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Effects of moisture and pressure on densification process of raw material from *Artemisia dubia* Wall.

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ABSTRACT

At present, active scientific research studies are being carried out worldwide on alternative biomass resources that could replace wood. One possibility is to use plants belonging to the group of fast rotation energy crops, which includes *Artemisia* genus plants such as mugwort (*Artemisia dubia* Wall.). These plants easily adapt to the prevailing agricultural-climate conditions in Lithuania and can offer yields from 22 to 27 t ha^{-1} in dry matter. However, due to the low bulk density of the harvested biomass, extensive use of *A. dubia* for energy production is not sufficiently effective.

This study analyses the effects of the moisture content of *A. dubia* biomass and comparative pressure on the pellet formation process and pellet characteristics. A study was carried out on milled *A. dubia* biomass with six different moisture content levels (4.3, 7.8, 10, 12.9, 15.5 and 21.5%). Depending on the raw material press load and moisture content, it was determined that the pellet density was between 912 and 1214 kg m^{-3}. As a result of plastic deformation and depending on the moisture content of the raw material used, the original pellet density decreased to 583 and 1064 kg m^{-3}, corresponding to 13.1 and 5.5% respectively The results of the study demonstrate that the optimal moisture content for producing *A. dubia* pellets is 9.4%.

1. Introduction

At present, fossil fuel is still the most widely used fuel source, with nearly 86% of total consumed energy being produced from fossil fuel [1]. Over the past 60 years, the intensive use of fossil fuel has been driven by a steadily increasing energy demand. This has resulted in an increase in greenhouse gas (CO_2) emissions into the environment of more than 7 times: from 4 million to more than 28 million tons per year [2]. Reducing greenhouse gas emissions and the ambition of gaining independence from the use of fossil fuels has resulted in increasing attention being paid to research on renewable energy sources and practical usage.

Biomass is the most promising renewable energy source in Lithuania, comprising almost 90% of total renewable energy [3]. Although the main biomass source in the solid biofuel segment is wood [4], increasing focus is being placed on the development of alternative biomass resources, such as fast rotation energy crops. *Artemisia* genus plants such as mugwort (*A. dubia* Wall.) are assigned to this group of plants. A. *dubia* is most commonly found in East Asian region. In Europe it is usually grown as ornamental plant. Kadžiuliene et al. argued that the *A. dubia* Wall. is a promising energetic plant with a relatively low ash content and a high thermal value of 18.5 MJ kg^{-1} [5]. Due to its chemical composition and accumulated biologically active substances, it has been evaluated and used in the food and pharmaceutical industries.

Various scientific studies have demonstrated that these plants easily adapt to the prevailing agricultural climate conditions in Lithuania, and the potential yield of the plants is reported to be 22.0–27.6 t ha^{-1} in dry matter (DM) [6]. Despite the fact that energy crops can produce high biomass yields, their use is rather complex. The density of chopped *A. dubia* biomass is low, and this is a typical characteristic for most energy plants. Cerniauskiene et al. [3] reported that the density of *A. dubia*, chopped to 23.2 ± 2.89 mm fractions, is 226.0 ± 6.1 kg m^{-3}. In comparison with charcoal, the

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transportation of low-density biomass for distances further than 200 km is costly [1] and requires a great deal of storage space. It was found from studies with straw that straw density, which is 40–200 kg m^{-3}, could be increased to 600–800 kg m^{-3} by means of pelleting [7]. Therefore, in economic terms, in order to utilise biomass as solid fuel effectively, it should be processed mechanically by producing homogeneous particles and increasing its density, for which purpose pelleting is the most widely used method.

Pelleting is a complex and high energy-consuming process, and its outcome is dependents on the initial raw material characteristics and the technology equipment. Several studies have found that the initial raw material characteristics such as moisture content, particle size and chemical composition, influence the quality of the final product [8–10]. Furthermore, the pellet density and stability are dependent on the raw material moisture content. According to previous studies, the optimal initial moisture content of raw materials ranges from 8 to 38% [11–13]. Literature sources indicate that the optimal moisture content for alfalfa (*Medicago sativa* L.), *Miscanthus* spp, fescue (*Festuca arundinacea*), sorghum (*Sorghum bicolor*) and willow *(Salix alba)* pelleting is 8–10% [10,14], for barley, wheat and rice straw it is 13–23% [8,15,16], and for rice straw it is 17% [7]. Researchers have noted that raw material moisture is important as a lubricant in the pelleting process [17,18]. Kaliyan et al. [10] reported that particle coarseness is a significant factor for pellet sustainability: pelleting of coarse particles resulted in the formation of rapture points for crack development, as well as pellet fracture. Furthermore, it was noted that smaller fractions of raw materials were conditioned more easily and evenly during the pelleting process, and the produced pellets were more resistant. The pressure force applied during the densification process has a great influence on pellet density and the total comparative energy consumption [19]. Therefore, prior to placing densified products on the market, it is very important that the corresponding quality requirements are met, which are governed by a series of normative documents and standards [19]. Moreover, it is important to obtain high-quality products at the lowest possible energy costs.

This study investigates the densification possibilities of *A. dubia* Wall. by determining the influence of raw material moisture content and pressure on the pelleting process and the final product characteristics.

2. Materials and methods

2.1. Objective of research

The research on the densification process was carried out on an above-ground part of the *A. dubia* Wall., which consists of masses of plant stems (73.73 ± 2.66%) and leaves (26.27 ± 2.66%). The initial raw material moisture content was 10 ± 0.46%. During the course of the experiment, the above-ground part of the plants was milled using a Retsch SM300 cutting mill (Retsch GmbH, Germany) at a speed of 3000 rpm with a three-blade rotor and 1 mm mesh sieve. The fractional composition of the milled material was evaluated with reference to the standard EN 15149 [20]. The *A. dubia* samples were fed through a set of eight different 200 mm diameter sieves (the diameters of the sieve mesh were: 6.3, 4.5, 3.15, 1.70, 1.00, 0.50, 0.315 and 0.125 mm), using the Haver EML Digital plus sieve shaker (Haver EML Digital plus sieve shaker, Haver & Boecker OHG, Germany). The mass fraction compositions are illustrated in Fig. 1. Particles of less than 1 mm formed the largest part of the total mass with 78.38 ± 4.87%, and the predominant particle size in this fraction was 1–0.5 mm.

2.2. Sample preparation

In order to determine the influence of the *A. dubia* raw material moisture content on pellet quality, six different moisture samples were formed (4.3 ± 0.12%, 7.8 ± 0.10%, 10.0 ± 0.16%, 12.9 ± 0.13%, 15.5 ± 0.15% and 21.5 ± 0.14%). For this purpose, the raw material with an initial moisture content of 10% was prepared in two manners:

a) Dried. Samples with moisture contents of 7.8 ± 0.10% and 4.3 ± 0.29% were prepared. They were dried in the oven, Memmert UPF700 (Memmert GmbH, Germany) at a temperature 45 °C;
b) Moistened. Samples with moisture contents of 12.9 ± 0.13%, 15.5 ± 0.15% and 21.5 ± 0.14% were prepared. The raw materials were moistened by spraying them with water. Then, they were contained in a desiccator and kept in a refrigerator for 24 h at 3-4 °C, periodically being mixed up. The amount of water required for the moistened samples is calculated according to Equation (1):

$$m_{H_2O} = (G_1(100 - \omega_1)/(100 - \omega_2)) - G_1 \quad (1)$$

where m_{H_2O} is the water required for raw material moistening to a particular moisture content in kg; G_1 is the dry weight of the raw material in kg; ω_1 is the moisture content of the raw material in %; and ω_2 is the desirable moisture content of the moistened raw material in %.

The moisture content of samples was determined in accordance with the method described in the standard EN 14774 [21]. Raw

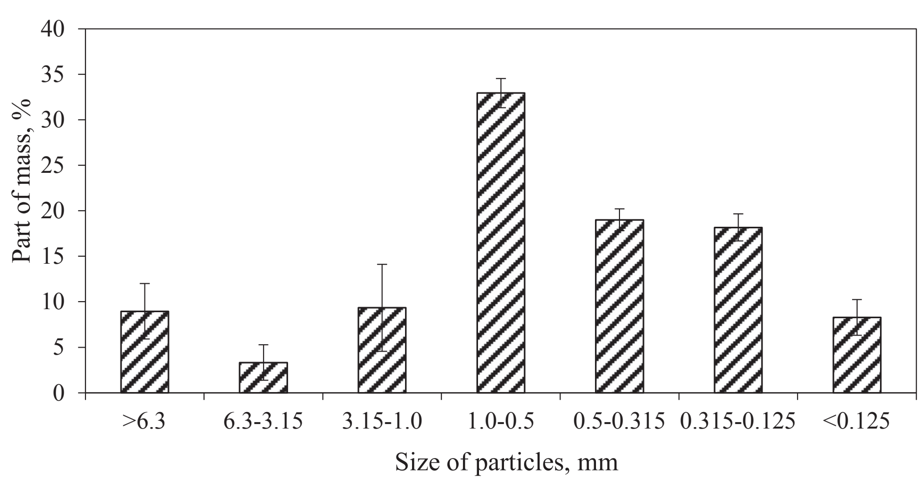

Fig. 1. Fractional composition of milled *Artemisia dubia* Wall mass, used for test purposes.