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Comparing energy demand of densified briquettes of ground and unground hazelnut husks under compression loading

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Abstract. The study compared the energy consumption (J) of briquettes produced from the ground and unground hazelnut husks using a universal compacting machine and a pressing chamber of 60 mm diameter with a plunger. Other parameters evaluated were deformation (mm), thickness (mm) and hardness (kN/mm). The analysis of variance results proved that the applied force, material type and interaction had a significant effect ($P < 0.05$ or F -ratio $> F$ -critical) on energy requirement of briquettes compaction from the ground and unground hazelnut husks. Ground hazelnut husks briquettes consumed more energy compared to unground hazelnut husks briquettes. The study is still ongoing where the varying effects of moisture content and particles size on energy demand and other biomass densification properties are under consideration. Therefore, the results presented here are preliminary.

1. Introduction

Biomass is one of the renewable energy sources that are of great importance regarding quantity and widespread production with a potential contribution towards the future global energy mix [1,2,3,4]. The conversion of agricultural residues such as hazelnut husks, maize stalks; and agro-industrial wastes such as waste paper and coconut husks into densified briquettes/pellets has been studied considerably in the literature [5,3,4,6]. Densification of biomass briquettes/pellets improves the handling, transportation and storage compared to loose or bulky biomass materials [6,7]. The literature, however, indicates that both the energy consumption and quality of biomass briquettes/pellets depend on several factors such as the applied pressure, material moisture content, particle size, initial bulk density, compaction technology, among others [7,8]. For industrial production of biomass briquettes, briquetting energy demand is very important for consideration. Therefore, in this preliminary study, the energy demand for compacting ground and unground hazelnut husks into briquettes was investigated using a universal compacting machine and a pressing chamber with a plunger.

2. Materials and Method

Samples of ground and unground hazelnut husks (Figure 1) were compacted into briquettes at compaction forces between 100 and 400 kN and a speed of 5 mm/min using the universal compression-testing machine (ZDM 50, Czech Republic) and a pressing vessel of diameter



60 mm with a plunger[9,10,11]. The initial volume of samples being constant was calculated to be $2.827 \cdot 10^{-4} \text{ m}^3$ using Eq. 1[12].

$$V = \frac{\pi \cdot D^2}{4} \cdot H_i \quad (1)$$

Where V is the volume of samples (m^3), D is the diameter of the pressing vessel ($D = 60 \text{ mm}$) and H_i is the initial height of samples ($H_i = 100 \text{ mm}$). The moisture content of the samples was also determined to be 12.64% and 10.80% on dry basis using the procedure given by [13]. The densified briquettes energy and hardness were calculated using the expressions given by the authors [9,12,14]. The thickness of the densified briquettes was measured using a digital calliper. The data were evaluated using the SPSS software, version 24.

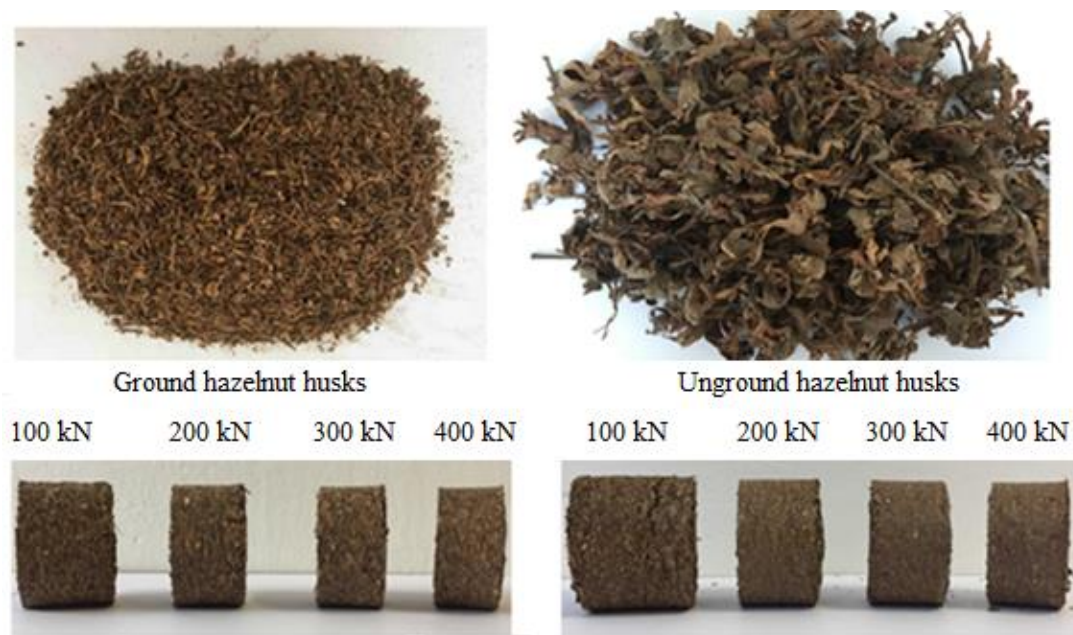


Figure 1. Densified briquettes produced from the ground and unground hazelnut husks at different compaction forces.

3. Results and discussion

The briquettes compaction results of ground and unground hazelnut husks are presented in Table 1. In this study, the energy requirement for compaction or densification of the biomass materials was of the greatest importance [7,8,9]. The analysis of variance results showed that the applied force, material type and interaction had a significant effect ($P < 0.05$ or $F\text{-ratio} > F\text{-critical}$) on energy consumption of the briquettes densification as shown in Table 2. The ground hazelnut husks briquettes consumed more energy compared to unground hazelnut husks as displayed in Figures 2.

Statistically, the deformation and hardness parameters in relation to the applied force and the interaction (applied force and material type) were not significant, that is ($F\text{-ratio} < F\text{-critical}$ or $P\text{-value} > 0.05$) as shown in Table 2. Generally, the corrected and/or whole model of the dependent variables namely energy, deformation, thickness and hardness in relation to the effects of the applied force, material type and interaction showed high values of the coefficients of determination (R^2) between 0.920 0.998. The data showed a normal distribution (Figure 3) suggesting that the preliminary data is reliable.

Table 1. Calculated amounts of densified briquettes of hazelnut husks (Mean \pm Standard Deviation)

Hazelnut husks	Forces (kN)	Energy (J)	Deformation (mm)	Thickness (mm)	Hardness (kN/mm)
Ground	100	1094.46 \pm 1.03	79.28 \pm 0.45	39.75 \pm 0.72	1.27 \pm 0.01
	200	1689.61 \pm 31.52	79.63 \pm 6.48	33.07 \pm 1.03	2.53 \pm 0.21
	300	2218.97 \pm 7.79	79.92 \pm 0.29	31.65 \pm 0.37	3.75 \pm 0.01
	400	2602.32 \pm 50.66	80.80 \pm 6.07	30.48 \pm 0.11	4.97 \pm 0.37
Unground	100	804.11 \pm 5.44	92.42 \pm 0.89	26.69 \pm 1.16	1.08 \pm 0.01
	200	1276.39 \pm 8.74	93.45 \pm 2.16	22.91 \pm 0.16	2.15 \pm 0.05
	300	1644.56 \pm 14.30	100.55 \pm 3.19	20.71 \pm 0.01	2.99 \pm 0.09
	400	2002.76 \pm 76.86	97.17 \pm 1.34	20.18 \pm 0.30	4.12 \pm 0.06

Table 2. Statistical values of a Two-way ANOVA analysis of dependent variables

Effect	Dependent variables	df (-)	Sum of Squares	Mean sum of squares	F-ratio	P-value
Corrected/whole Model	Energy (J)	7	5036380.78 ^a	719482.97	584.95	< 0.05
	Deformation (mm)	7	1107.75 ^b	158.25	13.11	< 0.05
	Thickness (mm)	7	650.02 ^c	92.86	232.42	< 0.05
	Hardness (mm)	7	26.31 ^d	3.78	151.87	< 0.05
Forces	Energy (J)	3	4091916.09	1363972.03	1108.92	< 0.05
	Deformation (mm)	3	50.73	16.91	1.40	> 0.05
	Thickness (mm)	3	150.36	50.12	125.44	< 0.05
	Hardness (mm)	3	24.81	8.27	334.34	< 0.05
Material type	Energy (J)	1	881277.38	881277.38	716.49	< 0.05
	Deformation (mm)	1	1022.56	1022.561	84.71	< 0.05
	Thickness (mm)	1	494.28	494.28	1237.12	< 0.05
	Hardness (mm)	1	1.19	1.19	48.03	< 0.05
Forces*Material type	Energy (J)	3	63187.32	21062.44	17.13	< 0.05
	Deformation (mm)	3	34.46	11.49	0.95	> 0.05
	Thickness (mm)	3	5.38	1.79	4.49	< 0.05
	Hardness (mm)	3	0.29	0.09	4.02	> 0.05
Error	Energy (J)	8	9839.99	1229.99	-	-
	Deformation (mm)	8	96.57	12.07	-	-
	Thickness (mm)	8	3.21	0.40	-	-
	Hardness (mm)	8	0.21	0.03	-	-
Total	Energy (J)	16	49489526.34	-	-	-
	Deformation (mm)	16	124828.64	-	-	-
	Thickness (mm)	16	13357.33	-	-	-
	Hardness (mm)	16	156.79	-	-	-
Corrected/whole total	Energy (J)	15	5046220.78	-	-	-
	Deformation (mm)	15	1204.32	-	-	-
	Thickness (mm)	15	653.22	-	-	-
	Hardness (mm)	15	26.49	-	-	-

df: degrees of freedom; ^a $R^2 = 0.998$ (-); ^b $R^2 = 0.920$ (-); ^c $R^2 = 0.995$ (-); ^d $R^2 = 0.993$ (-); α is the significance level; F -critical = 4.07; F -ratio $> F$ -critical or P -value < 0.05 indicates significant effect; F -ratio $< F$ -critical or P -value > 0.05 indicates non-significant effect; F -ratio is the value of the F test (-). F -critical is the critical value that compares a pair of model (-); P -value is the significance level used for testing a statistical hypothesis (-); R^2 is the coefficient of determination (-).

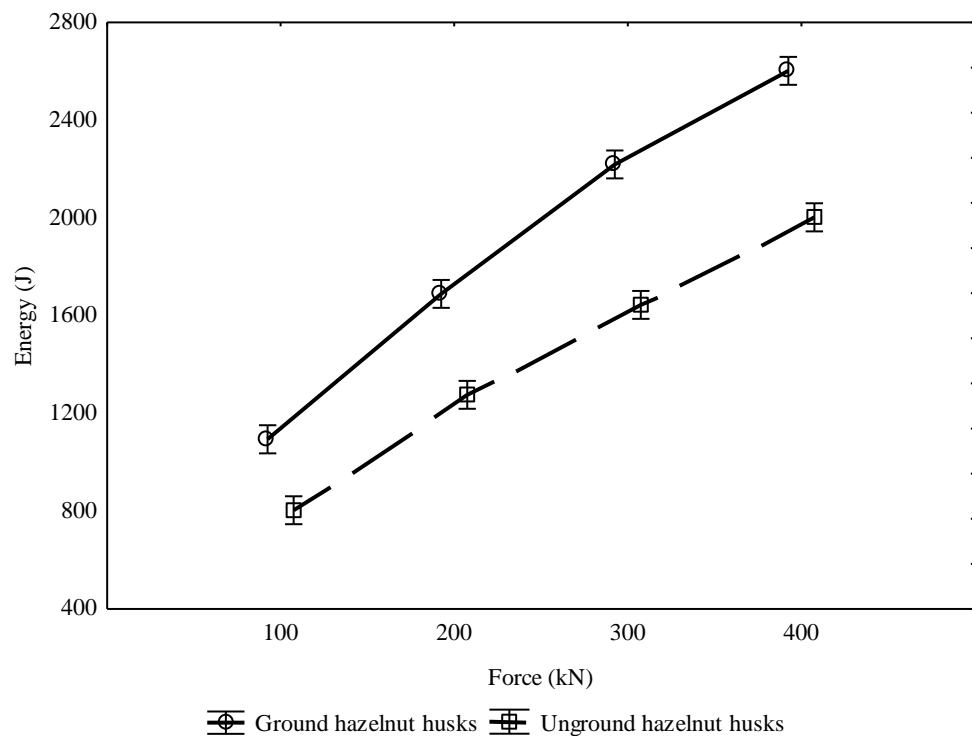


Figure 2. Energy and force relationship between ground and unground hazelnut husks briquettes

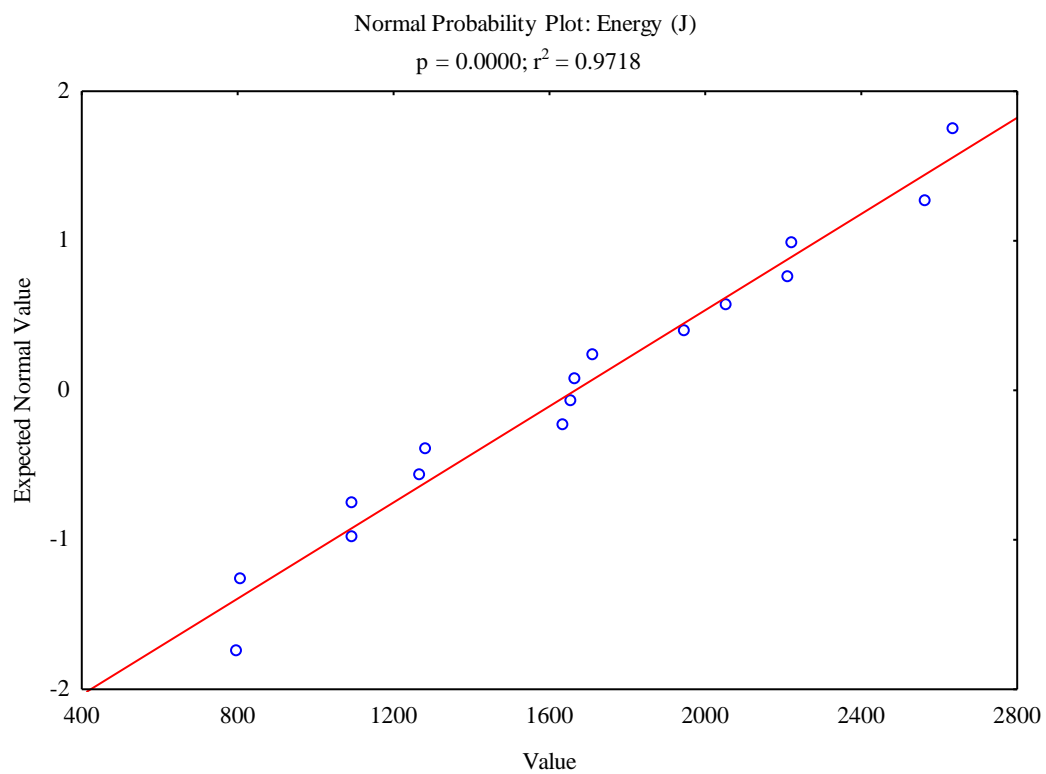


Figure 3. Normal probability plot of energy of ground and unground hazelnut husks briquettes

4. Conclusion

The energy requirements of briquettes produced from the ground and unground hazelnut husks were examined under compression loading. The applied force, material type and interaction had a significant effect on energy consumption for producing the briquettes. Higher energy was needed for ground hazelnut husks briquettes than unground hazelnut husks briquettes. The corrected model of energy, deformation, thickness and hardness in relation to the effects of the applied force, material type and interaction was highly significant at a 95% confidence interval or 5% significance level. The study on briquettes production from hazelnut husks and sunflower stalks is still ongoing where the first published results focused on ground hazelnut husks and ground sunflower stalks. In this document is discussed the second part of the results. The complete results, however, will take into consideration the varying effects of moisture content and particles size on energy requirement and other densification characteristics.

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