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# Energy Consumption Depending on the Durability of Pellets Formed from Sawdust with an Admixture of FFP2 Masks

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**Abstract:** At present, we are still feeling the effects of the COVID-19 pandemic in connection with the huge amount of waste generated. However, the reuse of the produced waste in other processes requires energy consumption. This article deals with the reuse of face masks FFP2, which were added as an admixture to spruce or beech sawdust and then processed into pellets. During the production process of the pellets, energy consumption was measured and further converted to one ton of pellets, and also the consumption was reflected in the price of electricity. After storage, the mechanical durability and dimensions of the individual pellets were measured, and their density was calculated. Based on the results, it can be concluded that spruce pellets with 10% face masks FFP2 (consumption 747.41 kWh; durability 97.53%) and beech pellets with 5% face masks FFP2 (consumption 721.27 kWh; durability 97.38%) achieved higher values of mechanical durability and also consumed more energy than the remaining samples with lower values of durability without considering the sample with spruce sawdust and 5% FFP2 face masks (consumption 872.63 kWh; durability 91.68%). The production of spruce pellets with 5% FFP2 face masks was affected mainly by cold outside weather.

**Keywords:** wood pellets; COVID-19; energy consumption; mechanical durability; particle density

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## 1. Introduction

Since the onset of the COVID-19 viral disease, various measures have been introduced in various countries around the world to prevent its further spread. The introduction of single-use face masks and FFP2 masks as one of the preventive measures to slow down the human-to-human transmission of COVID-19 has resulted in a worldwide shortage of face masks [1,2]. This demand has led to increased worldwide production of protective face masks made using polymer materials, mainly polypropylene. Other polymers such as polystyrene, polycarbonate, polyethylene or polyester are also used to produce these masks. The protective masks mainly consist of three layers from these materials [3]. The increase in the production and consumption of face mask products around the world has brought a new environmental challenge and caused a huge increase in plastic waste in the environment. Some of these materials enter watercourses, from where they enter the freshwater and marine environment, which enormously increases the presence of plastics in the water environment [1,4].

At present, we are still feeling the effects of the COVID-19 pandemic in connection to the huge amount of waste generated. However, the reuse of the produced waste in other processes requires energy consumption. The aim of this article is the reuse of one of the most widely spread waste due to the COVID-19 pandemic, face masks FFP2. For safety reasons, no contaminated protective masks were used in this work. Face masks FFP2 were used as an admixture in wood pellets, and the energy consumption in their production

was measured depending on their mechanical durability. These masks were used in their weight proportions of 5% and 10% to the main material, spruce and beech sawdust.

Energy is consumed in almost all processes that are associated with the production of pellets. The pelletization process consists of several energy-dependent processes: separating the input material, crushing, mixing, moistening, drying, transporting, cooling, and packaging. However, the majority of the electrical energy is used to press the input material in the pelletizer. The amount of energy consumed also depends on the press of pellets used. Energy consumption in pellet production can be defined as the work done by force during the pelletization process. Mohamed E. Mostafa et al. investigated the physical and mechanical properties, as well as the energy consumption in the production of biomass pellets. The force-displacement data during pellet pressing were recorded by the controller program connected to the compression machine. Energy consumption was then obtained by integrating a force-displacement curve [5]. The determination of energy consumption from force and displacement curves were also recorded by Mengjiao Tan et al., who examined various parameters in the pellet production from Camellia Oleifera shell as well as the energy consumption in their production [6]. Xianfei Xia et al. investigated the effect of additives and hydrothermal pretreatment on the rice straw pelletization process, energy consumption, and the quality of the produced pellets. Specific energy consumption was obtained by the displacement-stress curve recorded by the computer and calculated based on the energy consumption of per gram rice straw during the pelleting process [7]. Augusto Uasuf and Gero Becker dealt with the production, costs of wood pellets and energy consumption under different conditions in northeast1ern Argentina. The total energy consumed corresponded to the energy consumption of the hammer mill, dryer motor, cooler pelletizer, and other various devices. The total energy consumption was then calculated as the sum of the different energy inputs required for pelletization in GJ/year [8].

One of the imperative and crucial properties of biomass pellets is mechanical durability important due to handling, storage, and feeding. Sylvia H. Larsson and Robert Samuelsson investigated the validity of various measurement methods of pellet durability as predictors for ISO 17831-1:2015. They found that compressive strength of pellets could be modeled and predicted from pellet density and Ligno single pellet durability [9]. Andrzej Kuranc et al. dealt with the pellet durability by subjecting them to vertical and horizontal vibrations similar to vibrations during transport and then compared to durability tests based on ISO 17831-1. Vibrations had a lower impact in horizontal cases than in vertical cases. Further, pellets with a diameter of 8 mm had lower durability than pellets with a diameter of 6 mm. The strength of pellets was lower realized according to ISO 17831-1 compared to the vibration method [10]. Miloš Matúš et al. measured the mechanical durability by using the Tumbler tester 1000 device according to ISO 17831. The use of sludge had a positive impact on the increasing value of pellet durability [11]. Hamid Rezaei et al. measured mechanical durability by using pellet durability analyzer and calculated it according to EN 15210-1. The authors also calculated the consumed energy from the numerical integration of force versus displacement data. Produced pellets with increasing plastic content from 20% to 40% reduced the energy consumption during the pelletization process, but they generated more dust during vibrating. Increasing die temperature led to the production of pellet with higher durability. Produced pellets with increasing paper content from 30% to 50% increased although mechanical durability but increased also the consumed energy [12]. Jozef Jandačka et al. also measured mechanical durability according to EN 15210. The authors used the analyzer LignoTester. They found out that the concentrate of organic compounds from defibration as an additive had a good impact on durability values [13]. In general, the durability of pellets made in domestic conditions is lower than in large manufactories. In the work of Holubčík et al. domestic produced pellets (91.11%) had mechanical durability lower by about 6.5% compared with pellets produced in manufactory (97.62%) [14].

This article's main contribution is to reuse the FFP2 masks with a focus on the measurement of energy consumption during their formation into pellets with respect to the

quality of the produced pellets, mainly in terms of mechanical durability. In addition to energy consumption and measurements of mechanical durability, the produced pellets were tested for their dimensions, and their density was also determined.

## 2. Materials and Methods

The main input materials were spruce and beech sawdust. It was necessary to dry these materials from original moisture in the range of 45–55% up to 15–20%. The drying process and material preparation have not been included in the energy consumption. The size of particle sawdust was in the range of 0.01 mm to 3 mm. As an admixture were added into sawdust FFP2 face masks. These masks were processed into small elements by crusher and then mixed with sawdust with 5% and 10% of their proportion. The pellet proportions are stated in Table 1. The individual samples of produced pellets are stated in Figure 1.

**Table 1.** Weight proportion of produced pellets.

| Sample | Weight Proportion Sawdust (%) | Weight Proportion Face Masks FFP2 (%) |
|---|---|---|
| Spruce 100 | 100 | 0 |
| Spruce 95/face masks FFP2_5 | 95 | 5 |
| Spruce 90/face masks FFP2_10 | 90 | 10 |
| Beech 100 | 100 | 0 |
| Beech 95/face masks FFP2_5 | 95 | 5 |
| Beech 90/face masks FFP2_10 | 90 | 10 |

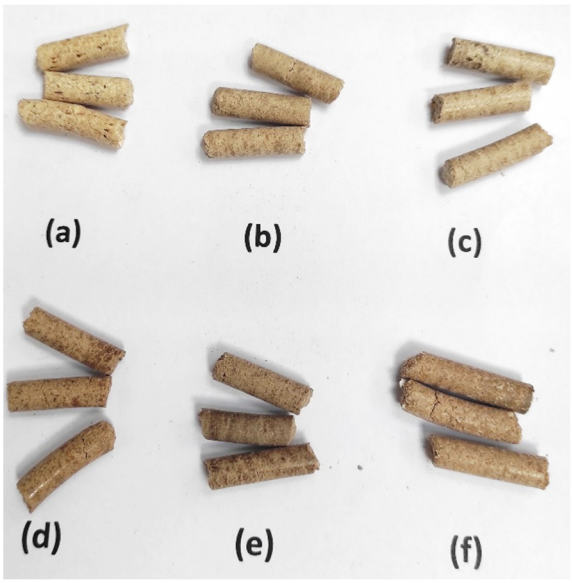



**Figure 1.** The samples of produced pellets: (**a**) Spruce 100; (**b**) Spruce 95/face masks FFP2_5; (**c**) Spruce 90/face masks FFP2_10; (**d**) Beech 100; (**e**) Beech 95/face masks FFP2_5; (**f**) Beech 90/face masks FFP2_10.

### *2.1. Energy Consumption*

Input materials were compressed by small pellet press with a power of 7.5 kW. The manufacturers state the efficiency of the used pelletizer is 150–200 kg/h. However, this is a theoretical performance mainly for feed mixtures. In our conditions, the real efficiency of the pelletizer was, at most, about 40 kg/h. During the compression, energy consumption was measured by using a four-quadrant electricity meter with continuous measurement SCHRACK LZQJ-XC shown in Figure 2.

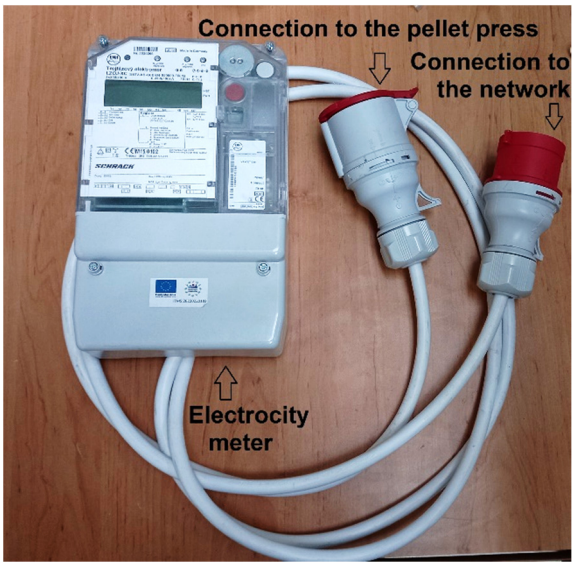



**Figure 2.** The used electricity meter.

It was necessary to connect the electricity meter to the network and also to connect the pellet press to the electricity meter. The connection of the electricity meter to the pellet press is shown in Figure 3. The pellet press starts and stops times were recorded during the measurements. Produced pellets that formed during this time interval were weighed. Based on these data it was possible to determine what weight of the pellets can be produced in a time interval. It was possible to record the measured values of electricity quantities every minute. The quantities were saved in the device memory. Energy consumption in kWh was one of the measured quantities. Measured data were evaluated by using the program EMH-COMBI-MASTER 2000. In this case, it was possible to determine the energy consumption required for pellet production with respect to a certain weight.

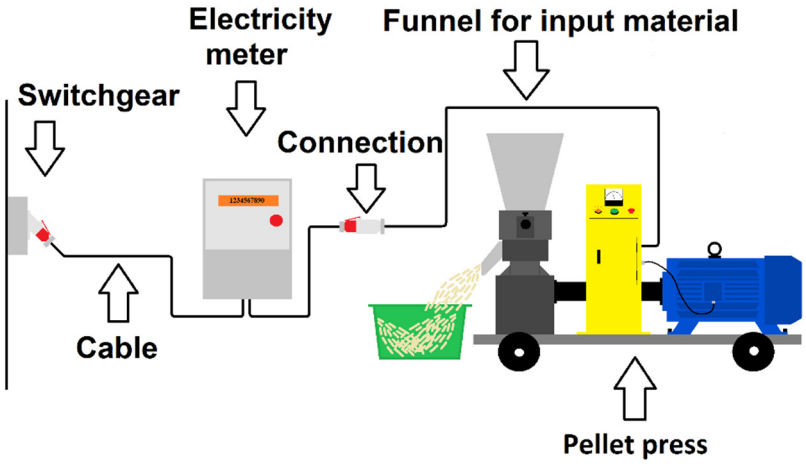



**Figure 3.** The connection of the electricity meter to the pellet press.

The measured data were then converted to one ton of weight according to Equation (1).

$$\frac{\text{x (kg)}}{\text{y (kWh)}} = \frac{\text{X} = 1000\ \text{(kg)}}{\text{Y (kWh)}} \quad (1)$$

In Equation (1) x represents the weight of produced pellets, y is measured energy consumption, X represents the weight of one ton of produced pellets, and Y is calculated energy consumption.

### *2.2. Mechanical Durability*

Produced pellets were stored at 20 °C and relative humidity from 40% to 50% for one week. Further, they were tested for their mechanical durability by using a Ligno-Tester Holmen device (Tekpro Ltd., North Walsham, UK). It was realized based on the standard EN 15210 (2010) [15]. First, the sample was sieved through a sieve with a diameter of 3.15 mm. Further, the samples were placed in a test device and subjected to shocks of each other and also into the wall of the device. The weights of the individual samples were 100 g ± 0.5 g. The F-test was performed for 30 s and the DU test for 60 s. The measurements were evaluated on the basis of Equation (2).

$$DU = \frac{m_2}{m_1} \cdot 100\ (\%) \quad (2)$$

In Equation (2) $m_1$ is the weight of pellets before the measurement, and $m_2$ is the weight of pellets after the measurement.

### *2.3. Pellet Dimensions*

Lastly were realized the measurements of the diameters and lengths of the formed pellets with a caliper. By their weight and Equation (3), it was possible to determine their density.

$$\rho = \frac{m}{V}\ \left(kg \cdot m^{-3}\right) \quad (3)$$

In Equation (3) ρ is density, m is the weight, and V is the calculated volume based on the dimensions of the pellet.

### *2.4. Sample Standard Deviation*

All experimental measurements were realized with repetitions from two to four times except the measurement of energy consumption, where the data were added together and then converted to one ton of weight. The result values are stated as mean measurement values with their sample standard deviations determined in the Microsoft Excel program.

The accuracy of results could be influenced by the lost materials or pellets during transport and manipulation and the accuracy of used measuring devices. The electricity meter belongs to class B and measures with an accuracy of ±1%. The used analytic weight measures with an accuracy of 0.1 mg. This weight belongs to verification class I with the verification value of 1 mg.

## 3. Results

Spruce sawdust pellets using 5% FFP2 face masks as an admixture were the first to be produced. In these measurements, the cold weather affected the production because the pelletizer required a longer time to warm up to operating temperature. The use of the small sample amount of input materials caused the pelletizer to have warmed up just a little and then cooled during the time between individual processes. The pelletization process was also affected by the high moisture of the input material, which caused the pellets to come out of the pelletizer wet and disintegrate immediately. The low moisture of the pellets caused the input material to fail to connect together, and the process had to be repeated several times. During production, the correct shape of the pellets and the length of the pelletization process impacted the setting of the pressure of the pellet rollers to the die too. The measurements were realized from turning on the pelletizer to turning off and included the initial heating of the pelletizer and a re-granulation process in which the pellets had to be re-pressed until they were of a suitable shape and length.

### *3.1. Energy Consumption*

The results from measurements of energy consumption of produced pellets are shown in Figure 4. Based on these results, the lowest energy consumption was during the production of the pure spruce pellets. The highest energy consumption was measured during the

production of spruce pellets with 5% face masks FFP2. However, to produce these pellets, the input materials had to be pelletized three times until the pelletizer was sufficiently heated and the pellets were of a suitable shape and length. From the measurements, it is possible to summarize that all four samples with face masks FFP2 had a higher energy consumption than the reference samples from the pure input materials. Compared to spruce and beech pellets, pure spruce pellets had lower energy consumption than pure beech pellets. However, beech pellets had a lower energy consumption at both 5% and 10% of the proportion of face masks FFP2, but they were not as qualitative as spruce pellets.

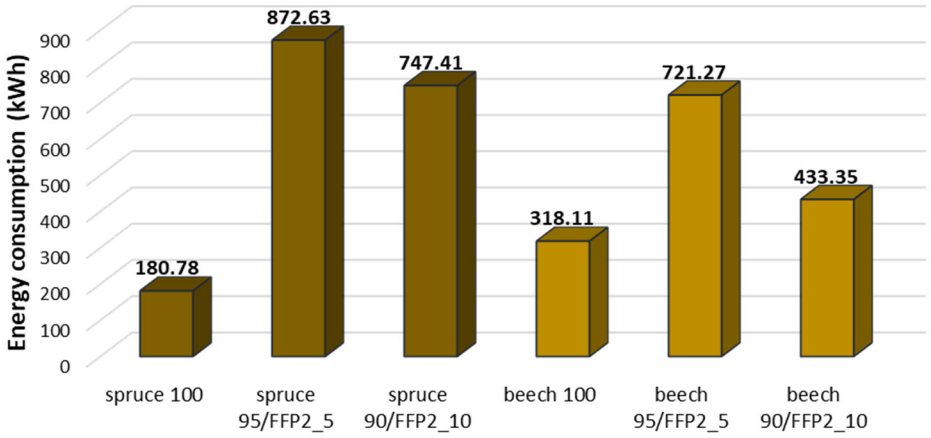



**Figure 4.** Energy consumption.

The energy consumption in the production of pellets will ultimately be reflected in the price of the produced pellets. The resulting prices can be divided into two categories, depending on whether it is the production of pellets in the household or in a pellet factory, according to which there are different tariffs and rates for electricity consumed. The calculated price includes only the energy consumption measured during the pelletization process, without other processes and costs associated with pelletization. The price list and rates necessary for the economic evaluation are considered with respect to the location of measuring energy consumption in the production of pellets, and local supplier and also are valid from the 1st of January 2022. Table 2 shows the average prices of electricity consumed in € per one ton of pellets produced for households and factories. Individual samples represent prices for households from 34.56 € for pure sawdust pellets to 166.84 € for spruce pellets with 5% FFP2 face masks. Individual samples represent prices for factories from 17.23 € for pure sawdust pellets to 83.16 € for spruce pellets with 5% FFP2 face masks. Pure spruce pellets would cost less than pure beech pellets. The lowest price for pellets containing face masks FFP2 would be for beech pellets with 10% FFP2 face masks. However, the pelletization process was influenced by weather conditions, the moisture of input materials and the setting of the pressure of the pellet rollers to the die. The production of pellets on a pelletizing line would be less energy demanding than their production on the used small pellet press.

**Table 2.** Economic evaluation.

| Sample | Weight Proportion (%) | Household Prices (€/1 ton) | Factories Prices (€/1 ton) |
|---|---|---|---|
| Spruce | 100 | 34.56 | 17.23 |
| Spruce/face masks FFP2 | 95/5 | 166.84 | 83.16 |
| Spruce/face masks FFP2 | 90/10 | 142.90 | 71.22 |
| Beech | 100 | 60.82 | 30.31 |
| Beech/face masks FFP2 | 95/5 | 137.90 | 68.73 |
| Beech/face masks FFP2 | 90/10 | 82.85 | 41.29 |

### 3.2. Mechanical Durability

The results from measurements of mechanical durability are shown in Figure 5. The standardized values for this property are given in ISO 17225-2 (2021) standard [16]. For category A1, the standard value for pellets with a diameter of 6 mm is higher than 98%, for A2 it is more than 97.5%, and for category B more than 96.5%. Based on the results from DU-test, only two samples (spruce pellets with 10% FFP2 face masks and beech pellets with 5% FFP2 face masks) met the set standard values. These two samples would fall into the A2 and B categories. The remaining samples did not meet the standardized limits, what may be caused by several factors, such as low temperature in the pellet press during pellet production, high moisture of the material during production, and the subsequent decomposition of samples after being stored in the laboratory, etc.

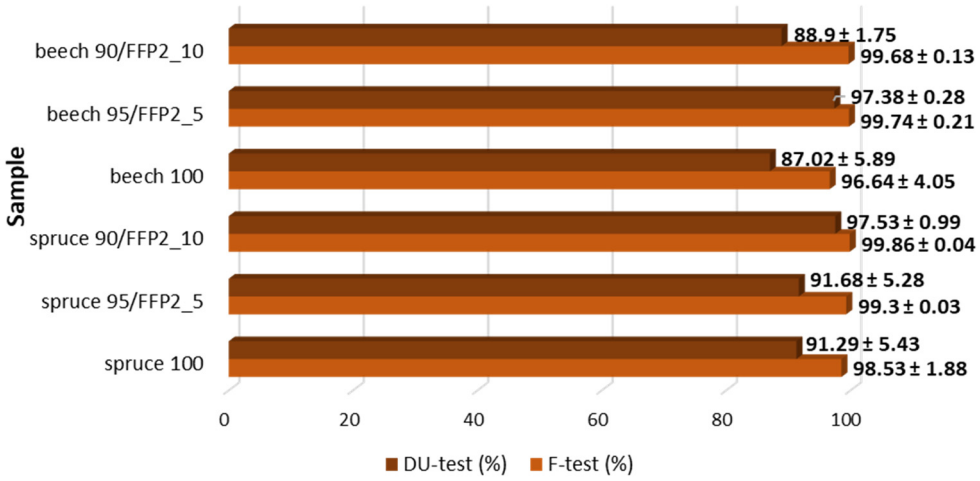



**Figure 5.** Mechanical durability.

Except for the highest energy consumption for the sample of sawdust pellets with 5% FFP2 face masks, which was mainly affected by cold outside weather, samples (spruce pellets with 10% face masks FFP2 and beech pellets with 5% face masks FFP2) that achieved higher values of mechanical durability also consumed more energy than the remaining samples with lower values of durability.

### 3.3. Pellet Dimensions

The results of the pellet dimensions and calculated density are shown in Table 3. ISO 17225-2 (2021) [16] defines a standardized pellet diameter 6 mm ± 1 mm. Based on the values measured by a caliper, it can be summarized that all samples met this value. The diameter of the pellets was primarily influenced by the die through which the material is forced under the action of pressure. The standardized length of pellets should range from 3.15 to 40 mm, while the produced pellet samples were around 22 mm. The length of the pellets mainly depended on the set height of the knife that cut the extruded material in the pellet press. Afterwards, the volume and density were calculated from the measured values. All produced pellets had a density ranging from 1078 kg·m$^{-3}$ to 1200 kg·m$^{-3}$. Based on the research of Stelte et al., wood pellets should have a particle density ranging from 1000 kg·m$^{-3}$ to 1400 kg·m$^{-3}$ [17].

The optimal variant in terms of reuse of FFP2 masks and energy consumption during their processing and the required quality of the mechanical durability could be a sample of spruce pellets with a 10% of weight proportion of FFP2 masks. Spruce sawdust connects together better than beech due to the higher proportion of lignin. Adding a higher weight proportion of FFP2 masks increases the gross calorific value of the pellets and at the same time eliminates more masks. The gross calorific value of the masks is at least twice the gross calorific value of the wood pellets. Sonawane et al. state that the gross calorific value of

polypropylene without a catalyst is 42.2 MJ/kg [18], while the net calorific value of spruce wood is 20.56 MJ/kg and 18.86 MJ/kg for beech wood according to Nosek et al. [19].

**Table 3.** Properties of produced pellets.

| Sample | Weight Proportion (%) | Diameter (mm) | Length (mm) | Volume ($mm^3$) | Density ($kg \cdot m^{-3}$) |
|---|---|---|---|---|---|
| Spruce | 100 | 5.96 ± 0.02 | 20.03 ± 0.93 | 558.52 | 1186.53 |
| Spruce/face masks FFP2 | 95/5 | 5.73 ± 0.09 | 22.14 ± 0.73 | 571.10 | 1132.32 |
| Spruce/face masks FFP2 | 90/10 | 5.88 ± 0.15 | 22.04 ± 0.33 | 598.73 | 1129.16 |
| Beech | 100 | 5.91 ± 0.03 | 22.15 ± 0.81 | 607.11 | 1199.62 |
| Beech/face masks FFP2 | 95/5 | 5.99 ± 0.05 | 21.07 ± 1.33 | 594.41 | 1078.38 |
| Beech/face masks FFP2 | 90/10 | 5.97 ± 0.03 | 21.47 ± 2.19 | 600.84 | 1163.40 |

## 4. Conclusions

The article deals with the reuse of FFP2 face masks, which were added as an admixture to sawdust and processed into pellets. During the pellet production process, energy consumption was measured, which was converted to one ton of pellets, and finally, the consumption was reflected in the price of electricity. After storage, the mechanical durability and dimensions of the individual pellets were measured, and their density was calculated. Based on the measurements, it is possible to summarize that the production of pellets containing face masks FFP2 requires higher energy consumption than the production of pellets from pure sawdust, which are commonly used. Higher consumption and the price of electricity were represented by pellets from mixtures of spruce sawdust with face masks FFP2 compared to pellets from beech sawdust with FFP2 face masks with lower quality, what could cause problems during transport or combustion. The highest energy consumption and the highest price of electricity were measured during the production of spruce pellets with 5% FFP2 face masks. However, the pelletization process was influenced by weather conditions, the moisture of input materials and by the setting of the pressure of the pellet rollers to the die. Except for the highest energy consumption for the sample of sawdust pellets with 5% FFP2 face masks, which was mainly affected by cold outside weather, samples (spruce pellets with 10% FFP2 face masks and beech pellets with 5% FFP2 face masks) that achieved higher values of mechanical durability also consumed more energy than the remaining samples with lower values of durability. Only these two samples also met the set standard values of mechanical durability according to ISO 17225-2 (2021). The values of mechanical durability could be affected by several factors, such as low temperature in the pellet press during pellet production, high material moisture during production, and thus the subsequent decomposition of samples after being stored in the laboratory, etc. However, all samples met the standardized pellet diameter and length according to this standard. Produced pellets had a density ranging from 1078 $kg \cdot m^{-3}$ to 1200 $kg \cdot m^{-3}$, what is in the line with values of particle density for wood pellets.

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## References


1. Fadare, O.O.; Okoffo, E.D. COVID-19 face masks: A potential source of microplastic fibers in the environment. *Sci. Total Environ.* **2020**, *737*, 140279. [CrossRef] [PubMed]
2. Klemeš, J.J.; Fan, Y.V.; Jiang, P. The energy and environmental footprints of COVID-19 fighting measures e PPE, disinfection, supply chains. *Energy* **2020**, *211*, 118701. [CrossRef] [PubMed]
3. Selvaranjan, K.; Navaratnam, S.; Rajeev, P.; Ravintherakumaran, N. Environmental challenges induced by extensive use of face masks during COVID-19: A review and potential solutions. *Environ. Chall.* **2021**, *3*, 100039. [CrossRef]
4. Taušová, M.; Mihalik, E.; Čulková, K.; Stehlíková, B.; Tauš, P.; Kudelas, D.; Štrba, Ľ.; Domaracká, L. Analysis of municipalwaste development and management in self-governing regions of Slovakia. *Sustainability* **2020**, *12*, 5818. [CrossRef]
5. Mostafa, M.E.; Hu, S.; Wang, Y.; Su, S.; Hu, X.; Elsayed, S.A.; Xiang, J. The significance of pelletization operating conditions: An analysis of physical and mechanical characteristics as well as energy consumption of biomass pellets. *Renew. Sustain. Energy Rev.* **2019**, *105*, 332–348. [CrossRef]
6. Tan, M.; Luo, L.; Wu, Z.; Huang, Z.; Zhang, J.; Huang, J.; Yang, Y.; Zhang, X.; Li, H. Pelletization of Camellia oleifera Abel. shell after storage: Energy consumption and pellet properties. *Fuel Process. Technol.* **2020**, *201*, 106337. [CrossRef]
7. Xia, X.; Zhang, K.; Xiao, H.; Xiao, S.; Song, Z.; Yang, Z. Effects of additives and hydrothermal pretreatment on the pelleting process of rice straw: Energy consumption and pellets quality. *Ind. Crops Prod.* **2019**, *133*, 178–184. [CrossRef]
8. Uasuf, A.; Becker, G. Wood pellets production costs and energy consumption under different framework conditions in Northeast Argentina. *Biomass Bioenergy* **2011**, *35*, 1357–1366. [CrossRef]
9. Larsson, S.H.; Samuelsson, R. Prediction of ISO 17831-1:2015mechanical biofuel pellet durability from single pellet characterization. *Fuel Process. Technol.* **2017**, *163*, 8–15. [CrossRef]
10. Kuranc, A.; Stoma, M.; Rydzak, L.; Pilipiuk, M. Durability Assessment of wooden pellets in relation with vibrations occurring in a logistic process of the final product. *Energies* **2020**, *13*, 5890. [CrossRef]
11. Matúš, M.; Križan, P.; Šooš, Ľ.; Beniak, J. The effect of papermaking sludge as an additive to biomass pellets on the final quality of the fuel. *Fuel* **2018**, *219*, 196–204. [CrossRef]
12. Rezaei, H.; Panah, F.Y.; Lim, C.J.; Sokhansanj, S. Pelletization of refuse-derived fuel with varying compositions of plastic, paper, organic and wood. *Sustainability* **2020**, *12*, 4645. [CrossRef]
13. Jandačka, J.; Holubčík, M.; Malcho, M.; Nosek, R. Modification of wood pellets parameters by using of concentrate of organic compounds from defibration. *Acta Fac. Xylologiae Zvolen* **2013**, *55*, 105–115.
14. Holubčík, M.; Jachniak, E.; Smatanová, H. Differences between pellets from biomass made in manufactory and in domestic conditions. *AIP Conf. Proc.* **2014**, *48*, 1608. [CrossRef]
15. *ISO 15210*; 1 Solid Biofuels—Determination of Mechanical Durability of Pellets and Briquettes—Part 1: Pellets. International Organization for Standardization: Geneva, Switzerland, 2010.
16. *ISO 17225*; 2 Solid Biofuels—Fuel Specifications and Classes—Part 2: Graded Wood Pellets. International Organization for Standardization: Geneva, Switzerland, 2021.
17. Stelte, W.; Holm, J.; Sanadi, A.; Barsberg, S.; Ahrenfeldt, J.; Henriksen, U. Fuel pellets from biomass: The importance of the pelletizing pressure and its dependency on the processing conditions. *Fuel* **2011**, *90*, 3285–3290. [CrossRef]
18. Sonawane, Y.B.; Shindikar, M.R.; Khaladkar, M.Y. High calorific value fuel from household plastic waste by catalytic pyrolysis. *Nat. Environ. Pollut. Technol.* **2017**, *16*, 879–882.
19. Nosek, R.; Holubčík, M. Energy properties of air dry firewood. *Acta Fac. Xylologiae Zvolen* **2016**, *58*, 105–112. [CrossRef]