DEVELOPMENT OF AN APPARATUS FOR MEASURING ANGLE OF REPOSE OF GRANULAR MATERIALS.

BY

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CERTIFICATION

This is to certify that this project work on the development and testing of an apparatus for the measurement of angle of repose of granular materials using selected Agricultural materials was presented by Akande, Fatai Bukola of the Agricultural Engineering Department, School of Engineering and Engineering Technology , Federal University of Technology, Minna,, in partial fulfillment of the requirement for the award of the degree of Bachelor of Engineering in Agricultural Engineering .

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DEDICATION

This project work is dedicated to my parents Mrs Yinyinola Salemotu Amonke and Mr , Adeshina Olatubosun Akande. May Allah give them long life so that they can reap the fruit of their labour. Amin

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My sincere gratitude goes to the Almighty God for His assistance throughout the course of my studies and for His promise to see me through the course of my life in this University. So may it be!

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ABSTRACT

The work here presents the development of an apparatus for measuring of angle of repose of granular materials. The two basic types of repose angle, the methods of measuring angle of repose of solids were discussed. The angle of repose and internal angle of friction of granular materials were compared. The effect of the physical properties of the granular solids on the measured angle of repose were also discussed in detail. The application of the angle of repose to design and construction of bias, hoppers and other storage facilities such as silos were briefly discussed. The materials used for the development of the apparatus, the method used in the determination of angle of repose of some selected agricultural materials were discussed in detail.

CHAPTER ONE

1.0 INTRODUCTION

In processing, storage and handling of agricultural produce, the term" granular materials" refers to grains, fruits and seeds(Mohsenin 1978). These granular materials posses frictional properties.

The need for knowledge of co-efficient of friction of agricultural materials on various surfaces has long been recognised by engineers concerned with the rational design of grain bins, silos and other storage structures.In design of agricultural machinery, however, the need for this information has been recognised rather recently(Hintz and Schnike,1952).For example in the design of a chopping and impelling unit, the engineers needed some information on the sliding co-efficient of friction of chopped Alfalfa and corn on steel, not finding this information in the handbook of published data, it become necessary to set up a friction test apparatus and obtain the information needed.(Hintz and Schnike 1952).

Obviously, before granular materials or unconsolidated materials can flow from a bin or a loaded auger can be started by a power source,the force of static friction must be overcome.Likewise, once the force flow has begun, the dynamic co-efficient of friction is needed before the power requirement for continued flow can be estimated.

A rapid method of assessing the behaviour of granular mass is to measure its "angle of repose". If a solid is poured on to a plane surface,it will form an approximately conical heap and the angle between the sloping side of the cone and the horizontal is the angle of repose.When determined in this manner it is referred to as dynamic angle of repose or the poured angle.In practice,the heap will not be exactly conical and there will be irregularities

in the sloping surface.Furthermore, there will be tendency for some materials to roll down from the top and collect at the base, thus giving a greater angle at the top and a smaller angle at the bottom.

ANGLE OF REPOSE

The angle of repose is the angle with the horizontal at which the materials will stand when piled (Mohsenin,1978).The physical properties of these materials such as the slope size, moisture content and the orientation of the materials have a decided influence on the angle of repose. Although, some engineers referred to angle of repose as the angle of internal friction,but Stewart(1964)has shown that for a granular material that he tested (sorghum grain)the two angles are different and the use of one in place of the other may introduce an error in design.

Angle of repose are of two types

[1] STATIC ANGLE OF REPOSE-This is the angle of friction taken up by a granular solid about to slide upon itself.

[2] DYNAMIC ANGLE OF REPOSE-This is related to a situation where a bulk of the materials is in motion such as the movement of sol id discharging from a bin and hopper.It is more important than the static angle of repose.

Co-efficient of friction between the granular materials is equal the tangent of angle of the internal friction for that

Materials.

1.1 **JUSTIFICATION**

Angle of repose and the internal angle of friction have application in problems of flow of granular materials encountered in the design of gravity and force flow equipment.

Bins and hoppers constitute most items of equipment in the handling of granular materials. Properly designed bins are to hold known volume of bulk solid and to feed it at the prescribed rate at the required time. An improperly designed bins may cause obstruction to flow, erratic flow, development of dead zone resulting in degrading of solid, segregation and several other problems.

For example in the design of groundnut shelling machine, the designer neglect the angle of repose of groundnut and the machine could not effectively perform its designed job. Modification was made on the machine and the angle of repose of groundnut was taken into consideration and the efficiency of the machine increased.

1.2 **OBJECTIVES**

The project work, "Development of an apparatus measuring angle of repose of granular materials," is aimed at measuring accurately the angle of repose of selected agricultural materials which serves as a useful parameter for the following:

(1) Designed of bins and hoppers

(2) designed of agricultural produce storage facilities such as silos

(3) Designed of flow characteristics in the hopper.

CHAPTER TWO

2.0 LITERATURE REVIEW

DEFINITION OF FRICTION:

Friction is the name given to force that oppose the relative sliding motion of bodies in contact with one another. The frictional force acting between surfaces at rest with respect to each other are called force of static friction. The friction force between surface with relatives motion is called force of kinetic friction.

Co-efficient of friction, f, is the ratio of the force of friction F, and the force normal to the surface of contact W. It is defined as $f = \frac{f}{W}$ --------- (1)

2.1 CONCEPT OF FRICTION

(i) The friction force may be defined as the force acting in plane containing the contact point or points in such a manner as to resist the relative motion of the contact surfaces.

(ii) The frictional force may be regarded as being compose of two main components ; a force required to deform and some times shears the asperities of the contacting surface and a force required to overcome adhesion and cohesion between the surfaces.

(iii) The frictional force depends on the nature of the materials in contact.

(iv) The frictional force depends on sliding velocity of the contacting surface because of the effect of velocity on the temperature of the contacting materials.

(v) The frictional force is not dependent on the surface roughness except in extreme very fine and very rough surfaces (Sharwood, 1951)

2.2 LAW OF FRICTION

(i) Frictional force is proportional to the normal load.

(ii) Frictional force is independent of the surface area of sliding.

(iii) Frictional force is largely independent of sliding velocity.

(iv) Frictional force depends upon the nature of the materials in contact.

Due to the increasing need of angle of repose and internal angle of friction of granular materials in the design of bins, hoppers and silos, many engineers have developed apparatuses and methods for determining the angle of repose and internal friction.

2.3.0 METHODS OF MEASURING ANGLE OF REPOSE OF GRANULAR MATERIALS

2.3.1 KRAMER'S METHOD

Kramer(1944) studied the angle of repose for milled rice on milled rice using a wooden frame full of rice mounted on a tilting top drafting table.The table was tilted until the rice began to move leaving an inclined surface.The angle of the inclined surface was then measured as the angle of repose for that particular sample. It was found that the angle increased very rapidly when the moisture content exceeded 16% - 17%. The device for measuring the repose angle of granular materials is as shown fig 1.0

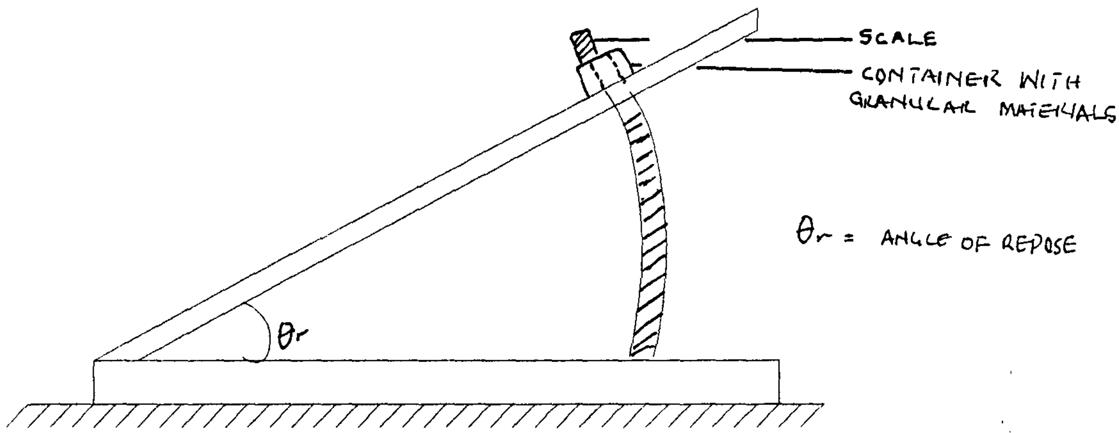


Fig 1.0 :Simple device for measuring angle of granular materials.

2.3.2 <u>FOWLER AND WYATT APPARATUS</u>

Fowler and wyatt(1960) made use of the apparatus presented as fig 1.1 which consisted of a circular platform immersed in a box filled with the granular solid and with a glass window in one side. The platform was supported by three adjustable screw legs and was surrounded by a metal funnel leading to a discharge hole. The solid was allowed to escape from the box leaving a free standing cone of solid on the platform. A cathetometer(travelling microscope) was used to measure the heights indicated in fig. 1.1. The angle of repose θ_r was obtained from the geometry of cone as shown in equation 2.

$$\theta_r = \tan^{-1} \frac{2(H_c - H_p)}{D_p} \qquad (2)$$

Where H_c, H_p and D_p are height of cone, height of platform and the diameter of platform respectively.

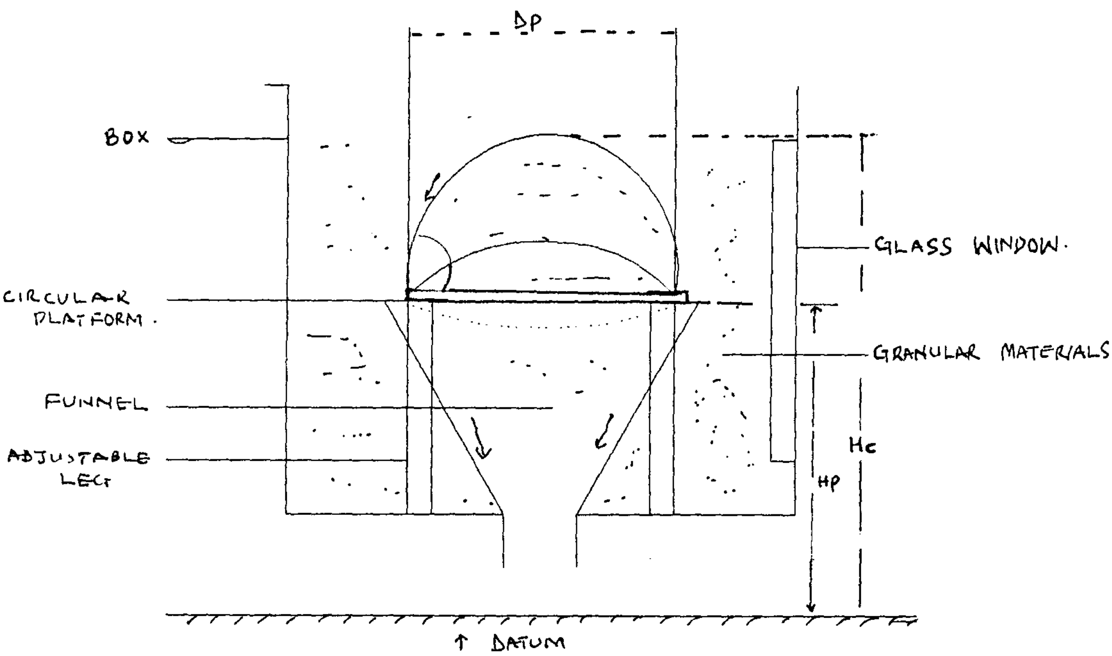


Fig. 1.1 - Fowler and Wyatt apparatus for measuring angle of repose of granular solid.

(MOHSENIN, 1978)

Angle of repose may vary from about 20° with free-flowing solid to about 60° with solid with poor flow characteristics.In extreme cases of high agglomerated solid, the angle of repose up to 90° can be obtained. Generally, materials which contains no particle smaller than 100μm or 10^{-4}m has a smaller angle of repose, if the angle of repose is large, a loose structure is formed initially and the materials subsequently consolidate if subjected to vibration.

2.4.0 ANGLE OF INTERNAL FRICTION

A measure of frictional forces between the granular materials is the angle of friction.

In predicting the lateral pressure on a retaining walls in storage bins or design of bins and hoppers for gravity flow, the co-efficient of friction between granular materials is needed as a design parameter.

For example, in design of shallow bins, Rankine equation (equation 3) is used,

$$\sigma_3 = Wy \tan^2[45 - \phi_I/2] \text{-----------} (3)$$

Where σ_3 is the lateral pressure against the wall at point y feet below the top of the wall, w is the weight density of the materials in lb/ft^3 and ϕ_I is the angle of internal friction.

In design of deep bins and other similar storage structures the pressure ratio K referred to the ratio of the lateral pressure σ_3 to the vertical pressure σ_1 at a given point in the material is needed.

$$K = \frac{\sigma_3}{\sigma_1} \quad \text{-----------(4)}$$

K can also be found from the angle of internal friction as seen from the expression

$$K = \frac{[1 - \sin \phi_I]}{(1 + \sin \phi_I)} \quad \text{-----------(5)}$$

The vertical pressure causes a column action while the lateral cause a bending action on the wall. In grain bins when the height of the materials in the bin exceed a certain limit [2 to 2.5 times the bin diameter], no increase in the bottom pressure can be detected with increase depth of the grain. This indicate that the wall must be supporting the additional weight. Ketchin[1919] and others have stated that "K is not constant but vary with the type of the material and the geometry of the bin as well as the depth function and cohesion properties and moisture content of the material." The influence of this various factors on pressure ratio, K, is illustrated by the Janssen's equation (equation 6) given for the lateral pressure δ_3 in deep bins.

$$\delta_3 = \frac{WR}{F_s} \left[1 - e^{-Kfsh/R} \right] \quad \text{---------(6) [Janssen's equation]}$$

where R = hydraulic radius of the ratio of cross sectional area to the circumference , (ft^2/ft)

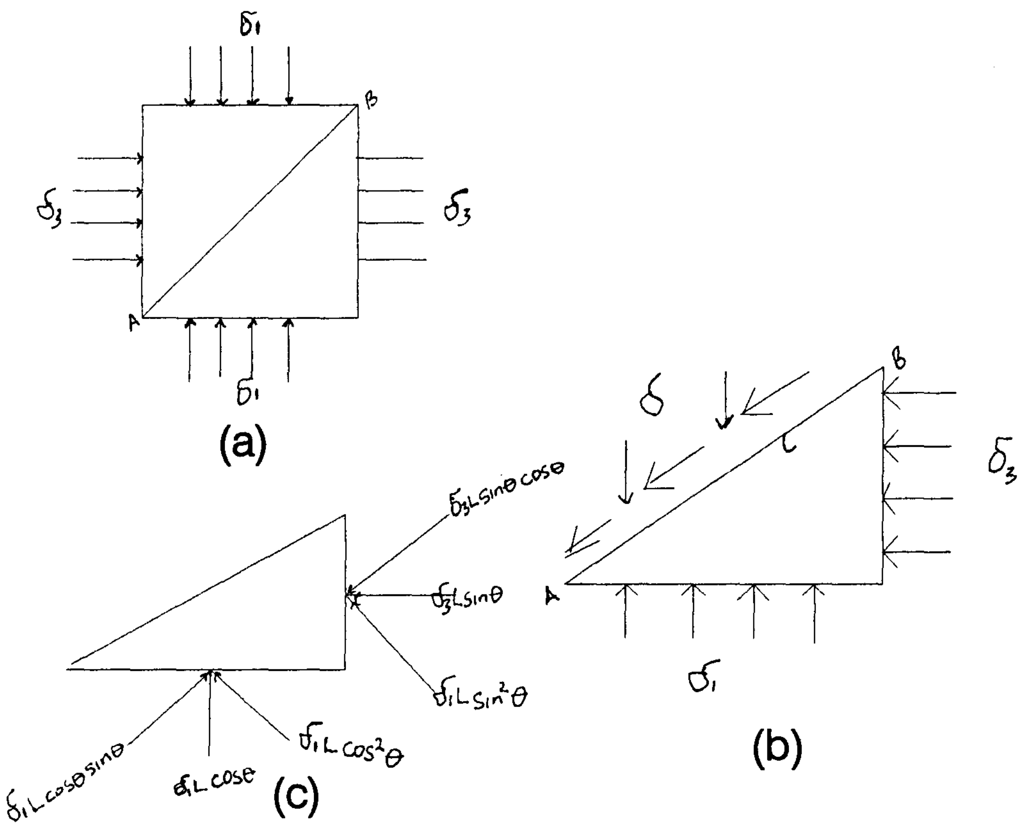
W = weight of the material in (lb/ft^2)

f_s = static co-efficient of the materials against the wall.

h = depth of the material in (ft)

2.4.1 DETERMINATION OF ANGLE OF INTERNAL FRICTION ϕi

The pressure ratio K is obtained either directly by pressure measurement in full-size or model bin or the use of triaxial compression test chamber and the Mohr's circle. According to Mohr's theory " a material under stress fails along the plane at which a certain combination of normal and shear stress occurs. From fig. 1.2b it shows the three principal planes-major, intermediate and minor in order of decreasing magnitude of direct stress through a point O on the granular mass.



(a,b)--Stress acting on cubical unit in a granular mass and a shear plane ab from this unit.

c--Equilibrium of force in direction normal and parallel to ab.

If the length of A,B is designated by L, the forces acting in the side of the element will be as shown in fig.1.2.6 Equilibrium of these forces in the direction normal to AB yield the equation for normal direct stress δ and the shear τ as follows:

$$\sigma = \sigma_1 \cos^2\phi + \sigma_3 \sin^2\phi \text{-------7a}$$

$$\tau = (\sigma_1 - \sigma_3)\sin\theta \cos\theta \text{------7b}$$

The two equations above were obtained after dividing through by L.

The graphical representation of stresses at any point in the granular mass can be given by a Mohr's circle as shown in fig.1.3 from which the following relationship can be deduced.

$$\sin\phi_i = \frac{(\sigma_1 - \sigma_3)}{(\sigma_1 + \sigma_3)} \Rightarrow \frac{\sigma_3}{\sigma_1} = \frac{(1 - \sin\phi_i)}{(1 + \sin\phi_i)} \text{--------(8)}$$

The value of σ_1 and σ_3 can be obtained by a triaxial compression text where a minor principal stress σ_3 will be equal to chamber pressure and the major principal stress ,σ_1 will be equal to the chamber pressure plus the intensity of axial thrust (Taylor 1948).

Fig 1.3:Mohr circle and Mohr envelope of failure

AC^1 shows the orientation of a plane of failure while AC shows the orientation of a stable plane.

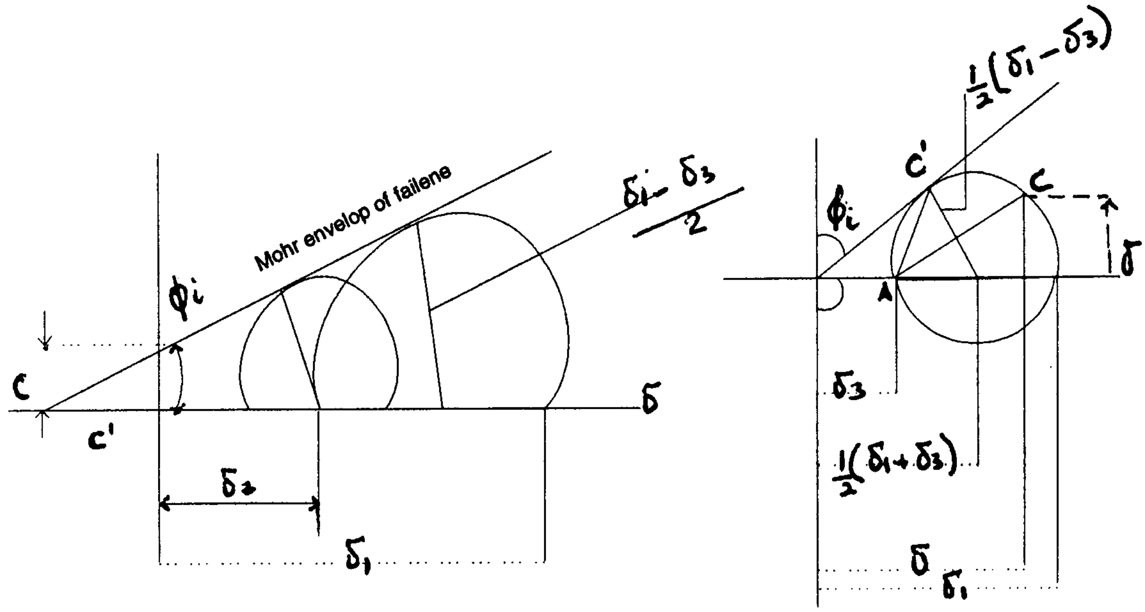


FIG. 1.3 : Mohr Circle And Mohr Envelope Of Failure

In the established Mohr envelope, at least two set of data are needed from which semi circle given in fig. 1.3 can be described and the tangent line established from this graphical method, shear strength and its angle of repose can be determine. This two parameters may also be calculated from the equation of Mohr's circle:

$$\cos\phi = \frac{[C' + \sigma_3 + [\sigma_1 + \sigma_3)/2]]}{(\sigma_1 - \sigma_3)/2} \quad \text{--------- (9)}$$

After simplification, the above yield the equation of Mohr's circle as

$$\sigma_3[\sigma_1/\sigma_3) - 1]\csc\phi_i - \sigma_3[\sigma_1/\sigma_3) + 1] - 2C' = 0 \quad \text{------} (9^*)$$

Having two sets of data, egn.9, can.be written twice and solved simultanously to obtained ϕ_i and C'. From this two parameters, the value of C in fig.1.3 can be determined. C. = C'tanϕ. The parameter,C is usually taken as cohesion of the

granular material, however some authorities consider C as the experimental error and not a property of the material.

If $K = \sigma_1/\sigma_3$ is substituted in eqn.9 and the granular martial is assumed cohesionless, i.e. C = 0.Then,

$$K = \frac{[1 - \sin\phi]}{[1 + \sin\phi]} \quad \text{------------- (10)}$$

Having known the value of K and by change of subject formular, the angle of internal friction, ϕ is calculated from eqn. 10 as

$$\phi: = \sin \frac{(1 - K)}{(1 + K)} \quad \text{------------- (10*)}$$

2.4.2 COMPARISON BETWEEN ANGLE OF REPOSE AND ANGLE OF INTERNAL FRICTION OF GRANULAR MATERIALS

Lorenzen(1957) attempted to relate the angle of internal friction, ϕ_i and repose angle ϕ_r, with the hope that a simple test of repose angle determination would yield the value of ϕ_i from which K could be determined.Result showed that the value of the two angles run almost parallel to each other for various moisture content,(fig.1.4).But no single relationship existed where ϕ_i could be estimated fromϕ_r.

Triaxial tests were used by other investigators which are more elaborate because of the difficulty of predicting the angle of internal friction from the angle of repose. Stewart(1964) applied a Triaxial compression test which was developed for studying the shear properties of soil,to the study of sorghum grain and the effect of density as well as the moisture content on internal angle of friction.Fig 1.5 shows the Triaxial compression test apparatus.Lorenzen(1957) investigated the effect of the same factors on internal angle of friction of wheat ,rice, corn barley and sawdust using a Triaxial compression apparatus.

When the value of internal angles of friction found by the method of Triaxial compression tests were compared with the angle of repose determined by means of simple repose apparatus, the angle of repose were consistently higher for grains of approximately the same moisture content and density.The values reported were 22.5° to 35° for internal friction to 32° to 38° for angle of repose (Lorenzen, 1957).

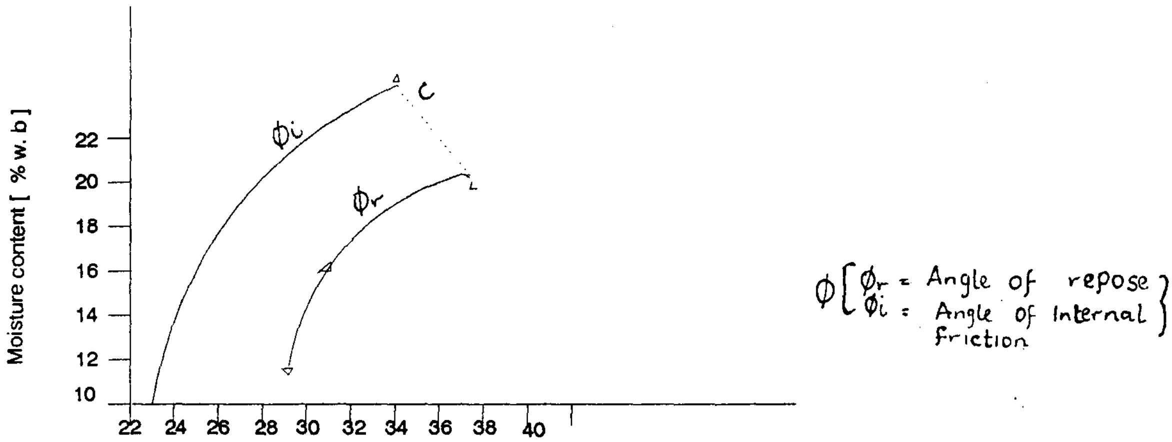


Fig 1.4:Variation of angle of repose and angle of internal friction with moisture content(Lorenzen, 1957).

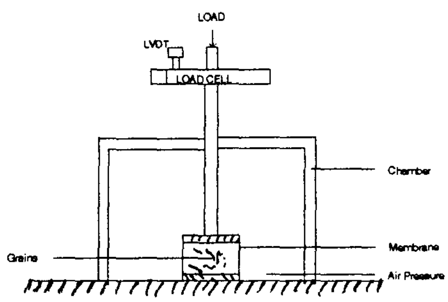


fig 1.5:Schematic for application of Triaxial compression test of agricultural grains.

2.5.0 EFFECT OF PHYSICAL PROPERTIES OF GRANULAR SOLID ON ANGLE OF REPOSE AND ANGLE OF INTERNAL FRICTION

Physical properties such as density,shape,size,moisture content and orientation of the material effect the angle of repose and internal angle of friction of the granular materials.

Shapes and sizes of granular materials have a considerable effect on the angle of repose.The rolling resistance or maximum angle of stability in rolling agricultural materials with rounded shape may serve as a useful design information.One example is the gravity conveying of fruits and vegetable.

Its is interesting to know that canary seed(millet) which has an elongated shape with shape factor of n = 1.78 predicts a higher angle of repose while the experimental values showed the angle begin less than that of wheat at any moisture content.

Density and moisture content of agricultural materials have an appreciable effect on the angle of repose and the internal angle of friction.As we shall see later, in some cases ,e.g wheat, the density of the material does not affect the internal angle of friction, where as the lower density of the materials the higher its angle of repose.

2.5.1 EFFECT OF MOISTURE CONTENT ON THE ANGLE OF REPOSE AND THE ANGLE OF INTERNAL FRICTION

Moisture content refers to the quantity of water found in the capillary cell of the material. This moisture content is measured in percentage with the aid of the moisture-meter.

When the moisture content of the granular solid was varied the experimental values of the angle of repose were highly correlated with the calculated value using the following empirical equation[Fowler and Wyatt, 1960,Stewart,1964]

$$\tan\phi_r = an^2 + b(m/D_{av}) + cs + d \text{-------} (11)$$

where ϕ_r = angle of repose

n = shape factor = specific surface of solid / specific surface of sphere

m = percent moisture content

D_{av} = average screen particle diameter

s = specific gravity

a,b,c,d are constant.Using the values of a = 0.4621, b = 0.0342, c = -0.098, d = 0.0978 in equation (9) a correlation co-efficient of 97% was reported(Stewart,1964) for a plot of experimental versus calculated angles of repose of wheat, sand, canary seed and a few other solids. For example the following data were obtained for a wheat sample :

s = 1.376, D_{av} = 0.3162,n = 1.12

using the above data and the given values of the constants in equ.(11), the calculated angles of repose at two different moisture contents will improve with the experimental values of the angle of repose as presented in table 1

Table 1:

Moisture content M%	Angle of repose ϕ_r(degree)	
	Calculated	Experimental
0	33.7	33.5
3.46	39.7	40.0

From table 1, the result of the added moisture with an increase in angle of repose it was suggested that the variation of angle of repose with the moisture contents is due to the surface layer of moisture that surrounds each particles and that surface tension effects become predominant in holding aggregates of solid together. The variation of angle of repose with moisture contents and that of internal angle of friction with moisture content are presented in Fig. 1.6a and Fig.1.6b respectively.

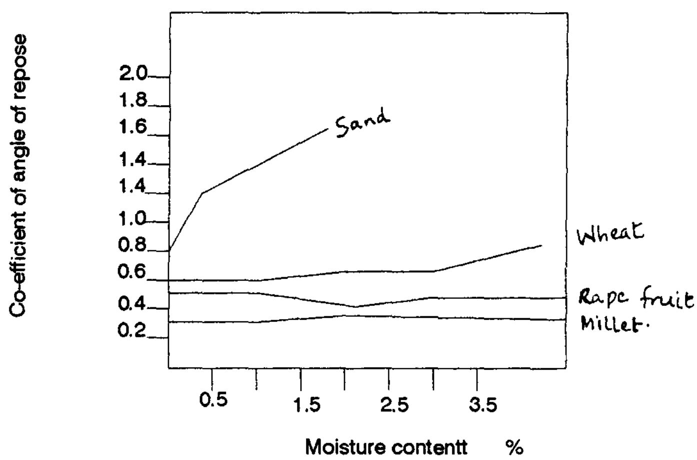


Fig.1.6a

Variation of angle of repose with moisture content

[Fowler and Wyatt 1960]

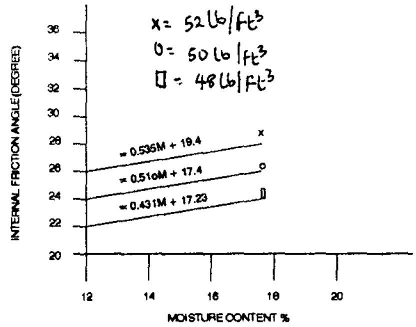


Fig.1.6b Variation of internal angle of friction with moisture content and density[Stewart, 1960].

2.6.0 APPLICATION OF REPOSE ANGLE AND ANGLE OF INTERNAL FRICTION

2.6.1 **Flow of bulk granular materials**

The angle of repose and internal angle of friction as mentioned earlier have application in problems of flow of granular materials encountered in the design of gravity and force flow equipment. For example, an important flow property of solid known as "critical flow factor"for conical hopper is dependent on the angle of friction between the solid and the wall of the hopper, the hopper slope, the outer diameter, the internal angle of friction of the solid, as well as the solid size distribution and moisture content.

2.6.2 GRAVITY FLOW IN BINS AND HOPPERS

Bins and hoppers constitutes major items or equipment in the handling of granular material.Properly design bins are to hold a known volume of bulk solid and feed it at a prescribed rate at required time. An improperly design bins may cause obstrution to flow, erratic flow, development dead zone resulting in the degradation of solid, segregation and several other problems. Jenike(1961,1964)developed a direct shear test apparatus for determination of flow properties of granular materials.

2.6.2.1 TYPES OF FLOW IN HOPPER

Having considered the flow of properties of the granular materials along the bin and hopper using the shear apparatus. The relationship between the angle of friction ϕ_w of a stored solid against the wall of a conical hopper and half included angle of the cone for the two types of flow, viz:-

(i) Mass-flow :- Mass flow is one in which the cone is sufficiently steep and the surface coeffiient is small,the channel expand from the outlet upward along the wall of the bin and all the solid is in motion.Since in mass flow, the flowing channel of the granular materials coincides with the wall of the hopper, the shape and frictional effects of the wall have a great influence on flow. In an ideal mass-flow, there is no dead zone and all the solid in the hopper are in motion whenever any of it is drawn out of the outlet.

(ii) Funnel-flow:-Here the solid flow towards the outlet in a channel formed within the solid itself.The solid surrounding this channel is at rest and has a tendency to spoil, cake or oxidize, if it is not emptied out.

The type of flow is presented by Jenike and Johnson, inc is shown in fig. 1.7

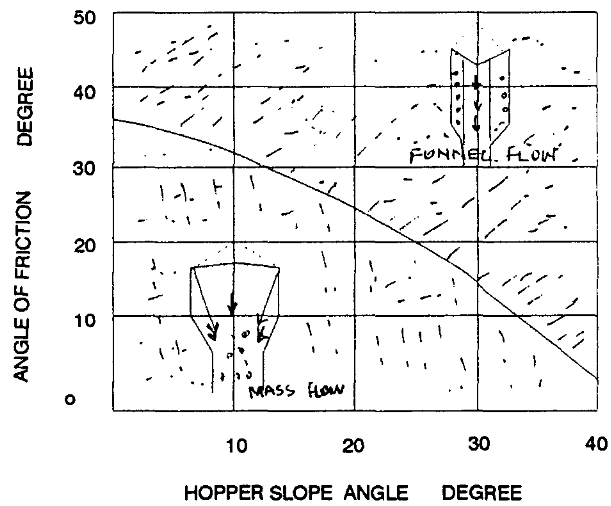


Fig.1.7- types of flow as affected by hopper slope angle and friction angle of solid hopper wall(Jenike and Johnson inc).

2.6.3 FLOW FUNCTION AND FLOW FACTOR.

During flow of granular materials from a hopper, as an element of solid flows down,it becomes consolidated under the prevailing pressure in the hopper. To every value of the consolidating pressure, there corresponds a strength of the solid referred to unconfined yield pressure of unconfined strength. Some of the problems associated with gravity flow of granular material from a bin or hopper are erratic feeding, flooding, sticking to the wall, and formation of obstruction such as "piping " and " arching". The strength of the solid depends on its moisture content, surface roughness and large the degree of consolidation. Greater consolidation result in greater strength.

Flow function, FF is the relationship between unconfined yield pressure of a solid and consolidated pressure

$$\sigma_c = f(\sigma_1) \Longrightarrow FF = \frac{d\sigma_1}{d\sigma_c} \qquad ----------(12)$$

In order to obtained the function curve of a solid, several shear tests are conducted for several consolidating load, w_c and the resulting σ_1 and σ_c are plotted as shown in fig.1.8

Jenike,1964 showed that for a given hopper, there exist a critical line such that as long as the flow function curve of the solid lies below this line, the strength of the solid is insufficient to support arch and there will be no obstruction to flow. This critical line is referred to as flow factor, flow factor denoted by FF is the ratio of the critical major consolidating pressure, σ_1 to critical unconfined yield pressure, σ_c determined experimentally.

$FF = [\sigma_1 / \sigma_c$ critical $= (f_1 / f_c)$ critical$]$.This is the condition at which bulk of materials is just on the point of forming and obstruction of low conversly, in a free flowing solid,

$$\sigma_c = f(\sigma_1) < \sigma_c \text{ critical} = (1 / FF)\, \sigma_1$$

$$\frac{\sigma_1}{\sigma_c} = FF$$

Flow function FF depends on material only, FF depends on both the materials and the hopper geometry.

Jenike,1964 classified granular solid according to their limiting flow function given by the letter FF.

$FF < 2$ - very cohesive and non-flowing

$4 > FF > 2$ - cohesive

$10 > FF > 4$ - easy - flowing

$FF > 10$ - free flowing

GRAPH OF UNCONFINED YIELD PRESSURE σ_c AGAINST MAJOR CONSOLIDATING PRESSURE σ_L

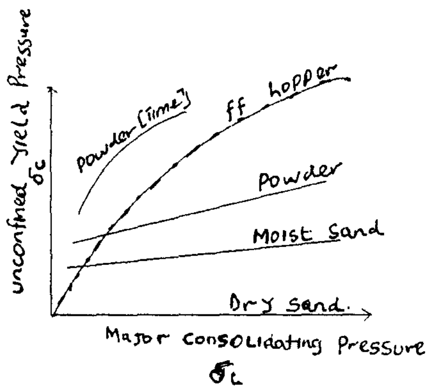


Fig.1.8: Critical flow factor FF of a hopper superimposed on flow function several solids(Jenike and Johnson Inc)

2.6.4 CRITICAL DIMENSIONS OF HOPPER OPENINGS(B).

To determine the critical dimension of hopper opening, failure condition must be established for two basic obstructions, namely "arching" - where no flow take place and "piping" - where may be reduced or limited. Fig.1.9 shows the free body diagram of a granular solid with bulk density, w, forming an arch with uniform thickness τ. Let B denote the diameter of circular hole or the width of the slot with length, L. For small arcs, the equilibrium of forces resulting from the weight of this mass acting downward and the vertical component of force due to compressive pressure P in the arch acting upward yields

WBLT = 2PLTcosαsinα---------(13)

B = (P/W) sin 2α(since 2sinαcosα = sin2α) for slot.

W(π/4)B^2T = PπBTcosαsinα---------(14)

B = $\frac{2P}{W}$(sin2α)-------------------(14') for circle

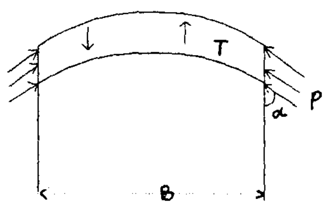


Fig 1.9

Free body diagram of mass of granular material forming an arc.

From the analysis, Johnson and Colijn(1964), suggested that in order for failure to occur, the major compressive pressure P should be equal to the unconfined yield strength, σ_c, substituting σ_c for P and assuming sin $2\alpha = 1$ in eqns.13 and 14* in which consider the strongest possible arch to form.

==> $B >= \sigma_c / W$ -- for slot opening and

$B >= 2\sigma_c / W$ -- for circular opening

2.6.5 BASE PRESSURE IN CIRCULAR HOPPERS

Small opening at the bottom of a circular hopper and insufficient static pressure at that point often result in arching over the opening and unsatisfactory discharge rate.

In a straight-sided hopper, with flat bottom the rate of flow varies as the cube of the bottom opening diameter(Ketchum,1919) and the base pressure estimated by equation (4) is little affected by the motion of the solid. In a slope-sided hopper, the change in base pressure may be appreciable upon closing and opening of the discharge rate. To avoid arching of the solid across the opening the base pressure must be larger than the pressure change when the gate is opened.

With fine solids, with a pressure ratio K of 0.1 to 0.2 a minimum value of 50lb/ft² base pressure was recommended

2.7 ANGLE OF REPOSE OF SELECTED AGRICULTURAL MATERIALS

The table 2.0 below shows the angle of repose of selected agricultural materials using the method of Fowler and Wyatt 1960, Stewart(1964)

TABLE 2.0:

Product	Hc(cm)	Hp(cm)	Dp(cm)	Hc-Hp	θ_r(degree)
Benni seed	29.8	26.0	11.0	3.8	34.6
Bambara nut	29.0	26.0	11.0	3.0	28.6
Locust bean	30.2	26.0	11.0	4.2	37.4
Tiger nut	31.0	26.0	11.0	5.0	42.3

From the table 2.0 above, it can be observed that tiger nut and locust beans have the higher angle of repose than benniseed, even though benni seed is smaller in size. This can be attributed to the hairy nature of tiger nut and the improper washing off of the locust bean. This make the seed adhere together when made to stand freely on the platform thus making it to have higher value.

The smooth nature of bambara nut do not allow it to adhere together. Therefore, the nut do not have high value of H_c and thus has lower angle of repose. [Olowu Alexander, 1995].

Although, an experimenter can approach his research with extreme care, errors arising from measurement are inherent in the system and need to be quantified. The main causes of error in the measured angle of repose was that, the grain profile was assumed linear, but in the actual sense, it is parabolic. Therefore assuming a parabolic grain profile, the true angle of repose (ϕT) can be calculated theoretically (Fig.2.0) from the expression.

$$\tan \phi T = 2(Hc-Hp) + D/Dp \quad \text{------------------(15)}$$

$$\phi T = \tan^{-1} (\tan \phi_r + D/Dp) \quad \text{------------(16)}$$

where the term D/Dp represents the experimental error and ϕ_r is the measured angle of repose.

Using this error analysis approach, Ezeike (1984) found the absolute error to be the range of ± 0.96 to ± 9 degree. (O.Chukwu, 1987)

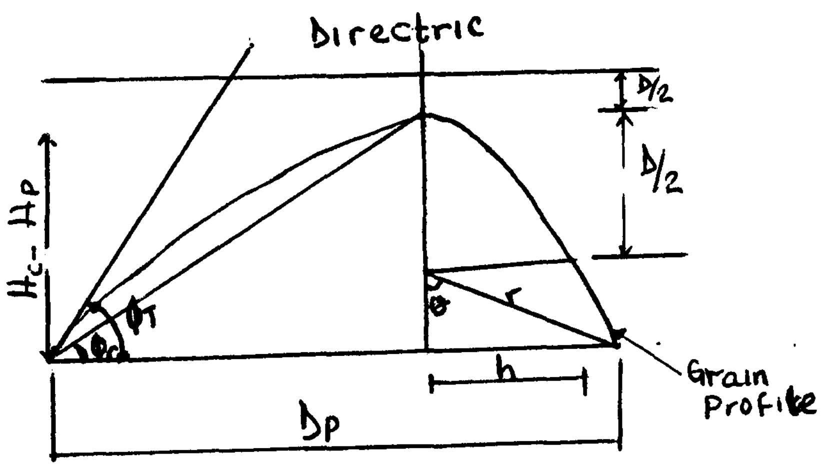


Fig. 2.0: Orifice of grain on Platform.

CHAPTER THREE

MATERIALS AND METHOD

The materials used for development of an apparatus (Fowler and Wyatt type) for measuring angle of repose of granular materials are: wood, glass and a sheet of metal.

3.1.0 WOOD

There are two major classes of wood: Decidous tree (hard wood) and soft wood (ever green). (Caleb horbostel).

Hardwood:- These are tres which shed their leaves at the end of each prowing season except in warmest regions. They have broadleaves.

Softwood:- Are trees which do not shed their scale-like or needle-like leaves at the end of each growing season with the exception of Cypress, Tamarack and Larch.

3.1.1 PHYSICAL AND CHEMICAL PROPERTIES OF WOOD

The physical and chemical properties of wood can be discussed under the following :

(i) **CONSTITUENT**:- All wood consist of the following four component.

(a) Cellulose:- Wood containes about 70% of cellulose. It is subdivided into two types : Alphacellulose and the Hemicellulose (Caleb hornbosten).

(b) Lignin :- It constitutes about 18% to 28% of wood. It is the adhesive that gives strength and rigidity to wood.

(c) Extractives :- Are not part of the wood structure but contributes such properties as colour, odour, taste and resistance to decay. They consists of tannin, colouring matter, starch, oils, resin, fat and waxes. They can be removed from wood by neutral solvents such as water, alcohol, acetone, benzene ether.

(d) Ash - Forming minerals make up from 0.2% to 1.0% of the wood and part of the wood structure. They are the nutrients-plants-food elements of the tree and are left as ash when lignin and cellulose are burned.

(ii) <u>LINEAR THERMAL EXPANSION</u>

The linear thermal expansion differs in any species according to the structural direction of the wood i.e expansion in longitudinal direction(Parallel to the fibre) and expansion across the fibres or in radial and tangential direction. The former is independent of the specific gravity of wood while the later is dependent on the specific gravity of wood.

(iii) <u>MOISTURE CONTENT (m.c)</u>

Wood shrinks as its loses water as swells as its absorbs moisture. The water in wood can be divided into two categories.

(a) Free water in the cell cavities and intercellular spaces of the wood.

(b) Absorbed waters held in the capillaries of the walls of such wood elements as fibres and ray cells. Shrinkage occurs at m.c percentages below the fibre saturation point(i.e when all free water is removed but the absorbed water remains, it is approximately 30% m.c of all species). Wood dried to 15% m.c as attained about one-half of the total shrinkage possible. For every 1% loss in moisture bellow the fibre saturation point, the wood shrinks about one-thirtieth of the total shrinkage, and likewise, for each 1% moisture increase, the wood swells also one-thirtieth of the total swelling possible.Wood shrinks the most in the direction of the annual growth rings less across this rings and generally very little parallel to the grain(Caleb hornbosten).

(iv) SEASONING

This is the process of drying lumber. Seasoning could either be by air drying or kiln-drying.

The advantages of air-dried wood over green wood are reduction of weight, reduction of shrinkage, checking honey combing and warping; increase in strength and nail holding power; decrease in attack of various fungi and insects; and improvement of the ability of the wood to held paint and receive preservative.

The advantages of kiln-dry over air-dry are: greater reduction in weight, control of m.c to any desired value, reduction in dry time, killing any fungi or insect, setting the resin in resinous wood and less degrade.

Degrade:-This is the loss in quality during seasoning of the lumber through :

(i) Unequal shrinkage e.g chelk, honey comb, warp, loosening of the Knot and collapse.

(ii) Action of fungi such as mould, stain and decay.

(v) RESISTANCE TO DECAY

Some species of both hardwood and softwood have high resistance to decay and can be used under conditions where decay hazards exist.Other species of wood will needs preservative treatment.

COMMERCIAL FORM OF WOOD

Wood is available as lumber, veneer, timber, pilings and plywood integrant. Board foot (board feet) is the unit of measurement of lumber equal to a board 1ft square(12in^2 304.8mm^2) since 1in = 25.4mm.(Caleb hormbustel).

3.1.2 **PLYWOOD**

This is a processed lumber. It is a general term used to define layers or plies of wood bounded together permanently with one or more layer at 90° to grain of the intervening layers .

Plywood could be classified into two large categories as: construction and industrial plywood, and decorative construction and industrial hardwood plywood.

ADVANTAGES OF PLYWOOD

(i) The approximate equalization of strength properties along its length and width.

(ii) Greater resistance to checking and splitting.

(iii) Less change in dimension with change in moisture content.

Assuming all plies are of equal thickness, the greater the number of plies for a given thickness, the more nearly equal are the strength and shrinkage properties along the length and width of the plywood, the greater the resistance to splitting.

Plywood is used in the construction of the adjustable table,circular platform and the box,wood is used in the construction of the stand.

3.2.0 GLASS

Scientifically, glass is defined as an in-organic production of fusion which has cooled to a rigid condition without crystallizing. Physicists consider glass to be undercooled or supercooled liquid, though physically solid, since its structure is not crystalline but amorphous as is characteristics of liquids.

Glass, then, is a solid, supercooled, liquid ceramic materials characterized by transparency, brittleness, hardness and chemical inertness.

Glass differs completely from either ceramics in that most ceramics are shaped cold then fired to produce the material, whereas, glass is shaped at high temperature and allowed to cool. Also, glass can reheated and shaped again. Glass therefore can be considered as a thermoplastic materials.

3.2.1 PHYSICAL AND MECHANICAL PROPERTIES OF GLASS

The physical and mechanical properties of glass vary with composition and cover the following ranges:-Specific gravity: 2.125 to 8.120, annealing point:- 622°F to 1634°F(350°C to 890°), softing point(500°C to 1100°),co-efficient of expansion; from 5.6 x 10^{-7}/°F to 1.4 x 10^{-6}/°F, compressive strength, 620.55 to 1241.10 MN/m^2,tensile strength(27.58 to 10342.5 MN/m^2)

(i) Strength:- The smaller the cross section of glass, the greater will be unit of length. Glass fibre have tensile strength of 10342.5N/m^2 whereas 6.45 cm^2 cross-section of glass has a strength of 34.48 MN/m^2.

(ii) Light transmission:- Commonly used glasses transmit 85% to 95% of visible light. Most glasses are impervious to ultraviolet light.

(iii) Workability:-Glass can be fabricated into desired shape, it can be cast, pressed, rolled, blown, polished and ground.

3.2.2 CHEMICAL PROPERTIES OF GLASS

The chemical properties of glass like physical and mechanical properties are controlled by its composition and can varied over a wide range. In general, glass is attacked only by hydrofloric acid, its very slowly dissolved by water and is more rapidly soluble in alkaline solution.

Constituents :- The oxide of silicon, sodium and calcium(sand , soda and lime) are the most widely used ingredients for glass.

The glass used in construction is usually a silicon- sodium-calcium type of composition(soda-lime glass) in which the difference in characteristic is controlled by the quantities of sodium and calcium used.

3.2.3 COMMERCIAL FORM OF GLASS

Glass is available for use in construction in flat form as window, heavy sheet float plate , tempered, heat, strengthened, patterned, heat absorbing, insulating (double glass) glare reducing, laminated, structural, corrugated and mirror glass.

In the development of an apparatus for measuring the angle of repose of granular materials,glass is used as a window.

3.30 METAL

A metal is define in chemistry as an element that yield positively charged ions in aqueous solution of its salt.

Metals are in general, those substances that have a peculiar lustre and hardness can conduct heat and electricity opaque and posses certain mechanical properties. The most begin the power to resist deformation.Other notable characteristics of metals includes :-ability to resist tensile, compressive, torsional and shear stress, malleability, hardness, toughness, durability and fabricability or workability.

3.3.1 DATA FOR CONSTRUCTION

What is important to know in the construction field is data on those physical, chemical and mechanical properties that influence the use of metallic material in construction. This should include:-melting point tensile strength co-efficient of expansion, corrosion resistance to various chemicals, workability ease of handling in both fabrication and reaction to weather.

3.3.2 HISTORY AND MANUFACTURE

Comparison of the abundance of various metals and the relative difficulties in obtaining them as metals gives an interesting and valuable insight into future technological development. The phenomenal development of knowledge or the physical science and their industrial application which has taken place in the last few decades will surely leads to new materials and new structural methods in the construction industry of tomorrow.

In the development of this apparatus for measuring angle of repose of granular materials, a piece of metal plate is fabricated as a funnel through which granular materials that roll down flow into to the receiver provided underneath, iron rod and a flat bar are used in the construction of the table with adjustable legs.

3.4.0 JOB PROCEDURE

A plywood of thickness 1/2"(12.74mm) with dimension 4ft x 4ft

(121.92 x 121.92 cm) was act into 9 pieces
using a hacksaw, try square measuring tape from which a box was constructed.

A piece of 3 mm thick glass(dimension 30 cm by 40 cm) was installed to one of the sides of the box to serve as window.

A hole of diameter, 32cm was made at the centre of the base of box through which a metal funnel with pipe 3cm diameter was installed.

An adjustable screw legs supporting the circular platform of diameter,22.5cm, was made using a round pipe of 15mm diameter which houses a rod of 13mm diameter, the length of the pipe is 10cm and at 2/3 of the length from the base a hole of 8mm diameter was drilled and nut is welded to that point for easy running of the bolt. Three of such pipe were made and were screwed to the base of the box.

Three-21.5cm long rod(13mm)were welded to the three point of the constructed equilateral triangular flat bars of length 15cm,holes were drilled on flat bars through which the circular platform was screwed.

Three holes of 13.5mm were drilled on the 28cm diameter funnel at 18cm appart through which the three adjustable legs(rods) passes hold the circular platform at a maximum height of 26cm from the base of the box.The height of the funnel was calculated to be 15.625cm.

A 50cm long ruler is placed inside the constructed box which was used to measure the height of the cone of granular materials through the window glass.

The developed apparatus which is a replica of Fowler and

Wyatt apparatus is as presented in fig 2.1.

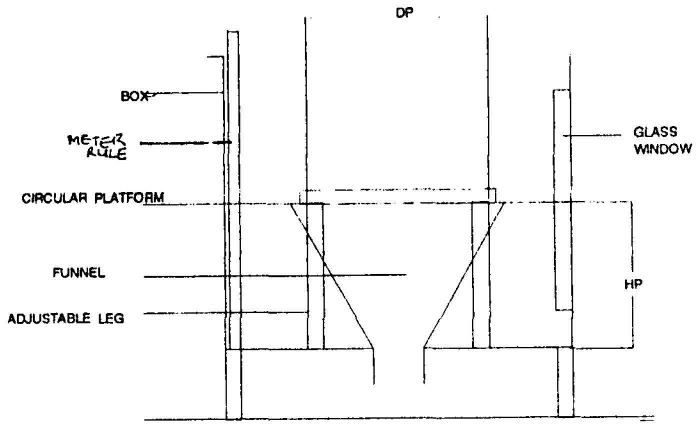


FIG. 2.1 DEVELOPED APPARATUS FOR MEASURING REPOSE ANGLE OF GRANULAR MATERIALS

3.5 MATERIALS COSTING

The cost of materials used in the development of an apparatus for measuring angle of repose of granular materials is as presented in Table 3

TABLE 3

MATERIALS	QUANTITY (DESCRIPTION)	COST(PRICE)#
1/2"(12.74)Plywood	4ft x 4ft(121.92cm x 121.92cm)	600:00
3mm thick Glass	1.30cm x 40cm	100:00
Metal Funnel	1(28cm diameter)	400:00
1 1/2"(3.8cm)Nail	1/2kg	50:00
15mm Pipe	50cm Long	100:00
13mm Rod	100cm Long	100:00
Ruler	1,50cm Long	250:00
Electrode	8 Pieces	20:00
Flat bar(2mm)	60cm	80:00
	Total =	1,700:00

3.6 METHOD USED IN DETERMINING REPOSE ANGLE OF GRANULAR MATERIALS

From literature review, two methods were discussed for measuring angle of repose of granular materials.The apparatus developed in this project is that of method two:Fowler and Wyatt apparatus(2.3.2), hence, this method by Fowler and Wyatt will be used to determine angle of repose of some agricultural materials.

3.6.1 FOWLER AND WYATT

The apparatus shown in fig. 2.1 is filled with the granular solid. The solid was allowed to escape from the box leaving a free standing cone of solid on the platform. With the aid of meter rule in the box, the indicated heights were measured and the angle of repose, θ_r can be obtained from the geometry of cone as in equ 2.

$$\theta_r = \tan^{-1} \frac{2[H_c - H_p]}{D_p} \text{ --------(2)}$$

H_c = Height of cone from Datum

H_p = Height of platform

$(H_c - H_p)$ = Height of cone

D_p = Diameter of circular platform.

CHAPTER FOUR

4.0 TESTING OF CONSTRUCTED APPARATUS

4.1 Determination of angle of repose of some selected local agricultural materials.

A total of twenty agricultural materials were selected and their angle of repose were determined using the developed apparatus, and applying equation (2).

4.1.0 MAIZE

Botanical Name :- *Zea mays*

Family Name :- Gramineae

Shape :- Truncate

Angle of repose, $\theta_r = \tan^{-1} \frac{2[29 - 23.5]}{22.5}$

$= \tan^{-1} 0.4889$

$= 26.1^\circ$

4.1.1 GROUNDNUT (UNSHELLED)

Botanical Name :- *Arachis hypogeae*

Family Name :- Leguminosae

Shape :- Long-cylindrical oblate

Angle of repose, $\theta_r = \tan^{-1} \frac{2[7.3]}{22.5}$

$= \tan^{-1} 0.64889$

$= 33.0^\circ$

4.1.2 SHELLED GROUNDNUT

Shape :- Ovate

$\theta_r = \tan^{-1} \frac{2[7.5]}{22.5}$

$= \tan^{-1} 0.6667$

$= 33.7^\circ$

4.1.3 GUINEA CORN(SOGHURM)

Botanical Name :- Sorghum bicolour

Family Name :- Gramineae

Shape :- Ovate

Angle of repose, $\theta_r = \tan^{-1} \frac{2[6.1]}{22.7}$

$= \tan^{-1} 0.5422$

$= 27.5°$

4.1.4 MILLET(Finger millet)

Botanical Name :- Eleusive coracana

Family Name :- Gramineae

Shape :- Elongated ellipsoidal

Angle of repose, $\theta_r = \tan^{-1} \frac{2[5.9]}{22.5}$

4.1.5 RICE(Paddy)

Botanical Name :- Oryza sativa, O.glabernma

Family Name :- Gramineae

Shape :- Long-thin ovate.

Angle of repose, $\theta_r = \tan^{-1} \frac{2[9.8]}{22.5}$

$= \tan^{-1} 0.8711$

$= 41.1°$

4.1.6 MILLED RICE(Local rice)

Angle of repose, $\theta_r = \tan^{-1} \frac{2[7.2]}{22.5}$

$= \tan^{-1} 0.64$

$= 32.6°$

4.1.7 **RICE HUSK**

Angle of repose, $\theta_r = \tan^{-1} \frac{2[9.1]}{22.5}$

$= \tan^{-1} 0.8089$

$= 39.0°$

4.1.8 **MELLON (UNSHELLED)**

Botanical Name :- Citrullus vulgaris,

Family Name :- Leguminosae

Shape :- Oblate

Angle of repose, $\theta_r = \tan^{-1} \frac{2[7.8]}{22.5}$

$= \tan^{-1} 0.6933$

$= 34.7°$

4.1.9 **SHELLED MELLON**

Shape :- Flat ovate.

Angle of repose, $\theta_r = \tan^{-1} \frac{2[6.9]}{22.5}$

$= \tan^{-1} 0.6133$

$= 31.5°$

4.1.10 **SOYA BEANS**

Botanical Name:- GLYCINE Max merril

Family Name :- Leguminosae

Shape :- Oblate

Angle of repose, $\theta_r = \tan^{-1} \frac{2[6.7]}{22.5}$

$= \tan^{-1} 0.5956$

$= 30.8°$

4.1.11 LOCUST BEANS

Botanical Name :- Parkia biglobosa

Family Name :- Leguminosae

Shape :- Oblong

Angle of repose, $\theta_r = \tan^{-1} \frac{2[6.2]}{22.5}$

$= \tan^{-1} 0.5511$

$= 28.9°$

4.1.12 COWPEA(BEANS)

Botanical Name :- *Vigna synesis*

Family Name :- Leguminosae

Shape :- Oblate

Angle of repose, $\theta_r = \tan^{-1} \frac{2[6.0]}{22.5}$

$= \tan^{-1} 0.5333$

$= 28.1°$

4.1.13 ACHA(HUNGRY RICE)

Botanical Name :- Dictaria exilis

Family Name :- Gramineae

Shape :- Round.

Angle of repose, $\theta_r = \tan^{-1} \frac{2[8.5]}{22.5}$

$= \tan^{-1} 0.7556$

$= 37.1°$

4.1.14 GARRI (CASSAVA PARTICULATE

Botanical Name of cassava:- Manihot esculentus

Family Name :- Euphorbiaceae

Angle of repose, $\theta_r = \tan^{-1} \frac{2[10.0]}{22.5}$

$= \tan^{-1} 0.8889$

$= 41.6°$

4.1.15 TIGER NUT

Botanical Name :- *Cyprus esculentus*

Classification :- Nut

Shape :- Oblong cylindrical

Angle of repose, $\theta_r = \tan^{-1} \frac{2[7.7]}{22.5}$

$= \tan^{-1} 0.6844$

$= 34.4°$

4.1.16 WHEAT

Botanical Name :- *Triticum spp*

Family Name :- Gramineae

Shape :- Oblique cylindrical

Angle of repose, $\theta_r = \tan^{-1} \frac{2[6.7]}{22.5}$

$= \tan^{-1} 0.5956$

$= 30.8°$

4.1.17 BENNISEED(SESAME)

Botanical Name :- *Sesamum indicum syn.*

Family Name :- Pedaliaceae

Shape :- Flat ovate

Angle of repose, $\theta_r = \tan^{-1} \frac{2[7.7]}{22.5}$

$= 34.4°$

4.1.18 BAMBARA NUT

Botanical Name :- *Voandzeie subterranea syn*

Vigna subterranea

Family Name :- Leguminosea

Shape :- Kidney shape/ Obvate

Angle of repose, $\theta_r = \tan^{-1} \frac{2[4.9]}{22.5}$

$= \tan^{-1} 0.4356$

$= 23.5°$

4.1.19 SAWDUST(LUMBER PRODUCT)

Angle of repose, $\theta_r = \tan^{-1} \frac{2[10.7]}{22.5}$

$= \tan^{-1} 0.9511$

$= 43.6°$

4.2 RESULTS AND DISCUSSION

The data obtained using the developed apparatus includes the height of the cone H_c, height of the platform H_p and the diameter of the platform D_p. Using equation (2), the angle of repose of each selected agricultural materials above were calculated and the summary of the results is as presented in table 4.0

Different materials posses different heights of cone H_c(cm) with sawdust, garri and paddy rice having the highest value while bambara nut and maize have the lowest value of H_c. The angle of repose is therefore proportional to the height of the cone at constant values of the platform diameter and the platform height D_p and H_p respectively.

The diameter of the platform D_p is 22.5cm and the height of the platform H_p was adjusted at constant value of 23.5..

The smooth nature of bambara nut do not allow it to adhere together hence, the nut do not have high value of H_c and thus has a smaller angle of repose.

Conversely, the rough nature of the paddy rice surface(coat) made it adhere together and a high value of H_c is obtained.

Angle of repose was calculated from equation (2) as stated below.

$$\theta_r = \tan^{-1} \frac{2[H_c - H_p]}{D_p} \text{-----------} (2)$$

Where Hc,Hp and Dp are as defined earlier.

Some of the physical properties (size - major, minor and intermidiate diameter, and moisture content) that affects the angle of repose of agricultural materials are presented in table 5.0

TABLE 4.0 ANGLE OF REPOSE OF SELECTED AGRICULTURAL MATERIALS.

Selected agric. Materials	D_p (cm)	H_p (cm)	H_c (cm)	$H_c - H_p$ (cm)	θ_r (degree)
Maize	22.5	23.5	29.0	5.5	26.0
Groundnut unshelled	22.5	23.5	30.8	7.3	33.0
Groundnut shelled	22.5	23.5	31.2	7.5	33.7
Sorghum	22.5	23.5	29.6	6.1	28.5
Millet	22.5	23.5	29.4	5.9	27.9
Paddy rice	22.5	23.5	33.0	9.8	41.1
Milled rice	22.5	23.5	30.7	7.2	32.6
Rice husk	22.5	23.5	32.6	9.1	39.0
Unshelled mellon	22.5	23.5	31.3	7.8	34.7
Shelled mellon	22.5	23.5	30.4	6.9	31.5
Soya beans	22.5	23.5	30.2	6.7	30.8
Locust beans	22.5	23.5	29.7	6.2	28.9
Cowpea (beans)	22.5	23.5	29.5	6.0	28.1
Acha	22.5	23.5	32.0	8.5	37.1
Garri	22.5	23.5	33.5	10.0	41.6
Tiger nut	22.5	23.5	31.2	7.7	34.4
Wheat	22.5	23.5	30.2	6.7	30.8
Benniseed	22.5	23.5	31.2	7.7	34.4
Bambara nut	22.5	23.5	28.4	4.9	23.5
Saw dust	22.5	23.5	34.2	10.7	43.5

Table 5.0: SOME PHYSICAL PROPERTIES OF SELECTED AGRICULTURAL MATERIALS

	SELECTED AGRICULTURAL MATERIALS	PHYSICAL PROPERTIES			
		SIZE			MOISTURE
		AVERAGE MAJOR DIA. (mm)	AVERAGE MINOR DIA. (mm)	AVERAGE INTERMI-DIATE DIA (mm)	CONTENT (%)
1.	maize	10.5	5.1	8.1	12.4
2.	Bambara Nut	10.8	8.5	9.0	12.8
3.	Unshelled G.Nut	24.3	10.4	11.5	11.0
4.	G.Nut (Shelled)	13.1	6.6	6.8	18.6
5.	Tiger nut	8.3	5.3	6.9	12.5
6.	Acha	1.0	0.7	0.8	13.4
7.	Paddy rice	9.1	2.2	2.9	12.1
8.	Soya beans	8.2	4.9	6.2	12.2
9.	Cowpea	7.7	4.5	6.2	11.2
10.	Sorghum	5.1	2.8	4.8	10.6
11.	Benniseed	2.8	0.4	0.8	8.8
12.	Milled local rice	7.1	1.7	2.1	13.8
13.	Wheat	5.5	2.5	3.0	14.0
14.	Millet	3.3	1.9	2.1	10.8
15.	Locust beans	8.1	2.9	6.1	11.0
16.	Unshelled mellon	11.8	1.9	7.9	10.4
17.	Mellon (shelled)	11.1	1.7	7.7	15
18.	Gari	-	-	-	8.0

PHYSICAL PROPERTY - METHOD/EQUIPMENT USED

SIZE - Venier caliper

MOISTURE CONTENT - Gravimentry method.

Analysis of Gravimentry method of determing moisture content

Temperature of oven - 105^{o}c

Period of drying - 24hrs

Inital weight of sample/materials - Xgrams

X = 5grams for all samples.

Final weight of sample after oven-dry-yg

Weight of water removed, Z = (x-y)g

$$\therefore \text{moisture content} = \frac{Z}{X} \times 100\%$$

The results obtained during the analysis is as presented in table 6.0.

Table 6.0: Gravimentry method of determining moisture content of selected Agric. materials.

S/No	SELECTED AGRIC.	INITIAL WEIGHT Xg	FINAL WEIGHT Yg	MASS OF WATER REMOVED Zg	MOISTURE CONTENT (m.c) %
1.	Maize	5.00	4.38	0.62	12.40
2.	Bambara Nut	5.00	4.36	0.64	12.80
3.	Unshelled G.Nut	5.00	4.45	0.45	11.00
4.	G.Nut (shelled)	5.00	4.07	0.93	18.60
5.	Tiger-Nut	5.00	4.37	0.63	12.50
6.	Acha	5.00	4.33	0.67	13.40
7.	Rice(Paddy)	5.00	4.39	0.61	12.20
8.	Soya beans	5.00	4.39	0.61	12.20
9.	Cowpea	5.00	4.44	0.56	11.20
10.	Sorghum	5.00	4.47	0.53	10.60
11.	Benniseed	5.00	4.56	0.44	8.80
12.	Milled local rice	5.00	4.31	0.69	13.80
13.	Wheat	5.00	4.30	0.70	14.00
14.	Millet	5.00	4.46	0.54	10.80
15.	Locust beans	5.00	4.45	0.55	11.00
16.	Unshelled mellon	5.00	4.48	0.52	10.40
17.	Mellon (shelled)	5.00	4.25	0.75	15.00
18.	Gari	5.00	4.60	0.40	8.00

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

Having tested the constructed apparatus with twenty different agricultural materials and comparing the result obtained with the work of some other people both in Nigeria and abroad i.e from literatures the difference of $\pm 0.96°$ to $\pm 9°$. It can therefore be concluded that the developed apparatus can accurately measure the angle of repose of selected grains which have application in the design of bins, hoppers and other storage equipment.

5.2 RECOMMENDATIONS

During the course of this project work, limitation were faced and slight problems were encountered which resulted to the deviation of some of the measured and calculated parameters from literatures values. For instance, the replacement of a cathetometer with a graduated rule to measure the heights of the cone formed by materials.

Secondly, the grain profile was assumed to be linear, but in the actual sense, it is parabolic, hence, mathematical derivation using the parabolic curve function should be used to reduced the error to minimum and corresponds with the standard values.

The discharge pipe of the funnel should be made larger than it is to allow the free flow or discharge of the material to be measured to form a perfect cone.

Lastly, the size of the box should also be reduced and corresponding reduction in the size of the other components, because of the cost of filling the box is high and the reduction in the size has no effect in the measurement of repose angle.

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APPENDIX A

Photographs taken during testing

PLATE1:- ACHA ON THE PLATFORM

PLATE2:- WHEAT ON THE PLATFORM

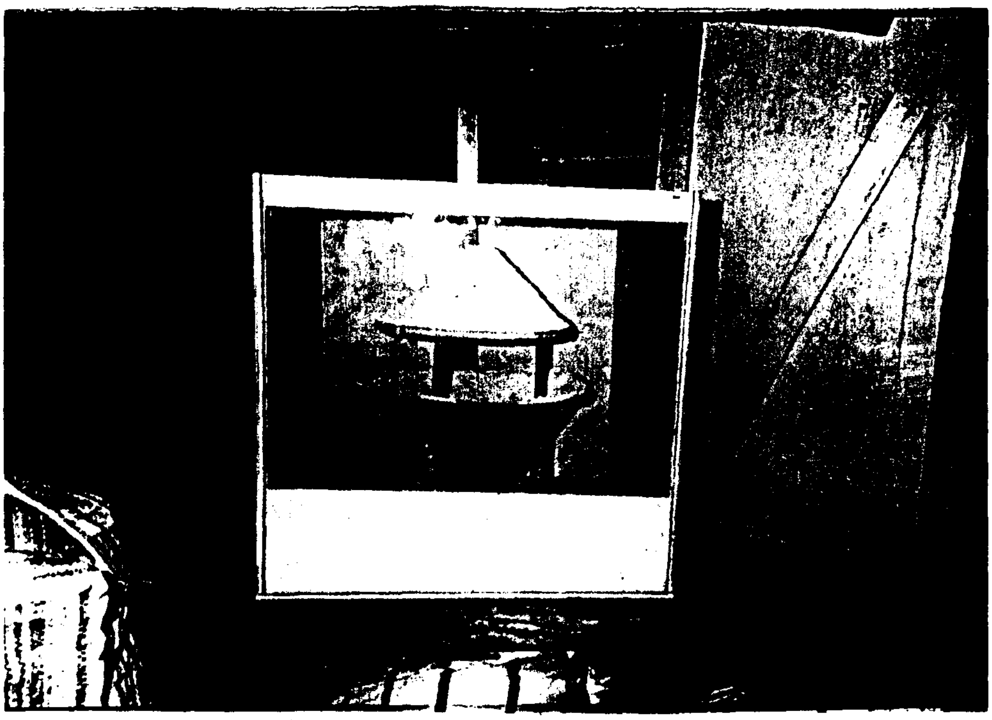

PLATE3:- GARRI ON THE PLATFORM

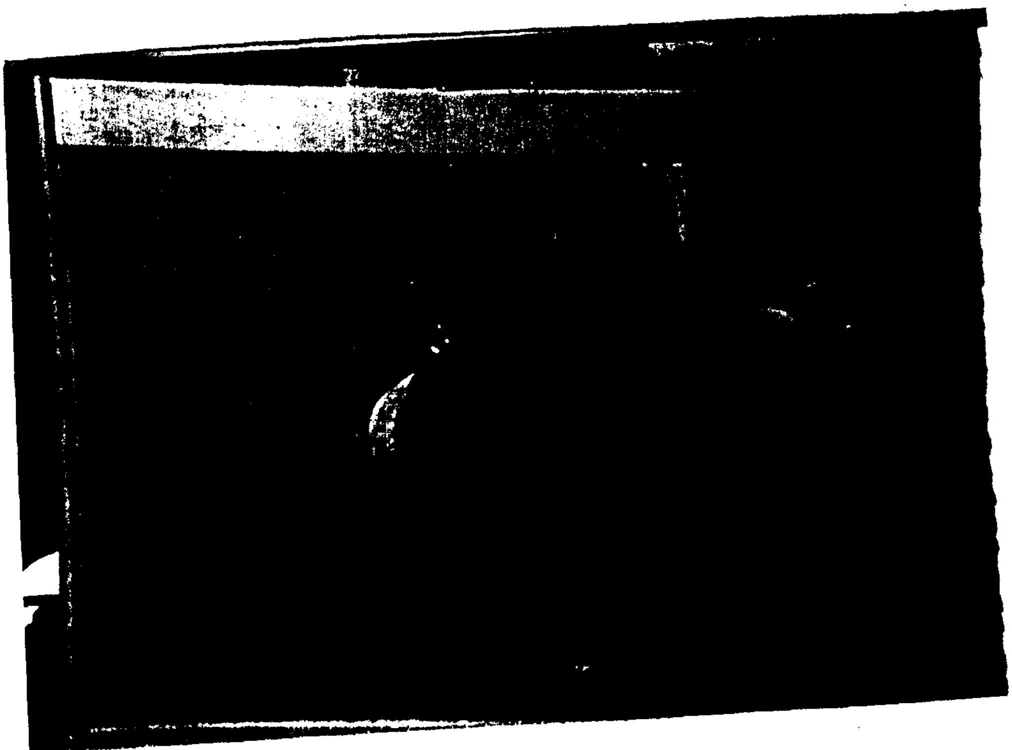

PLATE4:- TIGERNUT ON THE PLATFORM

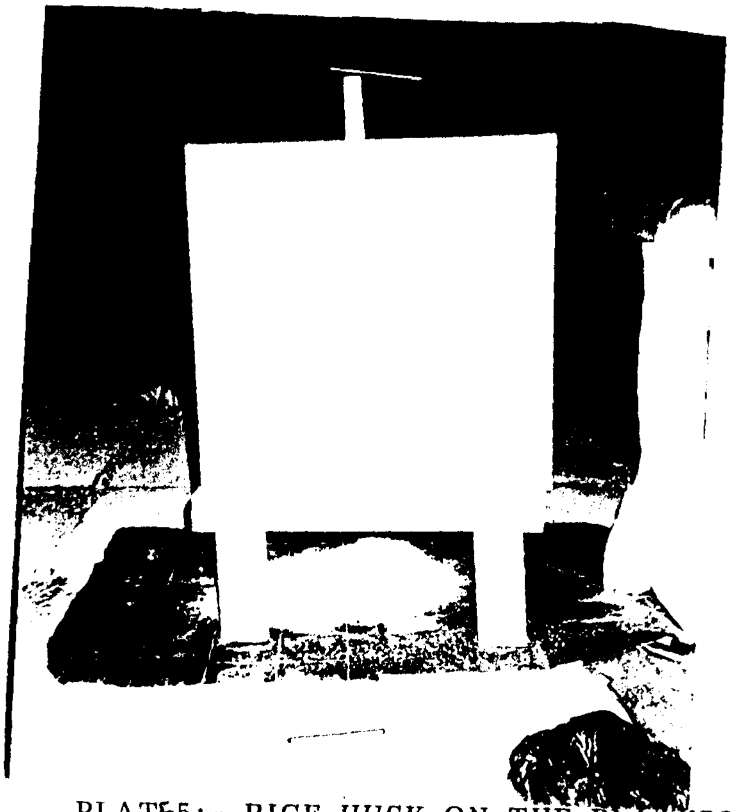

PLATE5:- RICE HUSK ON THE PLATFORM

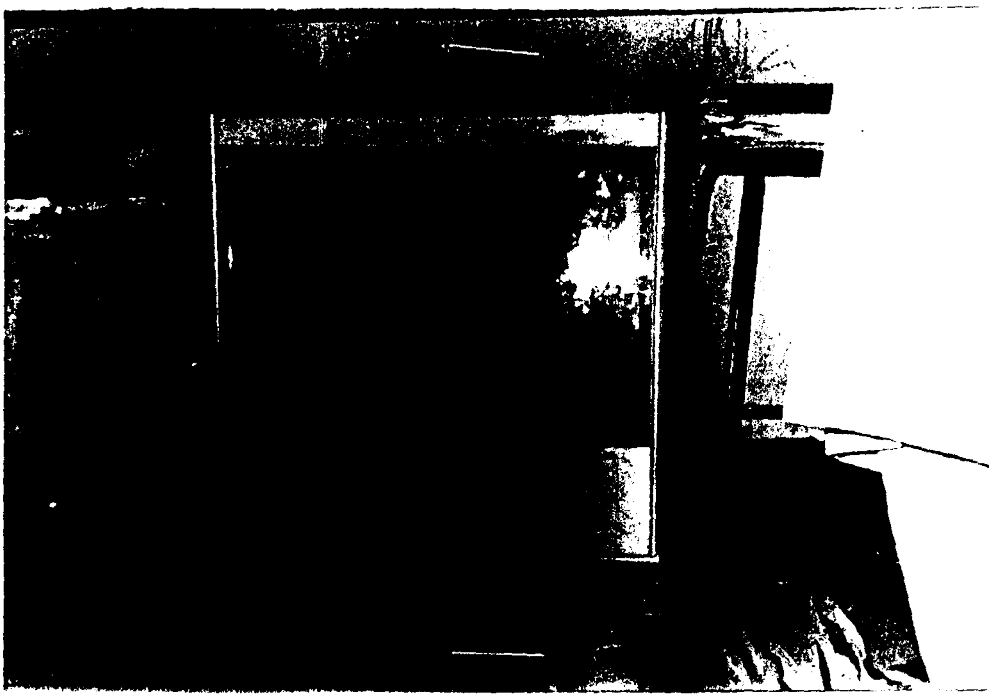

PLATE6:- SAWDUST ON THE PLATFORM

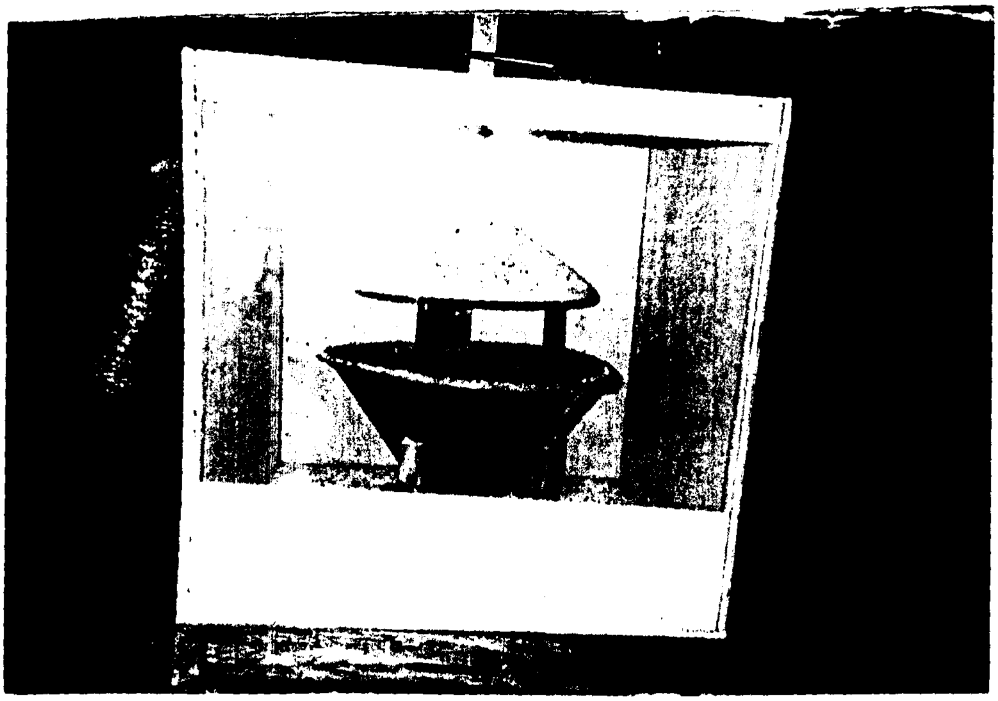

PLATE7:- BENNISEED ON THE PLATFORM

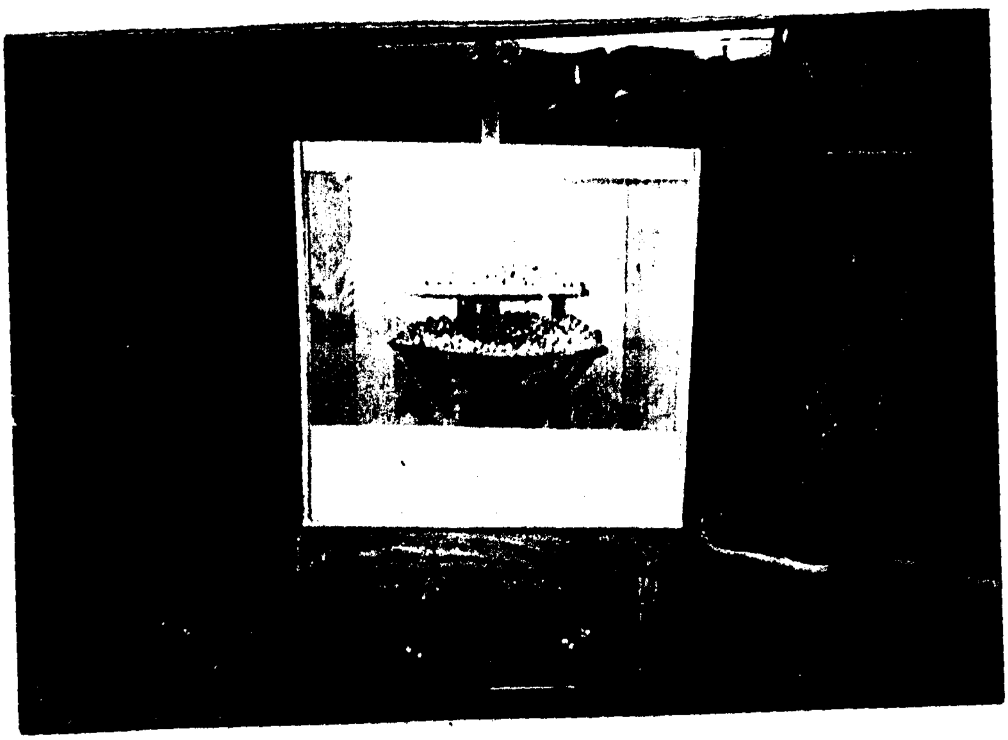

PLATE8:- BAMBARA NUT ON THE PLATFORM

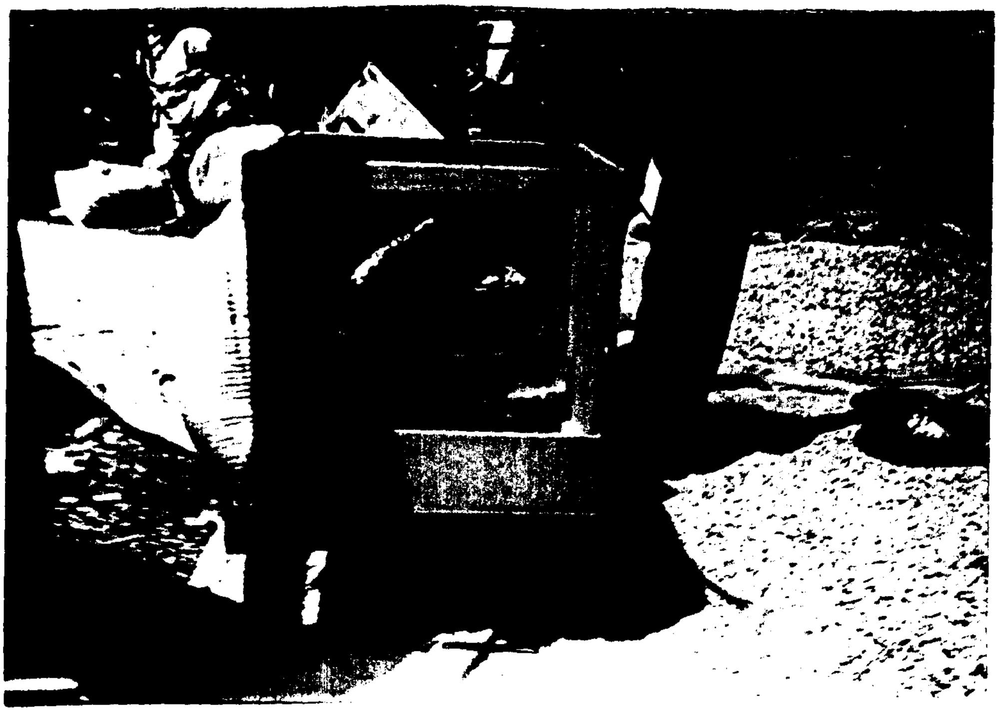

PLATE9:- SHELLED MELLON ON THE PLATFORM

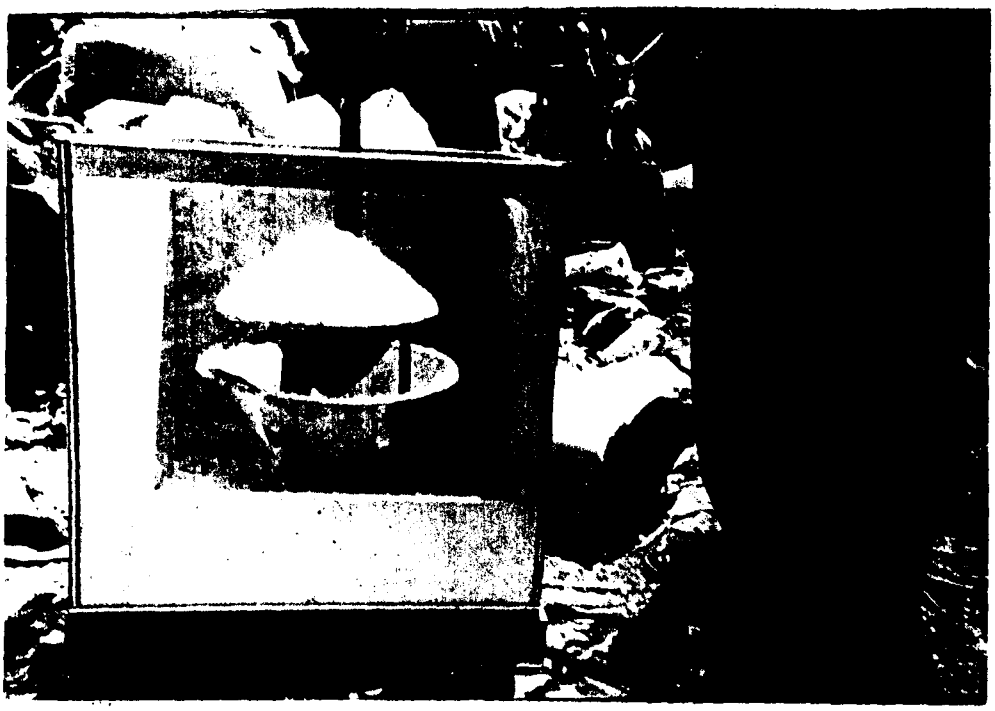

PLATE10:- MILLED LOCAL RICE ON THE PLATFORM