

EFFECT OF TEMPERATURE AND PARTICLE SIZE ON BEECH BIOMASS AGGLOMERATES

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ABSTRACT

Agglomeration of biomass such as tableting can increase bulk density, improve storability, reduce transportation costs, and increase the quality of products. The aim of this article is to analyze the effects of temperature and particle size on beech biomass and also to find the optimal conditions of the densification process for producing tablet with high density. Beech biomass was compressed in load cell by hydraulic piston press with 25 mm diameter. Effects of independent variables, including temperature (20°C to 100°C), and particle size of raw material (1 mm and 2 mm) were investigated. Results showed that on the same pressure, increasing temperature resulted in higher density of tablet. Increasing the temperature over 40°C resulted only a minimal density growth. Whereas, tablets made from raw material with smaller particle size have lower strength than tablets made from material with larger particle size.

Keywords: Agglomeration, densification, pelletizer, tableting, extrusion, biomass, beech.

1. Introduction

Agglomeration is the mechanical process, when the particle size of solid disperse materials (bulk materials, fine particles of slurry) is increased by bonding forces between the particles [4]. Agglomeration has three main types: pressure agglomeration (*briquetting, extrusion, tableting, pelletizing*) growth agglomeration, and sintering. In this paper pressure agglomeration is introduced especially for biomasses.

Wood pellet production in the European Union was estimated to be about 10 million tons (Sikkema et al. 2011) and 6.2 million tons for North America (Spelter and Toth 2009) for year 2009. Another study by Cocchi et al. (2011) estimated a slightly lower value for the global pellet production of about 14.3 million tons for the year 2010. The globally installed pellet production capacity for 2011 was estimated to be at about 30 million tons. All studies suggest a strong growth for both the European and North American pellet markets. The Finnish Pöyry Industry consulting company has predicted growth of the global pellet production capacity to 46 million tons by 2020 (Pöyry 2011) [5]. In this article the effects of temperature and particle size were investigated on the density and strength of beech biomass tablets.

2. Literature overview

During pressure agglomeration, new, enlarged entities (tablets, briquetts, etc.) are formed by applying external forces to particulate solids in more or less closed dies that define the shape of the agglomerated product (figure. 1) [3].

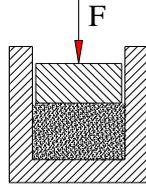


Figure. 1
Pressure agglomeration

Plenty of model exists for describing of the compaction behavior of bulk materials (compressibility), some of them are introduced in the followings, starting with the most relevant one. Follow Johanson's equation [6]:

$$\frac{\rho}{\rho^*} = \left(\frac{p}{P^*}\right)^{1/\kappa},$$

where κ is compressibility factor, ρ is agglomerate density, p is tableting pressure and p^* , ρ^* are reference values.

Compaction characteristics of chopped biomass with application of normal pressure was studied using the models developed by Kawakita and Ludde (1971) and Walker (1923). Walker (1923) proposed the following model for understanding the pressure-volume relationships of calcium carbonate and tetranitro-methylamine and subsequently various researchers used this model for biological material:

$$V = a_1 - K_1 \ln P,$$

where V is relative volume ratio, P is applied pressure (kPa), and a_1 and K_1 are constants. Another model widely used for understanding the pressure- volume relationship was developed by Kawakita and Ludde (1971) which has the form:

$$\frac{P}{C} = \frac{1}{a_2 b_2} + \frac{P}{a_2},$$

where P is applied pressure, a_2 and b_2 are constants, and C is relative volume decrease or engineering strain given by the equation:

$$C = \frac{V_0 - V_P}{V_0},$$

where V_0 is the initial volume and V_P is volume measured at any given pressure. The model was developed by Sone (1969) [1].

Hecket (1961) proposed a model to express the compaction behavior of compressed powder. The equation expresses the density of powdered materials in terms of packing fractions as a function of applied pressure:

$$\ln \frac{1}{1-\rho_f} = mp + n \quad \text{and} \quad \rho_f = \frac{\rho}{\rho_1 X_1 + \rho_2 X_2},$$

where ρ_f is packing fraction or relative density of the material after particle rearrangement; p is applied pressure (MPa); m , n are Heckel model constants; ρ is bulk density of compacted powder mixture (kg/m^3); X_1 , X_2 are mass fraction of components of the mixture.

Shivanand and Sprockel (1992) showed that constant n is related to relative density at particle rearrangement:

$$n = \ln \frac{1}{1-\rho_f}.$$

A high ρ_f value indicates that there will be a high volume reduction of the sample due to particle rearrangement. The constant m has been shown to be equal to the reciprocal of the mean yield pressure required to induce plastic deformation. A larger value for m (low yield pressure) indicates the onset of plastic deformation at relatively low pressure, a sign that the material is more compressible [2].

3. Materials and methods

3.1 Material

Beech sawdust was chosen as raw material for our experiments. It is originated from Miskolc, Hungary (Borsodwood Ltd.). It was dried and then ground using cutting mill (Retsch SM2000) in two steps (screen sizes: 2 mm, 1 mm). Biomass was stored at room temperature (25°C), in closed plastic bags. The moisture content of beech biomass were determined 1.47 % in the case of $x < 1$ mm, and 1.44 % ($x < 2$ mm).

3.2 Apparatus

Hydraulic piston press (figure. 2) is designed and produced by the University of Miskolc. The press is supported by a pump motor unit with pressure limiter and a heatable load cell ($20 \dots 140^\circ\text{C}$). The maximal force is 200 kN, and the maximal velocity of the piston is 30 mm/s. The measuring of the piston position is made by incremental method. The data acquiring is made by PC (LabWindows).



Figure. 2
Hydraulic piston press

3.3. Experimental procedure

The piston press diameter was 25mm, and each tablet were made by the compression of 5g sawdust. The applied temperatures were 20°C, 40°C, 60°C, 80°C and 100°C. Applied pressures on the surface of tablets were 50MPa, 100MPa, 150MPa, 200MPa and 250MPa. Experiments were carried out with two particle size fractions: <1 mm and <2 mm.

The quality of tablets can be described easily with the density. The diameters and heights of the tablets were measured by Vernier caliper (tablet can be extended after agglomeration), mass were measured and density were calculated.

Determination of tablet strength was carried out by falling test method. Tablets were released by freefall from height of 2 m on concrete floor so many times, until they were broken. Falling number is the number of times which is sustained by tablets undamaged. By each experiment three tablets were tested.

4. Results and discussion

4.1. Tablet density

Tablets produced by different parameters are shown in figure 3.

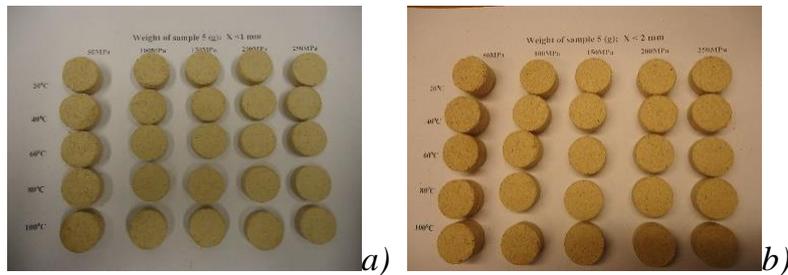


Figure. 3

Tablets made from particle size $x < 1$ mm (a); particle size $x < 2$ mm (b)

Table 1 and 3 shows the tablet density values which are recorded as an average of five measurements with particle size $x < 1$ mm and also for particle size $x < 2$ mm.

Table 1
Tablet density values (particle size $x < 1$ mm)

Pressure, p [MPa]	Density, $\bar{\rho}$ [kg/m ³]				
	$\bar{\rho}_{20^{\circ}C}$	$\bar{\rho}_{40^{\circ}C}$	$\bar{\rho}_{60^{\circ}C}$	$\bar{\rho}_{80^{\circ}C}$	$\bar{\rho}_{100^{\circ}C}$
50	639.0	679.8	712.6	689.4	744.8
100	829.0	898.2	910.6	912.4	916.0
150	942.2	1007.4	1008.2	1006.6	1013.0
200	1011.4	1022.8	1030.0	1034.6	1051.8
250	1040.0	1058.0	1065.0	1090.2	1099.6

The description of compression were made according to Johanson equation:

$$\rho = ap^{1/k}$$

Figure 4 shows the pressure-density values and the fitted curves in the case of <1 mm raw material on 20°C, 40°C, 60°C, 80°C and 100°C. Table 2 shows the constants of the fitted curves and coefficient of determination (R^2), residual mean square (σ) and calculated deviation (V_s). Results for particle size $x < 2$ mm are introduced in figure 5. and table 4.

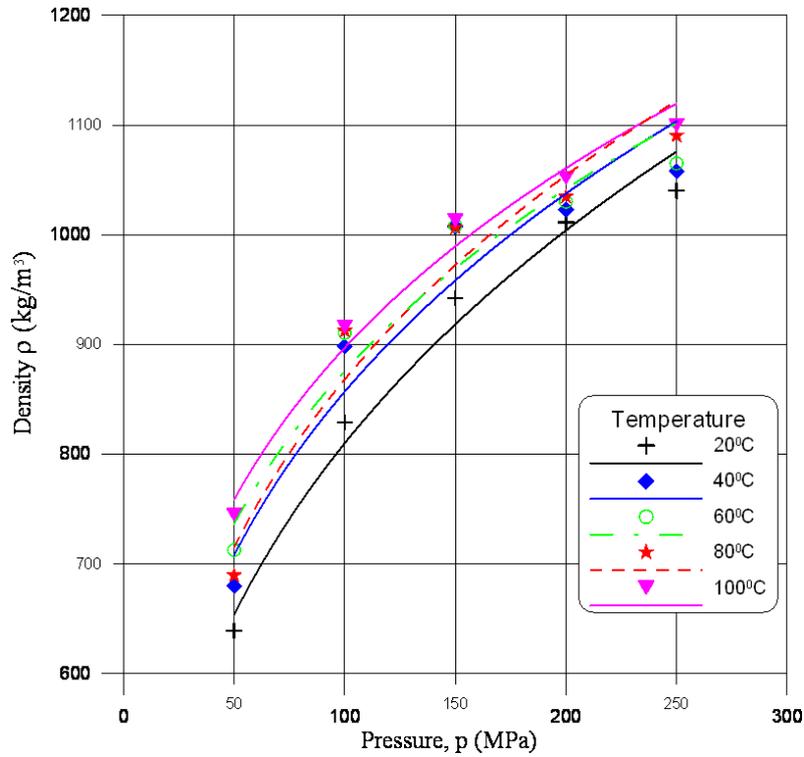


Figure. 4

Compressibility data for biomass with different temperature ($x < 1$ mm)

Table 2

Constants of Johanson's equation for different temperatures ($x < 1$ mm)

Temperature [°C]	Constant "a"	Constant "κ"	Spread deviation: V_s Coef of determination: R^2 Residual mean square: σ
20	194.5093	3.2283	$R^2=0.9816$; $\sigma=0.00096$; $V_s = 2.78\%$
40	240.7600	3.6271	$R^2=0.9366$; $\sigma=0.00276$; $V_s = 4.53\%$
60	276.8318	3.9980	$R^2=0.9492$; $\sigma=0.00180$; $V_s = 3.64\%$
80	239.2337	3.5727	$R^2=0.9535$; $\sigma=0.00205$; $V_s = 3.79\%$
100	294.5099	4.1350	$R^2=0.9820$; $\sigma=0.00057$; $V_s = 2\%$

Table 3
Tablet density values with particle size $x < 2$ mm

Pressure, [MPa]	Density ($\bar{\rho}$), [kg/m ³]				
	$\bar{\rho}_{20^{\circ}C}$	$\bar{\rho}_{40^{\circ}C}$	$\bar{\rho}_{60^{\circ}C}$	$\bar{\rho}_{80^{\circ}C}$	$\bar{\rho}_{100^{\circ}C}$
50	659.6	684.0	748.4	727.0	722.2
75	737.4	780.4	814.2	836.6	808.2
100	849.6	901.6	864.0	922.4	914.0
125	908.2	937.2	949.6	972.2	956.6
150	952.6	988.6	1004.2	1010.2	1013.4
175	985.2	1013.4	1020.0	1023.0	1033.4
200	1012.2	1031.0	1027.4	1054.8	1047.8
225	1026.0	1037.2	1051.4	1071.2	1079.6
250	1030.8	1052.8	1073.4	1090.6	1097.8
275	1055.4	1071.4	1092.8	1098.0	1112.0

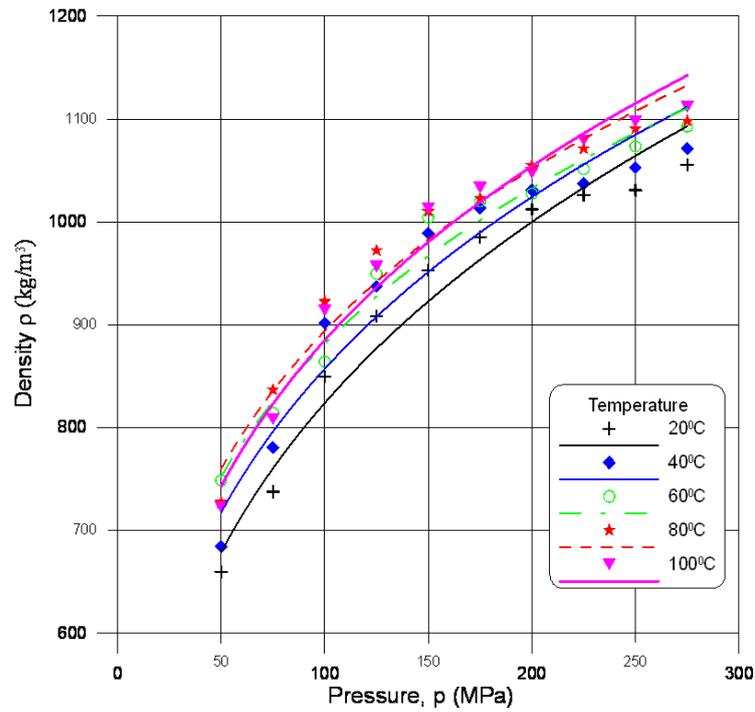


Figure. 5

Compressibility data for biomass with different temperature; $x < 2$ mm

Table 4
Constants of Johanson's equation for different temperatures ($x < 2$ mm)

Temperature, [°C]	Constant "a"	Constant "κ"	Spread deviation: V_s Coef of determination: R^2 Residual mean square: σ
20	227.3821	3.5775	$R^2=0.9647$; $\sigma=0.00098$; $V_s = 4.18\%$
40	262.2798	3.8892	$R^2=0.9438$; $\sigma=0.00135$; $V_s = 4.24\%$
60	307.4255	4.3731	$R^2=0.9767$; $\sigma=0.00042$; $V_s = 3\%$
80	303.8298	4.2682	$R^2=0.9617$; $\sigma=0.00075$; $V_s = 3.1\%$
100	276.6470	3.9605	$R^2=0.9725$; $\sigma=0.00062$; $V_s = 3.4\%$

4.2. Tablet strength

Table 5 and 6 shows the result of the falling tests in the case of <1 mm and <2 mm raw materials. Falling number is shown on figure 6, as a function of temperature on different pressure values.

Table 5
Falling number of tablets (particle size $x < 1$ mm)

Temperature [°C]	Pressure				
	50MPa	100MPa	150MPa	200MPa	250MPa
	Falling number				
20	0.00	0.00	0.33	2.00	2.33
40	0.00	0.66	2.66	3.00	4.33
60	0.00	1.00	2.66	4.66	3.33
80	0.00	1.00	2.66	4.33	5.00
100	0.00	0.00	3.33	4.66	6.00

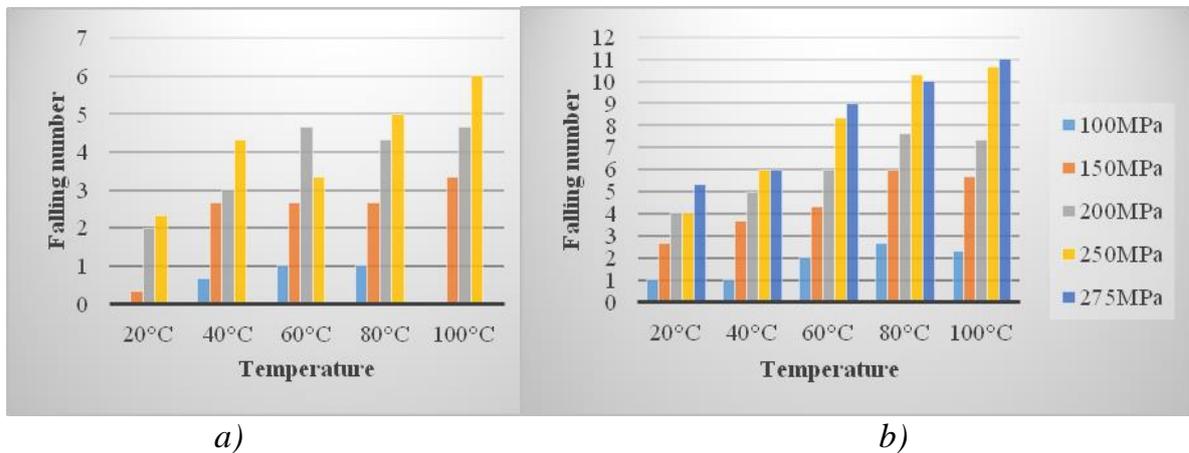


Figure. 6
Relationship between falling number, temperature and pressure
(a) particle size <1 mm
(b) particle size <2 mm

Table 6
Falling number of tablets (particle size $x < 2$ mm)

Temperature [°C]	Pressure					
	50MPa	100MPa	150MPa	200MPa	250MPa	275MPa
	Falling number					
20	0.00	1.00	2.66	4.00	4.00	5.33
40	0.00	1.00	3.66	5.00	6.00	6.00
60	0.00	2.00	4.33	6.00	8.33	9.00
80	0.00	2.66	6.00	7.66	10.33	10.00
100	0.00	2.33	5.66	7.33	10.66	11.00

5. Conclusions

This paper has presented tools and methods to evaluate the effect of temperature pressure and particle size on tablet density in the case of beech saw dust. The description of the processes is essential to be able to determinate the optimal parameters. The applied Johanson functions describes well the processes (on 60°C, in the case of <1 mm raw material $V_s=3.64\%$, using <2 mm raw material $V_s=3.00\%$).

With the same pressure and particle size, increasing temperature resulted in higher density of tablets (in the case of <1 mm raw material on 100 MPa the tablet densities: 829 kg/m³ (20°C) and 916 kg/m³ (100°C)). Increasing of temperature over 40°C does not result in a relevant density rising.

Increasing temperature resulted in higher tablet strength on the same pressure and with same particle size. Tablets made from material $x<2$ mm have higher strength (falling number: 7.33 on 200 MPa and 100°C) than tablets made from $x<1$ mm biomass (falling number: 4.66 on 200 MPa and 100°C) if temperature and pressure are constant.

The method can be used with other materials to find the optimal conditions of pressure, temperature and particle size during the agglomeration process.

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References

- [1] Chevanan, N.: **Bulk density and compaction behavior of knife mill chopped switchgrass, wheat straw, and corn stover**. Bioresource Technology 101, 2010. p.207-214.
- [2] Mani, S.: **Evaluation of compaction equations applied to four biomass species**. Canadian Biosystems Engineering Volume 46, 2004. p.355-361.
- [3] Pietsch, W.: **Agglomeration in Industry Occurrence and Applications**, 2005.
- [4] Tarján, G.: **Mineral Processing** (Volume II), 1986.
- [5] Stelte, W.: **Recent developments in biomass palletization a review**. Bioresources 7(3), 2012. p.4451-4490.
- [6] Stiess.: **Mechanische Verfahrenstechnik 2**, Springer Lehrbuch, 1993.