Effect of moisture content and particle size on energy consumption for dairy cattle manure pellets

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Abstract: Physical and mechanical properties of pellets are needed to make pellet form in storage of raw materials and energy consumption. Dairy cattle manure, sieved by a two-level size of 30 and 50, were used to make pellets by a hydraulic press with mold diameter of 6 mm, in five moisture levels of 15%, 17.5%, 20%, 22.5% and 25% and two pressure levels of 100 and 150 MPa. The results of the tests were analyzed using Excel and MATLAB softwares. Results showed that the compression energy as well as friction energy of size 30 increased with the increasing moisture content from 15% to 20%, and decreased with the increasing moisture content from 20% to 25%, and both are under pressure levels of 100 and 150 MPa. The compression energy and friction energy of the size 50 decreased with the increasing moisture content for both pressure levels of 100 and 150 MPa. The energy consumption of compression was found to be greater at the pressure of 150 MPa than that of 100 MPa. The greater amount of energy consumption was used for compression. The maximum amount of friction energy was 16.7%, while the minimum was 11.23% for both pressure levels of 100 and 150 MPa.

Keywords: energy consumption, compression energy, dairy cattle manure, friction energy, pellet, pressure

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1 Introduction

High moisture content, high volume and non-uniformity of the materials in manure are the factors that limit the usage of the manure in agriculture. Normally, because of low specific gravity the transportation of manure fertilizers is difficult and expensive. Biomass is very difficult to handle, transport, store and utilize in its original form (Sokhansanj et al., 2005). One of the methods to get easy transportation and to decrease the costs is to reduce the volume of the manure by compression in pellet form. The compressed manure can be used as the fertilizer in agricultural farms. This also eliminates the need for manure plants and reduces the cost of manure (Adapa et al., 2003).

Physical and mechanical properties of pellets are needed to make pellets for storage of raw materials and to optimize the consumption energy. Compression of materials is complex, and in this case there is no coherent theory (Granada et al., 2002). There are many ways to compress the biomass materials. Conventional processing methods for compressing biomass can be classified into three types: extrusion, die roller and berry-making (Li and Liu, 2000). From the analysis done by Serrano, the moisture ratio should not be too high or too low, because excessive moisture ratio will cause loose pellets due to excessive water between pellets, and this will yield a poor briquetting effect (Serrano et al., 2011). Nelson used mold and plunger method to quantify the consumed energy for synthesis of pellet form (Nielsen et al., 2009).

Researchers have already carried out experiments on biomass materials process in pellet in order to analyze and evaluate the required energy to process the pellet (Sampson et al., 2000; Jannasch et al., 2001). They found that the average hardness of the pellets will increase with the decreasing particle size sieve from 2.3

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to 8.2 mm. Hara Japan, studied on produced pellets by using extruder from animal manure in order to investigate the effect of moisture content and dust levels on pellet strength (Hara, 2001). The obtained results showed that the strength pellets reduced with increasing moisture content and the percentage of the soil in manure. The most relevant moisture content level was proposed to be 45% for forming the pellets and below 20% for storage of manure pellets.

The pelleting process has advantages of high adaptability of raw material, wide application of moisture ratio, low power consumption per ton of material and high production, thus making it suitable for application in rural area where straw wastes are extensively disposed (Xie et al., 2002). In a research, Kai offered the relationship between velocity of mold (Die) and energy consumption for the pellet form as the theory of modeling, analytical and experimental (Kai et al., 2010).

Reinders and Bestelaere stated that after the processing operation, the moisture of mixture should be about 15% to 15.5% (Reinders and Bestelaere, 1971). Wellin stated that the most favorable moisture content was from 13% to 17%. A substance when have the upper pellet form property that first required the low pressure to form a compact structure. Secondly, it is expected that the dense materials have a high quality and durability (Wellin, 1976). Drzymała presented several criteria of pellet form capabilities for the materials (More piston displacement for the same pressure for better storage capability of the masses) and offered multiple pellet form capabilities related to building mass and testing hardness (Drzymala, 1988).

The main objective of this research is to determine effects of moisture content and particular size of dairy cattle manure on consumption energy of compression and friction energy to make pellet form.

2 Material and methods

2.1 Materials

The required dairy cattle manure was collected from rural dairy cattle and prepared in different particle size for testing. The manure was considered enough, and was crushed and storage by grinding electric in the Department of Agrotechnology, College of Abouraihan, University of Tehran. According to ASTM standards for testing manure bed, the samples were prepared with the desired size (Standard S358.2). The initial moisture content of the manure was determined in five replications by drying of the samples in the oven at temperature 103 ±3℃ for 48 hours. The moisture content was determined according to Equation (1) in terms of wet basis (ASAE Standards. 1998. S269.4)

$$MC(w.b.)\% = \frac{m_w}{m_w + m_d} \times 100\% \qquad (1)$$

where, MC ($w.b.$) % = Moisture content of fresh manure, %; m_w = Mass of water in the manure,g; m_d = Mass of dry matter in the manure, g.

To achieve the desired moisture for preparing the samples, an amount of distilled water was added to the manure based on Equation (2).

In this equation:

$$m_w = \frac{m_i(M_{wf} - M_{wi})}{1 - M_{wf}} \qquad (2)$$

where, M_{wi} = Initial moisture content of fresh manure, %, w.b.; M_{wf} = Final moisture content of manure, %, w.b.; m_i = Initial mass of manure, g; m_w = Mass of added distilled water, g.

After adding distilled water the samples were kept at 5℃ in the refrigerator plastic package for 72 hours until the moisture is distributed uniformly in the samples. In this study, samples were taken at five moisture levels of 15%, 17.5%, 20%, 22.5% and 25% (w.b.).

The hydraulic press device, built in the College of Abouraihan, University of Tehran, was used for measurement of compression and of movement of the pellet form. The device was equipped with a Ohmic ruler with an accuracy of 0.01 mm to measure the piston motion and the 1,000 kgf load cell (Figure 1), and the press device has the ability to measure the force on the piston during the compression and movement of the pellet form within the framework simultaneously and both were connected to data logger (PardazeshTamKar, Islamic republic of Iran). The data was transferred to a computer for further calculation.

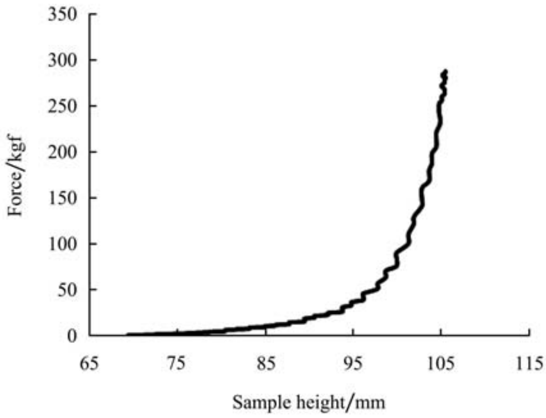
2.2 Methods

For calculating of consumption power to make pellet form in die roll, it is necessary to consider moisture content and particular size effects on compression and friction energy, and compression and friction energy ratio for total consumption energy. This study was performed using the method of Nielsen et al. (2009).

For each test an amount of 0.75 g of material was weighed by a digital balance and charged into the closed mold. The compression was conducted at two pressure levels of 100 and 150 MPa, which was adjusted by pressure control valve. The valves were removed to exit the pellets and the pellet was moved inside the die for 3.5mm to measure the friction energy. A flow control valve was used to have a constant speed of 127 mm/min during the movement of the pellet inside the die (Nilsen et al., 2009).

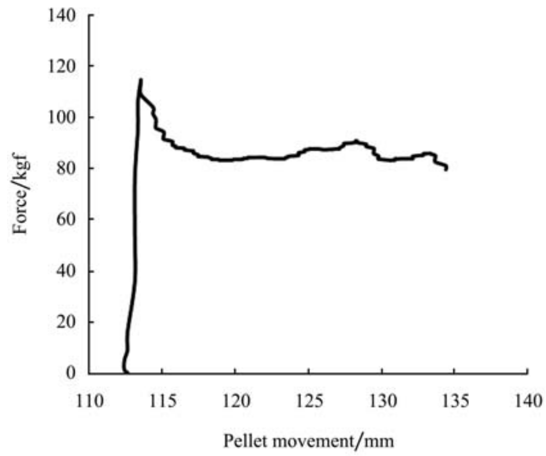
a. Cylinder hydraulic b. Motion control system c. Load cell d. Ruler measure e. Data logger f. Flow control valve g. Mold

Figure 1 Hydraulic presses



Note: the below area of the graph shows compression energy

Figure 2 Compression energy in maximum pressure of 100 MPa, moisture15% and size 30



Note: the area below the graph shows friction energy

Figure 3 Friction energy in maximum pressure of 100 Mpa moisture 15% and size 30

The force on the piston was calculated using Equation (3):

$$P = \frac{F}{A} \tag{3}$$

where, P= Pressure inside the mold, MPa; F = Force on piston, N; A = Area of mold, mm^2.

Force on the rod (288 and 433 kgf) was calculated.

The consumption energy for compression and friction was calculated and analyzed by programming in MATLAB and Excel for all experiments. Some results showed in Figure 2 and 3. The sample with 15% moisture content and size 30 has been compressed under maximum pressure of 100 MPa, In Figure 2, area under curve indicated level of compression energy and in Figure 3 showed level of friction energy.

Figure 4 shows the compression energy at pressure 100 MPa for the size 30 at moisture content ranging from 15%, 17.5%, 20%, 22.5% and 25%. The compression energy increased with the increasing moisture from 15% to 20%, and decreased with the increasing moisture content from 20% to 25%. The compression energy for size 50 decreased with increasing moisture content in range of 15% to 25%. The compression energy for size 50 was always higher than the size 30 except in moisture range of 15% to 16% that was equal at moisture content of 16% for both sizes. The decreasing rate of compression energy was almost equal for both sizes after 20% moisture content, while it was different at the values lower than 20% moisture content.

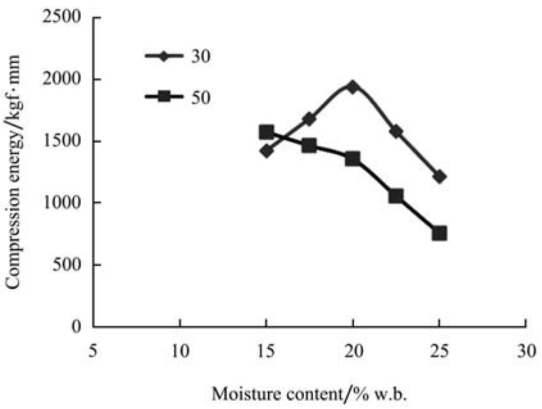


Figure 4 Effect of particle size and moisture content on compression energy pressure at 100 MPa

The friction energy at pressure of 100 MPa increased for size 30 with the increasing moisture from 15% to 20%, and decreased with the increasing moisture content from 20% to 25%. The friction energy for size 50 decreased with the increasing moisture content. The energy consumption reduced, and the loss rate of friction energy consumption is greater than that of the energy consumption compression. In the range of 15% to 17.5% of moisture the energy consumption of size 50 is more than size 30 and in 17.5% moisture the energy in both the size is equal and of moisture the rate of energy loss size 50 and the rate of increase size 50 is equal and in the range 20% to 25 % of moisture the loss rate for both is equal (Figure 5).

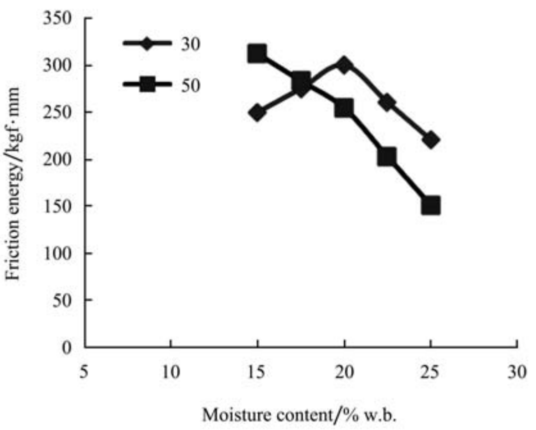


Figure 5 Effect of particle size and moisture content on friction energy pressure at 100 Mpa

The compression energy at pressure of 150 MPa was more than that of 100 MPa. As can be seen in Figure 6, the compression energy for size of 50 decreased with incising of moisture content, but for size of 50 had increasing trend from 15% to 20% and decreasing trend from 20% to 25%. Compression energy of the sample with moisture content of 15% for size of 50 was higher than the corresponding value of size of 30, but the both values were equal at moisture content of 17.5%. The compression energy values at the range of 20% to 25% for size of 30 were more than that for size of 50.

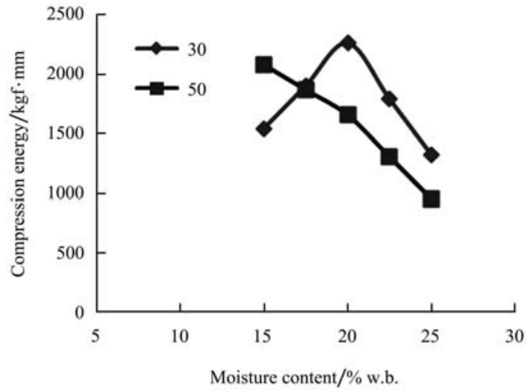


Figure 6 Effect of particle size and moisture content on friction energy pressure at 150 MPa

The friction energy was higher at pressure 150 MPa than the pressure of 100 MPa. The rate of the friction energy change was greater than 100 MPa. The friction energy in range of 15% to 17.5% moisture content for the size 50 was greater than the size 30, and it was equal for both sizes at 17.5% moisture content. In the range of 20%-25% moisture the reducing and increasing rates of consuming the friction energy in the size 50 and size 30 are equal, but in the size 30 the reducing rate is more than that in the size 50 (Figure 7). Studies of Nielsen et al. (2009) on the sawdust to pellets form show that friction and compression energy decreased with the increasing in moisture content, and also the compression energy was more than the friction energy.

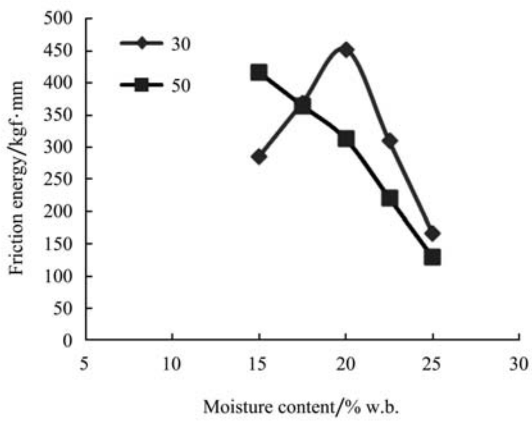


Figure 7 Effect of particle size and moisture content on friction energy at pressure at 150 MPa

At pressure of 100 MPa, the highest percentage of friction energy (16.7%) was belonged to size of 50 with moisture content of 25%, and the lowest value (13.42%) was for size of 50 with moisture content of 15%. The results indicate that a greater share of energy has been spent on compressed and a smaller percentage to overcoming friction.

Table 1 Percentage of energy used in compression and friction pressure of 100 MPa and a size of 30 and 50 and the moisture levels of 15, 20 and 25%

Moisture content/%	Size number	Compression energy%	Friction energy/%
15	30	84.54	15.45
	50	86.57	13.42
20	30	84.57	15.42
	50	83.43	16.57
25	30	84.15	15.84
	50	83.29	16.70

The highest percentage of the friction energy at pressure of 150 MPa is anent to the size 50 and the moisture content of 20%, which is equal to 16.7%. The lowest percentage of friction energy is anent to size 30 and the moisture content of 20%, which is equal to 11.23%. The results indicated that in both pressure levels, the highest percentage of energy has been used for compression and the least percentage of energy has been used for friction (Table 2).

Table 2 Energy compression and friction that used in pressure of 150 MPa and the sizes 30 and 50 and at moisture contents of 15, 20 and 25%

Moisture content / %	Size number	Compression energy%	Friction energy /%
15	30	84.37	15.62
	50	83.32	16.68
20	30	88.76	11.23
	50	83.30	16.70
25	30	84.12	15.87
	50	88.02	11.97

4 Conclusions

The results indicated that the compression and friction energies for the size 30, first increased and then decreased by the increasing moisture content from 15% to 25%, whereas for size 50 the compression and friction energy decreased by the increasing moisture content from 15% to 25%. The consumption energy for size 30 was always greater than that of size 50. For both studied sizes, the percentage of the compression energy was higher than that of the friction energy.

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