TRANSFORMATION OF HIGH-DENSITY GREEN ENERGY WITH SIMULTANEOUS DECONTAMINATION OF THE ENVIRONMENT

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ABSTRACT

In recent years, there has been an increased emphasis worldwide on the quality of the environment, especially with an orientation towards the application of renewable energy sources. In addition, we are increasingly encountering experimentation aimed at obtaining new green energy sources. One of such sources is biomass. Biomass has been used since the middle ages as a source of heat and light energy. Today, however, we have technologies that allow us to obtain not only heat but also electricity from biomass, or to convert biomass into materials with high energy density and purity. The energy thus transformed can then be used, for example, as a propellant. At the same time, this valuable source of clean energy can be easily transported to the place of consumption. By applying biomass as a source of green energy, we can make a significant contribution to relieving the environment from harmful effects. In recent years, an increased interest in energy obtained from biomass can be observed in Slovakia. Its technical potential is the greatest among other renewable energy sources, and its non-use would essentially be wastage. Therefore, the aim of the paper was to describe two possibilities of transformation of biomass in the form of its energy recovery into the type of energy used for the production of mechanical, thermal and electrical energy. At the same time, in addition to obtaining a suitable form of energy from biomass, another environmental benefit was sought in the form of soil decontamination. In this regard, there is an energetically important crop, which is known under the Latin name Amaranthus caudatus. It is an energy crop that can be grown on slightly contaminated soil with some restrictions. Two methods of energy recovery of this crop were compared. In the first case it was its compaction into briquettes, in the second case it was a process of anaerobic fermentation with subsequent production of biogas. Based on the performed analysis, it was found that these are almost equivalent energy sources. Although both methods of transformation and energy recovery of the green part of Amaranthus caudatus crops have a number of advantages and disadvantages, it can be clearly stated that the positives significantly outweigh the negatives. Therefore, it is recommended to apply this crop as a valuable source of energy for use in real conditions.

Keywords: *biogas, calorific value, efficiency, energy, environment*

INTRODUCTION

New energy sources are being sought due to the ever-tightening of emission limit quotas. The primary attention is paid especially to the so-called green energy sources, which are obtained on the basis of renewable energy. The main reason is that these energy sources make it possible to produce environmentally friendly energy [1]. At the same time, by changing the legislation in Slovakia towards improving the quality of the environment by supporting the use of renewable energy sources, we are increasingly encountering the search for reserves of the potential of renewable energy sources. We see this reserve especially in the area of green biomass [3]. Of course, the advantage is that these new renewable energy sources have the least possible negative impact on environmental degradation. The ideal case is if their use not only does not harm the environment but on the contrary, can eliminate the amount of emissions in the air or harmful substances in the soil. In terms of geographical location and the current level of agriculture, Slovakia has a number of advantages in the field of obtaining energy from renewable energy sources [7]. It has free energy potential mainly in the field of biomass production [2]. At the same time, it is mainly the cultivation of the so-called energy crops. In addition to ecologically clean energy production, its ecological transformation into mechanical, thermal or electrical energy is also important. One of the alternative ways of ecological use of energy crops grown in Slovakia is their energy recovery through compaction in the form of briquettes or in the form of anaerobic fermentation with subsequent production of biogas.

ENERGY POTENTIAL OF BIOMASS IN SLOVAKIA

Currently, the total available technical potential of biomass in Slovakia is estimated at more than 160 PJ (25.10^6 t) [9]. Of this potential, approximately 56.8 PJ falls on purpose-grown biomass in the form of energy crops, e.g. cereal straw represents 10.4 PJ ($0.7.10^6$ t), rapeseed straw 2.9 PJ ($0.2.10^6$ t), corn straw 9.4 PJ ($0.6.10^6$ t), sunflower straw 2.8 PJ ($0.2.10^6$ t). Various crop species characterized by high yields are bred, the calorific value of which ranges from 8.1 to 18.6 $MJ.kg^{-1}$ depending on the water content, e.g. straw with a water content of about 15% has a calorific value of 14.3 $MJ.kg^{-1}$ (4.0 $kW.kg^{-1}$), winter rapeseed straw 17.5 $MJ.kg^{-1}$, rapeseed oil 37.1 $MJ.kg^{-1}$ (10.3 $kW.kg^{-1}$)

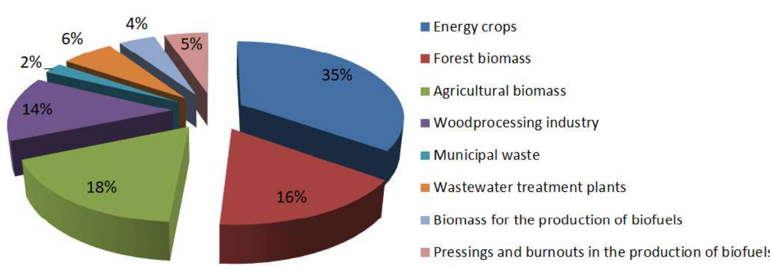

Fig. 1. *Technically usable potential of biomass in Slovakia*

However, of the current technical potential of biomass, only a small amount is actually used in Slovakia. There are considerable reserves, especially in the use of green biomass and its transformation for ecologically clean energy [5]. In this regard, the situation can greatly improve the cultivation of so-called energy crops. One such energy crop is also Amaranthus caudatus.

BASIC DESCRIPTION OF THE ENERGY CROP AMARANTHUS CAUDATUS

Amaranthus caudatus is an annual monocotyledonous crop with a height of the aboveground part in ripeness from 0.30 to 0.80 m. The stem is recumbent to erect, densely leafed with a short inflorescence. The fruit is a small, broadly ovoid stem or capsule. In terms of soil quality requirements, it is a crop with minimal requirements. Based on several analyzes performed, the crop Amaranthus caudatus was generally assessed as an energetically important and fully valuable crop. Therefore, it is quite realistic to assume that this crop can become a valuable renewable energy source in Slovakia in a few years.

Fig. 2. *Energy crop Amaranthus caudatus*

Both the above-ground part and its root are considered to be energetically valuable parts. In addition to the above-ground part, its root can also be used for energy. The advantage of this crop is also the ability to extract a lot of heavy metals from the soil, while its energy treatment can permanently remove these harmful substances from the contaminated soil. Table 1 shows the values of the heavy metal content in the soil before sowing and after the harvest of the Amaranthus caudatus crop in comparison with the limit values of the heavy metals in the soil.

Table 1. *Heavy metal content of soil before sowing and after harvesting of Amaranthus caudatus*

Element	Original contamination [mg.kg^{-1}]	Residual contamination [mg.kg^{-1}]	Limit values [mg.kg^{-1}]
As	50.0	26.0	25.0
Cu	321.0	300.0	60.0
Hg	1.2	1.2	0.5
Pb	66.0	30.0	70.0

From the above overview in table 1, it can be observed that in three of the four monitored parameters of heavy metals in the soil (As, Cu and Hg) the limit was exceeded before sowing of the Amaranthus caudatus crop. In the case of the metal Pb, its value approached the limit value. After the collection of the energy crop Amaranthus caudatus with both above-ground and underground parts, a decrease in the content of heavy metals was recorded. At the same time, a sub-limit value of the monitored parameter was reached in all monitored parameters. Subsequently, the crop was analyzed for heavy metal content. The values recorded are given in table 2 below.

Table 2. *Recorded content of heavy metals in individual parts of the energy crop Amaranthus caudatus*

element examined [mg.kg^{-1}]	uncontaminated crop	contaminated crop	crop root
As	0.03	0.06	1.68
Cu	8.00	31.00	25.00
Hg	0.05	0.06	0.12
Pb	do 0.50	1.11	3.59

When examining the content of heavy metals, which the energy crop absorbed from the soil, it was found that for all monitored indicators, the highest values were recorded in the underground part. The above-ground part absorbed less heavy metals. At the same time, Table 2 shows the differences in the recorded values of heavy metals, which the energy crop absorbed when growing in uncontaminated and contaminated soil.

Crops with a height of 0.30 to 0.80 m and a weight of 0.01 to 0.05 kg were used in the experiment. The weights of the individual laboratory crops in the dehydrated state are demonstrated by the following graph in figure 3.

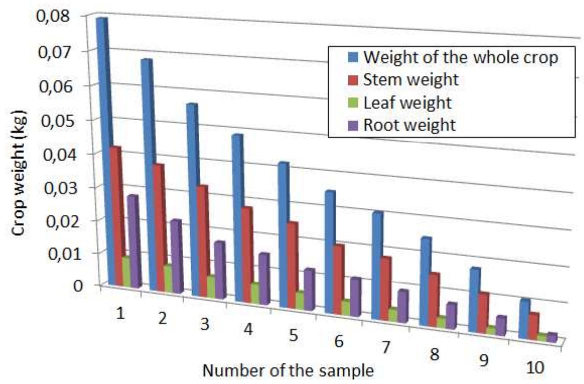

Fig. 3. *Weights of individual parts of energy crops with relative dry matter moisture of 15%*

From the point of view of the practical application of the energy crop Amaranthus caudatus for energy purposes, it is necessary to compact it in the form of pellets or briquettes. For demonstrative purposes, laboratory pressing of the crushed dry matter was performed using a pressing jig at a pressure of 400 kN, which is shown in figure 4.

Fig. 4. *Laboratory pressing preparation for the crushed powder of the energy crop Amaranthus caudatus*

The volume of the cavity in the laboratory pressing preparation was 160 ml (16.10^{-6} $m^{3)}$. Dry crushed powder with a moisture content of approx. 15% was used for pressing the briquettes.

ENERGY BALANCE OF AMARANTHUS CAUDATUS CROP

An experimental sample of the compacted dry matter of the energy crop Amaranthus caudatus in the form of briquettes was examined from an energy point of view. The parameters of its combustion heat and calorific value were identified using a calorimeter. Combustion heat can generally be understood as the amount of heat in kJ that can be obtained by perfectly burning a certain amount of fuel with air, at a constant pressure, all the flue gases being cooled to the initial temperature of the input components [12]. At the same time, in the case of combustion heat, it is considered that the water formed by the reaction and originally contained in the fuel is in a liquid state. The condensing heat of water that is released during combustion is then added to the energy balance. Based on the experimental value of combustion heat Q_s, it is possible to calculate the calorific value of dry matter Q_i of the potential energy raw material Q_{ir} at the actual humidity. It is the value of combustion heat reduced by the heat of vaporization. It is advantageous to convert the combustion heat of the combustible fuel Q_s to the calorific value of the dry matter Q_i and then to convert this value to the water content of the fuel. This procedure is very advantageous in case we have a significantly moist potential energy raw material, which is a relatively common case for biomass. At the same time, from the point of view of achieving the highest possible calorific value, the optimal value of dry matter moisture is important. The combustion heat of the fuel then represents for a given type of fuel, resp. energy raw material constant expressing the quality of the energy carrier [8]. The combustion heat of the combustible then represents for a given type of fuel (energy raw material) a constant expressing the quality of the energy carrier. The table 3 shows a comparison of the calorific value of briquettes from Amaranthus caudatus with selected types of biomass.

Table 3. *Comparison of calorific value of briquettes from Amaranthus caudatus with selected types of biomass*

Biofuel type	Water content [%]	Calorific value [MJ.kg^{-1}]	Bulk density [kg]
Wood chips	10 - 40	16.4 - 10.1	170 - 225
Cereal straw	15 - 20	15.5	120 pcs
Oilseed rape straw	15 - 20	16.0	100 pcs
Amaranthus caudatus	15 - 20	14.0	127 pcs

Among other things, the overall energy potential, which includes fast-growing crops, also depends on yields and energy content in dry matter.

Another possibility of energy recovery of the Amaranthus caudatus crop is its anaerobic fermentation in order to obtain biogas. It is a biochemical process that results in a mixture of methane (CH_4), carbon dioxide (CO_2) and by products [4]. The decomposition of organic substances through the fermentation of the green parts of the crop occurs without the access of air in a humid environment by the action of anaerobic cultures of microorganisms [10]. Ideal conditions for these anaerobic bacteria are temperatures close to 50°C. In general, it is a relatively complex chemical process, while biogas as a final product is usually produced only in its final phase [11]. Anaerobic fermentation takes place in four phases, which are referred to as hydrolysis, acidogenesis, acetogenesis and methanogenesis. The following diagram in figure 5 describes in detail the biochemical process of anaerobic fermentation, which results in the formation of biogas (CH_4 + CO_2).

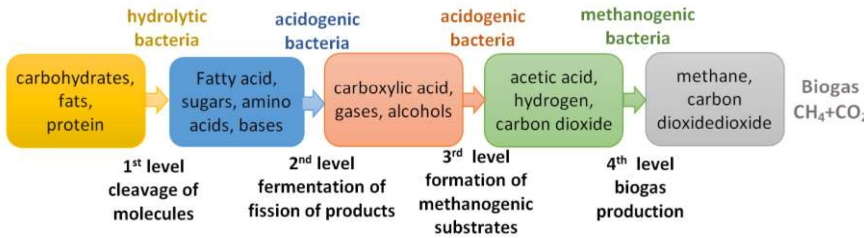

Fig. 5. *Biochemical process of biogas production through anaerobic fermentation*

The time course of a given biochemical process is closely related to many factors. Constant temperature is especially important, as anaerobic bacteria often die during rapid temperature changes. Another important parameter is the appropriate pH. For these purposes, it is advisable to maintain a pH in the range of 6.5 to 7.5. It is also necessary to ensure the presence of trace elements such as iron, cobalt, selenium, molybdenum and tungsten. It is also important to maintain the required ratios of nitrogen, carbon and phosphorus, as well as the overall quality of the biomass in terms of dry matter content. At present, a predominantly wet anaerobic fermentation process is applied in the production of biogas from the green parts of crops [6]. It processes a substrate with a water content of 85% or more. In the following figure 6 is a diagram of a process for the wet anaerobic fermentation of green parts of crops.

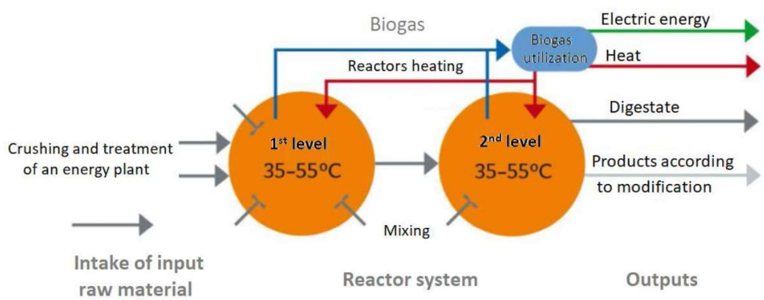

Fig. 6. *Scheme of the process of wet anaerobic fermentation of green parts of crops*

In the following table 4 shows selected properties of biogas produced by the process of wet anaerobic fermentation of green parts of crops.

Table 4. *Selected properties of biogas produced from green parts of crops*

Selected properties of biogas							
Parameter	Calorific value	Density	Density relative to air density	Ignition temperature	Range of ignition concentration of gas in the air	Theoretical need for air	Maximum speed of flame advance in the air
Biogas	$6 kWh.m^{-3}$	$1.2 kg.m^{-3}$	0.9	700°C	6 - 12%	$5.7\ m^3.m^{-3}$	$0.25\ m.s^{-1}$

From the above overview in table 4 it can be observed that the calorific value of biogas produced from green parts of crops reaches a value of $6kWh.m^{-3}$ at a density of $1.2kg.m^{-3}$.

FINAL EVALUATION OF THE GREEN ENERGY APPLICATION

Based on experimental research and subsequent analysis, it can be stated that the calorific value of briquettes from the dried crop Amaranthus caudatus is 14.0 $MJ.kg^{-1}$. The calorific value of biogas obtained by the process of wet anaerobic fermentation of green parts of Amaranthus caudatus crops is $6kWh.m^{-3}$. Although the amount and calorific value of biogas obtained by the wet anaerobic fermentation process of green crops of Amaranthus caudatus is slightly lower compared to the amount and calorific value of briquettes obtained from dried crops, this process is less energy-intensive. In the case of briquette production, a large amount of energy is required to dry the green parts of the crops, to crush them and then press them. This significantly reduces the overall energy balance. Therefore, it is not possible to unambiguously recommend the first or second method of energy recovery of the crop Amaranthus caudatus. From our point of view, these are energy-equivalent energy sources. At the same time, we offer a simplified overview of the significant pros and cons of both types of green energy obtained.

Benefits: obtaining a valuable renewable energy source, the possibility of transforming the obtained source into mechanical, thermal and electrical energy, possibility of energy storage, soil decontamination, job opportunities.

Disadvantages: for the energy recovery of the Amaranthus caudatus crop, the application of highly sophisticated technological equipment is required, retrofitting of installations using this transformed green energy source is often required, there is a risk of recontamination of soil if the waste product of green energy transformation is improperly handled.

It is therefore evident from the above overview that the advantages of energy recovery of the crop Amaranthus caudatus significantly outweigh its shortcomings. Therefore, this source of green energy can be clearly recommended for practical application in both ways.

CONCLUSION

Growing crops for energy purposes is undoubted of societal importance. The main reason for the production of energy crops not only in the world, but also in Slovakia is the production of clean energy from renewable sources. At the same time, this energy source provides a wide range of job opportunities for local people. The use of biomass as a source of green energy, of course, requires active and flexible cooperation with the Ministries of agriculture, the Ministry of finance and the environment. It also requires support from national and international legislation. A certain limitation in obtaining green energy through energy crops is their technological processing. This is mainly due to the need for technologically advanced infrastructure. In many cases, the adaptation of existing technological equipment is also required for their use. Therefore, especially for the above reasons, the environmental and regional benefits of these energy crops are currently not fully appreciated. On the other hand, due to the constant tightening of emission quotas and rising fossil fuel prices, increased pressure on the massive expansion of green energy production and use can be expected in the future. Therefore, the aim of the paper was to provide an extended view of two basic possibilities of energy transformation of the crop Amaranthus caudatus, which can be easily grown in Slovakia. The possibility of producing briquettes and biogas was described, while the two products of the energy crop Amaranthus caudatus were compared not only from an energy point of view, but also from an environmental point of view. Based on the performed analysis, it can be stated that each of these methods of energy recovery of green parts of the crop has its benefits and disadvantages. Therefore, it is not possible to exclusively recommend one or the other method of its energy recovery.

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