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Densification and Combustion of Cherry Stones

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Abstract: The aim of the presented research was to determine the suitability of cherry stones as a solid fuel. Mixtures of cherry stones with the addition of 10%, 15%, and 20% rye bran as a binder were subjected to the pressure agglomeration process in a rotary matrix working system (170, 220, and 270 rpm). The density of pellets, their kinetic durability, and power demand of the granulator's device for each mix were determined. The highest quality was characterized by pellets containing 20% rye bran, which were combusted in a 25 kW boiler with a retort grate. The concentration of CO, CO_2, NO, SO_2, HCl, and O_2 in the exhaust gas was tested. On the basis of the results of combustion, high heating value (HHV), low heating value (LHV), and elemental analysis, it was found that pellets from cherry stones with the addition of rye bran can serve as a substitute for wood pellets in low-power installations.

Keywords: cherry stones; agglomeration; combustion; emission; kinetic durability

1. Introduction

Each production system, including agri-food processing, results in the creation of various types of residues. As a result of agricultural activity and the agri-food industry, mainly organic residues of vegetable and animal origin are created with specific fertilizing, energy, and nutritional properties [1].

Estimates for the European Union in 2016 showed that 88 million metric tonnes (±14 Mt) of food waste is generated along the food production chain, which gives 173 kg (±27 kg) per capita per year [2]. Difficulties in the management of the above-mentioned waste are felt throughout the country in various clusters, dependent primarily on natural conditions, and have a mostly periodic occurrence (only in the harvest period). The waste has low durability, is cumbersome, produces harmful products during decomposition, and has a high heterogeneity of chemical composition and physical characteristics [3–5].

Solid agri-food waste can be subjected to a process of pressure agglomeration (granulation), as a result of which they obtain a permanent geometric form of a granulate (pellet, agglomerate) or briquette [6,7]. The granulation (agglomeration, densification) of waste materials facilitates their transport and storage (high bulk density) and allows their use in installations with automatic feeding of fuel. Through compaction, it is possible to obtain a product that is a combination of two or more components, allowing a great deal of freedom in handling the properties of the fuel produced [8]. Kraiem et al. [9] conducted experiments of compaction and combustion pellets from post-production tomato residues and grape marl, observing high calorific value (dry basis: db) of fuel from tomato residues (19.5 MJ·kg^{-1}) and grape marc with sawdust 1:1 (16.6 MJ·kg^{-1}) with increased NOx and SOx emissions for the combustion technology used. Celmaet al. [10] determined that the heating value of pellets from tomato waste is 27.08 MJ·kg^{-1} for dry matter, and kinetic durability is 91.02% at a moisture content of approximately 9%. Kang et al. [11] examined the process of burning dried coffee grounds. The described research shows high quality coffee grounds as a biofuel, as evidenced by the high carbon content (53.05%), which directly translated into a low heating value (LHV)of 18.5 MJ·kg^{-1}. The combustion was carried out in a low-power boiler (6.5 kW), and the recorded emission value for NOx was 163 mg·Nm^{-3}, which is a result similar to wood biomass. The high quality of coffee grounds as a fuel is confirmed by Allesinaet al. [12], giving a high heating value (HHV) of 20.484 MJ·kg^{-1}. Zając and Szyszlak-Bargłowicz [13], studying granules from safflower with an addition of rye bran, found that along with the increase in the amount of added bran, the calorific value of the fuel decreases and the amount of ash formed after combustion increases. Wattana and colleagues [14] performed a comparison of granulate quality from palm and rubber tree waste (leaves and branches) in various combinations (in 1:1 ratios). Thermogravimetric analyses of the obtained fuels show that granules from palm tree leaves and rubber tree leaves are characterized by the highest temperature of ignition and the lowest reactivity and ash content. Wongsiriamnuay and Tippayawong [15] in their work describe the problem of developing post-production maize waste, proposing the production of fuel pellets from them. The tests carried out on a laboratory bench with a closed chamber show that the produced pellet had favorable physical properties, in other words, a density of more than 1000 kg·m^{-3} (db) if the compaction temperature was higher than 80 °C. Mami et al. [16] found that the gaseous emissions from olive waste pellets are produced in acceptable concentrations compared to Germany and European standards and the quality of pellets obtained in their experiment was similar to standard wood pellets, which are used currently in European markets.

Differences in the presented research create the need for selection of the materials of biological origin with favorable granulation conditions: the appropriate level of humidity and the size of densified particles [7,17,18].

This paper presents the results of tests assessing the usefulness of agri-food waste in the form of cherry stones and rye bran as raw materials for the production of solid fuels in pressure agglomeration processes. Poland is one of the largest cherry producers in the European Union. According to Nowicka and co-workers [19], on average, 70% of the cherry harvest is directed for processing purposes, in other words, the production of frozen foods, concentrates, juices, nectars, jams, preserves, and spirits. In addition, cherry seeds are heterogeneous in their structure (soft center, hard shell), which in the combustion processes can cause increased emission of harmful compounds to the atmosphere and lower the efficiency of thermal processes. The scope of work included assessment of the physical and chemical parameters of waste (i.e., determination of carbon, hydrogen, nitrogen, sulfur, chlorine, oxygen, and moisture content, volatile parts, and ash), pressure agglomeration process of waste, and assessment of the effects of the granule's combustion in a retort grate boiler.

2. Materials and Methods

2.1. Materials

2.1.1. Plum Stones

The cherry stones used for the tests are shown in Figure 1 in a crushed form for the granulation process and the form in which they left the processing plant. Over 80% of the particles of crushed stones were between 2 and 4 mm in size.

The cherry stone, which is usually removed from the fruit, depending on the variety, constitutes from 8% to 15% of the total weight of the fruit [20,21], thus, tens of thousands of tons of waste are produced annually in the world, and at the present time they are only used to a small extent [22]. Cherry stones after purification from the remains of the pulp and drying can fulfill the role of filling in toys for children or in so-called dry hot water bottles [20]. Another one of their uses is in the production of activated carbon used in the food industry to remove ochratoxin A in the production of red wine [22,23]. Shells in small quantities are sometimes added to pig feeds to enrich their diet with dietary fiber and minerals, or are sometimes used in the cosmetics industry as an additive to epidermal exfoliating cosmetics [19]. In addition, the cosmetics industry uses cherry seed oil as a source of unsaturated fatty acids and tocopherols that have anti-wrinkle effects [22,24].

(**a**) (**b**)

Figure 1. Cherry stones used for the granulation process: (**a**) in the form in which they left the production plant;(**b**) in a crumbled form.

According to Purgał and Pasternak [25] and Rzeźnik et al. [26], cherry stones can be used as an ecological biofuel with high calorific value and low ash content. However, due to the limited availability of raw material and the necessity to introduce constructional changes that make it possible to adapt stone burning furnaces, these solutions are not in common use.

2.1.2. Rye Bran

Rye bran used in the research is shown in Figure 2.

Figure 2. Bran used for the granulation process.

Rye bran represents 10% rye grain and is separated, as a residue, in flour milling processes [27,28]. Rye grain is a rich source of fiber, it contains about 17% fiber [29], with rye bran containing up to 39% [30], hence they are used as a food additive to support gut peristalsis and lower the energy density of food (providing a longer feeling of satiety) [31]. Rye carbohydrate components can be divided into starch and non-starch polysaccharides [27]. Starch contained in the bran, due to the presence of moisture and the high temperature during the granulation process, gelatinizes to form of a sticky gel. The binding properties (binder) of rye bran are used in granulation processes, where they can improve the course of the agglomeration process and reduce its energy expenditure [12,32,33].

2.2. *Methods*

2.2.1. Determination of the Physicochemical Properties of the Raw Materials

The carbon, nitrogen, hydrogen, and sulfur content were determined using the LECO CHN628 analyzer: the carbon and hydrogen content in dry biomass was determined by high-temperature combustion with IR detection (infrared radiation), nitrogen content by means of a catarometer according to [34], and sulfur content determined by high-temperature combustion method with IR detection, in accordance with [35]. The chlorine content in the waste materials was tested by the Faculty Chemical Laboratory of the Faculty of Civil and Environmental Engineering at Białystok University of

Technology in accordance with the method given by the manufacturer of the S2 PICOFOX fluorescence spectrometer. Moisture content (according to [36]), volatile parts content (according to [37]), and ash content (according to [38]) testing in cherry stones and rye bran was carried out on the TGA-701 analyzer from LECO. The heat of combustion (high heating value, HHV) was determined in accordance with [39], using the Kl-12Mn calorimeter. The low heating value (LHV) was calculated based on the moisture content of the material and its hydrogen content. Bulk density of the analyzed materials was determined according to [40].

2.2.2. Pressure Agglomeration Process

The granulation process of the tested waste materials was carried out on the SS-4 test stand (Figure 3), whose main element is the P-300 granulator from Protechnika. The stand was described in previousworks [32,41–43]. The granulator matrix used in this research was 28 mm in length and had holes with a 6 mm diameter.

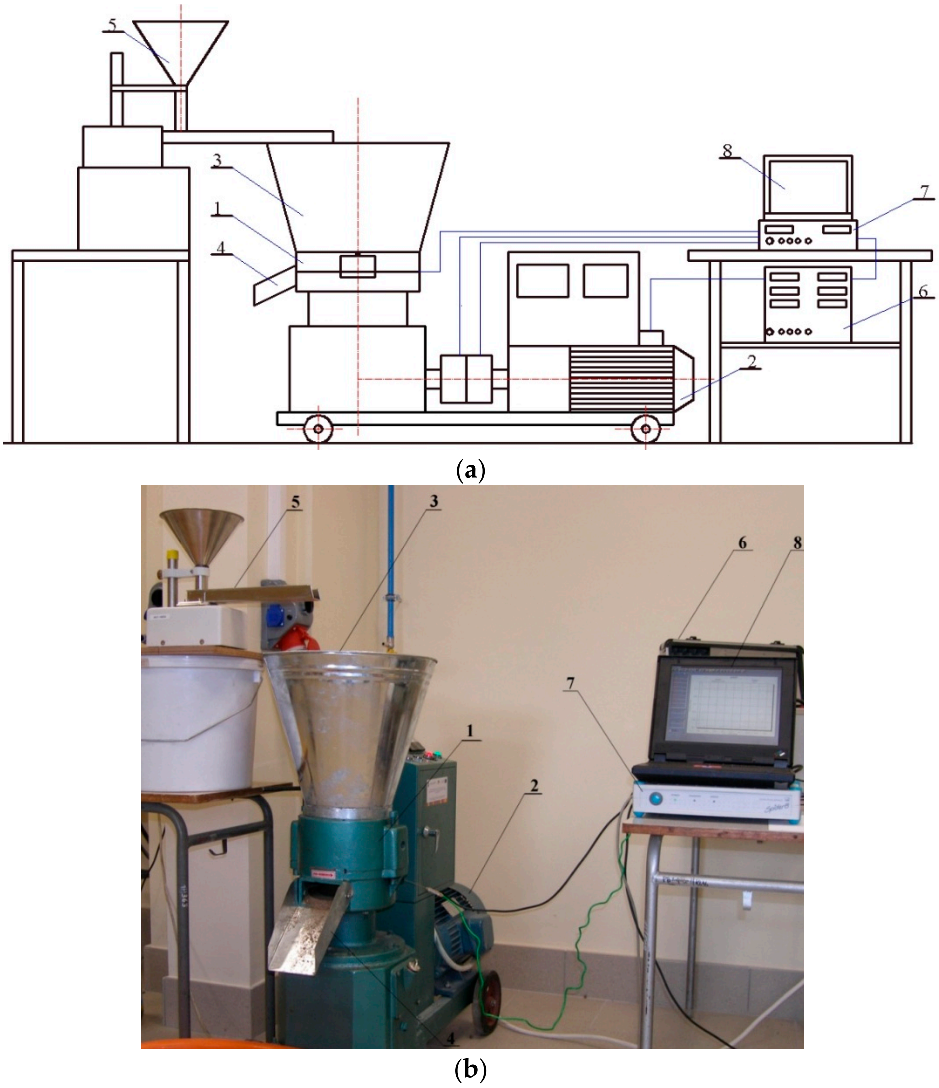

Figure 3. Stand SS-4: (**a**) scheme of the station: 1—working system of granulator with a flat matrix, 2—electric motor driving the granulator (Y132M, 7.5kW, 1440obr·min^{-1}), 3—feed of raw material, 4—spill granulate, 5—vibrating dispenser (FRITISCH LABORET 24), 6—universal meter for measuring the power demand (METROL KWS 1083, max 20kW0), 7—recorder Spider 8, 8—PC computer; (**b**) view of the laboratory stand.

The tests of densification of a mixture of ground cherry stones and rye bran were carried out where the input values were material and construction parameters:

$x_1 = z_w$ —rye bran content (10%, 15%, and 20%),

$x_2 = n_m$ —rotational speed of the granulator matrix (170, 220, and 279 rpm).

The tests for independent variables were the tests for kinetic durability and density of the obtained pellets and the granulator demand for power.

The kinetic durability of the obtained pellets was determined by the Holmen method (according to [44]). In order to determine the physical density of pellets, the mass of ten randomly selected granules (whose edges were ground beforehand in order to approximate their shape to the roll as closely as possible) was measured with an accuracy of 0.0001 g, and their height was measured using a conventional caliper with an accuracy of 0.05 mm. The density of the granules was calculated as the weight and volume quotient of each granule, then averaged.

2.2.3. Combustion of Pellets

Combustion of the produced pellets, in order to verify their combustion effects in low-power boilers (Figure 4), was carried out at the laboratory of Low Emission Combustion Technologies described previously [17]. For comparison, whole cherry stones in the form they leave the processing plant (not chipped) were also combusted.

Figure 4. Laboratory stand at Low Emission Combustion Technologies: 1—Moderator Unica VentoEko boiler, 2—boiler controller, 3—fuel tank, 4—exhaust sampling, 5—MCA10 analyzer, 6—Microsoft tablet for archiving measurement results.

The stand includes a Moderator 2 Unica VentoEko boiler equipped with a 25 kW retort grate and MCA10 flue gas analyzer from Dr. Födisch.

Samples of a mass of approximately 10 kg were fed into the boiler via a controlled automatic screw feeder. The settings of the fuel mass flow and the airflow into the combustion chamber were selected by the boiler controller in the Fuzzy Logic mode; the mass flow of fuel to the combustion chamber was 3.2 $kg \cdot h^{-1}$. The boiler controller, after establishing stable combustion conditions, can change the flow conditions to a small extent, which are negligible for the nature of the analyses in this experiment.

The CO_2, CO, NO, SO_2, and HCl content in the flue gases was normalized to 10% oxygen content (O_2) according to the formula [45]

$$Z_{s2} = \frac{21 - O_2'}{\left(21 - O_2''\right) \cdot Z_{s1}} \left(\%,\ \ mg \cdot m^{-3}\right) \quad (1)$$

where Z_{s1} is the actual chemical content in the exhaust gas (%, mg·Nm^{-3}), Z_{s2} is the content of the chemical compound in the exhaust gas for a given oxygen content (%, mg·Nm^{-3}),O_2′ is the set oxygen content in the exhaust (%), and O_2" is the actual oxygen content in the exhaust gas (%).

The excess air factor λ was calculated based on the following formula used for technical calculations:

$$\lambda = \frac{21.5}{21.5 - O_2''} \quad (2)$$

3. Results and Discussion

3.1. Physicochemical Properties of Raw Materials

Table 1 presents the results of the elemental composition as well as the moisture, volatiles, and ash content for the investigated waste.

Table 1. Properties of cherry stones and rye bran.

Property	Cherry Stones	Rye Bran
Moisture (%) wb	9.30 ± 0.08	10.54 ± 0.16
Bulk density (kg·m^{-3}) wb	472.88 ± 6.84	279.85 ± 2.02
Volatile matter (%) db	70.20 ± 0.25	69.71 ± 0.45
Ash (%) db	1.40 ± 0.001	3.77 ± 0.01
Carbon (%) db	52.72 ± 0.06	46.33 ± 0.04
Hydrogen (%) db	6.50 ± 0.02	6.00 ± 0.02
Nitrogen (%) db	1.34 ± 0.01	2.42 ± 0.01
Sulphur (%) db	0.107 ± 0.001	0.095 ± 0.005
Chlorine (%) db	0.001	0.002
Oxygen [1] (%) db	37.93	41.38
HHV (MJ·kg^{-1}) db	22.32 ± 0.10	18.86 ± 0.15
LHV (MJ·kg^{-1}) db	20.618	17.45

[1] By difference. db: dry basis; HHV: high heating value; LHV: low heating value.

Both wastes are characterized by similar moisture content, and due to the construction and process conditions of the pelleting system, before their pressure agglomeration the mixtures had to be moistened to a moisture content of approximately 20% by adding water to the mixture 24 h before agglomeration.

The volume of volatile components is an important parameter when assessing the energy efficiency of solid fuels. Środa and colleagues [46] reported that the main feature distinguishing biomass from other solid fuels is the high content of volatile parts, which causes its high reactivity. Both tested materials were characterized by a similar content of volatile parts of about 70%, which is similar to woody biomass [47]. Rye bran contains more than twice as much ash than plum seeds, which indicates a higher content of mineral salts that were chemically linked to the carbon structure (natural ashes) or mineral soil particles that were taken up by the plant during growth or transferred to biomass during harvesting and transport [48]. The content of ash in biomass is much smaller than that in coal, although its different origin and chemical nature affect the operation of boiler equipment, where they cause, among other things, increased settling of slag and ash in the furnace or increased rate of wear of metal boiler elements due to corrosion [49,50].

Another parameter, which is significantly different in the tested wastes, is nitrogen content. During combustion, the nitrogen contained in the fuel is almost completely converted into nitrogen N_2 and nitrogen oxides [51]. The emission of nitrogen oxides from combustion processes and high-temperature industrial processes is a serious environmental problem. Nitrogen oxides, collectively referred as NOx, are formed essentially in all combustion processes, mainly as nitrous oxide (NO), and in smaller amounts as nitrogen dioxide (NO_2) and nitrous oxide (N_2O). Nitric oxide is then oxidized to NO_2 in an atmosphere of air. Nitric oxide and nitrogen dioxide are precursors to acid rain and contribute to the formation of photochemical smog, while nitrous oxide is a greenhouse gas [52]. The relatively high nitrogen content in rye bran limits its use in combustion processes and reduces its share in fuel.

An increase in the rye bran content from 10% to 20% in a mixture with cherry stones caused a slight decrease in the low heating value by approximately 1.7% (Figure 5).

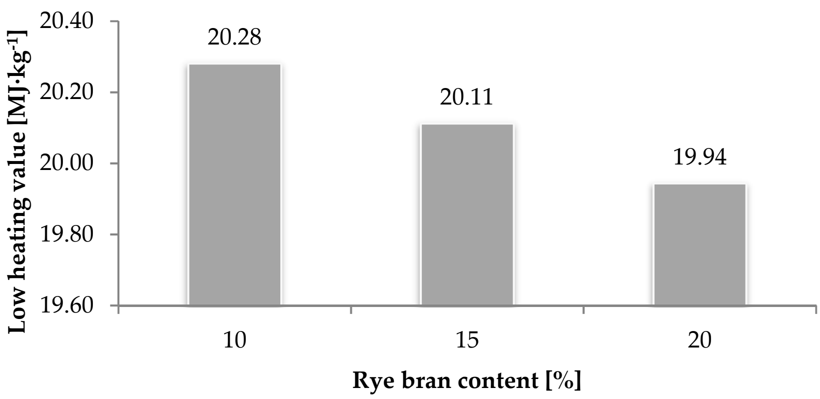

Figure 5. Dependence of the LHV of cherry stone granules on the content of rye bran.

The decrease in the LHV results from the fact that cherry stones have about a 3.5 $MJ \cdot kg^{-1}$ higher calorific value than rye bran. Zając and Szyszlak-Bargłowicz [12], using the addition of rye bran for safflower mallow, also observed a slight decrease in the calorific value of the produced pellets. Obidziński et al. [32], using an addition from 5% to 25% of rye bran to sawdust, also obtained granules whose calorific value decreased with increasing rye bran content.

3.2. Pressure Agglomeration Process

Figure 6 shows the influence of process factors (rotational speed of the matrix) and materials (rye bran content) on the kinetic durability of granules obtained from cherry stones.

The obtained results (Figure 6) allow us to state that increasing the amount of rye bran from 10% to 20% in a mixture with cherry stones increases the granule kinetic durability at each of the rotational speeds of the granulator's matrix. For example, at 170 rpm, the kinetic durability of pellets increased from 57.13% (with 10% rye bran) to 87.57% (with 20% rye bran). The binding properties of rye bran were also previously confirmed [32], where it was used as an additive to sawdust and improved the kinetic durability of the fuel pellet. Rye bran was also used by Szyszlak-Bargłowicz and co-workers [33] in a mix with Virginia mallow to improve the course of the pelleting process. Chou and coworkers [53,54] carried out agglomeration of rice straw and rice bran in the piston-matrix system and found that with the increase of rice bran in the thickened mixture, the strength of the briquettes increased. The majority of standards for wood pellets, produced industrially, determines the kinetic durability as not less than 97.5%.

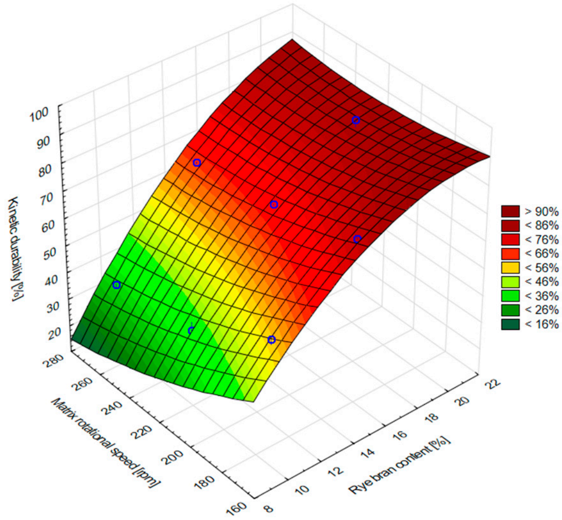

Figure 6. The impact of rye bran and rotational speed of the matrix on the kinetic durability of cherry stone granules.

Increasing the rotation speed of the granulator matrix resulted in a decrease in the kinetic durability of pellets. The decrease was most visible for pellets with 10% rye bran content, in other words, kinetic durability at 270 rpm was only 33.83%, and at 170 rpm it was 57.13%. This is related to the high fat content in the endosperm of cherries [19] (lowering the content of bran in the mixture causes an increase in the total fat) and a decrease in thickening pressures as the rotational speed increases [6,55].

There were attempts to agglomerate cherry stones without using rye bran, however, the kinetic strength of the obtained products was very low (below 20%) which would prevent the transport of granules and their use in installations with an automatic dispenser. For this reason, only the mixture containing 20% rye bran was subjected to the combustion process.

The bulk density of the obtained pellets was approximately 470 kg·m^{-3} and was similar to the bulk density of whole cherry stones.

Figure 7 shows the influence of process factors (rotational speed of the matrix) and materials (rye bran content) on the physical density of the granules obtained from cherry stones.

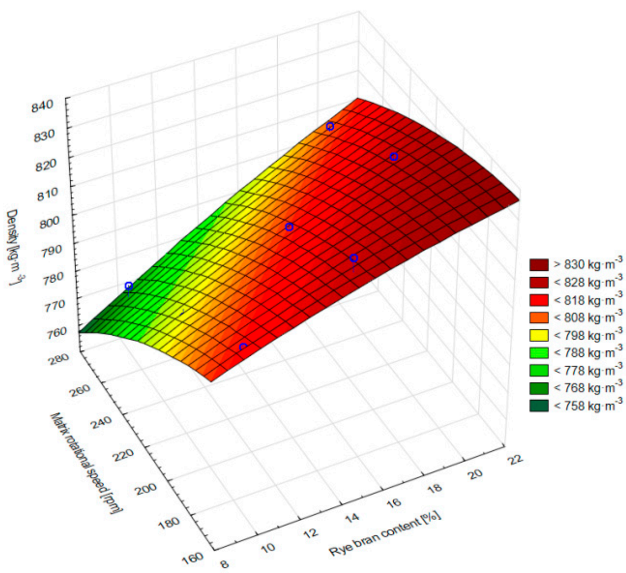

Figure 7. The impact of rye bran and rotational speed of the matrix on the density of cherry stone granules.

On the basis of the obtained test results (Figure 7), it was found that increasing the content of rye bran from 10% to 20% in a mixture with cherry stones increased the physical density of the obtained pellets at each of the rotational speeds of the granulator's matrix. The highest physical density (829.51 kg·m^{-3}) was obtained from granulated cherry stones obtained with a 20% rye bran fraction, with the rotational speed of the matrix equal to 170 rpm. The addition of rye bran significantly influenced the increase in the density of the obtained granules. Similar observations are described in a previous work [32], where the addition of rye bran to sawdust produced pellets of higher density. Miranda et al. [56] thickened the olive pulp waste resulting from oil production, and they found that in order to achieve high granule quality (high kinetic durability and physical density), the high fat material should be mixed with other low fat waste.

An increase in the rotational speed of the die from 170 to 270 rpm resulted in a slight decrease in the density of pellets, with the highest difference (about 4%) recorded at a 10% addition of rye bran in the compacted mixture. High fat content in cherry stones [57] improves the lubricating properties of the compacted mixture and reduces the friction between the material and the walls of the die holes, which results in a decrease in thickening pressures and a decrease in product density.

Figure 8 shows the influence of process factors (rotational speed of the matrix) and materials (rye bran content) on the demand for granulator power during the manufacture of cherry stone granules.

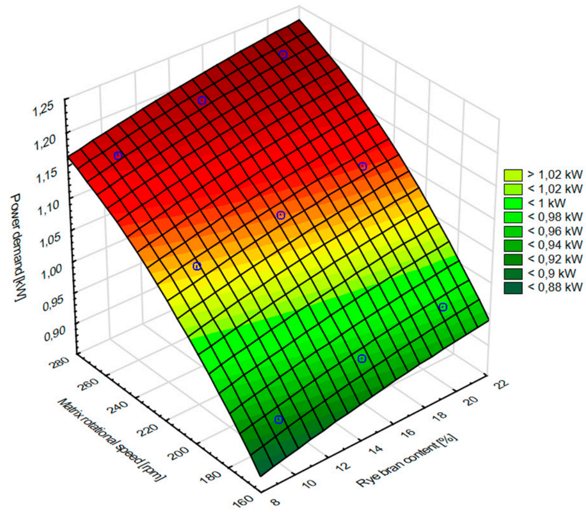

Figure 8. Influence of rye bran and rotational speed of the matrix on the granulator demand for power during the production of granulated cherry stones.

The research (Figure 8) shows that the increase in the amount of bran from 10% to 20% in the agglomerated mixture affects the increase of the granulator's demand for power to a small extent. For example, the increase in the amount of bran from 10% to 20%, at the matrix rotational speed of 270 rpm, resulted in a increase in the pellet demand for power from 1.16 to 1.21 kW.

It should be noted that in the case of ground fruit seeds, in the granulator's working system (between the rolls and the matrix), besides the process of molding the material into the matrix holes, the larger particles of the seed shell were also crushed [58]. The addition of rye bran caused an increase of the demand for the granulator's power due to the increase of the material's frictional force with the matrix (lower content of fat containing endosperm in the mixture). According to Obidziński et al. [32] and Buksa [59], rye bran contains arabinoxylans that form solutions of high viscosity in water, which in the compaction processes increase the compaction susceptibility of the mixture and thus create granules with high kinetic durability at reduced energy expenditure.

The highest values of the power granulator's demand were obtained at the matrix rotational speed of the 270 rpm and ranged from 1.16 kW (for a mixture containing 10% bran) to 1.21 kW (for a mixture containing 20% bran).

3.3. Combustion

Pellets with the highest obtained kinetic strength (80% cherry pits and 20% rye bran) were used for the combustion process due to the automatic fuel dosing system to the boiler. Granules containing 10% and 15% rye bran would crumble in the dispenser, causing operational problems of the installation. Table 2 presents the average results obtained during the combustion of cherry stone granules with a 20% addition of rye bran and cherry stones in the form in which they left the processing plant.

Table 2. Flue gas composition and conditions of combustion of cherry stones with 20% rye bran and cherry stones without any preparation.

Parameter	Value	
	Pellets	**Cherry Stones**
CO_2 (%)	7.20	7.76
CO (mg·Nm^{-3})	432.45	745.91
SO_2 (mg·Nm^{-3})	38.62	56.29
NO (mg·Nm^{-3})	264.69	356.44
HCl (mg·Nm^{-3})	4.38	8.99
The actual oxygen concentration in the exhaust (%)	10.96	14.19
λ	2.04	2.94
Average flue gas temperature in the boiler outlet (°C)	170	160

In Table 2 the actual average proportion of oxygen in the exhaust gas is given, based on which the air excess ratio λ was calculated. The difference in the coefficient λ for fuel in the form of pellets and whole cherry stones is clearly visible, which confirms the pellet's advantageous use in low-power boilers with a retort grate. According to Pudlik [60], λ depends on the type of fuel and the device in which it is incinerated, and in the case of waste it can reach values of 2–2.5. Particular attention is paid in the combustion processes to the contribution of CO in the exhaust gas as an indicator of the presence of soot, hydrocarbons, dioxins, and furans [61]. The maximum CO content in the flue gas for boilers with a heating capacity <0.5 MW is determined by the Ecodesign directive and amounts to a maximum of 500 mg·m^{-3} when feeding with automatic biomass fuel, which was also a condition of [62] for 5-class boilers.

Kordylewski and Mościcki [63] indicate that when combusting agro-type biomass in retort burners, increasing the excess air ratio λ may result in increased CO emission in the exhaust gas. Mustafa and co-workers [64] report that in addition to the high coefficient λ, the CO emission can be affected by the combustion temperature, since at higher temperatures the amount of CO should be lower.

According to Ravichandran and Corscadden [65], the emission of sulfur oxides depends primarily on the sulfur content in the fuel to be burned. Certified wood pellets burned in the same installation generated a sulfur dioxide emission of approximately 23 mg·m^{-3}. The Ecodesing directive will limit the emission of NO to <200 mg·m^{-3}. Cherry stone pellets did not achieve the level of nitrogen oxide emissions required by the Ecodesing directive. Wielgosiński and colleagues [66] observed a decrease in NO emissions due to an increase in the combustion temperature and lower air flow, which according to the authors is a result of changes in the course of NO synthesis under these conditions. This may be confirmed by the results obtained in the experiment for the whole stones and for the pellets. In the examined biomass burning conditions, the main source of nitrogen oxides is nitrogen contained in the fuel, due to the combustion temperatures below 1300°C. As a part of this research, using the K thermocouple, the temperature in the furnace was examined while burning granulated cherry stones with the addition of rye bran, and the temperature was approximately 730 °C. It is assumed, therefore, that Zeldowicz's reaction does not take place and that due to the high λ coefficient there are no so-called processes, in other words, prompt NO-atmospheric combustion of N_2 and hydrocarbons in a rich mix [67]. Williams and co-workers [68] suggest controlling nitrogen oxide emissions through stoichiometric control, which mainly concerns the compounds released during combustion of volatile fuels.

Chlorine contained in the biomass during most of the combustion is released in the form of hydrogen chloride HCl, which can further react with other exhaust components, resulting in the production of dioxins [69]. In this experiment, the hydrogen chloride content was twice as high for the combustion of whole cherry stones than for that of the cherry stones and rye bran pellets. Król [70] on the basis of German standards gives an acceptable limit for HCl emissions as <5 mg·m^{-3}, which was fulfilled in the case of pellets. As reported by Liu et al. [71], biomass with a high chlorine content is an undesirable fuel, although it can also bring some benefits, such as oxidation of mercury, and thus facilitate its capture and control. According to Szczepaniak [72], this phenomenon occurs at temperatures below 427 °C, at higher temperatures the importance of chlorine in the binding of mercury is marginal.

4. Conclusions

The compaction process (pressure agglomeration), its efficiency, energy consumption, and the quality of the product obtained, are closely related to material, apparatus, and process factors.

The overriding objective of creating fuel pellets from agri-food waste is the management of production residues, which allows for the reduction of costs of their utilization due to their use in energy systems.

Cherry stones are a material with high calorific value and low nitrogen, sulfur, and chlorine content, for which reason they might be used as an alternative solid fuel. Due to the high fat content of cherry stones, a product with low kinetic durability is obtained as a result of their agglomeration without additives. This prevents its transport and application in automatic fuel feeding systems. The use of binder in the form of rye bran for agglomeration of cherry stones has the effect of increasing the kinetic durability of pellets and at the same time slightly reducing their low heating value (LHV). An increase in rye bran content from 10% to 20% resulted in a decrease in the LHV by approximately 0.3 MJ·kg^{-1}, while the increase in the kinetic durability was up to 40%. In connection with the above, the pellet was evaluated with the addition of 20% rye bran as the highest quality product among those tested.

An important environmental aspect of waste utilization in direct combustion processes is their emissivity. Through the use of cherry pellets, in comparison to whole stones, almost two times the reduction of carbon monoxide emissions was achieved (while maintaining the same thermal and flow conditions of the boiler system) and the emissions of sulfur dioxide, nitric oxide, and hydrogen chloride were also reduced. The calculated excess air coefficient λ indicates a better contact of the combustible particle with the oxidizing agent when using pellets for the combustion process than when using whole cherry stones. Hence, these results motivate future investigations to reuse the cherry stones for producing alternative biofuels that might be used for heat and/or electricity production, either in domestic or in industrial plants.

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