Development of an Apparatus for Measuring Angle of Repose of Granular Materials

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Abstract

This work presents the development of an apparatus for measuring the angle of repose of granular materials. The basic types of angle or repose, the methods of measuring angle of repose of solid, were discussed. The effect of the physical properties of the granular materials on the measured angle of repose to design and construction of bins, hoppers and other storage facilities such as silos were briefly discussed. The angles of repose of twenty different agricultural materials were determined using the developed apparatus.

Keywords: *Bins, hoppers, silos, agricultural produce***,** *static angle, dynamic angle***.**

Introduction

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

Therefore, knowledge of coefficient of friction of agricultural materials on various surfaces has long been recognized by engineers concerned with rational design of grain bins, silos and other storage structures. In design of agricultural machinery, however, the need for this information has been recognized rather recently (Hintz and Schinke 1952). For example, in the design of a chopping and impelling unit, the engineers needed some information on the sliding coefficient of friction of chopped Alfalfa and corn on steel. Not finding this information in the handbook of published data, it became necessary to setup a friction test apparatus and obtain the information needed (Hintz and Schinke 1952).

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Obviously, before granular materials or unconsolidated materials can flow from a bin or an 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 coefficient 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 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.

The angle of repose is the angle with horizontal at which the materials will stand when piled (Mohsenin 1978). The physical properties of these materials such as the shape, 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 (1968) 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. The angle of repose is of two types.

- Static angle of repose: This is the angle of friction taken up by a granular material about to slide upon it.
- Dynamic angle of repose: This is related to a situation where a bulk of the materials is in motion such as movement of solid discharging from a bin and hopper. It is more important than the static angle of repose.

The coefficient of friction between the granular materials is equal to the tangent of the angles of the internal friction for the materials.

Materials and Methods

The materials used for the development of an apparatus, Fowler and Wyatt (1960) type, for measuring angle of repose of granular materials are plywood, wood, glass, galvanized metal sheet and iron rod and flat bar.

A plywood of thickness ½ inch (12.74mm) with dimension 4ft x 4ft (121.92 x 121.92cm) was cut into four places (400mm x 400mm) using a hacksaw, try square, and measuring tape from which a box was constructed.

A piece of 3mm glass (dimension 30cm by 40cm) was installed to one side of the box to serve as a window. A hole of diameter 32cm was drilled at the centre of the base of the box through which a metal funnel with 3cm diameter was installed. Adjustable screw legs supporting the 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 points for easy running of the bolt. Three of such pipes were made and were screwed to the base of the box.

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

Three holes of 13mm were drilled on the 28cm diameter funnel at 18cm apart through which the three adjustable legs (rods) pass to hold the platform of main height of 26cm. From the base of the box, the height of the funnel was calculated to be 15.62 cm.

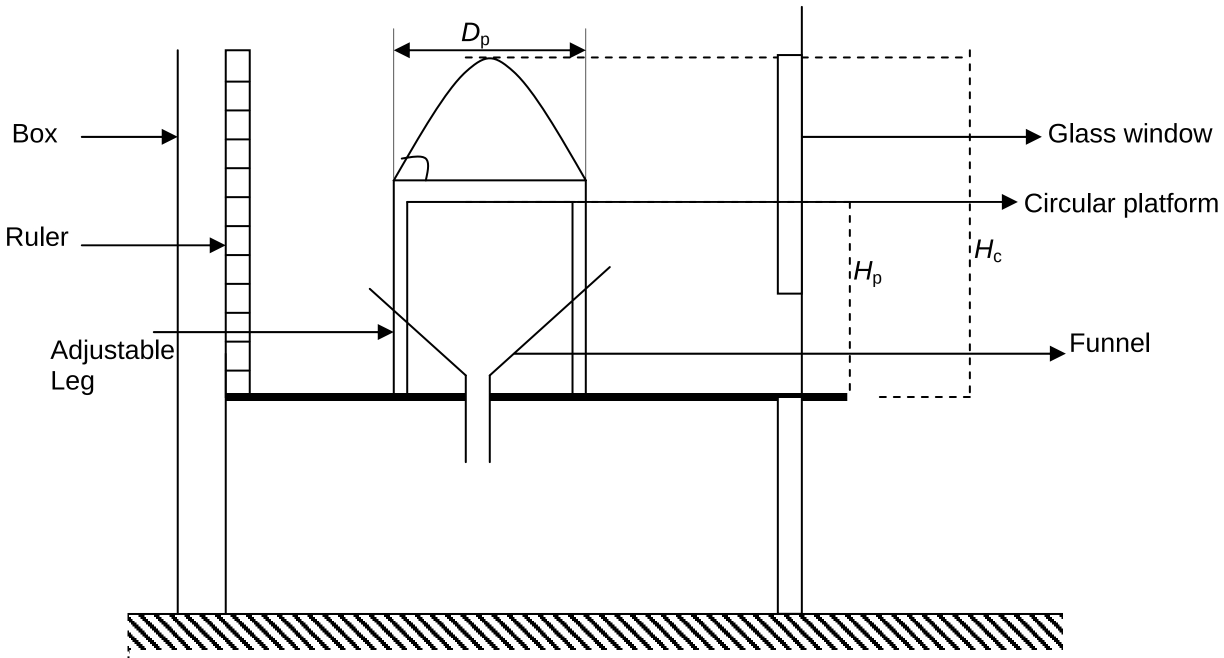

Fig. 1. Developed apparatus for measuring angle of repose of agricultural materials.

A 50 cm-long ruler was screwed to one side of 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 replica of Fowler and Wyatt (1960) apparatus, is presented in Fig. 1.

Materials

The apparatus shown in Fig. 1 is filled with granular solids whose angle of repose is to be determined. The solid is allowed to escape from the box leaving a free standing cone of solid on the circular platform. With the aid of the 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 from Eq. 1 below:

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

where: H_c = height of cone from datum; H_p = height of platform; $H_c - H_p$ = height of cone of solids; D_p = diameter of circular platform.

Results and Discussion

The data obtained using the developed apparatus includes the height of the cone, H_c, the height of the platform, H_p, and the diameter of circular platform, D_p. Using Eq. 1, the angle of repose of each selected agricultural material was calculated and the summary of the results is presented in Table 1 in the Appendix.

The size and moisture contents of the granular materials whose angles of repose were determined were calculated using Vernier caliper to measure the major, minor and the intermediate diameters and gravimetric method respectively. The results are presented in Table 2 in the Appendix.

Different materials possess different height of cone H_c with gari and paddy rice having the highest values while Bambara nut and maize have the lowest values of H_c. The angle of repose is therefore proportional to the height of cone formed at constant values of the platform diameter. The platform was adjusted at a constant value of 23.5 cm.

The smooth nature of Bambara nut does not allow it to adhere together, hence, the nut does not have high value of H_c and thus has a smaller angle of repose. Conversely, the rough nature of paddy rice surface coat made it adhere together and a higher value of H_c was obtained.

Conclusion

Having tested the developed apparatus with twenty different agricultural materials and comparing the results with the standard from literature, a difference of $\pm$ 0.96^0 to $\pm$ 9^0 was noticed. In conclusion, the developed apparatus can be used to determine the angle of repose of selected grains, which have application in the design of bins, hoppers and other storage structures.

Recommendations

During the course of this work, limitations were faced and slight problems encountered which resulted to the deviation of some of the measured and calculated parameters from the literature values. For instance, there was a replacement of a cathetometer with a graduated rule to measure the height of cone formed by the materials. Secondly, the grain profile was assumed to be linear, but in the actual sense it is parabolic, hence, mathematical derivation using parabolic cone function should be used. Lastly, the size of the box should be reduced with a corresponding reduction in the other components because of the cost of filling the box, since the size of the box is immaterial.

References

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Appendix

Table 1. Angle of repose of selected agricultural materials.

Selected agricultural 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
Unshelled groundnut	22.5	23.5	30.8	7.3	33.0
Shelled groundnut	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 melon	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
Gari	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 2. Some physical properties of selected agricultural materials.

Selected agricultural materials	Physical properties			
	Size			Moisture content % (wb)
	Average major diameter (mm)	Average minor diameter (mm)	Average intermediate diameter (mm)	
Maize	10.5	5.1	8.1	12.4
Bambara nut	10.8	8.5	9.0	12.8
Unshelled groundnut	24.3	10.4	11.5	11.0
Shelled groundnut	13.1	6.6	6.8	18.6
Tiger nut	8.3	5.3	6.9	12.5
Acha	1.0	0.7	0.8	13.4
Paddy rice	9.1	2.2	2.9	12.1
Soya beans	8.2	4.9	6.2	12.2
Cowpea	7.7	4.5	6.2	11.2
Sorghum	5.1	2.8	4.8	10.6
Benniseed	2.8	0.4	0.8	8.8
Milled local rice	7.1	1.7	2.1	13.8
Wheat	5.5	2.5	3.0	14.0
Millet	3.3	1.9	2.1	10.8
Locust beans	8.1	2.9	6.1	11.0
Unshelled melon	11.8	1.9	7.9	10.4
Shelled melon	11.1	1.7	7.7	15
Gari	-	-	-	8.0