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Comparison of quality and production cost of briquettes made from agricultural and forest origin biomass

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ABSTRACT

This paper presents the quality and cost of small-scale production of briquettes, made from agricultural and forest biomass in north-eastern Poland. The experiment involved production of eight types of briquettes. The highest net calorific value was determined for briquettes made from pine sawdust (18,144 MJ t^{-1}). The value measured for briquettes made from perennial energy plants was over 1500 MJ t^{-1} lower, and for those made from straw 2000 MJ t^{-1} lower than for sawdust briquettes. The sawdust briquettes left significantly the lowest amount of ash (0.40% of dry mass). The significantly highest content of hydrogen, sulphur and nitrogen was found in briquettes containing the highest portion of rapeseed oilcake. The quality of briquettes varied and only some of them met the requirements of DIN 51731. Briquettes made from pine sawdust were of the highest quality. The briquette production cost ranged from 66.55 € t^{-1} to 137.87 € t^{-1} for rape straw briquettes and for those made from a mixture of rape straw and rapeseed oilcake (50:50), respectively. In general, briquette production was profitable, except for the briquettes made from a straw and rapeseed oilcake mixture.
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1. Introduction

Recently in Poland, as well as elsewhere in the EU, renewable sources have been used increasingly often in the generation of energy. In 2009, energy from renewable sources in the EU accounted for 18.3% of the total primary energy, with 9.0% on average in Poland. According to the guidelines set out in the EU directive [1], energy from renewable sources in Poland must account for 15% of total energy by 2020. Currently, most of energy from renewable sources in Poland is produced from solid biomass – 86.1% [2].

The majority of solid biomass for energy generation in Poland is supplied by forests and the wood processing industry. However, the majority of biomass is ultimately to be obtained from perennial energy crops, cultivated on agricultural land, such as *Salix* coppice (*Salix* spp.), *Sida hermaphrodita* (Virginia mallow) and *Miscanthus giganteus* [3–7] as well as cereal and rape straw as post-production biomass.

In order to meet the goals set by the EU with respect to production of renewable energy, the domestic Regulation of the Minister of Economy of 14 August 2008 provides for a significant increase in non-forest biomass consumption for energy production [8]. Large power plants and combined heat and power plants buy biomass fuel from large producers, which reduces biomass availability on the local markets. Pellet production in Poland is growing very rapidly. It amounted to about 20 thousand tonnes in 2003, to reach 410 thousand tonnes s in 2009 and about 595 thousand tonnes s in 2010 [9,10]. Pellet consumption for energy production is also growing in the EU; it amounted to 1.3 million tonnes s in 2002, about 10 million tonnes s in 2009 and it is estimated to exceed 11 million tonnes s in 2010 [10,11]. Due to the high demand for pellets, large pellet-producing plants have been established with an annual production output from 10 thousand to 100 thousand tonnes, which has led to an increase in the demand for large amounts of uniform biomass.

Paradoxically, this provides an opportunity for smaller plants, with an annual production output of 1–5 thousand tonnes, which process locally obtained biomass and produce briquettes, supplying fuel to individual consumers and to local heat-generating plants. This is currently happening in Poland. These briquette producers generally stand a low chance of purchasing sawdust for briquette production due to strong competition from large pellet-producing plants. Therefore, small briquette production plants seek new sources of biomass, including energy plants. Production of raw material (biomass) on one's own plantation of perennial plants is

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one of the possibilities of reducing the cost of material for briquetting. In such a case, the cost of material purchase would be equal to the cost of its production; moreover, such a system would ensure stability of supply of material for production. It should also be emphasised that small-scale briquette production enables local biomass utilisation and limits the money-energy circulation system to a small area, which is important from the economic and environmental point of view. Locally produced briquette is an attractive energy carrier for individual consumers in different parts of the world, especially in developing countries [9,12–17].

In general, briquette fuel has better energy parameters, higher density, higher calorific value (especially per volume unit) and lower moisture content as compared to the raw materials. Briquette production consumes different types of materials and uniform fuel is obtained from mixtures of materials (agricultural residues and energy plants) [18–25].

Considering the facts mentioned above, this study aimed to assess the possibility of producing briquettes from agricultural and forest biomass and to determine the production cost and the quality of the produced fuels.

2. Material and methods

2.1. Experiment design and biomass for briquette production

The experiment was conducted with biomass obtained from perennial energy plants (*Salix viminalis* clone UWM 006 and *Sida hemaphrodita* Raspy, both from three-year-old rootstocks), rape straw and rapeseed oilcake (*Brassica napus* L.) and also pine sawdust (*Pinus sylvestris* L.). Biomass from perennial energy plants was obtained from field experiments (0.2 ha for each plant) conducted at the University of Warmia and Mazury in Olsztyn (UWM) (N: 53°35′ E: 20°36′). In March 2010 all *S. viminalis* and *S. hemaphrodita* were collected in three and one year rotation coppice, respectively.

The plants were manually cut down with a petrol trimmer at 5 cm above the ground surface. Collected *S. viminalis* and *S. hemaphrodita* shoots were stored on special piles for drying up under wind and sun influence to the end of August 2010. After this time, shoots were crumbled to chips (3–5 cm length) with a Junkkari HJ 10 G wood chipper (Junkkari, Finland), connected with a New Holland tractor (New Holland, United Kingdom) with 130 kM power. In this form the material was transported to works of briquette production.

Rape straw was transported to the production plant in small bricks with the dimensions of 80/40/40 cm (h/w/d). Rapeseed oilcake was obtained by cold-pressing oil from rapeseed. Pine sawdust was obtained at the briquette production plant, where it is received as a by-product in parquet floor production.

2.2. Characteristics of the soil

According to the PTG 2008 classification [26], the plants grew on sandy loam, in which the percentage of sand (2–0.05 mm), silt (0.05–0.002 mm) and clay (<0.002 mm) was 60, 36 and 4%, respectively. Samples of the soil on which the tested plants grew were characterized by selected parameters described in Supplementary material.

2.3. Assessment of quality of biomass raw materials and the obtained briquettes

Samples of each kind of biomass (raw material) were taken for analysis before briquette production started. Subsequently, eight types of biomass briquettes were produced from: *S. viminalis; S. hemaphrodita*; a mixture of *S. viminalis* and *S. hemaphrodita* in 50:50 ratio; rape straw; a mixture of *S. viminalis* and rape straw in 50:50 ratio; a mixture of rape straw and rapeseed oilcake in 75:25 ratio; a mixture of rape straw and rapeseed oilcake in 50:50 ratio; and from pine sawdust for comparison. For preparation of appropriate mixtures, the materials were ground in an OSMEKA HZ2100 mill (PONAR, Łódź), and blended by mixer BWE 260 (ZREMB "50/50 Project", Poznań) about 300 dm^3 value. The material was highly homogenous (12 mm) The following were determined in all the raw materials and in briquettes: moisture content, gross calorific value, net calorific value, ash content, volatile matter content, bulk density and chemical composition. Each analysis was performed in triplicate at the UWM laboratory in Olsztyn.

2.4. Characteristics of the materials used in briquette production

The bulk density of the materials used in briquette production ranged from 89.33 kg m^{-3} to 383.00 kg m^{-3} for chips of *S. hemaphrodita* and rapeseed oilcake (Table 1).

Rapeseed oilcake also had significantly the lowest moisture content (9.80%). The gross calorific value for rapeseed oilcake was significantly the highest and was equal to 22,551 MJ t^{-1} of d.m., and its net calorific value was equal to 20,341 MJ t^{-1}. The value was higher by about 23% for *S. viminalis* chips and by about 20%, 17%, and 14% for straw, *S. hemaphrodita* and sawdust, respectively. Sawdust contained the lowest amount of ash (0.35% of d.m.). *S. viminalis* chips contained fourfold more ash and also straw and rapeseed oilcake 16- and 18-fold more ash than sawdust. Rapeseed oilcake contained the highest amounts of hydrogen, sulphur and nitrogen of all the materials. The sulphur content in sawdust was about 155-fold lower and that of nitrogen – about 75-fold lower than in oilcake. The content of those elements in *S. viminalis* and *S. hemaphrodita* biomass was 14- to 29-fold lower. Rapeseed straw contained the highest amounts of chlorine (0.75% of d.m.); the value found for the other materials was lower, from 16- to 39-fold.

2.5. Production of briquettes and economic analysis

Production of briquettes from agricultural and forest biomass was examined at the Max-Parkiet sp. z.o.o. plant. The biomass of each type, as well as their mixtures, was briquetted on a Polish piston-briquetting machine BT86M (WAMAG, Walbrzych). The main unit of the device was a horizontal crank-and-piston briquetting press. An integral part of the press was a briquetting unit, consisting of a briquetting bush, pre-forming bush, a piston and a two-part clamping bush with a pneumatically adjusted clamping pressure. Another integral element of the device was a material feeding-compacting worm unit and the third one was a briquette conveyor, 5 m long, on which the briquette thermal and strength stabilisation took place. The device also included a storage and dispensing container with a worm scraper, a cyclone for pneumatic transport of material and a control cabinet. The set was fitted out with three electric motors. The main motor had the power of 15.0 kW, whereas the two motors of the worm feeders had the power of 2.2 and 1.1 kW. The required air pressure of the clamping

Table 1
Market prices of raw materials used for briquette production.

Material	€ t^{-1}
Natural dried willow chips	56.3
Natural dried chips of Virginia mallow	58.8
Rape straw	30.0
Rapeseed oilcake	180.2
Dry pine sawdust	50.1

Source: authors' data based on market information.

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