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INVESTIGATION OF AVALANCHE TIME AND CARR'S INDEX OF POULTRY LITTER POWDER AS FLOWABILITY INDICES

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ABSTRACT. The world's dependence on chemical fertilizer as the primary source for enriching agricultural fields is continually increasing that cause nature pollution. This has led researchers to aggressively investigate renewable fertilizer resources, biomass, to produce organic crops and reduced wastage. Poultry litter is a bulk solid and biomass feed stocks. Flow behavior of bulk solid is a critical factor in designing and developing suitable equipments (e.g. pelletizing machine). The bulk density, tap density, Carr's index and powder avalanche time technique were applied to evaluate the flow properties of poultry litter. The experiments were carried out at moisture content (10, 20 and 30% w.b.), particle size (0.3, 0.6 and 1.18 mm) for the bulk and tap densities as well as Carr's index. In addition to the moisture content (10, 20 and 30 %w.b.) and particle size (0.3, 0.6 and 1.18 mm) the rotational speed of drum (0.5, 1 and1.5 rpm) were also investigated for the avalanche time. The results showed that with increasing moisture content Carr's index increased significantly ($P<0.01$) in the ranges of 16.2% to 18.5% and with increasing particle size the Carr's index decreased from 20.35% to 14.78%. The litter powder avalanche time (AT) increased significantly ($P<0.01$) with increasing moisture content and decreasing rotational speed and particle size. The bulk and tap densities of the litter powder was decreased with increasing moisture content and increasing the particle size. The bulk and tap densities of the driest and finest poultry litter sample were higher than other ones.

Key words: Avalanche time; Compressibility index; Poultry litter; Flowability.

INTRODUCTION

The world's dependence on chemical fertilizer as the primary source for enriching agriculture and horticulture fields is continually increasing that cause nature pollutions (e.g. water contamination). This has led researchers; health and agriculture officials and government agencies to begin investigate for using biomass to produce organic crops, fertilizing soil,

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environmental protection and reduced amounts of byproduct wastage.

Biomass is biological material derived from living, or recently living organisms. Biomass can equally apply to animal and vegetable derived material including but not limited to agricultural wastes, food, feed and fiber crop residues, aquatic plants, forestry and wood residues, bio based segments of industrial and municipal wastes (Fasina, 2008).

Poultry litter is bulk solid and biomass feedstock, which is a combination of accumulated chicken manure, feathers, and bedding materials found in poultry houses (Bernhart, 2007). Integrated use of farmyard manure and poultry manure along with 100% NPK (Nitrogen, Phosphorous, Potassium) also resulted in significant increase in grain yield compared to 100% NPK alone (Behera *et al.*, 2007).

Similar to most other byproducts from agro-processing, poultry litter is lightly-dense and therefore cannot be efficiently and economically transported over long distances to areas where they can be effectively utilized (Mavaddati *et al.*, 2010). Furthermore, storage, dust and mechanization problems are another dilemma. So knowledge about flow properties of poultry litter powder is very important when developing powder process equipments and handling procedures (e.g. pelleting equipment machines).

Many studies have been carried out on mechanical properties of various biological, agricultural, and biomass materials that evaluated the effect of parameters such as moisture content and particle size (Balasubramanian, 2001; Nimkar and Chattopadhyay, 2001; Barbosa-Canovas *et al.*, 2005; Hassan-Beygi *et al.,* 2009). It was revealed that with increasing the moisture content of poultry litter the compressibility increased (Bernhart and Fasina, 2009). The best moisture content and particle size were determined for pellet formation of urban compost (Mavaddati *et al.*, 2010). Particle size and moisture content affected the pellet density of barley straw, corn stover and switch grass (Mani *et al.*, 2006).

Several methods are currently used to characterize powder flow including bulk and tap densities (Abdullah and Geldart, 1999), angle of repose, flow through an orifice (Bolhuis and Chowhan, 1996), and Jenike shear cell (Lee *et al.*, 2000; Staniforth, 2002). In the shear test powder flow occurs in response to applied stress (Munjack and Hogg, 2010). The novel avalanche time method (Kaye *et al.*, 1995) and Carr's compressibility index are further commonly used as markers of powder flowability (Nalluri and Kuentz, 2010).

An aero flow apparatus was developed in order to characterize the avalanching behavior of a powder rotated in a drum that can distinguish between poorly and freely flowing powders, blends and granulations (Kaye *et al.*, 1995). A simple stress (e.g. vibration or rotation) is applied to the sample powder until the powder shears and an avalanche occurs (Hancock *et al.*, 2004). This is of special interest because flowing process of blends is essentially complex, since flow properties are not only influenced by the physical-chemical material factors, but also, to a great extent, by the particle packing (Nalluri and Kuentz, 2010).

Avalanche process has three phases: the pre-avalanche, the avalanche, and the post avalanche (Lavoie *et al.*, 2002). In the pre-avalanche phase cohesion forces maintain particulate arrangement inside granular material (Rastogi and Klinzing, 1994). In the avalanche phase, an avalanche occurs when the balance between cohesion and gravity is broken. During the resting period following the avalanche, the powder slope changes.

In an avalanche a shorter avalanche time indicates that the powder flows more readily under the conditions of the test (i.e. low shear agitation in a dilated state). Thus, one might expect powders displaying a small avalanche time to be the easiest to blend in low shear mixers, such as in a twin-shell (Hancock *et al.*, 2004). Short and reproducible times between avalanches indicate a good flow characteristic, while long and/or irregular times indicate poor flow characteristics (Kaye *et al.*, 1995). One can discriminate between ordered mixtures with a relatively good flow but not between the more cohesive mixtures of this series (Thalberg *et al.*, 2004).

The most commonly used measure related to the particulate interactions is the compressibility index often referred to Carr's index (Carr, 1965). This suggested the compressibility of a powder material as an indicator of the tendency of the powder to flow; it is expressed as the ratio between the tapped density and the bulk density of powder (Thalberg *et al.*, 2004). Materials having Carr's index greater than 20 - 25 % are classified as non-free-flowing.

Knowledge about the flowing characteristics of poultry litter is very important when designing and developing litter processing and handling equipments. The objectives of the present research were to investigate the flowing characteristics of poultry litter powder using the avalanche time technique and Carr's index. The effect of the poultry litter powder moisture content, particle size and rotational speed of drum on the avalanched time were studied. The Carr's index was also investigated as affected by moisture content and particle size of the litter powder.

MATERIALS AND METHODS

Material preparation

The samples of hen litter used in this study were supplied from a chicken farm of the Veterinary Medicine College, University of Tehran, Iran. The experiments were carried out in the physical properties laboratory of the Agro-technology Department, Abouraihan College, University of Tehran. The samples were grinded using a hammer mill with three different hammer mill screen sizes (1.18, 0.6 and 0.3 mm). In order to evaluate the moisture content, the oven temperature was set at 105±3ºC and the samples were weighed every 30 minute until the weight difference between two consecutive weighings was less than 0.2% of the initial weight (Hassan-Beygi *et al.*, 2010). The sample was either dried in an oven set at 60ºC to reduce the moisture content or wetted by adding distilled water (Kingsly *et al.*, 2006) to increase moisture contents and stored at 5ºC in a cooled box for a minimum of 72 h.

Bulk density, tap density and Carr's Index

The bulk density (ρ_b) of the litter powder was determined using the mass and volume relationship, by filling an empty container of predetermined volume and weight (ASABE S269.4, 2002). The material was leveled across the top of the surface of the container and weighed. The tap density test was carried out using a tapper tester (*Figure 1*), according to ASTM Standard B527 (ASTM, 2005). A 250 ml graduated cylinder was filled with the ground poultry litter and weighed. The cylinder was placed in the tap density tester and was tapped (500 times) at a rate of 300 taps/min 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 poultry litter 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 greater than 2%, the process was repeated; otherwise the experiment was completed. The tap density (ρ_t) was measured after the completion of tapping. Carr's index was calculated using Equation (1).

$$\text{Carr's index} = \frac{100(\rho_b - \rho_t)}{\rho_b} \qquad (1)$$

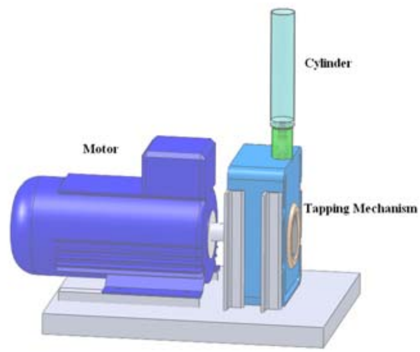

Figure 1 - Schematic of tapper tester

Avalanche time

The experimental apparatus is shown in *Figure 2*. It consisted of three horizontal drums made from Teflon with equal lengths of 150 mm and different inner diameters. The drums were driven by an electro-gear box motor using chain drive. The rotary speed of the electro-gear box was adjusted accurately by means of an inverter device. At the end of the drums a transparent glass plate was fixed, with for visual observation of the cross section of the poultry litter bed. The inner wall of the drum was lined with sandpaper of mean particle size of 100 µm to prevent slipping between the bed of poultry litter and the wall (Liu *et al.*, 2005; Thalberg *et al.*, 2004; Khazaei and Ghanbari, 2010). The drum was rotated after it was loaded with the poultry litter powder sample.

A digital Canon-PC1210 video camera with 10 mega pixel resolution was used to record the motion of the litter powder within the drum. The camera was placed in such a way that the centre of the camera lens pointed exactly to the centre of the rotary drum. During avalanche time testing, as the drum rotated, the movie was taken by means of the camera. The captured films were analyzed with Ulead Video Studio 11 Plus software, so that the time between successive avalanches was measured. The avalanche testing of poultry litter was conducted with the rotary drum with 150 mm inner diameter and 0.33 filling degree. The drum rotated with a rotational speed of 1, 1.5 and 2 rpm. In these rotational speeds and filling degree, the poultry litter bed powder was in the slumping mode. The particle size and moisture content of litter powder were 0.3, 0.6 and 1.18 mm and 10, 20 and 30 (%, w.b.), respectively. The data was statistically analyzed using the three factors completely randomized design in order to study the effects of rotational speed, particle size and moisture content on the avalanche time of the litter powder. Further, Duncan's multiple range tests was used to compare the means. Each experiment was replicated three times.

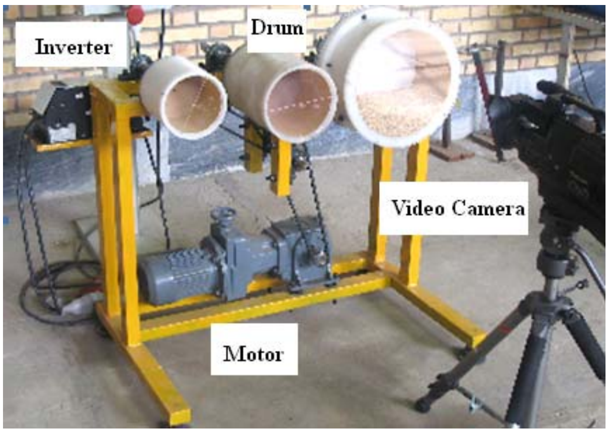

Figure 2 - Rotary drum used in this study

RESULTS AND DISCUSSION

Bulk and tap densities

The effect of moisture content on the bulk and tap densities of the poultry litter powder with different particle size is shown in *Figures 3* and *4*, respectively. The bulk and tap densities of poultry litter were varied from 0.360 to 0.607 gcm^{-3} and 0.415 to 0.702 gcm^{-3} , respectively within the moisture content range of 10 to 30 (%, w.b.) and particle size of 0.3 mm to 1.18 mm. As depicted from *Figure 3* the bulk density increased with decreasing the particle size at moisture contents of 10 and 20 (%, w.b.). The bulk density of poultry litter powder decreased when the moisture content increased in the range of 0.607 - 0.362 gcm^{-3} for 0.3 mm particle size, 0.544 - 0.361 gcm^{-3} for 0.6 mm particle size, and 0.508 - 0.360 gcm^{-3} for 1.18 mm particle size. *Figure 4* reveals that the tap density increased with decreasing the particle size at moisture contents of 10 to 30 (%, w.b.). The tap density of poultry litter powder was decreased with increasing moisture content in the ranges of 0.702 to 0.439 gcm^{-3} for 0.3 mm particle size, 0.683 to 0.428 gcm^{-3} for 0.6 mm particle size, and 0.632 to 0.415 gcm^{-3} for 1.18 mm particle size. This means that the rate at which the poultry litter 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 poultry litter will increase as moisture increases. The trend of reducing the bulk density when moisture content increases is similar to the reported bulk density-moisture content relationship for biomass (Fasina, 2008), granular biological materials (Balasubramanian, 2001; Deshpande *et al.*, 1993; Nimkar and Chattopadhyay, 2001) and three Mollic soils (Lucia and Martin, 2012).

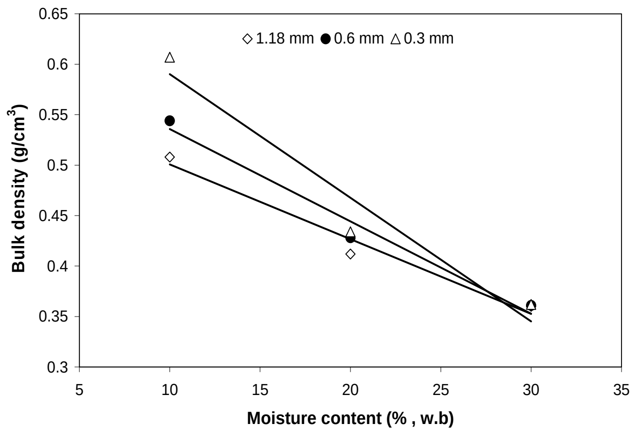

Figure 3 - Effect of moisture content on the bulk density of poultry litter powder for different particle size

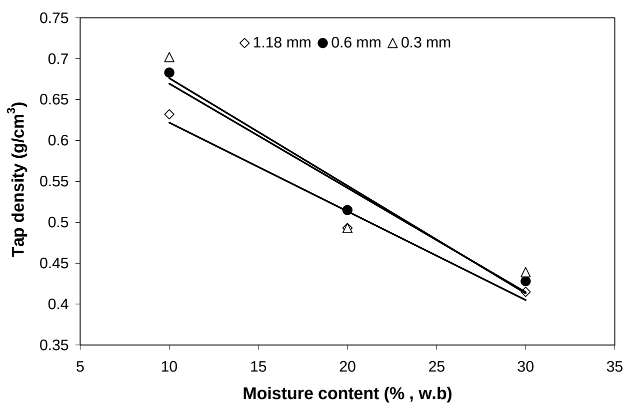

Figure 4 - Effect of moisture content on the tap density of poultry litter powder for different particle size

Carr's index

The results of the analysis of variance (ANOVA) showed that the effect of moisture content and particle size over the Carr's index was significant ($P<0.01$), while the interaction of the moisture content by the particle size over the Carr's index was not significant (*Table 1*). The effects of moisture content and particle size over the Carr's index are shown in *Figures 5* and 6, respectively. As shown in *Figure 5*, when increasing the moisture content from 10 to 30 (%, w.b.) the Carr's index increased significantly in the ranges of 16.2% to 18.5%. The increasing value of the Carr's index when increasing the moisture content may be attributed to the fact that bulk and individual particulates of the poultry litter were expanding volumetrically at a faster rate than it was gaining weight while absorbing moisture (Bernhart, 2007). A similar trend was also observed for other biological materials (Joshi *et al.*, 1993; Deshpande *et al.*, 1993).

As depicted from *Figure 6*, increasing the particle size led to the significant decrease of the Carr's index, from 20.35% to 14.78%, thus improving the poultry powder flowing characteristics. According to Bodhmage (2006) this could be due to the breaking of interparticle lack. A larger diameter is an indication of a lesser amount of fines in the powder bulk (Abdullah and Geldart, 1999).

Table 1 - Analysis of variance of effective parameters on the litter powder avalanche time and Carr's index

Source of variations	Degree of freedom	Avalanche time mean square	Carr's index mean square
Moisture content	2	2.04**	76.13**
Particle size	2	3.42**	13.66**
Rotational speed	2	210.93*	
Moisture content × Particle size	4	1.18**	0.2749ns
Moisture content × Rotational speed	4	1.10**	
Particle size × Rotational speed	4	0.50**	
Rotational speed × Particle size ×Moisture content	8	0.49 **	
Error	54	0.16	0.1779
C.V.	-	11.21	2.4045

**,*stand for significant at 1% and 5% probability levels, respectively, ns means non-significant

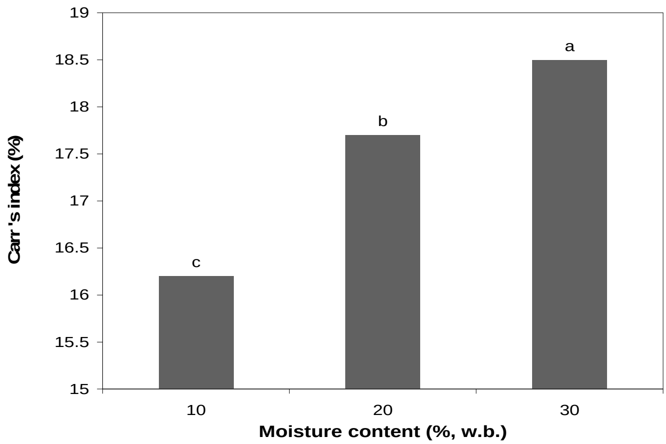

Figure 5 - Effect of moisture content of the litter powder over Carr's index

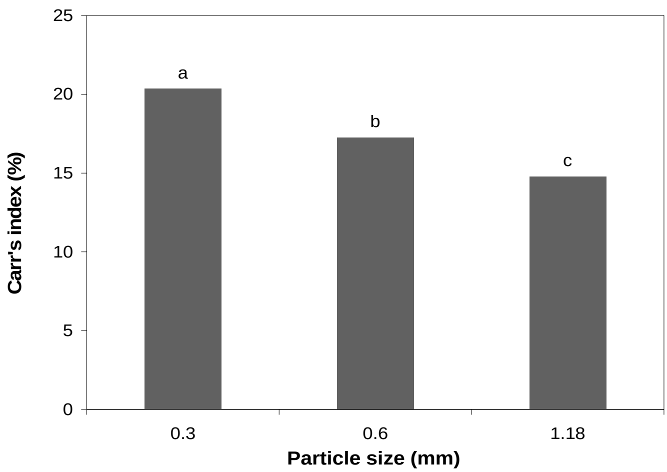

Figure 6 - Effect of particle size of the litter powder over Carr's index

Avalanche time

The results of analysis of variance (ANOVA) showed that the effects of moisture content and particle size over the litter powder avalanche time were significant ($P<0.01$). The effect of drum rotational speed over the litter powder avalanche time was significant ($P<0.05$). The interactions of the moisture content × the particle size, moisture content × rotational speed and particle size × rotational speed as well as the triple effect of parameters were significant on the poultry powder avalanche time (*Table 1*).

The interaction of particle size × moisture content on the litter powder avalanche time (AT) is shown in *Figure 7*. As depicted from this figure, with the increase of moisture content from 10 to 30 (%, w.b.) the AT was increased significantly (P<0.01) in the range of 3.13 to 4 seconds for the 0.6 mm particle size and of 2.7 to 3.86 seconds for the particle size of 1.18 mm. The variation of AT with moisture content was not significant for the particle size of 0.3 mm. It is clear that increasing the particle size from 0.3 to 1.18 mm led to a significant decrease of AT (P<0.01), from 3.8 to 2.7 seconds for the moisture content of 10 (%, w.b.) and from 3.9 to 3.26 seconds for the moisture content of 20 (%, w.b.). The variation of AT with particle size was not significant for the moisture content of 30 (%, w.b.). The maximum AT was recorded for the moisture content of 30 (%, w.b.) and the particle size of 0.3 mm and may be contributed to the higher cohesiveness of the litter powder (due to higher level of moisture content and stronger connection among the litter particles).

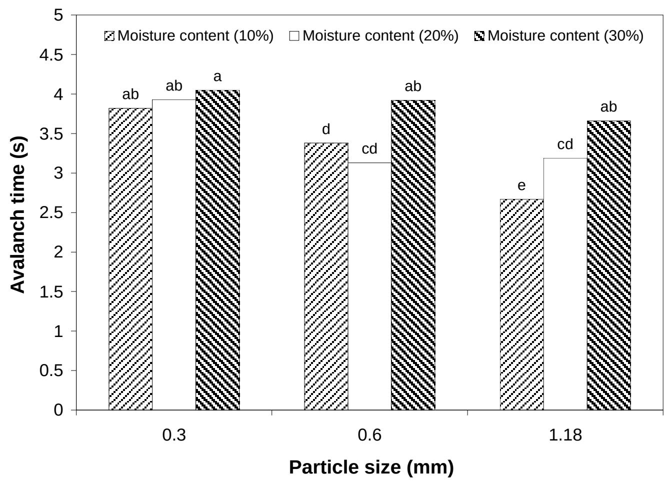

Figure 7 - The interaction of particle size by moisture content on the litter powder avalanche time

Figure 8 shows the interaction of rotational speed by moisture content on the litter powder avalanche time. According to this figure, increasing the moisture content in the range of 10 to 20 (%, w.b.) increased the AT significantly (P<0.01) for all the rotational speeds, although a further increase in moisture content, from 20 to 30 (%, w.b.), did not increase the AT significantly. The AT increased in the ranges of 6.2 to 7.01 seconds for the 0.5 rpm drum rotational speed, 2.12 to 3.12 seconds for the 1 rpm drum rotational speed, and 0.86 to 1.46 seconds for the 1.5 rpm drum rotational speed. Decreasing the AT with increasing moisture content can be attributed to higher cohesiveness among the constituent particles of the poultry litter. As depicted from the figure, with increasing the rotational speed of the drum the AT was decreased significantly (P<0.01) for all moisture contents. This decreasing was due to more unstable condition of bulk solid and indicated the poorer flow characteristics of the poultry litter when increasing moisture content. Shear tests proved that increasing moisture content has a decreasing effect on the flowability of biomass material (Bernhart and Fasina, 2009).

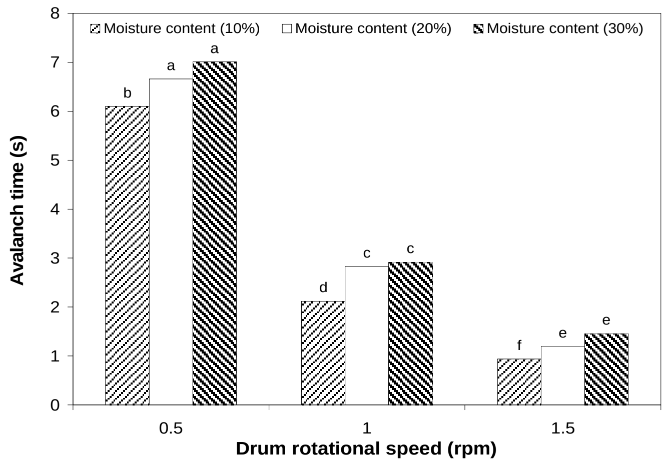

Figure 8 - The interaction of rotational speed by moisture content on the litter powder avalanche time

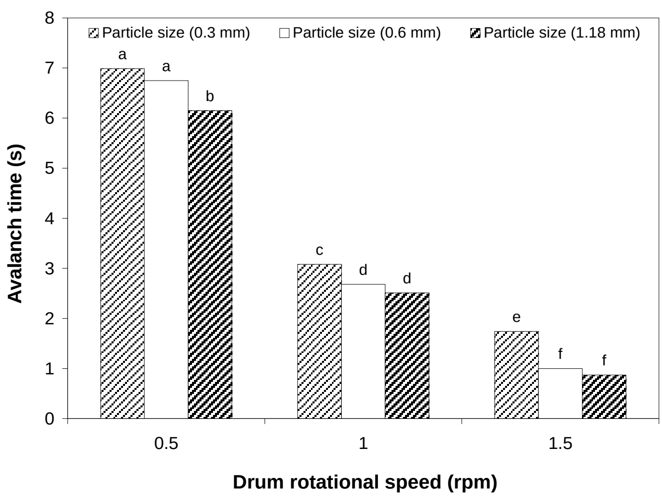

Figure 9 - The interaction of rotational speed by particle size on the litter powder avalanche time

The interaction of drum rotational speed by particle size on the litter powder avalanche time (AT) is shown in *Figure 9*. As depicted from this figure, with increasing the particle size from 0.3 mm to 1.18 mm the AT decreased significantly for all of the rotational speed levels. This decreasing trend could be due to less inter particle lock with increasing particle size. When the rotational speed of rotary drum increased the AT decreased significantly ($P<0.01$), for all of the particle size levels. Previous research on the flow characteristics of powders with an avalanche testing instrument revealed that when increasing the rotational speed the avalanche time decreased (Hancock *et al.,* 2004).

From *Figures 7* to *9* it can be stated that when increasing the moisture content and decreasing the rotational speed the AT increased. When increasing the particle size the AT decreased significantly. Increasing value of the AT with moisture could be attributed to particle cohesiveness and increase in liquid bridges and capillary forces acting between the powder particles, reducing the litter flowability. Decreasing the AT with particle size could be attributed to the weak connections between particles.

CONCLUSIONS

The average values of bulk density, tap density, Carr's index and avalanche time were 0.44 g/cm^3, 0.53 g/cm^3, 17.54% and 3.53 s, respectively.

The bulk and tap densities were decreased with increasing the moisture content and the particle size: the maximum densities were achieved by the driest and finest poultry litter powder.

The effect of the moisture content and particle size over the Carr's index of the litter powder showed that the litter powder flowability decreased when increasing the moisture content and decreasing the particle size.

The shorter time of avalanche, the better flow characteristics; the avalanche time was higher for the cohesive samples than for the less cohesive samples. The litter powder flowability decreased with increasing moisture content and decreasing drum rotational speed and particle size form AT point of view.

The obtained data is important for the design of hoppers, conveyers and facilities for poultry litter, as well as for the handling and processing equipment such as pellet processing.

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