

## The Use of Binders of Natural Origin to Improve the Technology of Creating Fuel Briquettes from Wood Waste

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### ABSTRACT

The method of wood waste utilization by pressing it into fuel briquettes is considered. It is proposed to use sulfate soap, a multi-tonnage waste of the pulp and paper industry, as an astringent. It is proven that as a result of adding a binder to the raw material, it is possible to carry out the process of forming briquettes with lower pressures, while ensuring the necessary statistical strength of the briquette. An appropriate method of supplying the binder is its preliminary mixing with wood waste. The most suitable concentration of the binder for fuel briquettes amounts to 6%. The use of a binder made it possible to reduce engine power by 40%, as well as increase the density of the obtained fuel briquettes by 10%.

**Keywords:** fuel briquettes, sulfate soap, pressing, binder, statistical strength, briquette density.

### INTRODUCTION

The problems of environmental protection intensify with the development of human society, and their solution becomes a priority task for the further existence of humanity in general. A successful solution to the problems of environmental protection includes the use of adsorption technologies (Kostenko et al., 2017, Malovanyy et al., 2019) and biological methods (Jozwiakowski et al., 2020, Malovanyy et al., 2021) for cleaning water environments, effective monitoring of the hydrosphere (Odnorih et al., 2020, Magas et al., 2018), utilization of sewage sludge (Tymchuk et al., 2020a, Tymchuk et al., 2020b, Tymchuk et al., 2021), environmental protection from negative impacts of the mining and chemical industry (Knysh et al., 2014) and oil pollution (Karabyn et al., 2019) and many other aspects. In the aspect of protecting the atmosphere

from pollution by power plants, it is important to use household and industrial waste for energetic purposes, to expand the overall energy balance of renewable energy sources, in particular with the use of biomass as an energy source.

It is promising to use biomass for the preparation of fuel briquettes, the technologies for which are used in power plants have been sufficiently researched and implemented. In various countries of the world, searches for resources for the fuel briquette production, the optimal composition of raw materials, technologies for forming briquettes, their transportation, storage and dosing in power plants are being conducted. The use of industrial, agricultural and household waste for these purposes is a priority task, since, in this case, it is possible to localize the environmental danger from the uncontrolled accumulation of this waste and to obtain resources for renewable energy sources at the same time.

A large number of researchers have studied various options of using wood waste to create fuel pellets and briquettes. In particular, the use of wood waste to create fuel briquettes was investigated (Malovany et al., 2006, Masikevych et al., 2019). The authors have suggested using paper production waste (sulfate soap, the main component of which are sodium salts of fatty resin acids and oxy-acid salts – a product of wood decomposition) as a binder. Madhuka et al. (2023) propose utilizing pine needles in the raw material mix for producing fuel briquettes. Various combinations of animal fat, molasses, bentonite powder, and starch were considered as binders in five different ratios (ranging from 1% to 20%) to enhance binding properties for briquette formation. The briquette containing 20 wt.% animal fat exhibited superior quality, with a density of 462.24 kg/m<sup>3</sup> and a calorific value of 31.17 MJ/kg. The authors (Otieno et al., 2022) have suggested using sawdust with the addition of other organic waste as a material for fuel briquettes, and using molasses (10%) as a binder. The briquettes had a higher calorific value equal to 19.8 MJ/kg, and, according to the authors, co-combustion of charcoal with briquettes is a promising approach to obtaining safe and sufficient thermal energy. The authors (Martinez et al., 2019) have suggested a mixture of bush coffee residues and pine wood as a raw material for briquettes. The briquettes were formed without a binder in a piston press at a temperature of 120°C and a pressure of 8.27 MPa. The best thermotechnical and strength parameters of the briquettes were obtained with the content of 75% pine wood in the raw material.

A large number of studies has been devoted to the use of vegetable agricultural waste as a raw material for briquettes. The authors (Lubwama et al., 2019) have suggested rice husk, coffee husk and peanut shell in different proportions as raw materials for carbonized biocomposite briquettes. Starch was used as an astringent. The calorific value of briquettes ranged from 16.6 MJ/kg to 22 MJ/kg. The drop strength results for the developed composite briquettes were above 86%, indicating satisfactory performance. The authors (Pilusa et al., 2013) have suggested using spent coffee beans, corn, sawdust, paper pulp and coal fine fraction as raw materials for fuel briquettes. The higher calorific value of the briquettes amounted to 18.9 MJ/kg, the burning rate equaled 2 g/min, however, no data was given on the statistical or dynamic strength of the obtained fuel briquettes.

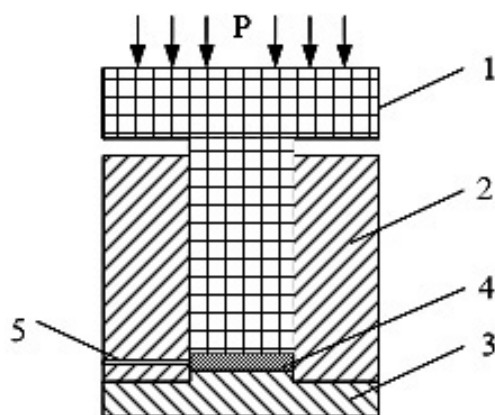
A large amount of research has been devoted to the usage of animal manure as an astringent and as an element of the fuel mixture. The authors (Mainkaew et al., 2023) investigated the possibility of obtaining fuel briquettes using elephant dung. This method of utilization can increase the value of elephant dung and can be used in response to the demand for proper disposal of the large volume of dung generated in elephant camps. The resulting briquettes had a high calorific value (17 MJ/kg) and increased the overall thermal efficiency of the furnace by 22%. An emissions study showed that burning briquettes released mainly CO<sub>2</sub> (5.49·10<sup>4</sup> ppm), while the content of other gases was insignificant. A complicated complex raw material composition for the production of fuel briquettes was proposed (Song et al., 2019). Cold press briquetting technology was employed to produce cow dung briquettes, using coal and cow dung as raw materials. A mixture of potassium nitrate, manganese dioxide, and citric acid served as a combustion stimulator, while a blend of calmodulin and molybdenum acted as a smoke suppressant. Sodium humate and red clay were used as binders, and acidified calcium oxide functioned as a desulfurizer. The resulting briquette had a calorific value of 19.1 MJ/kg, an ash content of 29.5%, volatile substance content of 13.0%, and achieved a desulfurization degree of 70.02%.

The authors (Czekała et al., 2018) have proposed a two-stage processing of the solid fraction of cellulose (industrial multiton waste). At the first stage, it was proposed to obtain biogas, and to use the digestate to obtain solid biofuel, the calorific value of which can be compared with the calorific value of biofuel obtained from sawdust. The use of digestate for the production of fuel briquettes after anaerobic fermentation of pig and cow manure was also studied by the authors (Ogwang et al., 2021).

## MATERIALS AND METHODS

The formation of briquettes was carried out on the experimental installation shown in Figure 1. The necessary compression pressure of the wood mass was created by a hydraulic press, in which a mold was placed to form a briquette. Starting substances with a certain composition were placed in the device.

For briquette pressing, a fixed quantity of wood waste and a calculated amount of



**Fig. 1.** Experimental installation for forming fuel briquettes: 1 – piston; 2 – matrix; 3 – base; 4 – composition; 5 – drainage hole

binder were combined. As per recommendations (Malovanyy et al., 2006; Masikeyvych et al., 2019), paper production waste, specifically sulfate soap containing sodium salts of fatty resin acids and oxy-acid salts (a product of wood decomposition), was utilized as the binder. Experiments were conducted with component mixing or direct binder supply into the center of the wood waste without mixing. The resulting mixture was placed into a briquette-forming device, then subjected to a hydraulic press to create pressure for shaping the briquette. An excess binding component with fine wood waste particles was expelled through a drainage hole. After reaching the designated pressure, the formed mixture was held for 10 seconds to allow for the final bonding of wood waste particles. Subsequently, the finished briquette was pressed, and its physical parameters (mass, height, density) were determined. The overall appearance of the briquette is depicted in Figure 2.

The static strength of the briquette was determined using the MII-100 device (Sanytskyi et al., 2001). The sample was installed on the supports of the device so that its horizontal faces during manufacture were in a vertical position. The samples were placed between two standard metal plates with an area of  $25 \cdot 10^{-3} \text{ m}^2$  so that the lateral faces, which during manufacture were adjacent to the walls of the mold, were placed on the planes of the plates.

The limit of compressive strength of an individual sample was calculated as a fraction of the division of the magnitude of the destructive load  $P(H)$  by the working area of the sample  $S(\text{m}^2)$ , according to the formula:



**Fig. 2.** Photo of a briquette obtained by the method of forming under high excess pressure, before the experiment with the determination of dynamic strength

$$R = \frac{P(H)}{S} \quad (1)$$

## RESULTS AND DISCUSSION

Briquetting efficiency was evaluated according to the following criteria: maximum briquette density, minimum mass loss during forming, high static and dynamic strength. Before pressing wood waste to obtain fuel briquettes, different percentages of binders were added to the composition of the raw material, ranging from 4 to 20%. At high concentrations (greater than 6%), there was significant removal of the binder through the drainage holes, which in some cases led to 50% losses, which is unacceptable. Therefore, lower concentrations (from 4 to 6%) were considered in the next series of experiments.

Figures 3–5 show the results of experiments with the addition of 4%, 5% and 6% of the binder and determination of the briquette density, respectively.

The research results indicate that briquette density increases with a higher initial addition of binding material to the raw material mix before pressing. This is attributed to the superior adhesive properties offered by the binder compared to briquettes without binders. During the briquette formation process, some mass was lost through the drainage hole, and the magnitude of this loss was determined as the difference in mass before and after forming, as shown in Figure 6.

Based on the experiment results in Figure 6, it can be concluded that the most effective method of introducing the binder is through mixing. This ensures a uniform distribution of the binding substance throughout the

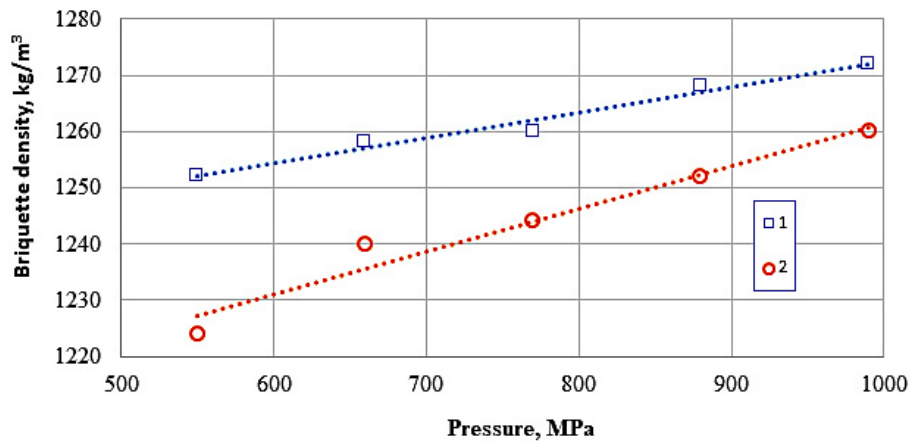


Figure 3. Change in the density of the briquette under the condition of adding 4% of the binder depending on the pressure: 1 – supply of the binder to the center of the mixture; 2 – provided the mixture is stirred

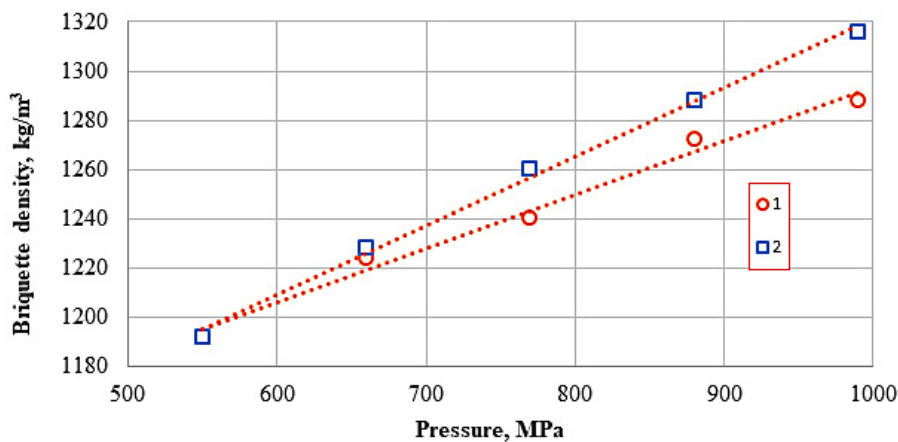


Figure 4. Change in the density of the briquette under the condition of adding 5% of the binder depending on the pressure: 1 – supply of the binder to the center of the mixture; 2 – provided the mixture is stirred

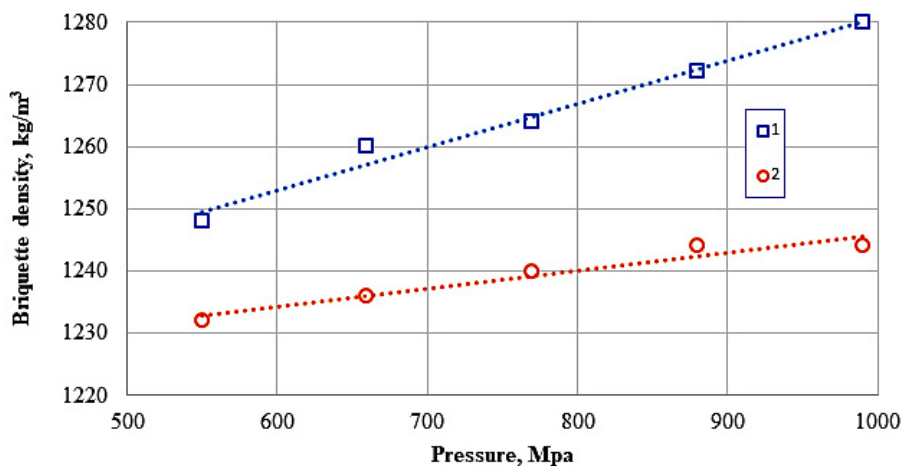
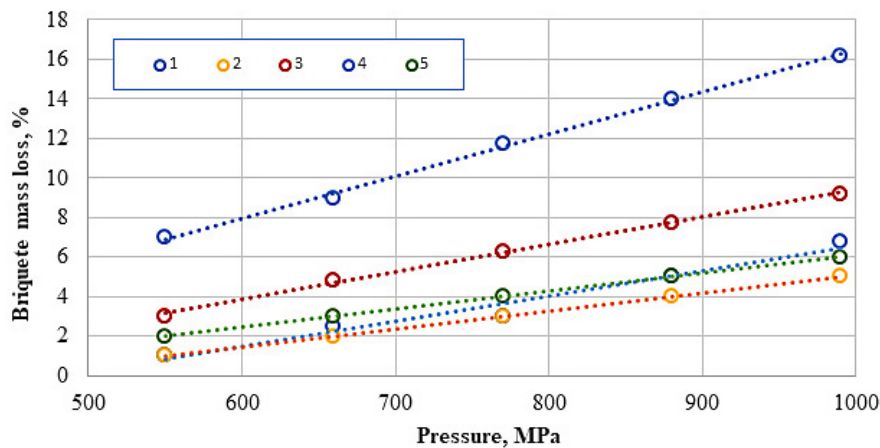


Figure 5. Change in the density of the briquette under the condition of adding 6% of the binder depending on the pressure: 1 – supply of the binder to the center of the mixture; 2 – provided the mixture is stirred

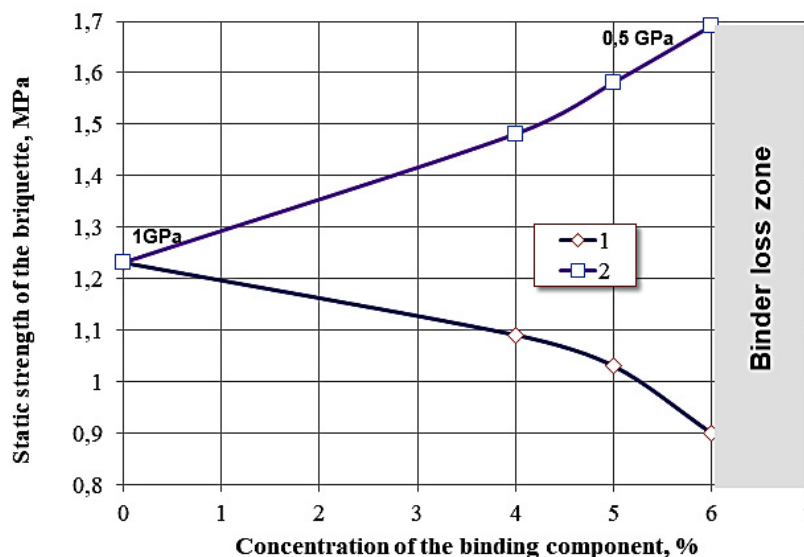
wood waste mass, reducing mass loss during briquette formation. These experiments demonstrate that binder addition enhances the briquette’s density and, consequently, its dynamic strength, preventing breakage during

transportation. A higher dynamic strength implies less mass loss during transport.

The assessment of briquette’s static strength, considering varying binder concentrations, is depicted in Figure 7. The figure shows that



**Figure 6.** Change in briquette mass loss with the addition of a binder depending on the pressure: 1 – supply of 4% of the binder into the center of the mixture; 2 – mixing of 4% and 5% of binder with wood waste (experimental data of 2 series of studies coincide); 3 – supply of 5% of the binder into the center of the mixture; 4 – supply of 6% of the binder into the center of the mixture; 5 – mixing 6% of binder with wood waste



**Figure 7.** Change in the static strength of the briquette depending on the concentration of the binder: 1 – supply of the binding component into the center of the mixture, 2 – mixing the binding component with wood waste

briquettes with mixed binders exhibit increased static strength. This is attributed to improved binder distribution within the briquette volume, forming a reinforcing wooden framework that prevents breakage (Masikevych et al., 2019). Adding more than 6% binder is deemed impractical, as it increases binder loss during pressing, expelling finely dispersed wood waste fractions from the pressing zone.

Based on the results of the experiments, it can be concluded that in the process of implementing the technology of forming high-pressure briquettes in the case of using a binder:

- their density increases,
- their calorific value increases,
- their dynamic and static strength increases.

It should also be noted that the effectiveness of the binding agent on the formation of briquettes is enhanced if it is previously mixed with wood waste.

The mechanism of pressing pellets from wood waste consists of several successive stages. At the initial stages, the raw material is consolidated as a result of minimizing the free volume between the raw material particles. Further the particles themselves are subjected to deformation changes directly, and due to this, the compaction process deepens, which is accompanied by the effect of molecular adhesion. An increase in pressure at each of the following stages of pressing causes the appearance of both elastic and plastic deformations. This, in turn, further strengthens the molecular cohesion between fine particles. A positive



consequence of this is an increase in the strength of the briquette. In order to ensure the necessary strength of the briquette, the pressing process in existing technologies is carried out under a pressure of 100–200 MN/m<sup>2</sup>. Experiments have shown that in order to minimize energy costs for the production of briquettes and ensure their high strength, it is advisable to add binders to finely dispersed particles of wood waste. In this case, a similar quality of briquettes is obtained with a pressure of 10–50 MN/m<sup>2</sup> (Masikevych et al., 2019).

Since high pressures are used in the pressing method, it is advisable to use this method to produce not only small, but also larger fuel briquettes, which can be divided into separate pieces after forming. The technological process of manufacturing large briquettes consists of the same stages as the process of manufacturing small briquettes, but, unlike it, a cooling stage is introduced into the technology. Stages of formation of large briquettes:

- grinding of raw materials (if necessary),
- drying,
- briquetting,
- cooling,
- screening,
- storage / packaging.

Content of the pressing and cooling stage:

- Briquettes are pressed using a granulator press,
- Cooling is a very important stage during the production of large briquettes.

After pressing, the temperature of the briquettes is approximately 90 °C. During cooling, the briquette stabilizes, the molten lignin hardens on its surface, so the shape of the briquette remains unchanged.

## CONCLUSIONS

Research has shown that pressing wood waste into fuel briquettes with the use of naturally occurring sulfate soap as a binder is a promising method of utilization of wood waste, which is a waste produced in the process of boiling lysine from wood pulp in pulp and paper production. This makes it possible to minimize the ecological danger from the pollution of the environment with wood waste and waste from pulp and paper production, as well as to obtain high-quality biofuel.

When using a binding component, briquettes are formed with lower pressures, which provides a certain statistical strength. The binding substance serves as a lubricant, which reduces frictional forces, and therefore, energy costs for overcoming them. An appropriate method of supplying the binder is its preliminary mixing with wood waste. The most suitable concentration of the binder for fuel briquettes is 6%.

The use of a binder made it possible to reduce engine power by 40%, as well as increase the density of the obtained fuel briquettes by 10%. The pressure due to which the formation took place without the addition of a binder was more than 1 GPa, with the addition of a binder – from 500 to 990 MPa.

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