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MODELLING OF THE ENERGY BALANCE FOR THE TREATMENT OF SOLID BIOMASS FUEL BY COMPRESSING

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Abstract

The aim of the presented research is the implementation of a mathematical model to analyse and plan the production of solid biomass fuel by compressing. The mathematical model reflects the current experimental state of the art of effectiveness of fuel compressing machines. The process of making briquettes is considered to be fairly energy-intensive. Nevertheless, if we compare the energy expenditures to the heating value of the fuel, then it is less than 10%, even when converted into primary energy. The experiments that were conducted by the authors illustrate that the actual energy expenditure is significantly smaller. The main expenditure comes from moving the working parts of the device. The energy that is needed for briquetting is insignificant. The residual bulk-material from agricultural and forest industry has low bulk density which consequently causes several management problems. However, it is beneficial to produce fuel with homogeneous properties using pressure processing. Unfortunately, the raw material does not correspond well to the pressure from the briquette machine; yet, the management can be substantially improved with adding wood to the mixtures.

Keywords: compressing, fuel, pressure, density, volume

Introduction

Increasing value of resources is one of the smart priorities of Estonia, beside other sectors like medicine and information technology. Thus, the waste that agricultural industry and wood-industry produce as fuel should be considered as a raw material. South Estonia is rich in forestry and agricultural industries, therefore, usage of production waste of grain and wood-industry should receive full attention.

Many authors have previously studied pressure processing behaviour. In their papers they use density as a parameter for describing the product. In this paper it is discussed that instead of density it might be more efficient to use the opposite value of it that is described as special volume in the mathematical model.

The user experience from common users who added the above described briquette to the Estonia's prevalent stoves with ordinary fireplace note that this fuel did not catch fire as well as wood logs. The burning was also calmer and it resulted in more ash. This can also be an advantage: this fuel is better in case a calmer fire is needed e.g. to braise food.

State of Art

The efficiency of the briquetting process has been recently discussed in various studies. In research the focus is on density (Guo, Wang, Tabil, & Wang, 2016). Other researchers focus on various binders, (Guo et al., 2016), but practice of authors of this article illustrates that a small amount of additional wood is sufficient. In current article the reciprocal of density enables to visualize the work of compression.

Several higher rank static models that are based on experiments have been developed by other researchers (Wang, Wu, & Sun, 2018) The test machine is in figure 1. The mathematical model that is used by authors of this article is based on the Second law of Newton: work is the distance of force. The study focuses on the fuel properties of briquetting and on the composition and size of the raw material. The authors have noted the relatively small influence of the treatable fuel material on the energy consumption of briquetting. Previous studies have focused on density not on specific volume (Shuma, Madyira, & Oosthuizen, 2017). The energy consumption is determined and various side effects are taken into account, similarly to the study from Alanya-Rosenbaum et al(Alanya-Rosenbaum, Bergman, Ganguly, & Pierobon, 2018). The press that is used, has a similar construction to the press used in the current study. Sawdust is used as a binder. The change of volume is only considered in the context of the relaxation period that follows the briquetting (Rahaman & Salam, 2017). The economical calculations of briquetting are commonly in the focus of studies on field- and forest residues. This study focused on the energy balance. The used amounts of energy are comparably small, but they can change fast (Stolarski et al., 2013).

The effect of hot curing before briquetting on the energy density of final product have been studied previously. The conclusion has been that it does not have significant effect (Araújo et al., 2016). The combustion process of different briquettes in a test furnace with a grate has been analysed and the authors conclude that the process is unstable and polluting (Deac, Fechete-Tutunaru, & Gaspar, 2016). The current research shows that using the fuel in a ceramic slit furnace (Umvelt-Plus) has considerably cleaner emissions. The work of a pelletizing machine using statistical methods and focusing on density has been researched by (Xia, Sun, Wu, & Jiang, 2016).

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Theory

In theory, the energy which is needed for briquetting can be expressed directly with force and distance. As it is known, Newton's second law states that it is possible to calculate the work done by force during the distance by multiplying force with the distance. Based on the average density of the raw briquette which is 300 kg/m^3 (Stolarski et al., 2013) and the density of the finished product approximately 1000 kg/m^3 (Žandeckis et al., 2014), it possible to convert 15 cm raw briquetting material to 5 cm of finished briquette. The speed of briquetting during the process is 0.01 $m \cdot s^{-1}$. Assuming that the exiting is caused by the working-cylinders constant pressure up to 200 kN 0.001963 m^2 to the surface, it is possible to estimate the real required power would be

$$P = \frac{l \cdot F}{S} = \frac{0.01 \cdot 200}{0.001963} = 1020 \text{ kW} \quad (1)$$

Nevertheless, as the maximum pressure is implemented only short term and the actual energy expenditure is substantially smaller. Measuring the working-pressure of the pressure-cylinder could give more precise data about the actual energy requirement.

Methods

The trial batch of agricultural briquettes was produced during the summer of 2014 in the Estonian University of Life Sciences. The main aim was to produce compressed fuel for the further burning experiments with the LUK-50 automatic solid fuel boiler with a stoker Bioburner40 from factory Rapla Metall. The mixture of grain production waste and saw dust was made in the ratio of 3 to 1. It means that the saw-dust was briquetted and grain waste was added in the volume of 25%. In addition to the mixture that was made from rape, barley and oat production waste (which was gathered from the grain purifying machine of farm Rannu Seeme), a comparison experiments with aspen wood chips and birch bark were made. The electricity energy used for the press Weima C-150 was registered with energy-meter ISKRA. The data of producing brick bark briquette was recorded with network analyser Janitza UMG 605. The experiments were followed with idle tests, which showed the following: if the briquetting machine electrical power is 4.9 kW and idle test power is 4.4 kW then the difference is only 0.5 kW which is 9.8 percent of the aggregate capacity.

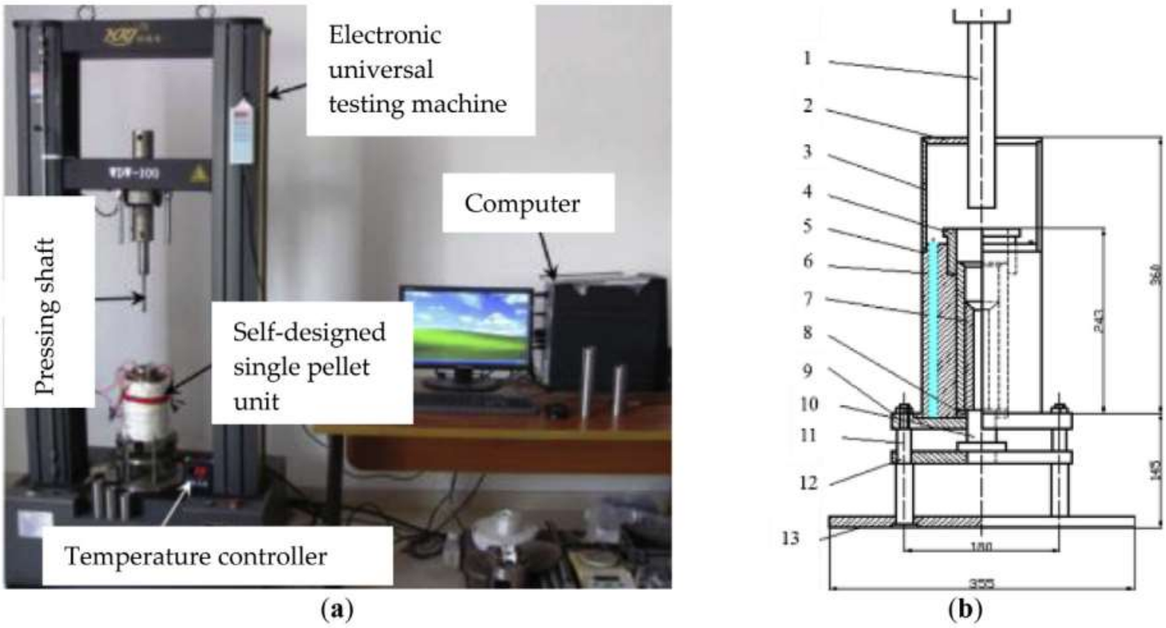

Figure 1. One briquette making setup test device; (b) Self-designed single pellet unit: (1) Pressing shaft, (2) guide device, (3) supporting cylinder, (4) inner sleeve, (5) heating sleeve, (6) heating device, (7) briquetting mold, (8) mold block, (9) mold supporter, (10) back stop, (11) supporting column, (12) back stop supporter, and (13) foundation support. (Source: Wang, Wu, & Sun, 2018)

The conclusion of the experiment is that the indirectly assessed efficiency of the briquetting machine is very small: less than 10 percent. This is due to the friction that is caused by the work of the appliance.

Coffee residue was used as a bulk material. It was thermally changed anhydrous and left to ambient conditions to achieve equilibrium. The described material was selected for testing due to its homogeneous structure and good accessibility (Figure2).

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Example of briquetting with hydraulic press

The compression of solid fuel is widely used technological process to increase the management of the fuel. For example, grinding of energy bark, pellet briquetting and production of pellets (Olt & Laur, 2009). Unfortunately, the effectiveness of named devices is low. According to the experiments that have been made by the authors, it is approximately 10% (Hovi & Hovi, 2014). Therefore, it should be possible to increase the efficiency with little effort.

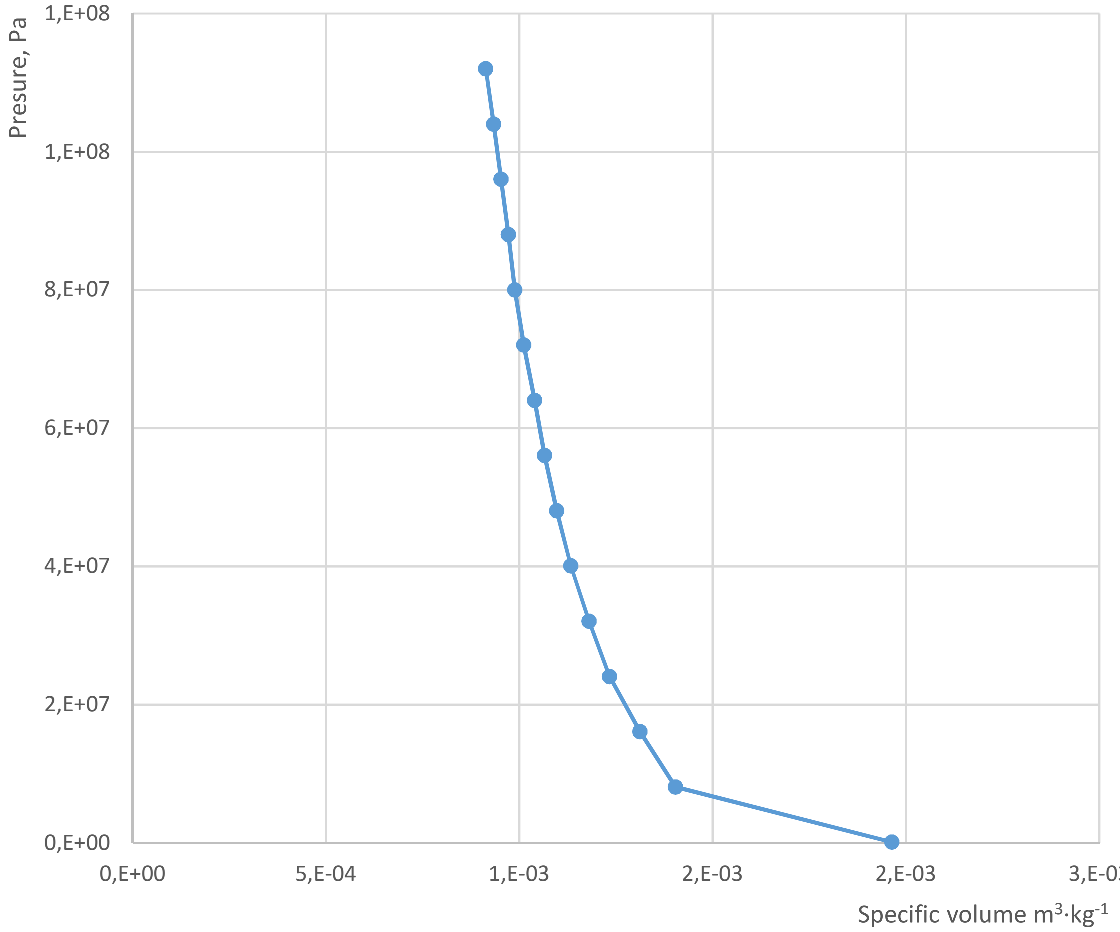

Figure 2. Process of making one briquette in p-v-diagram (Pa and $m^3 \cdot kg^{-1}$)

In order to determine the work required for briquetting, lot of experiments for making one briquette with hydraulic press was made. The resulting data was converted into special volume of the material and axially effective pressure (Figure 3).

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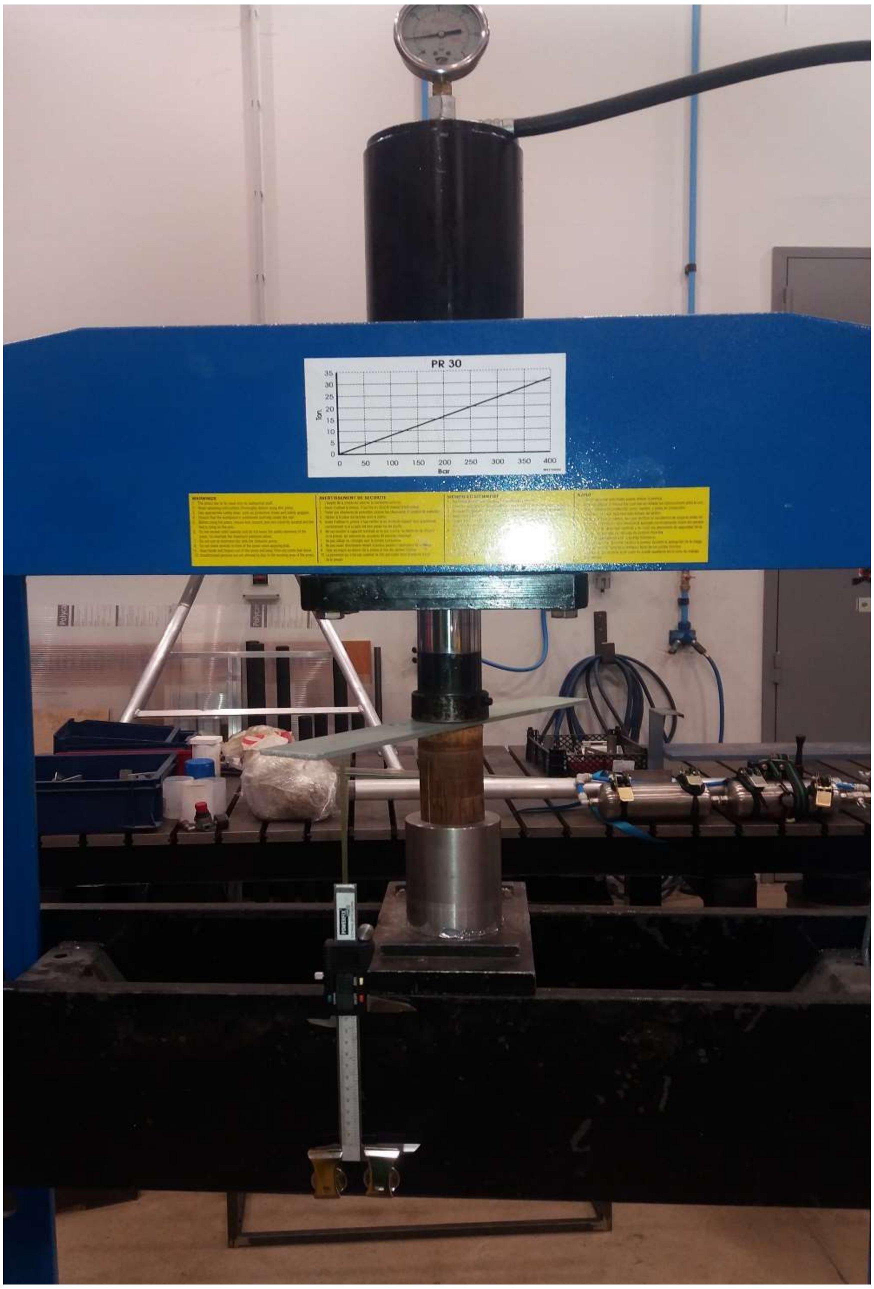

Figure 3. Experimental setup for making one briquette with hydraulic press PR-30

The diameter of the cylinder is d=0.05 and the height is h=0.1 meters. It holds m=0.1 kg of examined bulk material. Therefore, the initial density of the test piece is calculated with the following formula:

$$\rho = \frac{m \cdot 4}{h \cdot \pi \cdot d^2} = \frac{0.1 \cdot 4}{0.1 \cdot 3.14159 \cdot 0.05^2} = 509.3\ kg \cdot m^{-3} \tag{2}$$

To visualize the work that was done to make briquette, authors use specific volume instead of density. It is calculable as the inverse of density. The initial specific volume is $v=1.964 \cdot 10^{-3}\ m^3 \cdot kg^{-1}$. It is widely known that the work on p-v-scale is equal to the surface area which is under the line that depicts the process, if the absolute pressure unit is Pa and volume unit is cubic meters. As the aim is to achieve the residual density of the briquette to be more than 1000 $kg \cdot m^{-3}$, the piston route should be at least 0,05 meters. This would result in doubling the initial density. However, the specific volume should decrease twice and remain below $10^{-3}\ m^3 \cdot kg^{-1}$. In case of the sample specimens, this is the case.

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Figure 4. Processing briquette with hydraulic press Weima C-150

The second set of experiments was carried out with the Weima C-150, which is designed to produce small production of wood briquette. Network analyser Janiza saved the power supply circuit parameters. After few minutes of idle running, 10 kg of before described bulk material was added (Figure 4).

Table 1. The energy consumption of sample batches

Item	Energy consumption $kWh \cdot kg^{-1}$
Leaf briquette	0.1349[1]
Sawdust briquette	0.0148
Coffee briquette	0.2233

It is visible in Table 1, high difference on energy consumption, which is caused by different processing properties of input.

Conclusion

This type of processing provides an opportunity to spread the usage of raw material, which is otherwise hard to manage. The described round-briquette is usable with the automatic-burner with stoker where scatter material may form an arch. Briquette is also suitable for the manually services firebox, where it is possible to guide the burning process with wider range of fuel choices. According to the experience of an ordinary user, the agricultural briquette is suitable to braise food, when calmer fire is needed. The authors conclude that the valuating of fuel through briquetting or other mean of pressure-treatment should be examined further. Especially with using various agricultural waste products described herein.

Based on the information we have provided in this paper, we can conclude that using specific volume as the parameter in the mathematical model is more efficient than using density.

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References

ALANYA-ROSENBAUM, S., BERGMAN, R. D., GANGULY, I., & PIEROBON, F. 2018. a Comparative Life-Cycle Assessment of Briquetting Logging Residues and Lumber Manufacturing Coproducts in Western United States. *Applied Engineering in Agriculture*, *34*(1), 11–24. https://doi.org/10.13031/aea.12378

ARAÚJO, S., BOAS, M. A. V., NEIVA, D. M., DE CASSIA CARNEIRO, A., VITAL, B., BREGUEZ, M., & PEREIRA, H. 2016. Effect of a mild torrefaction for production of eucalypt wood briquettes under different compression pressures. *Biomass and Bioenergy*, *90*, 181–186. https://doi.org/10.1016/j.biombioe.2016.04.007

DEAC, T., FECHETE-TUTUNARU, L., & GASPAR, F. 2016. Environmental Impact of Sawdust Briquettes Use - Experimental Approach. *Energy Procedia*, *85*(November 2015), 178–183. https://doi.org/10.1016/j.egypro.2015.12.324

GUO, L., WANG, D., TABIL, L. G., & WANG, G. 2016. Compression and relaxation properties of selected biomass for briquetting. *Biosystems Engineering*, *148*, 101–110. https://doi.org/10.1016/j.biosystemseng.2016.05.009

HOVI, M., & HOVI, K. 2014. The energy balance of the wooden briquette with additives. In *EMÜ* (p. 98...102). Tartu: TEUK koverents. Retrieved from http://tek.emu.ee/userfiles/yksused/tek/taastuvenergia_keskus/TEUK XVI/kogumik TEUK XVI_sisu_web.pdf

OLT, J., & LAUR, M. 2009. Briquetting different kinds of herbaceous biomaterial. *Engineering for Rural Development. Proceedings of the Inernational Scientific Conference (Latvia)*. LLU.

RAHAMAN, S. A., & SALAM, P. A. 2017. Characterization of cold densified rice straw briquettes and the potential use of sawdust as binder. *Fuel Processing Technology*, *158*, 9–19. https://doi.org/10.1016/j.fuproc.2016.12.008

SHUMA, M. R., MADYIRA, D. M., & OOSTHUIZEN, G. A. 2017. Combustion behaviour of loose biomass briquettes resulting from agricultural and forestry residues. *Proceedings of the 25th Conference on the Domestic Use of Energy, DUE 2017*, *7*, 38–44. https://doi.org/10.23919/DUE.2017.7931822

STOLARSKI, M. J., SZCZUKOWSKI, S., TWORKOWSKI, J., KRZYZANIAK, M., GULCZYŃSKI, P., & MLECZEK, M. 2013. Comparison of quality and production cost of briquettes made from agricultural and forest origin biomass. *Renewable Energy*, *57*, 20–26. https://doi.org/10.1016/j.renene.2013.01.005

ŽANDECKIS, A., ROMAGNOLI, F., BELOBORODKO, A., KIRSANOVS, V., BLUMBERGA, D., MENIND, A., & HOVI, M. 2014. Briquettes from Mixtures of Herbaceous Biomass and Wood: Biofuel Investigation and Combustion Tests. *Chemical Engineering Transactions*, *42*(November 2014), 67–72. https://doi.org/10.3303/CET1442012

WANG, Y., WU, K., & SUN, Y. 2018. Effects of raw material particle size on the briquetting process of rice straw. *Journal of the Energy Institute*, *91*(1), 153–162. https://doi.org/10.1016/j.joei.2016.09.002

XIA, X., SUN, Y., WU, K., & JIANG, Q. 2016. Optimization of a straw ring-die briquetting process combined analytic hierarchy process and grey correlation analysis method. *Fuel Processing Technology*, *152*, 303–309. https://doi.org/10.1016/j.fuproc.2016.06.018

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