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Characterizing of Flow Property for Wormy Compost by Using Newest Methods

[1]HadiRahmanzadeh Bahram, [1]Mohammad Hossein Kianmehr,
[1]Seyed Reza Hassan-Beygi, [1]Iman Valaei and [2]Hoseinali alikhani

[1]Department of Agro Technology, College of Abouraihan, University of Tehran, Tehran, Iran
[2]University College of Agriculture and Natural Resource, University of Tehran, Karaj, Iran

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Abstract: Much research regarding handling and storage characteristics of bulk solids has beenconducted over the years. Physical properties of granular solids play a significant pattern intheir resulting storage and flow behavior and are thereforeessential to design appropriate,efficient and economic bulk solids handling and storage equipment and structures. Wormy compost flow is problematic as it often becomes restricted by caking and bridging which occursduring transportation and storage. This issue probably results from a number of factors,including storage moisture, temperature, relative humidity, particle size, time, ortemperature variations, to name a few. The objective of this study was to review theprimary factors affecting flowability, handling and storage of granular solids and powders,as well as appropriate testing methodologies for this biomass material. It has been found that cohesion values increase with increasing normal stress valuesand high moisture content and small particle size.Besides, there is significant difference between the flow function valuesat different stress levels. Also in all of these methods, it can be said that high moisture content and small particle size has an adverse effect on the flow index of wormy compost.

Key words: Shear testing · Wormy compost · Jenike shear tester · Flow properties · Repose angle · Hausner ration · Fertilizer

INTRODUCTION

Processing organic waste in different ways, such as incineration, land filling and recycling can be done in certain places if it is possible. However, new methods of recycling can effectively reduce pollution in the environment and make waste materials to useful materials. This is due to the limited natural and a nonrenewable resource in the future is inevitable. Organic matter usage can cause positive effect on the physical, chemical and biological properties in the soil [1]. Also, high attention to organic manure and replacing that with chemical fertilizer is necessary [2].

Therefore the low-cost production technology of wormy compost that could be run by minimal facilities is taken in many regard by public, bring many economic resources. This process consists of using organic residues included industrial, agricultural and urban wastes and converting them to an organic fertilizer without any unpleasant smell, best quality and features to improve the physical, chemical and biological soil profile by soil worms.

Powder flow properties are important in handling and processing operations, such as flow from hoppers and silos, transportation, mixing, compression and packaging. Powder flow characteristics are commonly investigated by various measurements, such as handling angles, tap testing, shear cell measurements, etc. All these approaches allow the calculation of indices characterizing powder flowability [3, 4]. Changes in particle properties (moisture content, particle size) and storage conditions may influence the flowability of powders; sometimes even small changes can have significant effects. Storage conditions include storage temperature, exposure to humidity of air, storage time and consolidation [5-7]. Moisture content usually has a significant impact on powder flowability. Decreasing moisture content leads to increased flowability due to the decrease in liquid bridges and capillary forces acting between the powder particles. Even a self-flowing powder may effect on flow problems after the period of storage. This effect is due to time-consolidation, where a powder consolidates under its own weight over time [8]. It is obvious that flow characteristics of powders are directly affected on their compaction.

Corresponding Author: Hadi Rahmanzadeh Bahram, Department of Agro Technology, College of Abouraihan, University of Tehran, Tehran, Iran.

Powders can be more or less expanded or contracted when stressed, thus leading to a large variety of inter-particle forces. Factors associated with the inherent feature of the particles are size, shape, surface morphology [9, 7]. Packing ability should be intended when studying powder flow properties, but interaction between particles related with these factors should also be taken into consideration. Then, a powder must be intended as a whole medium that sums up all these interactions at the contacts together. Powder flow characteristics are commonly investigated under loading conditions of gravity, using determination such as the angle of repose and other handling angles, standardized flow rate, apparent and 'tapped' densities and derived indices such as defined by Abdullah and Geldart [10], Carr [11]or Hausner [12]. Such measurements have demonstrated the dependence of powders flow on particle shape and size distribution, but they have been proved difficult to relate to features at particulate level. Thus, a more fundamental and physical measurement should be easily available using shear cells [13-16]. These cells are designed to condition powders under that is similar to natural conditions [5, 17]. This measurement is able to provide useful indications of powder start to flow, while the load was used for powder bed. Then, if the forces applied on a powder are approximately known during a given process, intrinsic information regarding the frictional and cohesive nature of granular material can be prepared. This information could then be affiliate during a real process. It is important to note that this methodology is time and product consuming and that accurate and renewable preparation of samples is quite difficult to achieve and results can be very operator and know-how dependent. Once frictional properties of a given powder have been specified by shear testing, tap testing and repose angle measurement can be beneficial used for useful studying or to Maintain matching of different batches because empirical relationships have been found between tap density values and shear cell measured flow functions [4] between Hausner ratio and angle of repose between angle of internal fraction also As the Properties of flowability, wide acknowledgment was obtained by the flow function FF explained by Jenike (1964), being the dependence of the unconfined yield strength, σ_c on the major consolidating stress, $\sigma_{.1}$ The flow function FF features the capability of a material to disturbances of free outflow from container under the force of gravity and applies it for design engineering of silo hoppers. Besides, results of shear cell tests make conceivable the qualitative evaluation of different bulk materials, on the basis of a parameter introduced by Schubert [18] and Jenike and Carson [19]. Major Principal Stress in the steady state flow is called major consolidation stress (σ_1).

σ_1, applying on critical consolidation condition, is determined by drawing the Mohr circle (steady state Mohr circle) passing through the point (σ_c, τ_c) which represents the consolidation conditions in shear tests (Figure. 1).

The circle is tangent to the yield locus and the section of circle with normal stress axis gives σ_1 value. There is a corresponding value of σ_c for each consolidation stress (σ_1). If σ_c values are plotted against σ_1 values, flow function (FF) of the material is obtained and it characterizes the flow potency of a bulk material [19, 20]. The flow index (FF_c), defined as the inverse slope of the flow function (FF), is used to classify powder flowability with higher values representing an easier flow [21]. This classification is given in Table 1. The aim of this work was to evaluate the influence of moisture content, particle size and consolidation on wormy compost flowability.

Angle of Repose: The angle of repose is the angle discharged bjZsolids makes with the hjZontal plane [22]. It injZnt the limit balance ofjjerials without stress [23]. For free-flowing powders, the angle of repose approximately equals the angle of internal friction φ and offers a simple method for pointing the latter [3]. For cohesive powders the angle of repose □ is larger than φ and depends on the thickness of the powder layer [24].

Aoriginal challenges is to be able to forecast the flowability of a powder. A variety of modeling methods have been used to investigate slope angles, all of which vary in their complexity. In this paper we present of careful measurements of the angle of repose and its relations to the result determined from the other two test method. This classification is given in Table 2.

Compaction Measurement: The ratio between tapped (a defined number of taps) and loose bulk density is known as the Hausner ratio and it is often used as an internal friction index in cohesive powders [25, 26]. Determining the Hausner ratio is very popular for powder characterization because of its Itssimply and quickly. Recommendations procedure to measure the Hausner ratio is the following. Table 2 shows the empirical relations between the obtained Hausner ratio and the flowability of the powder.

Table 1: Classification of powder flowability by index(FF_c)

Flowability	Hardened	Very cohesive	Easy Cohesive	Flowing	Free flowing
Flow index (FF_c)	<1	<2	<4	<10	>10

Table 2: Empirical relation between the flow properties and the results obtained with two Well-known powder tests (repose angle and Hausner ratio measurements).

Flow property	Angle of repose (°)	Hausner ratio
Excellent	25-30	1.00-1.11
Good	31-35	1.12-1.18
Fair	36-40	1.19-1.25
Passable	41-45	1.26-1.34
Poor	46-55	1.35-1.45
Very poor	56-65	1.46-1.59
Very very poor	>65	>1.60

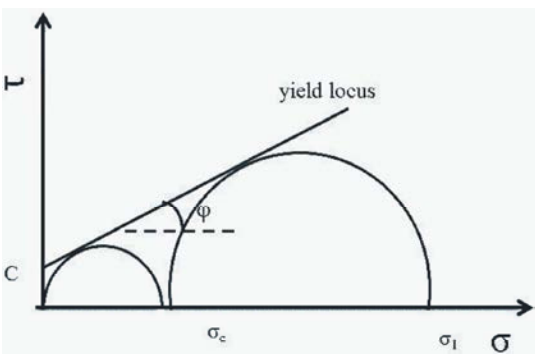

Fig. 1: Determining of major consolidation stress by using geometric method using yield locus

MATERIALS AND METHODS

Crop Residues: Samples of wormy compost selected from karaj campus that was produced by the College of Soil Science in the wormy culture farm, west north of Tehran, Iran. Biomass samples were ground using a hammer mill (Glen Mills Inc. NJ) with three different hammer mill screen sizes (1.18, 0.6 and 0.3 mm). A sample of 100 g was placed in a stack of sieves arranged from the largest to the smallest opening. The sieve series selected were based on the range of particles in the sample. For the samples from 1.2mm hammer mill screen opening, Canadian series sieve numbers 18, 20, 30, 40, 50, 70, 100, 140 and 200 (sieve sizes: 1.0, 0.85, 0.59, 0.43, 0.30, 0.21, 0.15, 0.11 and 0.075 mm, respectively) were used. For samples from 0.6mm hammer mill screen opening, sieve numbers 40, 50, 70 and 100 (0.43, 0.30, 0.21 and 0.15 mm, respectively) were used. For the finely ground samples from 0.3mm hammer mill screen opening, sieve numbers 70, 100 and 140 (0.21, 0.15 and 0.11 mm, respectively) were used. The set of sieves was placed on the Ro-Tap sieve shaker (Tyler Industrial Products, 507-007 Ro-Tap Sieve Shaker). The duration of sieving was 10 min, which was previously determined through trials to be optimal. After sieving, the mass retained on each sieve was weighed. Sieve analysis was repeated three times for wormy compost. The particle size was determined according to ANSI/ASAE standard S319.3 JUL 97[27]. The geometric mean diameter (dgw) of the sample and geometric standard deviation of particle diameter (Sgw) were calculated according to the aforementioned standard.

Moisture Content: The moisture content of the wormy compost was determined following the procedure given in ASTM Standard D 3173-87 [28] for coal and coke. One gram of pulverized sample passing through sieve number 50 was taken and oven-dried for 12 h at 103^{oc}. The average moisture content was 15% (wb). The moisture content of the samples was determined by weighing and expressed in percent w.b. Then calculated quantity of water was added and mixed with the wormy compost in a shop-fabricated mixer for 15 min. The samples were wetted by sprinkling water on them to moisture contents of 25, 30 and 35% (wb) and stored in a cooler kept at 4 ^{oc} for a minimum of 72 h.

Chemical Composition: Biomass samples were analyzed by a commercial animal feed testing laboratory in abureyhan campus of Tehran University (Environ-test Laboratory). Protein, crude fat, acid detergent lignin (ADL), acid detergent fiber (ADF), neutral detergent fiber (NDF) and total ash were determined. The protein content of the biomass was determined using the AOAC method 976.06 [29], where the nitrogen content was multiplied by a factor 6.25. Crude fat was determined using the AOAC method 920.29 [30]. ADF and ADL were determined using the AOAC method 973.18 [31], whereas the NDF was determined using the method reported by van Soest *et al*. The total ash content was determined using AOAC method 942.05 [32].

Shear Cell Measurements: All measurements were performed with a Jenike shear cell (laboratory made model, diameter of 9.5 cm). Under a uniaxial normal stress, σ, a powder bed may develop irreversible packing, resulting in consolidation and leading to a tangential force needed to shear the bed. The shear cell was then placed in a chamber, with a temperature of 26C, where the shear tests for measuring the instantaneous flow function were conducted. The procedure used to measure the instantaneous flow function, using the Jenike shear cell. For any flow function, four yield loci and four points for each yield locus were obtained. To construct a yield locus, the powder was critically consolidated under a known normal consolidating stress, σ1 and the shear stress, τ, required to cause the powder to fail under 75,50,25% of consolidating stress (normal stress σ) and at the consolidating stress were measured. A yield locus is a plot of failure shear stress versus normal stress for a given consolidating stress. This is repeated for four different consolidating stresses to obtain four yield loci. Every point of the yield locus was repeated four times. A yield locus is presented in Fig. 1. The results of shear stress measurements are classically interpreted as yield loci in the Mohr space [18, 33]. The intercept of the yield loci with τ axis gives the cohesion parameter τ and the slope gives rise to kinematic angles, φ of internal friction. From each yield locus, the following two quantities were estimated by two specific Mohr circles tangent to the yield loci give rise to the major consolidating stress, σ1 and to the unconfined yield strength, σc. It gives the stress needed to make an arch collapse and make the material flow. A plot of σc versus major consolidating stress, σ1 can be obtained and represents the flow function FF [34].

Angle of Repose: The Hele-Shaw cell was chosen as this allows observation of processes inside the slope structure [35] Photos taken in static mod of materials that are discharged in the case for Data extracting are analyzed by solid works 2011 in sketch mode.

Hausner Ratio: Tap bulk density of poultry litter was measured using an automated tap density meter (Model made that can able to supply standard test condition according to ASTM Standard B527 [36].

A 250 mL graduated cylinder was filled with Wormy compost and weighed. The cylinder was then placed in the tap density tester. Tapping of the cylinder (500 times) at a rate of 300 taps/min was then done by the tester. Each tap consisted of the cylinder being raised 14 mm and then dropped under its own weight. After the first 500 taps, the new volume of the sample was recorded. The cylinder was then tapped 750 times and a second new volume recorded. If the difference in volume after the 500 taps and the 750 taps was <2%, the process was repeated; otherwise the experiment was completed. The tap bulk density (qt) was taken after the completion of tapping.

RESULTS AND DISCUSSION

Chemical Composition: The composition of the wormy compost sample are given in Table 3. It is worth mentioning that the high ash content of the wormy compost implies that about one-third of the wormy compost will have to be removed as residue if this material were used for combustion. This residue will mostly contain minerals and therefore could be a valuable source of fertilizer.

Bulk, Particle and Tap Density: Table 4. shows the geometric mean diameter, bulk density and particle density of six wormy compost species. It can be observed that the larger the screen openings, the lower were the bulk and particle densities. Bulk and particle densities of dry and finest were higher than that of other sample. Wormy compost in 25% moister content from a hammer mill screen size of 0.3mm had the highest bulk density of 0.854 gcm^{-3}.

Table 4 shows that the bulk density of wormy compost decreased from 0.854 to 0.658 gcm^{-3} within the moisture content range of 25-35% (wb) and increase particle size 0.3mm to 1.18mm. This means that the rate at which wormy compost particle volume increased was faster than the rate at which the mass of the particles increased as a result of moisture addition. Therefore, the amount of volume that will be required to store a unit mass of wormy compost will increase as moisture increases. The reduced bulk density of wormy compost with moisture content increase is similar to the reported bulk density-moisture content relationship for biomass (poultry litter [37]and granular biological materials (cashew nut [38]; soybean [39]; alfalfa cubes and pellets [40]; green gram [41]). The measured bulk density of wormy compost (>0.658 gcm-3) was also considerably higher than the values that have been reported for other bioenergy feedstock such as switch grass and peanut hulls (typically <0.2 gcm-3). This is because of the relatively high amount of ash (32% - Table. 3.) Present in wormy compost.

The particle density of wormy compost decreased from 1.652 to 1.443 gcm-3 as its moisture content increased from 25% to 35% (Table. 4). This shows that the volume of the particles of the wormy compost increased at a higher rate than the increase in mass as moisture content increased. A similar trend was observed in various biological materials by Deshpande *et al*. [39], Joshi *et al*. [42], fasina [43]and Nimkar and Chattopadhyay [41].

Table 3: Chemical composition of wormy compost

Components Biomass species	Protein Dm[a]	Crude fat DM	Lignin DM	Cellulose[b] DM	Hemicellulose[c] DM	Ash DM
Present of content (%)	10.4	3.2	2.3	5	7.2	32.3

[a]DM-dry matter.[b]Cellulose percentage is calculated indirectly from acid detergent fiber (ADF) and lignin (ADF-lignin). [c]Hemi-cellulose percentage is also calculated indirectly from neutral detergent fiber (NDF) and ADF (NDF-ADF).

Table 4: Physical properties of wormy compost

Moisture content (%, wb)	Hammer mill screen size (mm)	Geometric mean diameter (mm)	Geometric standard deviation (mm)	Bulk density (gcm^{-3})	Particle density (gcm^{-3})
25	0.3	0.174	0.214	0.854	1.652
	0.6	0.211	0.387	0.814	1.554
	1.18	0.246	0.312	0.732	1.493
30	0.3	0.232	0.362	0.77	1.587
	0.6	0.253	0.436	0.736	1.545
	1.18	0.274	0.364	0.689	1.466
35	0.3	0.237	0.394	0.743	1.543
	0.6	0.282	0.466	0.685	1.531
	1.18	0.288	0.412	0.658	1.443

Table 5: Cohesive strength and angle of internal friction of wormy compost on three consolidation stresses

Consolidating pressure (KPa)																							
Moisture content (%, w.b.)	17				13										7								
Particle size(mm)																							
	1.18	0.6			0.3	1.18	0.6	0.3	0.6	0.6	0.3	0.3	0.6	0.3	1.18	0.6	0.3	0.6	0.6	0.3	0.3	0.6	0.3
Cohesive strength (KPa)																							
25	1.16	0.61			0.22							0.81	0.41	0.16	0.23				0.16				0.08
30	0.82	0.93	1.12	2.08	2.23							1.01	1.55	1.67	0.48				1.41				1.30
35	0.97	2.11			2.88							1.12	1.63	1.61	0.74				0.86				1.06
Angle of internal friction (º)																							
25	32.1	33.1			31.4																		
	35.9	33.7			29.7																		
	26.6	28.7			32.7																		
30	34.8	33.6			35.1							35.4	34.8	31.7	35.6				34.3				29
35	31.8	33.3			37.2							28.6	35.7	36	27.7				25.3				30.1

Flowability: The ultimate yield stress (UYL) versus the major consolidating stress (MCS) at various moisture contents is shown in Fig. 2. The flow function (the slope of the plots in the figure) increased with moisture content.

This indicates that the stress needed to make an arch (formed when flow from a hopper stops) collapse [44] increased with moisture content. Using the classification of Jenike (1964) given in Table.1. the flow index values (inverse of the flow function) indicate that the flowability of wormy compost reduces as moisture content increased (Fig.2.). Teunou and Fitzpatrick (1999) also found similar results when they compared the flow functions of flour (at 12.0% moisture content), tea (at 6.5% moisture content) and whey (at 4.0% moisture content) [45]. They concluded from their study that the flour with the highest moisture content had the most difficult flow.

As expected, the cohesion for wormy compost was significantly ($P < 0.01$ and $P \geq 0.05$) affected by moisture content, particle size and applied pressure (Table 5). The angle of internal friction for wormy compost was also significantly ($P \geq 0.05$) affected by moisture content, particle size and applied pressure. The cohesive strength data are generally lower than the values obtained for high-rising wheat flour (1.5-3.5 kPa), for fine tea powder (1.0-2.3 kPa) [45], poultry litter (0.41-3.26 kPa) and for chickpea flour and components (3.22-7.11 kPa) [46] but comparable to the values obtained for spray dried whey permeate powder (0.5-1.0 kPa) and for sugar and wheat flour (0.6-1.3 kPa) [15].

The measured angle of internal friction and cohesive strength in most cases were greater than the critical values of <30 and 2 kPa required for gravity discharge of bulk materials from storage bins and silos [47]. Therefore, gravity discharge alone may not be used to unload wormy compost from storage bins and silos.

One empirical constant that is sometimes used to assess the flowability of a powder material is the Hausner ratio (HR). Even though HR is not useful in the design of hoppers and silos, it is useful in quality control, where a change in measured value may be indicative of change in the flow behavior of a given material [48]. HR is calculated from the measured values of bulk and tap density as follows:

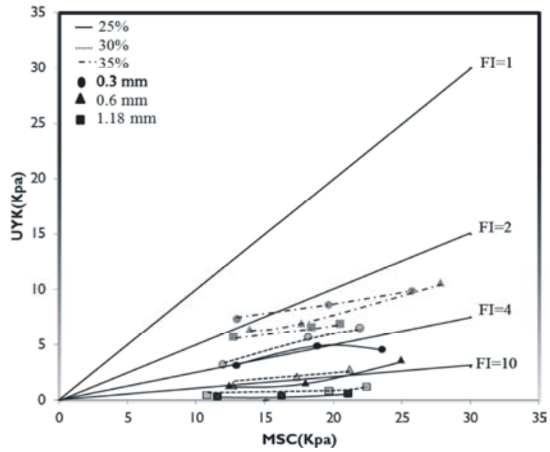

Fig. 2: Unconfined yield stress, σ_1 versus major consolidating stress, σ_c for wormy compost in three different moister content and particle size.

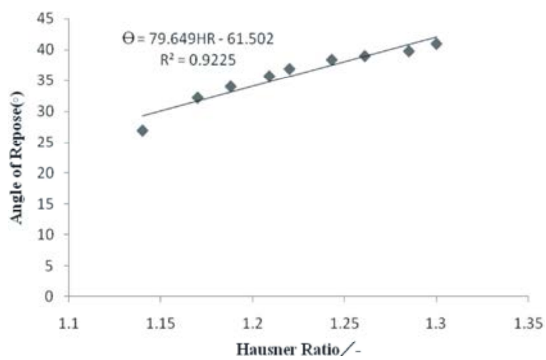

Fig. 3: Angle of repose versus Hausner ratio.

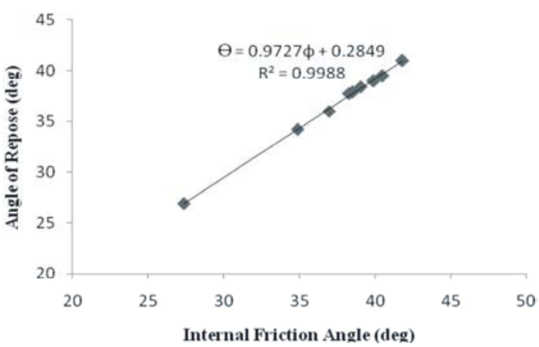

Fig. 4: Comparison between repose angle and internal friction angle

$HR = \rho t / \rho b$

Statistical analysis using ANOVA procedure in SAS statistical software (SAS, 2005) showed that moisture content has significantly affect ($P \geq 0.05$) the Hausner ratio of wormy compost. This is because the rate of decrease in bulk density was similar to the rate of decrease of tap density of the wormy compost as moisture content increased (Table. 4). The Hausner ratio for wormy compost was found to be in range of 1.14- 1.3, which according to (Table. 2.) Wormy compost classed in poor to possible flowable material. The near-perfect linear relationships observed between Hausner ratio and angle of repose (Fig. 3) confirm that both parameters are good indicators of powder flowability.

As mentioned earlier, direct shear tests were performed to obtain the wormy compost internal friction angle using the Mean values of samples in moisture content 25-35% and for internal friction angle mean values in 17(kpa) normal consolidation load. Figure 4 compares the repose angle and internal friction angle.

$$\theta = 0.97\varphi + 0.28 \quad (1)$$

Where θ and φ are the angle of repose and internal friction angle in degrees, respectively. This expression shows that when the wormy compost is deposited in a loose state, the friction angle is equal that the repose angle.

So, according to the jenik, Hausner and hele-shaw wormy compost is almost classed in free flow powder. For free-flowing powders, the angle of repose equals the angle of internal friction φ and offers a simple method for determining the latter [3]. For cohesive powders the angle of repose O is larger than φ and depends on the thickness of the powder layer [24].

CONCLUSION

Higher angles of internal friction are due mainly to interlocking among particles during direct shear and depend very much on the normal stress. However, friction values are intrinsic and have the potential to be effectively used for bulk characterization. Cohesion values increase with increasing normal stress valuesand high moisture content and small particle size.Besides, there is significant difference between the flow function valuesat different stress levels. Also it can be said that high moisture content and small particle size has an adverse effect on the flow index of wormy compost that all three methods confirm that the each other.

List of Abbreviations Used:

- φ - angle of internal friction, deg
- ☐-angle of repose, deg
- $\sigma 1$- major consolidating stress

- σc - unconfined yield strength
- FFc - flow index (σc/σ1)
- HR- Hausner ratio
- ρt- tap densty
- ρb- bulk densty
- w.b- moister content in wet base

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REFRENCE

1. Kabirinejad, S. and M. Hoodaji, 2012. The effects of biosolid application on soil chemical properties and *Zea mays* nutrition. International Journal Of Recycling of Organic Waste in Agriculture, 1: 4 doi:10.1186/2251-7715-1-4
2. Düring, R.A., T. Hoß and S. Gäth, 2003. Sorption and bioavailability of heavy metals in long-term differently tilled soils amended with organic wastes. Sci Total Environ, 313: 227-234.
3. Peleg, M., 1978. Flowability of food powders and methods for its evaluation - a review. J. Food Process Eng., 1: 303-328.
4. Tchoreloff, P., B. Leclerc, E. Guerin, D. Tanguy, M. Deleuil and G. Couarraze, 1999. Rheological characterization of pharmaceutical powders using tap testing, shear cell and mercury porosimeter. Int. J. Pharmaceutics, 189: 91-103.
5. Fitzpatrick, J.J., T. Iqbal, C. Delaney, T. Twomey and M.K. Keogh, 2004b. Effect of powder properties and storage conditions on the flowability of milk powders with different fat contents. Journal of Food Engineering, 64(4): 435-444.
6. Horabik, J., 2001. Characteristic of physical properties of plant granular solids important for storage (in Polish). Acta Agrophysica, pp: 54.
7. Teunou, E. and J.J. Fitzpatrick, 1999. Effect of relative humidity and temperature on food powder flowability. J. Food Eng., 42: 109-116.
8. Teunou, E. and J.J. Fitzpatrick, 2000. Effect of storage time and consolidation on food powder flowability. J. Food Eng., 43: 97-101.
9. Molerus, O. and M. Nywlt, 1984. The influence of the fine particle content on the flow behavior of bulk materials. Powder Technol., 37: 145-154. ASAE; 2001. pp: 573-6. European pharmacopoeia 7.0, Chapter 2.9.36. : Powder flow, p. 308. expressing fineness of feed materials by sieving. St. Joseph, Michigan: Powder Technology, 88: 285-290.
10. Abdullah, E.C. and D. Geldart, 1999. The use of bulk density measurements as flowability indicators. Powder Technol., 102: 151-165.
11. Carr, R.L., 1965. Evaluating flow properties of solids. Chemical Eng., 72: 163 167.
12. Hausner, H.H., 1967. Friction conditions in a mass of metal powder. Int. J. Powder Metallurgy, 3: 7-13.
13. Horabik, J. and M. Grochowicz, 2002. Strength characteristics and dilatation of food powders. Int. Agrophysics, 16: 183-189.
14. Jenike, A.W., 1964. Storage and Flow of Solids (Bulletin No. 123), Utah Engineering Experiment Station, University of Utah, Salt Lake City-Utah,
15. Kamath, S., V. Puri, H. Manbeck and R. Hogg, 1993. Flow properties of powders using four testers-measurement, comparisonand assessement. Powder Technol., 76: 277-289.
16. Schulze, D., 1996. Vergleich des Flie ß verhal ten sleicht flie ß ender Schüttgüter. Schüttgut, 2: 347-356.
17. Knowlton, T.M., J.W. Carson, G.E. Klinzing and Wen-Ching Yang, 1994. The importance of storage, transfer and collection. Chem. Engin. Progress, 90(4): 44-54.
18. Schubert, H., 1987. Food particle technology. Part I: Properties of particles and particulate food systems. J. Food Eng., 6(1): 1-32.
19. Jenike, A.W. and J. Carson, 1985. Measurement principles of the flowability of powders. Advance Ceramic, 21: 759-766.
20. Kamath, S., V.M. Puri and H.B. Manbeck, 1994. Flow property measurement using the Jenike Cell for wheat flour at various moisture contents and consolidation times, Powder Technology, 81: 293-297.
21. Fitzpatrick, J.J., S.A. Barringer and T. Iqbal, 2004. Flow property measurement of food powders and sensitivity of Jenike's hopper design methodology to the measured values, Journal of Food Engineering, 61: 399-405.

22. Carson, J.W. and B.H. Pittenger, 1998. Bulk properties of powders. In R. J. Davis (Ed.), Powder metal technologies and applications. ASM international handbook committee (pp: 287-301). Materials Park, OH: ASM International.
23. Reimbert, M. and A. Reimbert, 1981. Determination of the mechanical properties of cohesive and non-cohesive powdered materials. Bulk Solids Handling, 1(1): 37-41.
24. Rietema, K., 1991. Mechanics of powders at rest. In The dynamics of fine.
25. Guo, A., J.K. Beddow and A.F. Vetter, 1985. A simple relationship between particle shape effects and density, flow rate and Hausner ratio. Powder Technology, 43: 279-284.
26. Malave, J., G.V. Barbosa-Canovas and M. Peleg, 1985. Comparison of the compaction characteristics of selected food powders by vibration, tapping and mechanical compression. Journal of Food Science, 50: 1473-1476.
27. ASAE Standards 47th Ed. S319.3 - method of Determining.
28. ASTM Standard. ASTM Standards D 3173-87-standard test method for moisture in the analysis sample of coal and coke. In:Furcola NC, editor Annual book of ASTM standards, section 5, vol.05.05. West Conshohocken, PA, USA: American Society for Testingand Materials; 1998. pp: 301-2.
29. AOAC. AOAC method 976.06-protein (crude) in animal feeds. In: Helrick K, editor. Official method of analysis of the Association of Official Analytical Chemists, 15th ed. vol. 72. Arlington, VA: Association of Official Analytical Chemists, 1990.
30. AOAC. AOAC method 920.29-fat (crude) or ether extract in animal feed. In: Helrick K, editor. Official method of analysis of the Association of Official Analytical Chemists, 15th ed. Arlington, VA: Association of Official Analytical Chemists, 1990.
31. AOAC. AOAC method 973.18-fiber (acid detergent) and lignin in animal feeds. In: Helrick K, editor. Official method of analysis of the Association of Official Analytical Chemists, 15th ed. vol. 82. Arlington, VA: Association of Official Analytical Chemists; 1990.
32. AOAC. AOAC method 942.05-ash in animal feeds. In: Helrick K, editor. Official method of analysis of the Association of Official Analytical Chemists, 15th ed. vol. 70. Arlington, VA: Association of Official Analytical Chemists, 1990.
33. Schwedes, J., 1996. Measurement of flow properties of bulk solids.
34. Schwedes, J., 2000. Testers for measuring flow properties of particulate solids. Powder Handl. Process. 12: 337-354.
35. Robinson, D.A. and S.P. Friedman, 2002. Observations of the effects of particle shape and particle size distribution on avalanching of granular media, Physica, A 311: 97-110.
36. ASTM Standard, 2005. B 527: Standard Test Method for Determination of Tap Density of Metallic Powders and Compounds. ASTM, West Conshohocken, PA.
37. Bernhart, M. and O.O. Fasina, 2009. Moisture effect on the storage, handling and flow properties of poultry litter. Waste Management, 29: 1392-1398.
38. Balasubramanian, D., 2001. Physical properties of raw cashew nut. Journal of Agricultural Engineering Research, 78(3): 291-297.
39. Deshpande, S.D., S. Bal and T.P. Ojha, 1993. Physical properties of soybean. Journal of Agricultural Engineering Researc, 56(2): 89-98.
40. Fasina, O.O. and S. Sokhansanj, 1992. Hygroscopic moisture absorption by alfalfa cubes and pellets. Trans. ASABE 35, pp: 1615-1619.
41. Nimkar, P.M. and P.K. Chattopadhyay, 2001. Some physical properties of green gram. Journal of Agricultural Engineering Research, 80(2): 183-189.
42. Joshi, D.C., S.D. Das and R.K. Mukherjee, 1993. Physical Properties of PumpkinSeeds. J. Agric. Eng. Res., 54: 219-229.
43. Fasina, O.O., 2008. Physical properties of peanut hull pellets. Bioresource Technology, 99: 1259-1266.
44. Williams, J.C., 1990. The storage and flow of powders. In: Rhodes, M.J. (Ed.), Principles of Powder Technology. John Wiley and Sons, New York, NY, pp: 91-118.
45. Teunou, E. and J.J. Fitzpatrick, 1999. Effect of relative humidity and temperature on food powder flowability. J. Food Eng., 42: 109-116.
46. Emami, S. and L.G. Tabil, 2007. Friction and compression characteristics of chickpea flour and components. Powder Technol., 175: 14-21.
47. Puri, V.M., 2002. Characterizing powder flowability. Chem. Process. 65: 39-42. Quirijns, E.J. van Boxtel, A.J.B. van Loon, W.K.P. van Straten, G. (2005). Sorption isotherms, GAB parameters and isosteric heat of sorption. J. Sci. Food Agric., 85: 1805-1814
48. Fitzpatrick, J.J., 2003. Food powder flowability. In: Onwulata, C. (Ed.), Encapsulated and Powdered Foods. Taylor and Francis Group, New York, NY, pp: 247-260.