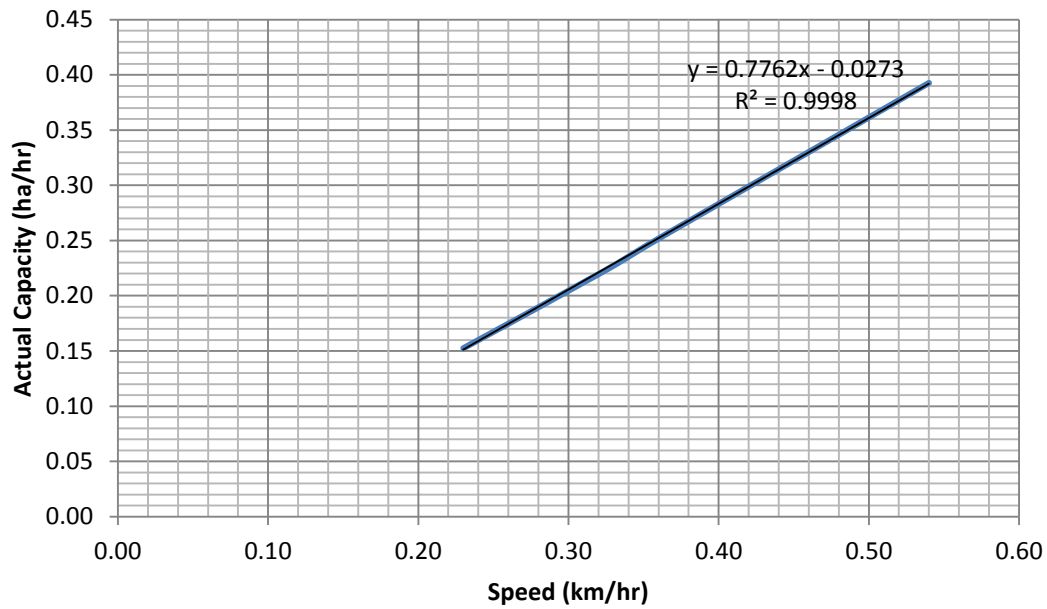


Figure 2: Actual Capacity against Speed

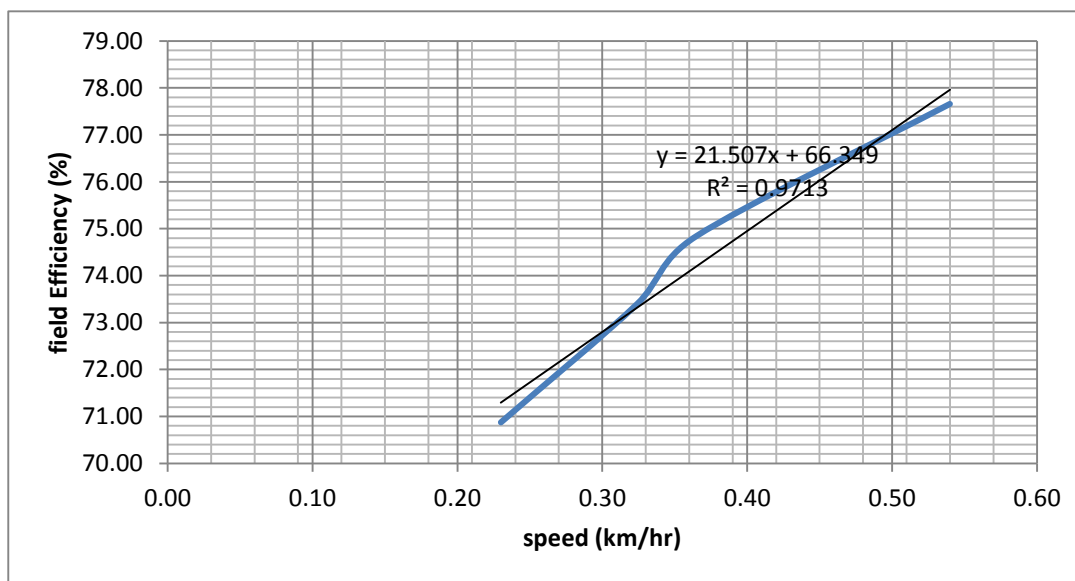


Figure 3: Field Efficiency against Speed of travel

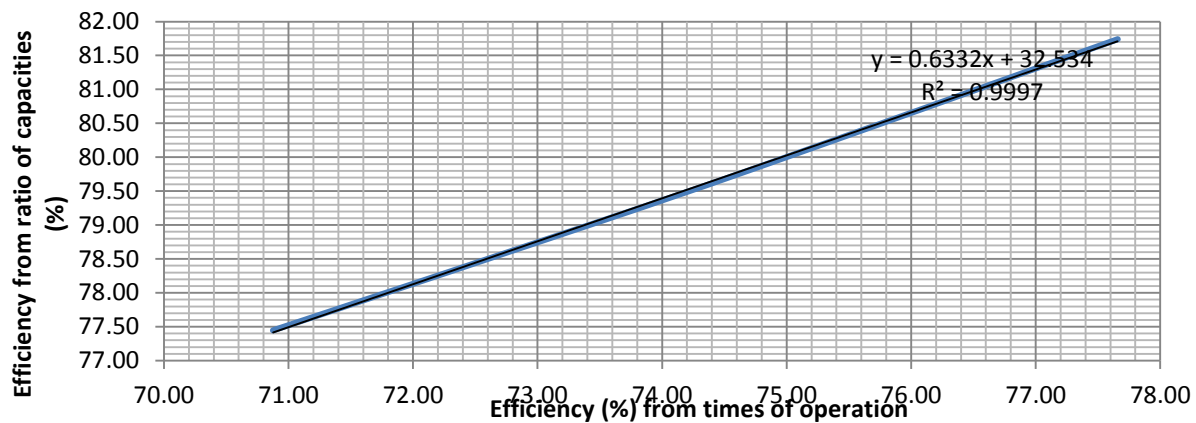


Figure 4: Comparison of two efficiencies

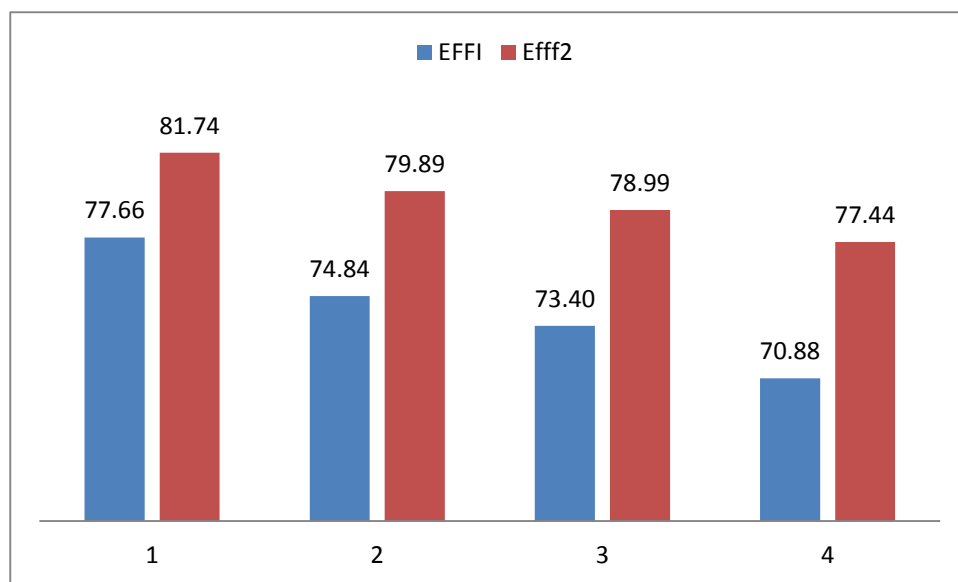


Figure 5: Bar Chart for the comparison of efficiencies

Table 2 t-test results of the methods of calculating efficiencies

SSE	T cal	T tab
1.069	10.29	10.13

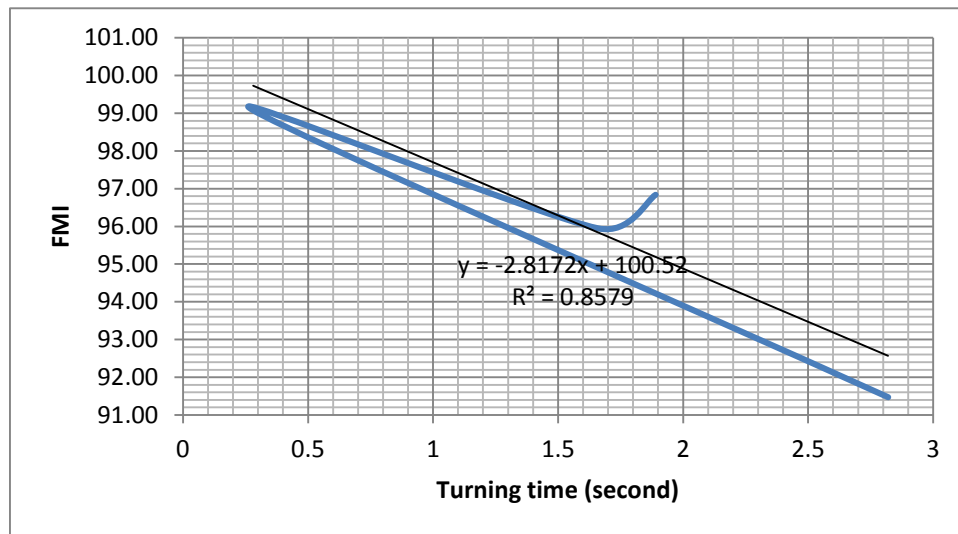


Figure 6: FMI verses Turning time

4. CONCLUSION

The capacitive performance of combine for harvesting rice was investigated in northern Nigeria. It was found that the field capacity of the combine was low due to the nature of the surface of the rice field. The low forward speed of 0.36 km/hr is responsible for the low field capacity of 0.26 ha/hr. Thus it can be concluded that field capacity is dependent on field capacity. The field efficiency of the combine harvest for harvesting rice was found to be above 70%. There exist a correlation between the forward speed of a mobile machine and the field efficiency of the machine. There is significant difference between the methods of determination of field efficiency as a ratio of activities time and as a ratio of actual to theoretical field capacities. Field efficiency from ratio of actual to theoretical field capacities is lower when compared with the field efficiency gotten from ratio of time of primary activity and total field time.

APPRECIATION

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EFFECT OF OSMOTIC DEHYDRATION PRETREATMENTS AND DRYING TEMPERATURE ON DRYING RATE AND QUALITY OF MANGO CHIPS

M. M. Odewole¹, A. M. Olaniyan² and L.A.Olalekan³

^{1,3}Department of Agricultural and Biosystems Engineering, Faculty of Engineering and Technology, University of Ilorin, P.M.B. 1515, Ilorin, Kwara State, Nigeria;

Corresponding author: Email: odewole2005@yahoo.com.

²Department of Agricultural and Bioresources Engineering, Faculty of Engineering, Federal University Oye-Ekiti, P. M. B. 373, Oye-Ekiti 371101, Ekiti State, Nigeria;

Email: amolalan397@yahoo.com

ABSTRACT

Osmotic dehydration pretreatments combined with further drying have been considered a good method of processing fruits and vegetables as it improves their organoleptic properties and makes them safe for storage. In this study, a 3³ factorial experiment in Randomized Complete Block Design was used to investigate the effect of osmotic solution concentration (45% w/w, 55% w/w and 65% w/w), osmotic process duration (30 min, 60 min and 90 min) and drying temperatures (60°C, 70°C and 80°C) on drying rate and quality of dried mango chips. Results revealed that osmotic dehydration pretreatments had significant effect on drying rate and quality of mango chips at $P \leq 0.05$. Osmotic solution concentration reduced the loss of quality (vitamin A and C) with the mean value not dropping below 6.461mg/100g and 80.661mg/100g respectively. However, osmotic process duration and drying temperature increased the drying rate at reduced the drying time. The drying rate however did not drop below 0.416g/hr. Further studies can be carried out on the optimization in order to know the best process conditions suitable for this work.

KEYWORDS: Osmotic dehydration, quality, drying rate, mango (*Mangifera indica* L)

1 INTRODUCTION

Mango (*Mangifera indica* L.) is one of the favoured fruits in the tropical and subtropical regions. It has an excellent flavour, attractive fragrance, delicious taste and high nutritional value that have made it one of the best fruits (Pal, 1998). The fruit is very much relished for its succulent, exotic flavour and delicious taste (Godson, 2008). Mangoes are rich source of beta - carotene, a provitamin A carotenoid that is converted to vitamin A in the body. Vitamin A is an essential nutrient required for normal growth, reproduction, vision and boost body's immunity. Mangoes are also important source of Vitamin C (essential nutrient) which is necessary for normal collagen breakdown and prevents a health disorder called scurvy. It also serves as a cofactor for some enzymes in the body and it is a powerful water soluble antioxidant that prevents free radical damage to cells (Godson, 2008). The species, which belongs to the family Anacardiaceae is native to Asia, particularly eastern India, Burma and Andaman Islands from where it spread to other parts of the world. But while the Persians introduced it to East Africa in the 10th Century, the Portuguese were responsible for its introduction to West Africa in the 16th Century (Morton, 1987).



Figure 1: Fresh Mango Fruits

Osmotic dehydration has received greater attention in recent years as an effective method for preservation of fruits and vegetables. Being a simple process, it facilitates processing of tropical fruits and vegetables such as banana, sapota, pineapple, mango, and leafy vegetables etc. with retention of initial fruit and vegetables characteristics viz., colour, aroma and nutritional compounds (Pokharkar & Prasad, 1998). It is less energy intensive than air or vacuum drying processes because it can be conducted at low or ambient temperature. It has potential advantages for the processing industry to maintain the food quality and to preserve the wholesomeness of the food. It involves dehydration of fruit slices in two stages, removal of water using as an osmotic agent (osmotic concentration) and subsequent dehydration in a dryer where moisture content is further reduced to make the product shelf stable (Ponting, 1973).

Drying is an ancient method of preservation of food and this involves the removal of majority of the moisture normally present in the food by evaporation, or in other cases freeze drying by sublimation under vacuum to yield a dried product. This occurs under controlled conditions of temperature and pressure (Mazza and LeMaguer, 1980). This definition excludes the processes which involves the mechanical extraction of water out of food such as membrane concentration, gravity concentration, and mechanical separation and baking, as these normally removes less water as compared to drying (Treybal, 1980). During drying, water is removed in the form of vapour as heat is supplied to the food material; therefore, heat and mass transfer occur simultaneously. It requires a safe place to spread the food where dry air in large quantities can pass over and beside thin pieces (DeLong, 1979). Drying is achieved by the direct use of energy produced by the sun or from other means of heating such as electricity and fuel, of all these, sun is the most abundant and economical (Treybal, 1980).

Drying is a simple, low-cost way to preserve food that might otherwise spoil. Drying removes water and thus prevents fermentation or the growth of moulds. It also slows the chemical changes that take place naturally in foods, as when fruit ripens. Surplus grain, vegetables, and fruit preserved by drying can be stored for future use. People have been drying food for thousands of years by placing the food on mats in the sun. This simple method, however, allows the food to be contaminated by dust, airborne moulds and fungi, insects, rodents, and other animals. Furthermore, open air-drying is often not possible in humid climates (DeLong, 1979). The objective of this study is to study the effects of pre-drying treatments and drying conditions on drying rate and quality attributes of mango chips. This information should elucidate the problems involved in mango drying and will be useful to establish parameters for industrial drying of mango chips.

2. MATERIALS AND METHODS

2.1 Experimental Equipment and Materials

The following equipments and materials were used for the experiment: electric oven (NAAFCO BS OVH – 102) having a dimension of 66.0cm x 66.0cm x 88.5cm with a load 2.4kw 10 amps, digital weighing balance(CAMRY EHA251) calibrated in grams with 0.1g accuracy, thermometer, stainless steel tray and knife, distil water, sugar and mangoes.



Figure 2: Mango Chips in Oven Drying

2.2 Experimental Design

A 3^3 factorial experiment in a Randomized Complete Block Design (RCBD) was used to investigate some process variables on drying rate and qualities (vitamin A and C) of mango chips. The process variables are: osmotic solution concentration at these levels (45% w/w, 55% w/w and 65% w/w), osmotic process duration (30 min, 60 min and 90 min) and drying temperature (60°C, 70°C and 80°C). All the experimental runs tested and measured in three replicates were 81. The experiment was carried out in the processing laboratory of Agricultural and Biosystems Engineering Department, Faculty of Engineering and Technology, University of Ilorin, Ilorin, Kwara State, Nigeria. All the experiments were conducted in the month of May, 2014 and the average relative humidity of the laboratory was about 28% throughout the period of the osmotic dehydration process.

2.3 Experimental Procedure

Fresh and ripe matured mangoes were purchased from local market in Ilorin, Kwara State, Nigeria for the purpose of this work. The ones without blemish were chosen, washed with clean water, peeled on stainless steel tray using sharp stainless knife and the pulp separated from the pit (stone). The separated pulp was sliced to 5mm thickness (chips). The slices were weighed (50g) and transferred into different prepared osmotic solution concentrations of sugar syrup 45% (w/w), 55% (w/w) and 65% (w/w)] for 30 min, 60 min and 90 min osmotic process durations according to experimental design layout. The pretreated slices were removed after the completion of osmotic process durations, washed with running water and drained. The weight of each sample was taken after osmotic dehydration. A constant weight of 40g each was introduced into the oven for further drying at different drying temperatures of 60°C, 70°C and 80°C and the weight of each sample was taken at an interval of one hour until a safe moisture content for the mango chips was reached (8% - 16%(wb)). Thermometer was used to check constantly the preset temperature inside the oven to ensure that there was significant no change in temperature.

2.4 Output Parameters

2.4.1 Drying Rate

This is the rate of moisture removal per time during the drying process. It can be obtained by determining the moisture content of samples as drying progresses. Mathematically expressed as:

$$DR = \frac{w_1 - w_2}{t} \quad (1)$$

Where: w_1 = Weight of product before drying (g), w_2 = Weight of product after drying (g)
 t = Drying time (hr), DR = Drying rate (g/hr).

2.4.2 Qualities Determination

The qualities (vitamin A and C) were determined in the Chemistry Laboratory of the University of Ilorin, Kwara State, Nigeria using AOAC procedure of 1990.

2.5 Statistical Analysis

The data obtained from the experiment were subjected to statistical Analysis of Variance (ANOVA) at $P \leq 0.05$ in SPSS 16.0 statistical computer software package. A further analysis to compare the means of result among different levels of experimental conditions was also carried out with Duncan's New Multiple Range Test (DNMRT).

3. RESULTS AND DISCUSSION

Table 1 shows the results of the analysis of variance (ANOVA) of the effect of osmotic solution concentration, osmotic process duration and drying temperature on drying rate and quality of mango chips. It can be seen from the table that all the process variables and some of their interactions had significant effect on drying rate and quality of the mango chips at $P \leq 0.05$.

Table 1: Results of the Analysis of Variance (ANOVA) of the Effect of Process Conditions on the Drying Rate and Quality of Mango Chips: A-Osmotic Solution Concentration; B-Osmotic Process Duration; C-Drying Temperature

SV	DF	SS	MS	F	P>F
Drying Rate (g/hr)					
A	2	42.864	21.432	19.169	0.002*
B	2	29.018	14.509	12.977	0.010*
C	2	361.196	180.598	161.537	0.000*
A X B	4	1203.416	300.845	269.100	0.020*
A X C	4	2.200	0.550	0.492	0.320
B X C	4	1.504	0.376	0.336	0.628
A X B X C	8	3.300	0.413	0.369	0.260
Error	54	60.365	1.118		
Total	80	1703.863			
Vitamin A (mg/100g)					
A	2	62.460	31.230	20.600	0.100*
B	2	73.527	18.764	12.377	0.001*
C	2	441.183	220.592	145.509	0.002*
A X B	4	103.416	25.854	17.054	0.020*
A X C	4	2.750	0.688	0.454	0.420
B X C	4	1.880	0.470	0.310	0.526
A X B X C	8	3.300	0.413	0.272	0.160
Error	54	81.857	1.516		
Total	80	770.373			
Vitamin C (mg/100g)					
A	2	52.296	26.148	4.500	0.000*
B	2	53.527	26.764	4.605	0.003*
C	2	541.179	270.560	46.560	0.008*
A X B	4	203.416	50.854	8.750	0.020*

A X C	4	2.750	0.688	0.118	0.320
B X C	4	1.880	0.470	0.081	0.326
A X B X C	8	3.300	0.413	0.071	0.267
Error	54	313.857	5.812		
Total	80	1172.205			

*Significantly different at $P \leq 0.05$

3.1 Effect of Osmotic Solution Concentration on Drying Rate and Quality of Mango Chips

The result of Duncan's New Multiple Range Test (Table 2) revealed that drying rate decreased and later increased as the osmotic solution concentration increased from 45% w/w to 65% w/w with the mean values as shown in the table. This effect could be due to uneven distribution of hot air to samples in the conventional oven used in drying. However, vitamin A and C increased with increase in osmotic solution concentration. The mean values of vitamin A and C did not drop below 6.461mg/100g and 80.661mg/100g respectively at 65% w/w osmotic solution concentration.

Table 2: Effect of Osmotic Solution Concentration on Drying Rate and Quality of Mango Chips*

Osmotic Solution Concentration (% w/w)		45	55	65
Drying Rate (g/hr)		20.105 ^c	18.151 ^b	25.261 ^a
Vitamin A (mg/100g)		2.104 ^b	3.706 ^b	6.461 ^a
Vitamin C (mg/100g)		45.205 ^c	61.151 ^b	80.661 ^a

*In each row, means with the same letters are not significantly different ($P \leq 0.05$) using Duncan's Multiple Range Test

The effect of osmotic solution concentration on drying rate and quality was also determined using histogram as seen in Figures 3–5. From the figures, it is clear that increase in osmotic solution concentration caused a noticeable decrease the drying rate which at 80°C drying temperature, also at this same drying temperature, the drying rate maintained a uniform value of about 0.2g/hr for all osmotic solution concentrations at osmotic process duration 60 min. Furthermore, there was nearly constant rate of drying and sharp increase at 65% (w/w) at 30 min osmotic process duration for 60°C drying temperature. This effect could be due to the presence of dissolved solids in the sugar syrup that has been transferred into the sample which contributed to slow drying rate (Dennis, 1993). Also, the hygroscopic nature of the sugar could influence the final moisture content of the dried product by lowering the rate of drying in the pre-treated samples. In addition crystallization of these solutes especially sugars could minimize the rate of heat transfer during drying (Mazza and LeMaguer, 1980). The Figure explained particularly at 80°C that as osmotic solution concentration increases, the better the retention of Vitamin A which is also confirmed by DNMRT (Table 4.12) that the maximum value of Vitamin A is at 65% w/w osmotic solution concentration with a mean value of 6.461mg/100g. This situation that occurred is one of the advantages of carrying out osmotic dehydration on products before drying to a shelf stable moisture content in a dryer (Pokharkar & Prasad, 1998). The effect of osmotic process duration on vitamin C is also shown. According to the Figure, there was no regular pattern in the effect of osmotic process duration on vitamin C content, but the highest value of above 53 mg/100g was obtained at 45 % w/w with drying temperature 60°C in 90 min osmotic process duration.

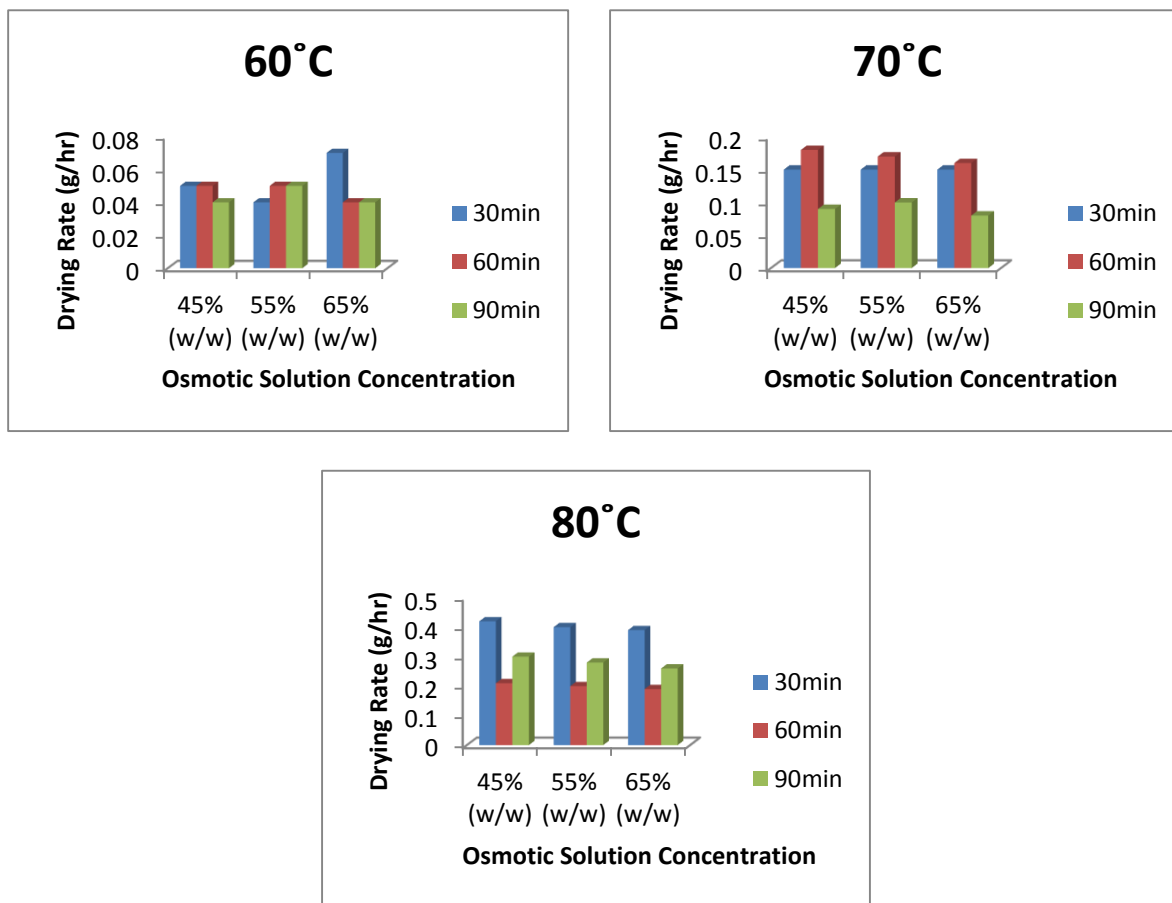
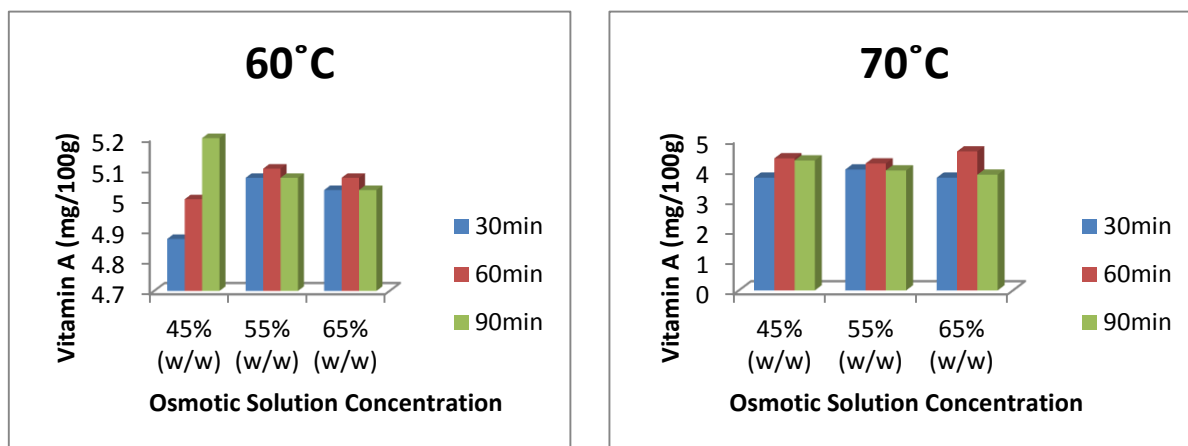


Figure 3: Effect of Osmotic Solution Concentration on Drying Rate at different Osmotic Process Duration for Drying Temperatures of 60, 70 and 80°C.



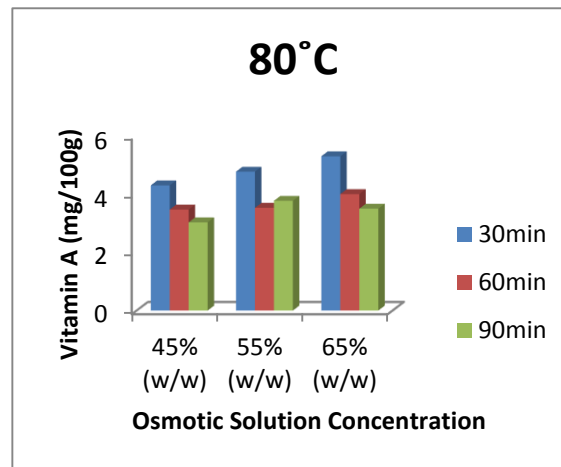


Figure 4: Effect of Osmotic Solution Concentration on Vitamin A at different Osmotic Process Duration for Drying Temperatures of 60, 70 and 80°C

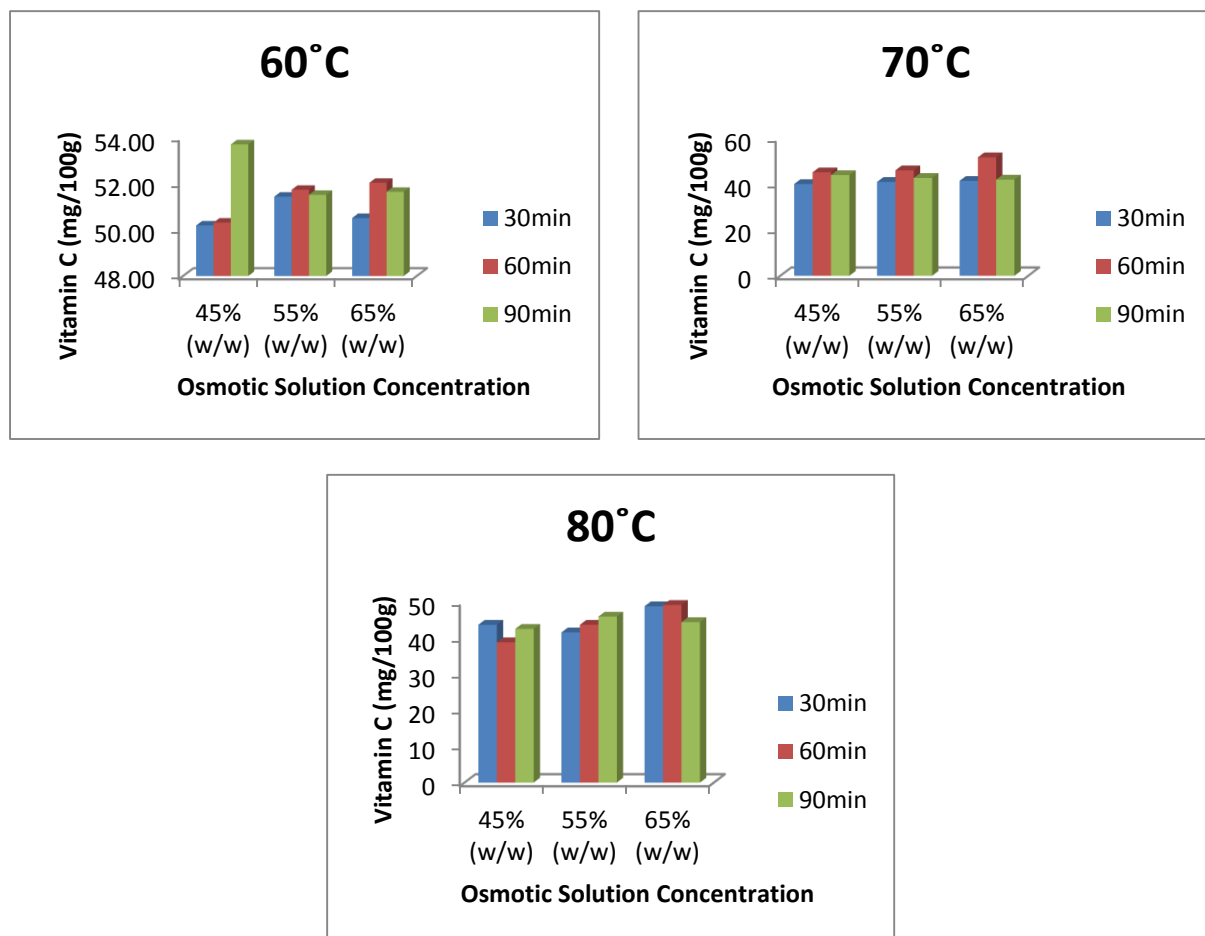


Figure 5: Effect of Osmotic Solution Concentration on Vitamin C at different Osmotic Process Duration for Drying Temperatures of 60, 70 and 80°C

3.2 Effect of Osmotic Process Duration on Drying Rate and Quality of Mango Chips

The result of Duncan's New Multiple Range Test (Table 3) showed that as the osmotic process duration increased from 30 min to 90 min, the drying rate increased as well with mean values as revealed in the

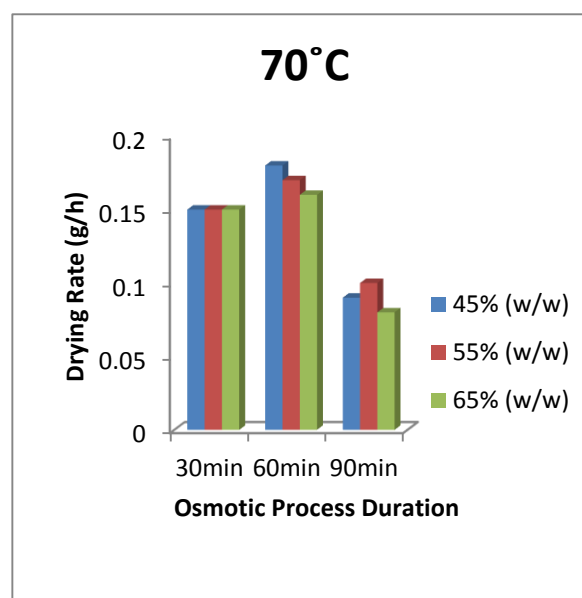
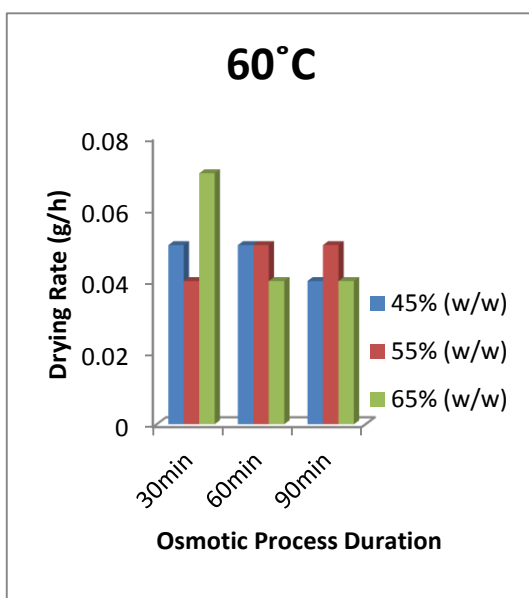
table. This can be expected because increase in osmotic process duration leads to increase in water loss but the rate at which it increases decreases with time as reported by Tiwari and Jalali (2004) which could contribute to high drying rate. The reverse however was the case for vitamin A and C. As the osmotic process duration increased, the values of vitamin C decreased successively but vitamin A increased and later decreased to a mean value of 4.148mg/100g at 90 min osmotic process duration. But the rate of decrease was not really significant as the value of decrease for vitamin C did not drop below approximately 1.30mg/100g and less than 1.0mg/100g for vitamin A.

Table 3: Effect of Osmotic Process Duration on Drying Rate and Quality of Mango Chips*

Osmotic Process Duration (min)		30	60	90
Drying Rate (g/hr)		34.047 ^c	40.181 ^b	51.961 ^a
Vitamin A (mg/100g)		4.013 ^c	4.980 ^a	4.148 ^b
Vitamin C (mg/100g)		22.701 ^a	21.598 ^b	20.144 ^c

*In each row, means with the same letters are not significantly different ($P \leq 0.05$) using Duncan's Multiple Range Test

The effect of osmotic process duration on drying rate and quality was also examined using histogram as seen in Figures 6-8. From the figures, it is seen that there was no steady pattern in response of drying rate to osmotic process duration. As the osmotic process duration increased from 30mins to 90mins, there was a decrease in the drying rate. The only exceptions are at 70°C (where there was sharp increase in drying rate at 60min osmotic process duration) and 80°C (where there was sharp decrease at the same 60min osmotic process duration). These exceptions may be due to factors associated with how the fibre arrangement of individual experimental samples, which also has the tendency of influencing measured responses. The 60°C drying temperature showed almost a constant drying rate. For vitamin A, there was no regular pattern in the way it was affected, but the drying temperature at 80°C showed a decreasing value of Vitamin A as osmotic process duration increased. Similarly, there was no regular pattern in the response of vitamin C to change in osmotic process duration.



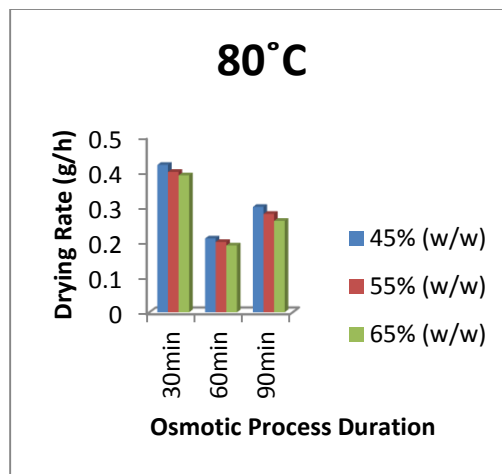


Figure 6: Effect of Osmotic Process Duration on the Drying Rate at different Osmotic Solution Concentration for Drying Temperatures of 60, 70 and 80°C

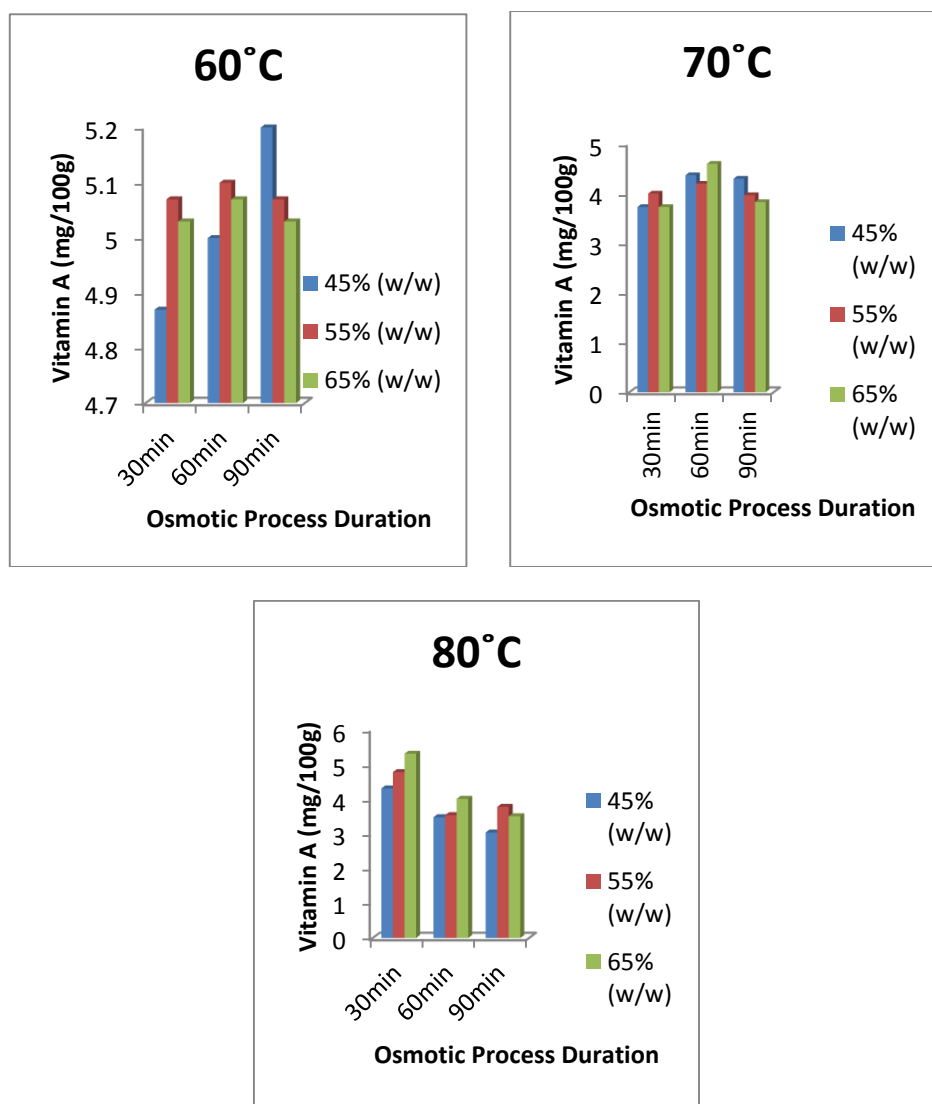


Figure 7: Effect of Osmotic Process Duration on Vitamin A at different Osmotic Solution Concentration for Drying Temperatures of 60, 70 and 80°C

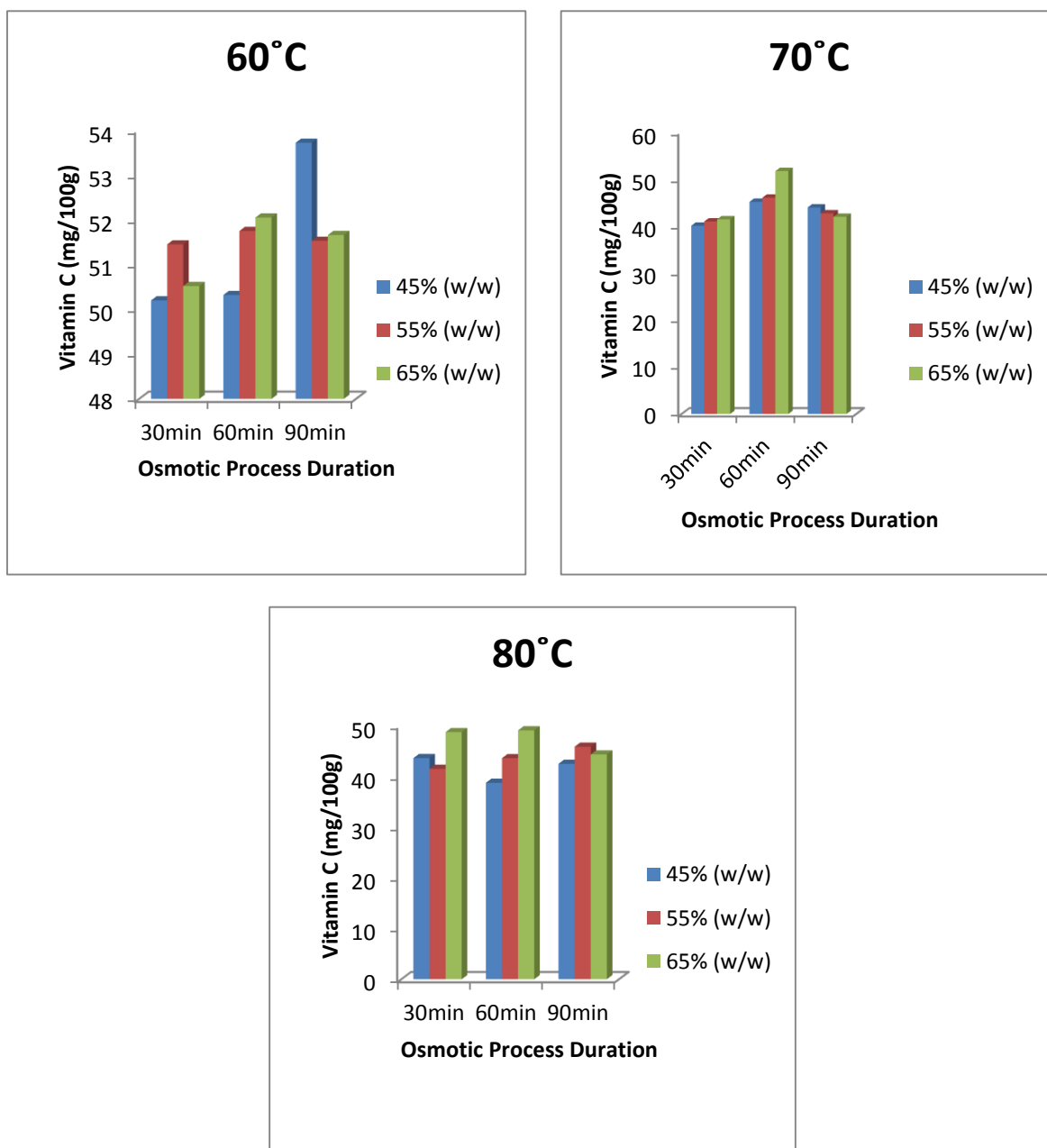


Figure 8: Effect of Osmotic Process Duration on Vitamin C at different Osmotic Solution Concentration for Drying Temperatures of 60, 70 and 80°C

3.3 Effect of Drying Temperature on Drying Rate and Quality of Mango Chips

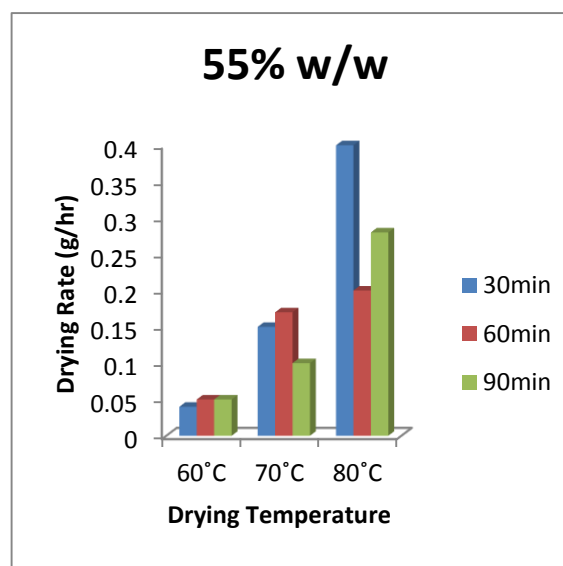
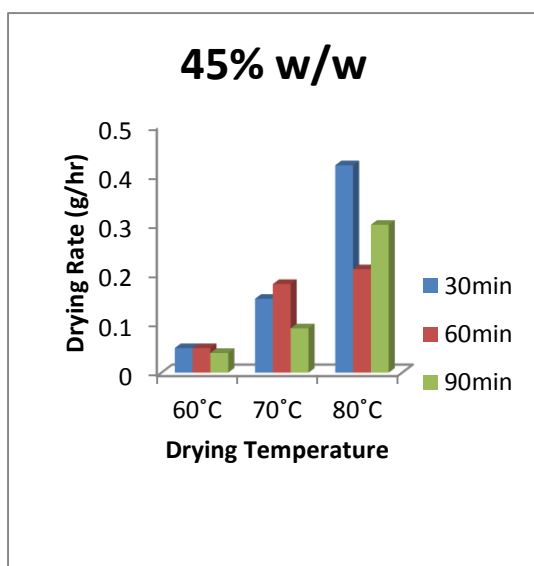
The result of Duncan's New Multiple Range Test (Table 4) revealed that increase in drying temperature resulted in increased drying rate with a mean value of 36.661g/h at 80°C drying temperature all test at $P \leq 0.05$. This could be expected as the moisture diffusion from product to its surface for evaporation to occur will be faster at high temperature which could eventually lead to high drying rate. Increase in drying temperature caused a decrease and later an increase in vitamin A with mean value of 4.068mg/100g at 80°C drying temperature. This result however showed that there was no much difference in the value of vitamin C for 60 and 70°C but falls at 80°C with mean value of 20.143mg/100g. This reduction in vitamins could be due to sensitivity of these qualities to temperature.

Table 4: Effect of Drying Temperature on Drying Rate and Quality Mango Chips*

Drying Temperature (°C)	60	70	80
Drying Rate (g/hr)	21.446 ^c	27.181 ^b	36.661 ^a
Vitamin A (mg/100g)	4.081 ^a	3.145 ^c	4.068 ^b
Vitamin C (mg/100g)	32.231 ^a	29.698 ^{ab}	20.143 ^b

*In each row, means with the same letters are not significantly different ($P \leq 0.05$) using Duncan's Multiple Range Test

The effect of drying temperature on drying rate and quality was also determined using histogram as seen in figures 9-11. From the figures, shown that increase in drying temperatures caused an increase in drying rate; this is usually expected in drying operation because the moisture diffusion from inside of material to the surface for it to evaporate will be faster at higher temperature than at the lower one; this is also seen in Figure 9. Figure 10 showed the effect of drying temperature on vitamin A. The figure gave pictures of slight reduction in of vitamin A values with increase in drying temperatures; this trend is not unusual because higher drying temperatures could lead to loss of essential vitamins. For Vitamin C, increase in drying temperatures caused a decrease in the values of Vitamin C for at various osmotic solution concentrations; however, the drop in Vitamin C values between two adjacent drying temperatures was not sharp. The highest values of Vitamin C (above 50 mg/100g) were obtained at the lowest drying temperature of 60°C for the three osmotic solution concentrations used. The reason for the drop in value of Vitamin C could most likely be the fact that, at higher drying temperature, there is high tendency of destroying heat sensitive vitamins of which Vitamin C is inclusive.



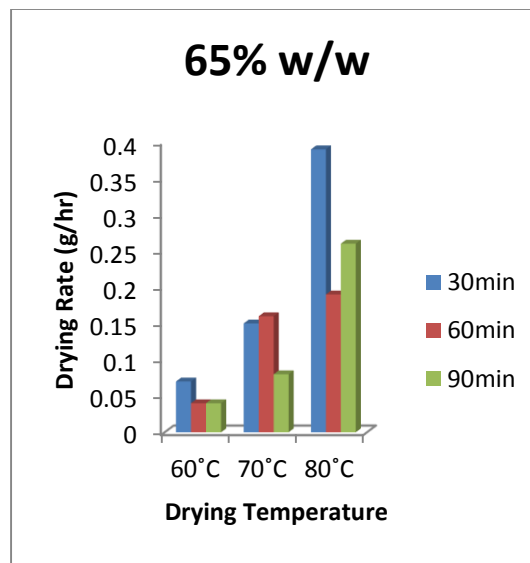


Figure 9: Effect of Drying Temperature on Drying Rate at different Osmotic Process Duration for Osmotic Solution Concentration of 45% w/w, 55% w/w and 65% w/w

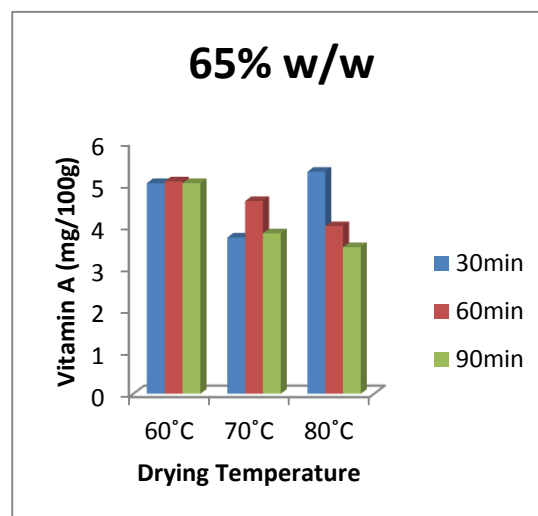
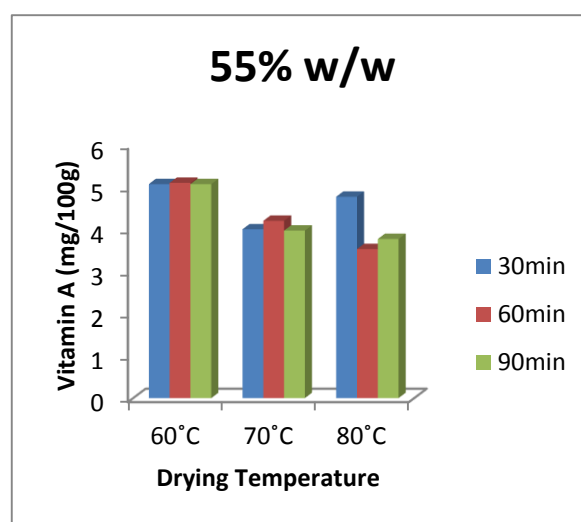
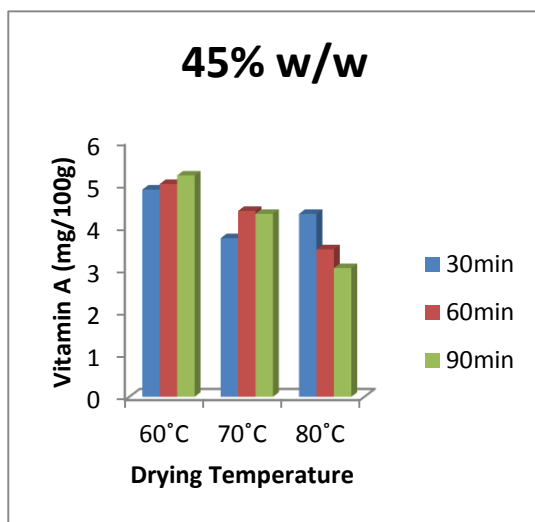


Figure 10: Effect of Drying Temperature on Vitamin A at different Osmotic Process Duration for Osmotic Solution Concentration of 45% w/w, 55% w/w and 65% w/w

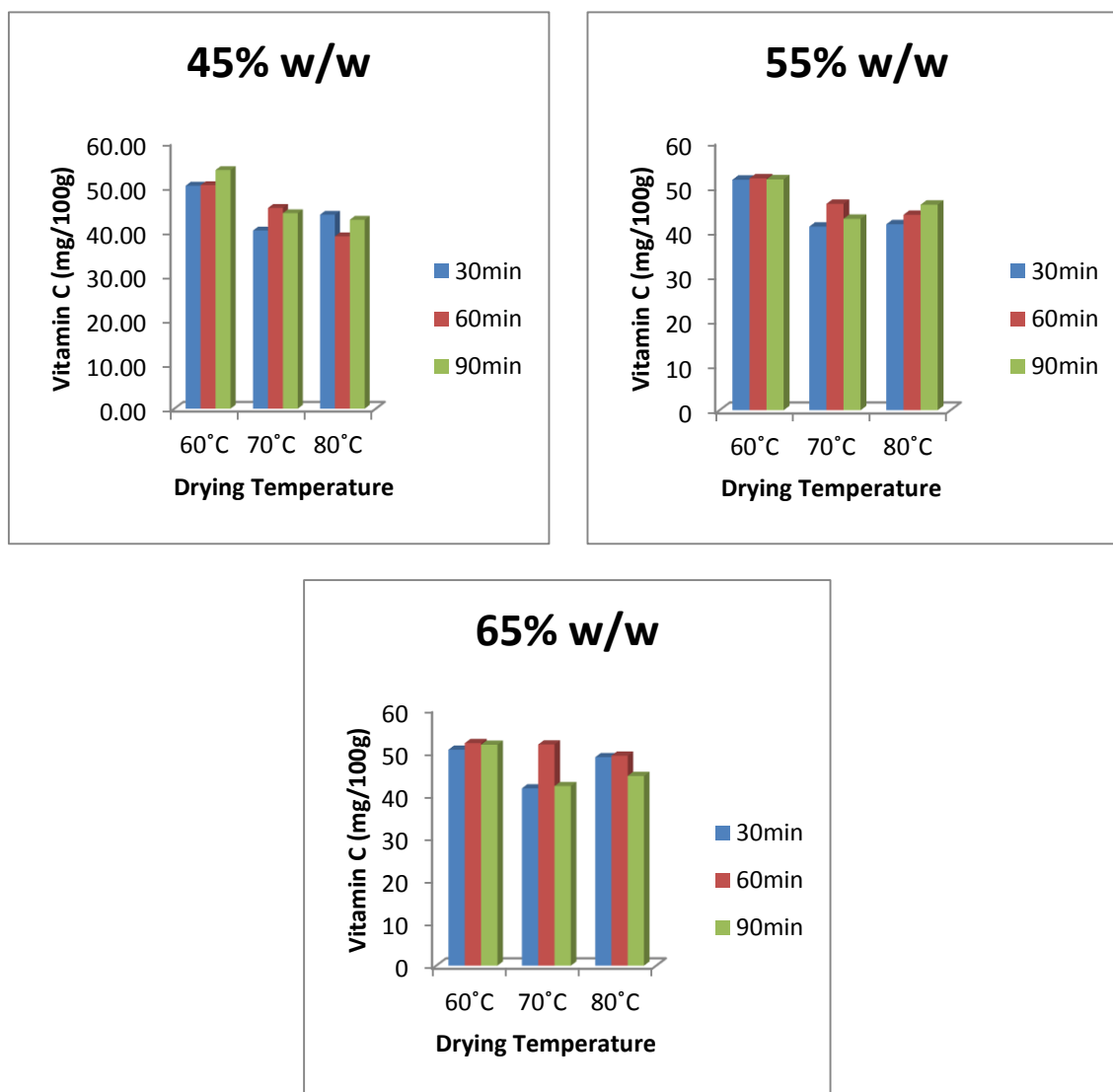


Figure 11: Effect of Drying Temperature on Vitamin C at different Osmotic Process Duration for Osmotic Solution Concentration of 45% w/w, 55% w/w and 65% w/w

4. CONCLUSION

From the study, it can be concluded that all the process conditions considered were significant on drying rate and quality attributes of mango chips. Increase in osmotic solution concentration caused retention of the quality attributes of mango chips whose mean values of vitamin A and C did not drop below 6.461mg/100g and 80.661mg/100g respectively. However, increase in osmotic process duration and drying temperature had slight negative effect on quality attributes of mango chips but led to increase in drying rate whose value did not drop below 0.416g/hr.

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DEVELOPMENT OF CONTINUOUS MAIZE DEHULLING, CLEANING AND MILLING MACHINE

M. C. Ndukwu and C. A. Onyenwoke

Department of Agricultural and Bioresources Engineering

Michael Okpara University of Agriculture, Umudike,

P.M.B 7267, Umuahia Abia State

Email: ndukwumcu@gmail.com, ndukwumcb@yahoo.com

ABSTRACT

A continuous maize dehulling, cleaning and milling machine was developed. The machine consists of three sections for dehulling, cleaning and milling which processes the maize to the desired product. The dehulling speed was 450rpm while the milling speed was 2333rpm. The dehulling efficiency of the machine at initial maize cob moisture content of 0 -1.33% ranges from 61.94% to 77.16% at longitudinal axial dimension of 10-17.7cm and mass of cob range of 58 – 116.66g, while the throughput capacity ranges from 13.32 to 23.4kg/hr for the same range of axial length and weight. The axial dimension and weight of the cob affected the dehulling efficiency and throughput capacity. The efficiency of dehulling decreased with increase in the axial length and reached the minimum of 61.94% at 13.6cm before it started to increase again reaching the maximum of 77.16% at 15.5cm. The sieve analysis showed that the product from the mill consists of fine flour, coarse flour, broken grain and whole grain. The milling efficiency ranged from 38.91 – 50.86% with a throughput capacity of 37.84 – 50.89kg/hr.

KEYWORDS: Dehulling, cleaning, milling, maize, design

1. INTRODUCTION

Maize botanically known as “Zea mays” is a tall grass that has large ears with many seeds and belongs to the family gramineae. It is the most important crop grown in many countries of the world after wheat (Simonyan et al., 2010; Okaka, 1997). It has a wide variety of food uses and rank second after wheat in world grain production (Hawkworth, 1985; Purse Glove, 1992; Osagie and Eka, 1998). The kernels (grains) can be eaten directly or used as components of many food products. Yellow dent is used primarily as livestock feed while white dent is used for human consumption as meal and cereals. Maize is also used in the manufacturing of non food products including ceramics, drugs, paints, paper goods and textiles (Benton Jones Jr, 2003). Maize can be processed into different products for various end uses at tradition level and on an industrial scale. Large proportion of agricultural products utilized in developing countries is processed manually. However, significant changes are occurring throughout the developing countries in the processing of grains for major uses. The tendency is the adoption of simple processing machine for shelling, cleaning and milling. Maize processing starts mainly from harvest and the bulk of the processing work is done on its dehuling of the kernels from its cob, cleaning of the kernel before it is processed into another form for consumption or storage. These operations are done manually with hand and with some traditional methods, using hand tool which make the process laborious, less productive, time consuming and it does not support large scale post harvest processing, especially for commercial and industrial purposes. However it has been observed that some areas in Nigeria uses mechanical method to dehull and mill their maize, but most of the existing machine were designed for a single unit operation. This slows down the rate of processing and involves series of machines for each unit operation. These machines occupy valuable spaces and are not cost effective. Also valuable time is wasted in moving the processed maize from one machine to the other.

This research paper presents a low cost combine maize dehauling, cleaning and milling machine for small holder farmers in Nigeria. The improvement, production, adoption and commercialization of this locally produced prototype combine maize dehuling, cleaning and milling machine will not only save foreign

exchange for the country but will also create job for the teeming youths of this country. It will also save power and cost of performing different unit operation and accommodate a lesser space in the farm.

2. MATERIALS AND METHODS

2.1 Design Considerations

Engineering design has to do with the various activities that lead to proper and effective development of machines and engineering processes. In the design of the combined maize dehuling, cleaning and milling machine, the following factors were considered:

1. Strength of material should withstand the forces acting in the various component of the machine
2. Reduction in drudgery associated with the traditional method of dehuling and milling
3. Higher capacity than the traditional method of dehuling and milling
4. Physical and aerodynamic properties of the maize and the chaff as a falling body was considered
5. Form and size of the machine based on human ergonomic and anthropometry
6. More efficient use of power, space and time in unit operations in the farm

2.2 Components Design

The various components were designed based on the established relationship as presented in the machine design text book by Khurmi and Gupta (2007).

Hopper Design

The hopper was designed to accommodate the maximum linear dimension of maize (17.7cm) determined by preliminary measurement of the cobs during the determination of the physical properties of the maize and the cobs.

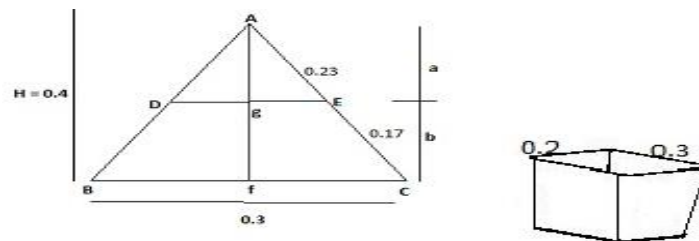


Figure 1. Outline of the hopper

The hopper is in the form of an inverted frustum of a pyramid BCDE (Fig. 1). Therefore the volume of the hopper is the difference of the two rectangular based pyramids with side ABC and ADE. Therefore the volume of the hopper was calculated as 0.006757m³.

Dehauling Barrel

The dehauling unit comprises of the dehauling barrel made up of a cylindrical drum lined horizontally with round galvanized steel bars (Fig. 2). Thickness of the galvanized steel bars was calculated by assuming that the projections of the bars are cantilevers (Ahemen and Raji, 2008). If the shear stress at the bottom of the projection is τ , the horizontal force F (force at removal of maize kernel) per unit length of projection L, is given by the following expression, Stephens (1988):

$$F = \tau tL \quad (1)$$

Where t is the thickness of steel sheet/plate/bars required, L is 2 mm (measured), and F is 728.52 N (Ahemen, 2008). Using the maximum shear stress theory on failure relationship stated by Krutz *et al.* (1984)

$$\tau = \frac{1}{2} \text{ tensile stress} \quad (2)$$

The ASTM-A621 AISI-DQ gave the tensile stress of low carbon steel as 430 MPa (430 N/mm²). Therefore the shear stress at the foot of the projection is calculated as 215 N/mm². Substituting the values into Equation 1, gives the dehulling barrel bar thickness as 1.7 mm. The total weight of the dehulling drum assembly was obtained as 33.6 N.

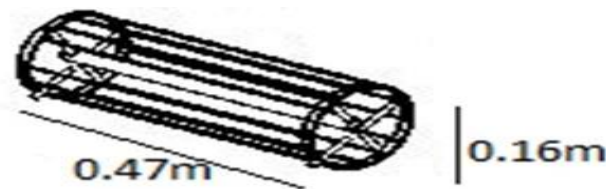


Figure 2: Outline of the dehulling drum

The dehulling barrel has the shape of a cylinder. Therefore the volume is given by

$$V = \pi r^2 h \quad (3)$$

$$V = 0.00945 \text{ m}^3$$

Circumference of the base of the barrel

$$\text{Circumference} = 2\pi r \quad (4)$$

Circumference is calculated as 0.0527m

Belt Design

The configuration of the belt is shown in Fig. 3

Diameter of driver (D_1) = 80mm = 0.08m

Diameter of the driven (D_2) = ?

Number of turns of the driver N_1 = 1200rpm (electric motor speed)

Number of turns of the driven N_2 = 450rpm. This is selected since the dehulling speed that will give low maize damage, but high dehulling output is between the range of 300-650 rpm (Fashina and Abdulahi, 1994)

$$\frac{N_1}{N_2} = \frac{D_2}{D_1} \quad (5)$$

Therefore D_2 is calculated as 0.213m

Length of belt (L) is given by

$$L = \frac{\pi}{2} (D_1 + D_2) + 2x + \frac{(D_1 - D_2)^2}{4x} \quad (6)$$

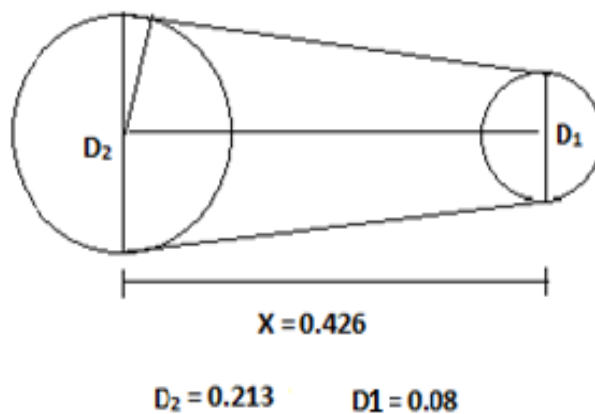


Figure 3: Belt outline

X is the center distance

Therefore L is calculated as 1.3226m

Angle of lap (θ) is given by

$$\theta = (180 - 2\alpha) \pi / 180 \quad (7)$$

θ is calculated as 2.823 rad.

Tension on the belt is given as

$$2.3 \log \frac{T_1}{T_2} = \mu \theta \csc \beta \quad (8)$$

μ = coefficient of friction between the belt and pulley

T_1 = Tension on the tight side of the belt

T_2 = Tension on the slack side of the belt

β = Groove angle of pulley.

The coefficient of friction for rubber belt on cast iron or steel operating on dry surface is $\mu = 0.3$ (Ogunwede 2003).

Using groove angle for v-grooved pulley for belt type A

$$2\beta = 34^\circ$$

Therefore $\beta = 17$

$$T_2 = 18.1677 T_1$$

$$T_1 = T - T_c \quad (9)$$

T is the maximum tension on the belt, T_c is the centrifugal tension on the belt

$$T_c = Mv^2 \quad (10)$$

Where M is the mass of the belt (mass = Area x length x density)

V = Velocity

$$T = \delta \times a \quad (11)$$

δ is the allowable stress

Area was calculated as 104 mm^2

T_c was calculated as 3.466N

Assuming allowable stress 2Nm^{-2}

T was calculated as 208N

T_1 was calculated as 204.53N

T_2 was calculated as 11.26N

Power transmitted by belt

$$P = (T_1 - T_2) V \quad (12)$$

P was calculated as $972.148\text{kw} \sim 1.303\text{hp}$

Design of Shaft

Bending moment of shaft due to the belt tension

$$M = (T_1 + T_2 + 2T_c) \times 2d. \quad (13)$$

M was calculated as 95Nm

Equivalent twisting moment

$$T_e = \sqrt{(T^2 + M^2)} = \pi/16 \times \tau \times d^3 \quad (14)$$

Where d is the diameter of the shaft and τ is Share stress

$$\text{But } T = \frac{\text{power} \times 60}{2 \times \pi N_2} \quad (15)$$

T_e is calculated as 95Nm

Maximum permissible stress for shaft with allowance for key ways = $42 \text{ MPa} \sim 42 \times 10^6 \text{ Nm}$

d was calculated as 23mm but 25mm was used given a 2mm factor of safety.

Force Required to Dehull Maize

$$F = m \omega^2 r \quad (16)$$

where:

F = centripetal force;

m = mass of dehuller

ω = angular velocity;

r = radius of dehuller.

F was calculated as 623.267N

Determination of Dehulling Torque

The torque, T , is given by:

$$T = F \times r \quad (17)$$

where:

F = Force available on the dehuller

r = radius.

T was calculated as 49.8614 Nm^{-1}

Power Delivered by Shaft along the Length of the Dehuller

The power is given by

$$power = (T_1 - T_2)v \quad (18)$$

The power is calculated as $727 \text{ W} = 0.727 \text{ kW}$

2.3 Design of the Milling Section

The various equation applied in the designing of the shaft for the dehulling section was also applied in the milling design the following results were derived

N_1 = Rotational speed of electric motor = 1200rpm

D_1 = Diameter of driver = 0.08m

D_2 = 0.0411m

N_2 = 2333rpm

L = 0.858 m

Angle of lap (θ) = 3.05 rad

Tension on the belt

$$T_1 = 290.5 \text{ N}$$

T_2 = 6.72N

Power transmitted by belt p

P = 1662.95W

d = 14.5mm

2.4 Design of the Cleaning Section

The terminal velocity of the maize kernel and the chaff which is a function of their weight was used in the design of the cleaning section. The cleaning basically involves the use of blower. The air velocity should be in between the terminal velocity of the two materials to be separated. The terminal velocities were calculated with the equation given by Sitkei (1986)

$$V_{cv} = \sqrt{\left(\frac{2Gg}{C_w A \rho}\right)} = \sqrt{\left(\frac{4d \rho_w w g}{3C_w \rho}\right)} \quad (19)$$

Where V_{cv} is the terminal velocity of the particles

G is the resistance force identical to the weight of the body

d is the diameter of the particle

ρ is the density of the air

ρ_w is the specific weight of the particles

A is the cross sectional area

g is the acceleration due to gravity

w is the weight of the particles

C_w is the drag coefficient calculated from the Reynolds number

The air flow rate at the chute outlet is calculated from the continuity equation

$$Q = AV \quad (20)$$

A is the area of the fan blade

V is the air velocity

2.5 Description of the Machine

The machine figure 4 and 5 consist of three sections for dehulling, cleaning and milling. The hopper, dehulling components, the cleaning components and the milling components are supported by a steel frame made of angle steel bar of 50 mm x 50mm x 5mm. The frame support the entire weight of the machine. The blower and dehulling barrel were fabricated from 1.6mm gauge iron plate. The first section is the dehulling section which removes the maize kernel from the maize cob. The maize cob is fed through a hopper in the shape of an inverted frustum of a pyramid made up of 2.5mm mild steel plate that is welded at an angle of repose of 27° (Richey et al., 1961) to 2.5mm gauge cylindrical barrel. The maize cob moves by gravity into the dehulling chamber. The dehulling chamber consists of the housing barrel made of 1.6mm gauge mild steel and a rotating dehulling drum lined horizontally with a 1.7mm thick round iron bars to remove the maize kernel from the cobs. The dehulling drum is powered by the electric motor through the v- belt and 25mm gauge mild steel shaft. The smooth round horizontal bars on the drum strike the maize on impact and detach the grains from the cobs. The dehulled maize and the chaff pass through a sieve with 6mm round hole size (Olugbogi, 2004) located directly under the dehulling barrel while the cob is transported by gravity through a discharge chute. The dehulling barrel was inclined to allow the cob to move by gravity out of the housing barrel. The grain and chaffs leaving the sieve falls by gravity into another collector chute which discharges into another inclined chute located below a centrifugal blower. The blower is constructed with iron plate to generate enough air streams that can overcome the terminal velocity of the chaff. The blower is driven by a pulley via pulley and belt assembly and powered by the electric motor. As the grains and chaff falls into this chute, the blower cleans the grain by winnowing the chaff while the grain falls into the inclined chute and moves by gravity into the milling hopper. The milling shaft passes through the mill hopper into the milling chamber. The portion of the milling shaft inside the mill hopper is attached worms which helps in agitating the maize kernel and also convey them into the milling chamber. The milling chamber consists of attrition disc or burr, which and consists of one adjustable and one rotating hard surface circular plates, which rotates with relative motion that reduces the grain size to fine flour. The size of the product depends on the clearance between the plates. The milled maize leaves the final discharge chute where they are collected and bagged. All the moving components of the machine derive their power from a single prime mover (3hp electric motor)



Figure 4. The combined maize dehulling, cleaning and milling machine

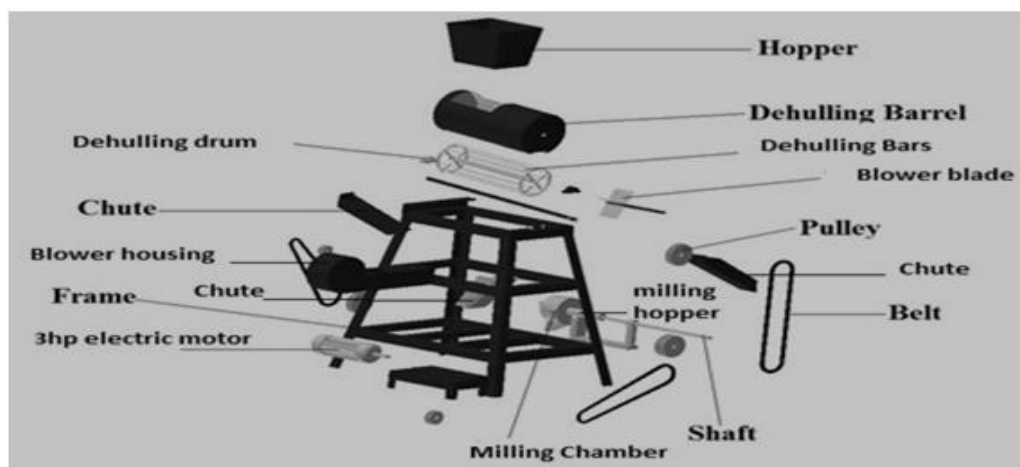


Figure 5: Exploded view of the combined maize dehulling, cleaning and milling machine

2.6 Performance Test Procedures

A bulk sample of threshed and dried cobs of yellow maize variety was procured from the open market near Umudike Nigeria. They were examined to ascertain the quality. Some samples were collected to determine the initial moisture content. The moisture content ranged from 0.5 – 1.33%w.b. The maize cobs were grouped based on its length and intermediate diameter after determining some of their physical properties. The maize cob within the length range of 9.6 - 17.7cm which forms the mode of the distribution was selected. The machine was evaluated based on dehulling time, weight of completely removed grain, weight of grain remaining on the cob, at different feeding weight and moisture content at a constant operating speed. Before the dehulling, the machine was switched on and run on no load for 15minutes to enable the machine to stabilize. The maize cob was fed through the hopper one after the other. The stopwatch was used to time the dehulling and milling. This was completed in triplicate. The weight of the completely removed grain and grain remaining on the cob and the time of dehulling were recorded and used in performance evaluation. Also the milled flour was sieved to separate the fine, coarse, whole and broken grain.

2.7 Performance Criteria

Throughput Capacity and Efficiency

Throughput capacity and efficiency for the dehulling were calculated using the formula according to (Onwualu et al., 2006). The throughput capacity (T_p) in kg/hr is given as

$$T_p = \frac{W_a}{T_t} \quad (19)$$

Where W_a the total weight of material handled, which include dehulled and unde-hulled maize grain.

T_t is the total time taken in handling the material

The efficiency is the percentage of the ratio of the total weight of grain actually handled W_a (kg), to the total weight of grain removed from the cob W_t (kg)

$$\eta = \frac{W_t}{W_a} \times 100 \quad (20)$$

$$\text{Milling efficiency} = \frac{\text{Coarse flour} + \text{Fine flour}}{\text{Total milled sample}} \times 100 \quad (21)$$

3. PERFORMANCE EVALUATION RESULTS

The result of the test of the performance evaluation of the prototype motorized combined maize dehulling, cleaning and milling machine is shown in Figures 6, 7, 9 and 9 at different axial length, weight, moisture content and speed of 450 rpm for dehuller and 2333 rpm for milling. Figure 6 and 7 showed that the dehulling efficiency ranges from 61.94% to 77.16% at longitudinal axial dimension of 10-17.7cm and mass of cob range of 58 – 116.66g, while the throughput capacity ranges from 13.32 to 23.4kg/hr for the same range of axial length and weight. The axial dimension and weight of the cob affected the dehulling efficiency and throughput capacity. The efficiency of dehulling decreased with increase in the axial length and reached the minimum of 61.94% at 13.6cm before it started to increase again reaching the maximum of 77.16% at 15.5cm. However the dehulling throughput capacity increased with increase in axial length of the cob reaching the maximum value of 23.4kg/hr at 13.4cm. The dehulling efficiency also decreased with increase in cob weight. The efficiency of milling was calculated at the first milling run. The sieve analysis showed that the product from the mill consists of fine flour, coarse flour, broken grain and whole grain. Although the cobs could be regarded as dry cobs (0-1.33%), however the individual moisture content varied and this was considered when analyzing the milled product at the first milling run. Moisture content and the weight of the grain affected the milling efficiency and throughput as shown in Figure 8 and 9. The milling efficiency ranged from 38.91 – 50.86% with a throughput capacity of 37.84 – 50.89kg/hr. The milling efficiency increased with increase in moisture content and weight of maize grain while the throughput capacity decreased with the weight of maize grain at the first run of milling. The increase in milling efficiency might be because of the moisture content of the maize grain which is almost 0%. The cleaning efficiency of the grain was evaluated by visual examination of the preliminary run with the mill hopper closed and dehulled maize grain collected in small plastic bowl. The grain was approved to be clean by several observers. The values above show a good performance for the motorized maize dehulling, cleaning and milling machine.

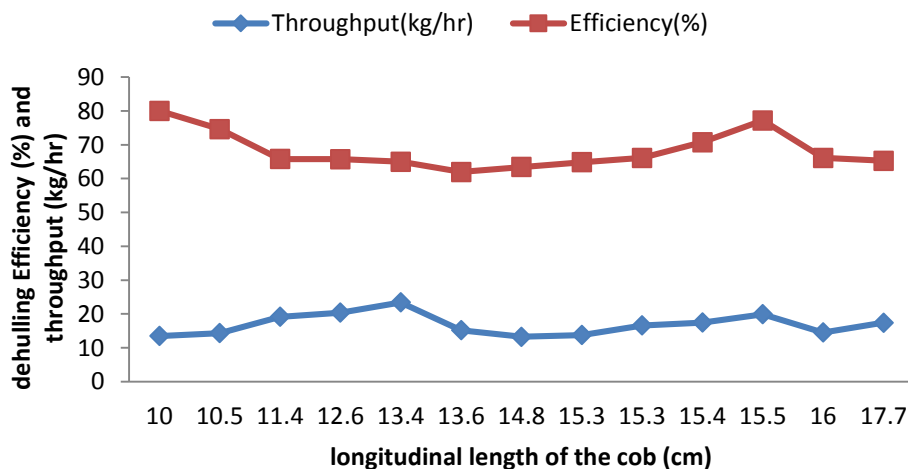


Figure 6: Throughput capacity, dehulling efficiency and longitudinal length of the cob.

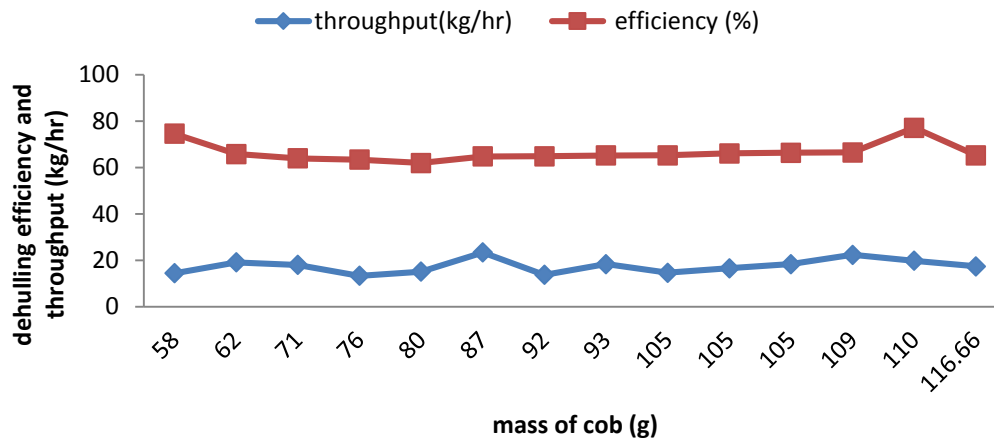


Figure 7: Throughput capacity, dehulling efficiency and mass of the cob.

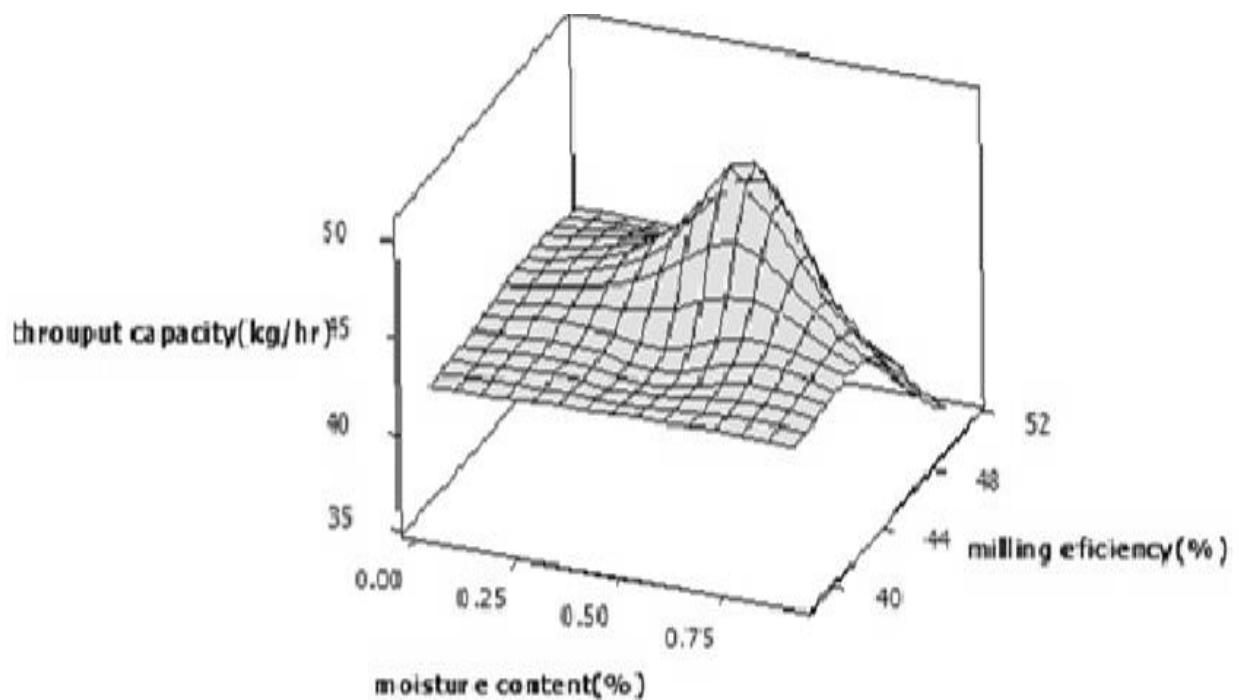


Figure 8: surface plot of moisture content, milling efficiency and throughput capacity

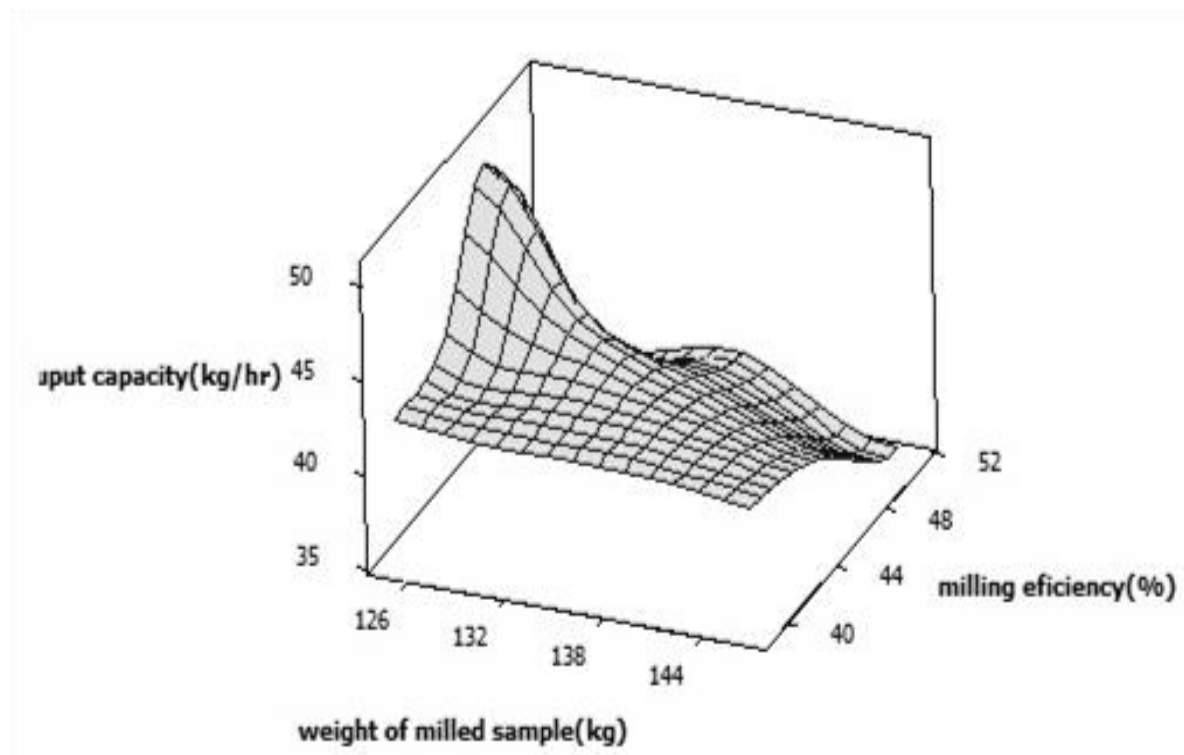


Figure 9: Surface plot of weight of milled sample, milling efficiency and throughput capacity



Figure 10: Sieve samples of milled grain

4. CONCLUSION

A machine for dehulling, cleaning and milling of maize was developed. The overall performance of the machine is above average.

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SELECTED PHYSICAL AND AERODYNAMIC PROPERTIES OF NERICA

P. C. Eze and S. I. Oluka

Department of Agricultural and Bioresource Engineering
Enugu State University of Science and Technology, Enugu, Nigeria.
ezepaul@yahoo.com, ikeoluka@yahoo.com

ABSTRACT

Some physical and aerodynamic properties of NERICA (New Rice for Africa) were studied at varying moisture contents of 13%, 17%, and 20% (w.b). Four varieties of NERICA namely; FARO 44, FARO 51, FARO 52 and FARO 57 were selected to represent the different size ranges common to NERICA. The physical properties of NERICA such as shape, size, volume, moisture contents, bulk density, weights, surface area, aspect ratio and sphericity were obtained through physical measurement of the grains samples of each of the four varieties using vernier caliper, electronic weighing balance and electric oven. A locally constructed air velocity measuring rig was used to determine the terminal velocities of the NERICA seeds and husks. The other aerodynamic properties such as drag force, drag coefficient and Reynolds number were calculated from terminal velocity relationship.

Results indicate that FARO 57 recorded highest value of size range of 3.924mm to 4.019mm, while FARO 44 recorded the lowest size characteristic range of 3.653mm to 3.858mm all at 13%, 17% and 20% moisture contents. These indicate that NERICA grains have wide size ranges and no single sample of the grains can effectively represent the other. The average terminal velocity was found to range from 0.4943m/s to 0.8886m/s, 0.5325m/s to 0.9655m/s and 0.6315m/s to 1.0355m/s at 13%, 17% and 20% moisture contents respectively for the seeds and the terminal velocities of the husks ranges from 0.0975m/s to 0.2588m/s, 0.1143m/s to 0.2969m/s and 0.1254m/s to 0.2991m/s at 13%, 17% and 20% moisture contents respectively. The terminal velocity increases with increase in size. Therefore the optimum air velocity necessary for effective separation of the husks from its mixture with the seeds after threshing was found to fall within the range of $0.2888\text{m/s} < V_t < 0.0975\text{m/s}$ at 13% (w.b), $0.2969\text{m/s} < V_t < 0.1143\text{m/s}$ at 17% (w.b) and $0.2991\text{m/s} < V_t < 0.1284\text{m/s}$ at 20% (w.b). This indicates that optimum separation can be achieved effectively without any loss of the seeds if the results obtained are properly applied.

KEYWORDS: NERICA, aerodynamic, drag force, reynolds number, physical properties.

1. INTRODUCTION

The term NERICA stands for “New Rice for Africa” and is used to refer to genetic materials derived from the successful crossing of the two species of cultivated rice, the African rice (*O. glaberrima* steud) and the Asian rice (*O. Sativa* L.), to produce progeny that combine the best traits of both parents, (WARDA, 2008). The increasing economic importance of food materials, together with the complexity of modern technology for their production, handling, storage, processing preservation, quality evaluation, distribution, marketing and utilization, demands comprehensive information on physical properties of these materials. Information on physical and aerodynamic properties of agricultural products is needed in the design and adjustments of machines used during harvesting, separating, cleaning, and handling and storing of agricultural materials and converting them into food, feed and fodder. The properties which are useful during machine designs need to be known and these properties must be determined at laboratory conditions (Gursoy and Guzel, 2010). Therefore for the purpose of machine designs, properties such as size, shape, volume, surface area, weights, density, porosity, angle of repose, coefficient of friction are of prime importance. These properties influence the design and evaluation of rice processing including drying, husking, whitening and polishing as well as grading machines, storage and grain moving equipment (Mehdi et al, 2007). For example, the knowledge of the coefficient of friction of paddy or cowpea on the equipment wall and on the silo wall surface are necessities and fundamentals for a rational and safe design of grain handling equipment, processing and storage (Mohsenin, 1986; Milani;1993).

The terminal velocity and drag coefficient are the most important aerodynamic properties, which should be known for pneumatic conveying, separation, cleaning, harvesting and drying of agricultural products. The terminal velocity at which the particles are suspended stationary in vertical air stream can be determined by using different methods. These methods are free-fall, vertical air tunnel and elutriator method (Mohsenin, 1980; Grift et al; 1997, Gursoy and Guzel, 2010). The terminal velocity of grains can be calculated by using the equations developed theoretically as well as laboratory studies. A few methods were developed to determine theoretical terminal velocity for some grains (Gorial and O'Callaghan, 1990; Song and Litchfield, 1991).

The value of aerodynamic drag coefficient, which is used for determining the aerodynamic drag force (F_d), acting upon a particle moving through air depends upon particle characteristics (mass, projected area, shape and terminal velocity) as well as the conditions of airflow (Gursoy and Guzel, 2010). The projected areas and drag coefficient of agricultural grains changed because of irregular shape and contains the variation of positions. In studies carried out, the projected area and drag coefficient of grains were usually determined by using the diameter of the sphere equivalent to seed (Mohsenin, 1986; Gorial and O'Callaghan, 1990; Hawk et al, 1966).

The objective of this study is to determine some useful data on the physical and aerodynamic properties of NERICA grains that will influence the design of a cost effective machine or equipment that can contribute to improving the efficiency or performance of existing equipment for processing and general handling of grains. The main objectives are to determine some physical properties of NERICA grains to develop appropriate technologies in design and adjustment of machines used during harvesting, separating, cleaning, handling and storage and convert them into food, feed and fodder and to determine the aerodynamic properties such as, terminal velocity and drag coefficient which is important in pneumatic conveying, separating and cleaning machines for the vital processing of rice grains for effective results.

2. MATERIALS AND METHOD

The research materials include four varieties of NERICA grains, namely; FARO 44, FARO 51, FARO 52 and FARO 57. These varieties were obtained from the Ebonyi State Agricultural Development Program (EBADEP) at average moisture of 13% (dry base).

The grains were hydrated to obtain three more different moisture content levels at which the tests were conducted. A total of 1000 grains were used for the experiments. These samples were taken to the Enugu State University of Science and Technology for the physical and aerodynamic tests in the Agricultural and Bioresource Engineering's Laboratory.

2.1 Test Apparatus

The test apparatus used to carry out this research work include a vernier caliper of 0.01mm sensitivity used to measure the major diameter, minor diameter and the thickness of the grains; a metler Toledo electronic weighing balance of model XP 204 and 0.0001g sensitivity, used for weight measurement; an electric oven of model OP 100 by the LTE Scientific Ltd, used to determine the moisture content of the grains and a well constructed Air velocity measuring rig was used for the aerodynamic test.

2.2 Description of the Air Velocity Measuring Rig

An air velocity measuring rig was locally constructed for the determination of terminal velocity of the NERICA varieties at different moisture contents. The air velocity measuring rig was constructed with sheets of metal, plexiglass and has a total size of 90 x 120cm (Fig. 1). It operates with a geared electric motor of 3 horse power of triple phase with average maximum speed of 1400/2 rpm. The seed sample used to be placed on the mesh screen in the vertical tube made of plexiglass where observation is usually carried out.

The fan blades are six in number to allow maximum flow of air to the vertical tunnel. These blades were made of metal sheets and the sizes are 12 x 20cm each. The belt connection system between the shaft connecting the blower and motor is called secondary belting system. Comprises of two belts; one for the connection of blower shaft and the connecting shaft at the center between the blower shaft and the electric motor, while the second belt connects the electric motor and the center shaft. This system is to allow adequate speed of the blower for a determined air velocity.

The machine worked appropriately in the determination of terminal velocity of NERICA with a reasonable experimental data determined.

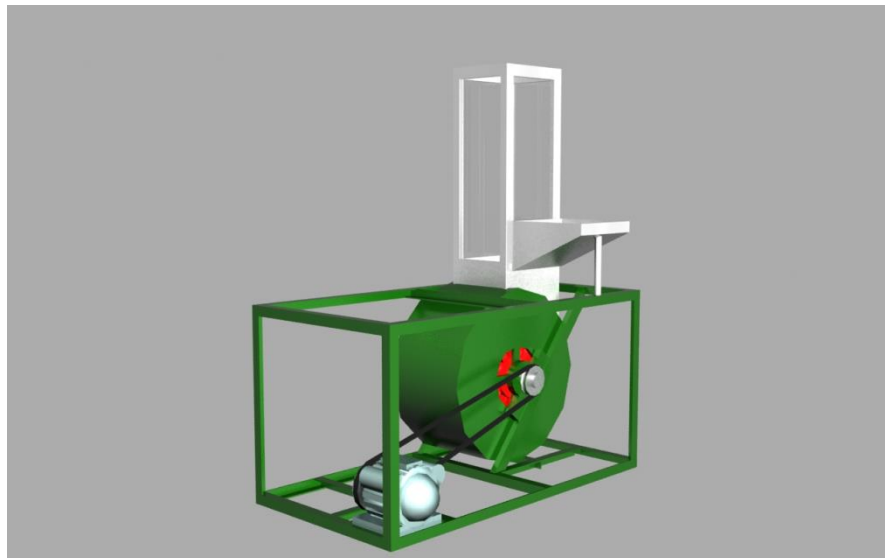


Fig. 1. Air Velocity Rig

2.3 Experimental Procedure for Physical Properties of NERICA Grains

i) Determination of Size and Shape

The vernier caliper was used to measure the three dimensions (major diameter, minor diameter and thickness) of the grains selected randomly from each variety of three different moisture content levels. The results of the measurements (the reading obtained) were used to evaluate the size of the grains using the following equation.

$$\text{Size} = (abc)^{1/3} \text{ ----- (3.1)}$$

a is the major diameter, b is the minor diameter and c is the thickness.

The shapes of the grains were assumed to approximate to a sphere. The sphericity was therefore used to determine the shape (Mohsenin, 1986). The sphericity, which is a measure of how close a material is to being spherical, was calculated using the following equation.

$$S = \left(\frac{abc}{a^3}\right)^{1/3} \text{ ----- (3.2)}$$

Where;

S is the sphericity, a , is the major diameter, b is the minor diameter and c is the thickness. Measurements were replicated twenty times.

ii) Determination of Aspect ratio of the grains:

The aspect ratio (Ra) is used in classification of grain shape and it was calculated using the equation by Varnamkhasti et al (2007), thus;

$$Ra = \frac{b}{a} \text{ ----- (3.3)}$$

Where; Ra is the aspect ratio, b is the minor diameter and a , is the major diameter.

iii) Determination of Weight of the grains:

A metler Toledo electronic weighing balance of model XP 204 and 0<0001g sensitivity was used to measure the weight of the grains. Measurements were replicated 20 times. Also thousand-grain seed weight was determined by counting 100 kernels and weighing them in an electronic balance and then multiplied by 10 to give the mass of 1000 grains (Nalladulai et al., (2002).

iv) Determination of Volume:

The volume of the grains was determined using specific gravity method. In this method, the weight of the grains at different moisture content levels were determined in air and in water and the volume computed using the following equation.

$$\text{Volume} = \frac{\text{weight in air} - \text{weight in water}}{\text{weight density of water}} \text{ ----- (3.4)}$$

Twenty replications of the measurements were taken. Also, Jain and Bal (1997) have stated grains volume, V_1 as; $V = 0.25 (\pi/6) L (W + T) \text{ ---- (3.5)}$

Where;

V is the grain volume, L is the length/major diameter of grain, W is the width/minor diameter of grain and T is the thickness of the grain.

v) Determination of Bulk Density and Specific gravity of the grains:

The bulk density of the grains was determined from the expression;

$$\text{Bulk density} = \frac{Ws}{Vs} \text{ ----- (3.6)}$$

Where; Ws are the weight of grain and Vs is the volume of grain.

The specific gravity was determined from the relationship.

$$\text{Specific gravity} = \frac{\text{Bulk density}}{\text{Density of water}} \text{ ----- (3.7)}$$

vi) Determination of surface area:

The surface area of the grains was determined from the formula as suggested by Gannett and Brooker (1995).

$$A = \frac{\pi D^2}{4} \text{ ----- (3.9)}$$

Where;

A is the surface area of grains of spherical shape, and D is the minor diameter and

$$\pi = \left(\frac{22}{7}\right).$$

Jain and Bal (1997), also stated surface area, S as;

$$S = \frac{\pi BL^2}{(2L-B)} \quad \text{----- (3.10)}$$

$$\text{Where; } B = \sqrt{wT} \quad \text{----- (3.11)}$$

Where; w is the width/minor diameter of the grain and L is the length/minor diameter of the grain.

vii) Determination of Porosity

Porosity, which is also referred to as packing factor, PF , was evaluated from the following relationship suggested by Mohsenin (1986).

$$pf = \frac{\text{Solid density of particles} - \text{density of packing}}{\text{solid density of particles}} \quad \text{----- (3.12)}$$

But the solid density of the particles is the average density of the solid grain while density of packing is the bulk density of the grains. In practice, this equation was modified as thus;

$$I = \frac{\text{Bulk density of the grain}}{\text{Average density of the solid grain}} \quad \text{----- (3.13)}$$

Jain and Bal (1997) described porosity, E as the percentage of air between the particles compared to a unit volume of grains and it was computed using the formula below;

$$\varepsilon \frac{\rho_t - \rho_b}{\rho_t} \times 100 \quad \text{----- (3.14)}$$

Where ε is the porosity of grains, ρ_t is the true density given by;

$$\rho_t = \frac{M}{V} \quad \text{----- (3.15)}$$

Where M is the mass of individual seed (kg); V is the volume of the seed (m^3) and ρ_b is the bulk density (kgm^{-3}).

viii) Determination of Moisture Content

The oven-dry method of moisture content determination was used to determine the moisture (wet-basis) of the grains using an electric oven of model OP 100 by LTE scientific Ltd. The weight air-dry samples and the weight of oven-dry samples were determined and the moisture content evaluated from the expression.

$$Mc = \frac{W_w - D_w}{D_w} \times 100\% \quad \text{---- (3.16)}$$

2.4 Experimental Procedure for Aerodynamic Properties of NERICA Rice grains

A locally constructed vertical air tunnel with a Plexiglas tube was used to determine the terminal velocities of the NERICA varieties at different moisture contents. Thirty seeds from each grain variety were randomly selected for measurement of terminal velocity. The seed sample was placed on a mesh screen in vertical tube. The air velocity was adjusted by increasing the speed of motor until the seed began suspended, the height of suspension was recorded and then the air velocity at that suspension point was calculated as terminal velocity (V_t). And for each specimen, three readings were taken. The mean of these readings was computed and used as the working terminal velocity.

From the measured terminal velocities and some physical properties of NERICA grains, the Reynolds Numbers of the seeds were calculated using an equation according to Oluka and Nwuba (2001), thus;

$$RN = \frac{V_t f D}{N \mu} \quad \text{----- (3.19)}$$

Where; RN is the Reynolds number, (kgm^{-2}s), f is the fluid density (kgm^{-3}), D is the effective dimension of particle, (m), V_t is the terminal velocity (ms^{-1}).

According to Douglas et al (1983), Oluka and Nwuba (2001); the air or fluid density of 1.15kgm^{-3} and kinematic viscosity of $1.88 \times 10^{-6}\text{kgm}^{-2}\text{s}$, were assumed with consideration that the density and viscosity of air were constant at the laboratory temperature and pressure. Also the geometrical mean diameter of the NERICA seed was computed and used as the mean effective diameter (Mohsenin, 1986; Oluka and Nwuba, 2001). In the husks, the mean effective diameter was calculated from the measured values of terminal velocities and some physical properties of NERICA using equation below as according to Oluka and Nwuba (2001);

$$D_c = 2W (\rho - f) / V_t A_p \rho \quad \text{----- (3.20)}.$$

Where;

D_c is the Drag Coefficient of seed or particle.

V_t is the Terminal Velocity of the seed or particle, m/s.

f is the fluid density, kg/m^3 .

ρ is the mass density of seed or particle, kg/m^3 .

A_p is the Projected Area of seed or particle, m^2 .

W is the weight of seed or particle, kg.

2.5 Data Analysis

The data collected from this experiment was presented and analyzed using tables with descriptive statistical methods and graphs. These data were obtained from the measurements of dimensions of the grains; calculations of some physical and aerodynamic properties.

3. RESULTS AND DISCUSSIONS

3.1 Dimensional Properties

Tables 1 and 2 show the size characteristics of the NERICA grains at different moisture contents (wet base). The dimensions increased with increased in moisture contents and the differences between the values were statistically significant at $P > 0.01$. This shows that there is an increase in the dimensions which contributed to expansion as a result of moisture intake within the grains. The size observations show that FARO 57 recorded highest value of size range of 3.924mm to 4.019mm, while FARO 44 recorded the lowest size characteristic range of 3.653mm to 3.858mm all at 13%, 17% and 20% moisture contents. These indicate that NERICA grains have wide size ranges and no single sample of the grains can effectively represent the other. This indication is in line with Oluka and Nwuba (2001) that no single variety can effectively use to represent the size characteristics of other varieties in design and post harvest handling of the crop.

Table 1: The Size Characteristics of NERICA Seeds at Different Moisture Contents

Moisture Content (w.b)	Varieties	Major Diameter (mm)	Minor Diameter (mm)	Thickness (mm)	Size (mm)	Coefficient of Variation (%)	Variance (mm)	Standard Error (mm)
13%	FARO 44	8.38 (0.51)	2.57 (0.22)	20.1 (0.01)	3.653 (0.10)	5.399	0.156	0.082

	FARO 51	8.07 (0.42)	(2.76 (0.34)	2.00 (0.21)	3.685 (0.12)	9.477	0.105	0.074
	FARO 52	8.48 (0.40)	2.63 (0.23)	2.01 (0.04)	3.674 (0.15)	4.921	0.071	0.049
	FARO 57	8.84 (0.31)	2.91 (0.13)	2.11 (0.10)	2.924 (0.16)	4.170	0.040	0.040
17%	FARO 44	8.51 (0.62)	2.75 (0.21)	2.18 (0.02)	3.789 (0.17)	8.111	0.143	0.078
	FARO 51	8.51 (0.40)	2.95 (0.12)	2.10 (0.02)	3.900 (0.10)	4.062	0.085	0.057
	FARO 52	8.58 (0.42)	2.76 (0.16)	2.11 (0.03)	3.817 (0.13)	3.858	0.068	0.046
	FARO 57	8.88 (0.50)	2.98 (0.09)	2.17 (0.09)	3.984 (0.15)	4.588	0.089	0.051
20%	FARO 44	8.58 (0.42)	2.81 (0.11)	2.11 (0.03)	3.858 (0.11)	8.131	0.134	0.064
	FARO 51	8.52 (0.58)	2.89 (0.11)	2.11 (0.04)	3.916 (0.14)	4.054	0.082	0.048
	FARO 52	8.63 (0.41)	2.84 (0.15)	2.13 (0.03)	3.863 (0.12)	2/957	0.052	0.039
	FARO 57	8.92 (0.48)	2.99 (0.12)	2.19 (0.12)	4.019 (0.19)	4.562	0.084	0.042

Each value is the mean of 30 test samples. Values in parenthesis are the standard deviation (SD).

Table 2: Some Physical Properties of NERICA Seeds at Different Moisture Contents

Moisture Content (w.b)	Varieties	Weight (g)	Volume mm ³	Bulky Density g/mm ³	Sphericity	Aspect Ratio	Porosity %	Surface Area (mm ²)
13%	FARO 44	0.028 (0.021)	25.92 (1.321)	0.011 (0.096)	0.385 (0.211)	0.271 (0.199)	8.333 (0.461)	5.984 (0.312)
	FARO 51	0.029 (0.018)	26.84 (1.371)	0.011 (0.094)	0.403 (0.391)	0.304 (0.281)	8.342 (0.482)	6.683 (0.311)
	FARO 52	0.028 (0.019)	26.44 (1.375)	0.010 (0.092)	0.392 (0.221)	0.280 (0.198)	23.08 (1.267)	5.988 (0.294)
	FARO 57	0.031 (0.029)	32.47 (1.467)	0.010 (0.092)	0.399 (0.218)	0.296 (0.188)	18.18 (1.281)	6.951 (0.310)
17%	FARO 44	0.035 (0.017)	29.05 (1.461)	0.012 (0.094)	0.398 (0.219)	0.289 (0.192)	14.29 (1.287)	5.940 (0.319)
	FARO 51	0.036 (0.015)	32.03 (1.521)	0.011 (0.093)	0.411 (0.386)	0.134 (0.279)	15.38 (1.282)	6.806 (0.294)
	FARO 52	0.033 (0.022)	29.63 (1.431)	0.012 (0.091)	0.398 (0.219)	0.287 (0.194)	21.43 (1.271)	5.941 (0.319)
	FARO 57	0.037 (0.014)	33.91 (1.463)	0.011 (0.092)	0.403 (0.391)	0.299 (0.182)	21.43 (1.270)	6.836 (0.298)
20%	FARO 44	0.043 (0.013)	32.23 (1.521)	0.013 (0.092)	0.392 (0.221)	0.300 (0.281)	18.75 (1.281)	6.698 (0.310)
	FARO 51	0.044 (0.013)	34.49 (1.467)	0.013 (0.092)	0.413 (0.386)	0.319 (0.278)	18.76 (1.281)	7.501 (0.287)
	FARO 52	0.040 (0.015)	33.28 (1.461)	0.013 (0.092)	0.412 (0.382)	0.312 (0.276)	17.63 (1.280)	6.699 (0.296)
	FARO 57	0.049 (0.014)	36.24 (1.428)	0.014 (0.088)	0.419 (0.342)	0.318 (0.218)	22.46 (1.248)	7.941 (0.272)

Each value is the mean of 30 test samples. Values in parenthesis are the standard deviation (SD)

Table 3: Terminal Velocity of Four Varieties of NERICA Seeds and Husks at Different Moisture Contents

Variety Moisture Content	FARO 44	FARO 51	FARO 52	FARO 57
At 13 % (w.b)				
Seeds -----	0.4943 (0.124)	0.6235 (0.136)	0.5325 (0.126)	0.8886 (0.139)
Husks -----	0.0975 (0.024)	0.1975 (0.029)	0.1643 (0.025)	0.2888 (0.072)
At 17 % (w.b)				
Seeds -----	0.5325 (0.126)	0.7055 (0.137)	0.6714 (0.137)	0.9655 (0.201)
Husks -----	0.1143 (0.021)	0.1992 (0.029)	0.1788 (0.026)	0.2969 (0.073)
At 20 % (w.b)				
Seeds -----	0.6315 (0.136)	0.8356 (0.138)	0.7311 (0.142)	1.0355 (0.221)
Husks -----	0.1284 (0.023)	0.1999 (0.029)	0.1881 (0.028)	0.2991 (0.026)

Each value is the mean of 20 test samples. Values in parenthesis are the standard deviation (SD)

Table 4: Reynolds Numbers of Four Varieties of NERICA Seeds and Husks at Different Moisture Contents

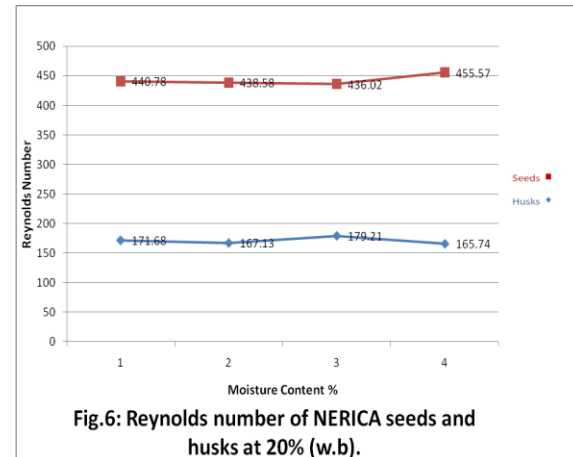
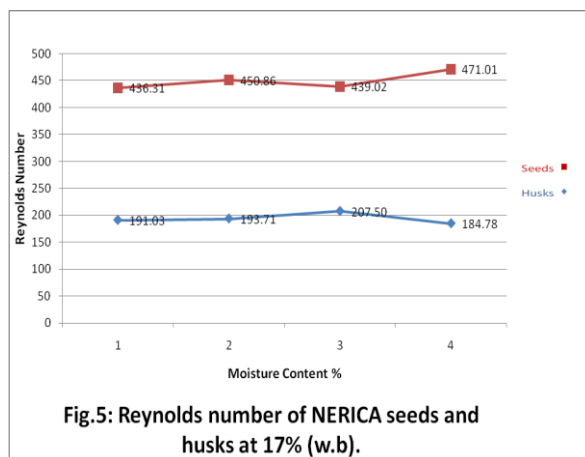
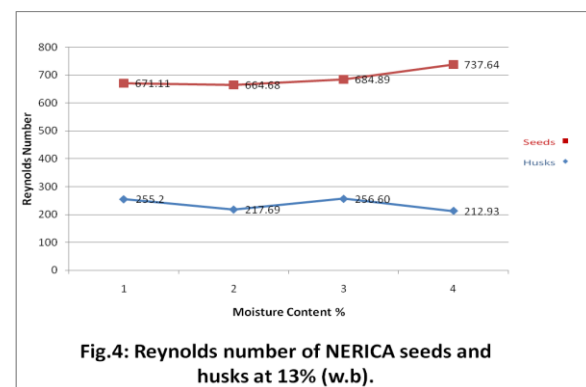
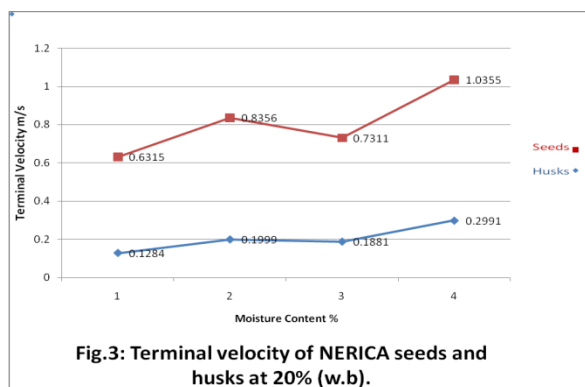
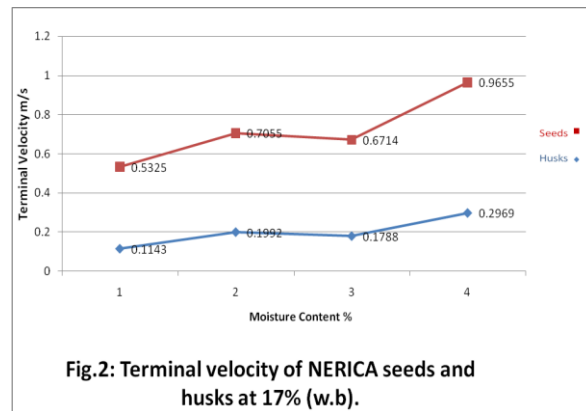
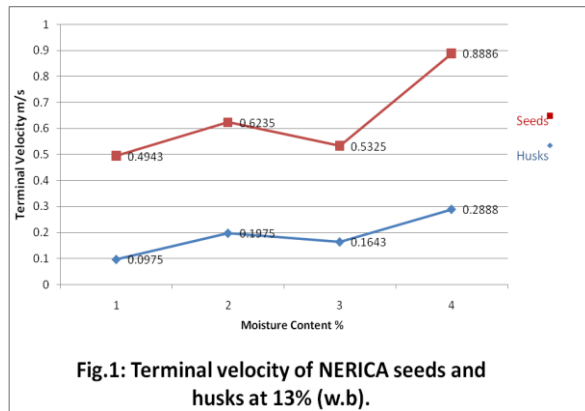
Variety Moisture Content	FARO 44	FARO 51	FARO 52	FARO 57
At 13 % (w.b)				
Seeds -----	671.11 (169.03)	664.68 (221.56)	684.89 (136.98)	737.64 (184.41)
Husks -----	255.20 (63.80)	217.69 (72.56)	256.60 (51.32)	212.98 (53.29)
At 17 % (w.b)				
Seeds -----	436.31 (109.08)	450.86 (112.72)	439.02 (146.34)	471.01 (109.08)
Husks -----	191.03 (63.68)	193.71 (64.57)	207.50 (41.50)	184.78 (61.59)
At 20 % (w.b)				
Seeds -----	440.78 (110.20)	438.58 (87.716)	436.02 (109.08)	455.57 (113.74)
Husks -----	171.68 (42.92)	167.13 (41.78)	179.21 (59.74)	165.74 (55.25)

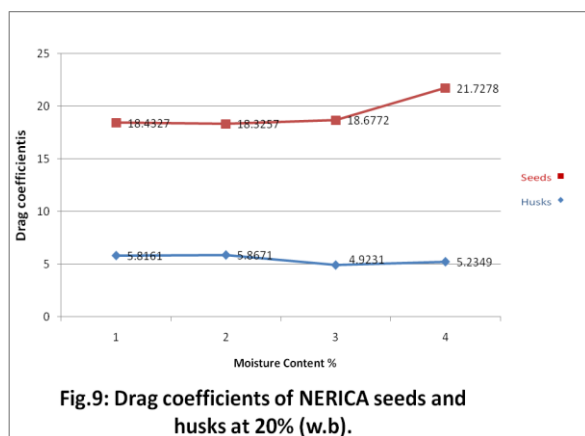
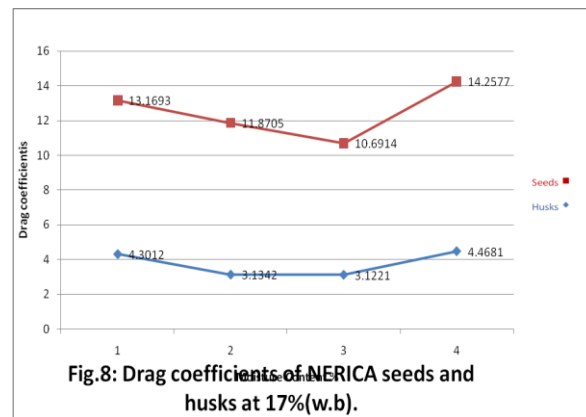
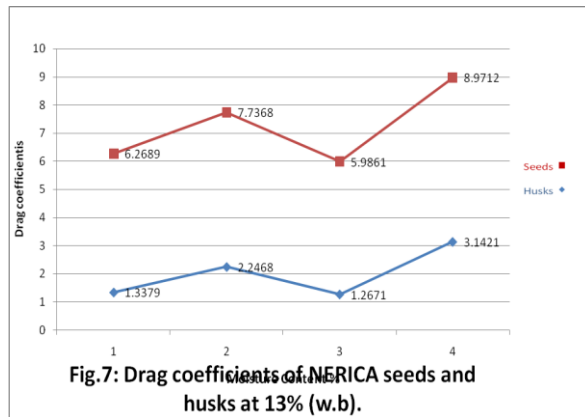
Each value is the mean of 30 test samples. Values in parenthesis are the standard deviation (SD).

Table 5: Drag Coefficients of Four Varieties of NERICA Seeds and Husks at Different Moisture Contents

Variety Moisture Content	FARO 44	FARO 51	FARO 52	FARO 57
At 13 % (w.b)				
Seeds -----	6.2689 (1.567)	7.7368 (1.934)	5.9861 (1.497)	8.9712 (2.243)
Husks -----	1.3379 (0.334)	2.2468 (0.562)	1.2671 (0.422)	3.1421 (0.786)
At 17 % (w.b)				
Seeds -----	13.1693 (2.634)	11.8705 (2.374)	10.6914 (2.138)	14.2577 (3.564)
Husks -----	4.3012 (0.860)	3.1342 (0.784)	3.1221 (0.781)	4.4681 (1.117)
At 20 % (w.b)				
Seeds -----	18.4327 (4.608)	18.3257 (4.581)	18.6772 (4.669)	21.7278 (5.432)
Husks -----	5.8161 (1.454)	5.8671 (1.467)	4.9231 (0.985)	5.2349 (1.309)

Each value is the mean of 20 test samples. Values in parenthesis are the standard deviation (SD)





3.2 Sphericity

The sphericity of NERICA grains in Table 2 increased with increased in moisture content, indicating that sphericity of the grain was statistically significant ($P > 0.01$) as the moisture content increased. FARO 57 recorded highest value of sphericity of range from 0.399 to 0.419, while FARO 44 recorded lowest sphericity value of range from 0.385 to 0.392 all at 13%, 17% and 20% moisture contents. This indicates that relative proportional changes occurred in the dimensions of the NERICA grain samples.

3.3 Volume

The NERICA grain volume increased with the increased of moisture content in Table 2. The volume increased from 25.92 mm³ to 32.47 mm³, 29.05mm³ to 33.91 mm³ and 32.23 mm³ to 36.24 mm³ all at 13%, 17% and 20% moisture contents respectively. This increase in volume may be attributed to expansion in size dimensions which was as a result of weight increase of the grains that resulted to the displacement of more liquid (Mohsenin, 1986).

3.4 Bulk Density

In Table 2, the bulk density of NERICA paddy varies slightly from 0.010 g/mm³ at 13% moisture content to 0.013 g/mm³ at 20% moisture content. This result indicates a slight change in the bulk density with an increase in moisture content indicating that bulk density of the grain was statistically significant ($P > 0.01$).

3.5 Surface Area

In Table 2, the surface area of the NERICA paddy increased from 5.984 mm² to 7.941 mm² when the moisture content increased from 13% to 20% moisture content ($P > 0.01$). The results indicate that the increase in the values may be attributed to their dependence on the size dimensions of the NERICA paddy which can be linked to Oluka and Nwuba (2001) report for Cowpeas.

3.6 Aerodynamic Properties

Tables 3 to 5 and Figures 1 to 9 represent the aerodynamic properties of NERICA seeds and husks at three (13%, 17% and 20%) moisture contents and showed a significant effect on aerodynamic properties. In Table 3 which contains the terminal velocities, FARO 57 variety recorded the highest terminal velocities of 0.8886m/s, 0.9655m/s and 1.0355m/s at 13%, 17% and 20% moisture contents respectively, while FARO 44 variety recorded the lowest terminal velocities of 0.4943m/s, 0.5325m/s and 0.6315m/s at 13%, 17% and 20% moisture contents respectively for NERICA seeds. In the case of the NERICA husks, FARO 57 also recorded the highest terminal velocities of 0.2888m/s, 0.2969m/s and 0.2991m/s at 13%, 17% and 20% moisture contents respectively, while FARO 44 also maintains the lowest value of 0.0975m/s, 0.1143m/s and 0.1284m/s at 13%, 17% and 20% moisture contents respectively. These results reveal that the sizes of the NERICA seeds and husks influence their terminal velocities, noting that the terminal velocities of the NERICA seeds and husks increase with increase in the sizes of the seeds and husks and moisture contents.

Also it is observable from the results in Table 3 that the terminal velocities of the NERICA seeds and husks differ reasonably, showing that a thorough pneumatic separation of seeds from the mixture of seeds and husks is possible.

It could be concluded from the results that with the terminal velocity ranges of 0.4943m/s to 0.8886m/s at 13% (w.b) 0.5325m/s to 0.9655m/s at 17% (w.b) and 0.6315m/s to 1.0355m/s at 20% (w.b) for the seeds, and 0.0975m/s to 0.2888m/s at 13% (w.b), 0.1143m/s to 0.2969m/s at 17% (w.b) and 0.1284m/s to 0.2991m/s at 20% (w.b) for the husks, that good separation of the husks from the seeds could be achieved at the air velocities of $0.2888\text{m/s} < V_t < 0.0975\text{m/s}$ at 13% (w.b), $0.2969\text{m/s} < V_t < 0.1143\text{m/s}$ at 17% (w.b) and $0.2991\text{m/s} < V_t < 0.1284\text{m/s}$ at 20% (w.b) without any loss of the seeds. The result was in accordance as stipulated by Oluka and Nwuba (2001), "Physical and Aerodynamic Properties of Cowpea Seeds, Hulls and Stalks" with ranges of $0.302\text{m/s} < V_t < 0.256\text{m/s}$, Uhl and Lamp (1966), Song and Litchfield (1991) and Gursoy and Guzel (2010), Khoshtaghaza and Mehdizadeh (2006).

In the case of Reynolds numbers, Table 4 shows that Reynolds numbers are highest for the seeds at the range of 664.68 to 737.64, 436.31 to 471.01 and 436.02 to 455.57 at 13%, 17% and 20% respectively and lower the husks at the range of 212.98 to 256.60, 191.03 to 207.50 and 165.74 to 179.21 at 13%, 17% and 20% respectively. The bigger the sizes, the lower were the Reynolds number obtained. It did not follow the same trends with the terminal velocity incase of which variety has the highest or lowest range.

Table 5 shows the drag coefficients, the trend is the same with the terminal velocity. The drag coefficients are higher for the seeds and lower for the husks in which FARO 57 still recorded the highest range of 8.9712 to 21.7278 while FARO 52 recorded the lowest range of 5.9861 to 18.6772 all at the three levels of the moisture contents (13%, 17% and 20%).

Generally, Tables 4 and 5 shows that the higher the drag coefficients, the lower the Reynolds numbers of the seeds and husks. Again, as the terminal velocities increases, Reynolds numbers decreases correspondingly. For the drag coefficient, the terminal velocities of the seeds and husks increased with an increase in drag coefficients of the four varieties.

These results show that at higher terminal velocities of air, better cleaning will be achieved because flow regulation of air must be higher for effective cleaning of the seeds from a mixture of NERICA rice seeds and husks.

Figure 1 to 9 shows the graphs of terminal velocities, Reynolds numbers and drag coefficients of NERICA rice seeds and husks at three levels of moisture contents (13%, 17% and 20%). From the graphs of the terminal velocities, it indicates that the terminal velocities increase with increase in size of the seeds and husks at 13%, 20% and 30% (w.b) respectively. The same trend occurs in both the Reynolds numbers and drag coefficients.

3.7 Summary of Findings

From the results of this research work, the following findings were made;

- i. There is significant effect ($P > 0.01$) in the sizes of NERICA varieties. This indicates that no single variety can be used to represent effectively the size of other varieties in terms of physical and aerodynamic properties, (Oluka and Nwuba, 2001).
- ii. The FARO 57 variety has the highest size value range of 3.924mm to 4.019mm while FARO 44 recorded the lowest size characteristic range of 3.653mm to 3.858mm all at 13%, 17% and 20% moisture contents.
- iii. The NERICA grains in different species and moisture content levels have varying shapes and sizes. Though increase in moisture content results to increase in shapes and sizes.
- iv. Terminal velocities obtained shows that good separation of the husks from the seeds could be achieved at the air velocities of $0.2888\text{m/s} < V_t < 0.0975\text{m/s}$ at 13% (w.b), $0.2969\text{m/s} < V_t < 0.1143\text{m/s}$ at 17% (w.b) and $0.2991\text{m/s} < V_t < 0.1284\text{m/s}$ at 20% (w.b) without any loss of the seeds. The result was in accordance as stipulated by Oluka and Nwuba (2001), "Physical and Aerodynamic Properties of Cowpea Seeds, Hulls and Stalks" with ranges of $0.302\text{m/s} < V_t < 0.256\text{m/s}$.

4. CONCLUSION

This study has identified some of the physical frictional and aerodynamic properties of NERICA grains. These properties can be used in the design of post harvest handling machines for NERICA grains. The distinctive shapes and sizes of the grains as identified by the values of sphericity, surface area and size distribution pattern can be effectively utilized for the selection of appropriate speeds that can be employed in aerodynamic separation of NERICA husks from seeds. These sizes of the seeds were found to influence the terminal velocities, Reynolds numbers and the drag coefficients. The terminal velocities and drag coefficients increased as the size of the seeds increased. The Reynolds numbers decreased as the size increased. The optimum air velocity necessary for effective separation of the husks from its mixture with the seeds after threshing was found to fall within the range of $0.2888\text{m/s} < V_t < 0.0975\text{m/s}$ at 13% (w.b), $0.2969\text{m/s} < V_t < 0.1143\text{m/s}$ at 20% (w.b) and $0.2991\text{m/s} < V_t < 0.1284\text{m/s}$ at 30% (w.b) without any loss of the seeds.

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DEVELOPMENT OF A BIOMASS GASIFIER STOVE

M. O. Iyanda and M. I. Mohammed
Department of Agricultural and Biosystems Engineering,
University of Ilorin, Ilorin, Nigeria.
E-mail: iyandamo@yahoo.com, iyanda.mo@unilorin.edu.ng

ABSTRACT

The use of biomass in our local and primitive stove (three stone stove) has a negative impact on the health of household members especially women and children that are mostly exposed to the pollutants produced by this stove. Biomass combustion provides basic energy requirements for cooking and heating of rural households and for processes in a variety of traditional industries in the developing countries. A study was conducted to develop a biomass gasifier stove using locally available materials like mild steel, clay and wood to save the cost of production. It converts biomass fuel into a combustible wood gas or producer gas that is directly burn to produce luminous blue flame. The power supply unit is a rechargeable battery which provides 25.9KJ of energy to drive the fan assembly unit and forces air through the fuel column in the reactor. The performance of the stove was determined using water boiling test. The results show that the specific gasification rate (SGR), fuel consumption rate (FCR), combustion zone rate(CZR), percentage char produced, input power and output power to be 186.19kh/m²hr, 5.85kg/hr, 0.67cm/m, 13%, 130kW and 29069.24kW respectively.

1. INTRODUCTION

Biomass combustion provides basic energy requirements for cooking and heating of households and for processes in a variety of traditional industries (Reric, 2003). Firewood and charcoal accounts for a major fraction of the total biomass used and this causes deforestation in the country. Apart from contributing to deforestation which endangers our environment, it also consumes time and labour in its collection (Yohannes, 2011). Currently in Nigerian, the high cost of fossil fuel prevent people from using other heat energy sources like kerosene stove, pressure stove, gas cooker and even electric stove is not reliable due to epileptic power supply. As we know, every home needs cooking to sustain life and the only alternative is this biomass as a renewable source of energy. Although, biomass offers itself as sustainable and carbon-neutral source of energy, its inefficient use in household cooking results in wastage, indoor air pollution and causes related respiratory and other health problems (Yohannes, 2011). More so, excessive use of fuel wood is exerting pressure on the regions forest cover and causing global warming. There are large quantities of surplus biomass residue such as rice husk, corn cob, cotton shell, palm kernel, plant straw etc. which their use has been severely restricted due to certain difficulties experienced in using them for cooking (Yohannes, 2011).

The biomass gasifier stove has the potential to replace Kerosene stove, gas cooker and old method of burning firewood for cooking that uses a lot of wood in an inefficient combustion that produce smoke and causes serious health hazard. It also reduces household expenditure on conventional fuel source, such as kerosene, gas, wood and wood charcoal. So, it substitute the expensive fossil fuel with wood and agricultural waste such as saw-dust, wood shaving, rice husk, corn cob, coconut shell, palm kernel, plant straw etc. It can provide employment opportunity and source of income for the country's unemployed youth if they engage in the production and marketing of the stove.

The use of biomass in our local and primitive stove (three stone stove) has a negative impact on the health of household members especially women and children that are mostly exposed to the pollutants produced by this stove. Such exposures are linked to acute respiratory infections, chronic obstructive lung disease, low birth weight, lung cancer and eye problems (Kaoma and Kasali 1994).

The most common pollutant produced from the combustion of biomass fuels are particulate matter, carbon monoxide, hydrocarbons, nitrogen oxides and sulfur oxides (Yohannes, 2011). The composition of the

pollutants emitted during the combustion of biomass fuel depends on several factors; such as original compositions of the fuel, ambient and combustion temperatures, air flow into the fire, mode of burning and type of stove (Yohannes, 2011). Biomass combustion provides basic energy requirements for cooking and heating of rural households and for process in a variety of traditional industries in the developing countries (Reric, 2003). In general, biomass energy use in such cases is characterized by low energy efficiency and emission of air pollutants. Biomass fuels currently used in traditional energy systems could potentially provide a much more extensive energy service than at present, if these were used efficiently. For example, new stove design can improve the efficiency of biomass used for cooking by a factor of 2 to 3. (Reric, 2003).

According to Yohannes (2011), four different processes can be distinguished in gasification as illustrated in Fig. 1.

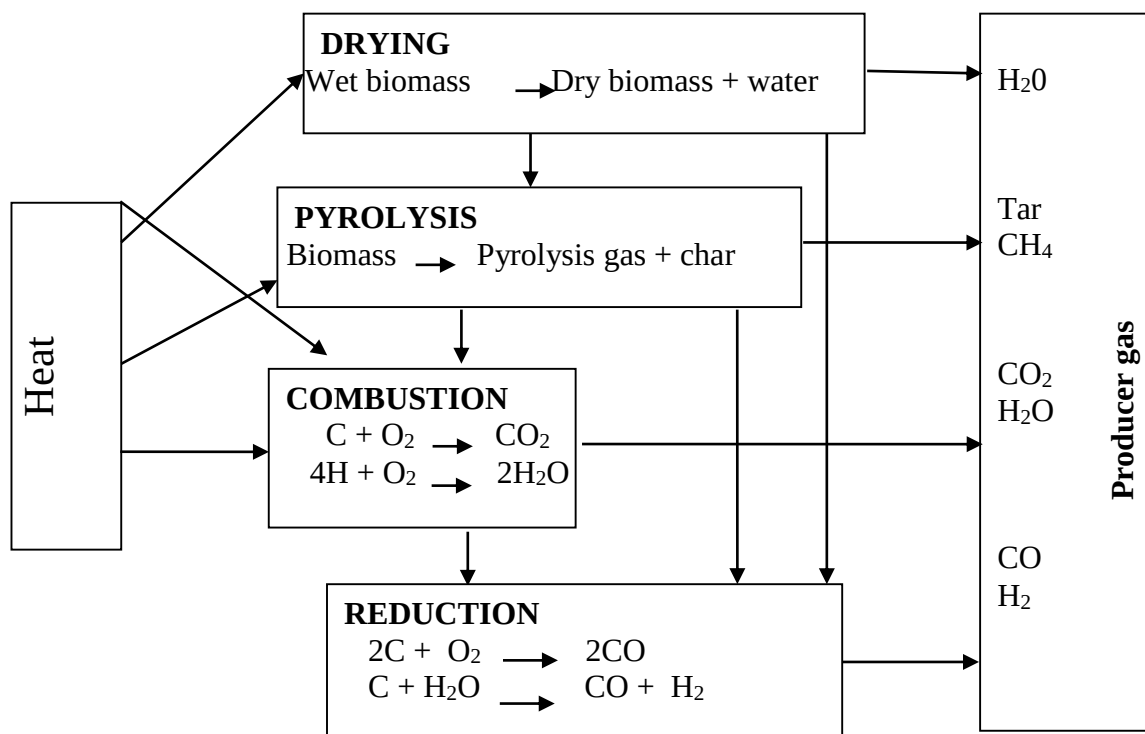


Fig. 1. The reaction mechanism of biomass gasification processes (Source: Yohannes 2011)

Several factors influence the gasification of biomass which include; energy content of the fuel, moisture content, size and form of fuel e.t.c. (Kaupp, 1984, Bellonio, 2005). Fuel with high energy content provides better combustion in biomass gasifier. The moisture content of biomass also affects gasification. Fuel with low moisture content can be properly gasified than that with high moisture content. The biomass fuel should be of a form that will not lead to bridging within the reactor. Bridging occurs when unscreened fuels do not flow freely axially downwards in the gasifier. Therefore, particle size is an important parameter in biomass gasification because it determines the bed porosity.

Therefore the objective of this project is to develop a stove that will burn biomass fuel in an efficient manner, and to carryout performance evaluation test so as to determine its usefulness.

2. METHODOLOGY

2.1 Functional Units of the Design

This stove consists of five functional units, which are burner assembly, reactor, ash chamber, fan assembly and the power supply or control units (Figs 2, 3, 4). Some of its parts are made up of mild steel sheet, refractory material, and wood. It's mode of operation is based on the principle of Top lit up-draft fan assisted method of gasification, burning different type of fuel such as rice husk, corn cub, wood shaving, saw dust, palm kernel, plant straw and other agricultural waste to produce luminous blue flame like that of gas cooker.

2.2 Design Calculations

Some of the parameters required in determining the appropriate size and power of gasifier stove reactor are computed as follows:

Energy demand: This is the amount of heat energy required to be developed by the stove. This can be determined based on the amount of food and/or water to be boiled and their corresponding specific heat energy values (Yohannes, 2011).

The amount of energy required to cook food was calculated using equation 1

$$Q_n = \frac{M_f \times E_s}{T} \quad (1) \quad (\text{Yohannes, 2011})$$

Where, Q_n - Energy needed, KJ/hr, M_f - Mass of food, Kg

E_s - Specific energy, KJ/Kg, T - Cooking Time, hr

Energy Input: It is the amount of energy to be supplied into the stove in terms of fuel. This stove can handle a variety of dry biomass of reasonable size that will allow the passage of primary air. Such biomass include saw dust, rice-husks, wood shaving, wood waste, plant straw and other agricultural residue. The fuel consumption rate is determined using equation 2

$$FCR = \frac{Q_n}{H_{vf} \times E_g} \quad (2) \quad (\text{Yohannes, 2011, Belonio, 2005})$$

Where, FCR - Fuel consumption rate, Kg/hr, Q_n - Heat energy needed, KJ/hr

H_{vf} - Heating value of fuel, KJ/Kg, E_g - Gasifier Stove Efficiency, %

Reactor Diameter: This is the size of reactor in terms of the diameter of cross-section of the cylinder where biomass is being burned. It is a function of the amount of fuel consumed per unit time (FCR) to the specific gasification rate (SGR) of biomass material; which is in the range of 110 to 210 kg/m²-hr or 56 to 130 as revealed by the results of several test on biomass material gas stoves (Belonio, 2005).

The reactor diameter is calculated using equation 3

$$D = \left(\frac{1.27 \times FCR}{SGR} \right)^{0.5} \quad (3) \quad (\text{Belonio, 2005, Yohannes 2011})$$

Where, FCR - Fuel consumption rate, Kg/hr, SGR - Specific gasification rate of biomass material, Kg/m²-hr, D - Diameter of reactor, m.

Height of the Reactor: This is the total distance from the top and the bottom end of the reactor and it determines the operation time of the stove. Basically, it is a function of a variables such as operating time (T), the specific gasification rate (SGR) and the density of the biomass material ρ (Yohannes, 2011). The height of reactor can be calculated using equation 4.

$$H = \left(\frac{SGR \times T}{\rho} \right) \quad (4) \quad (\text{Belonio, 2005, Yohannes, 2011})$$

Where, H - Height of the reactor, m, SGR - Specific gasification rate of biomass fuel, Kg/m²-hr, T - Time required to consumes the biomass fuel, hr

ρ - Biomass material density, Kg/m³

Time to consume the biomass fuel: This is the total time required to completely gasify the biomass material inside the reactor. This includes the time to ignite the fuel, time to generate the gas, plus time to completely burn all the fuel in the reactor (Yohannes, 2011),

Time required to consumes the Biomass material, hr is calculated using equation 5

$$T = \frac{\rho \times V_r}{FCR} \quad (5) \quad (\text{Belonio, 2005, Yohannes, 2011})$$

Where, T - Time required to consumes the Biomass material, hr

V_r - Volume of the reactor, m³, ρ - Biomass material density, Kg/m³

FCR - Fuel Consumption rate, Kg/m³

Therefore, a cylindrical reactor made of clay material supported by mild steel cylinder of 1.2mm thick with the following configuration was selected for the stove

The parameters required in selecting the type and size of the fan is the amount of air Needed for Gasification, This is the rate of flow of air into the stove reactor. It helps in determining the size of fan or blower needed for the reactor in gasifying biomass material. It can be calculated using equation 6.

$$AFR = \frac{E \times FCR \times SA}{\rho_a} \quad (6) \quad (\text{Belonio, 2005})$$

Where, AFR - Air flow rate, m³/hr, E - Equivalence ratio, 0.3 to 0.4

FCR - Fuel consumption rate, Kg/hr, SA- Stoichiometric air of biomass fuel, 4.5kg air per kg of fuel., ρ_a - Air density, 1.25Kg/m³

Superficial Air Velocity: This is the speed of air flow through the fuel bed as shown in equation 7.

$$V_s = \frac{4AFR}{\pi(D)^2} \quad (7) \quad (\text{Belonio, 2005})$$

Where, V_s - Superficial gas velocity, m/s, AFR - Air flow rate, m³/hr

D - Diameter of reactor, m.

Resistance to Airflow: This is the amount of resistance exerted by the fuel and by the char inside the reactor during gasification. This is important in determining whether to use a fan or blower to supply the required air for the reactor. It can be calculated using equation 8.

$$R_f = T_f \times S_r \quad (8) \quad (\text{Belonio, 2005})$$

Where, R_f - Resistance of fuel, cm of H₂O, T_f - Thickness of fuel column, m

S_r - Specific resistance, cm of water/m of fuel.

Power supply unit. Power requirement by the 2 fans is calculated using equation 9.

$$\text{Power, } P = IV \quad (9)$$

Where, P – Power in watt, I – current in A, V – Voltage in V

The specifications of the fan selected were 12V and 0.30A.

$$\text{Power, } P = IV = 0.30 \times 12 = 3.6W$$

$$\text{For the two fans, Power} = 2 \times 3.6W = 7.2W$$

$$\text{Energy needed by the two fans} = \text{Power} \times \text{Time}$$

The stove is to be operated for the maximum periods of one hour (Assumption)

$$\text{Energy needed} = 7.2W \times 3600\text{sec} = 25920J = 25. KJ$$

For the power supply output power; Output voltage = 12V, Maximum current = 1A

$$\text{Output Power} = 1A \times 12V = 12W$$

The battery capacity is determined using equation 10:

$$\text{Battery Power (Ah)} = \frac{\text{Load in watt}}{\text{Battery voltage} \times \text{Backup hour}} \quad (10)$$

(Electroschematics.com/5645/home/Inverter/)

$$\text{Battery power (Ah)} = \frac{7.2W}{12V \times 1\text{hour}} = 0.6Ah$$

According to the above calculation, a 12V battery with 1Ah capacity can supply the required current for the stove operation for one hour. But, in Nigeria there may be power failure for 2 or more days at times and cooking must be done. For this reason, two 6V batteries with 4.5Ah capacity were selected for the project and it was connected in series to give 12V, 4.5Ah. Backup time is expressed as follows:

Required Battery power for 1 hour = 0.6Ah

Selected Battery power for 1 hour = 4.5Ah

$$\text{Backup time} = \frac{\text{Selected battery power}}{\text{Required battery power}} = \frac{4.5Ah}{0.6Ah} = 7.5 \text{ hours} \quad (11)$$

Backup time = 7 hours, 30 minutes.

Therefore, the power supply unit can supply the stove for up to 7 hours continuously before the battery run down.

2.3 Procedures for Testing and Performance Evaluation

The test equipment such as weighing scale, thermometer, measuring cylinder, weighing balance, pot, digital multi-meter and stop-watch were prepared. The stove was set up with the power supply unit connected. Measured weight of fuel (biomass) was loaded in batches till the stove reactor filled up and total weight of fuel loaded was recorded. Small amount of kerosene was poured on top of fuel bed and ignited with match stick and stop-watch started. Fire was fully established after about 1 minute. After this, the burner and stove cover put in place. Blue flame was fully established after about 5 minutes. 1 litre of water measured with volumetric cylinder and poured into the pot, covered and placed on the burner. The water boiled after about 3 minutes. This step was repeated three times using 1 litre of water and initial and final temperature of water, as well as weight of water left in each case was measured. Pot filled with 1 litre of water and placed on the stove without cover. Initial temperature of water and simmering water temperature was measured at 1 minute interval till the water boils. The stove was left in operation on till the fuel was completely gasified. Char was discharged from the ash chamber and measured with weighing balance.

The results of the test are as presented in tables 1, 2 and 3. The summary of the stove performance was presented in table 4. The parameters in table 4 were obtained as stated below;

- a) **Fuel Consumption Rate:** This is the amount of fuel used in operating the stove divided by the operating time.

$$\text{Fuel Consumption Rate, FCR} = \frac{\text{weight of fuel used (Kg)}}{\text{Operating Time (hr)}} \quad (12) \quad (\text{Belonio, 2005})$$

- b) **Specific Gasification Rate, (SGR):** This is the amount of fuel used per unit time per unit area of the reactor.

$$\text{SGR} = \frac{\text{weight of fuel used(Kg)}}{\text{Reactor area(m}^2\text{)} \times \text{Operating time(Hr)}} \quad (13) \quad (\text{Belonio, 2005})$$

- c) **Combustion Zone Rate (CZR):** This is the time required for the combustion zone to move down the reactor.

$$\text{CZR} = \frac{\text{length of the reactor (m)}}{\text{operating time (hr)}} \quad (14) \quad (\text{Belonio, 2005})$$

- d) **Power Input P_{in} :** This is the amount of energy supplied to the stove based on the amount of fuel consumed.

$$p_{in} = 0.0012 \times \text{FCR} \times \text{HVF} \quad (\text{kW}) \quad (15) \quad (\text{Belonio, 2005})$$

Where, FCR – Fuel consumption rate, KJ/Kg

- e) **Power Output P_{out} :** This is the amount of energy released by the stove for cooking.

$$P_{out} = \text{FCR} \times \text{HVF} \times \text{TE} \quad (\text{kW}) \quad (16) \quad (\text{Belonio, 2005})$$

Where, FCR – Fuel consumption rate, Kg/hr, HVF – Heating value of fuel, KJ/Kg, TE – Thermal efficiency, %

- f) **Percentage Char Produced:** This is the ratio of the amount of char produced to the amount of fuel used.

$$\% \text{ Char} = \frac{\text{Weight of Char, Kg}}{\text{Weight of Fuel used, Kg}} \times 100 \quad (17) \quad (\text{Belonio, 2005})$$

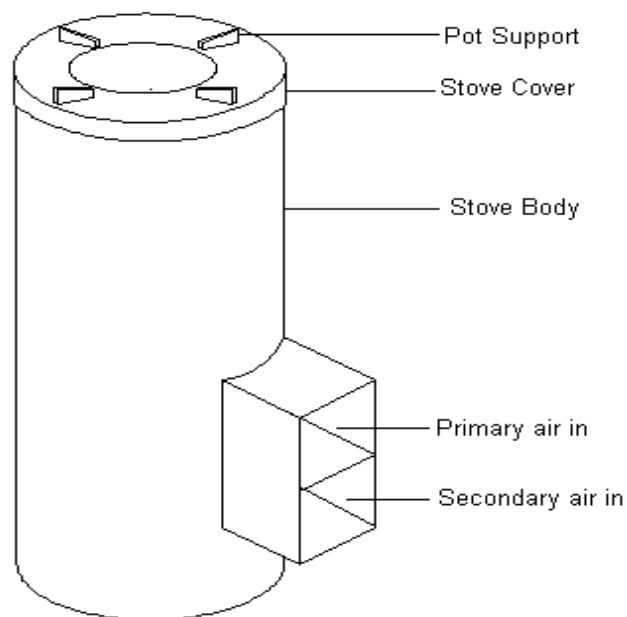


Fig 2: Isometric View of the Gasifier stove

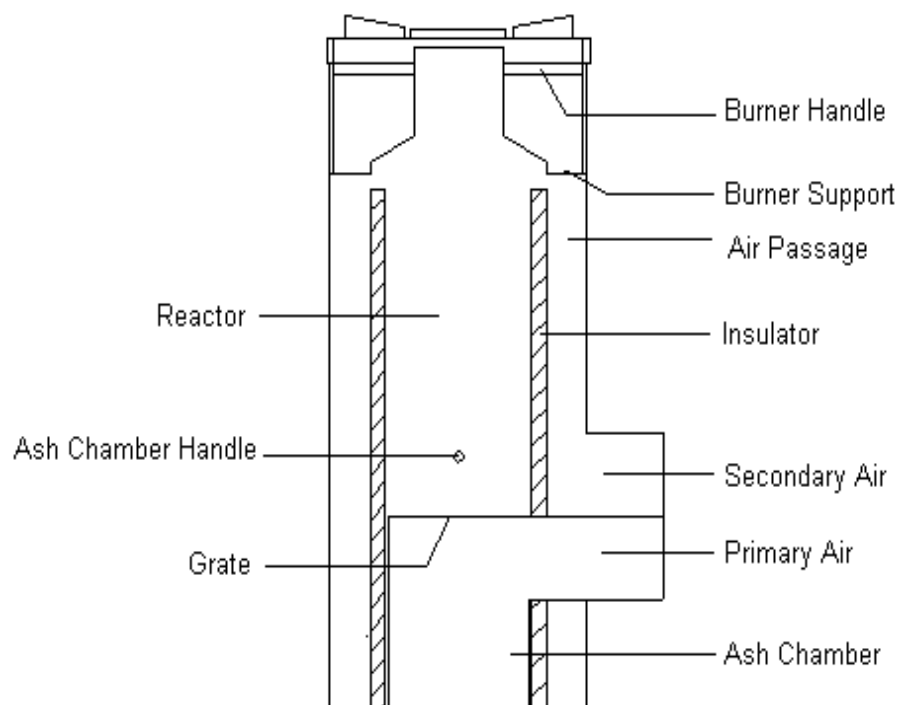


Fig 3: Sectional View of the Gasifier stove



Fig. 4. Completed Stove and Power Supply Unit

3. RESULTS AND DISCUSSIONS

The results of the tests carried out on the stove are as shown in Tables 1, 2, 3 and 4. Table 1 shows the change in weight of water as its temperature rises from room's to boiling point. About 300g of water is lost as its temperature rises by 74°C (4g/°C). Table 2 shows the water simmering test. The table shows that it takes the stove an average of 5 minutes to boil a litre of water. About 15°C/min. rise in temperature of water was recorded throughout the test period. Table 3 shows the performance of the stove in terms of fuel consumption rate, specific gasification rate, combustion zone rate, input and output power and thermal efficiency. The ratio of output to input power of 223.6 shows that the power output was very high.

Table 1: Water Boiling Tests

S/NO	WATER PARAMETERS	TEST 1	TEST 2	TEST 3	AVERAGE
1	Initial weight	1000g	1000g	1000g	1000g
2	Final weight	700g	680g	690g	690g
3	Initial temperature	26°C	27°C	27°C	26.7°C
4	Final temperature	100°C	100°C	100°C	100°C

Table 2: Water Simmering Tests

TIME	WATER	TEMPERATURE		
	TEST 1	TEST 2	TEST 3	AVERAGE
0	26°C	27°C	29°C	27.3 °C
1	35°C	38°C	37°C	36.7°C
2	41°C	42°C	42°C	41.7°C
3	54°C	54°C	55°C	54.3°C
4	73°C	76°C	75°C	74.7°C
5	98°C	100°C	100°C	99.3°C
6	100°C	100°C	100°C	100.0°C

Table 3: Stove Operating Parameters.

S/NO	Parameters	Value
1	Weight of fuel	5.85Kg
2	Weight of ash	0.76Kg
3	Ignition time	1 minute, 12 seconds
4	Time when blue flame begins	2 minutes, 43 seconds
5	operating time	58 minutes, 7 seconds
6	Total operating time	1 hour, 2 minutes

The stove performances are summarized in Table 4 below:

Table 4; Summary of stove performance

S/N	Parameters	Values
1	Fuel consumption rate	5.85kg/hr
2	Specific gasification rate(SGR)	186.19kg/m ² hr
3	Combustion zone rate (CZR)	0.67cm/m
4	Power input	130kW
5	Power output	29069.24kW
6	Percentage Char produced	13%

4. CONCLUSIONS AND RECOMMENDATIONS

A biomass gasifier stove has been design and constructed using locally available materials to minimize cost. It makes use of agricultural and wood waste as fuel to produce luminous blue flame like that of gas cooker. The stove was equipped with power supply unit that has a battery backup for up to 7 hours in case of power failure which helps in supplying the air needed for gasification.

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ANALYSIS OF MAINTENANCE IN BREWING INDUSTRIES USING EQUIPMENT UNIFORM ANNUAL COST (EUAC) METHOD

C. O. Nwajinka¹ and B. Udoeye²

¹Department of Agricultural & Bioresource Engineering, Nnamdi Azikiwe University, Awka, Nigeria.

²Department of Mechanical Engineering, Federal Polytechnic, Oko, Anambra State, Nigeria.

Email: obinwajinka@yahoo.com

ABSTRACT

A study of replacement and maintenance related problems of brewery industries was carried out with view of appraising the maintenance policy of the industry in Nigerian situation. Equivalent Uniform Annual Cost (EUAC) method was used in performing the analysis using data collected from PAL breweries LTD, which they kept for a period of ten years (from 1990 to 1999). Three machines were selected for this study based on their perceived importance in the brewery industry. They are: ammonia compressor, washing machine and filling machine.

The results show that ammonia compressor and filling machine should be replaced or overhauled in their seventh and sixth years respectively. However, this was not done as revealed by the study. The washing machine however did not show visible sign of economic deterioration and should be retained with routine maintenance for the period of study. There was inadequate personnel's training for manpower development, which could be responsible for accelerated machine deterioration. These technical lapses should be addressed by the management of the industry for optimal performance of the industrial machines.

KEYWORDS: Maintenance, replacement, brewery industry, equipment cost.

1. INTRODUCTION

Maintenance can be defined as all activities aimed at keeping the available permanent means of production in a condition or bringing them back into a condition that is considered necessary for a proper fulfillment of their function. This definition implies that a well worked out maintenance schedule contributes greatly to the realization of the company's objectives (Nwajinka, 2005). Therefore a good maintenance and replacement model should be able to predict optimal maintenance and replacement time that will reduce to the possible minimum, the down-time of the equipment (or maximize the undisturbed production time). This undisturbed production time is an inverse function of the time of replacement of the equipment. Replacement and maintenance are not clearly separated. Ackof and Sasien (1984) argued that maintenance is always associated with replacement of components of equipment or the entire equipment, hence all problem situations concerned with controlling the condition of equipment are termed, "problems of maintenance and replacement". Economic replacement theory models attempt to answer the question: "what is the optimum economic life of this piece of equipment? This question suggests that the goal of any replacement is to find an optimum length of time a given piece of equipment is kept in service. After this service life, there is at least one alternative which is more economical than keeping the machine in its present state. This other alternative may be to replace, retire or rebuild (remanufacture) etc.

The objective of this work was to develop a computer program capable of keeping the data base needed for the computation of the Equipment Uniform Annual Costs (EUAC) for major sub-Units of brewing plants as a tool for predicting the replacement and maintenance periods.

2. MATERIALS AND METHODS

2.1 Replacement and Maintenance Models

Decision on equipment maintenance and replacement should be made on sound economic principles and not emotions or mere intuition (Schaevitz, 1988). There are three basic theories in field of economic replacement, which are used in performing the analysis. These are: the cost minimization model, the profit maximization model, and the repair limit model.

2.1.1 Cost Minimization

The theory of cost minimization can be explained quite well graphically. The cost minimization model is depicted graphically in fig 1. Most costs associated with a machine can be placed in one of the two categories: ownership costs and operating costs. The average cost of ownership for a given machine should decrease with its length of service, since most of the capital costs involved with owning a machine are incurred as soon as it is purchased. As time goes on, the initial purchase price is spread over a longer time span and thus the average cost decreases. On the contrary, the average cost of operating a given machine should increase the longer it is kept in service. This is because as a machine is operated, repairs become more frequent and probably more costly. Cost minimization, therefore strives to find a balance point between decreasing ownership costs and increasing operating costs. Three curves depict these phenomena: average ownership costs, average operating cost and average total cost. These cost components are expressed mathematically as follows:

$$\text{Average ownership cost} = \frac{P_o - S_t}{L_t} \quad (1)$$

$$\text{Average Operating Cost} = \frac{\sum_0^t E_p}{L_t} \quad (2)$$

$$\text{Average Cost Per Period at Age } L_t = \frac{P_o + \sum_0^t E_p - S_t}{L_t} \quad (3)$$

Where, P_o = initial purchase price

E_p = expenditure for period

S_t = salvage value at time, t

L_t = machine age at time, t .

Average costs are calculated by taking the cumulative costs incurred up to a given point in time and dividing these costs by machine age. Average cost curves are developed for ownership costs and for operating costs. The sum of these two curves (the average total costs curve), slope downwards initially when operating costs are low and the average cost of capital is decreasing. The minimum value of average total cost I^* , the point where the slope of the curve is zero. The optimum economic life L^* , is the period which ends when the sum of owning and operating costs reaches a minimum.

2.1.2 Profit Maximization Basic Model

This alternative method of solving replacement problems was developed in 1925 by Hotelling (Rickards, 1980). Just as in the cost minimization model, profit maximization model can be depicted in a graph. Three lines are depicted on the chart to represent the average total cost, the revenue and the average profit. The average revenue is the average amount of income generated by the asset, while the average profit is determined by subtracting the average costs from average revenue. The optimum economic life occurs at the apex of the average profit curve. If average revenue were constant, the average profit curve would be an exact mirror image of the average cost curve, and the profit maximization economic life would be the same as the cost minimization economic life. However, the amount of revenue generated by an asset often declines with use as the machine suffers from both determination and obsolescence as it ages. As a result of this, the economic lives for profit maximization and cost minimization are not always the same (1975). The cost models for profit maximization are mathematically expressed as follows:

$$\text{Average Revenue} = \frac{\sum_0^t R_p}{L_t} \quad (4)$$

2.1.3 The Repair Limit Theory

A third method of tackling replacement problem is the repair Limit theory presented by Drinkwater and Hasting (1967). This method is still in use for replacement decisions. This was defined as a limit on the amount of money which can be spent on the repair of a machine at any particular job. The values of the repair limit are dependent on the type, age, and in some cases on the location of the machine. One of the limitations of repair limit theory is that it is not applied until a machine has broken down. The concept is that there exists some amount, not below which it is economically sound to repair the machine. If the estimated cost of the repair is greater than not, the repair should not be undertaken and the machine should be discarded or replaced. A popular expression for estimating the future cost per year if the machine is repaired:

$$F_c = \frac{r + m(t)}{g(t)} \quad (5)$$

Where, r =the cost of the repair in question; $m(t)$ = the expected total cost of future repairs from time, t , forward; $g(t)$ = the expected remaining life of machine from time, t ; t = the time in the machine's life at which point the repair limit evaluation is taken place.

If a field machine is scrapped, then the future cost per year is θ , which is found by determining the average future annual cost of the replacement system. The replacement system is either a new copy of the defender or a challenger that is different. The result of equation (5) is compared to θ . If;

$$\frac{r + m(t)}{g(t)} < \theta \quad (6)$$

The machine should be repaired and returned to service as soon as possible. If the inequality is not true, then the machine should be scrapped and replaced. The repair limit is the value of r for which both sides of the inequality would be equal. Solving for r , the repair limit comes;

$$r_0(t) = (\theta \cdot g(t)) - m(t) \quad (7)$$

The line OAD is cumulative repair cost against age of machine. The value OA is the original capital cost. The curve AQPD represents the cumulative repair cost over time. The slope θ , represents the average cost of similar machine against which the machine of interest is to be judged. The straight sloping line is tangential to the cumulative cost curve at the point P. the average cumulative repair cost at any point on the cumulative cost curve is given by the slope of the line drawn from that point to origin of the plot. At a point in the machine's life L_t , the line OW represents the repair limit. Beyond age L_{tp} the repair limit is zero.

The major limits of this model include: (i). It is limited to one type of decision, (ii). The theory cannot be applied until the machine breaks down.

2.2 The Case Study

The case study, PAL Breweries LTD Oko, was established in 1985 under the factories ordinance of 1955 of Federal Republic of Nigeria. The chief products of the company on stream were PAL lager beer and Royal malt. In 1989 the breweries suffered a setback when it had its lager beer product riddled with the problem of gushing. This technical problem caused a hiccup that almost crippled the industry. It however got over this setback and introduced the malt line of production which sustained industry though the lager

beer line remained out of circulation. The single line plant was designed to produce 250, 000 hectoliters of the products per annum.

2.3 Machines Studied

To gather data for this study, three machines were selected because of their important positions in the production line (Udoeye, 2005). Their importance is underscored by the reason that the breakdown of each of the machines held down production operations with the attendant losses to the company both in time and money. The machines are; Ammonia Compressor, Washing machine (washer), and filling machine (filler). Their purchase and installation prices, year of purchase/installation and their salvage values were extracted from the fixed asset card of the company.

2.3.1 Ammonia Compressor

The Huppman Refrigeration Compressor was purchased and installed in 1986 at the cost of four hundred and seven thousand eight-five kobo (N 407,083.25). its function was provide cold storage for liquid products components. It's perfect operating condition is based on the permissible load, skilled attendance and regular maintenance.

2.3.2 Washing Machine

The contitakt single-end brand of washing machine was purchased in 1986 at the cost of seven hundred and thirty-two thousand, seven hundred and forty-nine Naira eighty-five kobo (N732, 749.85). The function was to provide clean bottles for filling the products. The prescribed operating condition was highly dependent on the preventive/plan maintenance as stipulated in the Huppman Engineering Company, PBL machines manual.

2.3.3 Filling/Crowner Machine

The Ohansa brand filler/crowner was purchased and installed in 1986 at the cost of six hundred and two thousand four hundred and eighty three Naira twenty-one kobo (N602,483.21). the function of this machine was to fill washed bottles with the liquid products while the crowning machine attached to it seals the bottles with crownorks.

2.4 Equipment Uniform Annual Cost (EUAC)

The EUAC method of replacement analysis was used in this study. The computation involves the annual step calculation of EUAC as shown below:

$$(EUAC)_N = \sum_{i=0}^N GN(A/P, i\%, N)$$

$$GN = LN(P/F, i\%, N)$$

$$LN = DN + RN + iSN$$

$$P/F = \frac{1}{(1+i)^N}$$

$$A/P = \frac{i(1+i)^N}{(1+i)^N - 1}$$

Where, DN=Depreciation for, 1...N years; RN= Operating cost for, 1...N years; SN= Salvage value for, 1...N years; iSN= Cost of capital at I interest rate; N=Infinite number of years; P/F=Present worth factor; A/P=Capital recovery factor

2.5 Computation of EUAC

A program was written in Dbase III+ to assist in handling the tedious computational effort and large volume of data required in the database management for the machines' EUAC and maintenance records. The main menu provides platform for machine programs, update and editing of record. The sub-programs include the following: add record, edit records, display record, print or generate report, and computation of EUAC. The illustrative systems flow chart is presented in Fig. 1 and 2.

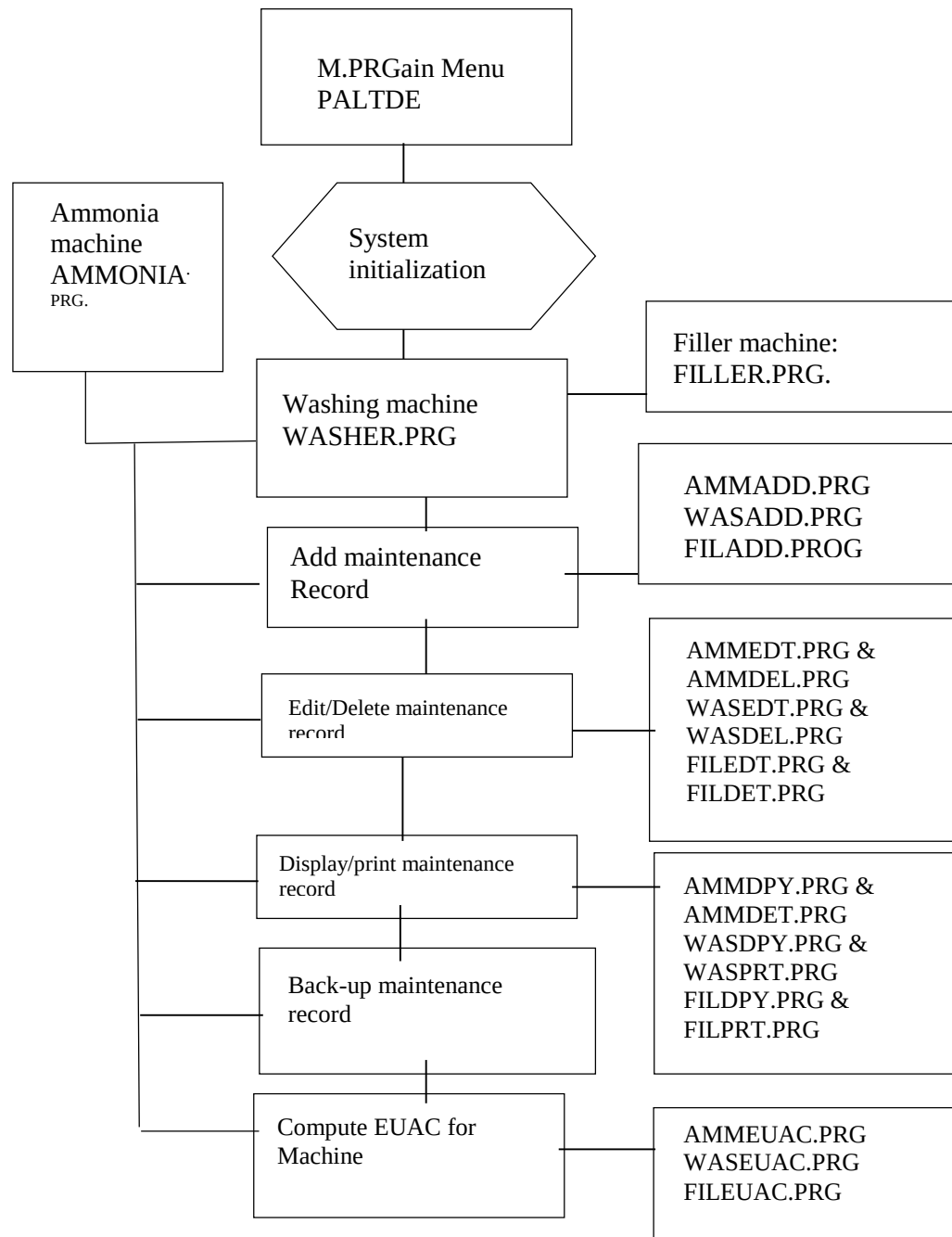


Fig. 1: The system flowchart for computation of EUAC

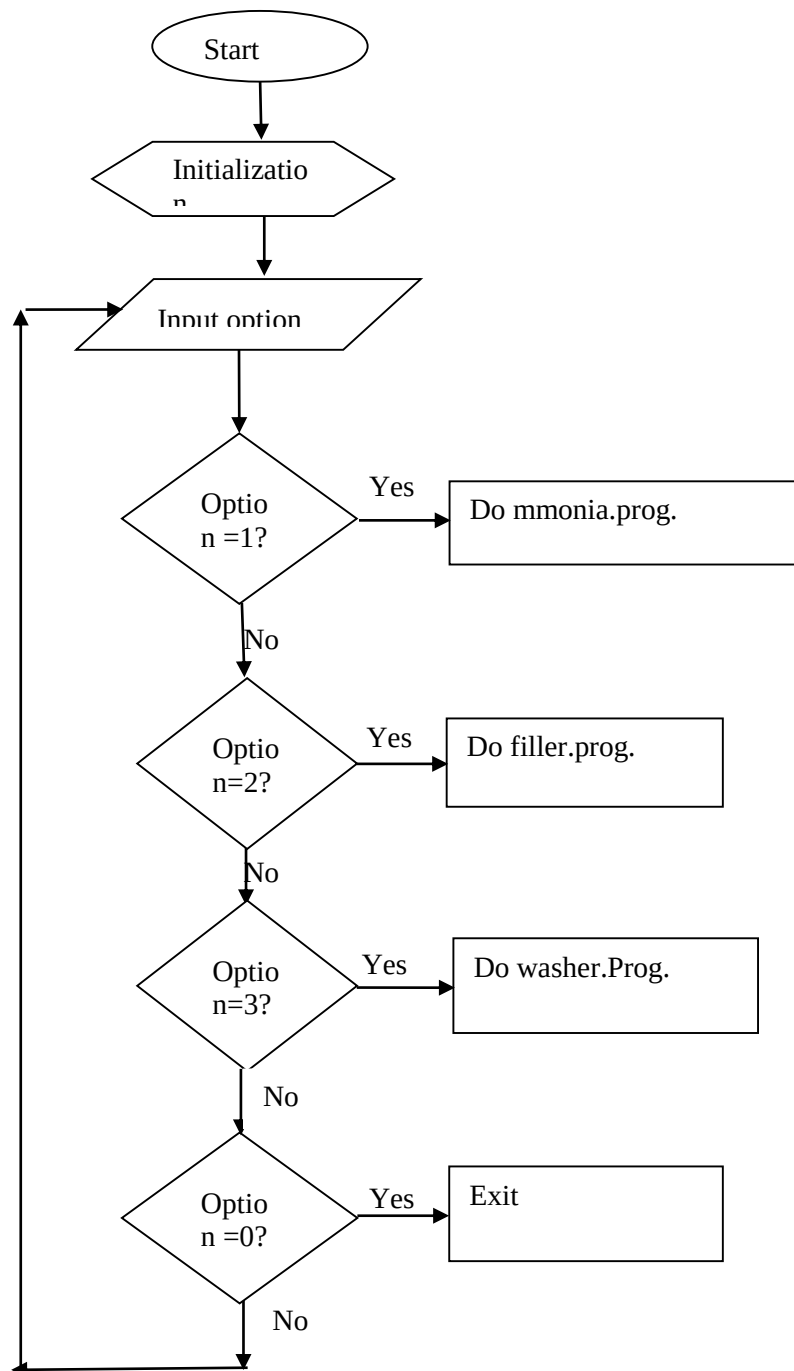


Fig. 2. System flowchart for computation of EUAC

3. RESULTS AND DISCUSSION

The results of the computations are shown in Tables 1 – 3 and Figs 3 – 5.

Table 1: Result of computation of Depreciation of Ammonia Compressor using Declining balance method (interest rate =15% and rate of return=10%)

N (Yrs)	SN(~~N~~)	DN(~~N~~)	RN(~~N~~)	iSN(~~N~~)	LN (DN+RN+ iSN)	GN [LN(P/F, i%,N)]	$\Sigma \quad GN(A/P, i\%, N)$
1990	250,0 00.00	-	-	-	-	-	-

1991	212,500.00	37,500.00	21,095.00	25,000.00	83,595.00	75,996.21	83,595.83
1992	180,625.00	31,875.00	10,240.00	21,250.00	63,365.00	52,364.84	73,961.64
1993	153,531.25	27,093.75	10,660.00	18,062.50	55,816.25	41,934.75	68,475.94
1994	130,501.56	23,029.69	2,200.00	15,353.13	40,582.82	27,718.07	62,473.38
1995	110,926.33	19,575.23	0.00	13,050.16	32,625.39	20,257.10	57,579.88
1996	94,287.38	16,638.95	5,740.00	11,092.63	33,471.58	18,894.71	54,453.24
1997	80,144.27	14,143.11	68,400.00	9,428.74	91,971.85	47,199.95	58,408.70
1998	68,122.63	12,021.64	113,250.00	8,014.43	133,286.07	62,177.95	64,942.27
1999	57,904.24	10,218.39	69,500.00	6,812.26	86,530.65	36,723.09	66,535.09

Table 2: Result of computation of Depreciation of Washing machin using Declining balance method (interest rate =15% and rate of return=10%)

N (Yrs)	SN(₦)	DN(₦)	RN(₦)	iSN(₦)	LN (DN+RN+i SN)	GN [LN(P/F, i%,N)]	$\Sigma GN(A/P, i\%, N)$
1990	450,000.00	-	-	-	-	-	-
1991	382,500.00	67,500.00	25,784.00	45,000.00	138,284.00	125,713.98	138,285.38
1992	325,125.00	57,375.00	37,573.50	38,250.00	133,198.50	110,075.24	135,861.75
1993	276,356.25	48,768.75	18,992.00	32,512.50	100,273.25	75,335.29	125,103.17
1994	234,902.81	41,453.44	9,694.00	27,635.63	78,783.07	53,808.84	115,136.47
1995	199,667.39	35,235.42	0.00	23,490.28	58,725.70	36,462.79	105,888.30
1996	169,717.28	29,950.11	6,350.00	19,966.74	56,266.85	31,762.64	99,453.26
1997	144,259.69	25,457.59	16,130.00	16,971.73	58,559.32	30,052.64	95,143.63
1998	122,620.74	21,638.95	28,200.00	14,425.97	64,264.92	29,979.59	92,424.00
1999	104,227.63	18,393.11	45,870.00	12,262.07	76,525.18	32,454.33	91,252.03

Table 3: Result of computation of Depreciation of filling machine (filler) using Declining balance method (interest rate =15% and rate of return=10%)

N (Yrs)	SN(₦)	DN(₦)	RN(₦)	iSN(₦)	LN (DN+RN+i SN)	GN [LN(P/F, i%,N)]	$\Sigma GN(A/P, i\%, N)$
1990	370,000.00	-	-	-	-	-	-
1991	314,500.00	55,500.00	25,735.00	37,000.00	118,235.00	107,487.44	118,236.18
1992	267,325.00	47,175.00	43,800.00	31,450.00	122,425.00	101,172.02	120,229.58
1993	227,226.25	40,098.75	19,865.00	26,732.50	86,696.25	65,134.89	110,092.71
1994	193,142.32	34,083.94	8,590.00	22,722.63	65,396.57	44,665.86	100,474.20
1995	164,170.97	28,971.35	0.00	19,314.23	48,285.58	29,980.52	91,918.66
1996	139,545.32	24,625.65	74,850.20	16,417.10	115,892.95	65,421.57	95,022.78
1997	118,613.52	20,931.80	121,154.43	13,954.53	156,040.76	80,080.12	101,455.77
1998	100,821.49	17,792.03	65,070.00	11,861.35	94,723.38	44,188.46	110,315.77
1999	85,698.27	15,123.22	52,120.00	10,082.15	77,325.37	32,793.69	107,885.37

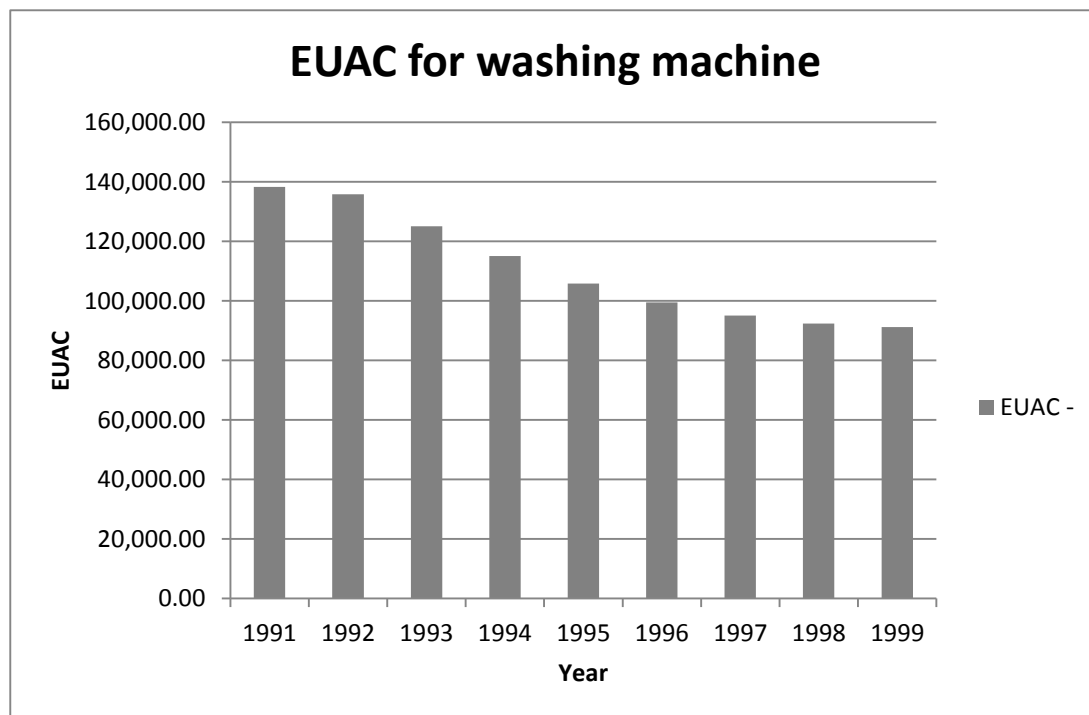


Figure 3: A plot of EUAC against year for washing machine at 10% interest rate and 15% depreciation rate.

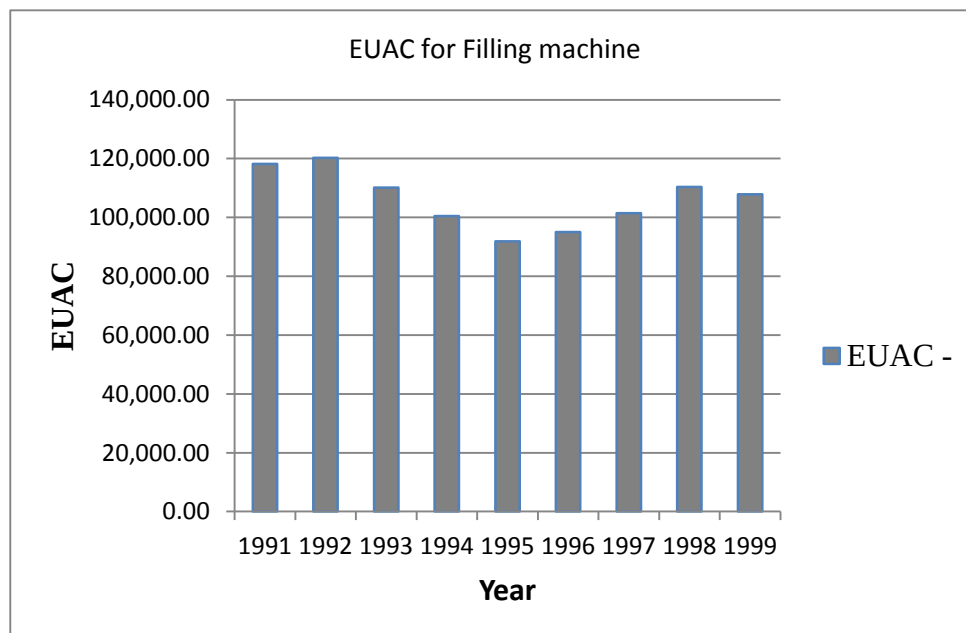


Figure 4: Plot of equivalent Uniform Annual Cost of filling machine against year at 10% interest rate and 15% depreciation rate.

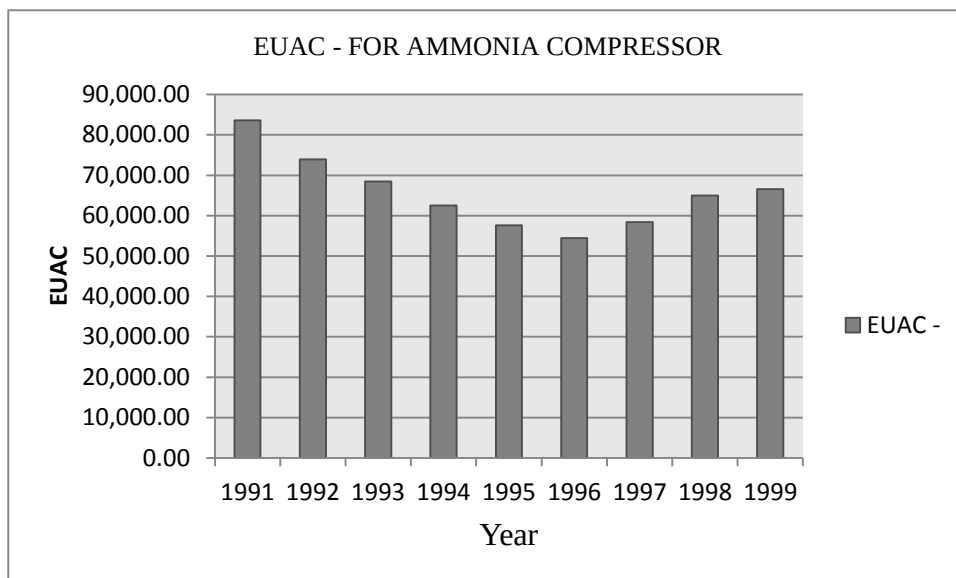


Figure 5: Plot of EUAC against year for Ammonia Compressor at 10% interest rate and 15% depreciation rate.

For a favorable machine condition, the EUAC for a particular year will be less than that of the previous year. When the EUAC of a particular year is greater than that of the previous year, it signifies deterioration of the machine, given that all other conditions for effective running of the machine are in place. At this point, it may be apt to embark on major repair or outright replacement of the equipment. Where this is ignored and the machine continues to run, there is an accumulation of running cost that is usually exorbitant.

For the Ammonia Compressor, the EUAC started to increase from the seventh year (ie. In 1997: see table 6) having reached the minimum value in 1996. This shows that the machine was due for either major maintenance or replacement at that point (1996) for optimal performance and costs minimization.

For the washing machines, the EUAC did not show any minimum value within the years studied. This indicated that the machine had a longer service life than the period of study and should go on with routine maintenance and checks. This is a favorable attribute for the machine.

The EUAC for the filling machine was minimum in the fifth year (1995) and started increasing in 1996. As is the rule it was due for major maintenance or replacement in the year 1996, whichever is more convenient to the company.

It was observed that output result for all the machines' RN was zero in 1995. This was explained by the reason that the company did not engage in production that year due to the technical problem that propped up in the factory which forced it to shut down. It was not possible to extend the study to the year of purchase of the machines studied due to non-availability of the maintenance and replacement records.

Inadequate technical data records which were observed could be traced to unskilled workers which dominated the industry. Interaction with staff of the company revealed that junior staff made up about 70% of roughly 250 staff engaged by the company. There was no training scheme for the technical personnel and machine operators. Inadequate stocking of spare parts and purchase of inferior and used parts prolonged down-time of the broken down machines and resulted in poor maintenance jobs. Above all, there were poor records of inventory and maintenance operations.

4. CONCLUSIONS

The EUAC method of replacement and maintenance analysis used in this study was found to be useful as a veritable tool for techno-economic analysis of machine systems. The record keeping for such analysis is usually very tedious and requires a robust database to keep and make data records available for use in a time-saving and convenient manner. These computer-aided models could run the database as well as compute EUAC needed for decision making in replacement and maintenance situations within a very short time by any person who can drag the mouse of a computer.

The results show that ammonia compressor and filling machine should be replaced or overhauled in their seventh and sixth years respectively. However, this was not done as revealed by the study. The washing machine however did not show visible sign of economic deterioration and should be retained with routine maintenance within this period of study. This could be as a result of underutilization of the machines. Inadequate manpower development could be responsible for accelerated machine deterioration. These technical lapses are recommended for redress by the management of the industry for optimum performance.

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PERFORMANCE EVALUATION OF INVERTED T AND V-SHAPED PIPES WITH DIFFERENT PERFORATIONS ON COMPOSTING PROCESS

G.A. Ogunwande¹, J.A. Osunade¹ and A.Y. Sangodoyin²

¹Department of Agricultural and Environmental Engineering,
Obafemi Awolowo University, Ile-Ife, Nigeria

Email: gbolawande@gmail.com; gbolawande@oauife.edu.ng

²Department of Agricultural and Environmental Engineering, University of Ibadan, Ibadan, Nigeria

ABSTRACT

Inverted T (IT) and V-shaped (Vs) pipe configurations were perforated at three different sizes (15, 25 and 35 mm diameter) in a two-factor passive aeration composting experiment using chicken litter. The results showed that thermophilic temperatures (42-69 °C) for effective composting were attained in all the piles. However, pile with IT15 failed to meet the sanitation requirements for hygienic compost. Both pipe configuration and perforation size had significant ($p \leq 0.05$) effect on pile temperature, pre-replenishment moisture content and electrical conductivity. Pipe configuration affected ($p \leq 0.05$) total carbon while perforation size affected ($p \leq 0.05$) pH and total phosphorus. Both pipe configurations were effective for uniform composting rate, although Vs pipe was more. Summarily, the results showed that IT15 was not promising for passive aeration composting while Vs35 was the most effective for uniform composting rate. IT35 and Vs25 were the most suitable for minimizing total nitrogen and total phosphorus losses, respectively.

KEYWORDS: Passive aeration composting, pipe configuration, perforation size, chicken litter, composting rate

1. INTRODUCTION

Composting is the aerobic decomposition of organic wastes in the thermophilic temperature range (40-65 °C) (Wortmann et al., 2006) to stabilize and transform the wastes into an aesthetic soil amendment (Barrington et al., 2003) free of phytotoxicity and pathogens and with certain humic properties (Zucconi and de Bertoldi, 1987). Based on the method of aeration, composting technologies can be classified as turned windrow, in-vessel system, natural aeration, passive aeration, and forced aeration. However, the acceptance of composting technology depends on how well the operating strategies being employed are developed for product quality (Tiquia et al., 2000) and environmental protection (Savage, 1996). Passive aeration composting is a promising technique as it is more economical (Barrington et al., 2003) and effective in conserving nitrogen (Sartaj et al., 1997) than forced aeration composting, and as efficient (Patni et al., 2001; Solano et al., 2001). It involves fewer on-going labour and equipment costs compared to forced aeration and turned-windrow methods, and has a higher process rate than natural aeration system (Sartaj et al., 1997). As a result, different pipe orientations: horizontal (Fernandes et al., 1994; Lyncht and Cherry, 1996; Sartaj et al., 1997; Solano et al., 2001) and vertical (Sylla et al., 2003a,b; Sylla et al., 2006), and different pipe configurations: V-shaped (Ogunwande, 2011) and inverted T (Ogunwande et al., 2012) have been developed to aid the distribution of air to the composting piles. Studies have also shown that vertical pipe (Sylla et al., 2006; Ogunwande et al., 2012), inverted T pipe (Ogunwande et al., 2012) and V-shaped pipe (Ogunwande, 2011) improved air delivery and produced uniform composting rate within the pile than horizontal pipe. Also, the effects of pipe orientation and perforation size on compost elements were studied (Ogunwande and Osunade, 2011).

This study was therefore a follow-up to the recently developed V-shaped pipe and inverted T configurations (Ogunwande, 2011; Ogunwande et al., 2012) with the aim of (1) investigating the effects of configuration and perforation size on some physico-chemical properties of chicken litter during passive aeration composting and (2) determining the optimum combination of pipe configuration and perforation size that will minimize compost elements losses.

2. MATERIALS AND METHODS

2.1 Materials Collection and Pile Construction

The experimental set up was a 2×3 completely randomised block design with pipe configurations (PCs) of IT and Vs and perforation sizes (PSs) of 15, 25 and 35 mm diameters. Polyvinyl chloride pipes of 76.2 mm inner diameters used for the construction of the APs were purchased from a plumbing materials dealer in Ile-Ife town, South-West of Nigeria. The fresh chicken manure and sawdust were collected from a poultry farm and a sawmill plant, respectively also in Ile-Ife town. The design of the PCs had been presented in Ogunwande (2011) and Ogunwande et al. (2012). Three of each PC had 8 perforations of 15, 25 and 35 mm diameters. Fig. 1a,b show the side view of the APs. The perforations were covered with plastic mesh to prevent chicken litter from dropping into the pipes. The initial properties of the manure and sawdust were determined and a chicken litter of C:N ratio 32:1 was obtained by mixing calculated quantities of manure and sawdust, according to Wortmann et al. (2006).

The initial moisture content (MC) of the chicken litter was adjusted to and replenished fortnightly to 60% (wet basis) through the addition of tap water (Brake, 1992) with pH of about 7.6. The initial properties of the composting materials are shown in Table 1. Each of the six chicken litter piles, pyramidal in section, with bottom and height dimensions of $1.2 \text{ m} \times 1.1 \text{ m}$ and 0.72 m , respectively, was built on top of 100 mm thick sawdust base and an AP. A 40 mm layer of sawdust was added to the outside of the piles to reduce moisture loss and conserve heat in the piles. Each treatment was replicated three times.

2.2 Sampling and Analytical Methods

The ambient temperature and temperatures within each pile were measured daily, using a K-type digital thermometer with thermocouple probe, at two levels (0.21 m and 0.42 m from the top of the base material). The temperatures were measured between the hours of 06:00 am and 08:00 am when the ambient temperature was fairly stable. Samples were collected fortnightly at three levels (170 mm, 340 mm and 510 mm from the top of the base material) in each pile. A total of three samples were collected at each of the levels, homogenized and ground. Samples were analyzed at 105°C dry weight basis for the following parameters: MC (105°C for 24 h); ash (expressed as a percentage of residues after combustion at 550°C for 5 h); total nitrogen (N_T) using regular-Kjeldahl method (Bremner 1996); total phosphorus (P_T) (after acid digestion) using ultra-violet visible, scanning spectrophotometer of wavelength 190-900 nm (Model Unicam Pye UV4-100) (APHA 1995); pH and electrical conductivity (EC) (1:10 w/v sample: water extract) using digital pH meter (Model 8000) and Conductivity/TDS meter (Model YK-22CT), respectively. The total carbon (C_T) was estimated from the ash content according to the formula (Mercer & Rose 1968):

$$TC (\%) = [100 - Ash (\%)] / 1.8 \quad (1)$$

Loss of elements from the piles was calculated as a mass balance, taking into account the dry weight reduction of the pile, instead of only the difference in concentrations of the elements in the composting mass. Hence, the initial (X_1) and final (X_2) ash concentrations were used to estimate the losses, according to the formula by Sanchez-Monedero et al. (1996):

$$Y \text{ loss} (\%) = 100 - 100 \left[\frac{X_1 Y_2}{X_2 Y_1} \right] \quad (2)$$

where Y represents an element, and Y_1 and Y_2 represent the initial and final concentrations of Y .

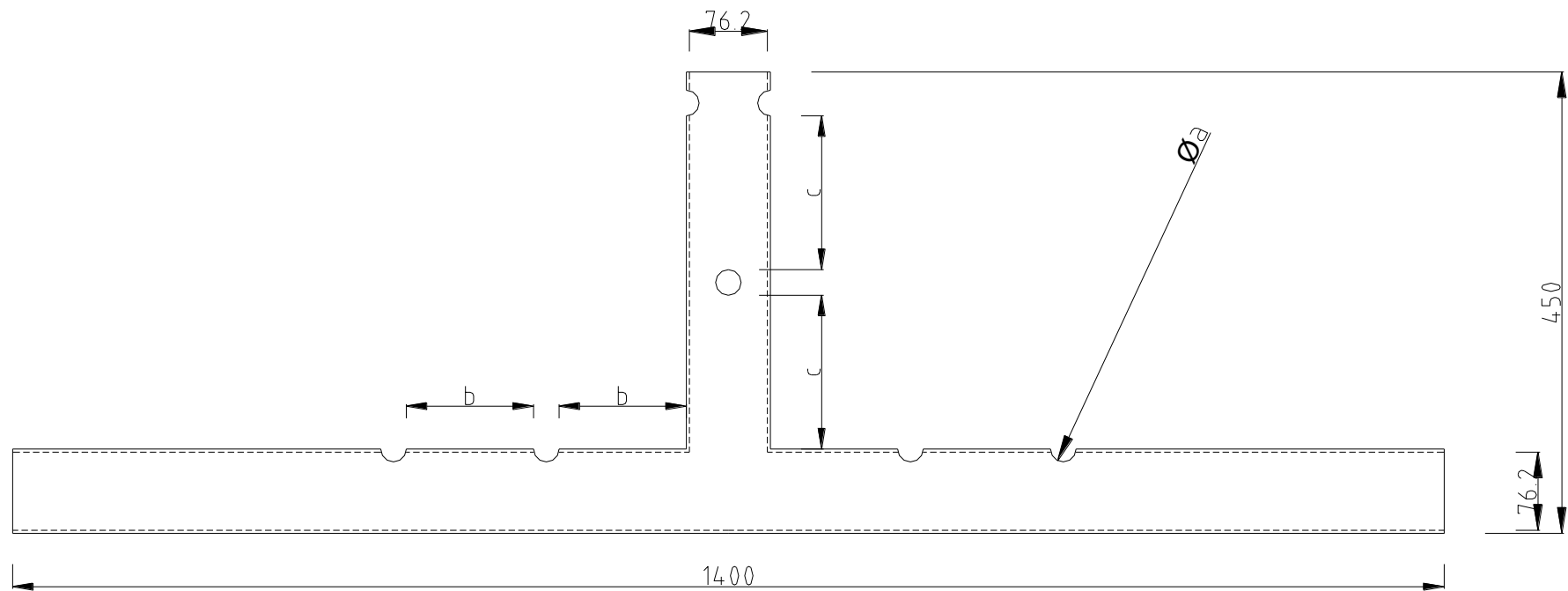


Fig. 1a. Side view of a perforated inverted T pipe (All dimensions in mm): For 15 mm diameter perforation, $a = 15$, $b = 134.45$, $c = 160$; For 25 mm diameter perforation, $a = 25$, $b = 124.45$, $c = 150$; For 35 mm diameter perforation, $a = 35$, $b = 114.45$, $c = 140$

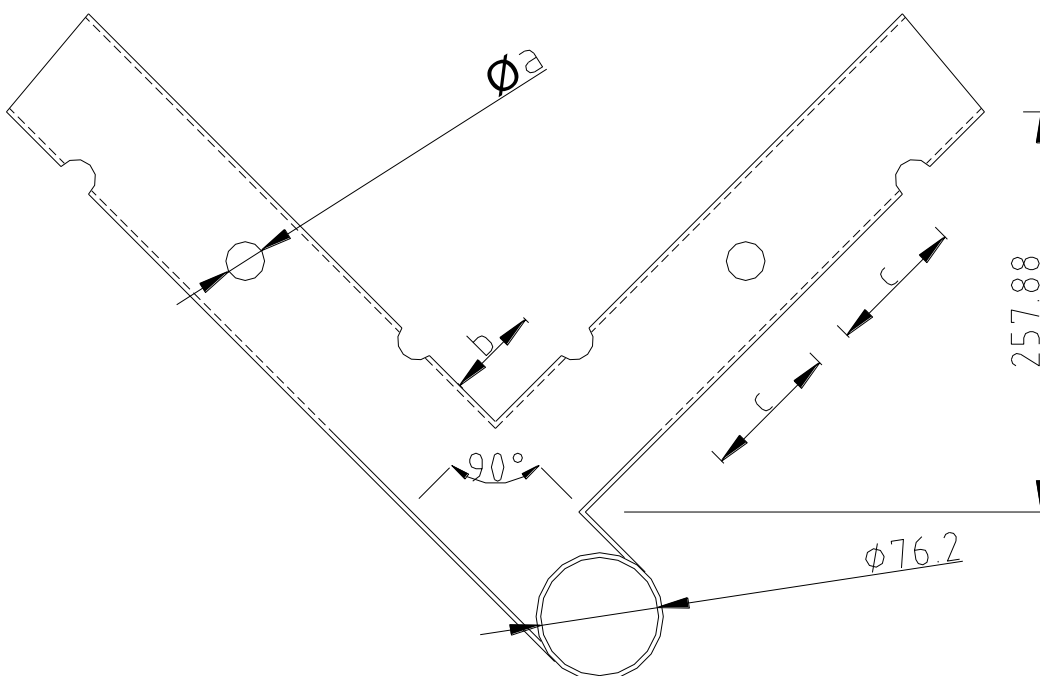


Fig. 1b. Side view of a perforated V-shaped pipe (All dimensions in mm): For 15 mm diameter perforation, $a = 15$, $b = 65.04$, $c = 105.98$; For 25 mm diameter perforation, $a = 25$, $b = 60.01$, $c = 89.6$; For 35 mm diameter perforation, $a = 35$, $b = 56.01$, $c = 80.47$

Table 1. The initial concentrations of the composting materials

Parameter	Composting material		
	Sawdust	Chicken manure	Chicken litter
MC* (%)	31.7 ± 0.58	71.8 ± 0.87	49.6 ± 1.13
Ash (%)	2.31 ± 0.06	33.9 ± 2.65	32.8 ± 7.65
Total C (%)	54.3 ± 0.05	36.7 ± 1.47	37.3 ± 4.25
Total N (%)	0.21 ± 0.03	2.24 ± 0.17	1.15 ± 0.05
C:N ratio	259:1	16:1	32:1
Total P (%)	0.08 ± 0.03	0.82 ± 0.92	0.53 ± 0.17
pH	7.82 ± 0.01	7.62 ± 0.04	7.84 ± 0.04
EC (mS/cm)	0.51 ± 0.02	5.74 ± 0.55	2.24 ± 0.48

Mean $\pm$ standard deviation are shown ($n = 3$).

* MC was measured on wet weight basis.

2.3 Statistical Analysis

The data obtained were subjected to statistical analyses using the GLM procedure of Statistical Analysis System software (SAS, 2000). Two-way analysis of variance (ANOVA) was performed to compare variations in compost properties. Where significance was indicated at $p \leq 0.05$, Least Significant Test (LSD) was used to establish which treatment(s) was significantly different. Multiple regression analysis with stepwise selection of variables was used to establish relationships among compost properties.

3. RESULTS AND DISCUSSION

The piles stabilized within 115 days of composting; a duration which fell within the range of 90 and 168 days reported for converting poultry manure into stabilized compost (Fernandes et al. 1994, Tiquia and Tam 2002, Silva et al. 2009; Ogunwande and Osunade, 2011). Seepage losses were considered insignificant as there was no free flow of water from the piles.

3.1 Pile Temperature

The results of the ANOVA showed that PC, PS and the interaction of PC and PS (PC*PS) had significant ($p \leq 0.05$) effect on pile temperature (Table 2). The LSD test (Table 3) showed that piles with IT pipe had higher temperature than piles with Vs pipe. The low temperatures recorded in piles with PS of 15 and 35 mm diameters may have been due to inadequate and excessive air, respectively supplied to the piles. Diaz et al. (1993) had reported that inadequate air supply reduces microbial activities and consequently heat produced while excessive air supply reduces pile temperatures. Perforation size of 25 mm diameter appeared to have resulted in a balanced temperature for the piles. The daily temperature profiles obtained with the average of the temperature values recorded at the two levels within the piles during composting process are shown in Fig. 2a,b. The temperature evolution followed similar pattern. Thermophilic temperatures within the range of 46.0 °C and 56.8 °C registered within 24 h of composting was an indication of high microbial activities (Bernal et al., 2008) and that the initial C:N ratio of 32:1, MC of 60% and the pile configuration were ideal for composting chicken litter. The peak temperatures between 54.3 °C and 69.0 °C observed within 2-4 days was close to results obtained by Mathur et al. (1990) and Zhan et al. (1992). The temperatures dropped from peak values to 32.7-34.5 °C and 31.9-34.7 °C by week 6, and rose slightly to 33.8-36.8 °C and 35.8-36.7 °C by week 10 in piles with IT and Vs pipes, respectively and decreased to stable values (30.8-31.8 °C) by the end of composting. The slight increments noticed in the pile temperatures after moisture replenishments in the early days of composting suggest that periodic moisture replenishment may have had significant effect on the re-activation of microbial activities. The thermophilic phase ranged between 20-23 days while pile IT15 failed to attain temperatures >55 °C (for at least three days) required for weed abatement and hygienic compost. This could be attributed to the airflow resistance in the IT pipe, coupled with the inadequate air supplied by the 15 mm diameter perforations. It was observed that the thermophilic temperatures increased as airflow resistance coefficient (K) decreased, suggesting that PC may have influenced airflow in the pipe and consequently, the pile temperatures. The K values computed, according to Steidel, Jr. et al. (1987), were 3.0 and 2.5 for IT and Vs pipes, respectively. As a result, pipe IT15 was adjudged not suitable for PAC.

The effectiveness of each AP for producing uniform composting rate within the pile was evaluated by comparing the upper and lower level thermophilic temperatures. The results of the t -test analysis showed that the two temperatures were the same ($p > 0.05$) in all the piles (Table 4). This implied that all the APs were effective for uniform composting rate; hence the quality of the compost within each pile would not differ significantly ($p > 0.05$). However, pipe Vs35 which had the highest p -value appeared to be the most effective.

Table 2. The results of the ANOVA showing the effects of PC and PS on compost properties

Parameter	Source	Df	SS	MS	F-value	Pr>F
Temperature	PC	1	0.56	0.56	16.30	0.002
	PS	2	6.08	3.04	88.54	<.0001
	PC*PS	2	1.11	0.56	16.21	<.0001
	Error	12	0.41	0.03		
Pre-r MC (%)	PC	1	12.54	12.54	19.67	0.001
	PS	2	23.65	11.83	18.55	<.0001
	PC*PS	2	29.07	14.53	22.79	<.0001
	Error	12	7.65	0.64		
pH	PC	1	0.01	0.01	1.83	0.201
	PS	2	0.08	0.04	14.80	0.001
	PC*PS	2	0.01	0.01	1.69	0.226
	Error	12	0.03	0.01		
EC	PC	1	0.68	0.68	25.39	<.0001
	PS	2	0.71	0.35	13.08	0.001
	PC*PS	2	0.33	0.16	6.05	0.015
	Error	12	0.32	0.03		
Total C	PC	1	345.14	345.14	20.89	0.001
	PS	2	96.12	48.06	2.91	0.093
	PC*PS	2	112.99	56.49	3.42	0.067
	Error	12	198.28	16.52		
Total N	PC	1	498.70	498.70	3.47	0.087
	PS	2	312.52	156.26	1.09	0.368
	PC*PS	2	86.85	43.43	0.30	0.745
	Error	12	1726.34	143.86		
Total P	PC	1	386.82	386.82	4.48	0.056
	PS	2	1015.03	507.52	5.87	0.017
	PC*PS	2	83.65	41.82	0.48	0.628
	Error	12	1036.85	86.40		
C:N ratio	PC	1	4.29	4.29	0.66	0.433
	PS	2	8.85	4.42	0.68	0.526
	PC*PS	2	16.96	8.48	1.30	0.309
	Error	12	78.32	6.53		

Pre-r: pre-replenishment.

Table 3. Least Significant Difference (LSD) test of PC and PS on compost properties

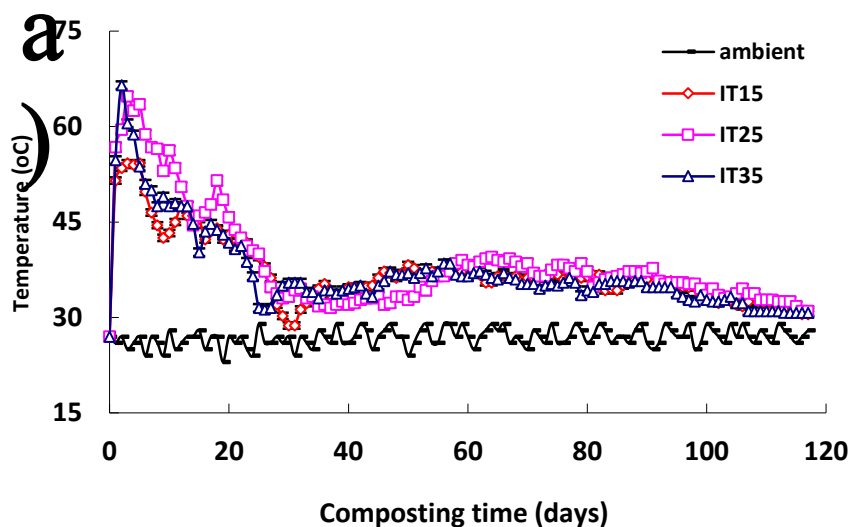
Parameter	Pipe configuration			Perforation size (mm diameter)			
	IT	Vs	LSD	15	25	35	LSD
Temperature (°C)	37.5 ^b	37.2 ^a	0.19	37.4 ^a	38.0 ^b	36.5 ^c	0.23
Pre-r MC (%)	48.1 ^a	49.7 ^b	0.82	47.7 ^a	48.6 ^a	50.4 ^b	1.00
pH	8.08 ^a	8.11 ^a	0.05	8.03 ^a	8.19 ^b	8.05 ^a	0.07
EC (mS cm ⁻¹)	2.74 ^b	3.13 ^a	0.17	3.07 ^b	2.65 ^a	3.07 ^b	0.21

Total C (%)	47.2 ^a	56.0 ^b	4.07	53.4 ^a	53.1 ^a	48.3 ^a	4.98
Total N (%)	9.22 ^a	19.7 ^a	10.6	15.0 ^a	19.3 ^a	9.13 ^a	13.0
Total P	13.5 ^a	4.22 ^a	14.1	-1.77 ^b	14.2 ^a	14.1 ^a	17.3
C:N ratio	19.4 ^a	18.4 ^a	0.77	18.1 ^a	19.8 ^a	18.7 ^a	0.94

Superscripts with the same letter are not statistically different at $p \leq 0.05$; Pre-r: pre-replenishment.

3.2 Pre-replenishment Moisture Level

It was observed that PC, PS and PC*PS had significant ($p \leq 0.05$) effect on pre-replenishment MC (Table 2). More moisture was lost from piles with IT pipe (Table 3), probably as a result of the low C_T loss and consequently high porosity of the piles. Although, same ($p > 0.05$) but lower level of pre-replenishment moisture was observed using 15 and 25 mm diameter perforations, the trend of moisture loss was contrary to expectation that loss would increase as PS increases. The initial MC (60%) of the chicken litter dropped to the lowest pre-replenishment values of 41.5-44.2% and 39.8-43.5% within 2 weeks of composting in piles with IT and Vs pipes, respectively. This was as a result of high microbial activities in the chicken litter due to intense OM degradation during this period. The pre-replenishment moisture levels picked up thereafter as the level of microbial activities were decreasing in the piles.



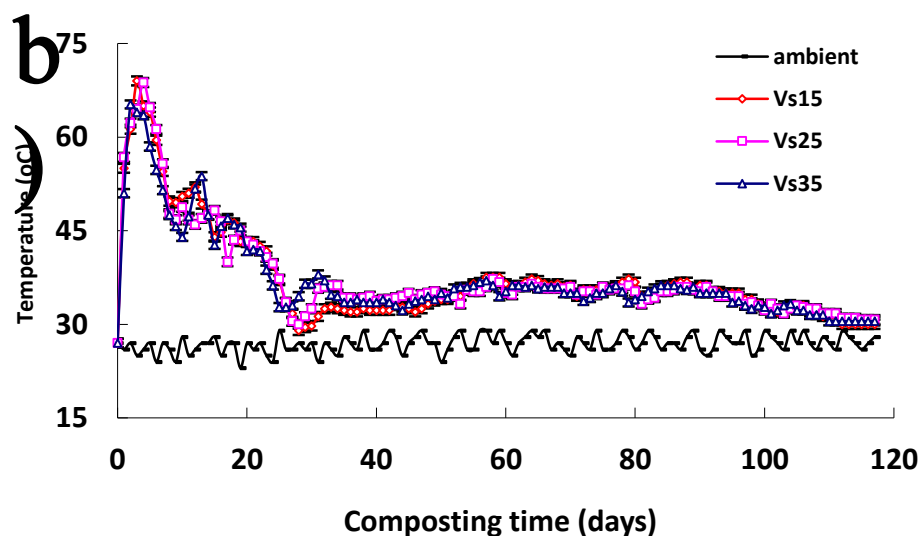


Fig. 2. Daily temperature profiles of composting piles with (a) inverted T, and (b) V-shaped pipes. Error bars show standard errors of means ($n = 3$)

Table 4. Thermophilic characteristics of the piles

Pile	Duration (days)		Temperature (°C)			<i>p</i> -value
	> 42 °C	> 55 °C	Peak	Upper	Lower	
IT15	23	0	54.3	46.7 ^a	45.7 ^a	0.486
IT25	22	10	64.8	52.0 ^a	53.1 ^a	0.605
IT35	20	4	66.5	49.9 ^a	48.5 ^a	0.550
Vs15	23	5	69.0	50.4 ^a	51.6 ^a	0.610
Vs25	22	5	68.8	52.2 ^a	49.6 ^a	0.327
Vs35	22	5	65.3	49.5 ^a	49.9 ^a	0.843

Superscripts with the same letter are not statistically different at $p \leq 0.05$.

3.3 pH and Electrical Conductivity

The chicken litter had an alkaline pH throughout the composting process. The initial value was within the range of 6.0-9.0 recommended for rapid composting (Rynk et al., 1992; Metcalf and Eddy Inc., 2003). Perforation size influenced ($p \leq 0.05$) the pH during composting (Table 2). The mean values showed that piles with 15 and 35 mm diameter perforations had same ($p > 0.05$) but lower values. This may be related to the inadequate and excessive air, respectively supplied to those piles. The pH of pile IT25 was consistently the highest during composting, in piles with IT pipe (Fig. 3a). The pH of pile IT15 maintained a low profile while that of pile IT35 decreased and increased remarkably. The pH of piles with Vs pipe followed nearly similar patterns (Fig. 3b). The initial pH increased to high values between weeks 4 and 12 and decreased thereafter. Generally, increase in pH could be linked to the biodegradation of the organic acids, mineralization of organic compounds and the consequent release of volatile NH_3 (Huang et al., 2004; Said-Pullicino et al., 2007). The drops in pH noticed in some piles in the early days of composting (IT35- weeks 4 and 6, and Vs35- week 6) may have been due to the production of organic acids during decomposition of OM contained in the chicken litter (Charest and Beauchamp, 2002). The decrease in pH towards the end of composting could be attributed to increased nitrification process by nitrifying bacteria in the chicken litter (Caceres et al., 2006) or an indication of maturity process. The final pH values (7.87-8.15) were within the range of 6.0-8.5 compatible with most plants (Lasaridi et al., 2006).

Electrical conductivity was significantly ($p \leq 0.05$) affected by PC, PS and PC*PS (Table 2). Piles with Vs pipe had higher EC (Table 3). Electrical conductivity of piles with 15 and 35 mm diameter perforations had higher but same value of EC. The effect of PS on EC was similar but oppositely related to that of pH. The evolution of EC followed the same pattern in all the piles (Fig. 4a,b). It increased from the initial value of 2.24 mS/cm to between 3.13 mS/cm and 4.03 mS/cm, and 3.74 mS/cm and 4.24 mS/cm in piles with IT and Vs pipes, respectively within 4 weeks. Thereafter, the EC decreased to low values (2.02-2.78 mS/cm) between weeks 8 and 10 and increased to final values between 2.44 mS/cm and 4.37 mS/cm. The increase in EC observed in the piles may be due to the release of mineral salts through decomposition of OM, and the concentration effect due to net loss of dry mass (Silva et al., 2009).

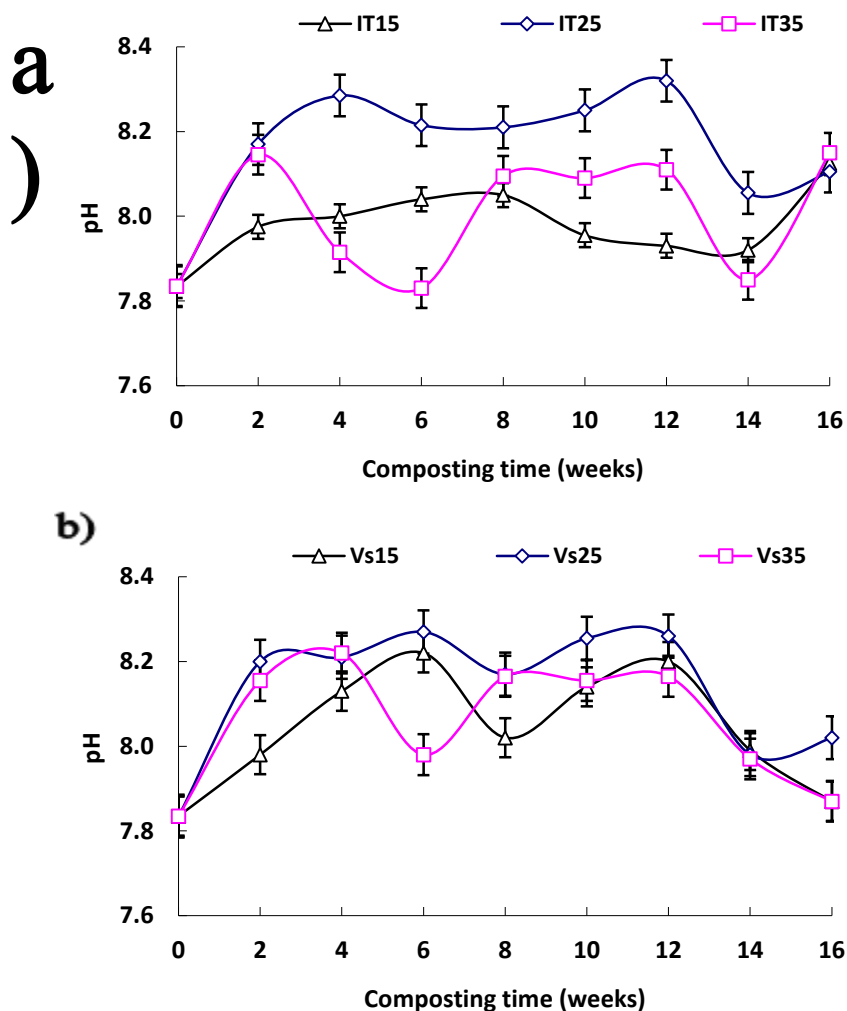


Fig. 3. Changes in pH with time in piles with (a) inverted T, and (b) V-shaped pipes. Error bars show standard errors of means ($n = 3$)

The decrease in EC noticed in the middle of the composting process could be due to volatilization of NH_3 and precipitation of mineral salts (Wong et al., 2005). By the end of composting, piles Vs15 and Vs35 had their EC above the upper limit of 4.0 mS/cm considered tolerable by plants of medium sensitivity (Lasaridi et al., 2006). Therefore, composts from these piles must be mixed well with soil or other materials with low EC before it can be used for growing crops.

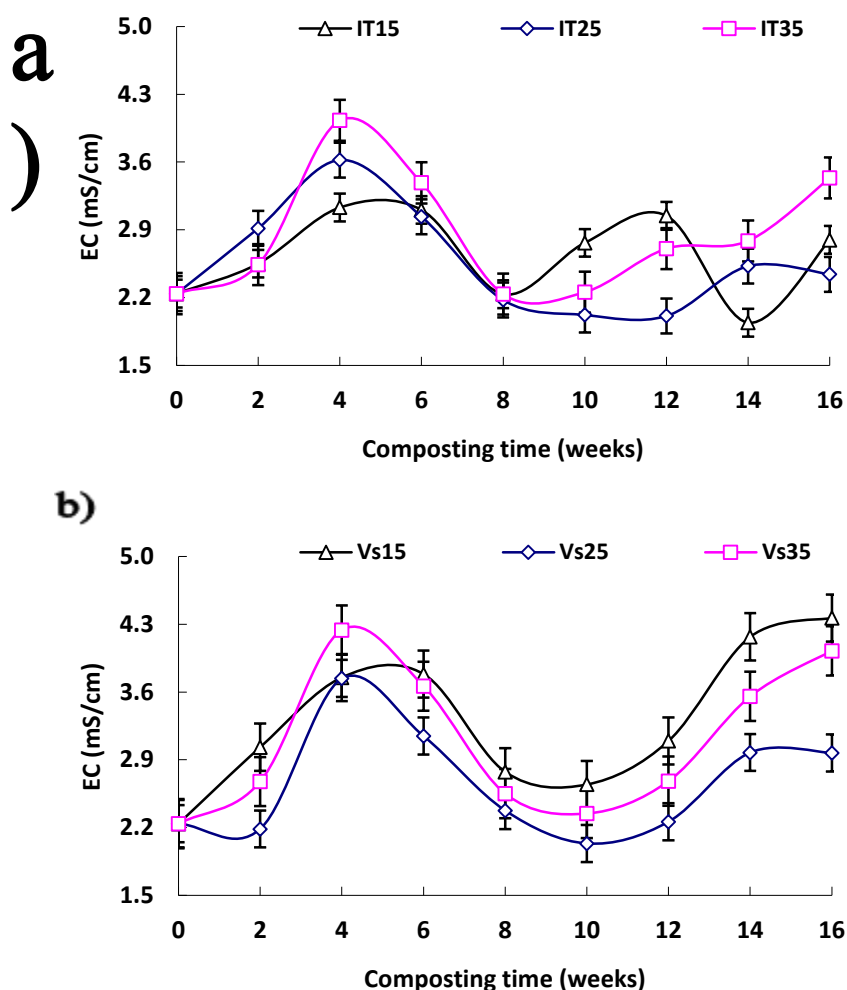


Fig. 4. Changes in EC with time in piles with (a) inverted T, and (b) V-shaped pipes. Error bars show standard errors of means ($n = 3$)

3.4 Total Carbon

As the OM degradation occurred in the piles, the ash content increased and C_T decreased with composting time. The results of the ANOVA revealed that only PC had significant ($p \leq 0.05$) effect on C_T loss (Table 2). The effect was higher in piles with Vs pipe (Table 3), probably as a result of the losses during the thermophilic phase which was higher in piles with Vs pipe (24.7-53.7%) than in piles with IT pipes (14.5-51.2%). The C_T losses, which increased gradually to final values between 53.4% and 76.1% (Fig. 5a,b) could be attributed to bio-oxidation of OM resulting in the evolution of CO_2 and heat (Said-Pulicino et al., 2007). The high losses in the early days of composting indicated a high level of OM biodegradation in the piles (Fang et al., 1999). Some noticeable drops in losses in some piles (IT15 and IT35 during week 4 and IT15, Vs15, Vs25 and Vs35 during week 10) may have been due to increased carbon concentration in those piles. Pile IT15 recorded the least loss by the end of composting (Table 5). Although, the loss was correlated with N_T loss ($R^2 = 0.60$), it could also have been as a result of the relatively low thermophilic temperatures in the pile.

3.5 Total Nitrogen

The N_T concentration increased gradually with time during the composting process; a phenomenon reported in previous composting studies (Charest and Beauchamp, 2002; Huang et al., 2004; Liang et al., 2006; Said-Pullicino et al., 2007) as due to the concentration effect caused by the weight loss as OM is biodegraded and mainly liberated as CO_2 . The mass balance analysis indicated losses (except in pile IT15) in final N_T contents (Table 5). The results of the ANOVA showed that neither PC, PS nor the interaction had significant ($p > 0.05$) on the loss observed in the piles (Table 2). Although not significantly different, the mean values showed that the losses were greater in piles with Vs pipe and piles with 25 mm diameter perforations (Table 3). The final losses (0.30-25.2%) recorded in this study were lower than 45-92% (Tiquia and Tam, 2002; Ogunwande et al., 2008; Silva et al., 2009), probably as a result of the passive aeration method used. Pile Vs35 recorded gain in N_T content in the first two weeks of composting while pile IT35 recorded it in the first four weeks of composting (Fig. 6a,b). The gain could be attributed to increased nitrification (formation of NO_3-N) process by nitrifying bacteria which can easily develop at moderate temperature in chicken litter (Caceres et al., 2006) and also, to the significant ($p \leq 0.05$) positive relationship between pile temperature and N_T ($R^2 = 0.61$ and 0.33 for piles Vs35 and IT35, respectively) during the thermophilic phase.

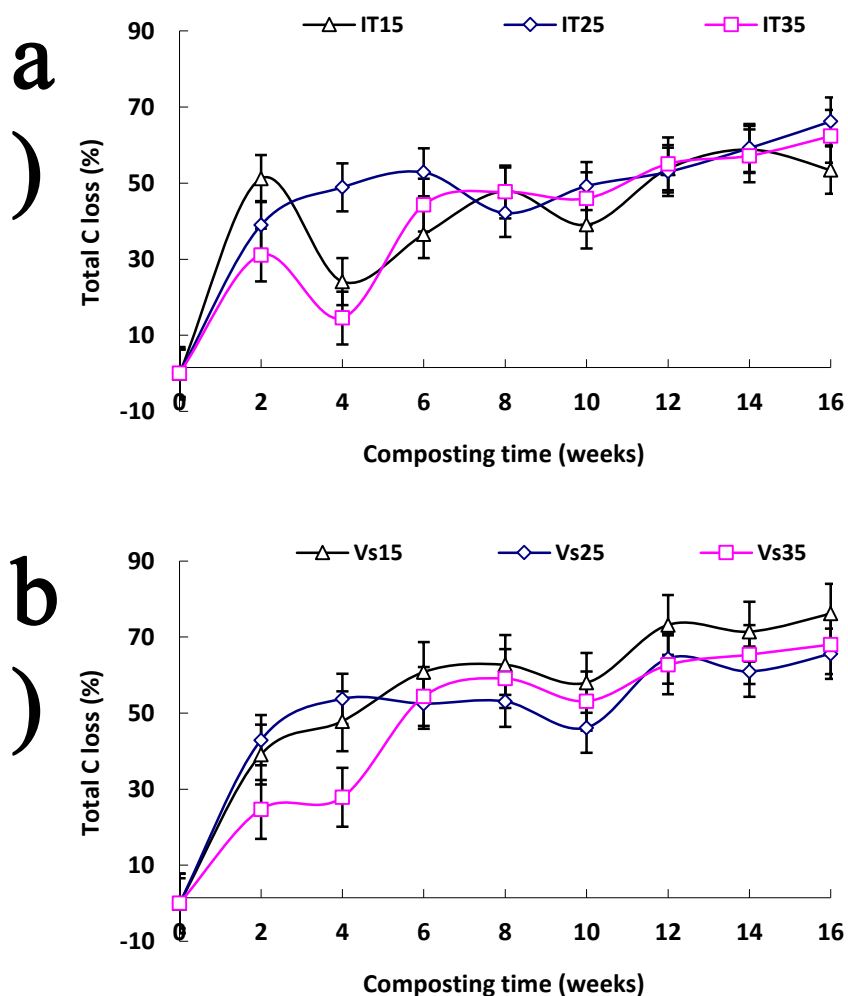


Fig. 5. Variation of total C losses with time in piles with (a) inverted T, and (b) V-shaped pipes. Error bars show standard errors of means ($n = 3$)

Table 5. Final characteristics of compost piles

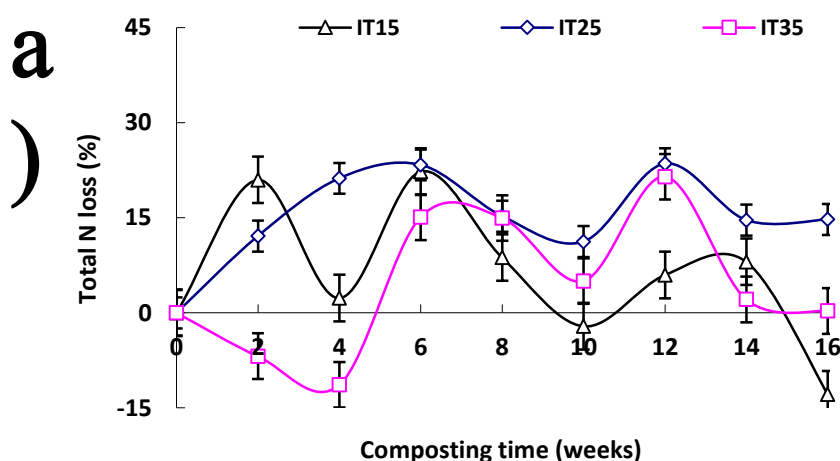
Pile	Ash (%)	Total C (%)		Total N (%)		Total P (%)		C:N ratio
		Conc	Loss	Conc	Loss	Conc	Gain	
IT15	51.2 ^a (1.90)	27.1 ^c (1.05)	53.4 ^a (3.55)	2.04 ^a (1.13)	12.8 ^{*a} (3.21)	1.24 ^a (0.08)	50.3 ^b (8.61)	13.3:1 ^b (1.40)
IT25	59.3 ^b (3.15)	22.6 ^b (1.74)	66.3 ^b (4.38)	1.77 ^a (0.17)	14.7 ^{b,c} (5.52)	1.14 ^a (0.17)	19.8 ^a (6.37)	12.8:1 ^b (0.22)
IT35	56.6 ^b (2.97)	24.1 ^b (1.65)	62.3 ^b (4.54)	1.97 ^a (0.22)	0.30 ^{a,b} (1.24)	1.10 ^a (0.10)	19.6 ^a (5.10)	12.3:1 ^b (0.53)
Vs15	67.3 ^c (2.56)	18.2 ^a (1.43)	76.1 ^c (2.77)	1.77 ^a (0.07)	25.2 ^c (5.94)	1.12 ^a (0.12)	3.84 ^c (2.20)	10.3:1 ^a (0.38)
Vs25	58.6 ^b (0.69)	23.0 ^b (0.38)	65.6 ^b (0.98)	1.70 ^a (0.09)	17.8 ^{b,c} (3.20)	1.36 ^a (0.04)	43.3 ^b (5.49)	13.5:1 ^b (0.91)
Vs35	60.7 ^b (4.33)	21.8 ^b (2.40)	68.0 ^b (5.75)	1.70 ^a (0.15)	19.7 ^{b,c} (4.91)	1.11 ^a (0.18)	14.9 ^c (6.10)	12.9:1 ^b (0.26)
<i>p</i> -value	0.001	0.001	<0.001	0.060	0.006	0.153	0.018	0.002

Mean and standard deviation (in parenthesis) are shown ($n = 3$).

* Percent gain.

Superscripts with the same letter in one column are not statistically different at $p \leq 0.05$; Conc: concentration.

The other piles recorded high losses within six weeks of composting (Fig. 6a,b). The losses were largely attributed to NH_3 volatilization (Tiquia and Tam, 2002; Huang et al., 2004; Zhu et al., 2004; 2006; Liang et al., 2006; Silva et al., 2009), which was favoured by the high pile temperatures ($>33^\circ\text{C}$) and pH (>8.04) during the period. The peak losses observed during the mesophilic phase in piles IT25, IT35, Vs15 and Vs35 suggest that N_T may have been lost by denitrification due to the aerobic nature of certain denitrifying bacteria (Mahimairaja et al., 1995; Liang et al., 2006). Analysis of the final losses showed that pipe IT35 was equally as effective ($p > 0.05$) as pipe IT15 in minimizing N_T loss (Table 5).



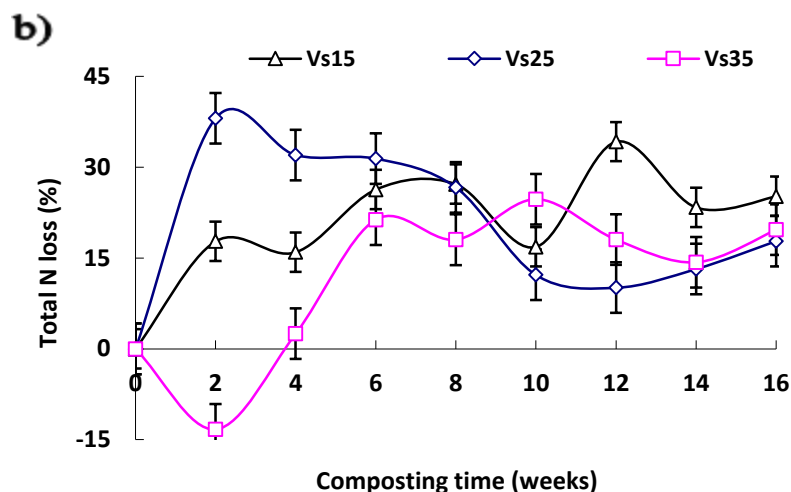
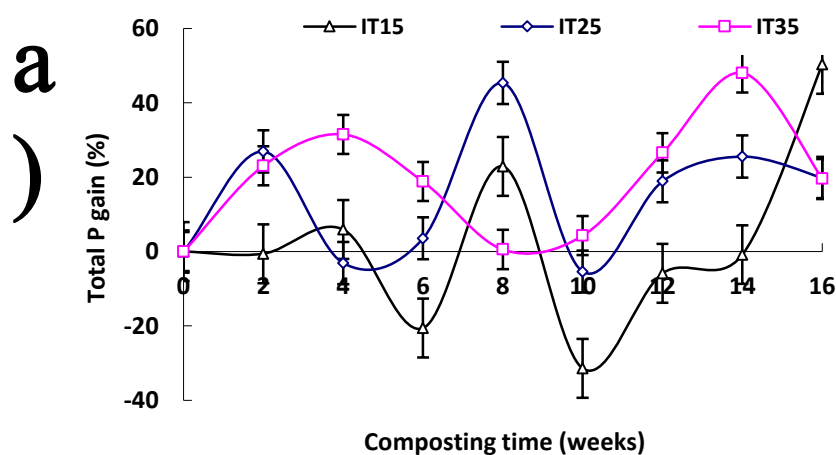


Fig. 6. Variation of total N losses with time in piles with (a) inverted T, and (b) V-shaped pipes. Error bars show standard errors of means ($n = 3$)

3.6 Total Phosphorus

The P_T concentration increased significantly during composting; a situation that was attributed to net loss of dry mass as a result of decrease in the OM content (Charest and Beauchamp, 2002; Tiquia and Tam, 2002; Huang et al., 2004), and to conservation of inorganic ions in the chicken litter (Sartaj et al., 1997). The results of the ANOVA showed that PS affected ($p \leq 0.05$) P_T during composting (Table 2). The P_T variation in each pile followed a sinusoidal pattern and was characterised by gain and loss in P_T content (Fig. 7a,b). The final values showed that all the piles had gain in P_T content (Table 5). Although, the evolutions of P_T during composting of livestock manure have been scarcely reported in the literature, however, in this study, significant ($p \leq 0.05$) correlations were found between P_T and pile temperature ($R^2 = 0.76$ and 0.58 ; pile IT35 and Vs35, respectively), pH ($R^2 = 0.51$; pile Vs15) and N_T ($R^2 = 0.62$; pile Vs35). The final gains revealed that pipe Vs25 was equally as effective ($p > 0.05$) as pipe IT15 in minimizing P_T loss (Table 5).



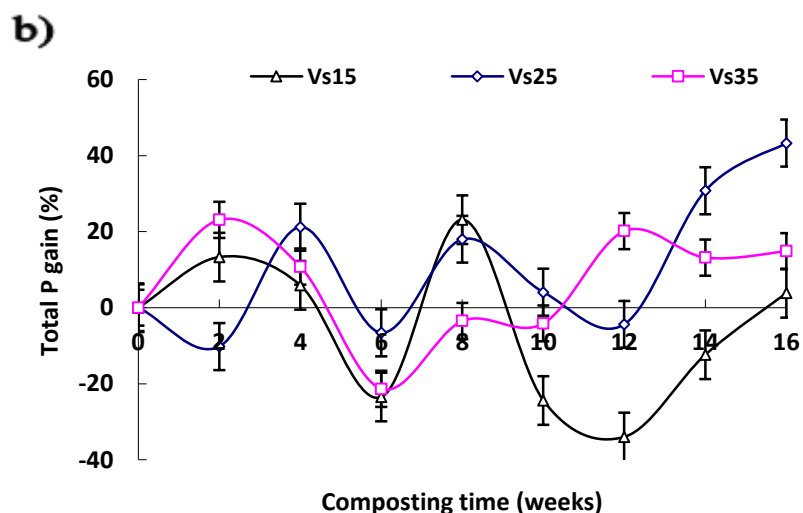
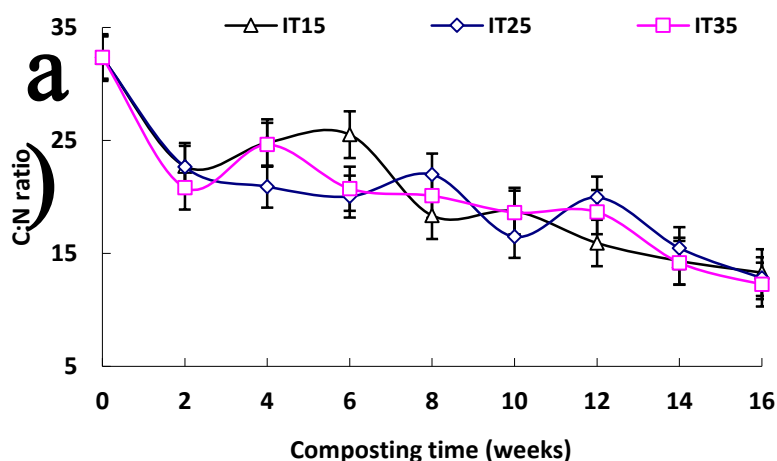


Fig. 7. Variation of total P gains with time in piles with (a) inverted T, and (b) V-shaped pipes. Error bars show standard errors of means ($n = 3$)

3.7 C:N ratio

The initial C:N ratio (32:1) of the chicken litter was within the range of 20:1-35:1 recommended by Rynk et al. (1992) and Metcalf and Eddy Inc. (2003) for rapid composting. It was observed that neither PC nor PS had significant ($p > 0.05$) effect on the C:N ratio of composting piles (Table 2). A gradual decrease was noticed in all the piles (Fig. 8a,b) due to either the mineralization of OM present in the chicken litter or increase in total N concentration resulting from a concentration effect as C is biodegraded. Decrease in C:N ratio with time have also been reported in previous composting studies (Solano et al., 2001; Charest and Beauchamp, 2002; Zhu et al., 2004; Sylla et al., 2006). The final C:N ratios ranged between 10.3:1 and 13.5:1 (Table 5). These values were within the range of 10:1 and 15:1 for final composts (Misra et al., 2003), and an indication of compost stability (Hoornweg et al., 2000) and compost maturity (Bernal et al., 1998; CCQC, 2001).



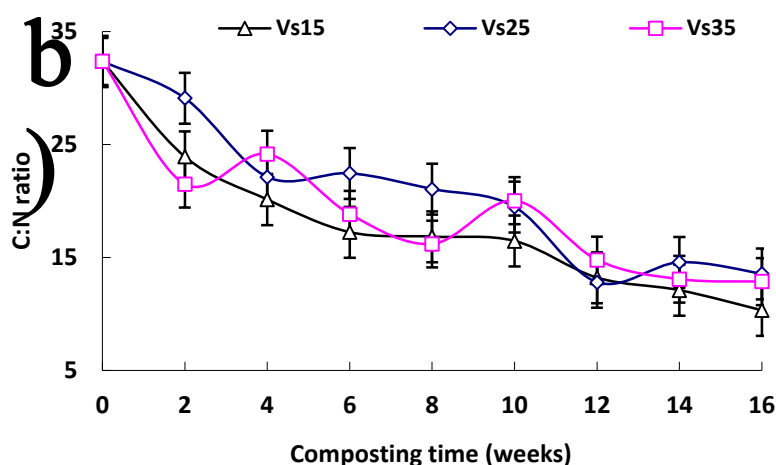


Fig. 8. Variation of C:N ratio with time in piles with (a) inverted T, and (b) V-shaped pipes. Error bars show standard errors of means ($n = 3$)

4. CONCLUSIONS

The results of the study showed that all the piles attained thermophilic temperatures for effective biodegradation, and that pipe IT15 was not promising for composting as the pile equipped with it failed to meet the sanitation requirements for hygienic compost. Pipe configuration had significant effect on pile temperature, pre-replenishment MC, EC and C_T while perforation size had significant effect on pile temperature, pre-replenishment MC, pH, EC and P_T . Neither PC nor PS affected N_T and C:N ratio. Although both PCs were effective for uniform composting rate, Vs pipe appeared to be more effective. Pipes IT35 and Vs25 were equally as effective as pipe IT15 in minimizing N_T and P_T losses, respectively.

NOMENCLATURE

IT15 inverted T pipe with 15 mm diameter perforations
 IT25 inverted T pipe with 25 mm diameter perforations
 IT35 inverted T pipe with 35 mm diameter perforations
 Vs15 V-shaped pipe with 15 mm diameter perforations
 Vs25 V-shaped pipe with 25 mm diameter perforations
 Vs35 V-shaped pipe with 35 mm diameter perforations

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URBAN SOLID WASTE CHARACTERISATION AND MANAGEMENT FOR ABAKALIKI TOWN: ENGINEERING APPROACH

P. C. Eze¹ and C. N. Edu²

¹Department of Agricultural and Bioresource Engineering,
Enugu State University of Science and Technology, Enugu

²Ministry of Agriculture, Abakaliki, Ebony State.

ezepaul2@yahoo.com, educhukwumanwofe@yahoo.com

ABSTRACT

A survey research was conducted to work on the management and characteristics of solid waste generation and disposal for Abakaliki urban, the capital of Ebonyi State. The study area was divided into five zones that make up Abakaliki urban. Fifty households were selected in all the zones through stratified random sampling method for the study. The study revealed that 1.95 kg/hh/month and 0.18kg/Cc/Day of solid waste was generated from the selected areas. It was also observed that about 60% of the household make use of plastic dust bin for their waste storage, 10% make use of metal dust bin, 25% use polyethylene bags, 2% make use of basket and about 3% do not have storage containers in their houses, so they drop their waste indiscriminately around the environment. Result shows that putricible waste is the highest generated solid waste in Abakaliki followed by plastic wastes and waste papers. Metals, glasses and textiles waste materials are the least generated. It also revealed that the month of August is the period when the area has the highest waste generation. It was equally observed from the study that Abakaliki urban has only one approved solid waste disposal site, this makes the people to pile up their refuse indiscriminately in open dumps along the road and streets which give rise to environmental pollution and encourages the growth of rodents, cockroaches and mosquitoes. It is therefore recommended that State government should create more disposal sites. More workforces, solid waste disposal facilities for proper and adequate handling should be provided. There should also be enforcement of laws that will prohibit people from indiscriminate dumping of refuse within the area. Finally there should be public enlightenment on the management and disposal of solid waste in the area.

KEYWORDS: Solid waste, Abakaliki, environment, management, government

1. INTRODUCTION

Urban solid waste management is the term applied to all the activities associated with management of solid waste generated by the urban dwellers Tchobanoglous et al., (1993). Solid waste is a system of Engineering, involving substantial engineering content, that is particularly set for actions which best accomplish the overall objectives of the decision makers, within the constraints of law, morality, economic resources, political and social pressures and which govern the physical life and other natural sciences, Otti., (2010). The basic goal of urban solid waste management is to manage their waste in such a manner that meets public health and environmental concerns and the public's desire to reuse and recycle waste materials.

Problem with the disposal of waste can be traced from the time when man first began to congregate in tribes, villages, towns which the accumulation of waste becomes a consequence of life. People littering food and other solid waste in the town by the practice of throwing waste into the streets, roadways and vacant land resulted in the breeding of flies, rats and other agents of epidemic diseases that increase high risk of death tolls. Public health authorities have shown that vectors, diseases agents were bred in open dumps and poorly maintained housing and in food storage facilities. The U.S. Public Health Services (USPHS) has published the result of a study tracing the relationship of twenty-two (22) human diseases to improper solid waste management. Water and air pollution have been attributed to improper management of solid waste. Poorly engineered landfill has also contaminated surface water and groundwater. In 1965,

the United States Congress concluded that inefficient and improper method of disposal of solid waste in scenic blight create serious hazard to public health, including pollution of air and water resources, accident hazard and increase in insect's vectors of diseases which have adverse effects on land value that interfere with community life and development. Therefore, the overall goal of urban solid waste management is to collect, treat and dispose solid waste generated by the urban population groups in an environmentally and socially satisfactory manner using the most economic means available. Rapid urbanization along with its increasing human activities in urban areas imposes great challenges to urban environmental management (Xiao et al., 2006). One of the most important environmental problems in the cities is the production and contaminant of urban solid waste Buenristro et al., (2003) and Pokhrel et al., (2005). Global generation of municipal solid waste in 1997 was 0.49 billion tones with an estimated annual growth rate of 3.2-4.5% in developed nations and 2-3% in developing nations Snocheng et al., (2001). Inappropriate management of urban solid waste not only increases the pollution of the environment but also threatens human health through its collection, transfer and disposal processes Xiao et al., (2006).

Problems and issues of solid waste characteristics and management in Abakaliki have posed risks to the environment have posed risks to the environment. They were based on the way the solid wastes were handled, stored, collected and disposed of. What motivated this study is that there are no major and well designed dumping sites of solid wastes in Abakaliki let alone weighing facilities in the disposal sites, and there are no private sectors potentials for recycling.

Objectives of this study are; to determine the characterisation and management of urban solid wastes in Abakaliki municipality; to determine municipal solid wastes generation rate in Abakaliki urban; and also to recommend the best management practices for Solid Wastes Management in Abakaliki Urban.

2. MATERIALS AND METHOD

Abakaliki is the capital city of Ebonyi state which came into being in the year 1996 and was carved out from former Enugu state and Abia state. According to the ministry of environment, the city's population is estimated at 208,654. Abakaliki urban is made up of five major zones, namely, Abakaliki Central, Abakaliki North, Abakaliki South, Abakaliki East and Abakaliki West. These five zones have sub-divisions or unit.

Three sets of primary data were collected for the study. The first were drawn from solid waste disposal sites located at Enugu/Abakaliki express way. The second were drawn from questionnaires from the five zones that make up Abakaliki town. Ten buildings from each zone were selected for sampling. The samplings were spread among the households in each building of the selected area. Therefore the entire households in each building of the selected area were surveyed. About four hundred and seventy structured questionnaires were administered.

Another set of data were based on measurement of solid waste generated in one fifth of the buildings sampled with questionnaire. Therefore 10% of the sampled household had their waste measured. Most residents use a range of waste receptacles including; baskets, polythene materials, plastic container, open metal drums, paper/cardboard container. The study employed graduated plastic containers for convenience of volumetric determination.

Two groups of graduated plastic containers labeled "A" and "B" and a weighing machine, were used in the study. The population of each sampled household was noted. The containers labeled 'A' were used to collect solid waste of food and fruit materials. The ones labeled B were used to collect polythene, rags, nylon, rubber materials, paper, metals and pieces of broken bottle. The two graduated containers were first measured empty. Two households from each major zone have their solid waste measured, making a total of ten households in all. A pair of labeled containers was given to each household for their daily collection

of solid waste. Every day, the “A” and “B” containers with their content were measured to determine both the volume and weight of solid waste. This was done for a period of five months for each household representing a zone. At the end, the data generated were used to determine the waste density and waste generation rate (kg/capital/day).

3. RESULTS AND DISCUSSION

The collection of solid waste is one of the functions of Ebonyi State Environmental Protection Agency (EBSEPA). Informal collectors also aid the agency in providing the services with a token payment mainly in market areas of the city. Ebonyi State ministry of environment provides stationary containers for waste collection. The waste container is stationed at various points of waste generation within the town and the residents deliver their waste to the storage containers. It is distributed among the major zones that make up Abakaliki urban. The containers were kept at some open spaces and some were located at road junctions from where the agency picks them up with their truck on daily bases. This arrangement is however inadequate as people still dump their waste in the stream (Iyiokwu stream) and in open spaces.

In Abakaliki urban, solid waste is collected and transported by trucks directly to the disposal site. The data collected from this study was presented and analyzed using tables with descriptive statistical methods and graphs. Table 1 shows the sex distribution of the respondents. 58.7% of them are females while only 41.3% are males. The high rate of female respondents was because the respondents could either be husband or wife. Most men allowed their wives to fill the questionnaire on behalf of their household since household waste comes from the kitchen which traditionally is managed by wives. It was also observed that some of the women had their husbands working in other places outside Abakaliki, making them automatic household heads in the absence of their husbands.

Table 1: Sex Distribution of the Respondents

Sex	No of respondents	Percentage (%)
Male	190	41.3
Female	270	58.7
Total	460	100

Table 2: Household Size and Solid Waste Generation

Household group	Household Size (persons)	Solid Waste Generation (%)
W	1-2	3.5
X	3-5	24
Y	6-10	32
Z	11 and above	40.5
	Total	100

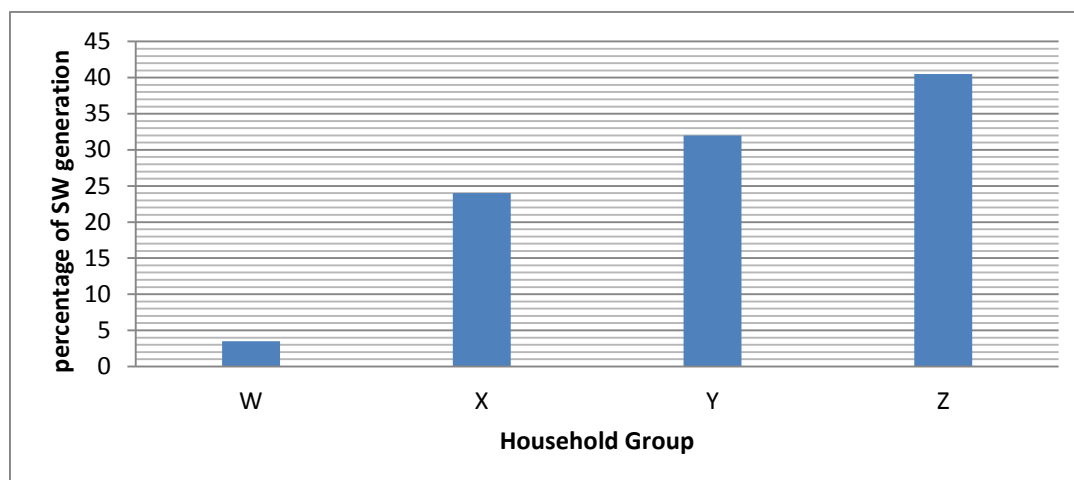


Figure 1: Household Sizes and Solid Waste Generation

Table 2 and Figure 1 contain the relationship between the household size and waste generation. It could be observed that households in group W with 1-2 persons had smallest percentage waste generation of 3.5% while the households in group Z with 11 and above had the highest percentage waste generation of 40.5%. This indicates that waste generation is proportional to the population or sizes of each household. The implication is that more refuse dump sites and disposal facilities should be provided with respect to household sizes and general population of an area. In Abakaliki, there is only one disposal site which is along the Abakaliki-Enugu express way, besides the Iyiokwu stream. The numbers of truck loads that enter the site everyday were counted to generate the data shown in Table 3.

Without a weighing bridge to weigh the loaded trucks, the quantity of the solid waste generated per day was noted but its weight was unknown. The volume was estimated by measuring the dimensions of the refuse space in each truck that entered the site. The quantity of waste transported to the site daily was thus noted.

Table 3: Monthly Solid Waste Generation in Abkaliki Urban (load count)

Period	Estimated Population	No. of Trucks	Volume of SW/Month (m ³)
July 2010	208,654	183	1152.9
August 2010	208,654	190	1197.0
September 2010	208,654	188	1184.4
October 2010	208,654	179	1127.7
November 2010	208,654	176	1108.8
December 2010	208,654	160	1008.0
January 2011	208,654	165	1039.5
February 2011	208,654	170	1071.0
March 2011	208,654	172	1083.6
April 2011	208,654	175	1102.5
May 2011	208,654	178	1121.4
June 2011	208,654	180	1134.0

Table 3 shows the volume of solid waste generation in Abakaliki urban. It could be observed that the least volume of waste generation of 1008.0m³ is in the month of December, while the highest waste generation of 1197.7m³ is in the month of August. The implication of this is that more trucks should be engaged in this

period to transport the generated waste from collection points to the final disposal sites to reduce much refuse being piled up at the collection or storage points.

Table 4: Composition of Waste Stream Characteristics for the Sampled Area (%)

S/n	Zone	Putricible	Plastic	Paper	Textile	Metal	Glass	*Others
1	A	60.0	10.0	12.0	4.5	5.2	3.5	4.8
2	B	50.0	20.0	10.0	1.0	10.2	2.9	5.9
3	C	35.0	22.0	30.0	2.2	3.6	2.3	4.9
4	D	40.0	25.0	5.0	6.2	15.2	7.2	1.4
5	E	62.5	10.2	7.8	4.3	5.6	6.7	2.9
Average		49.5	17.44	12.96	3.6	7.96	4.52	3.98

* **Others:** rubbers, dust, ash, soil, bones and ceramics.

Table 4 shows the major types of waste materials that are generated at the study area at different periods. It indicates that the highest percentage of the waste materials were recorded by putricible wastes having mean waste generation of 49.5%, followed by plastic with 17.44%, and papers with 12.96%. metals, glasses and textiles recorded the least average percentage waste generation of 7.96%, 4.52% and 3.6% respectively. Other waste materials such as rubbers, ashes, and ceramics have average generation of 3.98%. The result shows that industrial recycling/conversion of organic waste from putricible waste such as food and food related materials are viable for Abakaliki urban. It was observed that wastes of plastic origin should be a major source of concern. Plastic wastes from packaged water (pure water) are growing in quantity and bounds because of its very slow rate of decay. It poses the major source of soil and environmental pollution in the near future.

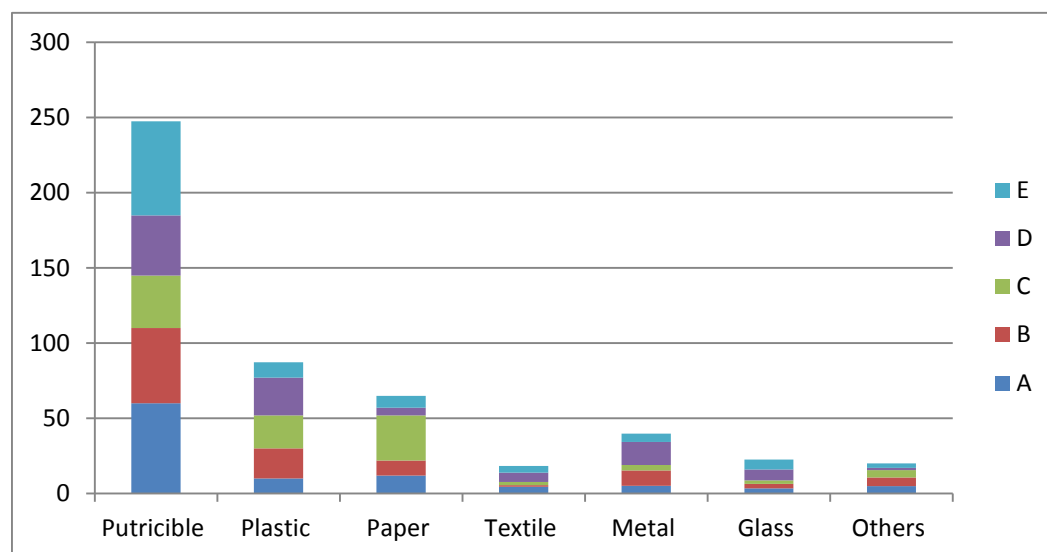


Figure 2: Waste Stream Characteristics

Figure 2 is the bar chart of types of waste generation plotted against the percentage amount of wastes generation for the five zones of the study area. The graphs slope downward from the highest waste generation for all the zones and vary horizontally for various types of waste generation. The graph shows that zone E has the highest putricible waste generation of 62% and least textile waste materials generation of 4.3%, followed by zone A with highest putricible waste generation of 60% and least glass waste materials generation of 3.5%. This is also followed by zone B with 50% putricible waste generation and least textile waste material generation of 1%. Zone C and Zone D have least putricible waste generation of 40% and

35%. From the bar chart, it is recommended that more work force and disposal facilities should be provided in zone E, A and B with highest percentage waste generation to enhance quick waste removal from such areas to the disposal sites to avoid refuse pile at the collection and storage points.

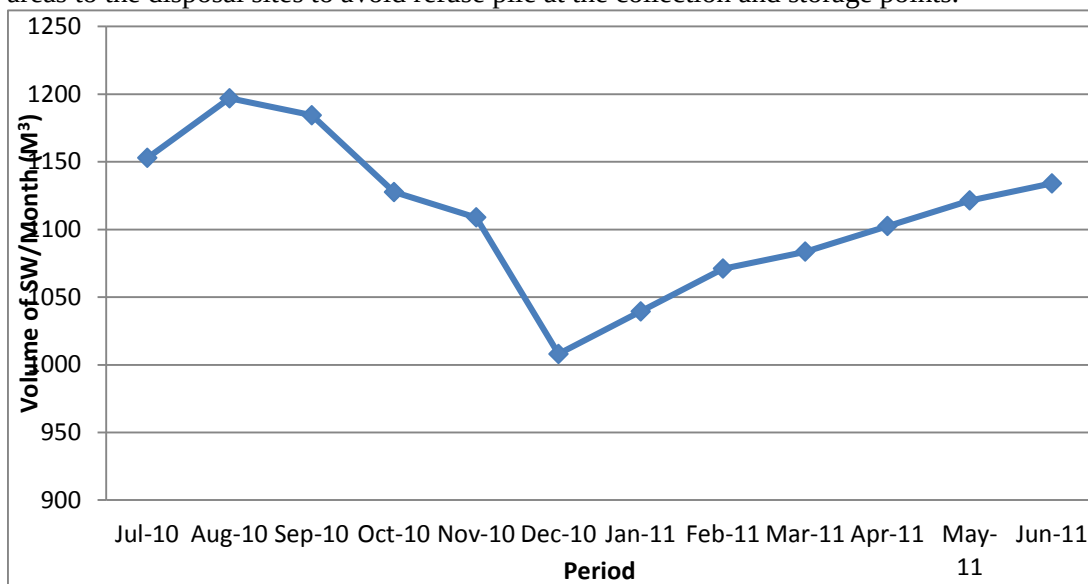


Figure 3: Volume of Solid Waste Generation (m³)

Figure 3 is the graph of volume of waste generation plotted against months. The curve shows maximum waste generation of 1197m³ recorded on the month of August. This implies that more workforce and disposal facilities should be provided at the month of August to enhance fast and adequate waste disposal.

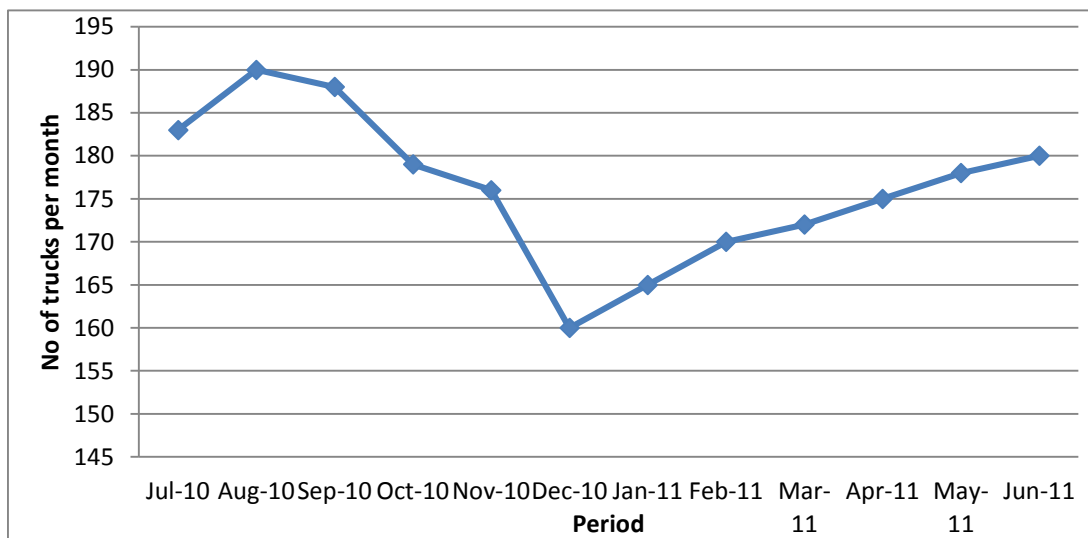


Figure 4: Number of Trucks Used Per Month

Figure 4 is the graph of number of trucks contracted to evacuate the solid waste generated plotted against month. It is a parabolic curve showing that at the month of August, highest number of trucks of 190 trucks have been contracted to haul the wastes generated to the disposal site. It simply shows that waste generated is at its peak of the year and need serious attention.

Table 5: Urban Solid Waste Generations

S/n	Zone	No persons	Volume (m ³)	Kg/ HH/Month	Kg/Cc/Day (x)
-----	------	------------	--------------------------	--------------	---------------

1	A	14	0.00042	2.89	0.21
2	B	16	0.00048	1.58	0.26
3	C	17	0.00051	1.27	0.07
4	D	11	0.00033	1.16	0.11
5	E	11	0.00035	2.84	0.26
			0.00209	9.74	0.91

Cc is the weight of the waste generated per person per day.

$$\text{Estimated density for the sampled household} = \frac{\text{mass}}{\text{volume}} = \frac{9.74}{0.00209} = 4660 \text{ kg/m}^3$$

$$\text{Mean of kg/Cc/Day} = \frac{\sum x}{n} = \frac{0.91}{5} = 0.18 \text{ kg/Cc/Day}$$

$$\text{Mean of kg/hh/Month} = \frac{\sum x}{n} = \frac{9.74}{5} = 1.95 \text{ kg/hh/Month}$$

Table 5 contains population of each household sampled at the various zone with the solid waste generated per month. This helps to estimate the quantity of waste generate per person per day which is 0.18kg/Cc/day

Table 6: Waste Receptacle

S/N	Container	Respondents (%)
1	Metal dustbin	10
2	Basket	2
3	Plastic bucket	60
4	Polythene bag	25
5	*Others	3
	Total	100

*Others: Carton, Pot, and Cardboard

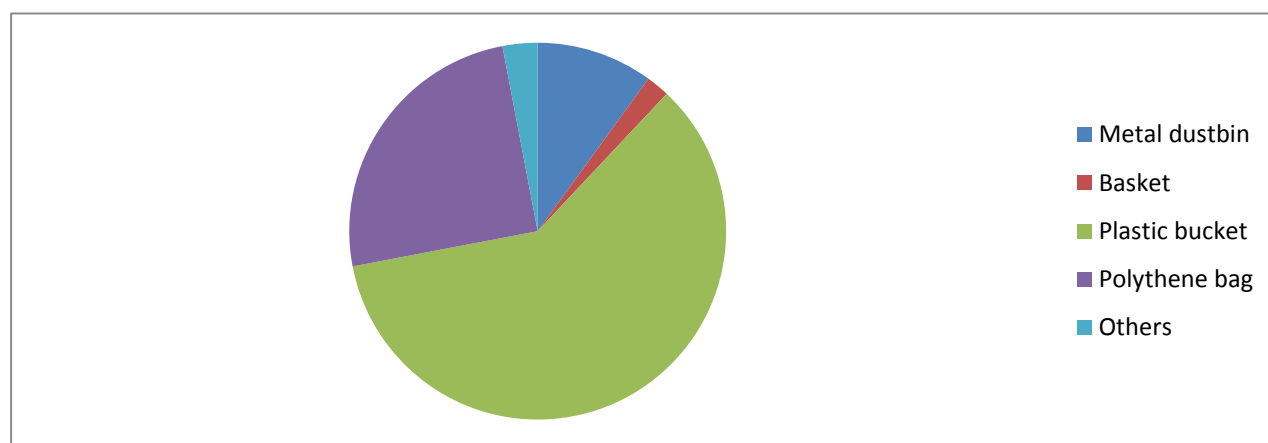


Figure 5: Waste Receptacle in the sampled area

Table 6 and figure 5 show that 60% of household in Abakaliki is using plastic solid waste bin for their temporal storage. While 25% uses polythene bags. The figure 4 presents the waste receptacle components. The high percentage of plastic solid waste bin was the impact of EBSEPA. The agency enforces each household in Abakaliki urban to have at least one covered plastic solid waste bin. It is more affordable to metal waste bin.

4. CONCLUSION

The result from study reveals that per capital municipal solid waste generation rate is 0.18 kg/capital/day. The per capital generation rate for various areas sampled in Abakaliki urban is shown in table 5. It is also shows that about 80% of people living in the urban area dispose their solid waste in containers whereas 20% littered theirs on the road side or street. It also discloses that only few people segregate their solid waste (biodegradable and non-biodegradable). About 85% use plastic and polythene bags for solid waste storage and disposal which are not biodegradable and pose problems to the environment. Inappropriate sitting, design, operations, and maintenance of dump sites increase the transfer and disposal cost and inadequate onsite storage facilities. Lack of institution arrangement: lack of expertise and manpower to run solid waste management program in Abakaliki. Majority of environmental workers have little or no functional background or training in engineering and management, so the operations result in inefficient and ineffective solid waste management.

It is recommended that more disposal site should be created by the State Government; provision of more workforce and waste disposal facilities for proper and adequate handling of solid wastes; preparation and enforcement of laws that will support solid waste management and there should be public enlightenment on the management and disposal of solid wastes.

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EFFECT OF RAINFALL VARIABILITY ON CROP PRODUCTIVITY IN IDOFIAN, KWARA STATE, NIGERIA

M. B. Makanjuola, D. James and M. Y. Kasali
National Centre for Agricultural Mechanization, Ilorin, Nigeria.
Email: makanju2@yahoo.com

ABSTRACT

Rainfall data for Idofian were analyzed for monthly and weekly rainfall probabilities at various thresholds and correlated with yield. The mean annual rainfall is 1195 mm with a coefficient of variation (CV) of 19.6% while the mean weekly rainfall is 21.5 mm with a CV of 56% indicating very high weekly rainfall variability. 40% of the years received rainfall above annual mean value which was distributed unevenly during the cropping season. The months of May to September had high probabilities of occurrence with September having the highest for the thresholds considered. Positive correlation between yield and rainfall was recorded for cowpea, melon, rice. The predictability of yield using rainfall was however, low.

KEYWORDS: Rainfall variability and distribution, specific rainfall threshold, yield

1. INTRODUCTION

Generally, there are many factors influencing crop production; these include soil, relief, climate and diseases among others. Hence, precipitation, solar radiation, wind, temperature, relative humidity and other climatic parameters determine the global distribution of crops and livestock as well as their productivity. Agriculture largely depends on climate to function; it is one of the most weather-dependent of all human activities. In relation to climate, rainfall is the dominant controlling variable in tropical agriculture since it supplies soil moisture for crops and grasses for animals. Rainfall is a key factor in shaping the vegetation, hydrology, and water quality throughout the earth. Along with temperature, the occurrence and variability of precipitation, to a large extent determine which crops can be grown in different regions throughout the world. Rainfall is particularly critical to agriculture. Thus, any changes occurring in climatic conditions affecting rainfall patterns will have an adverse impact on agriculture and eventually affect the economic well-being of the people (Dahal, 2009). As weather pattern changes, the economy of farmers, which depends on traditional subsistence-based agriculture, becomes more vulnerable and difficult.

IPCC (2001) gives a clear difference between climate variability and climate change. Climate variability is the fluctuations of climate naturally on a time scale ranging from days, weeks and years to few decades, including altered frequencies of extreme events while climate change is a longer term fluctuation from decades to centuries. As additional insight into precision farming is gained, the importance of rainfall variability becomes more apparent. An accurate understanding of precipitation characteristics and soil variability is critical to optimizing farm production and to precision farming. The ability to make informed decisions regarding precision farm management depends upon an understanding of seasonal and spatial variability of rainfall. Rainfall studies particularly probability analysis are of great help in selection of crops and varieties, crop management practices, contingent crop planning, plant protection measures and related farm operations for sustaining crop production in an area (Mehta *et al.*, 2002).

Rainfall has now become very unreliable in terms of commencement, distribution and quantity (Audu *et al.*, 2010). Annual rainfall records at a single station have large variations that are sometimes larger than the mean annual rainfall. Sumner (1988) observed that the large variability, asymmetry, and non-normal distribution of rainfall over several decades completely mask any long-term trend that might exist in that record. Rainfall variability, a major index of climate change, affects cropping activities such as land preparation and sowing, particularly in rain-fed agricultural systems. Rainfall variability is one of the main determinants of agricultural production in both developing and developed countries (FAO, 2001). It is an important characteristic of climate in SSA that imposes crop production risks, especially on rain-fed

subsistence cultivation systems on marginal land (Koo, 2010). Inter-annual rainfall variation, defined as the annual deviation from long-term averages or the differences in rainfall between years, has been the key climatic element that determines the success of agriculture in a region (Ayanlade *et al.*, 2009). High inter-annual rainfall variability, coupled with increase in temperature, portends serious implications for African soils.

In Nigeria, an agrarian country, agricultural productivity is strongly linked to rainfall variability because farmers rely on rain-fed agriculture. Nigeria's wide range of climate variation allows it to produce a wide variety of food and cash crops. However, food production is grossly below the rate of population growth. Ideally, crop cultivations should be situated in areas with high rainfall with low variability; however, subsistence farming can be found in a wide range of environmental conditions from very suitable to marginal lands. Food shortage is therefore linked with climate change (Adefolalu, 2004). Rainfall variability from season to season greatly affects soil water availability to crops, and thus poses crop production risks. Variability in the onset of the rainy season has led to variation in the start of the planting season of varied crops.

Various studies have revealed that rise in temperature and changes in the amount of rainfall and its distribution have altered availability of water resources consequently affecting the productivity of crops grown in the different parts of the country. Tunde *et al.* (2011) studied the impacts of temperature, relative humidity, rainfall and number of rainy days on food production and found that maize production correlated highly with rainfall amount (0.73) while other variables were very weak. Transpiration through plant parts utilizes a lot of moisture from the soil. The amount of rainfall received during the life period of crop, therefore, plays an important role in the yield of the crop. The distribution of rainfall within the crop period is however, more important than the total amount of rainfall in a season. It is, thus, possible to estimate crop yields from total rainfall received during crop period.

The objective of this study therefore was to statistically analyze rainfall variability and develop yield prediction models using rainfall and yield data available in the region. This will reveal whether or not changes in climatic variables have positive or negative effect on crop yield in the study area. It will also reveal the pattern of crop production to be adopted within the study area.

2. METHODOLOGY

Rainfall data for Idofian, Kwara State, Nigeria, covering the period from 1990 to 2004 (15 years) obtained from the NCAM Meteorological Station was used in this study. The data was subjected to statistical tests for trends, inconsistency and stability. The mean, standard deviation (SD) and coefficient of variation (CV %) of weekly and seasonal rainfall (for the cropping period) was calculated using SPSS 20.0 statistical packages. The probability of getting more than 1mm, 5mm, 10 mm, and 20mm was obtained by simple probability method. This is expressed as:

$$Probability (\%) = \frac{m}{n} \times 100$$

where m = total frequency of rainfall at specific threshold, n = number of days in the month

The regional average yield data for selected crops for the years under review was obtained from Kwara State Agricultural Development Project (KWADP). The regression was performed using rainfall (X) as independent variable and yield (Y) as dependent variable and a correlation between rainfall and yield was established. Yield prediction models for important crops such as maize, sorghum, melon, cowpea, millet, rice, yam and cassava were developed.

3. RESULTS AND DISCUSSION

3.1 Statistics of Mean Annual Rainfall of Idofian

The annual rainfall of Idofian for the period under review (Fig. 1) varied from 872.40 mm (1992) to 1595.10 mm (1998) with a mean seasonal value of 1195.45mm and a standard deviation of 239.42. The number of rainy days, set as days with ≥ 0.3 mm rainfall event, also varied from 19 to 84 days. From the available record, excess rainfall above the mean value was received in 6 years (40%). About 95 % of the mean annual rainfall occurred between the months of April – October while the months of November – March contributed just 5 % of the mean annual rainfall.

Rainfall usually determines the type of crop to be grown in different environment as well as the type of agricultural system to be practiced in different parts of the country. Thus, it directly affects crop production and can alter the distribution of agro-ecological zones. In this region the dominant crops produced are maize, sorghum, melon, cowpea, millet, rice, yam and cassava.

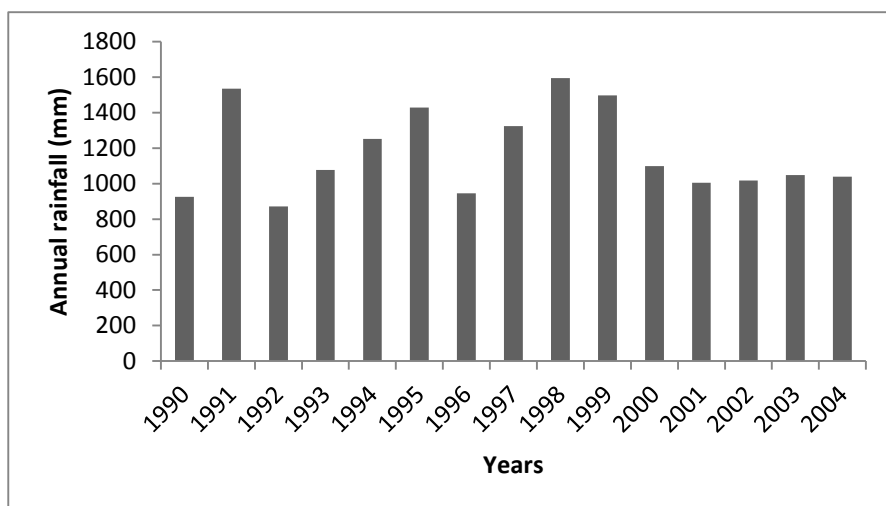


Fig. 1: Seasonal rainfall amount at Idofian (1990 – 2004)

3.2 Weekly Rainfall Analysis

The distribution of rainfall received weekly is presented in Fig. 2. Rainfall is usually well established by the month of May which is denoted as meteorological week (mw) 18 and ends by October (mw 44). The rainfall pattern in Idofian comprises of two rainfall peaks in the months of June and September, with a period of dry spell referred to as August break. This bimodal rainfall pattern is characteristic of rainfall in the south western part of Nigeria.

The analysis of weekly rainfall showed a lot of variability within the rainfall season (CV of 56%). The largest rainfall received in a single week (322 mm) was recorded in September 2001, which corresponds to meteorological week 38 (Table 1).

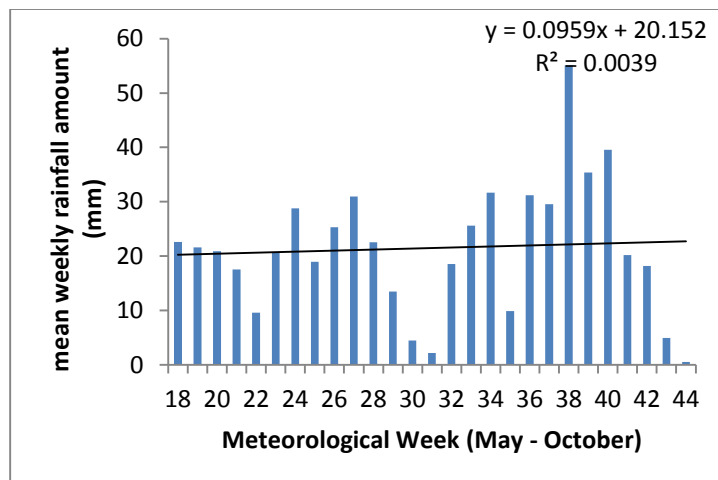


Fig. 2: Weekly rainfall distribution for the months of May to October at Idofian

Table 1. Weekly rainfall data analysis for Idofian (1991 – 2004)

Met. Week	Mean	SD	CV (%)	Maximum rainfall in a single week (mm)	Year
18	22.59	23.3204	103.2	76.9	1997
19	21.6	21.98409	101.78	75	1999
20	20.92	26.58632	127.08	89.5	1997
21	17.55	14.15	80.6	66.5	1999
22	9.6	9.266667	96.5	32	2000
23	20.76	14.50139	69.85	72	2001
24	28.78	20.3125	70.58	67	1997
25	18.97	13.96667	73.63	58.5	1999
26	25.3	20.88333	82.54	70.5	1996
27	30.96	20.41111	65.93	86.3	2002
28	22.53	23.97222	106.40	85.5	1996
29	13.49	13.60556	100.85	56.5	2002
30	4.48	5.111111	114.09	17.6	1991
31	2.21	3.680556	166.54	19.5	2001
32	18.54	18.91944	102.05	107	2002
33	25.63	24.09444	94.01	116	2002
34	31.68	32.94649	103.99	85	1991
35	9.92	13.26621	133.73	47.5	2002
36	31.23	42.8037	137.06	148.0	1997
37	29.57	23.81708	80.54	74.5	1997
38	55.08	87.83348	159.46	322.0	2001
39	35.4	27.97713	79.03	102.8	2000
40	39.58	40.11064	101.34	105.5	1991
41	20.23	24.19434	119.59	58.5	1995
42	18.23	20.2041	110.83	53.1	1995
43	4.98	11.86797	238.31	41.5	1994
44	0.54	1.37276	254.21	4.5	1991
Mean	21.5	12.16	56.56		

Table 2: Mean Rainfall and Probability of occurrence for Idofian (1991 – 2004)

Month	Mean Rainfall (mm)	Rainfall Threshold					
		$\geq 0.3\text{mm}$	$\geq 1\text{mm}$	$\geq 5\text{mm}$	$\geq 10\text{mm}$	$\geq 15\text{mm}$	$\geq 20\text{mm}$
Jan	1.5	0	0	0	0	0	0
Feb	5.4	0	0.107	0.036	0	0	0.036
Mar	36.5	0	0.193	0.032	0.129	0.0645	0.097
Apr	85.5	0.1	0.4	0.267	0.20	0.1	0.433
May	150.3	0.097	0.806	0.452	0.452	0.258	0.710
Jun	181.0	0.033	0.933	0.567	0.33	0.367	0.633
Jul	153.7	0.032	0.935	0.452	0.355	0.290	0.355
Aug	148.8	0.067	1.13	0.533	0.33	0.167	0.70
Sept	268.9	0.233	0.833	0.80	0.60	0.367	1.00
Oct	127.4	0.097	0.774	0.548	0.193	0.290	0.516
Nov	14.9	0	0.167	0.067	0	0	0.033
Dec	3.6	0	0	0	0	0	0

The probabilities of occurrence of different rainfall thresholds obtained for Idofian is presented in Table 2. The result shows that the probabilities of occurrence of rainfall of lesser threshold values are generally more than the probabilities of occurrence of rainfall of higher threshold values. The highest probabilities were recorded for receiving $\geq 1\text{mm}$ rainfall. There is also a trend of progressive increase and decrease of rainfall probabilities at the onset and end of the year respectively while the month of September recorded the highest probabilities of receiving rainfall at all specific thresholds considered. The months of May to September might be categorized as having high probabilities of rainfall occurrence, March, April and October as average while December, January and February were considered to be low.

Since the distribution of rainfall within the crop period is more important than the total rainfall amount in a season, presenting the various rainfall thresholds available within the season reveals the rainfall distribution pattern of the study area thus enabling the user to select values of interest to suit field operations and crop requirement. Hence management decisions can be enhanced from this information.

For effective growth to occur, the amount of rainfall available must be able to provide sufficient soil moisture after accounting for losses to runoff and evaporation. Runoff losses for Idofian has been estimated as 20% (Ahaneku, 1997) whilst the consumptive use for the crops obtained from the crop coefficients and climatic data for the region will define the need for supplemental irrigation to meet the deficiencies.

3.3 Crop Productivity Analysis

The results of regression analysis between rainfall and crop yield are as in Figures 3 – 10. The graphs show positive correlations of different percentages between rainfall and crop yield for most of the crops considered. The total rainfall amount does not always correlate with higher yield due to other factors such as soil characteristics and rainfall pattern. The permeability of the soil and rainfall intensity determines how much rainfall percolates or is lost to runoff. A soil with high water holding capacity and long retention (clayey soil) will support crop production better than a porous sandy soil. Plants possess different sensitivity levels to water stress at different developmental stages. In most grain crops, flowering, pollination and grain-filling phases are especially sensitive to water stress. Crop yields are most likely to suffer if dry spells occur during critical developmental stages such as the reproductive stage. It is thus, important to know the water requirements of a crop and make provision for supplemental irrigation if rainfall becomes a limiting factor. Other contributory parameters that could affect crop productivity include; fertility of the land, seed viability and sowing time.

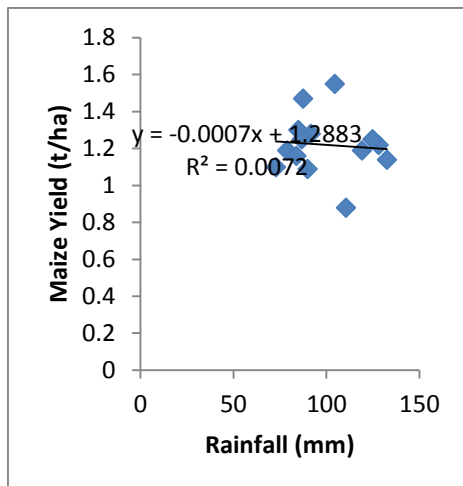


Fig. 3: Graph of Rainfall and Yield for Maize

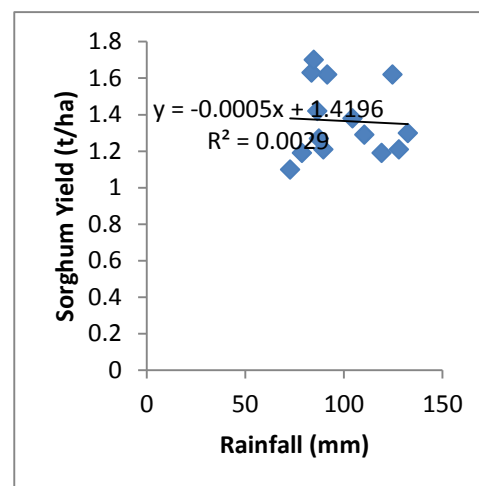


Fig. 4: Graph of Rainfall and Yield for Sorghum

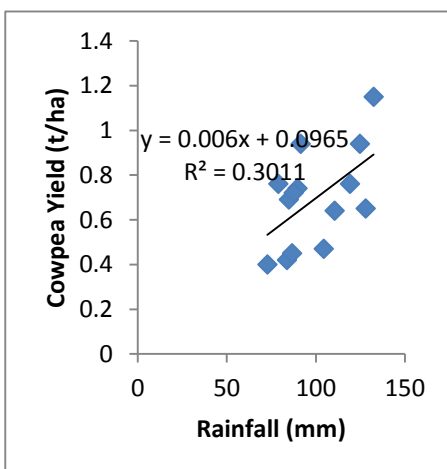


Fig. 5: Graph of Rainfall and Yield for Cowpea

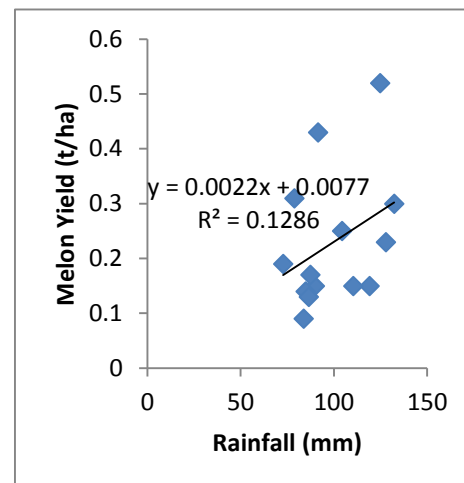


Fig. 6: Graph of Rainfall and Yield for Melon

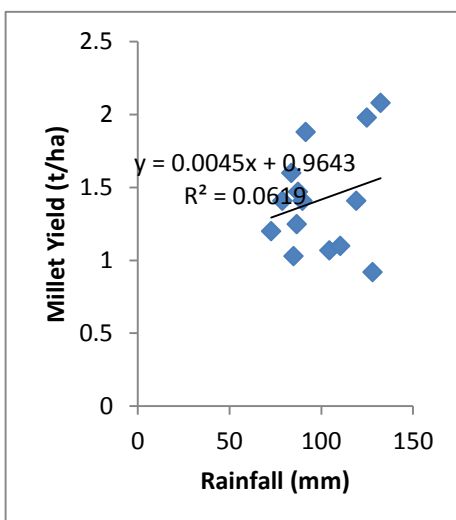


Fig. 7: Graph of Rainfall and Yield for Millet

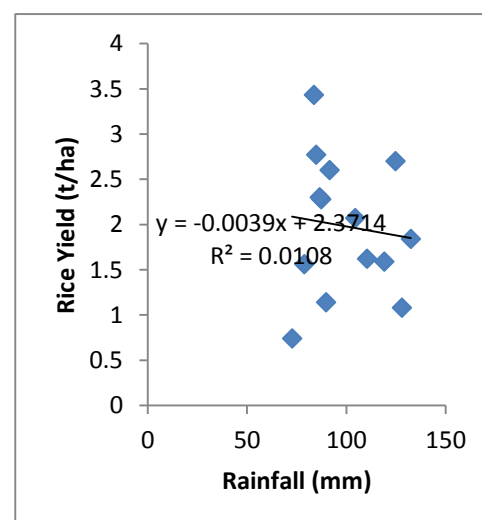


Fig. 8: Graph of Rainfall and Yield for Rice

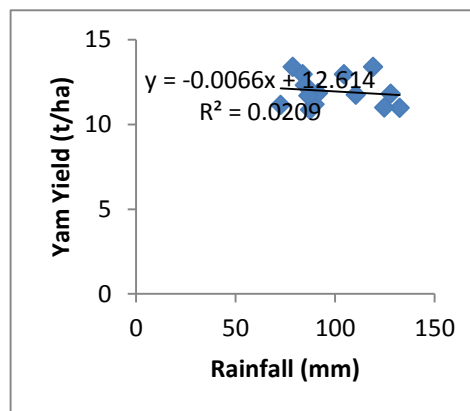
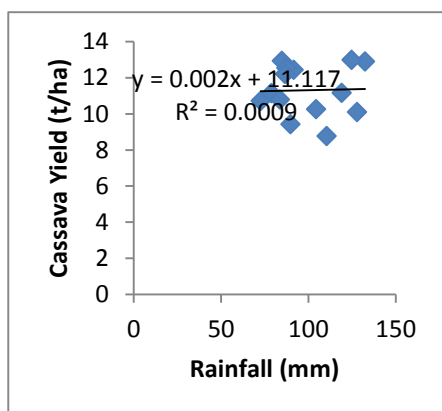


Fig. 9: Graph of Rainfall and Yield for Cassava Fig. 10: Graph of Rainfall and Yield for Yam

4. CONCLUSION

Water availability is the most critical factor for sustaining crop productivity in rain-fed agriculture. Different crop growth stages have different sensitivity levels of development to water stress; low availability of water during a critical stage can have a high impact on yield. Hence, to efficiently use water, it is important to understand when crop needs water the most and ensure that values that can be depended upon are known and available, thus stabilizing crop production.

Rainfall is the major source of water for plant use. Planning of agricultural activities is hinged on the availability of rainfall. Statistical analysis of past records was used to determine the total amount, variability and distribution. The study has shown that there is high variability (56%) in the distribution of weekly rainfall amounts during the season and the possibility of critical growth stages falling within periods of drought. This can account for the low correlation between yield and rainfall for some crops.

The result of this analysis will assist in decision making for both human and equipment input in field activities. For most crops, varieties exist with a wide range of maturities and climatic tolerances. Thus, improved cultivars need to be adopted as well as integrating supplemental irrigation to prevent adverse water stress at crucial developmental growth stages to prevent drastic yield reduction.

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IMPACT OF IRRIGATION PRACTICES ON SOIL NUTRIENTS IN KAMPE (OMI) SCHEME

J. O. Ojediran, M. A. Adejumobi and J. Adeyera

Department of Agricultural Engineering, Faculty of Engineering and Technology,

Ladoke Akintola University of Technology, Ogbomoso, Oyo State, Nigeria

E-mail: maadejumobi@lautech.edu.ng

ABSTRACT

Irrigation applications have impacts on soil properties and these impacts may be negative on soil, crop and groundwater quality. This could be as a result of the quality of water used, method of application and the nature of the soil viz the physical and chemical composition of the soil. For sustainable use of the soil, it therefore becomes necessary to evaluate the effects of irrigation application on the soil from time to time. This project work was aimed at investigating the impacts of irrigation on the soil nutrients on Kampe irrigation scheme. Soil samples were collected from three operating lands of the scheme. Samples were collected at depths 0 – 20 cm, 20 – 80 cm and 80 – 120 cm in accordance with the baseline data available. The samples were taken to the laboratory and analysed for physical and chemical parameters (K^+ , Mg^{2+} , Ca^{2+} , P and TKN). It was observed that there were little changes in the macronutrients such as Mg^{2+} and Ca^{2+} which reduced appreciably as compared to the baseline data for the operating lands. There is a need for proper monitoring of the soil condition in the irrigation scheme should be employed in order to prevent further deterioration since changes have been observed compared to the baseline data.

KEYWORDS: Irrigation, groundwater, soil nutrients, operating land.

1. INTRODUCTION

The increased use of irrigation technology though yielding the expected results in terms of agricultural productivity, has a far-reaching negative effect on the ecological sphere. The technology transforms the land in two major ways, first by direct modification of the land surface that occur when networks are constructed and land is cleared and leveled for irrigation" and secondly by indirect transformations that take place when the water and salt balances in the region are changed following the import of additional quantity of water and salts in the area ((Poustini and Siosemardeh, 2004). According to Poustini and Siosemardeh, (2004), Soil is the loose material that covers the land surfaces of Earth and supports the growth of plants. Soils vary widely from place to place. Many factors determine the chemical composition and physical structure of the soil at any given location. According to Poustini and Siosemardeh, (2004) "when irrigation is introduced to a piece of land, it affects soil aeration, soil moisture, soil microorganism, soil organic matter content soil pH, and soil texture and soil temperature". All these will invariably affect the level of exchangeable bases and extractable copper, iron, manganese and zinc in the soil. It should be noted that these soil nutrients are required for plant growth some in large quantities as the case of cations and micronutrients in small quantities.

During the last 3 - 4 decades due to increased demand for food, the use of irrigation has increased by about 300%. Due to scarcity of surface water resources especially in arid and semi-arid region for supplying irrigation water for agricultural lands, the excessive discharge of the ground water with low quality has occurred, which has imposed a further increase in soil salinization (Poustini and Siosemardeh, 2004).

Over-watering has a direct impact on water resources at a time when they are at their lowest. Overwatering will also result in increased drainage during the growing season, which increases nitrate leaching to groundwater. Under-irrigation may conserve water resources, but by reducing nitrogen uptake by the growing plant, may increase the risk of winter nitrate leaching. A good irrigation plan will set trigger deficits as high as possible and irrigation applications should leave sufficient storage capacity in the soil to allow for rainfall.

Type of irrigation methods can be broadly divided as under: Surface irrigation method, Subsurface irrigation method, Sprinkler irrigation system, and Drip irrigation system. In Surface Irrigation system of

field water application, the water is applied directly to the soil from a channel located at the upper reach of the field (Kharagpur, 2000). It is essential in these methods to construct designed water distribution systems to provide adequate control of water to the fields and proper land preparation to permit uniform distribution of water over the field. In subsurface, the application of water to fields in this type of irrigation system is below the ground surface so that it is supplied directly to the root zone of the plants (Kharagpur, 2000). The main advantages of these types of irrigation is reduction of evaporation losses and less hindrance to cultivation works which takes place on the surface. Sprinkler irrigation is a method of applying water which is similar to natural rainfall but spread uniformly over the land surface just when needed and at a rate less than the infiltration rate of the soil so as to avoid surface runoff from irrigation and Drip Irrigation system is sometimes called trickle irrigation and involves dripping water onto the soil at very low rates (2-20 litres per hour) from a system of small diameter plastic pipes filled with outlets called emitters or drippers. Water is applied close to the plants so that only part of the soil in which the roots grow is wetted, unlike surface and sprinkler irrigation, which involves wetting the whole soil profile (Kharagpur, 2000).

A critical problem confronting mankind today is how to manage the intensifying competition for water between expanding urban centres, traditional agricultural activities and in-stream water uses dictated by environmental concerns. Therefore, the required increase in agricultural production will necessarily rely largely on the affordability to apply new technologies, a more accurate estimation of crop water requirements, and on major improvements in the construction, operation, management and performance of existing irrigation systems.

Although several studies are carried out on the impacts of irrigation on soil in Nigeria, little or no attempt is made to look at impact of irrigation on the soil properties and the implications on crop production. Now irrigated agriculture is entering an "age of management" in which crop water deficit may not be totally avoided but instead, favourably controlled. So, there is need to adopt management practices that limit evaporation losses. The focus of this study is on the aspect of irrigation that affects the various properties of soil, which in many cases brought in deleterious impact on the biological environment. Therefore, the effect of irrigation on the distribution of soil nutrients and organic matter in Nigeria need to be determined.

Today, doing local research on irrigating the farmlands and studying the effects of which from different aspects have been of great importance. The major aim of this research is to determine the various effects of irrigation on soil nutrients. The objectives are to collect the baseline data and identify status of the soil nutrients in the scheme at inception, determine the present state of the soil nutrients on some parts of the scheme where irrigation is being carried out, evaluate the impacts of irrigation on the soil nutrients in these sections of the scheme and to make recommendations on the effects of the impact observed.

2. MATERIALS AND METHODS

Kampe Omi Dam Irrigation Project is located in Yagba West Local Government Area of Kogi State, Nigeria. It is about 146 km from Ilorin the capital of Kwara State. It lies between longitude $6^{\circ}37'1''$ and $6^{\circ}43'1''$ E of the Greenwich and latitude $8^{\circ}34'1''$ and $8^{\circ}38'1''$ N of the equator. (Figure 1).

Areas sampled were field OL18, OL20 and OL5.NB; OL5 which served as the control area since it has been long that it was left fallow without either of tillage or irrigation. Maize, Rice and potatoes were grown on this land. Each field was separated into sampling units representing a relatively uniform area. The criteria used to delineate a sampling unit include soil type, slope, drainage, and past management. Each sample unit was not more than forty acres (40a). A 120cm auger was drilled into the soil at each location of sample collection on the operating land which were (OL5, OL18 and OL20A & OL20B) as shown on figure 1. The soil (sample) was collected at each depth (0-20cm, 20 -80cm and 80-120cm) respectively with the help of the auger that was drilled into the soil and then dropped into a well labelled black polythene paper. At the end of sample taking, a total of 60 samples was taken.



Figure 1: Soil sampling points of the Kampe Omi Dam irrigation project

The samples collected were taken to lower Niger river basin laboratory for analyses; testing for micro and macronutrient present using Flame photometry to determined potassium (K) while Atomic Absorption Spectrometer (AAS) was used in determining calcium (Ca) and magnesium (Mg). Calcium helps plants respond better to environmental and disease stresses and Magnesium is another important macronutrient needed by plants, important for chlorophyll production or plant photosynthesis (Tesfai *et al.*, 2002). Crops with potassium at the low end of the range are classed as having a low K^+ content and crop yields are expected to be 50-80% of the yield that could be obtained with adequate fertilizer application. Potassium is important for over-wintering ability of perennial crops, overall growth and longevity and disease resistance, Potassium is important for legumes. Adequate amount of phosphorus in soils favours rapid growth, early fruiting/ maturity and improves the quality of produce (Amjad *et al.*, 2006). Nitrogen is a major plant macronutrient stimulating leaf and stem growth.

The results were analyzed using Microsoft excel spreadsheet, using average to find the value required according to the result of the analysis.

3. RESULTS AND DISCUSSION

3.1 Calcium (Ca^{2+})

There are reductions in Ca^{2+} in all the operating lands in the current data of the scheme as compared with the baseline data. From the figures 1a-c, Ca^{2+} values at all depths for the operating lands in the baseline are greater than values in recent years including the current data. Ca^{2+} deficiency may be reduced in the operating lands since the soil pH is adequate according to Marx *et al.*, (1997) and as shown illustrated in Figure 1a – c.

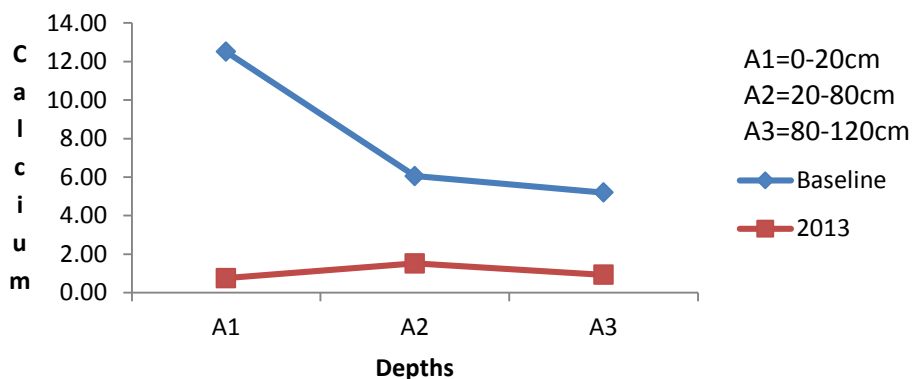


Figure 1a; chart for the values for Ca^{2+} with depth for OL5

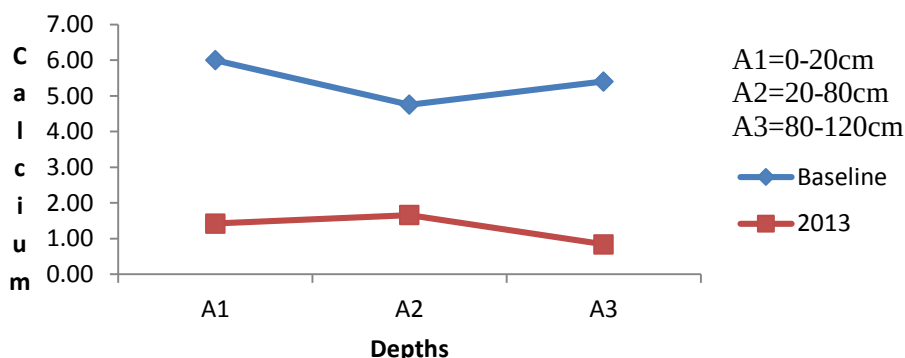


Figure 1b; chart for the values for Ca^{2+} with depth for OL18

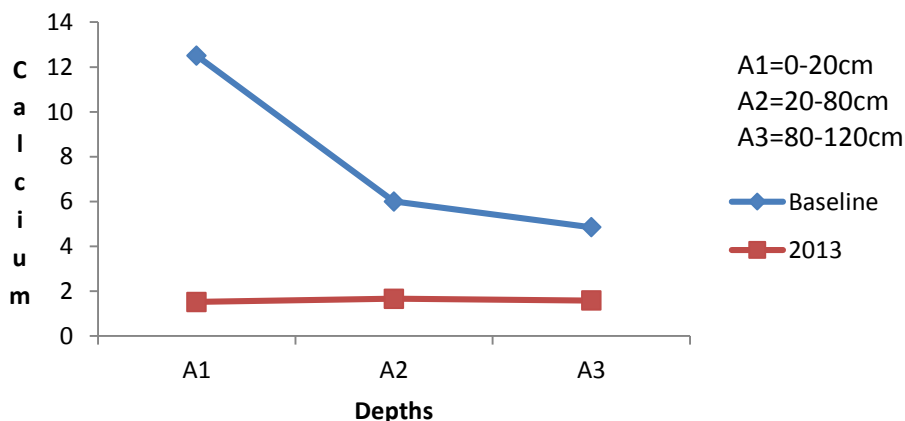


Figure 1c; chart for the values for Ca^{2+} with depth for OL20

3.2 Magnesium (Mg^{2+})

The values of Mg in the baseline data for all the operating lands fall under the medium class. In the current data, OL5 falls in the low class; OL18 falls in medium class only depth 80-120cm of OL20 falls in the medium class. The other two depths of OL20 fall in the low class but are close to the medium class (Oriola 2004). This is illustrated in Figure 2a – c.

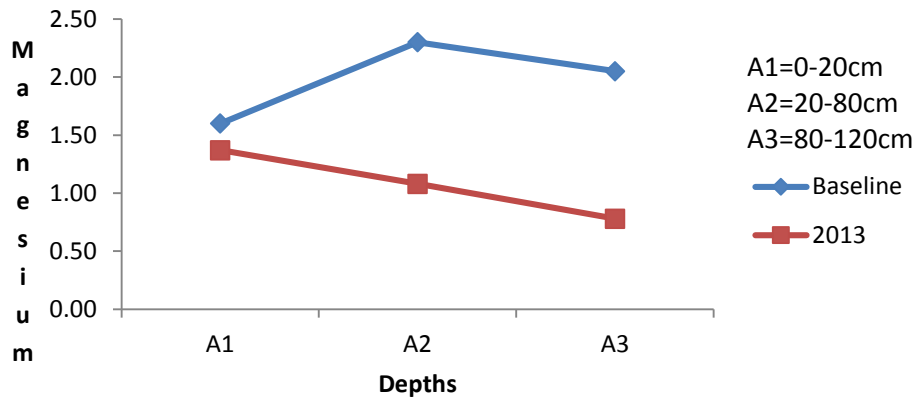


Figure 2a; chart for the values for Mg^{2+} with depth for OL5

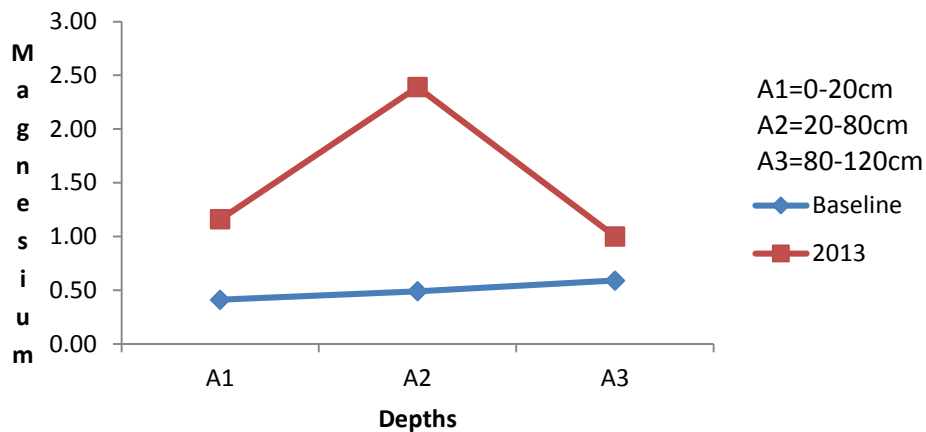


Figure 2b; chart for the values for Mg^{2+} with depth for OL18

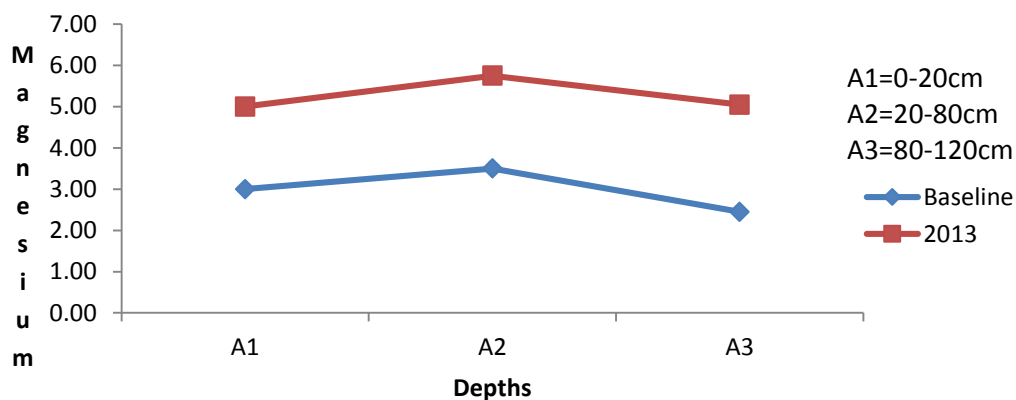


Figure 2c; chart for the values for Mg^{2+} with depth for OL20

3.3 Potassium (K^+)

Considering Figure 3a - c, it is shown that there is an increase in potassium levels compared to the baseline data and over the years at each depth and for all the operating lands. The values of K^+ at all depths for OL18 and OL20 are higher than that of OL5 and the irrigated land can yield 100 percentage without application of fertilizer (Oriola, 2004).

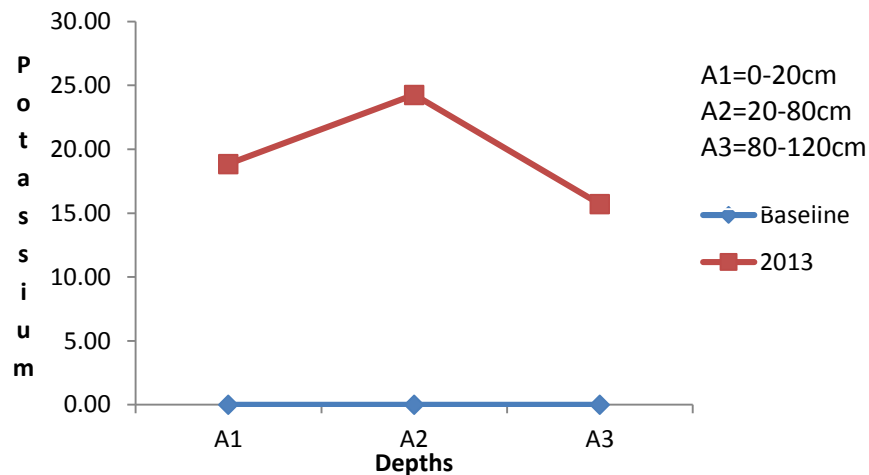


Figure 3a; chart for the values for Potassium with depth for OL5

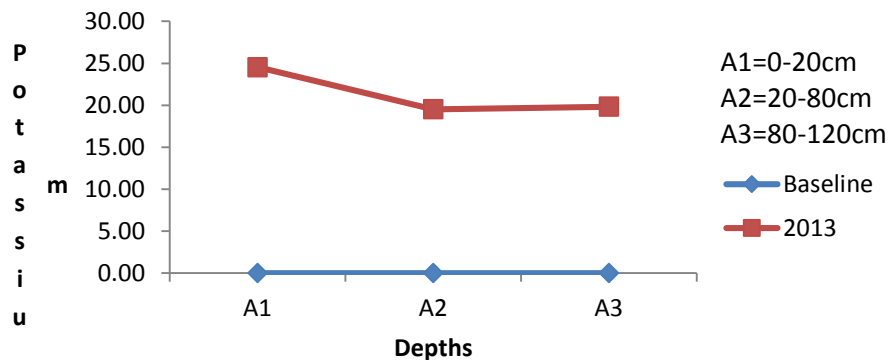


Figure 3b; chart for the values for Potassium with depth for OL18

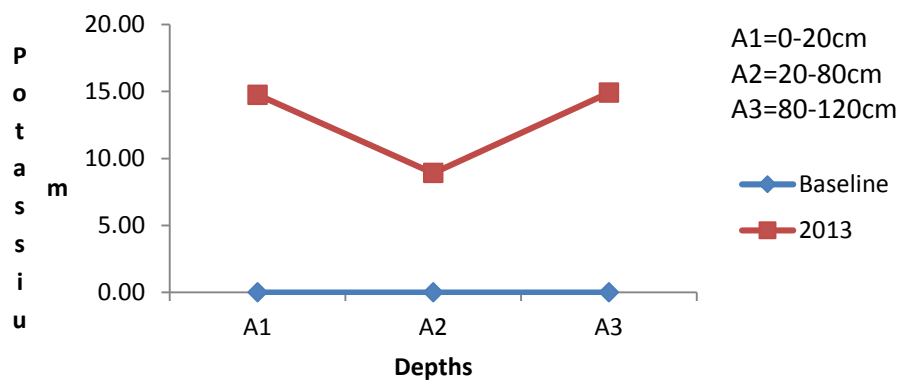


Figure 3c; chart for the values for Potassium with depth for OL20

3.4 Phosphorus

From Figure 4a, there is an increase in the phosphorous levels over the years but in comparison to the baseline data, a slight decrease occurred for the current data while in Figure 4b and c, an increase over the years with baseline data was observed at each depth. There is greater increase in phosphorus in the operating lands so there is sufficient phosphorus in all the lands for plant's root growth, protein synthesis and crop maturity.

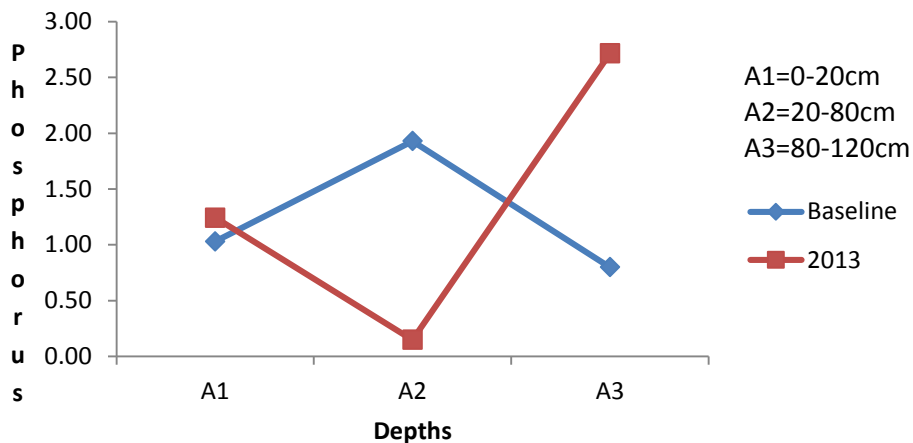


Figure 4a; chart for the values for Phosphorus with depth for OL5

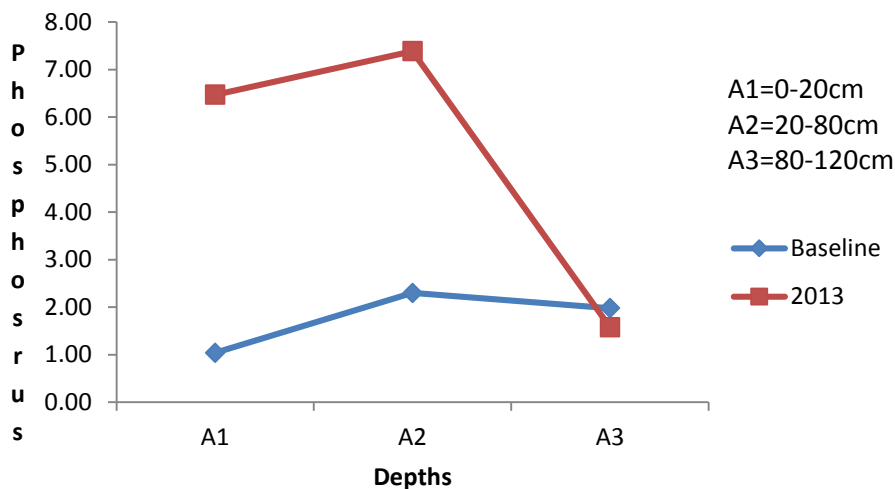


Figure 4b; chart for the values for Phosphorus with depth for OL18

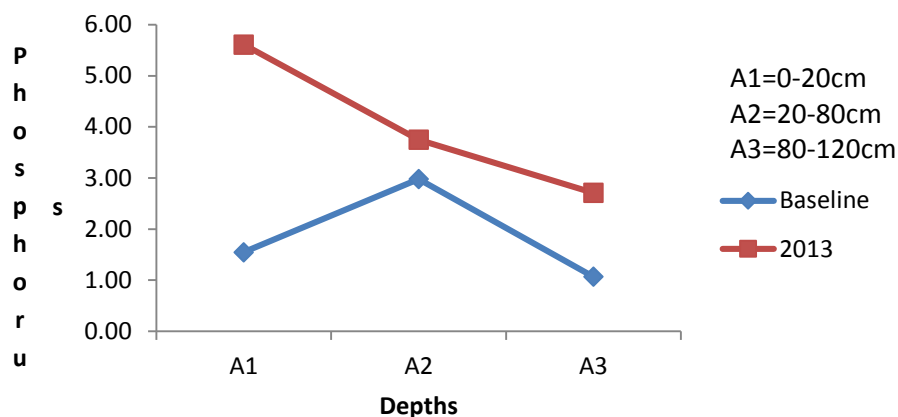


Figure 4c; chart for the values for Phosphorus with depth for OL20

3.5 TKN

The current result showed increase in nitrogen in all the operating lands. There is a drastic increase for current data compared with baseline data and over the years for the operating lands (OL 18 and OL20) at all depths. This may be as a result of different soil management employed by famers using the operating lands, especially the use of N.P.K fertilizer which has added some level of nitrogen to the soil as illustrated in Figure 5a – c.

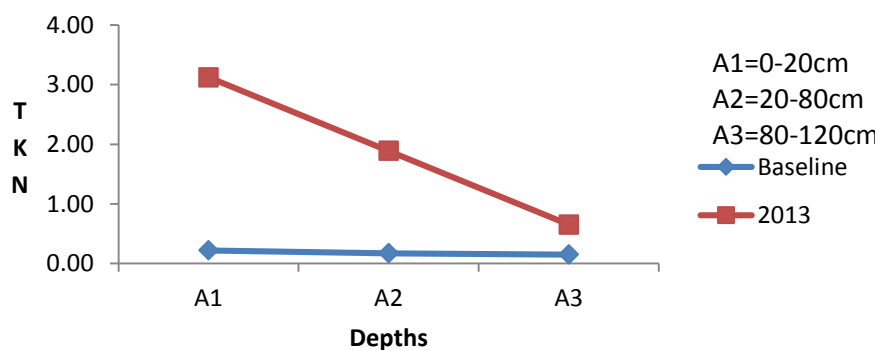


Figure 5a; chart for the values for TKN with depth for OL5

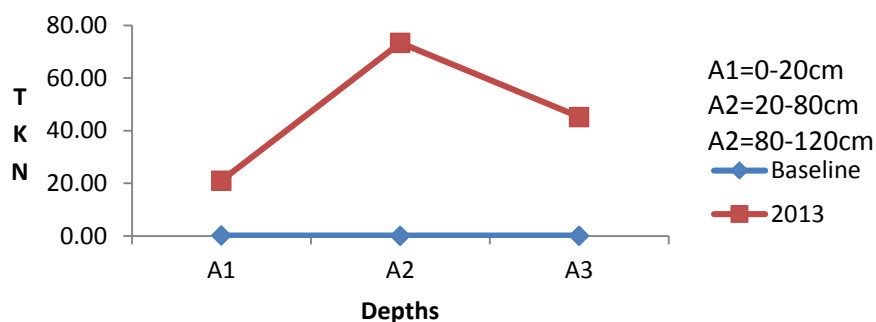


Figure 5b; chart for the values for TKN with depth for OL18

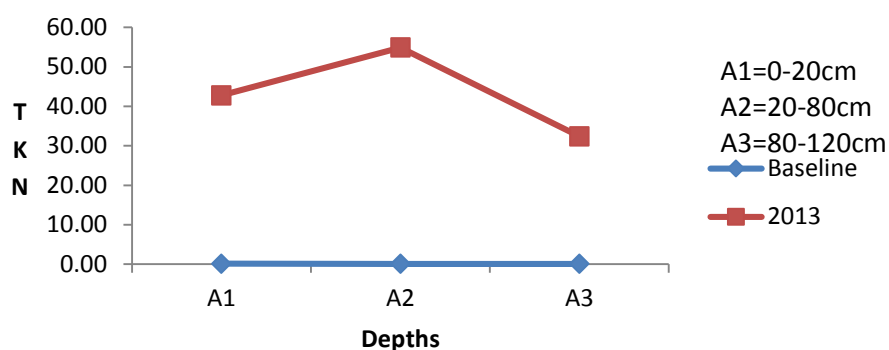


Figure 5c; chart for the values for TKN with depth for OL20

4. CONCLUSIONS

The current data shows macronutrients such as Ca^{2+} and Mg^{2+} required by crops have reduced compared to the baseline and this in turn could reduce the fertility of the soil due to the deficiencies. This reduction can also be traced to the decreased levels of base saturation and the slight acidity noted by the pH range.

There was an increase in K^+ and Phosphorous levels which makes them still available in the soil when they are removed in large quantity during harvest.

Nitrogen (TKN) largely increased and these high levels are detrimental to soil tilth and plant growth. Generally, the analysis indicated that a need for proper monitoring of the soil condition in the irrigation scheme in order to prevent further deterioration is highly encouraged since some changes have been observed compared to the baseline.

Improper soil management are the major problem in the scheme, the control of soil management problem, development and maintenance of successful irrigation project should be taken important. For efficient production output in the irrigation scheme, thus it is recommended that fertilizer should be applied in the appropriate proportion to stabilize and correct nutrient deficient in the soil of the irrigation scheme, allow proper decomposition of crop residues and cleared bush because if not, it could lead to water logging, Chemical and physical properties of the soil should be carried out often effectively to detect any sudden rise or fall of the nutrients in the soil and a drainage outlet should be provided in the field so that excess water used for irrigation practice can be drain away from the field (preventing accumulation of salt and water logging).

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THE EFFECT OF AUTOMOBILE INDUSTRIAL WASTEWATER ON SOIL QUALITY

S. N. Ugwu, C. C Anyadike and O. A. Nwoke

Department of Agricultural and Bioresources Engineering, University of Nigeria, Nsukka

Emails: sunjustice2001@yahoo.com; chi4jessy@yahoo.com; nwoke.oji@unn.edu.ng;

ABSTRACT

Reuse of industrial wastewater (effluent) for irrigation purposes is a common practice. However, lack of adequate treatment of the effluent can cause soil deterioration, plant die off and contamination of the aquatic environment. These adverse effects necessitated the study of wastewater irrigation in Emene Industrial Layout, Enugu State, Nigeria. Wastewater and soil samples were collected, analysed and subjected to Analysis of Variance (ANOVA) for CRD at 5% probability level using **GENSTAT** Software. The results obtained from the study were compared with FAO soil and water standards. The wastewater analysis suggested that contamination at the untreated stage was very high and results at the treatment level were within the FAO (1985) reuse range. The study also found wide variation in chemical status of industrial wastewater treated soil. Almost all the values for the wastewater treated soil were not within the FAO (1985) irrigated soil chemical properties standard. This suggests high re-contamination along the open channel (from non-point sources) before reuse. This calls for proper monitoring and treatment of the industrial effluent prior to irrigation application.

KEY WORDS: Automobile-industry, wastewater, irrigation, soil-quality

1. INTRODUCTION

The rapid population growths in many municipalities continue to place increasing demands on limited fresh water supplies. Many cities and districts are struggling to balance water use among municipal, industrial, agricultural, and recreational users. The population increase has not only increased the fresh water demand but also increased the volume of wastewater generated. In order to solve the problem of limited fresh water supply, wastewater is reused especially for agricultural purposes. Treated or recycled wastewater appears to be the only water resource that is increasing as other sources are dwindling (Westcot and Ayers 1985). According to the report of the US Directory of Industrial Establishment in 1988 about 2.15x10⁵ million gallons of industrial wastewater is being produced daily from industrial sectors in most countries. Some of these water are used in agriculture.

Worldwide, it is estimated that 18% of cropland is irrigated, producing 40% of all food (Gleick, 2000). A significant portion of the irrigation water is wastewater. Hussain et al. (2001) reported that at least 20 million ha in 50 countries are irrigated with raw or partially treated wastewater. Smit and Nasr (1992) estimated that one tenth or more of the world's population consumes foods produced on land irrigated with wastewater. Wastewater and excreta are also used in urban agriculture. A high proportion of the fresh vegetables sold in many cities, particularly in less-developed countries are grown in urban and semi-urban areas. For example, in Dakar, Senegal, more than 60% of the vegetables consumed in the city are grown in urban areas using a mixture of groundwater and untreated wastewater (FAO, 1985). It is generally accepted that wastewater use in agriculture is justified on agronomic and economic grounds but care must be taken to minimize adverse environmental impacts. However, very few industries employ primary treatment and chemical neutralization of effluent (World Bank Report, 1993). Hence, the possibilities of soil and water contamination in the area is not ruled out, since recycled wastewater contains different levels of dissolved solids, metals, nutrients (N and P), and other elements (Qian, 2004).

In Enugu State Nigeria, wastewater effluent by Anambra Motor Manufacturing Company (ANAMMCO) an automobile industry serves as a major source of water for irrigation of farm lands. The effects of these wastewater on the local soil is important. Therefore, the objective of the paper is to study the quality of

effluent wastewater from the industry and to determine their effects on the immediate environment(soil) where it is reused for irrigation of farm lands.

2. MATERIALS AND METHOD

2.1 The Experimental Site

Nkpologu area in Emene Enugu, Enugu State Nigeria is an industrial layout with scattered settlement; it is located on the latitude 6°25'N and longitude 7°30'E. The Emene area has a population of above 100,000 persons. Most of the population is involved in dry season vegetable farming (MOWL&T. Enugu, 2005).

2.2 Design of Experiment

The field layout was a Completely Randomized Design (CRD) with two treatments and four replications. The two treatments are (i) irrigation with wastewater (WWI) and (ii) irrigation with fresh water (TWI). The irrigation period was two (2) months. Vegetable was grown in all the blocks. Irrigation water was applied to the blocks using watering can. While the responses are the concentrations of the chemical constituents of the soil in each block when sampled and analyzed.

2.3 Soil Sampling and Analysis

Soil samples were collected from these plots at 25cm depth using soil auger. Parameters such as pH; extractable salt content (Ca, Mg, K, Na, Fe, Mn, and B); base saturation percent of Ca, Mg, K, and Na; soil organic matter (SOM) content; and cation exchange capacity (CEC) were analyzed according to the analytical methods from Australian laboratory handbook of Soil and Water chemical methods (Rayment and Higginson, 1992) and the Bouycos hydrometer method of soil analysis.

Base saturation percent of Ca, Mg, K, and Na was calculated by dividing the extracted Ca, Mg, K, and Na by the calculated CEC, respectively. Base saturation percent of Na was considered the exchangeable sodium percentage (ESP). Soil organic matter was determined by reaction with $\text{Cr}_2\text{O}_7^{2-}$ and sulfuric acid. The remaining un-reacted $\text{Cr}_2\text{O}_7^{2-}$ was titrated with FeSO_4 using ortho-phenanthroline as an indicator, and oxidizable organic matter were calculated by the difference in $\text{Cr}_2\text{O}_7^{2-}$ before and after reaction (Nelson and Sommers, 1982).

Additional soil samples from each site were also collected to measure soil electrical conductivity (EC) and sodium absorption ratio (SAR) of saturation. Electrical conductivity of soil saturation paste extract was determined with a conductivity meter. Cation (Ca, Mg, and Na) concentrations of saturation paste extracts was analyzed by inductively coupled plasma–emission spectrophotometry instrumentation and then SAR was calculated.

2.4 Wastewater Sampling and Analysis

Industrial wastewater samples were also collected at three different points for analysis (i) before treatment,(ii) as point source effluent and (iii) nonpoint source effluent(reuse point). Wastewater sample source from open canal was also collected. All wastewater was analyzed for total soluble salts, pH, soluble Ca^{2+} , Mg^{2+} , CO_3^{2-} , HCO_3^- and heavy metals such as Cu, Zn, Mn and Fe. The samples were also analyzed for the concentrations of the following chemical constituents: Na^+ , SO_4^{2-} , K^+ , Cl^- , NH_3^+ , B, EC, Coliform, BOD_5 , Sodium Adsorption Ratio (SAR) and Residual Sodium Carbonate (RSC) where calculated with equation (1) and (2) respectively.

$$\text{SAR} = \frac{\text{Na}^+}{\sqrt{(\text{Ca}^{2+} + \text{Mg}^{2+})/2}} \dots\dots\dots 1$$

$$RSC(meq/L) = (CO_3^{2-} + HCO_3^-) + Ca^{2+} + Mg^{2+} \dots\dots\dots 2$$

The data obtained were subjected to Analysis of Variance (ANOVA) for CRD at 5% probability level using GENSTAT Software.

3. RESULTS AND DISCUSSIONS

3.1 Soil Chemical Properties

The mean concentration of water and soil chemical properties for the treatments are presented on Table 1 and on Figure 1 and Figure 2. Tables 2a, b and c present the ANOVA result for the measured soil properties after irrigation using CRD. The summary of comparison of means to ascertain significance of difference of means based on the ANOVA results of Table 2a,b and c at 5% level using their respective Least significant Difference(LSD) are shown on Table 3.

Table 1: Mean Concentration of Chemical Properties of Wastewater Irrigated (WWI) Soil and fresh-Water Irrigated (TWI) Soil

Treatments	pH	KCL	C	OM	N (%)	Na+	K+	Ca2+	Mg2+	Fe2+	CEC (me/100g)	B (ppm)	EC	Mn (mg/l)	P (ppm)	SAR (mg/l)	TSP
WWI 1	6.1	5.3	3.17	5.47	0.238	0.27	0.31	4	1.4	3.92	17.2	5.94	12	6.2	37.31	0.104	0.016
WWI 2	6.4	5.5	3.52	6.07	0.266	0.29	0.14	9.2	2.2	1.68	20	1.19	17	7.2	24.25	0.122	0.015
WWI 3	6.2	5.3	3.2	5.98	0.264	0.29	0.29	5.5	1.6	3.48	17.8	1.19	12	7.4	30.45	0.154	0.016
WWI 4	6.3	5.3	3.52	5.56	0.24	0.27	0.15	7.7	2	2.92	19.4	4.97	17	6.4	31.31	0.123	0.014
TWI 1	4.8	3.7	1.87	3.22	0.112	0.29	0.16	1.6	1.4	2.8	18.4	1.19	5	5.2	5.6	0.2367	0.018
TWI 2	5.1	4	1.35	2.32	0.098	0.27	0.26	2.4	0.2	2.8	14.4	2.38	5	4	9.33	0.2368	0.019
TWI 3	4.9	3.8	1.42	2.68	0.11	0.27	0.26	1.8	0.8	2.9	18	1.19	5	3.8	6.53	0.2368	0.015
TWI 4	5	3.9	1.61	2.86	0.1	0.29	0.15	2.2	1.4	2.7	14.8	2.38	5	5	7.4	0.2162	0.020

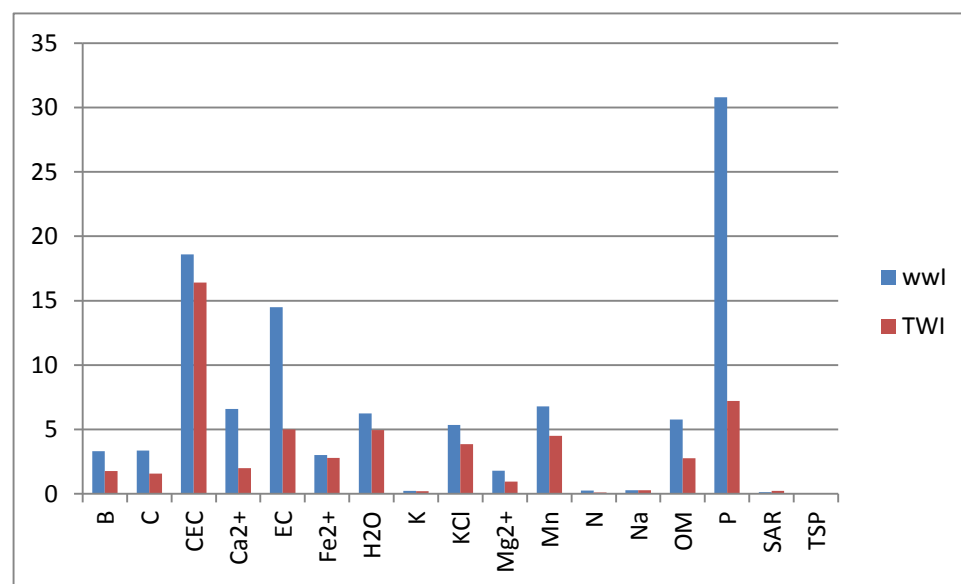


Fig.1: Bar chart showing Mean Concentrations of Soil Chemical Constituents for Wastewater and fresh-water Irrigated Soils

The mean pH value for wastewater treated soil was above 6.2, this agrees with the FAO (1985), which stated the tolerable range of pH for soil to be 5.0-8.2. This shows a recommendable irrigation using

wastewater from the automobile company. However, the KCl, with a treatment mean of about 5.4 for wastewater treated and 3.9 for clean water suggests liming of the soil.

In analyzing the organic matter content of the soil, consideration was given to the presence of carbon and OM percentages. The ANOVA analyses shows a significant difference between the organic matter content and percentage carbon content on soil irrigated with wastewater and fresh water (Table 3). The percentage carbon and OM were 3.3 and 5.8 respectively and these values are within the recommended standard for agricultural soils (FAO, 1985).

Similarly, the Nitrogen content of the soil analyzed for this experiment, showed a significant difference, since F-calculated was higher than the F- tabulated between the nitrogen content of soils that were treated with wastewater and with tap-water. The percentage nitrogen were 0.252 and 0.105 respectively for wastewater and fresh-water irrigated soil. The treatment with fresh-water was within tolerable limit for agricultural soils (FAO, 1985) while that of wastewater was above. This may be the reason for the massive vegetative growth around the experimental site.

Table 2a: Analysis of Variance Tables for Soil C,CEC,Ca²⁺,EC,Fe²⁺,pH and K

	ANOVA				
Variate: Organic carbon,c(%)					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	1	6.4082	6.4082	139.84*	<.001
Residual	6	0.27495	0.04583		
Total	7	6.68315			
Variate: Cation Exchange Capacity,CEC(meq/100g)					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	1	9.68	9.68	3.17*	0.125
Residual	6	18.32	3.053		
Total	7	28			
Variate: Calcium,Ca²⁺					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	1	42.32	42.32	15.54*	0.008
Residual	6	16.34	2.723		
Total	7	58.66			
Variate: EC					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	1	180.5	180.5	43.32*	<.001
Residual	6	25	4.167		
Total	7	205.5			
Variate: Fe²⁺					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	1	0.08	0.08	0.17 ^{NS}	0.696
Residual	6	2.8456	0.4743		
Total	7	2.9256			
Variate: pH					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.

Treatments	1	3.38	3.38	202.8*	<.001
Residual	6	0.1	0.01667		
Total	7	3.48			
Variate: K					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	1	0.00045	0.00045	0.08 ^{NS}	0.792
Residual	6	0.03535	0.005892		
Total	7	0.0358			

*=Significant (5% level)

NS=Non Significant(5% level)

(1)Variate: KCL					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	1	4.5	4.5	337.5*	<.001
Residual	6	0.08	0.01333		
Total	7	4.58			
(2)Variate: Mg²⁺					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	1	1.445	1.445	6.24*	0.047
Residual	6	1.39	0.2317		
Total	7	2.835			
(3)Variate: Mn²⁺					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	1	10.58	10.58	25.19*	0.002
Residual	6	2.52	0.42		
Total	7	13.1			
(4)Variate: N					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	1	0.043218	0.043218	313.17*	<.001
Residual	6	0.000828	0.000138		
Total	7	0.044046			
(5)Variate: Na⁺					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	1	0	0	0 ^{NS}	1
Residual	6	0.0008	0.000133		
Total	7	0.0008			
(6)Variate: OM					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	1	18	18	156.66*	<.001
Residual	6	0.6894	0.1149		
Total	7	18.6894			
(7)Variate: P					

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	1	1115.34	1115.34	71.77*	<.001
Residual	6	93.25	15.54		
Total	7	1208.58			

Table 2b: Analysis of Variance Tables for Soil KCL, Mg^{2+} , Mn^{2+} Na^+ , OM and P

Table 2c: Analysis of Variance Table for Soil SAR, TSP, and B

Variate: SAR					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	1	0.022419	0.022419	83.55*	<.001
Residual	6	0.00161	0.000268		
Total	7	0.024029			
Variate: TSP					
Source of variation	d.f.	S.s.	m.s.	v.r.	F pr.
Treatments	1	9.46E-06	9.46E-06	2.75*	0.148
Residual	6	2.06E-05	3.44E-06		
Total	7	3.01E-05			
Variate: B					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	1	4.728	4.728	1.41*	0.279
Residual	6	20.077	3.346		
Total	7	24.805			

*=Significant (5% level)

NS=Non Significant(5% level)

In analyzing the exchangeable bases of the soil; Na^+ , K^+ , Ca^{2+} , and Mg^{2+} were considered. The ANOVA showed that Na^+ had no significant difference between the groups at $P < 0.05$ while in K^+ , Ca^{2+} , Mg^{2+} , the F-calculated was higher than the F-tabulated showing that they had significant differences. Other parameter like iron, (Fe^{2+}) Cation Exchange Capacity (CEC), Boron (B), Electrical Conductivity, (EC), manganese (Mn), Phosphorous (P), Sodium Adsorption Ratio (SAR), exchangeable sodium percentages (ESP), showed the F-calculated greater than the F-tabulated. This indicates significant difference within the groups of wastewater treated soil and the fresh- water treated soil. Almost all the values for the wastewater treated soil were not within the FAO (1985) irrigated soil chemical properties standard.

Table 3: Comparison of Difference of means Using LSD (Least Significant Difference)

Difference of Means Table					
Response	Treatment Means		Difference	LSD	Remark
Variate	WWI	TWI			
B	3.32	1.78	1.54	3.165	NS
C	3.353	1.562	1.791	0.3704	*
CEC	18.6	16.4	2.2	3.023	NS
Ca^{2+}	6.6	2	4.6	2.855	*
EC	14.5	5	9.5	3.532	*
Fe^{2+}	3	2.8	0.2	1.192	NS
pH	6.25	4.95	1.3	0.2234	*
K	0.223	0.208	0.015	0.1328	NS
KCl	5.35	3.85	1.5	0.1998	*
Mg^{2+}	1.8	0.95	0.85	0.833	*
Mn	6.8	4.5	2.3	1.121	*

N	0.252	0.105	0.147	0.02033	*
Na	0.28	0.28	0	0.01998	NS
OM	5.77	2.77	3	0.586	*
P	30.8	7.2	23.6	6.82	*
SAR	0.1258	0.2316	0.1058	0.02834	*
TSP	0.01505	0.01723	0.00218	0.003209	NS

*=Significant (5% level)

NS=Non Significant(5% level)

WWI=Wastewater Irrigated Soil

TWI= Tap-water Irrigated Soil

Table 4: Comparison of Difference

Variate	WWI	TWI	FAO 1985 Standards
B	3.32	1.78	0.7-3.0
C	3.353	1.562	1.0
CEC	18.6	16.4	-
Ca ²⁺	6.6	2	400
EC	14.5	5	3.0
Fe ²⁺	3	2.8	5.0
pH	6.25	4.95	6.5 – 8.5
K	0.223	0.208	2.20
KCl	5.35	3.85	-
Mg ²⁺	1.8	0.95	60
Mn	6.8	4.5	2.0
N	0.252	0.105	2.1
Na	0.28	0.28	900
OM	5.77	2.77	6.34
P	30.8	7.2	>2.0
SAR	0.1258	0.2316	15
TSP	0.01505	0.01723	-

3.2 Wastewater Chemical Properties

The Result of wastewater analysis at three different points are shown in Tables 3.4. The pH values of the three tested samples were not within the FAO (1985) recommended range which is 6.5-8. It was also observed that from the plot of means, that the treated wastewater at the reuse point had more tolerable value than others. Mg²⁺, Ca²⁺ and Na⁺ also had the highest value at the point before exit, followed by that at the reuse point. This suggests contamination at the treatment level, although all were within the FAO (1985) reuse range of 60, 400, 900mg/l respectively. Cl⁻ showed the highest value at the reuse point and at the untreated stage than the point before exist and above the tolerable range for agricultural use. The relative high value of SO₄ and K at the reuse point were above the others tested points. This suggests high re-contamination along the open channel before reuse. NH₃, Ba²⁺, EC, Mn, and Coliform, all suggests abnormal high value at the reuse point and these were above the recommended tolerable limit of FAO (1985) standards of <20, 1.0, 3.0, 2.0 and 1000 respectively as listed in table 3.4. This situation may affect the plants in two ways: a) by creating salinity hazards and water deficiency; and b) by causing toxicity and other problems.

Table 4. The Quality of Automobile Industrial Wastewater at Different Points

Treatments	Untreated wastewater	After treatment before exit	A point before reuse	FAO Standards
pH	5.9	4.6	4.9	6.5-8
Mg ²⁺	1.6	2.2	1.4	60
Na ⁺ mg/l	0.29	0.29	0.27	900
Ca ²⁺	5.5	9.2	4.0	400
N(%)	0.238	0.266	0.264	30.0
K ⁺ mg/l	22.29	12.95	6.3	-
Cl mg/l	207	124.2	138	1100
SO ₄ mg/l	0.004	0.0026	0.0026	1000
Fe ²⁺ ppm	0.84	2.52	0.84	5.0
Mn mg/l	35.11	27.47	32.96	0.20
Ba mg/l	2.38	3.56	2.38	1.0
EC (dS/m)	26	27	22	3.0
NO ₃ ⁻	0.7583	4.2286	0.4764	5
NH ₃ -	340.6	85.15	510.9	-
Cu ²⁺	0	0.0089	0.0178	0.10
HCO ₃ ⁻	275	50	35.2	600
CO ₃ ⁻	0	0	0	0-1
Coliform MPN/100ml	>24,000	1100	120	1000
BOD ₅	44	12	43	-

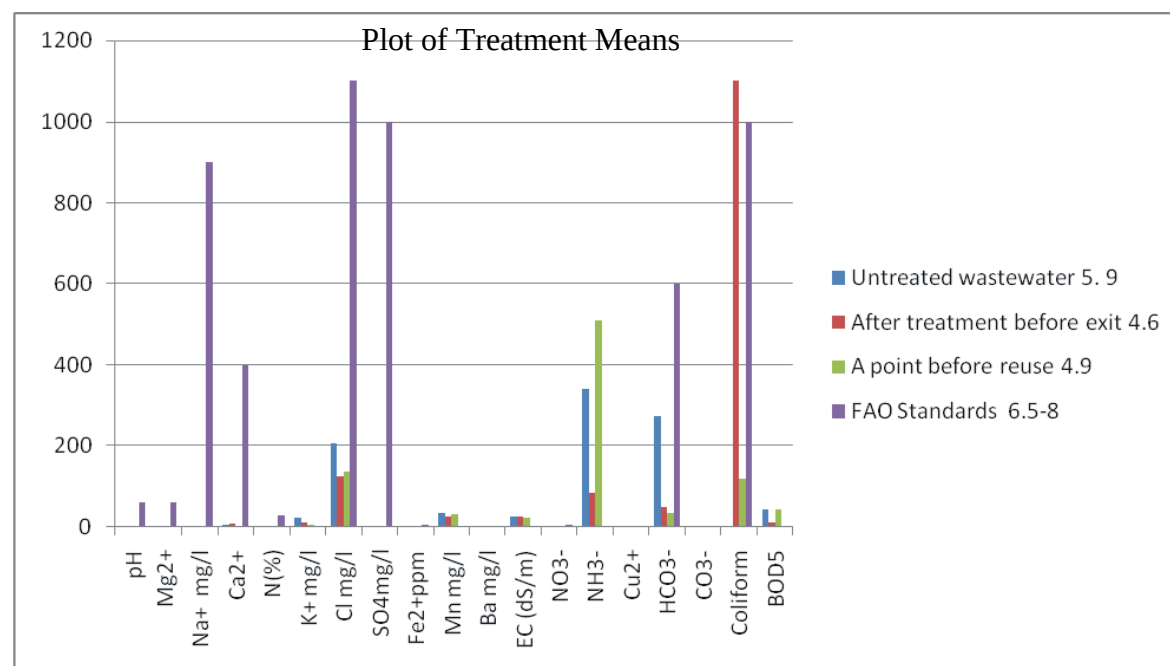


Fig.2: Bar Chart showing Mean Concentrations Chemical Properties of Wastewater at Different Points in Relation to the FAO (1985) Standards

4. CONCLUSIONS AND RECOMMENDATIONS

The study found wide variation in chemical status of industrial wastewater treated soil. High values of Mn, OM, N, C, K, Ca, Mg, Fe, CEC, P, EC, B, SAR and EC of wastewater at the reuse point call for proper monitoring and treatment of the industrial effluent prior to reuse. This will prevent possible reductions in

soil hydraulic conductivity and infiltration rate in soil with high clay content. Although these levels may not be high enough to result in short-term soil deterioration, however, salt leaching may become less effective when soil hydraulic conductivity and infiltration are reduced. Furthermore, these chemical changes may in part contribute to stress symptoms and die off in some plants.

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