Livestock manure management and pelleting

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Abstract: Densification of livestock manure, such as pelleting, can increase bulk density, improve storability, reduce transportation costs, and make these materials easier to handle using existing handling and storage equipment for grains. Determination of physical and rheological properties of composted manure is necessary to obtain the parameters related to designing and constructing a suitable pelleting machine for producing compost pellets. The objectives of this research were to study the physical properties, friction characteristics, and shearing behavior of composted cattle manure. The following properties, particle size distribution, bulk density, angle of repose, friction coefficient and shear strength were investigated, and the effects of moisture content (20%, 30%, 40%, 50% and 60%) and particle size (0.3, 0.6, 1.18 and 2 mm) on these properties were studied. The results show that the moisture content and particle size are critical parameters to design pelleting machine. It was found that the effects of moisture content and particle size on all measured parameters were significant.

Keywords: livestock manure, densification, pelleting, physical properties, moisture content, particle size

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1 Introduction

Livestock manure is an important resource for agriculture, because it contains a high level of nutrients and organic matter. In Iran, the number of livestock and quantity of livestock manure has been increasing. The total amount of livestock manure produced each year has now reached 100 million tons. The nitrogen content of this manure has been estimated at 7.5 million tons. However the direct use of animal wastes poses health and environmental risks that should be treated accordingly. Stabilization involves the decomposition of a waste substance to the extent where the hazards are eliminated, and is normally reflected by decreases in microbial activity and concentrations of labile compounds (Benito et al., 2003). Stabilization therefore reduces the environmental problems associated with the management of manure by transforming it into a safer and more stabilized material suitable for application to soil (Carr et al., 1995). Composting and vermicomposting are two of the best-known processes for the biological stabilization of solid organic wastes. Composting involves the accelerated aerobic degradation of organic matter by microorganisms under controlled conditions, in which the organic material undergoes a characteristic thermophilic stage that allows sanitization of the waste by the elimination of pathogenic microorganisms (Lung et al., 2001). Vermicomposting is a special composting process that involves the addition of certain species of epigeic earthworms to enhance the conversion of organic wastes (Edwards, N.Q., and Arancon, N.Q., 2004). Manure compost provides a stable organic matter that improves the physical, chemical, and biological properties of soils, thereby enhancing soil quality and crop production. Despite all the benefits of manure compost or any other compost, agricultural use of composts remains low for several reasons: 1) The product is very bulky that making it expensive to transport and use. 2) The nutrient value of compost is low compared

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with that of chemical fertilizers. 3) The nutrient composition of compost is highly variable compared to chemical fertilizers.

An effective solution is to apply densification technology. The densification process and pellet production is able to convert manure into a compressed form with advantages in transportation, handling and storage (Bhattacharya S. C., S. Sett, and R. M. Shrestha, 1989) and adjusting the nutrient content by adding material requirements. Single screw extruder is one of pelleting machine that has a barrel into which the raw material is forced by a screw. The material is then compressed into the die installed at the end of the machine, producing the pellet (Figure 1). One of the requirements to design, construct or improve designs in densification systems is based mainly on the knowledge of material variables (content and distribution of moisture, size and shape of particles, size distribution of particles, biochemical and mechanical characteristics) (Rehkugler G. E. and W. F. Buchele, 1969).

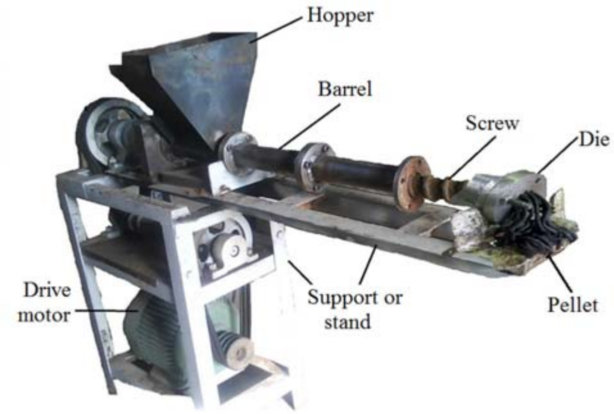

Figure 1 Single screw extruder

Since last years, several studies performed on physical and rheological properties of various biomass materials. Kumar, M., H. D. Bartlett and N. N. Mohsenin (1972) studied the flow properties of animal waste slurries. Glancey J. L. and R. K. Adams (1996) identified maximum lump size and moisture content as the physical properties presenting potential problems in raw manure conveying. Glancey J. and Hoffman (1996) measured the following properties: bulk density, moisture content, angle of repose, maximum lump size and static frictional characteristics. Agnew et al. (2003) used an air pycnometer to measure the air volume and density of compost. The free air space (FAS) and bulk density of manure compost, municipal solid waste compost, and mixtures of biosolids and amendment materials were measured at various moisture contents and compressive loads. Landry and Laguë (1999) studied selected physical properties of papermill residues. They measured bulk density, moisture content, angle of repose, friction coefficient over different materials and particle size distribution. Mohee, R. and A. Mudhoo (2005) evaluated some physical properties such as bulk density, moisture content, free airspace and etc, for feedstock compost. Ima, C. S. and D. D. Mann (2007) studied the effect of moisture content on bulk density, angle of repose, and coefficient of friction for wood chip. The objectives of this research were to study the physical properties, friction characteristics, and shearing behavior of cattle and poultry manure and evaluation effect of moisture content and particle size on these properties.

2 Material and methods

2.1 Sample preparation

Physical properties of cow manure is very variable. Also, properties of fresh and composted manure are different. So composted manure used in this study was obtained from animal husbandry around the Tehran that was accumulated more than one year and the processing period was completed. Dry manure was prepared and it was used in all experiments. The manure samples were ground using a laboratory mill.

2.2 Moisture content

Moisture content is a key environmental factor that affects many operational aspects of the pelleting machine, screw extruder particularly. This greatly influences the strength and the processing speed of the pellet. The moisture content of compost used in this study was 12% that obtained from placing the compost samples in oven at (105±3)℃ for 48 h (ASAE Standards, 1998). The best moisture content of composted manure is about 40% for an extruder (Hara, 1998). Therefore samples with moisture content between 20% and 60% were prepared to investigate the effect of moisture content. For sample preparation with the desired moisture content according to following equation samples were wetted by sprinkling water and stored in a cooler at 4℃ for a minimum 72 h.

$$m_w = \frac{m_1(MC_1 - MC_2)}{1 - MC_1} \quad (1)$$

where, m_w is mass of added water, g; m_1 is initial mass of sample, g; MC_1 is initial moisture content of sample, wet weight basis, %; MC_2 is final moisture content of sample, wet weight basis, %.

2.3 Particle size distribution

In the pelleting process to compress and bind the particles together, size of particle is very important so for production of pellet with desirable quality, particle size distribution of manure must be determined. Particle size distribution of manure was determined by using the screens that arranged from the largest to the smallest opening. American series screen numbers 10, 16, 30 and 50 according to ASTM E-11-70 (sieve sizes: 2, 1.18, 0.6 and 0.3 mm, respectively) were used and the screens were finally weighed on a laboratory scale to determine the amount of manure retained on each screen.

2.4 Bulk density

Pellets production is based on changes or increase of volumetric weight. Having volumetric weight or bulk density of material is essential. In this research, bulk density was measured by a device according to the specifications of ISO3923/1 standard as mentioned by Wong A. C.(2000). The opening of a conical funnel was blocked with a plug and powder material was charged in it. A graduated cylinder was placed exactly below the funnel opening. When the plug from the funnel was removed, the powder filled the cylinder directly underneath it. Bulk density was calculated by dividing the mass of the material by the volume of the material (Equation(2))

$$\rho = \frac{m}{V} \quad (2)$$

where, ρ is bulk density, kg/m^3; m is mass of sample, kg; V is volume of graduated cylinder, m^3.

2.5 Angle of repose

Standard of ISO3435 indicates the use of the angle of repose for quantifying the cohesiveness of a granular material (Cain, 2002). Cohesiveness of a granular material is important parameter that influenced compressibility of material. The static angle of repose is the angle made by a pile of material with the horizontal. The device used to measure the static angle of repose in the current study consisted of a glass conical funnel, with an outlet diameter of 0.9 cm, fixed on a metal stand, as shown in Figure 2. The funnel outlet was kept at a height of 6 cm above the base as per ISO3435/1. A digital camera was positioned exactly in front of the funnel to take digital images, which were then analyzed for static angle of repose using the computer software (Figure 3).

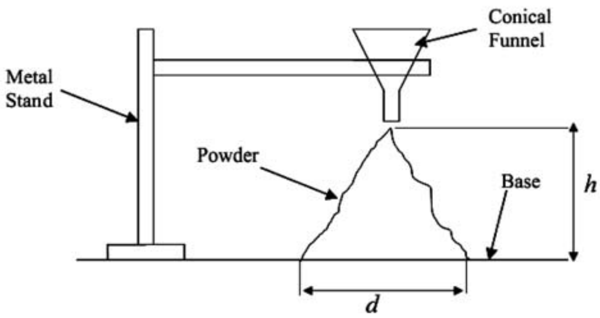

Figure 2 Measurement of static angle of repose

Figure 3 Tracing lines on diagonal faces of compost triangle

Static angle of repose showed in Figure 2 can be determined by:

$$\alpha = \arctan \frac{2h}{d} \quad (3)$$

2.6 Friction characteristics

Due to manure contact with barrel, screw and hopper, evaluation of manure friction coefficient in different particle size and moisture content for a proper design is essential. The values of the static friction coefficient of manure products on different surface materials were measured using the inclined plane method (Mohsenin N. N., 1986). Two different surfaces, representative of possible candidate materials for the construction of hopper, barrel and screw, were selected: galvanized iron and black steel. An inclined plane apparatus was designed and built to measure the static coefficients of friction of manure products (Figure 4). For performing the test a metal square frame with 10 cm×10 cm cross section and five centimeters height, while its top and bottom faces was open, used and filled with compost. For preventing friction between frame and friction surfaces, frame moved about 5 mm. The slope of sliding can be increased by spinning the handle on apparatus. At the position that frames with compost started to move, the tangent of angle made by height and length, showed in Figure 4 can be determined by:

$$\mu = \tan\theta = \frac{H_1}{L_1} \qquad (4)$$

where, H_1 the height of friction surface and L_1 is the length of horizontal image of friction surface.

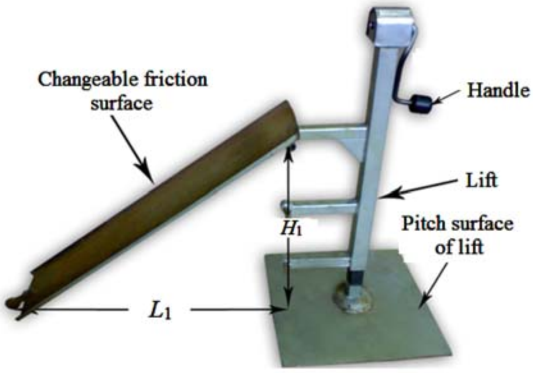

Figure 4 Apparatus used to measure the coefficient of friction

2.7 Shearing properties

Shear strength of manure is one of the most important parameters that affecting energy consumption in extruder also is a key property of interest for flow considerations of bulk materials. We have selected a shear vane apparatus to measuring the shear strength. The standard size 19 mm diameter by 29 mm high vane blade including shaft with thread for connecting directly to vane head or to extension rods (Figure 5). Hold the shear vane to the manure surface and push the vane blade into the manure to a depth at least twice the length of the vane blade, usually 70 mm to 80 mm and which is sufficient to ensure that shearing will take place on the vertical edges of the vane blade without movement of the undisturbed manure surface. The rotation causes shear of manure along the surface which is generated by vane. The torque which is necessary to rotate the vane is measured by a torque meter. For the calculation of the vane shear strength τ the maximum torque is dividing by a constant:

$$\tau = \frac{M}{K} \qquad (5)$$

where, τ is shear strength, N/m^2; M is maximum torque, N.m; K is a constant depending on dimensions and shape of the vane, m.

$$K = \pi D^2 \frac{H}{2} \times \left(1 + \frac{D}{3H}\right) \times 10^{-6} \qquad (6)$$

where, D is overall width of vane measured, m; H is the height of vane, m.

All experiments in this research were performed in triplicate and the mean of result was considered.

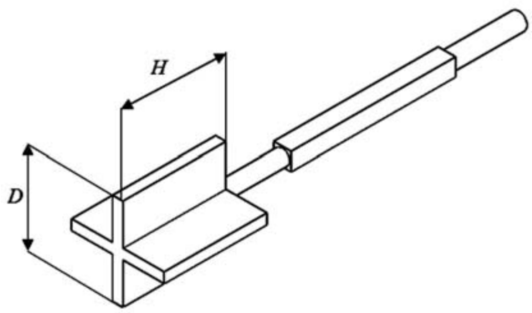

Figure 5 Schematic diagram of shear van used to shear strength measuring

3 Results and discussion

Results from particle size analysis are shown in Figure 6. It was determined that the most percent of particle size is smaller than 1.18 mm (16 mesh number) and the least percent larger than 2 mm (10 mesh number), but particles in the undisturbed dry manure are larger. Figure 7 shows the average bulk density of manure. It can be observed that the sample with larger particle have lower bulk density and in the all sample increasing of moisture content increase the bulk density. The liner regression equations describe the relationship between the angle of bulk density (ρ) and moisture content wet basis percent (MC) for all particle size and the regression coefficient of the fit were as follows.

$$\rho = 17.13\,MC - 2 \qquad (7)$$

(R^2= 0.99, for manure with 50 mesh size)

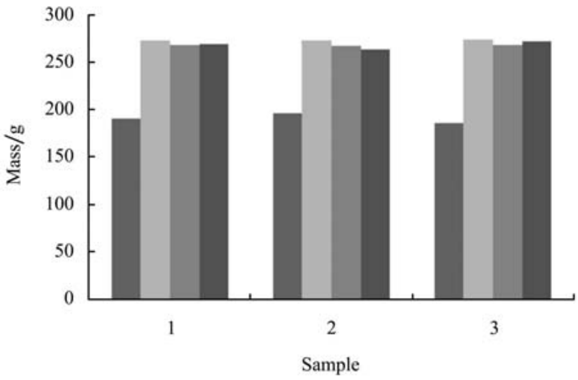

Figure 6 Results of particle size for composted manure

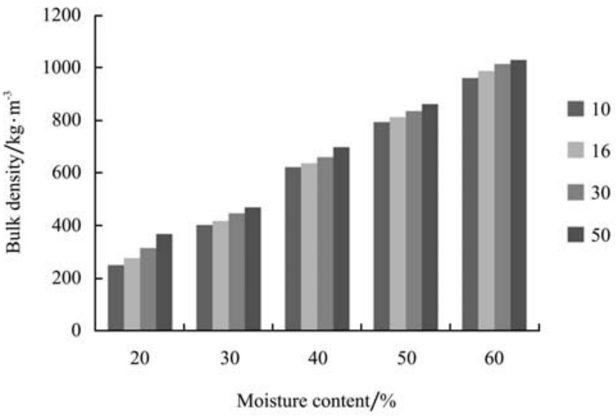

Figure 7 Diagram of bulk density

The effect of moisture content and particle size on angle of repose is shown in Figure 8. The static angles of repose decreased with increasing mean particle diameter. Smaller particles tend to have a greater number of contacts with neighboring particles. Thus, while measuring the static angles of repose, small particles are able to form a more dense packing which prevents the particles from rolling and hence increases the angle. Large particles cause failure of the slope by pushing other particles, hence avalanches happen more frequently and therefore lower the angle of repose values. The angle of repose increased linearly with the moisture content in all the particle size distribution, which can be seen in Figure 8.

$$\alpha = 0.079\,MC + 24.01 \quad (8)$$

(R^2 = 0.974, for manure with 50 mesh size)

Data obtained for coefficient of friction galvanized iron and black steel are shown in Figure 9 and Figure 10. The results show that the effect of moisture content, particle size and surface materials on coefficient of friction is significant. With increasing the moisture content due to increasing of adhesion force the coefficient of friction increase. Small particle have more contact surface with inclined plan so with decreasing the particle size the coefficient of friction increase. Effect of surface materials is shown in Figure 11.

$$\mu = 0.024MC - 0.205 \quad (R^2 = 0.98\text{, for black steel}) \quad (9)$$

$$\mu = 0.181e^{0.027\,MC} \quad (R^2 = 0.936\text{, for galvanized iron}) \quad (10)$$

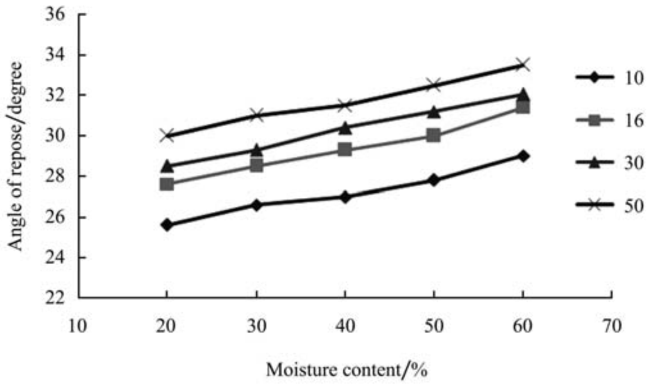

Figure 8 Effect of moisture content and particle size on angle of repose

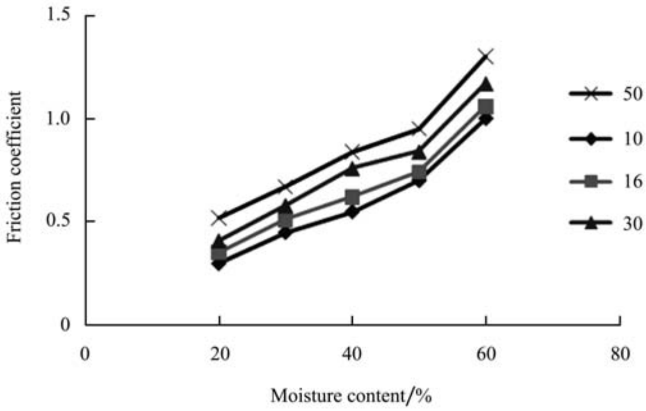

Figure 9 Effect of moisture content and particle size on friction coefficient in galvanized iron surface

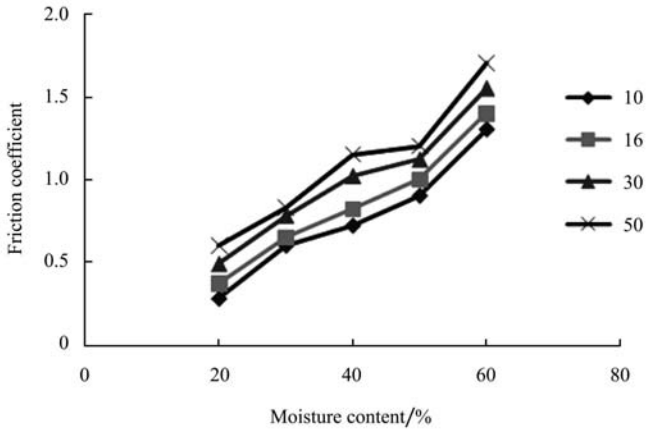

Figure 10 Effect of moisture content and particle size on friction coefficient in black steel surface

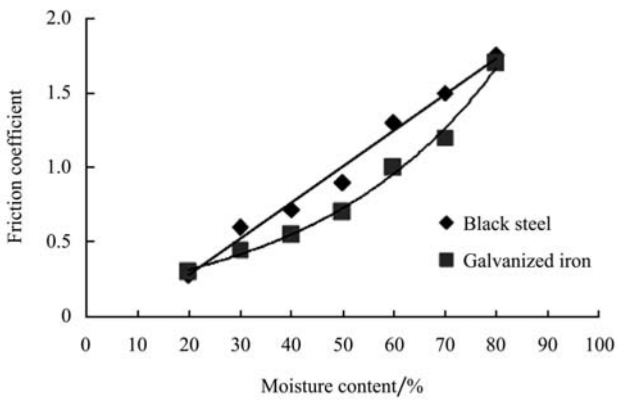

Figure 11 Effect of material surface on friction coefficient

Shear strength variation with respect to moisture content at different particle size is shown in Figure 12,

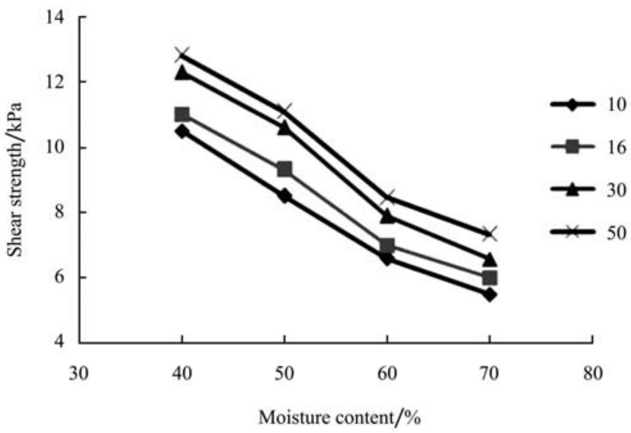

Figure 12 Effect of moisture content and particle size on shear strength

which shows that increasing moisture content was accompanied by decreasing shear strength. At a microscopic scale, an increase in moisture content would increase the spacing between soil particles and reduces the solid-solid interactions. Thus, the soil shear strength decreased. This trend was observed for all particle size. In contrast, with a decrease in particle size of manure, the volume of pore spaces would reduce and cause more solid-solid contact, thereby increasing the shear strength.

4 Conclusions

The following conclusions were derived from the results of this study:

1) The various properties measured will serve as a useful tool in process and equipment design and improve yield and quality of pellets.

2) The moisture content and particle size are effective parameter on physical, frictional and shearing properties of cattle manure compost.

3) With increasing the moisture content all parameter except shear strength are increased.

4) With increasing the particle size all parameter are decreased.

5) Effect of material surface on friction coefficient is significant.

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