Briquette densification from ground hazelnut husks and sunflower stalks under compression loading

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Abstract. Briquetting of ground hazelnut husks and sunflower stalks was examined to determine the energy requirement, deformation, thickness and hardness. Four compression forces from 100, 200, 300 to 400 kN and a single speed of 5 mm/min were applied using the universal compression-testing equipment and a vessel diameter of 60 mm with a plunger. The results show that compression force had a significant effect on numerical energy, thickness and hardness of the densified briquettes of ground hazelnut husks and sunflower stalks. Deformation values of the densified briquettes were not significant in relation to the force effect. The densified ground sunflower stalks required lower energy compared to densified ground hazelnut husks. However, in terms of hardness and/or strength and durability, ground hazelnut husks briquettes could be suitable for energy use.

1. Introduction

Agricultural residues such as hazelnut husks, sunflower stalks, maize stalks, rice husks, groundnut shells, etc. constitute one of the biomass feedstock as a renewable energy source [1, 2, 3]. To improve handling, transportation and storage, it is important that biomass residues be densified into briquettes/pellets to enhance efficient energy utilization per unit volume [4]. Densification of biomass materials also reduces particulate emissions per solid fuel transported and improves biomass combustion efficiency as well as conveyance efficiencies in commercial energy generation facilities such as boilers or gasifiers [2]. The purpose of this research was to determine and compare the energy requirement of briquettes produced from ground hazelnut husks and sunflower stalks under compression loading.

2. Materials and Method

Ground or milled hazelnut husks and sunflower stalks (samples) of moisture content of 12.64 and 11.23 % on dry basis respectively were used for the briquette densification using the universal compression-testing machine (ZDM 50, Czech Republic) [5]. The ground samples were densified under four compression forces: 100, 200, 300 and 400 kN at a speed of 5 mm/min. The initial height of the samples was measured at 100 mm using the pressing vessel diameter of 60 mm with a plunger as illustrated in Figure 1.

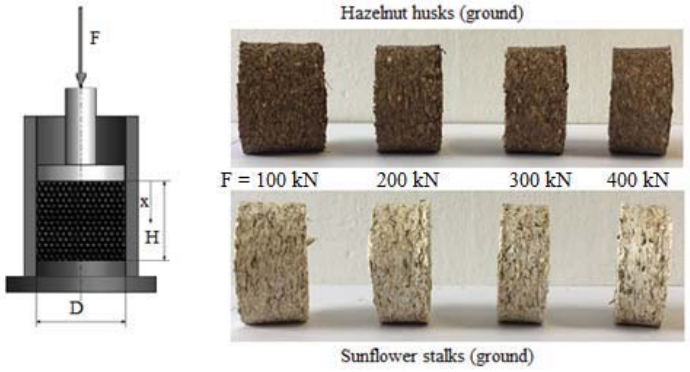

Figure 1. Schematic of pressing vessel diameter, *D* of 60mm with a plunger (*F* - force, *H* - initial height of sample, *x* - deformation of the samples) and densified samples.

The deformation values of the densified samples were obtained directly after the densification test. The energy of the densified samples was calculated using equation Eq. 1 as follows:

$$E = \sum_{n=0}^{n=i-1} \left[\left(\frac{F_{n+1} + F_n}{2} \right) (x_{n+1} x_n) \right] \quad (1)$$

where E is the energy (J), $F_{n+1} + F_n$ and $x_{n+1} - x_n$ are the values of the compression force (N) and deformation (mm), n is the number of data points and i is the number of subsections of the deformation axis (-) [6, 7, 8, 9]. The densified samples thickness was measured using a digital calliper where the measurements were read from the LCD display. The hardness of the densified samples was also calculated using Eq. 2 as follows:

$$H_d = \frac{F_r}{X_\delta} \quad (2)$$

where H_d is the hardness of densified briquettes (kN/mm), F_r is the compression force (kN) and X_δ is the deformation of densified samples (mm). The data were analysed using the software SPSS Statistics, version 24 and STATISTICA, version 13.

3. Results and discussion

The calculated and/or measured parameters of densified briquettes of ground hazelnut husks and sunflower stalks are presented in Table 1. The descriptive statistics of compression forces and samples effect on the normality of the data setare shown in tables 2 and 3 respectively. Generally, based on the Shapiro-Wilk's test (*P*-value > 0.05); the values of energy, deformation, thickness and hardness showed a normal distribution. The results of the Shapiro-Wilk's test for normal distribution of the above-mentioned parameters were similarly reported on the effect of biomass characteristics on the durability of cassava stalk residues pellets [10]. The two-way or repeated measures ANOVA analysis results are given in Table 4. The statistical results as a whole showed that compression forces had a significant effect (both increasing and decreasing trends) on energy, deformation, thickness and hardness values of densified briquettes produced from ground hazelnut husks and sunflower stalks. The significant effect was assessed on the basis that the *P*-values were less than the significant level of 0.05 or *F*-ratio values were greater than the *F*-critical values [12].

However, the univariate results indicated that the compression forces and/or the interaction effect between compression forces and samples did not statistically affect (either increase or decrease) the deformation and hardness values. On the other hand, compression forces and/or the interaction effect between compression forces and samples statistically increased and decreased the values of energy and thickness respectively. The differences between pairs of means of calculated parameters using Duncan's multiple range test indicated that the means of energy, hardness and thickness were significantly different from each other while that of the means of deformation were not significant (table 5). It is important to mention that the deformation values are relevant for analysing the theoretical energy of the samples by using the tangent curve mathematical model [11, 12]. The densified ground sunflower stalks required lower energy compared to densified ground hazelnut husks as illustrated in figure 2. However, in terms of hardness (figure 3) and/or strength and durability; ground hazelnut husks briquettes could be suitable for energy use.

Table 1. Calculated parameters of briquettes densification of samples

Samples	Forces (kN)	Calculated parameters (Mean ± Standard Deviation)			
		Energy energy (J)	Deformation (mm)	Thickness (mm)	Hardness (kN/mm)
Hazelnut husks (ground)	100	1094.46±1.03	79.28±0.45	39.75±0.72	1.27±0.01
	200	1689.61±31.52	79.63±6.48	33.07±1.03	2.53±0.21
	300	2218.97±7.79	79.92±0.31	31.65±0.37	3.75±0.01
	400	2602.32±50.66	80.80±6.07	30.48±0.11	4.97±0.37
Sunflower stalks (ground)	100	924.87±61.72	92.49±6.60	25.72±0.35	1.08±0.08
	200	1314.96±39.07	99.31±1.35	21.99±0.69	2.01±0.03
	300	1616.09±58.69	94.81±2.02	20.15±0.58	3.16±0.07
	400	1942.61±72.22	94.45±8.10	18.45±0.11	4.25±0.36

Table 2. Descriptive statistics of force effect on the normality of calculated parameters

Calculated parameters	Compression forces (kN)	Shapiro-Wilk's test (*P*-value)	R^2
Energy (J)	100	0.279	0.865
	200	0.187	0.837
	300	0.089	0.792
	400	0.183	0.836
Deformation (mm)	100	0.347	0.882
	200	0.425	0.899
	300	0.131	0.814
	400	0.934	0.986
Thickness (mm)	100	0.065	0.775
	200	0.141	0.819
	300	0.069	0.779
	400	0.031	0.739
Hardness (kN/mm)	100	0.373	0.888
	200	0.412	0.896
	300	0.116	0.807
	400	0.972	0.993

P-values > 0.05 indicate the data are normally distributed; *P*-values<0.05 indicate the data are not normally distributed R^2 is the coefficient of determination

Table 3. Descriptive statistics of samples effect on the normality of calculated parameters

Calculated parameters	Samples	Shapiro-Wilk's test (*P*-value)	R^2
Energy (J)	Hazelnut husks (ground)	0.303	0.902
	Sunflower stalks (ground)	0.733	0.952
Deformation (mm)	Hazelnut husks (ground)	0.539	0.932
	Sunflower stalks (ground)	0.205	0.884
Thickness (mm)	Hazelnut husks (ground)	0.028	0.800
	Sunflower stalks (ground)	0.321	0.905
Hardness (kN/mm)	Hazelnut husks (ground)	0.552	0.934
	Sunflower stalks (ground)	0.574	0.936

Table 4. Two-way or repeated measures ANOVA test of calculated parameters

Calculated parameters	*F*-ratio	*F*-critical	*P*-value	R^2
Energy (J)	293.28	4.07	< 0.05	0.996
Deformation (mm)	5.86	4.07	< 0.05	0.837
Thickness (mm)	321.82	4.07	< 0.05	0.996
Hardness (kN/mm)	96.26	4.07	< 0.05	0.988

F-ratio >*F*-critical or *P*-value < 0.05 indicates significant; *F*-ratio is the value of the *F* test (-), *F*-critical is the critical value that compares a pair of models (-), *P*-value is the significance level used for testing a statistical hypothesis (-), R^2 is the coefficient of determination (-).

Table 5. Post hoc test of calculated parameters using Duncan's multiple range test.

Compression forces (kN)	Calculated parameters (Means)			
	*Energy (J)	*Hardness (kN/mm)	**Deformation (mm)	***Thickness (mm)
(400)* (200)** 100***	2272.46^{a}	4.61^{a}	89.47^{a}	32.74^{a}
(300)* (400)** 200***	1917.53^{b}	3.46^{b}	87.63^{a}	27.53^{b}
(200)* (300)** 300***	1502.28^{c}	2.27^{c}	87.36^{a}	25.90^{c}
(100)* (100)** 400***	1009.66^{d}	1.17^{d}	85.89^{a}	24.46^{d}

Same letters indicate non-significant difference; different letters indicate significant difference; Asterisk (*), (**) and (***) indicate (Means) at compression forces in a descending order of magnitude

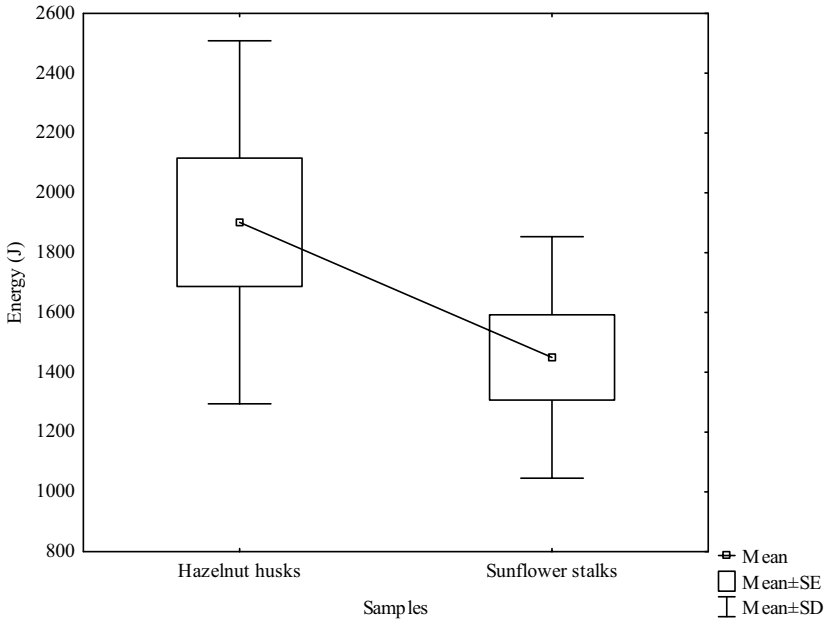

Figure 2. Box plot of energy grouped by samples (SE: Standard Error; SD: Standard Deviation)

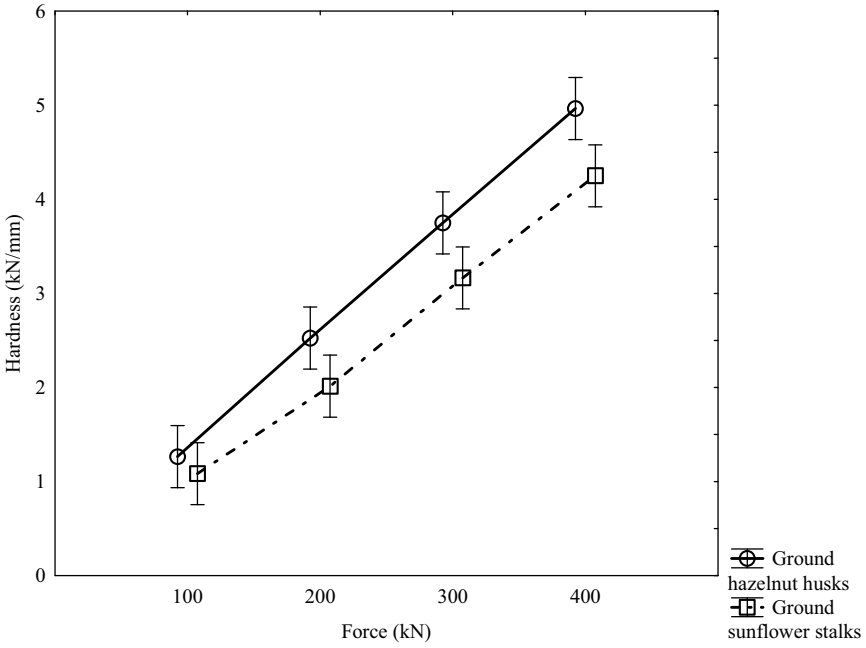

Figure 3. Comparison of the hardness of densified briquettes of ground hazelnut husks and sunflower stalks.

4. Conclusion

The effect of compression forces on energy, thickness and hardness of densified briquettes was significant (*P*-value < 0.05 or F-ratio > F-critical). Deformation of densified briquettes under the effect of compression forces was not significant (*P*-value > 0.05 or F-critical > F-ratio).

The densified ground sunflower stalks required minimum energy than the ground hazelnut husks. The mean difference of energy and hardness of the densified briquettes of ground hazelnut husks and sunflower stalks was found to be 451.71 J and 0.5 kN/mm respectively. The results presented herein are part of a full study still underway, which is important for improving the technology of the densification of agricultural residues or biomass for energy purpose.

5. References

[1] Okot D K, Bilsborrow P E and Phan A N 2018 Effects of operating parameters on maize COB briquette quality *Biomass and Bioenergy,* 11261–72

[2] Muazu R I and Stegemann J A 2015 Effects of operating variables on durability of fuel briquettes from rice husks and corn cobs *Fuel Pro. Tech.* 133137–145

[3] Purohit P P, Tripathi A K and Kandpal T C 2006 Energetics of coal substitution by briquettes of agricultural residues *Energy,* 31(8–9) 1321–1331

[4] Felfli F F, Mesa P J M, Rocha J D, Filippetto D, Luengo C A and Pippo W A 2011 Biomass briquetting and its perspectives in Brazil *Biomass and Bioenergy*, 35(1) 236–242

[5] Herak D, Kabutey A, Sedlacek A and Simanjuntak S 2013 Mathematical model of mechanical behaviour of Jatropha curcas L. seeds under compression loading *Bio. Eng.* 114(3) 279–288

[6] Demirel C, Kabutey A, Herak D and Gurdil G A K 2017 Numerical estimation of deformation energy of selected bulk oilseeds in compression loading *IOP Conf. Ser:Mat. Sci. and Eng.* 237(1) 1–5

[7] Divisova M, Herak D, Kabutey A, Sigalingging R and Svatonova T 2014 Deformation curve characteristics of rapeseeds and sunflower seeds under compression loading *Sci. Agric. Bohemica* 45(3) 180–186

[8] Herak D, Kabutey A, Sedlacek A and Gurdil G A K 2012 Mechanical behaviour of several layers of selected plant seeds under compression loading *Research in Agric. Eng.* 58(1) 24–29

[9] Kabutey A, Herak D, Dajbych O, Boatri W E and Sigalingging R 2014 Deformation energy of Jatropha curcas L. seeds under compression loading *Res in Agric. Eng.* 60(2) 68–74

[10] Kaewwinud N, Khokhajaikiat P and Boonma A 2018 Effect of biomass characteristics on durability of Cassava residues pellets *Res in Agric. Eng.* 64(1) 15–19

[11] Sigalingging R, Herak D, Kabutey A, Cestmir M and Divisova M 2014 Tangent curve function description of mechanical behaviour of bulk oilseeds: A review *Sci. Agric. Bohemica* 45(4) 259–264

[12] Sigalingging R, Herak D, Kabutey A, Dajbych O, Hrabe P and Mizera C 2015 Application of a tangent curve mathematical model for analysis of the mechanical behaviour of sunflower bulk seeds *Int. Agro.* 29(4) 517–524