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Effects of microwave drying on moisture content depending on wood chip size distribution †

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Abstract: Pine, birch, and cotoneaster wood chips were segregated and exposed to microwave radiation. Moisture content was measured before and after microwave treatment, and the surface temperature of wood chip samples was recorded. The results showed that due to the selective nature of the process, the duration of microwave radiation should be adjusted taking into account the size fraction of the examined material. Wood chips exposed to microwaves for more than 30 s heated up to over 100°C. Finer wood chips were found to lose moisture more slowly.

Keywords: wood chips, drying, microwaves, separation, moisture

1. Introduction

In its guidelines on renewable energy sources, the European Union makes it obligatory to implement sustainable biomass management. Biomass is the only renewable energy resource that can be utilized in three ways: via combustion, pyrolysis, and gasification. Woody biomass can be converted into wood chips, which constitute an excellent fuel for furnaces and boilers. However, their utilization for energy purposes can be hindered by their moisture content, which mostly depends on the harvest period and storage conditions. The moisture content of fresh biomass may exceed 100% [1], practically preventing combustion. Currently, the most widespread biomass drying technologies include rotary, conveying, fluidized bed, and pneumatic dryers, while microwave drying has been less popular [2]. Microwaves are commonly used in wood industry to disinfect wood [3,4], while attempts to use microwaves for drying wood and wood-based products were made by Wang et al. [5], Du et al. [6], Hong-Hai et al. [7]. On the other hand, there has been a growing interest in microwave use for industrial purposes, in addition to the traditional applications in telecommunication and radiolocation.

The advantages of microwaves include the selective delivery of radiation as well as the ease of drying automation and control. This enables shorter process times leading to savings at zero net greenhouse gas emissions [8]. These advantages encourage checking the effect of microwaves on wood chips, because current combustion technologies require the use of wood chips with a moisture content less than 30% enabling their effective combustion.

The objective of the study was to determine the drying effects of microwave radiation on wood chips. Investigations encompassed the characterization of wood chips including size distribution, as well as the determination of their initial moisture content, surface temperature during microwave irradiation, and final moisture content.

2. Materials and Methods

The study involved wood chips (a mixture of bark and wood) produced in the fall of 2018 from Scots pine (*Pinus sylvestris L.)*, silver birch (*Betula pendula Roth.)*, and shiny cotoneaster (*Cotoneaster lucidus* Schltdl.*)* using a Vermeer BC150 chipper coupled to a farm tractor. The wood chips came from pruning (approximately 20-year-old trees and shrubs). Before the test, the chips were stored in piles on an open surface for two weeks. The obtained chips were then separated into size fractions using a Łukomet separator (Łukomet, Całowno, Poland) [9](Fig. 1).

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

Figure 1. Łukomet separator and fractionated samples: (**a**) screen separator with round openings conforming to PN-ISO 565:2000 and PN-ISO 3310-2:2013; (**b**) pine chip size fractions.

The wood chips were separated into size fractions using screens with 3.15 mm, 8 mm, 16 mm, 31.5 mm, 45 mm, and 63 mm round openings consistent with the standards PN-ISO 565:2000 [10] and PN-ISO 3310-2:2013 [11] (the bottom fraction was also used). Five 10 L batches of wood chips were separated for each species over 120 s with an accuracy of 1 s. Individual fractions were weighed on a RADWAG WPS 600/C balance. The 16 mm, 8 mm, 3.15 mm, and bottom fractions were exposed to 800 W microwave radiation for 30 s, 60 s, and 90 s in a SHARP R-200 oven. After each irradiation, the wood chips were weighed, and at the end of the experiment they were placed in a Heraeus UT 6120 circulating air oven and dried at 105°C for 24 h to determine dry mass. The recorded masses of wood chips were used to calculate their moisture content. Selected samples were photographed using a VIGOcam v50 thermographic camera to determine their temperature (±0.1°C) during exposure to microwaves. The resulting images were processed with VIGO System Thermal software.

3. Results

The percentage shares of the various size fractions of wood chips from the three tested tree and shrub species are given in Table 1, while an image of segregated pine chips is shown in Fig. 1b. The percentage share of the >63 mm fraction was the lowest for all species (from 0.2% to 1.3%), while the fractions with the highest shares were 16–31.5 mm for pine chips (45.7%), 8–16 mm for birch chips (51.1%), and 3.15–8 mm for cotoneaster chips (52.4%).

Table 1. Size distribution of pine, birch and cotoneaster chips.

Screen no.	Particle size mm	Pine chips %	Birch chips %	Cotoneaster chips %
1	0 – 3.15	2.8	5.1	15.2
2	3.15 – 8	9.3	29.4	52.4
3	8 – 16	21.5	51.1	26.5
4	16 – 31.5	45.7	12.3	4.7
5	31.5 – 45	14.1	1.1	0.9
6	45 – 63	5.3	0.8	<0.1
7	> 63	1.3	0.2	0.3

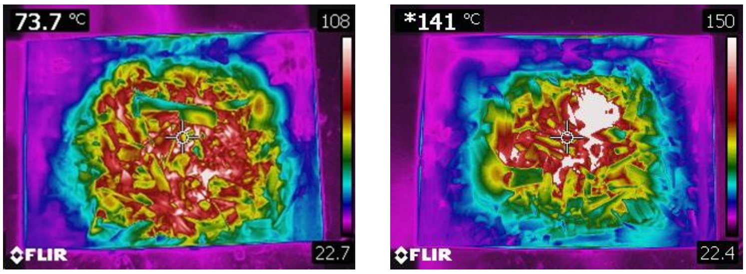
The mean initial moisture content of was 70.8% for pine chips, 37.3% for birch chips, and 39.7% for cotoneaster chips. The values obtained after microwave irradiation are given in Table 2.

Table 2. Moisture content (%) of pine, birch, and cotoneaster chips before and after irradiation.

Screen size	Time	SP			BI			SC		
mm	s	B	A	D	B	A	D	B	A	D
16	30	68.8 ±2.1	64.6 ±1.8	4.2	33.3 ±0.7	30.2 ±0.7	3.2	27.3 ±4.7	18.0 ±4.8	9.3
	60	69.0 ±2.7	47.8 ±1.6	21.2	37.5 ±2.6	24.9 ±2.6	12.6	28.5 ±1.0	16.6 ±2.3	11.9
8	30	75.7 ±4.1	71.6 ±3.4	4.1	35.7 ±1.0	33.1 ±1.7	2.6	33.5 ±1.5	31.1 ±0.1	2.4
	60	72.0 ±13.3	51.6 ±10.4	20.3	29.9 ±0.9	16.6 ±1.3	13.3	38.3 ±0.9	25.2 ±0.6	13.1
3.15	30	68.8 ±15.0	66.3 ±14.3	2.5	37.1 ±5.0	34.9 ±4.3	2.3	37.5 ±0.5	35.7 ±0.1	1.8
	60	81.4 ±6.7	61.0 ±5.3	20.4	40.9 ±1.9	31.5 ±0.8	9.4	40.0 ±3.2	28.3 ±2.0	11.7
	90	81.0 ±7.1	46.0 ±5.5	35.1	43.9 ±2.5	22.3 ±3.5	21.6	42.4 ±0.1	18.9 ±2.0	23.4
botton	30	59.7 ±1.7	57.5 ±1.5	2.2	39.8 ±3.2	38.9 ±2.7	0.9	49.8 ±2.6	48.4 ±2.3	1.4
	60	56.2 ±4.8	35.6 ±4.1	20.6	38.9 ±1.2	29.0 ±0.9	9.9	50.5 ±1.6	40.0 ±1.3	10.5
	90	54.7 ±6.2	23.1 ±3.3	31.6	30.7 ±2.2	12.5 ±0.7	18.2	52.7 ±0.7	29.5 ±0.5	23.2

SP – Scots pine (*Pinus sylvestris*), SB – silver birch (*Betula pendula*), SC – shiny cotoneaster (*Cotoneaster lucidus*), B – before irradiation, A – after irradiation, D – B–A difference

Following the microwave irradiation of 8–16 mm and 3.15–8 mm fractions for 30 s no significant differences in moisture content were found between pine and birch chips, while cotoneaster chips did differ significantly from the other two species. The 3.15 mm and bottom fractions revealed lower moisture content as compared to the 16 mm fraction. A 60 s exposure of 16 mm, 8 mm, and 3.15 mm fractions did not lead to any significant differences in moisture content between the studied species. The greatest loss of moisture was obtained for 90 s exposure of 3.15–8 mm and bottom fractions of pine chips.



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

Figure 2. A view of pine chips after exposure to microwaves for: (**a**) 30 seconds, (**b**) 90 seconds. Sample photos taken with a thermal imaging camera.

The >16 mm fractions were heated up to approx. 90°C after 30 s of exposure and to approx. 120°C after 60 s, with the corresponding average values for the finer fractions being 70°C and 80°C (Fig. 2a). Finally, the bottom fraction of pine chips (<3.15 mm) heated up to over 130°C (Fig. 2b).

4. Conclusions

The overall percentage share of wood chip fractions from screens no. 1–4 ranged from 79% (pine) to 99% (cotoneaster) of total wood chips by mass. The study indicates that due to the selective nature of the process, the duration of microwave irradiation should be adjusted taking into account the size fraction of wood chips, with some fractions heating up to over 100°C. Importantly, the finer fractions lose moisture more slowly. A comparison of images recorded with a thermographic camera showed that temperature differences within individual samples decreased with increasing sample homogeneity.

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