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Production of fuel pellets from a mixture of sawdust and rye bran

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Abstract. The purpose of the research was to assess the suitability of the milling industry waste, in the form of rye bran, as a supplement to sawdust, as a component of a granular blend, with its purpose for fuel purposes. The specific purpose of the study was to determine the effect of rye bran content in the mixture with sawdust on the power demand of a granulating-briquetting prototype device and on the quality of obtained granules (density, kinetic strength and calorific value). The experiment was conducted on a prototype granulating-briquetting unit using a flat die with a hole diameter of 12 mm and a thickness of 28 mm. The influence of rye bran content (5, 10, 15 and 20%) in the wood waste mixture on the power demand and on the density, kinetic strength and calorific value of the obtained granulate was determined. The research has confirmed that rye bran is an excellent binder material to obtain better quality granules at lower energy costs of the compaction process. The rye bran binder used is also a high energy content (high calorific value), leaving little ash content after the combustion process. Combustion studies have also shown that the addition of 20% rye bran does not significantly affect the pellet combustion conditions and the composition of the flue gases.

1. Introduction

According to Daniel et al. [1,2], agriculture and agri-food industry in Poland generates over 10 million tonnes of waste annually, which are under development. However, according to Daniel et al. [1], the problem of improper waste management is becoming increasingly common. The most common types of waste generated by agriculture and various sectors of the food industry are, for example, the potato pulp produced by the production of potato starch, the buckwheat husk produced in cereal production, the rapeseed pomace produced in the production of rapeseed oil, the herbal waste arising from the drying, packaging and segregation of dried herbs, etc. These wastes are often used to a small extent and are a huge problem for a given plant.

According to the Central Statistical Office (GUS) in 2012 [2], the share of waste recovered decreased by 9.2% between 2010 and 2011, and the share of waste collected increased by 21.1% in the years 2000-2005. These data indicate the need to develop waste processing technologies for useful products [3]. One way of managing the various types of waste of plant origin is to process them in the pressure agglomeration process into granules or briquettes, as was confirmed by numerous scientific papers [4-9].

In the production of fuel in the form of pellets or briquettes more and more often, apart from wood waste, other materials are used [9] i.e.: waste of fruit and vegetable industry [5-7,10].
Arranz [31] has conducted research on the production of pellets from mixtures of oak, pyrene, ore waste, grape marc and cork dust. Miranda et al. [11] concentrated the waste olive pulp resulted from the production of oil in admixture with other wastes. Nielsen [12] used the addition of waste (turnip cuttings) to various types of sawdust in industrial pellet production. Czekała et al. [13] investigated the energy efficiency of the solid biofuels produced from digested pulp. Oniszczuk et al. studied effect of natural fibres on the mechanical properties of thermoplastic starch [14], and addition of bark in the production of the starch-based composites [15].

Similar results have been obtained by Yaman et al. [16], whom conducted research on the production of waste briquettes made from paper waste and olive production waste, found that it is possible to obtain briquettes characterized by high mechanical strength from such blends.

According to Nasrin et al. [17], who investigated the physical properties of biomass waste briquettes produced during palm oil production, the unification of the composition of the compacted material i.e. the fragmentation and mixing of the seed sockets, fibers and grains influenced the improvement of the quality of the obtained briquettes, but at the same time the energy needed to produce the briquette was increased.

According to Ohman et al. [18], the quality of biomass pellets can be improved prior by the addition of hydrolytic post-production waste resulting from the production of ethanol from lignocellulose.

Stolarski [19] described an experiment of pellet production at the Max-Parkiet Wood Processing Plant, from the grain harvester (waste from the elevator) in the mixture (50%: 50%) with oak sawdust and from the waste obtained in apple juice production (100%).

The aim of the research was to assess the suitability of the milling industry waste, in the form of rye bran, as a supplement to sawdust, as a component of a granular blend, with its intention for fuel purposes. The specific aim of the study was to determine the effect of rye bran content in the mixture with sawdust on the demand for power of a granulating-briquetting prototype device and on the quality of obtained granules (density, kinetic strength and calorific value).

2. Methodology

The basic raw material used in the research was 50/50 residues (sawdust, chips, sawdust) of pine and spruce wood, which are a waste material in the production of sawn timber (boards, floor boards, battens, construction timber and other products) by PHU Konar Plant Staseluk Wojciech. During the research, rye bran (originating from the Mill Romaszówka near Korycin) was added to the waste.

Study of the granulation process was carried out using a prototype granulating and briquetting device described in the works [20], using a flat die with a hole diameter of 12 mm and a thickness of 28 mm. The influence of rye bran content (5, 10, 15 and 20%) in the wood waste mixture on the power demand and on the density, kinetic strength and calorific value of the obtained granulate was determined. Granulation experiments were conducted at a mass flow rate of 50 kg·h⁻¹, at a rotational speed of 170 rpm and a working gap between the thickening rollers and the die of 0.4 mm. After 24 hours from leaving the working system through the granulate, its density and kinetic strength were determined using the Holmen tester.

Determination of moisture content of rye bran, sawdust and mixtures of sawdust and rye bran before compaction were performed in accordance with PN-EN 14774-1:2010 [21] via Radwag MAX 60 with accuracy 0.001%. During the tests the moisture of five samples was determined in each case. Samples of 5 g were weighed and dried at 105°C until the moisture content of the moisture analyzer during the three consecutive readings at 15 s intervals remained unchanged. For the final result of the moisture determination, the mean value of the results obtained was taken.

Density of pellets was determined after 24 hours from the agglomeration process. The analyzes were performed by measuring the height and diameter of pellets by means of a caliper with an accuracy of ±0.02 mm and determining their mass by means of a WPS 360 laboratory scale with an accuracy of ±0.001 g. Physical density was calculated as the ratio of the mass of obtained pellets to the sum of their volumes.
Holmen NHP 100 kinematic strength tester was used to determine the kinetic strength of the obtained pellets. The test were performed with the accordance to PN-R-64834:1998 [22] and PN-EN 15210-1: 2010 [23]. During this test, the granules under the influence of compressed air were reflected against the walls of a perforated pyramid shaped chamber. The percentage value of kinetic strength is expressed by the weight ratio of the sample before and after the test.

The calorific value was determined on a KL-12Mn colorimeter according to PN-ISO 1928:2002 in accordance with the methodology presented in papers [10,25].

Emission testing of burned pellets was carried out in laboratory scale on a test bench equipped with a 25 kW retort grate equipped with an automatic fuel feeder with a digital controller. All experiments were carried out with an optimum mass flow rate of about 4.0 kg∙h\(^{-1}\) and an air flow of 78 m\(^3\)∙h\(^{-1}\). The composition of the flue gas was analyzed on-line using the MCA10 flue gas analyzer, which allows the percentage determination of CO\(_2\), H\(_2\)O, O\(_2\) and mg∙m\(^{-3}\) of CO, HCl, NO\(_2\), NO and NH\(_3\) in the exhaust gases. During the study, a sample of sawdust pellets by PHU Konar Staseluk Wojciech Plant and samples of pellets from these sawdust with 20% rye bran were burned. Each pellet sample weighing 10 kg was fed through an automatic feeder to a fixed bed. With each controlled combustion test, using the adjustable controller, optimum operating conditions were chosen - a suitable combustion air stream. During the study, the exhaust gas temperature (in the boiler flue) was also measured, which was 230-250°C.

### 3. Results

Table 1 presents the results of studies on the effect of rye bran content in the mixture with sawdust by the PHU Konar Staseluk Wojciech Plant on the granulation process (granulator demand for power registered in the pelletization of sawdust and rye bran) and kinetic strength and physical and bulk density granules.

| Amount of rye bran (%) | Power demand (kW) | Granulate quality | Physical density (kg∙m\(^{-3}\)) | Bulk density (kg∙m\(^{-3}\)) |
|------------------------|-------------------|-------------------|----------------------------------|-----------------------------|
|                        |                   | Kinetic strength (%) |                                   |                             |
| 0                      | 13.06             | 94.25              | 1183.73                          | 722.03                      |
| 10                     | 11.06             | 96.71              | 1190.72                          | 646.50                      |
| 15                     | 9.60              | 97.81              | 1196.03                          | 592.94                      |
| 20                     | 8.98              | 98.08              | 1218.60                          | 584.73                      |

Figure 1 shows the results of studies on the effect of rye bran content in the mixture with sawdust on the granulation process (granulator demand for power) recorded in granulation (thickening) of the sawdust and rye bran mixture and in figure 2,3 is shown the influence of the aforementioned parameters on the kinetic strength and density of the obtained granulate.
Figure 1. Dependence of granulator demand on power from rye bran content in mixture with sawdust.

Basing on the obtained results (figure 2, figure 3) a significant influence of rye bran content in the sawdust mix on the granulator’s demand of power was found. The rye barn content affected also the kinetic strength and density of obtained granulate.

Increasing the content of rye bran in the mix with sawdust from 10 to 20% (with a 14.8% moisture content) results in a decrease in the granulator’s demand for power by about 19% (from 11.06 kW to 8.98 kW).

Studies have shown that the addition of rye bran to sawdust has resulted in a significant increase in the susceptibility of the test mixture to densification, as evidenced by significant decreases in the value of the granulator’s demand for power with the increase in the content of rye bran.

The obtained values of the demand for granulator power during thickening of the sawdust and rye bran mix in the flat matrix granulator working system show that the addition of rye bran greatly favorably reduces the power requirement which is considerably lower than the corresponding need for the sawdust granulation, (with the same moisture content 14.8%) 13.06 kW.

The effect of the content of rye bran \( z_{o} \) in sawdust mix on the power demand values \( N_{g} \) of granulators was described by the equation:

\[
N_{g} = -1.37z_{o} + 14.1
\]

where:
\( z_{o} \) – amount of rye bran (%)
\( N_{g} \) – granulator’s Power demand (kW)

Based on the studies (fig. 2), it was found that increasing the content of rye bran in the mix with sawdust from 10 to 20% resulted in a slight increase in the kinetic strength of the pellets by about 1.5% (from 96.71% to 98.08%). The obtained kinetic granular strength at each of the rye bran addition levels is slightly higher than the kinetic strength of the pellet obtained from the sawdust itself (with the same sawdust moisture content of 14.8%), which was 94.25%.

Added rye bran containing high soluble arabinoxylans (in water forms high viscosity solutions) and small amounts of starch, which in combination with added water (increasing the moisture content of the mixture from about 10%, which had sawdust up to 14.8%) or water vapor (added in the future production process) as a result of the combination at high temperature, a binder (sticky gel) is formed which links the particles of granulated sawdust, which after drying form a stable agglomerate with high kinetic strength.
Figure 2. The dependence of the kinetic strength of the granulate on the content of rye bran in the mixture with sawdust.

The effect of rye bran content in blended with sawdust on the kinetic strength $P_{dxg}$ of pellets was described by equation:

$$P_{dxg} = 1.26z_o + 93.57$$

(2)

where:
- $z_o$ – amount of rye bran (%)
- $P_{dxg}$ – granulate kinetic strength (%)

This was earlier confirmed by Stahl and Berghel [26] who produce pellets of sawdust and post-production of turpentine velvet waste from turnips production, as they increase the amount of turpentine in the compacted mixture. Unfortunately, also the mechanical strength and the density of the obtained granules decrease. The results of their research [26] show that in the experimental studies the composition of the compacted mix should be chosen in such a way as to strike a compromise between reducing energy consumption and sustainability of the resulting pellet. Similar results were obtained by Nielsen [12], where was noted a decrease in energy consumption during the pelleting process with an increase in the addition of turnip waste to sawdust, while the mechanical stability of the resulting pellet decreased.

According to Miranda et al. [11], the addition of olive pomace to the Pyrenean oak waste provides a more efficient compacting of the mixture and also improves the kinetic strength of the resulting granulate and reduces the ash content in the resulting granules.

A similar course as the dependence of the kinetic strength of the granulate on the content of rye bran in the sawdust mixture also depends on the density of the obtained granulate from the content of rye bran in the mixture with sawdust (figure 3).

Basing on the studies (figure 3), it was found that the increase in the content of rye bran in sawdust mixed with sawdust from 10 to 20% resulted in a slight increase in the density of the granulate from 1190.72 kg·m$^{-3}$ to 1218.60 kg·m$^{-3}$. The granulate obtained at each level of rye bran addition has a slightly higher density than that of granulate obtained from sawdust itself (with the same sawdust moisture content and mix of 14.8%), which was 1183.73 kg·m$^{-3}$. 

![Graph showing the relationship between kinetic strength and rye bran content](image_url)
The obtained density values of sawdust and wiped pellets (more than 1000 kg·m⁻³) obtained with the use of rye bran in a mixture of sawdust in the range of 10% to 20% allow us to conclude that the produced granulate has a very good market quality and can be a fully innovative solid fuel – where a fuel with a density of more than 1000 kg·m⁻³ is considered, in accordance with existing standards for wood pellets in European countries: DIN 51731 - Germany, ÖNORM M 7135 - Austria or SS 18 71 20 - Sweden [27,28] and in accordance with the EN 14961 certified in 2011 and its Polish equivalent - EN 14961 (EN 14961). The values obtained comply with the latest ISO 17225 standard [29,30,31].

The obtained pellet from a mixture of rye bran and sawdust with a content of up to 20% rye bran can be used as a full-value fuel by the power industry in high efficiency boilers (with restrictive fuel parameters) as well as by individual consumers (users of conventional biomass fuel boilers).

The effect of rye bran content in the blend of sawdust on the density of pellets $\rho_g$ was described by the equations:

$$\rho_g = 10.994z_o + 1169.8$$

where:

- $z_o$ – amount of rye bran [%]
- $\rho_g$ – granulate density [kg·m⁻³].

The positive effect of adding plant waste to wood waste on sawdust density is confirmed by the Arranz study [32], which showed that the addition of olive residue and grape marc to Pyrenean oak waste increased the caloric value and bulk density of the pellet obtained.

An additional positive aspect of the use of rye bran as a component of the resulting solid fuel is the possibility of utilizing large quantities of post-production waste in the form of rye bran produced in cereal processing plants. These wastes are often not fully exploited, in stock stores, mills. Their development (use for pellet production) on a broader scale is part of the current EU policy on waste management, which is based on three principles: waste prevention, recycling and reuse, improvement of final disposal and monitoring.

The research has made it possible to determine the suitability of rye bran as an excellent binder material to obtain better quality pellets at lower energy costs for the compaction process. The rye bran binder used is also a high energy content (high calorific value), leaving little ash content after the combustion process.

The research also allowed us to conclude that a very important factor in the granulating process of rye bran mixes is the uniformity of mixing of the ingredients of the mixtures. Reducing the amount of rye bran resulted in a decrease in the amount of binder in the mix and an increase in the granulator's demand.
for power during the pelleting process. Therefore, during the preparation process of the rye bran mix, particular attention should be paid to the uniformity of the mixing of the ingredients. Table 2 shows the results of the HHV (high heating value) and LHV (low heating value) of raw materials (rye bran, sawdust and mixtures of sawdust and rye bran) used during the tests.

Table 2. Calorific values of raw materials used for testing.

| Analyzed waste (wt. % wet basis) | HHV (MJ∙kg⁻¹) | LHV (MJ∙kg⁻¹) |
|---------------------------------|---------------|---------------|
|                                 | dry basis     | wet basis     | dry basis     | wet basis     |
| 1 Sawdust (10.24%)               | 20.513        | 18.414        | 19.005        | 16.810        |
| 2 Rye bran (13.18%)              | 19.357        | 16.773        | 17.786        | 15.119        |

Basing on the research, the influence of sawdust moisture on HHV of sawdust $Q_s$ and LHV of $Q_l$ were determined:

$$Q_s = -0.2039 w_t + 20.513$$  \hspace{1cm} (4)

$$Q_l = -0.2144 w_t + 19.005$$  \hspace{1cm} (5)

And the dependence of the influence of rye bran on the HHV $Q_s$ and LHV $Q_l$:

$$Q_s = -0.196 w_o + 19.357$$  \hspace{1cm} (6)

$$Q_l = -0.2023 w_o + 17.786$$  \hspace{1cm} (7)

Based on the obtained relationships, the HHV and LHV of the analyzed mixtures of sawdust and rye bran (at 15% moisture content) were determined at different rye bran contents. Table 3 presents the results of studies on the effect of rye bran content in the mixture with sawdust on its calorific values.

Table 3. Effect of rye bran content in the mixture with sawdust by PHU Konar plant Staseluk Wojciech on its HHV and LHV.

| Amount of rye bran (%) | HHV (MJ∙kg⁻¹) 15% humidity | LHV (MJ∙kg⁻¹) 15% humidity |
|------------------------|-------------------------------|-----------------------------|
| 0                      | 17.455                        | 15.789                      |
| 5                      | 17.403                        | 15.737                      |
| 10                     | 17.351                        | 15.685                      |
| 15                     | 17.299                        | 15.633                      |
| 20                     | 17.247                        | 15.582                      |
| 25                     | 17.195                        | 15.530                      |

The obtained results show that on the HHV and LHV of the examined waste content of rye bran has a little effect. The obtained values (Table 2) show that the addition of rye bran will slightly reduce the energy values of the pellets produced. For example, adding 10% rye bran to the sawdust will reduce the combustion heat and calorific value by 0.104 MJ / kg (about 0.6%). From this point of view there are no contraindications for the use of rye bran as an additive for sawdust in the manufacture of pellets. The carried out study of the combustion emission of the obtained pellets allowed us to conclude that the obtained NO₃ and SO₃ values in the test samples from the sawdust pellet and the sawdust mixture from 20% rye bran were very close. A slightly higher emissivity of the aforementioned gases was observed in the sawdust pellets. The addition of 20% rye bran does not significantly affect the pellet combustion
conditions and the composition of the flue gases. The differences in the composition of the exhaust gases were about 12 mg·m⁻³ for SO₂ and about 11 mg·m⁻³ NOₓ, where higher values were recorded for pellets with added bran. The study did not demonstrate the need for additional exhaust gas filters other than those currently used in the so-called. Thus, the fuel can be used as an alternative to wood pellets in low power boilers fitted with a fixed grate.

Similar findings were made by Miranda et al. [11], according to which the results of pellet exhaust analysis of olive pomace are slightly worse than the pellet of oak waste alone, suggesting that it is not recommended to use a blend with over 50% olive pomace. Ohman et al. [18] found that, as a result of increased post-production of ethanol from lignocellulose to biomass, the increase in pellet calorific value, ash content, decrease in fuel tendency for slag and reduction of particulate matter emissions during combustion than in the case of biomass pellets. According to Stolarski [19], pellets produced from a mixture of cereal and sawdust waste are characterized by high ash content (5.91%). The impurities and humidity result in lowering their LHV to 15.203 MJ·kg⁻¹. On the other hand, applesauce pellets were characterized by high HHV (19.450 MJ·kg⁻¹) and more than twice lower ash content compared to pellets from cereal-wood mixture.

4. Conclusions

On the basis of the performed tests, the following conclusions have been formulated:

1. Sawdust used by the PHU Konar Staseluk Wojciech Plant, are characterized by high values of HHV and LHV. HHV for sawdust dry weight is 20.513 MJ·kg⁻¹ and LHV 19.005 MJ·kg⁻¹. At the 10.24% sawdust moisture content, the HHV is 18.41 MJ·kg⁻¹ and the LHV is 16.81 MJ·kg⁻¹.

2. Rye bran is an excellent binder material, which allows to obtain a better quality agglomerate (granules, briquettes) at lower energy costs of the compaction process. The rye bran binder has also a high energy (high HHV and LHV) and low ash content.

3. Increasing the content of rye bran in the mix with sawdust from 10 to 20% (at a moisture content of 14.8%) results in a decrease of 19% (from 11.06 kW to 8.98 kW) of the granulator’s Power demand. The demand for power is significantly lower than the corresponding demand for the sawdust granulation, which was 13.06 kW (at the same moisture content - 14.8%).

4. Increasing the content of rye bran in the mix with sawdust from 10 to 20% (at the moisture content of the mixture of 14.8%) results in an increase in the kinetic strength of the pellets by about 1.5% (from 96.71% to 98.08%). The obtained kinetic granular strength at each of the rye bran addition levels is slightly higher than the kinetic strength of the pellet obtained from the sawdust itself (with the same sawdust moisture content and mixture of 14.8%), which was 94.25%.

5. Increasing the content of rye bran in the mixture with sawdust from 10 to 20% results in an increase in the density of the granulate from 1190.72 kg·m⁻³ to 1218.60 kg·m⁻³ and the decrease in the bulk density of granules (from 646.50 kg·m⁻³ to 584.73 kg·m⁻³), as a result of increasing the length of the resulting granules.

6. The addition of 20% rye bran does not significantly affect the pellet combustion conditions and the composition of the flue gases. The differences in the composition of the exhaust gases were about 12 mg·m⁻³ for SO₂ and about 11 mg·m⁻³ NOₓ, where higher values were recorded for pellets with added bran. The study did not demonstrate the need for additional exhaust gas filters other than those currently used in the so-called. Thus, the fuel can be used as an alternative to wood pellets in low power boilers fitted with a fixed grate.

7. The most advantageous from the point of view of the quality of rye granulate is the additive level of 10-15%, which allows to obtain granules of satisfactory quality (high kinetic strength and density of granules), while reducing the energy consumption granulation process of the above mentioned mixture to about 27%, relative to the energy intensity of the thickening of the sawdust itself.

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