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The impact of mechanical pre-treatment of wood biomass on drying rate

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The work presents the process of drying wood biomass after pre-treatment involving either debarking or crushing. The biomass used for research came from a robinia species wood. The material was dried in free-convection, at the drying medium temperatures of 40, 50, 60, 70 and 80 °C, respectively. Pre-treatment proved to have a significant impact on the drying rate, including the time required to reach moisture content of 10%, essential to start further treatment of biomass for power industry purposes. It was found that debarked samples of robinia lost water more quickly than the crushed ones. Samples that did not undergo pre-treatment took the longest time to dry.

Keywords: renewable resources of energy, biomass, robinia, drying, pre-treatment

1. INTRODUCTION

In the age of continuous technological progress demand for electrical energy and heat, which requires finding new sources of energy and power, increases rapidly. Due to the specificity of climate in Poland, as well as natural conditions and farming traditions, the most important renewable resource of energy is biomass, including straw, industrial waste, sewage sludge, manure, liquid manure, as well as agricultural production waste, wood and fuel plants (Gołuchowska et al., 2015; Niedziółka et al. 2014). At present, wood is the most commonly used type of biomass in Poland, this being connected with the forest potential of the country and a large area of wasteland, where fuel plants may be grown. Willow is the species that first attracted attention as a source of energy. Drying is the most energy-intensive and time-consuming component of the wood preparing process (Li et al., 2008). This is process that takes about 20% of the total energy used in the industry. Restrictive regulations about sustainable development and rising energy costs make researchers search for more effective ways of drying, such as modernizing equipment and modification of the process (Kowalski and Pawłowski, 2010). However, due to high water requirements, it is recommended to grow willow on waterlogged or periodically flooded areas. Drought results in the decrease in yield by up to 50% (Szczukowski and Budny, 2003). Therefore, this plant should not be recommended for growing as a fuel plant in Poland, a country with very low groundwater reserves. Instead, alternative species of fuel trees have been searched for, and, consequently, interest in robinia (*robinia pseudacacia*) has increased in recent years, as this tree has very low climatic needs, and may be grown on soils poor in nutrients. This tree grows very fast, producing numerous shoots and sprouts difficult to remove. The heating value of robinia is comparable to that of willow or poplar, while having lower moisture content. Special features of this species are its drought tolerance and its ability to fix nitrogen.

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The results also show that the cultivation of R. pseudoacacia is economically competitive compared to other species (Grünewald et al., 2009).

Investigation of drying kinetics is one of the best methods to get sufficient information about drying performance. Experimental data from the drying curves can be used in simulation of wood particle drying to optimize the production process (Zarea-Hosseinabadi et al., 2012; Madaleno et al., 2017). To obtain fuel material characterized by sufficiently high heating value from wood biomass, drying in natural conditions or in a drier is often required. When forced condition drying technology is applied, heated air or a mixture of air and exhaust gases is used as a thermodynamic medium. The medium passes with a certain velocity through the bed of the material being dried, and removes water from the material. The efficiency of this process depends on the value of mass transfer potentials in the process of convective drying and on the structure of the material being dried. In case of wood biomass, the method of preparation of wood pieces for drying is extremely important (Głowacki et al., 2008). Wood is a material vulnerable to cracking during drying. The timber is using various drying techniques, the most common is convection under different conditions, or different methods of pre-treatment of the material (Gu, 2007; Minea, 2008). A study conducted in Finland, Italy and Scotland shows that barked or partially barked wood biomass dries faster than that which has not been previously prepared. The shoots to be dried will lose moisture more efficiently when bark is removed (Röser et al., 2011). Therefore in order to shorten drying time, and, simultaneously, decrease drying cost, wood undergoes pre-treatment, i.e. mechanical treatment including fragmentation, debarking and damaging internal structure of the material by crushing.

2. AIM AND SCOPE OF RESEARCH

The disadvantage of biomass, including wood biomass is large diversity of its properties. Knowing at least the moisture content, which the fuel value of biomass depends on, conditions its rational use as a fuel. So far, no norms or reference methods of measurement have been established for these properties. The values of the above mentioned properties of wood biomass found in literature vary greatly e.g. wood biomass with the moisture content ranging between 10 and 60% has the heat value between 6 and 17 $\mathrm{MJ \cdot kg^{-1}}$ while the heat value for dried biomass is equal 19 $\mathrm{MJ \cdot kg^{-1}}$ (Niedziółka and Zuchniarz, 2006). Also, no precise classification of various types of technologically used wood biomass exists, that would explicitly give the name of each class. Usually, they are simply called chips, sawdust and bark, with no distinctive characteristics being provided.

Therefore, the aim of the research was to define the impact of selected mechanical pre-treatment on the drying process of samples of homogeneous wood biomass. In this work, the general aim of research was limited to the studied material, i.e. three-year-old shoots of robinia, and to convective drying using air heated to the temperature ranging from 40 to 80 °C, without forced flow of air. Kinetics of drying samples made of pieces of shoots that did not undergo mechanical pre-treatment, as well as debarked pieces and pieces crushed in such a way so as not to cause cracks and additionally pieces of bark was examined.

3. METHODOLOGY OF RESEARCH

The subject of the research was robinia (*robinia pseudacacia*), also known as false acacia or black locust. Robinia is native to Northern America and USA, and was brought to Europe at the beginning of the 17th century (Kościk, 2003). Numerous studies on robinia confirm the existence of about 20 varieties of this species. Robinia is a tree found almost everywhere – in gardens, parks, forests, and even along the roads.

3.1. Description of research material

Three-year old shoots of robinia, from a wild roadside cluster of trees were used for research. The collected shoots, 0.25-metre-long each, were put into groups of five, with similar diameters (±0.003 m), followed by preparation of homogeneous samples for research, according to the following procedure:

- shoots were cut into 0.05-metre-long pieces,
- each sample consisted of 5 pieces, each of which was cut from a different shoot, samples were prepared as shown in Table 1,
- samples were put into hermetic plastic bags and stored at the temperature of 5 °C to prevent natural loss of moisture.

Table 1. Preparation of samples from labelled pieces of 5 shoots

	Labelling pieces of shoots				
	shoot 1	shoot 2	shoot 3	shoot 4	shoot 5
Sample a	1e	2b	3c	4d	5a
Sample b	1a	2e	3b	4c	5d
Sample c	1d	2a	3e	4b	5c
Sample d	1c	2d	3a	4e	5b
Sample e	1b	2c	3d	4a	5e

The samples were pre-treated immediately prior to drying. Fig. 1 shows photos of the samples.

a) b) c)

Fig. 1. Samples: a) debarked, b) crushed, c) no pre-treatment

3.2. Description of the equipment and measurements

The equipment consisted of a convective drier UNB 400 produced by Memmert, two electronic scales WPX 650 produced by Radwag and a computer with dedicated software for recording the weight of samples. The material was placed on two three-segment scale pans so as the pieces of wood in samples did not come into contact with each other. Prepared samples of robinia were dried at five temperatures of the drying medium, namely, 40, 50, 60, 70 and 80 °C, and changes in the weight of samples were recorded every 5 minutes. Dry mass of robinia was determined after drying the sample at the temperature of 105 °C, in accordance to PN-77/D-04100.

4. DISCUSSION OF RESEARCH RESULTS

The results of measurements of weight changes during drying were converted into water content with respect to drying time using the following formula:

$$u(\tau) = \frac{M(\tau) - M_s}{M_s} \quad \frac{\text{kg H}_2\text{O}}{\text{kg s.s.}} \tag{1}$$

Figure 2 shows the initial water content in the examined samples following pre-treatment and for samples not subjected to pre-treatment.

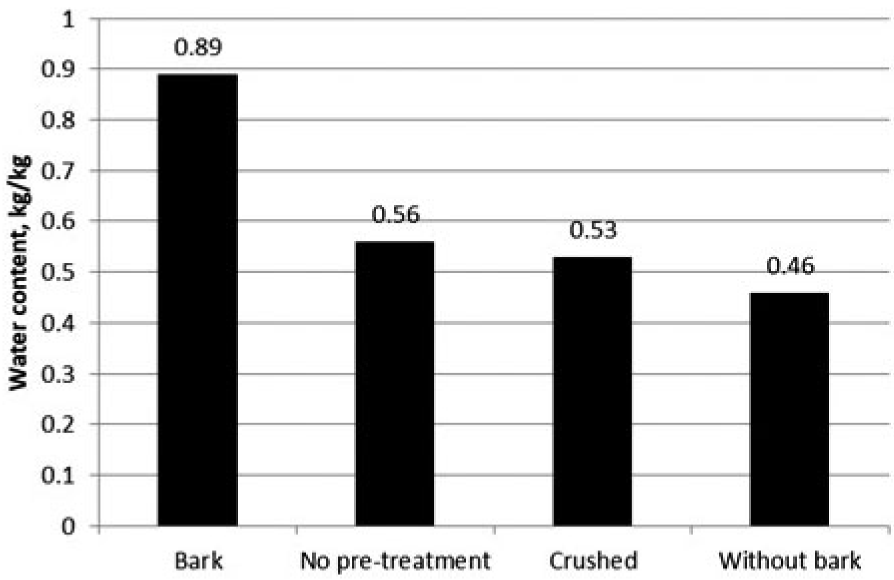

Fig. 2. Initial water content in the examined samples

Based on the performed examinations, it was found that the initial water content in the bark was twofold compared with debarked shoots. However, bark weight share in the total weight of the shoot and its large surface should result in the difference between drying times of debarked shoots and shoots with bark not being very significant, which would require empirical confirmation.

A set of water content-time data was recorded in an experiment. Such a drying curve is one of the most popular methods of processing data associated with drying (Kemp et al., 2001). The results of measurements concerning drying kinetics of robinia, subject to different pre-treatments, were presented in the form of graphs below.

By comparing graphs showing the kinetics of drying bark, a conclusion may be drawn that the higher temperature of the air, the markedly smaller the equilibrium water content for the material dried in the laboratory drier. For the temperatures of 40 and 50 °C, the drying process practically stopped when the water content reached a value of approx. 0.1 kg/kg, while at higher drying temperatures, the equilibrium water content may be smaller by one order of magnitude and amounts to approx. 0.01 kg/kg. It may also be observed that when drying bark at 80 °C, changes in the water content attained stability after first 200 minutes, while at the lowest applied temperature, i.e. 40 °C, it took as long as approx. 1300 minutes for the process of changes to end.

The process of drying debarked robinia takes much longer than drying bark. Figure 4 show that for the temperature of the drying medium of 80 °C, water content stabilizes after approx. 1200 minutes of drying,

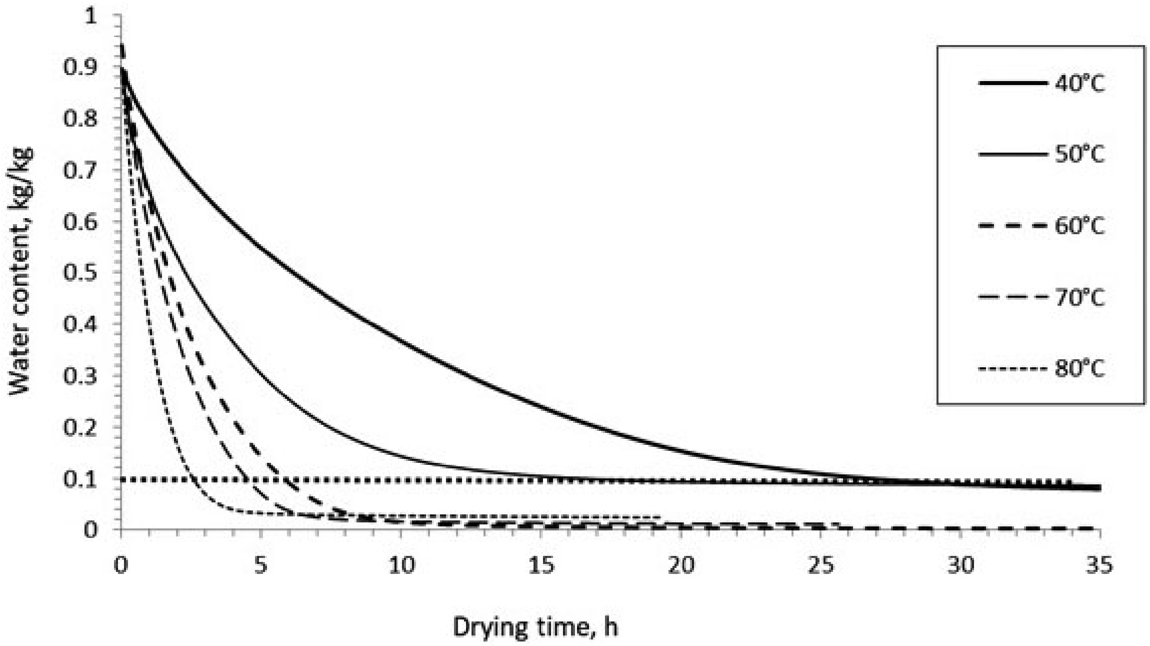

Fig. 3. Changes in the water content in the bark during drying with air heated to the temperatures of: 40, 50, 60, 70 and 80 °C

and for the 40 °C after approx. 4800 minutes. Doubling temperature results in drying time shortened four times. The equilibrium water content for debarked pieces of wood, dried under the laboratory conditions using air heated to 40 °C was twice smaller than that for the bark.

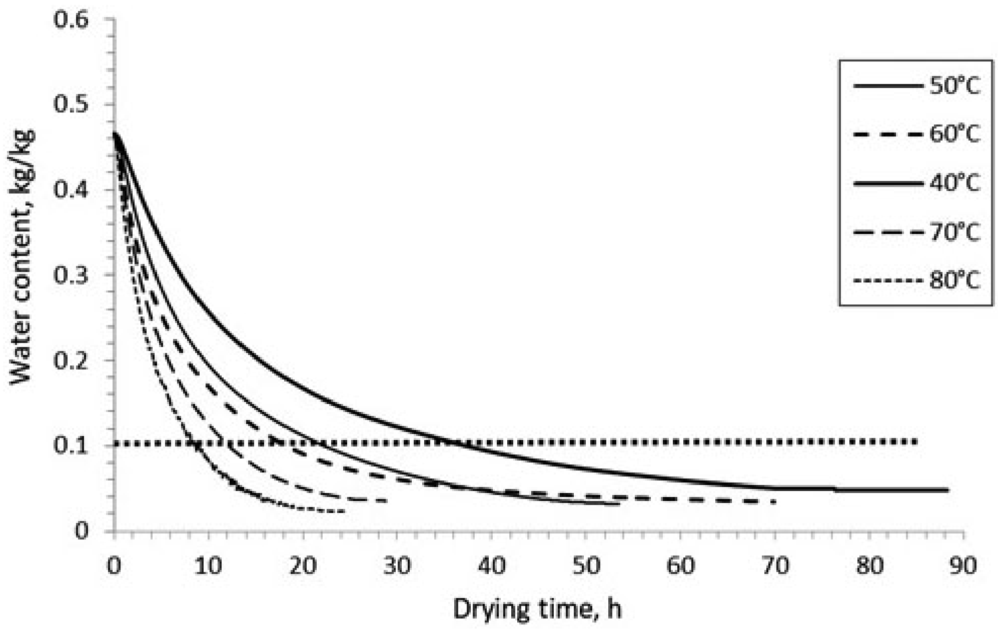

Fig. 4. Changes in the water content in debarked shoots of robinia during drying with air heated to temperatures of: 40, 50, 60, 70 and 80 °C

Drying curves presented in Fig. 5 prove that drying process of shoots that were not pre-treated takes the longest. It is approx. 8500 minutes for a sample to reach the equilibrium water content at the drying temperature of 40 °C, while at 80 °C it takes approx. 6100 minutes shorter to obtain the same result. The values of the equilibrium water content for not pre-treated shoots and for bark are similar.

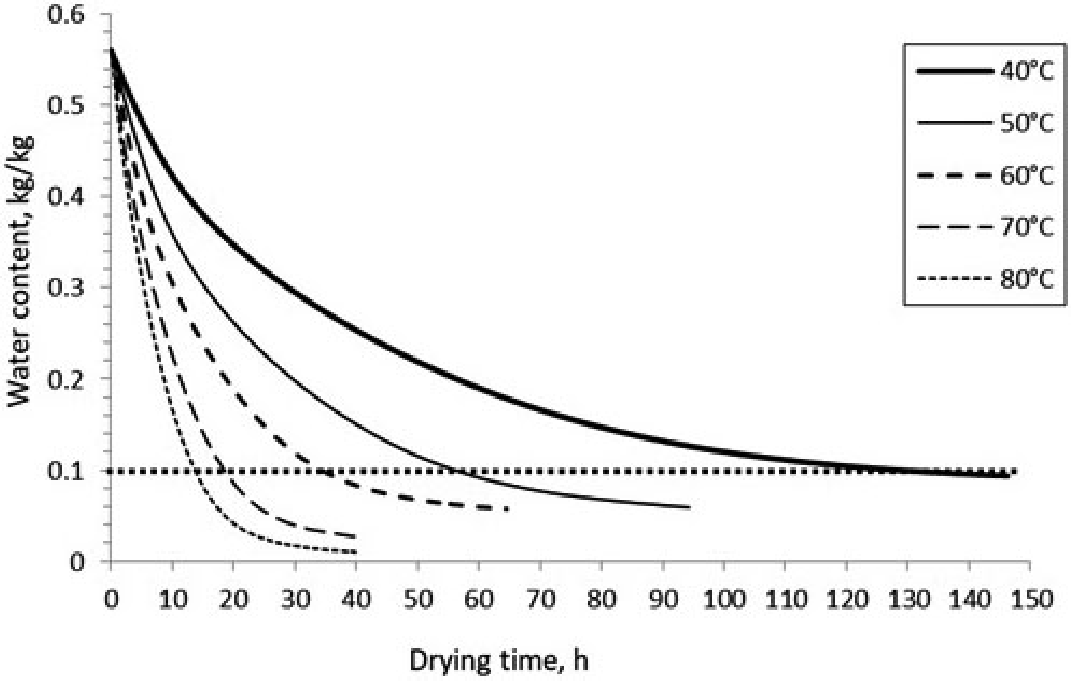

Fig. 5. Changes in the water content in shoots of robinia that did not undergo pre-treatment during drying with air heated to the temperature of: 40, 50, 60, 70 and 80 °C

The second type of pre-treatment involved crushing the shoots so as the cracks of the internal structure of the shoots were visible. As a result of crushing, the continuous structure of the bark of the shoots was damaged. Shoots, damaged to a similar degree, were selected for the purpose of the research.

The graphs showing the kinetics of drying shoots with a damaged internal structure show that the drying process begins to stabilize just after approx. 1800 minutes from the start of the experimental run at the temperature of 80 °C, while at 40 °C it takes almost 5 times longer, approx. 8400 minutes. Drying curves for crushed shoots with bark show that the equilibrium water content reached by the samples examined in the laboratory conditions are smaller than for the bark or debarked shoots.

Wood biomass used as a source of renewable energy is transformed into heat energy or electricity energy (Jin and Sutherland, 2018). The most common method of obtaining heat from wood is burning (Dudek et al., 2008). Both unprocessed and processed biomass, the latter in the form of chips, pellets and briquettes, may be used for that purpose. In order to obtain high quality fuel from wood biomass, the relative moisture of the wood must be as low as approx. 10%, which is an equivalent of the water content of approx. 0.1 kg/kg. Therefore, in Figs. 3, 4 and 5, where the process kinetics have been depicted, a broken line was marked that corresponds to biomass with 10% moisture content, recommended by energy producers and theoreticians of combustion processes. The line is also useful in reading the drying times required for the samples to reach the 10% moisture content as shown in Fig. 7.

Samples that did not undergo pre-treatment take the longest time to dry irrespective of the temperature of the drying medium, while the samples of crushed robinia shoots take shorter to dry at all temperatures. Debarked samples of robinia take the shortest time to dry. Although the samples of robinia bark had the highest initial water content (Fig. 2), drying took quite a short time compared with other samples, which can undoubtedly be attributed to twice as large surface of the bark removed from the shoots, in comparison with the surface of the bark on the shoots. It may also result from the porous internal structure of the bark, which gives up water more easily than the capillary structures of the shoots, which have relatively small surface of intensive mass exchange – cross-sections of shoots.

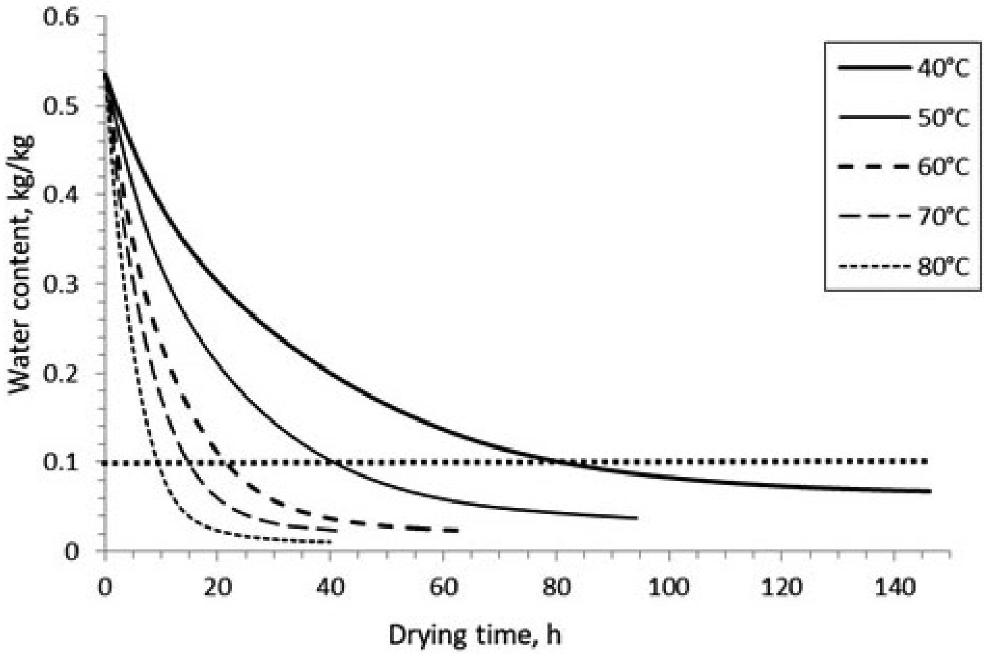

Fig. 6. Changes in the water content in crushed shoots of robinia during drying with air heated to the temperature of: 40, 50, 60, 70 and 80 °C

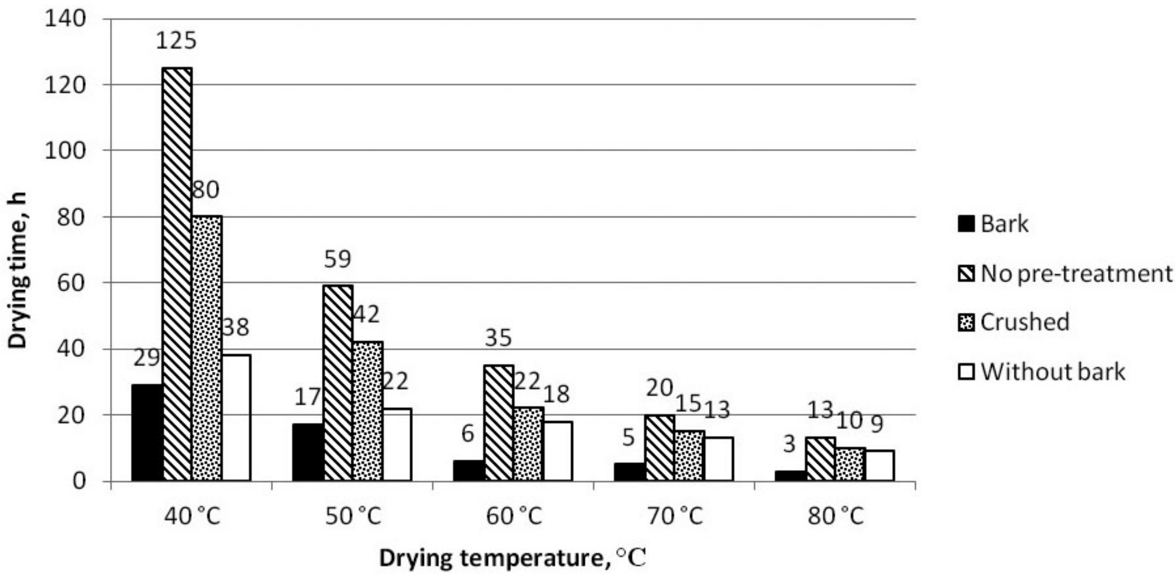

Fig. 7. Graphical comparison of drying times of robinia samples relative to drying temperature, needed to reach the 10% relative moisture by the samples, in the free convection conditions

5. CONCLUSIONS AND RECOMMENDATIONS

Based on the examination of the process of convective drying of robinia shoots, and the comparison of results for mechanically pre-treated samples, conducted in the laboratory, the following conclusions can be formulated:

- Mechanical pre-treatment of robinia shoots has an impact on the kinetics of drying.
- Bark of robinia has higher initial water content – 0.9–0.95 kg/kg, in comparison with the average water content in debarked shoots – approx. 0.47 kg/kg. Crushed and not crushed shoots have comparable initial water content amounting to approx. 0.55 kg/kg.

- Debarked shoots of robinia take the shortest to dry, followed by crushed shoots with bark. Shoots that did not undergo pre-treatment take the longest time to dry.
- Time of drying required for the debarked shoots to reach the equilibrium water content at the temperature of 40 °C, is 50% shorter compared with time of drying crushed shoots or not pre-treated shoots.
- Time of drying required for the crushed shoots to reach the equilibrium water content at the temperature of 70–80 °C, is approx. 30% shorter compared with time of drying not pre-treated shoots.
- Wood biomass obtained from robinia has properties similar to those obtained from other species of deciduous trees. However, it differs in terms of the values of these properties. Therefore, further research involving this product should be continued, in order to optimize its use for power industry purposes.

SYMBOLS

$M(\tau)$ sample weight changing in time τ of drying, min
M_s dry weight of a sample, kg
u water content, $\dfrac{\text{kg H}_2\text{O}}{\text{kg s.s.}}$
τ drying time, min

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