INFLUENCE OF MISCANTHUS BIOMASS TORREFACTION PARAMETERS TORREFIED PRODUCT QUALITY CHARACTERISTICS

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Abstract. Biomass energy is an important area of renewable energy. However, the efficient use of raw biomass for energy purposes does not always have the desired effect, so there is a need for biomass processing. One of the ways to improve the fuel characteristics of biomass is its torrefaction. Torrefaction allows to obtain fuel with a high energy density, which in energy terms will be close to coal. This retains most of the benefits of burning biomass over fossil fuels. There is no universal way to determine the optimal modes of heat treatment of biomass, so the study of effective methods and parameters of torrefaction for individual crops continues today. This paper investigates the influence of different regimes of heat treatment of Miscanthus Giganteus biomass on the fuel characteristics of the torrefied product and the changes that occur in the biomass. The research was conducted at the research facility for torrefaction in the educational and scientific laboratory "DAK GPS" of the higher educational institution "Podillia State University". The method of heat treatment in a static layer was used, which eliminates the influence of side factors on the process of torrefaction. Regularities between the initial parameters of raw biomass, selected modes of torrefaction and the characteristics of the final product are established. The results of these studies will allow to develop a system of recommendations for optimally balanced and energy efficient production of torrefied product from biomass of Miscanthus Giganteus. The research has established that the optimal temperature for torrefaction of Miscanthus Giganteus biomass can be considered 250-300 ºC.

Keywords: Miscanthus Giganteus, torrefaction, torrefied product, torrefaction parameters, biomass energy.

Introduction

The world is paying more and more attention to finding ways to use alternative energy. The world community is making significant efforts to slow down the rate of increase in the average annual temperature by reducing greenhouse gas emissions in the second half of the 21st century to a level that nature can process without harming itself. To this end, it is expected to attract $ 100 billion annually to replace traditional energy sources with renewable ones, among which a significant place is occupied by bioenergy [1].

Energy production from biomass is for many countries one of the best alternatives to fossil fuels. The raw materials for production of solid biofuels are mainly wastes from the woodworking industry (sawdust, wood chips), straw from cereals and legumes, sunflower husk. The supply of such raw materials is unstable and seasonal, which negatively affects the efficiency of solid biofuel plants. Therefore, special attention should be paid to the supply of raw materials for solid biofuels by growing new species of high-yielding trees and perennials, which will allow to obtain a given amount of biomass of the required quality [2].

One of such popular crops is Miscanthus Giganteus, which shows a high potential for biomass collection per unit area under different growing conditions. However, due to the fact that raw miscanthus biomass has the same disadvantages as any other biomass (high humidity, heterogeneous structure, low density, etc.), new methods are being developed to improve the properties of biofuels, such as: grinding, drying, pressing, etc. One of the most effective methods to increase the efficiency of solid fuels today is pre-torrefaction - heat treatment without access to oxygen [3-8]. Such processing is carried out in an oxygen-free environment at a temperature of 200-300 ºC. As a result of torrefaction, biomass improves its fuel properties and acquires a number of positive qualities, such as hydrophobicity, reduction of smoke and odors, absence of aggressive substances, reduced emission of greenhouse gases, etc [9; 10].

The process of torrefaction has recently been of interest to many scientists. Some of the works are aimed at studying the kinematics and dynamics of changes in the process of such heat treatment [3; 7; 9; 11-13], others are engaged in the search for optimal ways of carrying out such process [7; 14-16], many works are also devoted to assessment of emerging risks [16-18] and other aspects of thermal processing of biomass. Separately, it is possible to note scientific developments in the field of research on torrefaction of certain crops [4; 6; 10; 17; 19; 20]. The last question is the broadest and remains understudied due to the wide variety of possible biomass. The purpose of this study is to deepen knowledge about torrefaction of such common energy crop as Miscanthus Giganteus.

Materials and methods

The work was carried out on the basis of the educational and scientific laboratory “DAK GPS” of the higher educational institution “Podillia State University” [21-24]. The laboratory specializes in issues of assessing the energy use potential of agricultural and energy crops.

This work is designed to continue previously conducted studies of the bionergetic potential of Miscanthus Giganteus and factors affecting its growth. In it, the authors offer the results of the research on improving the properties of miscanthus biomass through its fuel properties, and also study the issue of transformations in the middle of the material.

Research with Miscanthus Giganteus was carried out in several stages. At the initial stage, the peculiarities of the formation of bioenergetic productivity of the plants depending on the timing of planting and the depth of rhizome wrapping were studied. The purpose of this work is to research the features of the process of biomass torrefaction and study of primary signs of changes in the biomass of Miscanthus Giganteus at different temperatures. To study torrefaction from the material of previous studies [25] samples were formed for torrefaction (Fig. 1a). Samples after one year of storage under a canopy were used as raw materials for the study of Miscanthus Giganteus torrefaction. The stabilized humidity of such raw materials was 9.1%. The material was not further dried.

For torrefaction of the prepared biomass, the conveyor installation for torrefaction was used (Fig. 1b). The installation allows to minimize the mechanical impact on the investigated material, and the uniformity of heating was ensured by limiting the size of the material layer to 4…5 cm. The torrefaction time was regulated by the conveyor speed, and it was 12 ± 1 min. To regulate and maintain the set temperature, the unit is equipped with temperature sensors and control automation, which, taking into account the inertia of the furnace, provided the temperature in the middle of the chamber with a deviation of ± 6 ºC.

a) b)

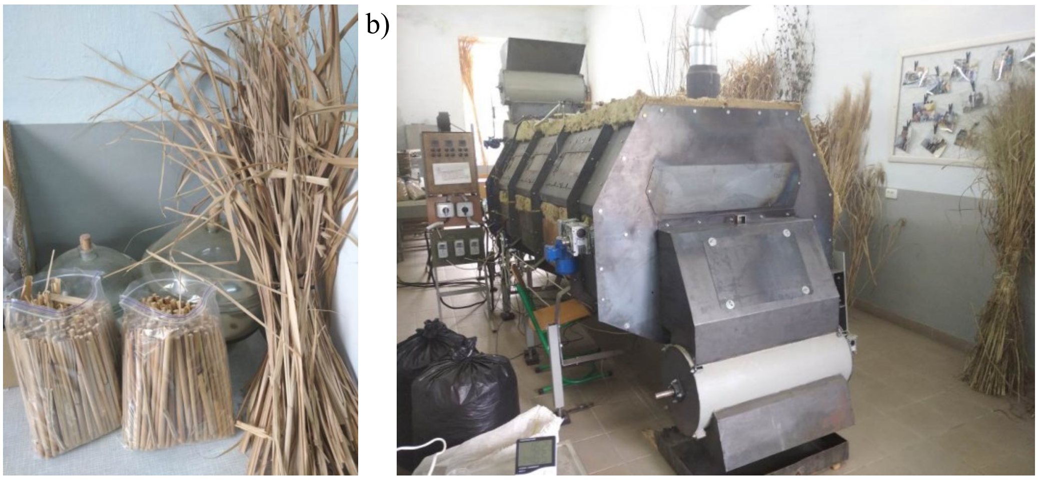

Fig. 1. **Materials and conveyor installation for biomass torrefaction:**
a – samples of raw materials; b – conveyor installation

Experiments with torrefaction included determination of qualitative and quantitative changes in different modes. There was a study of weight loss with a gradual increase in the temperature. The materials were subjected to heat treatment at temperatures of 180, 200, 220, 240, 260, 280, 300 ºC.

The material was miscanthus, the harvest of 2018, which was stored all season under a canopy on the street. Samples of miscanthus were taken and the humidity was determined by the previously defined method, which amounted to 9.09%.

Changes in the material were evaluated by weighing on laboratory scales and comparing the obtained values with the value of the source material.

Based on the weight loss of the tested samples of material M_0 at the appropriate torrefaction temperatures for the specified dry matter M_1, the weight loss caused by torrefaction in the biomass of miscanthus was calculated by the formula:

$$u = \frac{M_0 - M_1}{M_0} \cdot 100\% \quad (1)$$

where M_0 – mass before torrefaction, g;
M_1 – mass after torrefaction, g.

Results and discussion

When processing biomass at temperatures of 200-300 ºC is torrefaction, which is characterized by the degradation of the organic structure of the substance and the release of volatile products, which determines the mass loss of raw materials during processing.

This process significantly improves the quality, technological, ecological, logistical, and other properties of raw materials and allows the use of widely available plant biomass as a solid fuel.

Currently, various aspects of torrefaction are being actively researched by scientists from different countries. A significant role is given to the study of the change in the specific heat of combustion of torrefied fuel, the study of the change in the hygroscopicity of the product under the action of torrefaction, and the analysis of the change in the internal structure of such a product [12; 13; 16; 20; 26; 27].

One of the main criteria for evaluating the quality of a torrefied product is the specific body of combustion. During torrefaction, the known values of this indicator lose their relevance, since such processing releases volatile non-combustible substances from the product and transforms carbon compounds into easier-to-burn forms. Therefore, these specific energy values usually increase.

Analysis of the change in the specific heat of combustion in the torrefaction process [9; 13; 20] is usually carried out according to thermogravimetric curves. Usually, two peak values characteristic for a specific raw material are distinguished on such curves. The first peak is characterized by the completion of the process of removing moisture from the material as a result of drying. After that, there is a sharp change in the direction of the curve, which indicates the beginning of the process of internal transformations (in particular, hemicellulose) and corresponds to the process of torrefaction.

The relative weight loss expressed as a percentage for the studied samples of Miscanthus Giganteus are shown in Table 1.

Table 1

Relative weight loss of the stalks of Miscanthus Giganteus depending on the temperature of torrefaction

Samples	Torrefaction temperature, ºC						
	180	200	220	240	260	280	300
Miscanthus Giganteus	10.00	10.00	11.67	11.67	28.33	31.67	40.00

The results of the study are presented graphically in Fig.2.

Figure 2 shows the thermogravimetric torrefaction curve of Miscanthus Giganteus compared to some other crops. It can be seen from the figure that the dynamics of mass reduction under the influence of temperature changes is similar for different types of biomass. At the initial stage, the curves change their direction very weakly due to the fact that physical and mechanical moisture has already been removed at temperatures of about 100C, and the torrefaction process has not yet begun. For Miscanthus Giganteus, this process lasts a little longer than for other cultivated crops and ends at a temperature of about 240 ºC. At this stage, this curve is kept at the indicator determined by the initial moisture content of the biomass.

Further, the curve becomes quite steep, which characterizes the beginning of the internal destruction of organic compounds of biomass (primarily hemicellulose), which are destroyed at such temperature and the release of released volatile substances.

The next peak characterizes the return of the curve to a flat form, which indicates the completion of internal transformations. For Miscanthus Giganteus, this peak corresponds to 285-290 ºC. The temperature range at which a sharp loss of mass occurred can be considered the optimal mode of torrefaction of each specific raw material and for Miscanthus Giganteus this range reaches 250-300 ºC.

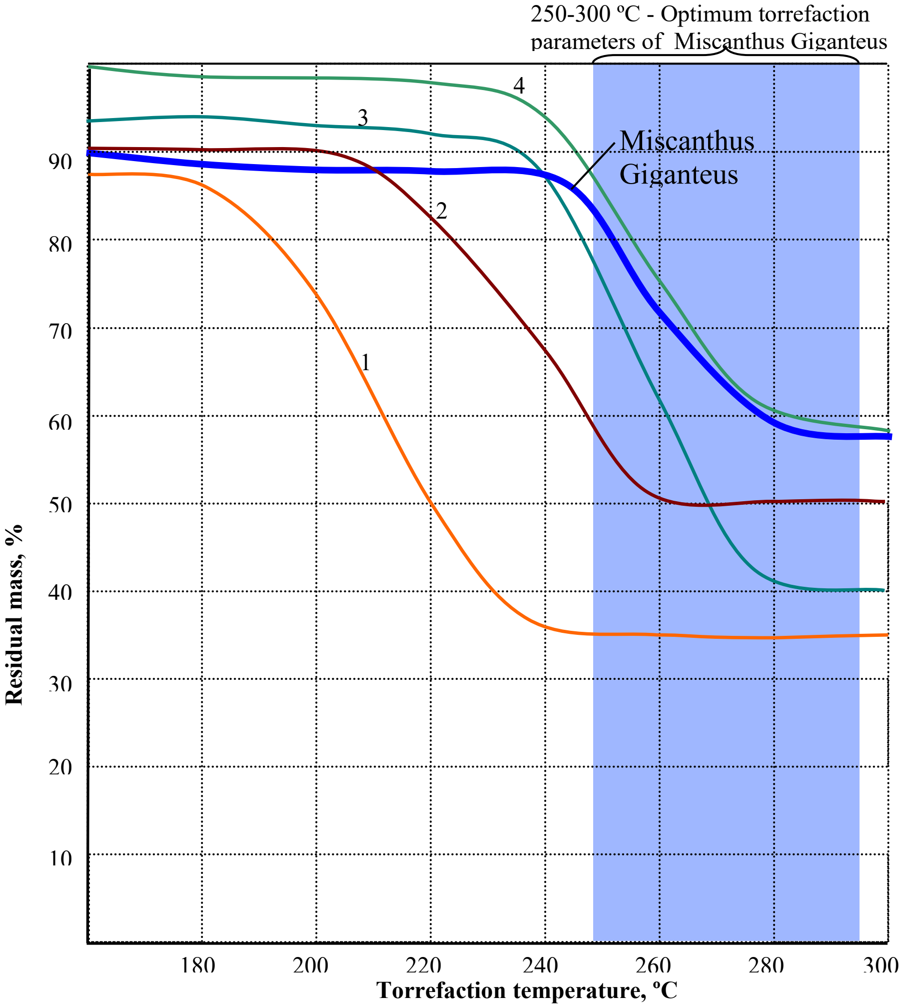

Fig. 2. **Dependence of residual mass on the temperature of torrefaction in comparison with some other crops:** 1) barley (straw) w_0 = 13%; 2) soybeans (chaff) w_0 = 0%; 3) poplar w_0 = 6.5%; 5) miscanthus (stems) w_0 = 10%; 4) willow w_0 = 0%

That is, for this crop at temperatures starting from 240-250 ºC, the obtained product is torrefied, which is also characterized by a change in color [28-30] of the samples (Fig. 3).

Fig. 3. **General view of torrefied stems of Miscanthus Giganteus:** a, b – 200 ºC; c – 220 ºC; d – 240 ºC; e – 260 ºC; f – 280 ºC; g – 300 ºC

As it can be seen from similar graphs for other crops, the general principle remains unchanged, but in Miscanthus Giganteus in comparison with the above types of biomass, active changes occur at slightly higher temperatures and the final weight loss is not so significant.

Conclusions

In the conditions of the general trends of the world energy transition to alternative sources of energy, the cultivation and production of energy from Miscanthus Giganteus biomass is a priority path for many countries. Such energy crop has proven itself as an effective raw material for the production of solid biofuels due to its high yield of dry biomass (up to 25 $t \cdot ha^{-1}$), high calorific value (18 $MJ \cdot kg^{-1}$), low natural humidity stems at the time of harvesting (up to 25%).

Heat treatment of Miscanthus Giganteus biomass makes it possible to use its energy potential even more effectively. At thermal processing of Miscanthus Giganteus biomass a rather high temperatures at which there are active changes of weight are noted. Thus, the beginning of the internal destruction of the material as a result of torrefaction is 240-250 º C, and the completion is close to 300 º C, which is a high figure compared to other similar crops.

The initial evaluation of changes in the properties of Miscanthus Giganteus biomass can be traced by organoleptic examination of the torrefied product formed as a result of heat treatment at different modes. According to these studies, it was found that when optimal parameters are reached, the Miscanthus Giganteus biomass acquires a noticeably dark color, which indicates a large proportion of pure carbon in the product.

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