# Effects of pressure, mold diameter and raw material properties on energy consumption in producing dairy cattle manure pellets

Kamel Ghadernejad*, Abedin Zafari, Mohammad Hossein Kianmehr

(*Department of Agrotechnology*, *College of Abouraihan*, *University of Tehran*, *Tehran*, *Iran*)

**Abstract:** Due to low density, the transportation of manure fertilizers is difficult and expensive. Reducing the volume of the manure by compression in pellet form is one way to facilitate transportation and decrease the costs. Information on physical and mechanical properties of raw materials and energy consumption is required in the pelleting process. In this research, dairy cattle manure, sieved by a two-level mesh of 30 and 50, in five moisture levels of 15%,17.5%, 20%, 22.5% and 25% and three pressure levels of 50, 100 and 150 MPa by a hydraulic press with mold diameters of 8 and 6 mm was studied. The results of the tests were analyzed by using EXCEL and MATLAB softwares. The findings indicated that the energy consumption for compression in 6 mm mold diameter was higher at all the three mentioned pressure levels and two meshes compared with that of 8 mm mold diameter. The results also revealed that for both mold diameters in each of the three pressure levels in mesh 30, energy consumption first increased as the moisture level increased from 15% to 20%, then it decreased following an increase in the moisture level from 20% to 25%. However, a reduction in energy consumption was noticed as the moisture increased from 15% to 25% in mesh 50. The results showed that with the increasing pressure from 50 to 150 MPa the energy consumption increased.

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

**Citation:** Kamel Ghadernejad, Abedin Zafari, Mohammad Hossein Kianmehr. 2012. Effects of pressure, mold diameter and raw material properties on energy consumption in producing dairy cattle manure pellets. Agric Eng Int: CIGR Journal, 14(4): 86−92.

## 1 Introduction

One of the objectives of organic agriculture in maintaining stable agriculture is to reduce the use of external institutions in order to prevent pollution of underground waters, to decrease the remaining of pesticides in food products, to keep soil and water resources from erosion, and finally to enhance the long-term profit (Regouin, 2001). Physically, manure is regarded as a mixture of water and solid materials. Solid materials are resolvable and irresolvable components inside the manure. Based on physical studies, manure is divided into four kinds, namely liquid, slurry, solid and semi-solid, which are a function of dry materials and rheological properties of manure (Landry, Laguë and Roberge, 2005). High moisture content, high volume and non-uniformity of the materials in manure are the factors which limit the usage of plant and cattle manure in the world. Pelleting is a method to increase the bulk density of biomass, facilitate transportation and decrease the costs. Pellets have low moisture content for safe storage, and a high bulk density for efficient transport and storage. If the agriculture soil lacks nutrients, the required chemical materials for the plant are combined and compressed with cattle manure during the compression process, which eliminates the need for manure plants and also reduces the cost of manure (Adapa et al., 2003). For each pellet producing device, the moisture content of archetypes is the most important physical factor. This factor exerts most effect on the

**Received date:** 2012-06-21 **Accepted date:** 2012-09-20

* **Corresponding author: Kamel Ghadernejad,** Email: Kgadernejad@ut.ac.ir.

resistance and the velocity of pellet production process. With the reducing moisture content, liquidity decreases and friction energy increases as it passes through the mold. Therefore, it is important to know about suitable moisture content before the work (Hara, 2000).

Compression of lignocellulosic materials is complex, and there is no coherent theory in this case (Granada et al., 2002). Wellin (1976) stated that the most favorable moisture content of the mixture ranged from 13% to 17%. A substance can have the upper pellet form property. First, the low pressure exists to form a compact structure; secondly, it is expected that the dense materials have a high quality and durability (Wellin, 1976). Drzymała (1988) presented several criteria of pellet form capabilities for the materials. He assessed the relationship between special density pressure and piston displacement (More piston displacement for the same pressure for better storage capability of the masses) and also offered multiple pellet form capabilities related to building mass, testing hardness etc. Theerarattananoon et al. (2010) studied the mechanical properties of pellets produced out of sorghum stalks, corn stover and wheat straw. In that study, the effect of corn size, thickness of the mold, proportion of length to mold diameter, and the pellets moisture content on pellet density and durability were assessed. Pressure compresses the particles with each other, and adhesive materials render chemical bond, absorb the particles and interlock them together (Grover and Mishra, 1996).

Compression time span has an effect on the quality of produced pellets. For oak sawdust the effect of using low pressure and longer time is more than the situation in which high pressure and short time is used while at higher pressures (138 MPa) the effect of maintenance time is negligible. Furthermore, when fixed material density is utilized in making pellets, the aggregate of the pellets is mainly for a mold with smaller diameter (Li and Liu, 2000). In briquette making process, the increasing moisture through strengthening and promoting the band with wandervalsi forces and increasing the interface of the particles can act as an adhesive element (Mani, Tabil and Sokhansanj, 2003).

There are several ways to compress the biomass materials. Conventional processes for compressing biomass can be classified into three types: Extrusion, Die Roller and Berry-Making (Li and Liu, 2000).

Kai et al. (2010) assessed the relationship between mold velocity (die) and energy consumption for producing pellets through laboratory modeling. Biomass compression was done through Plunger-Barrel method. For showing the significant effect of moisture, two moisture levels of 25% and 30% and a cylinder with internal mold diameter of 6 and external diameter of 40 mm and height of 65 mm were used (Adapa et al., 2002). It is hard to enhance the density degree only with pressure in fragile and breakable materials because the connection capability among them decreases due to the hydrostatic pressure and resistance (Pietsch, 1984). During compression in space next to the piston in cylinder and channel, pressure is not steady. Therefore, special weight of materials is a function of distance from piston because materials are affected by friction in vicinity of surrounding partitions in the density space, and the resulted axle pressure in materials decreases (Sitkey, 1986).

Nielsen et al. (2009) stated that during the pelleting process, information about properties of raw materials and energy consumption for producing pellets are required. They simulated wooden saw pelleting process in Die Roller device and showed that the requisite energy consumption for making pellets is divided into the following three energies: flow energy, compression energy and friction energy.

The main objective of this research is to determine effects of moisture content, particle size, mold diameter and pressure on energy consumption in producing dairy cattle manure pellets.

## 2 Materials and methods

### 2.1 Materials

Required dairy cattle manure was collected from rural dairy cattle and prepared in different particle size for testing. Before pelleting, the manure samples were ground using a hammer mill. The samples was screened through two sieves with mesh 30 and 50 (the American standard sizes) as shown in Table 1.

**Table 1 Dimensions of the utilized sieve holes (Based on ASTM E-11-70 Part 41 Standard)**

| Size of the sieve | 30 | 50 |
|---|---|---|
| Hole diameter/mm | 0.6 | 0.3 |

The initial moisture content of the manure was determined in five replications by drying of the samples in the oven at temperature103±3℃ for 48 h. The moisture content was determined according to Equation (1) in terms of wet basis (w.b.) (ASAE Standards. 1998. S269.4).

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

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:

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

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 5℃ temperature in the plastic package for 72 h until the moisture is distributed uniformly in the samples.

In this research, samples were prepared at five moisture levels of 15%, 17.5%, 20%, 22.5% and 25%. Manure compression was conducted through a hydraulic pressing device and a Plunger-Barell system in which a cylinder with internal mold diameters of 6 and 8 mm was utilized. Synchronous with the piston movement, hydraulic press equipped with an Ohmic ruler with 0.01 mm measurement precision and a load cell with 0.01 kg measurement precision. Then, the data was read by data logger and recorded on computer. In this test, the force on piston was calculated based on Equation (3) at pressure levels of 50, 100 and 150 MPa, in both mold diameters 6 and 8. The pressure of the forces on piston was adjusted through a control valve. The related calculations are shown in Table 2.

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$^2$.

**Table 2 Calculations of force in mold diameters 6 and 8 for three pressure levels of 50, 100 and 150 MPa**

| Pressure/MPa | Maximum Force (Kg.f) For mold diameter 6 mm | Maximum Force (Kg.f) for mold diameter 8 mm |
|---|---|---|
| 50 | 144 | 256 |
| 100 | 288 | 512 |
| 150 | 433 | 768 |

In each phase of the tests, an amount of 0.75 g of material was weighed by a digital balance (Kern and Sohn GmbH, Germany) with 0.01 g precision and charged into the closed mold. To achieve the velocity of 127 mm/min, the flow was adjusted by a control valve. For measuring the compression energy, the lower valve was launched in the mold and the materials inside the mold were compressed by the upper piston (Nielsen et al., 2009). For conducting the test, 3 replications occurred, and due to closeness of the data to each other, the sum of obtained energies was averaged.

### 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 to total consumption energy. This study was performed using the method (Nielsen et al., 2009). The data was analyzed using MATLAB and Excel.

The energy consumption for compression was calculated by programming in MATLAB by considering the lower area of the graph which is equivalent to Force multiplied by Transference. Due to the large number of graphs, only two graphs are presented as the representatives of all in which the compression has been done at the maximum pressure of 100 MPa with 15% moisture for mesh 30 (Figure 1).

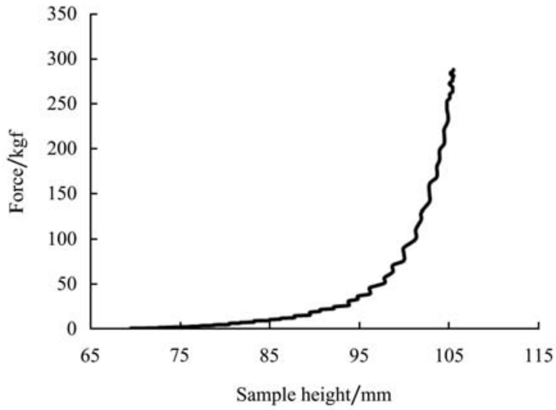



Figure 1 Compression energy in maximum pressure of 100 Pa, moisture 15% and size 30

## 3 Results and discussion

The results of the tests indicate that energy consumption for compression at pressures 50, 100, and 150 MPa and mesh 30 for mold diameter 6 is higher than that of diameter 8. With the increasing moisture from 15% to 20%, energy consumption for compression in both diameters increases. However, as the moisture gets an increase from 20% to 25%, consumption energy for compression in both diameters decreases (Figure 2).

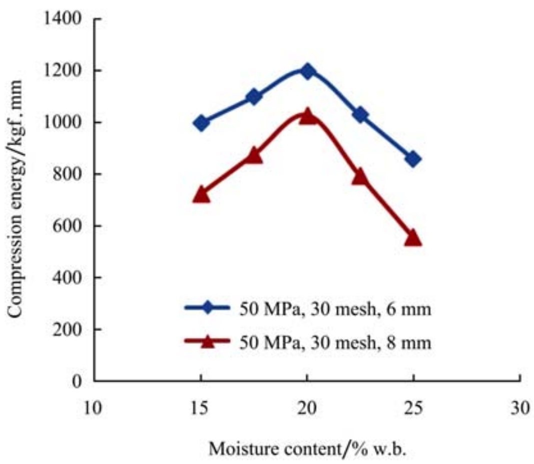



Figure 2 Effect of mold diameter and moisture on energy consumption for compression

The results from this study were in agreement with the results reported by Nielsen et al. (2009). The results of their study on the sawdust to pellets form show that compression energy decreased with the increasing in moisture content.

The trends of energy consumption for both diameters (6 and 8 mm) at pressures 50, 100 and 150 MPa and mesh 30 were similar to each other. The graphs were drawn, and the equation was fitted. Since the obtained regression coefficient was high, second-degree equation sufficed and the related coefficients have been mentioned in Table 1.

Energy consumption for compression at the pressure of 50 MPa and mesh 50 for mold diameter 6 mm is greater than that of diameter 8 mm, and with the increasing moisture content from 15% to 25% energy consumption for compression in both diameters 6 and 8 mm decreases.

The loss rate of compression energy consumption in moisture range of 20%-25% is greater than that of the range 15%-20% (Figure 3). The findings show that even one percent moisture takes effect on the energy consumption. This is in accordance with the results of Tylzanowski (1975) which indicated that the change in moisture content about 1% makes the mixture of under examination too dry or too wet, and subsequently influences the next work on the pellet form device. Optimum working point must be considered for compression in pelleting process.

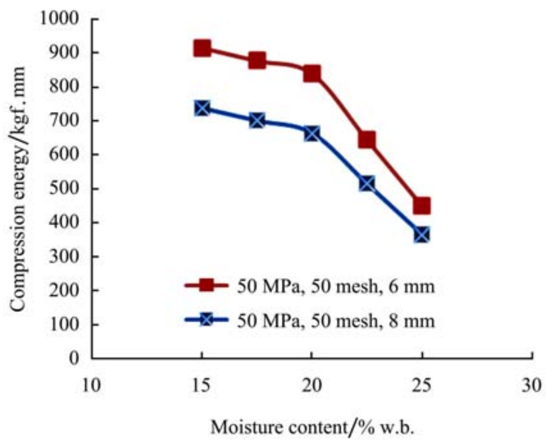



Figure 3 Effect of mold diameter and moisture on compression energy

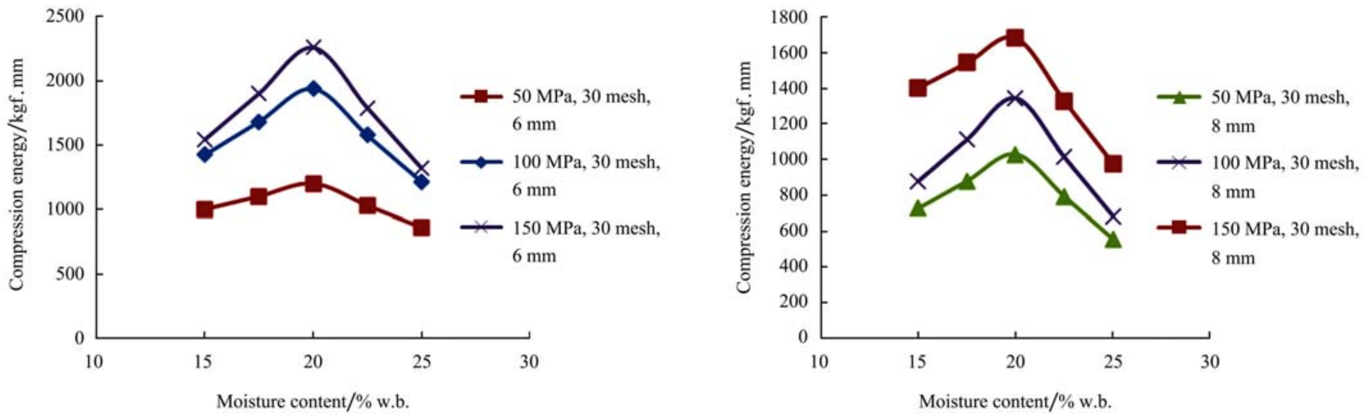
Regarding the effect of moisture on energy consumption for mold diameters 6 and 8mm in mesh 30 and at pressure levels of 50, 100 and 150 MPa, the results show that by increasing moisture from 15% to 20%, energy consumption increases at all of the three pressure levels. However, as the moisture increases from 20% to 25%, energy consumption decreases. Figure 4 shows that at pressure level of 150 MPa more energy is consumed compared to the pressure levels of 100 and 50 MPa, and this energy at 100 MPa is higher than that of 50 MPa. In other words, with the increasing pressure more energy is needed for compression. It also shows that the increasing pressure from 50 to 100 MPa, was more effective more effect on energy consumption.

As the moisture increases from 15% to 25%, the effect of moisture on energy consumption decreases for mold diameter 6 mm and mesh 50 at all of the pressure levels of 50, 100 and 150 MPa. As Figure 5 indicates, more energy is needed at the pressure of 150 MPa compared with two pressure levels of 50 and 100 MPa, and the energy for pressure 100 is higher than that of pressure 50.

The results show that with increasing particle size from mesh 50 (with 0.3 mm hole diameter) to mesh 30 (with 0.6 mm hole diameter) in pressure of 50 MPa, the compression energy consumption increases (Figure 6).

Regarding mold diameter 6 mm and meshes 50 and 30 at the pressure of 100 MPa, the findings of the test indicate that in mesh 50 at moisture range of 15%-16% energy consumption for compression is more than that of mesh 30, but at moisture range of 16%-25% energy consumption for compression in mesh 30 is greater than that of mesh 50 (Figure 7).

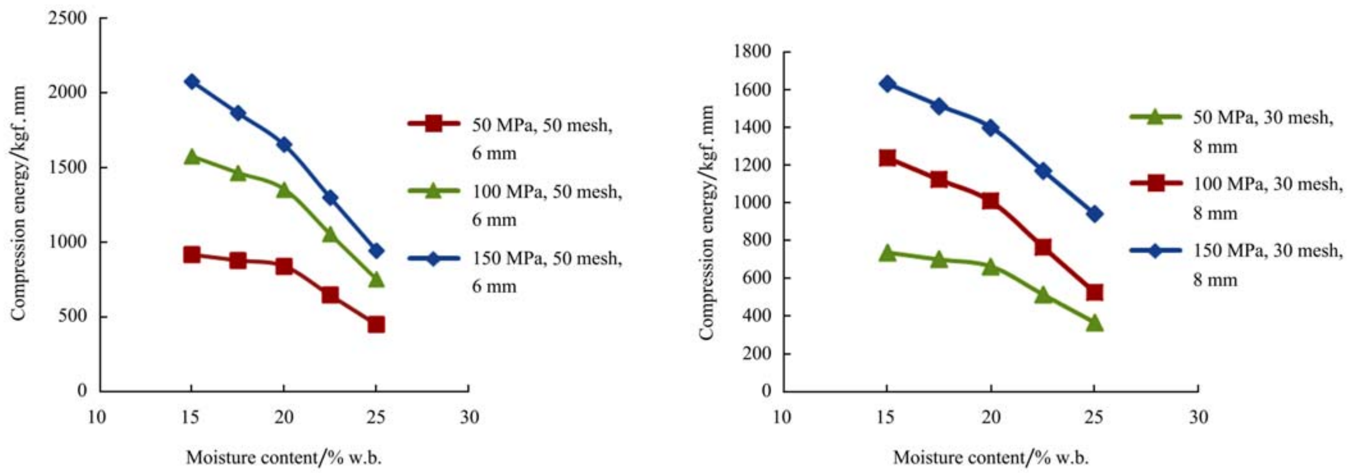
Regarding the mold diameter 8 mm for meshes 50 and 30 at pressure of 150 MPa, the results suggest that in mesh 50 at moisture range of 15%-17.5% energy consumption for compression is greater than that of mesh 30, but at moisture range of 15%-25% energy consumption for compression for mesh 30 is greater than that of mesh 50 (Figure 8).




a. Mold diameter 6 mm

b. Mold diameter 8 mm

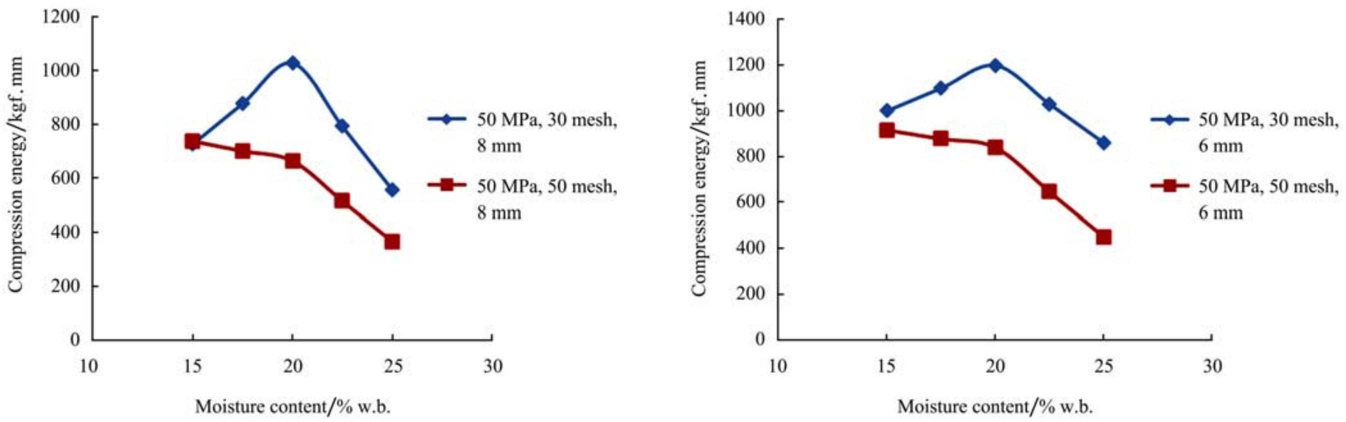
Figure 4 Effect of pressure and moisture on compression energy consumption




a. Mold diameter 6 mm

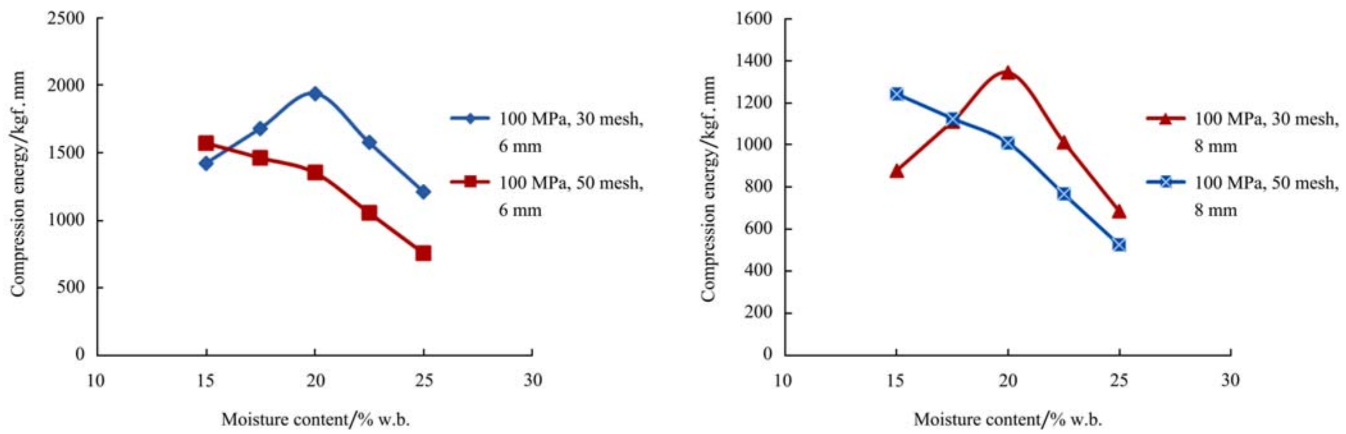
b. Mold diameter 8 mm

Figure 5 Effect of pressure and moisture on compression energy consumption



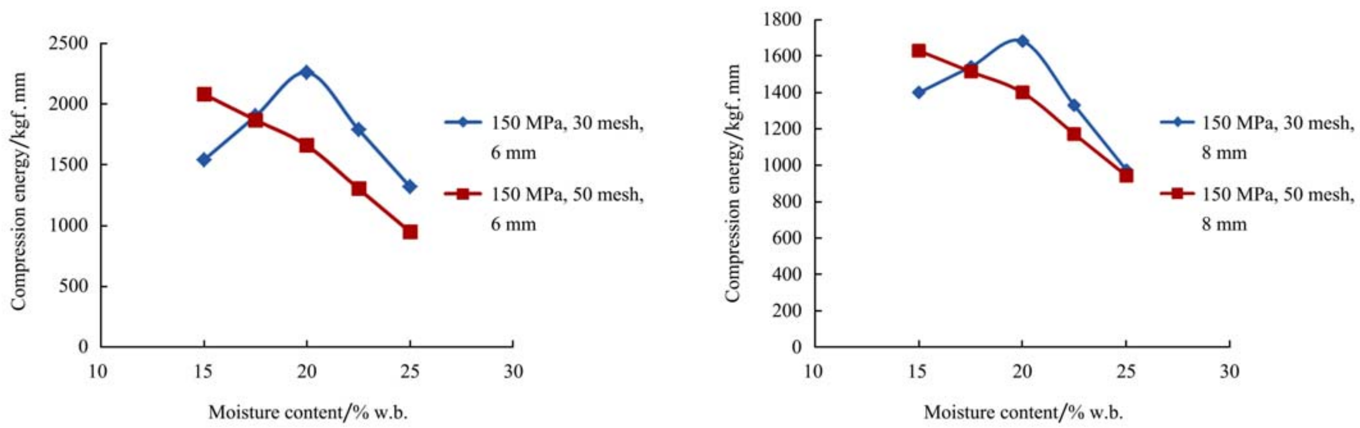

a. Mold diameter 6 mm b. Mold diameter 8 mm

Figure 6 Effect of particle size and moisture on energy consumption




a. Mold diameter 6 mm b. Mold diameter 8 mm

Figure 7 Effect of particle size and moisture on energy consumption




a. Mold diameter 6 mm b. Mold diameter 8 mm

Figure 8 Effect of particle size and moisture on energy consumption

The fitted equation coefficients on the laboratory data have been shown in Table 3. The high value for regression coefficient ($R^2$) of the equations is indicative of high precision of the equations in estimating energy consumption for compression (Table 3).

**Table 2 Coefficients of the energy consumption equations on moisture percent for mold diameters 6 and 8 and particle size at two mesh levels of 30 and 50 and three pressure levels of 50, 100 and 150 MPa**

| Pressure /MPa | Mesh | Mold diameter/mm | Coefficient $X^2$ | Coefficient $X$ | $C$ | $R^2$ |
|---|---|---|---|---|---|---|
| 50 | 30 | 8 | -13.28 | 514.5 | -4014 | 0.93 |
| | 50 | 8 | 3.849 | 116.7 | -1513 | 0.99 |
| 100 | 30 | 8 | -19.03 | 752.7 | -6087 | 0.92 |
| | 50 | 8 | -4.32 | 101.2 | 689.4 | 0.99 |
| 150 | 30 | 8 | -17.07 | 640.3 | 4367 | 0.95 |
| | 50 | 8 | -3.873 | 86.34 | 1203 | 0.99 |
| 50 | 30 | 6 | -9.257 | 356.2 | 2268 | 0.93 |
| | 50 | 6 | -5.382 | 168.7 | -408 | 0.99 |
| 100 | 30 | 6 | -21.23 | 828.2 | -6239 | 0.92 |
| | 50 | 6 | -6.54 | 179.8 | 344.3 | 0.99 |
| 150 | 30 | 6 | -28.44 | 1115 | 8815 | 0.92 |
| | 50 | 6 | -4.88 | 82.28 | 1941 | 0.99 |

## 4 Conclusions

The findings showed that the energy consumption for mold diameter 6 mm at all the three pressure levels of 50, 100 and 150 MPa was greater than that of diameter 8 mm. Energy consumption for compression in mesh 30 increased by the increasing moisture from 15% to 20%, but it decreased by the increasing moisture from 20% to 25%. However, in mesh 50, with increasing moisture from 15% to 20%, the energy consumption decreased. Furthermore, in all of the moisture levels (15%, 17.5%, 20%, 22.5% and 25%), in both mold diameters 6 and 8 mm and for both particle size levels of mesh 30 and mesh 50, the energy consumption increased with the increasing pressure level from 50 to 150 MPa.

## References


Adapa, P. K., G. J. Schoenau, L. G. Tabil, S. Sokhansanj, and B. J. Crerar. 2003. Pelleting of fractionated alfalfa products. ASABE Paper No.036069. ASABE, St. Joseph, MI.

Adapa, P. K., L.G. Tabil, G. J. Schoenau, B. Crerar, and S. Sokhansanj. 2002. Compression characteristics of fractionated alfalfa grinds. *Powder Handling & Processing,* 14(4): 252-259.

Anonymous ASAE Standards. 1998. S269.4 Cubes, Pellets and Crumbles-Definitions and Methods for Determining Density, Durability and Moisture Content ASAE DEC96. Standard S358.2 Moisture Measurement-forages. ASAE, St. Joseph, MI.

ASTM E-11-70 and U.S. National Bureau of standards official sieve designations (Part 41).

BS1377: Part 7:1990 Method 3- Determination of shear strength by the laboratory vane method.

Drzymała, Z. 1988. Industrial briquetting: Fundamentals and methods, (in Polish). PWN, Warszawa,

Granada, E., L. M. López González, J. L. Míguez, and J. Moran. 2002. Fuel lignocellulosic briquettes, die design and products study. *Renewable Energy,* 27: 561-573.

Grover, P. D., and S. K. Mishra. 1996. Biomass Briquetting. Technology and Practices. the FAO Regional Wood Energy Development Programmed in Asia, Bangkok, Thailand Field Document No.46

Hara, M. 2001. Fertilizer pellets made from composted livestock manure, Food and Fertilizer Technology Center.

Kai, W., S. Shuijuan, D. Wuxue, P. Binbin, and Y. Sun. 2010. Influence of Die Speed on the Energy Consumption in the Pelleting Process. International Conference on Computing, Control and Industrial Engineering, 247-250.

Landry, H., C. Laguë, and M. Roberge. 2004. Physical and Rheological Properties of Manure Products. *Applied Engineering in Agriculture*, 20 (3): 277-288.

Li, Y., and H. Liu. 2000. High pressure densification of wood residues to form an upgraded fuel. Biomass and Bioenergy,19: 177-186.

Mani, S., L.G. Tabil, and S. Sokhansanj. 2003. An overview of compaction of biomass grinds. *Powder Handling & Processing,* 15(3): 160-168.

Nielsen, N. P. K., D. J. Gardner, and T. Poulsen. 2009. Importance of Temperature, Moisture Content, and Species for the Conversion Process of Wood Residues into Fuel Pellets. *Wood and Fiber Science*, 41(4): 414-415.

Pietsch, W. B. 1984a. Size enlargement methods and equipment - Part 4. Roll pressing, isostatic pressing and extrusion. In Handbook of Powder Science and Technology, eds. Fayed, M.E. and L. Otten, 270-275. New York. U.S.A.: Van Nostrand Reinhold Co.

Regouin, E. 2003. To convert or not to convert to organic farming. In OECD, Organic Agriculture Sustainability, Markets and Policies (pp. 227–235). Wallingford, UK: CABI Publishing

Sitkey, G. 1986. Mechanics of Agricultural Materials Budapest, Elsevier Science Publishers. Pp: 420-438.

Theerarattananoon, K., F. Xu, J. Wilson, R. Ballard, L. Mckimey, S. Staggenborg, and P. Vaellani. 2010. Physical properties of pellets made from sorghum stalk, corn stover, wheat straw and big blue stem. Industrial Crops and Products.

Tylzanowski, J. 1975. Production technology of pellet form feedstuffs, (in Polish). Studium Przemysłu Paszowego, WCT NOT, Warszawa, 7

Wellin, F. 1976. Pelleting equipment and operations, Feed Manufacturing Technology, AFMA, Inc., Arlington.