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Poultry litter angle of wall friction

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Abstract: Dependence on chemical fertilizer is continually increasing. Continual increasing of using chemical fertilizer causes nature pollution (e.g. water contamination). This has led researchers to aggressively investigate renewable fertilizer resources and biomass to produce organic crops and reduced wastage. Poultry litter is a bulk solid and biomass feed stocks. The angle of wall friction (AWF) is a critical factor in designing and constructing suitable equipment for pelletizing. The results of this study showed that the simple effects of the moisture content (M) and surface types (S) as well as interaction of the S × particle size (P) and S × M were significant (P<0.01) on the AWF of the litter powder. As well, the effect of particle size was significant (P<0.05) on AWF. The average values of the AWF of poultry litter on the friction surfaces were in the range of 25 to 39 degree. With increasing moisture content and particle size the AWF decreased. The maximum values of AWF were occurred for steel, galvanized and aluminum surface, respectively.

Keywords: Jenike, kinematics, litter, poultry, wall friction

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1 Introduction

Chemical fertilizer is the primary source for enriching agriculture and horticulture fields. The widespread usage of this fertilizer causes some environmental pollution. Therefore, agriculture research workers lead to begin investigation for using biomass to produce organic crops, protect environment and reduce the amounts of by-product wastage. Biomass is organic materials including agricultural wastes, food, feed and fiber crop residues, aquatic plants, forestry and wood residues, and 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). The poultry litter contains high levels of nitrogen (4.0%), phosphorous (1.6%) and potassium (2.3%), and also low quantity of calcium, magnesium, manganese, copper and zinc (Bernhart and Fasina, 2009). Similar to the most of other by-products 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. Furthermore, storage, dust and mechanization problems are another dilemma.

Densification of poultry litter by pelletizing is the effective way to reduce their transportation and storage costs, no dust production, suitable for mechanization by implanting or scattering, ability of adding chemical materials for more enriching (Mavaddati et al., 2010).

Powder of poultry litter is stockpiled in conical hopper silo and often gravity discharged from the bottom. At discharge time, mass flow and funnel flow may be occurred. In the mass flow, particles flow uniformly when the outlet is opened. During the funnel flow, only some of the material flows when the outlet is opened while the rest remains stagnant. This may lead to rat holing, increased segregation and tendency of degradation in the

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stationary region. The mass flow of bulk solids also may cause problems such as arches. When arches formed within silos flow is halted. The rat holing and arching are common in discharging powder from hopper which can disturb the flow process. So, the wall friction is the critical parameter in the structural design, operation and stability of silos which was determined whether mass flow or funnel flow discharge will occur (Iqbal and Fitzpatrick, 2006).

Wall friction angle, φ_w, is the arc tangent of the coefficient of sliding friction between the bulk solid and hopper wall material. A suitable method for determining angle of wall friction in the literatures is Jenike's test (Schulze, 1996a, b; Bernhart and Fasina, 2009; Schulze, 2008b; Wu et al., 2011). It has investigated that both the Jenike's test (off-line tester) and the online tester showed the same trend, though there are some variations seen quantitatively (Pillai et al., 2007). The main disadvantage of the Jenike's test is difficult to conduct it (Schulze, 1996a, b). The results of Jenike's test are often used to determine the minimum hopper angle and the opening size for a mass flow system (Fitzpatrick et al., 2004). The knowing of wall friction angle could be contributed to decide whether or not the use of a liner or polishing of the wall surface (Schulze, 2008a). The wall friction angle is a complex subject because affected by many factors such as moisture content, material source (effecting the chemical composition) and type of structural wall surfaces (Prescott et al., 1999).

Since years ago, several studies have been performed on mechanical properties of various biological, agricultural, feedstock and biomass materials. The most of these studies have evaluated the effect of the parameters such as moisture content, particle size and equipment's wall types (Balasubramanian, 2001; Barbosa-Canovas et al., 2005; Nimkar and Chattopadhyay, 2001; Ima and Mann, 2007). It has revealed that with increasing the moisture content of poultry litter the compressibility increased. As well, modifying the surface types reduced the angle of wall friction of poultry litter (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 significantly affected the pellet density of barley straw, corn stover and switch grass but different particle sizes of wheat straw had not significant effect on pellet density (Mani, Tabil, and Sokhansanj, 2006). The optimum design of the processing equipment is critically dependent on the frictional behavior of the equipment wall (Adams et al., 1998). External friction analysis was investigated for some biomass materials (Shaw and Tabil, 2007)

The literature survey revealed that, there is no reported study on the effect of moisture content, particle size and surface types of equipment's wall simultaneously on the poultry litter angle of wall friction. The objective of this study is to investigate angle of wall friction of poultry litter as affected by moisture content, particle size and surface materials of equipment's wall using Jenike's methodology.

2 Materials and methods

Poultry litter was used in this study supplied from a chicken farm of veterinary medicine collage, University of Tehran, Tehran, Iran. The experiments were performed at physical properties laboratory of Agro-Technology Department, Abouraihan College, University of Tehran. The poultry litter was ground by hammer grinder. The powder litter was sized by standard sieves to three particle mesh sizes with numbers of 16, 30 and 50. The dimensions of each mesh sizes are shown in Table 1.

Table 1 Dimensions of mesh sizes according to ASTM E-11-70 (Part 41)

Mesh size number	Diameter /mm
50	0.30
16	1.18
30	0.60

The moisture content of the poultry litter was determined using air oven method. The oven temperature was set at 105±3℃ and the samples weighed every 30 min until the weight difference in two consecutive weighing was less than 0.2% of initial weight (Hassan-Beygi et al., 2011). The initial moisture content of the poultry litter sample was 20% wet base (w.b.). To adjust the moisture content of the sample to the desired levels that is 10%, 20% and 30% (w.b.), the poultry litter was either dried in an oven set at 60℃ or by adding distilled water (Kingsly et al., 2006). In both cases the samples were stored in an air tight container at 5℃ in a refrigerator for 24 h to allow moisture equilibration to take place.

The Jenike's shear test was used to determine the angle of wall friction as recommended by Schulze (2008b). The Jenike's shear tester was developed by Valaei et al. (2011). The three main components of this device including a shallow stainless steel ring with diameter of 95 mm, a driving unit (AC electric motor, inverter and reduction unit) and a data acquisition (load cell with resolution of 0.2 N, indicator, PC interface and software). The steel ring was rested on a sample of wall material which was fixed to the base plate of the tester (Figure 1 and Figure 2).

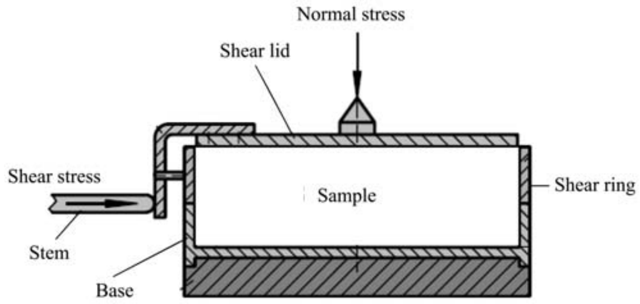


Figure 1 Shematic of Jenike's shear test

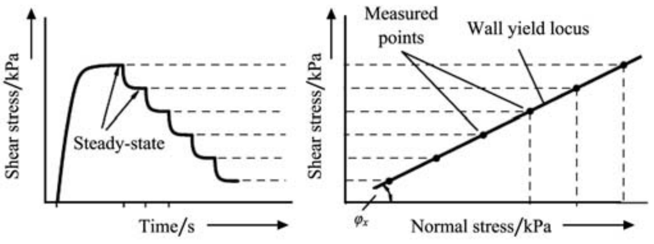
Figure 2 Jenike's shear tester used in this study which was developed by Valaei et al. (2011)

The poultry litter powder is compressible, so excess quantity provided to ensure full filling of the steel ring. A mould ring was placed on the steel ring. The volume of both rings was filled by the poultry litter sample. To consolidate the poultry litter sample within the rings a solid lid was placed on the top of the mould ring and compressed by 100 N loads. After this pre-compaction, the load, mould ring and lid were carefully detached from the steel shear cell ring and excess material was scraped with a knife.

The poultry litter sample, within the shear ring, was moved relative to the different wall friction surfaces. The various normal loads were applied to the lid during measuring the wall friction. The test was started with the greatest normal load which produced normal stress of 16 kPa and $\sigma_w = 16$ kPa, once a constant shear stress has been attained (Figure 3a) then the normal load decreased to diminish the normal stress value to 13 kPa. Whenever a constant shear stress has been reached again the normal stress decreased to 10 kPa. The process of decreasing the normal loads was continued to attain the normal stress values of 7 and 4 kPa. The pairs of the normal stress, σ_w, and shear stress, τ_w, in each stage were plotted in a $\sigma_w - \tau_w$ coordinate system. A linear curve was fitted through the points (Figure 3b). Slope of the fitted linear curve is the wall friction angle (Equation (1)).

$$\mu = \tan(\varphi_x) \tag{1}$$

where, μ = coefficient of wall friction, and φ = angle of wall friction /degree.



a. Shear stress versus time b. Shear stress versus normal stress

Figure 3 Wall friction test

The data was statistically analyzed using the three variables factorial experiments with basic completely randomized design to study the effects of wall materials, particle size and moisture content on the angle of wall friction. The wall materials used for friction testing in this research work were aluminum, steel and galvanized steel due to common application of these materials in design and development of silos, hoppers, bunkers and chutes in biomass storage and transportation industry. During testing, the surface of various materials was prepared with dimension of 20×20 cm^2, and no polishing was carried out.

3 Results and discussion

The Jenike's test of poultry litter was conducted at 27 treatments, three types of wall materials, three levels of particle size and three levels of moisture content. Each treatment was replicated three times. The results of analysis of variance (ANOVA) of the moisture content, the friction surface types and the particle size on the angle of wall friction (AWF) were given in Table 2. As depicted from this Table, the effects of the moisture content and surface types were significant ($P<0.01$) and the particle size effect was significant ($p<0.05$) on the AWF values. Furthermore, interaction of the surface types × the particle size and the surface types × the moisture content as well as the triple effect of the surface types × the particle size × the moisture content were significant ($P<0.01$) on the AWF.

Table 2 Analysis of variance of effective parameters on the angle of wall friction (AWF)

Source of variations	Degree of freedom	Mean sum of squares
Surface types	2	337.5**
Moisture content	2	25.5**
Particle size	2	9.7*
Surface types × moisture content	4	126.5**
Surface types × particle size	4	8.6**
Moisture content × particle size	4	2.38^{ns}
Surface types × particle size × moisture content	8	19.69**
Error	54	1.96
C.V.	-	4.16

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

The effects of particle size, surface type and moisture content on the AWF are shown as Figure 4, Figure 5 and Figure 6 respectively. As shown in Figure 4 with increasing in particle size from 0.3 to 1.18 mm the AWF was decreased significantly ($P<0.01$) from 33.1° to 33.6°. However, with increasing particle size from 0.3 mm to 0.6 mm and from 0.6 mm to 1.18 mm the AWF was not decreased significantly. Figure 5 shows that with surface replacement from steel to galvanize steel and aluminum respectively the AWF was decreased significantly ($P<0.01$) in the ranges of 37.2° to 30.2°. It is also clear from Figure 6 that with increasing moisture content from 10% (w.b.) to 30% (w.b.) the AWF was decreased significantly ($P<0.01$) in the ranges of 34.7° to 32.7°.

Previous research for preparation pellets by urban waste compost showed the similar trend for affection of particle size and surface types for example iron and aluminum on coefficient of friction, also their interaction had significant effect on coefficient of friction (Mavaddati et al., 2010). With an exaggerated view, the decreasing value of the AWF with increasing moisture content could be contributed to present of band water in poultry litter bulk solid processes that cause to create a thin layer of water in contact with frictional surfaces.

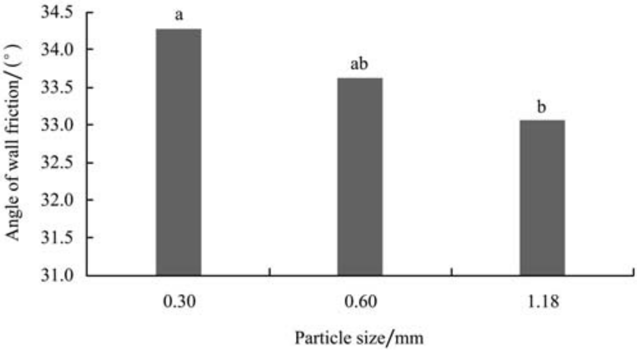


Figure 4 Effect of particle size on the AWF of litter powder

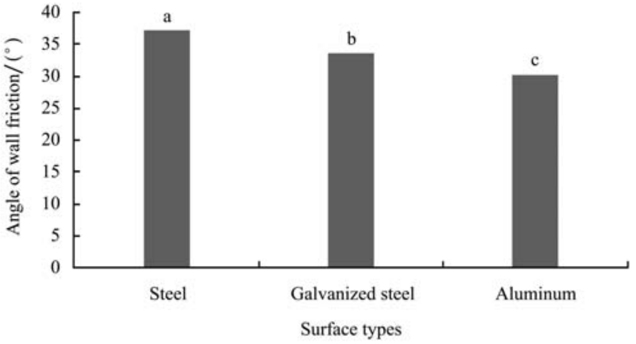


Figure 5 Effect of surface type on the AWF of litter powder

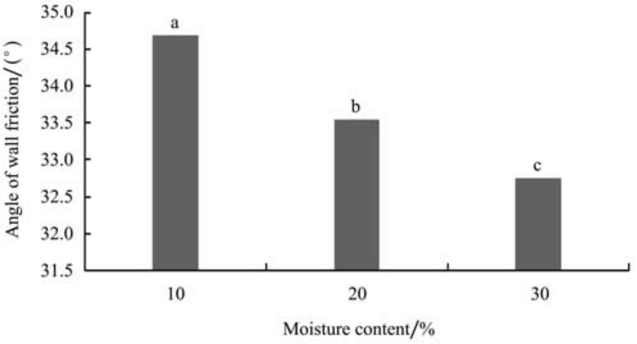


Figure 6 Effect of moisture content on the AWF of litter powder

The interaction of the surface types by moisture content on the AWF is given in Figure 7. As shown in this Figure there was significant difference among the mean values of the AWF of poultry litter on all of the friction surfaces. There was significant difference (P<0.01) among the mean values of the AWF of poultry litter on aluminum surface in 10% moisture content level from those of 20% and 30% moisture content level. The significant difference (P>0.01) was not observed among the mean values of the AWF on steel surface in all moisture content levels. Also there was no significant difference (P>0.01) between the mean values of AWF on galvanized steel. The maximum values of AWF were related to steel, galvanized steel and aluminum surface respectively for each moisture content level (Figure 7). The maximum values of AWF on steel surface could be contributed to more roughness of steel than the other surfaces. Previous research for determining coefficient of friction of saffron (*Crocus sativus* L.) flower and its components by using inclined plane method on steel, galvanized steel and polyethylene sheet surfaces revealed the friction coefficient of flower on galvanized steel was lower than that of steel and polyethylene and the friction coefficient for all of the components was the minimum on galvanized steel (Hassan-Beygi et al*.,* 2011). In compare with steel and galvanized steel, there is a possibility for hoppers, bins and other equipments in contact with poultry litter related to pellet machine that are made from aluminum with low wall friction due to existence the lowest AWF of poultry litter on the aluminum surfaces.

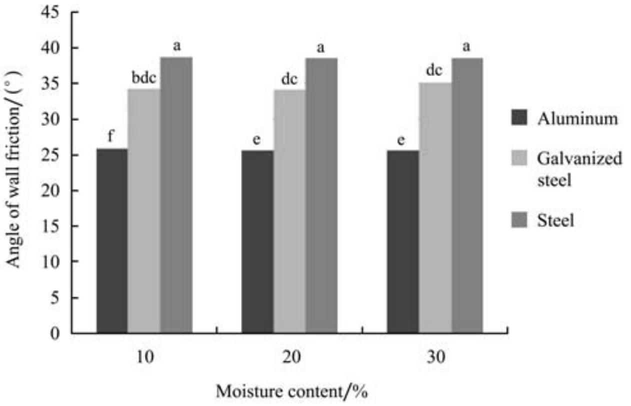


Figure 7 Interaction of moisture content × surface types on the AWF. Letters indicate that means with the same letters are not significantly different at $P = 0.01$

The interaction of the surface types by particle size on the AWF is given in Figure 8. As depicted from this picture, there was significant difference among the mean values of AWF of all the friction surfaces for each particle size. The maximum values of AWF were related to steel, galvanized steel and aluminum surface respectively in each mesh size. As the results with increasing particle sizes from 0.3 mm to 1.18 mm the AWF was not decreased significantly for steel surface. Also, for aluminum and galvanized steel surface types there was no significant difference between the mean values of the AWF with increasing particle size from 0.3 mm to 0.6 mm, but the results revealed with increasing mesh size the AWF had significantly (P<0.01) tendency to decrease. The maximum mean value of the AWF (37.9°) was for steel surface type at particle size of 0.3 mm, which might be contributed to more roughness of steel surface than the other surfaces and decreasing particle mesh size. The lowest mean value of the AWF (28.9°) was for aluminum surface at particle size 1.18 mm, which might be contributed to the smoothness of aluminum and increasing particle size.

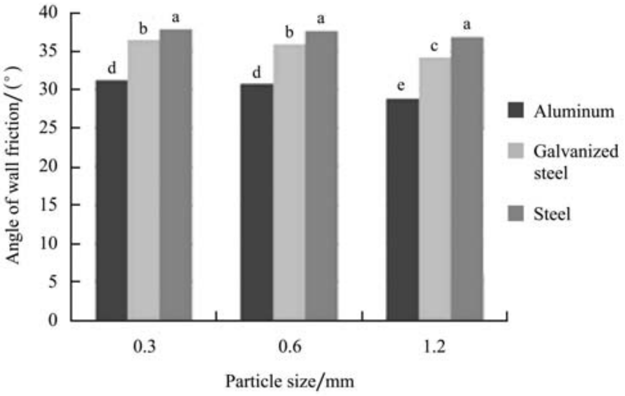


Figure 8 Interaction of the surface types by mesh size on angle of wall friction. Letters indicate that means with the same letters are not significantly different at $P = 0.01$

4 Conclusions

The test results show that the maximum values of AWF was occurred for steel surface, galvanized surface and aluminum respectively. Moisture content and particle size had a significant decreasing effect on the angle of wall friction of poultry litter powder.

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