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Assessment of the energetic and mechanical properties of pellets produced from agricultural biomass☆

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ABSTRACT

This paper presents an assessment of the energetic and mechanical properties of pellets produced from agricultural biomass. For the production of pellets the following raw materials were used: wheat straw, rape straw, and maize straw. Additionally, the mixtures of wheat-rape straw, wheat-maize straw, and rape-maize straw (each accounting for 50% of the mass) were applied. The studied resources were ground with the use of a universal shredder driven by a 7.5 kW electric engine. A pelleting machine fitted with a fixed flat matrix with two driven thickening rolls was used to produce the pellets. Analyses of the moisture and calorific value of resources as well as the bulk density and mechanical strength of pellets were performed according to biding standards. The moisture of resources ranged from 16.5% to 18.5% for rape and maize straw, respectively. The average calorific value fluctuated between 15.3 MJ kg^{-1} for a mixture of wheat and rape straw to 16.2 MJ kg^{-1} for maize straw. The bulk density and mechanical strength of pellets depended on the type of resources used. The lowest bulk density was recorded for wheat straw pellets (386–420 kg m^{-3}), and the highest (561–572 kg m^{-3}) for maize straw pellets. The lowest mechanical strength of pellets was noted for rape (95.4–96.8%), whereas the highest was for pellets made from a wheat and maize straw mixture (96.8–98.9%).

1. Introduction

The present global climatic, biological, food, fuel and water crisis has contributed to the spread of trends for “green energy”. The causes of this situation may vary; however, the main factor is the inappropriate allocation of capital, which still favours traditional sources of energy (non-renewable sources) [1]. The wide-spread use of fossil fuels to produce energy is the main human activity which contributes to decreasing their reserves and the emission of greenhouse gases, in particular carbon dioxide (CO_2), to the atmosphere, which consequently leads to the greenhouse effect [2,3].

It has become the main aim of many countries all over the world to improve the quality of life of their citizens, while at the same time maintaining social equality, biodiversity and the abundance of natural resources. This is closely connected with the need to reduce the release of excessive emissions of greenhouse gases and other substances to the environment in all areas of the economy. These policies have led to the mobilisation and development of a range of programmes which enable the promotion of a low-emission economy which provides both economic, social and environmental benefits. These changes are connected with the principle of sustainable growth linked to actions which aim at decreasing the emission of harmful substances by introducing innovations and implementing new technologies, lowering energy consumption, and creating new work places which are consequently conducive to the growth of a competitive economy [4–7]. The development of a low-emission economy and maintaining the sustainable growth of a country will improve energy efficiency and will involve the sensible management of resources and materials of different origin, from plant resources to industrial waste [8,9].

The negative impacts of the so-called greenhouse effect may be limited by increasing the absorption of CO_2, e.g. during the process of photosynthesis by increasing the crops participation of plants which produce high amount of biomass [10,11]. As a result of the extended production of agricultural biomass grown for energy

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purposes, social, economic and environmental benefits may be achieved [10,12]. In Poland, the main source of renewable energy is biomass. The basic solid fuel from biomass is biomass of plant origin. This includes biomass from fast growing trees and shrubs, mainly shrub willow, perennial grass, straw and organic residues [12–15]. Currently, potential resources of biomass, which could be utilised for energy production, are estimated at approx. 30 million tonnes a year, including approx. 10 million tonnes of straw, 6 million tonnes of wood residues (sawdust, bark, chips), as well as 6 million tonnes of sewage residues from the paper and food industries and communal landfills. Moreover, biomass as compared to other energy resources is characterised by its availability in the majority of regions in our country [16,17].

Agricultural biomass, and especially straw sourced from cereal and straw from other crops in its primary form requires much transportation and storage space, and at the same time has a low calorific value per unit of volume. Straw has a different chemical composition depending on the species of plant, location and growing technology so straw should be properly processed in order to improve its energy efficiency. Hence, efforts are being made to compact these plant resources by briquetting or pelleting [18–21], which leads to a higher concentration of mass and energy per unit of volume and the distribution and utilisation of this type of biofuel is significantly facilitated.

The capacity for plant resources to be compacted depends on numerous physical factors, e.g. the type of resource, its moisture, granulometric composition, etc. [22]. Plant resources during harvest often have high moisture levels, which hinder their calorific value. High moisture levels cause a significant decrease in combustion heat and the calorific value of biomass, and also unfavourably impact upon the process of compaction and the later storage of the resultant product [21,22]. Hence, resources designated for energy production purposes should meet specific technological requirements. Their usefulness is checked on the basis of moisture, the degree of withering, heat of combustion and calorific value. These parameters depend on the chemical composition and moisture of the resource. Excessive moisture causes a drop in the energetic value as well as an increase in the emission of pollution during the combustion of the resources [23]. There are also serious difficulties connected with their storage, the costs of transportation increase, heating installations function improperly and the efficiency of boilers drops. For this reason, standards have been established which determine the permissible moisture values for plant resources. The values vary for different compacting machines; however, most often they should stay within the limits of 15–25% [19,24].

Agricultural biomass is a fuel which is relatively difficult to use and requires proper processing. It is inhomogeneous and often moist; it has a low calorific value in relation to its volume. Consequently, there is a need to compact it, e.g. in the form of pellets made from dry fragmented biomass under high pressure and increased temperature. Their calorific value depends both on the type and the state of a resource and on its moisture [19,30,31].

According to various researchers [17,24,32], plant materials which undergo pressure densification should have a moisture content within the range of 8–15%. These researchers claim that an excessive content of material negatively influences the course of the process and the quality of the achieved product. This is primarily evidence in a decrease in both the quality of pellets and their calorific value.

The aim of this study was to determine the moisture and the calorific value of the studied resources of plant origin and assess the bulk density and mechanical strength of pellets produced in a pelleting machine fitted with a fixed flat matrix and two thickening rolls.

2. Materials and methods

2.1. Raw material

The research was conducted using straw of the following cereal species: winter wheat, winter rape and maize. The resources were obtained from three arable farms located in the Wyżyna Zachodniolubelska district [Lublin West Highland] of Lublin Voivodeship. This mesoregion of Poland is characterised by a moderately continental climate with an average total rainfall of approx. 600 mm and fertile soils created from loess and loess type dust deposits [25]. The collected research material was compacted within one species of straw as well as mixtures of wheat and rape straw, wheat and maize straw and rape and maize straw (each accounting for 50% of the mass).

2.2. Moisture content

The moisture content in plant resources was assessed with the use of the gravimetric method according to the standard [26]. Samples of moist plant resources (100 g each) were weighed on a WPE 200 analytical balance with ±0.1 g accuracy, and dried in a type K dryer to achieve their stable mass. The measurements of moisture were conducted in five replications. Before the process of compacting, fragmented resources were moistened with water and mixed with the use of a laboratory mixer until a moisture level of 16.5–18.5% was obtained. This procedure was aimed at achieving a higher quality of resulting pellets.

2.3. Calorific value

The calorific value of the studied resources was calculated on the basis of combustion heat determined by the calorimetric method with the use of a type KL-12Mn calorimeter. This apparatus enables measurements of the calorific value of organic resources to be performed according to the standard [27].

2.4. Pelletisation process

Before pelleting, the agricultural resources were initially fragmented with the use of a chaff cutting machine driven with a 7.5 kW electric engine with a theoretical cutting length of 20 mm. Next, to achieve the required fragmentation of resources a universal shredder driven with a 4.5 kW electric engine equipped with sieves with 6 mm apertures was used. To compact plant resources, a pelleting machine fitted with a fixed flat matrix and driven thickening rolls was used (Fig. 1). The technological-exploitation parameters of the pelleting machine are presented in Table 1.

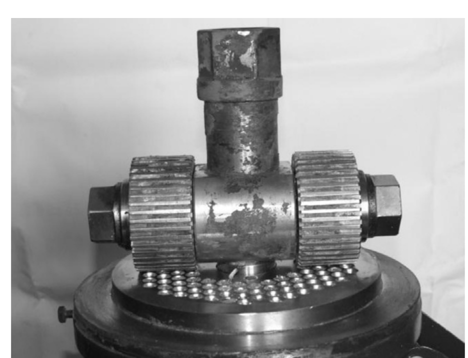

Fig. 1. Compacting complex of the pelleting machine.