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CO-FIRING OF CONTAMINATED WILLOW BIOMASS (*SALIX* L.) WITH LIGNITE IN THE ENERGY PRODUCTION PROCESS

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Abstract: *The share of renewable energy sources (RES) in energy production processes is growing every day in many countries. Globally, there is a very pronounced tendency to eliminate fossil fuels for energy production, which are replaced by RES. The path to decarbonization involves the successive reduction of fossil fuels and their replacement by RES. One of the possibilities of using RES, which could be used in co-firing processes with coal, is biomass obtained from fast-growing woody species, such as poplars and willows. Willows, as effective hyperaccumulators of heavy metals, successfully remediate the soil, producing biomass that can be used in energy production, both independently and through co-firing with coal. The aim of this paper is to determine the energy potential of contaminated willow biomass, as well as to determine the most favourable type of willow that would be used to improve the calorific value of lignite in co-firing processes, in different percentage ratios. The biomass obtained from willows contaminated with heavy metals (Cd, Cu, Cr, Ni, Pb and As) is characterized by a higher calorific value than the value of the examined lignite samples. Two types of willows, basket willow (Salix viminalis) and white willow (S. alba), clone B-44, as well as three coal samples, sampled from three different locations in Kolubara Mining Basin, Elektroprivreda Srbije AD, were examined. The obtained results indicate the dependence of the calorific value of lignite on the coal deposit, while the calorific value of willow depends on the type of willow. White willow (clone B-44) has a higher energy potential than basket willow, and co-firing processes are economically justified, if lower percentage ratios (about 10%) of biomass were used.*

Keywords: heavy metals, willows, coal, co-firing, energy potential.

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KOSAGOREVANJE KONTAMINIRANE BIOMASE VRBA (*SALIX* L.) SA LIGNITOM U PROCESU PROIZVODNJE ENERGIJE

Apstrakt: *Uvećanje procenta upotrebe obnovljivih izvora energije (OIE) u procesima proizvodnje energije svakim danom raste u mnogim zemljama. U svetu je veoma izražena tendencija eliminacije fosilnih goriva za proizvodnju energije, čiju supstituciju vrše OIE. Put ka dekarbonizaciji uključuje sukcesivno umanjivanje fosilnih goriva i njihovu zamenu OIE. Jedna od mogućnosti upotrebe OIE, koja bi mogla da se koristi u procesima kosagorevanja sa ugljem, predstavlja biomasa dobijena od brzorastućih drvenastih vrsta, kao što su topole i vrbe. Vrbe, kao dobri hiperakumulatori teških metala, uspešno vrše rekultivaciju zemljišta, proizvodeći biomasu koja se može upotrebiti u proizvodnji energije, kako samostalno, tako i kroz kosagorevanje sa ugljem. Cilj ovog rada je utvrđivanje energetskog potencijala biomase kontaminiranih vrba, kao i utvrđivanje najpovoljnije vrste vrba koja bi se koristila za poboljšanje kalorijske vrednosti lignita u procesima kosagorevanja, u različitim procentualnim odnosima. Biomasu, dobijenu od vrba kontaminiranim teškim metalima (Cd, Cu, Cr, Ni, Pb i As), karakteriše veća kalorijska vrednost od vrednosti ispitivanih uzoraka lignita. Ispitivane su dve vrste vrba, košarasta vrba (Salix viminalis) i bela vrba (S. alba), klon B-44, kao i tri uzorka uglja, uzorkovana sa tri različita lokaliteta u RB Kolubara, Elektroprivreda Srbije AD. Dobijeni rezultati ukazuju na zavisnost kalorijske vrednosti lignita od ležišta uglja, dok je kalorijska vrednost vrba zavisna od vrste vrba. Bela vrba (klon B-44) ima veći energetski potencijal od košaraste vrbe, a procesi kosagorevanja su ekonomski opravdani, ukoliko bi se koristili manji procentualni odnosi (oko 10%) biomase.*

Keywords: teški metali, vrbe, ugalj, kosagorevanje, energetski potencijal.

1. INTRODUCTION

In order to mitigate climate change, many countries have decided to take the path of decarbonization. This path implies a successive reduction in the use of fossil fuels for energy generation. Therefore, in order to compensate for the shortfall in the daily base load diagram and ensure the energy stability of the system, the reduced amount of fossil fuels is supplemented with renewable energy sources (RES). As one of the renewable energy sources there is the biomass obtained from fast-growing deciduous trees, such as willows and poplars. Thijs et al. (2018) point out that willows, compared to other species such as poplars, have by far the highest absorption potential of heavy metals in field conditions. According to Rodzkin (2014), the use of willows for economic purposes is successful due to their intensive growth, geographical distribution and ability to easily adapt to different environmental conditions, which is why they are classified in the group of short rotation coppices and their harvesting from energy plantation is possible every other year, for 20 years. The biomass obtained from energy plantations, according to Nixon et al. (2001), can be used for the production of charcoal, for direct combustion, because it contains a low ash content, moisture and alkali metals, for the production of electricity in special generators, or simply as a source of carbon in atmospheric CO_2 .

On the one hand the existence of a developed industry is the main indicator of the progress of any country. Yet on the other hand, the negative side of the presence of a large number of factories and industrial plants results in the emission of significant amounts of greenhouse gases, but also of heavy metals, and the production of electricity, using fossil fuels, results in the release of a significant amount of pollutants that threaten the environment. It is the obligation of every country to carry out the remediation of soil polluted by heavy metals and it represents a significant expenditure to every business entity. If willows were used on such devastated land, due to their highly branched root system, they would solve the problem of erosion with simultaneous phytoremediation of heavy metals, and in addition, the treated area would also produce biomass, which would be used for energy production (Heller et al., 2003). Also, according to Jerba et al. (2020), willow plantations have the ability to perform biodrainage, where excess groundwater is removed through transpiration. By doing so, the land originally intended for remediation, which would have been an expense, would instead generate financial returns through energy production. It is precisely for this reason that a large number of countries use biomass for energy production, both independently and in co-firing with coal. A new approach to the system of forest cultivation - the establishment of shoot plantations of fast-growing tree species, i.e. energy (bioenergy) plantations, is increasingly being applied in the countries of Europe and North America (Vacek et al., 2009).

Decarbonization, as the ultimate goal adopted by many countries around the world, implies the elimination of fossil fuels, but the path to this ultimate goal is very complex, because the power system stability of many countries depends, to a high percentage, on fossil fuels. In order to ensure the power system stability, a successive reduction of fossil fuels was agreed accompanied by an increase in the percentage of RES. This was the main reason why many countries are signatories to the international agreement from 1997, the Kyoto Protocol, which obliges them to increase the share of renewable energy sources. An example of the above is the process of co-firing of coal and biomass, as a way to generate energy while reducing coal as a fossil fuel. If the biomass of willows, grown on land loaded with heavy metals, were to be used for energy production (either independently or in the process of co-firing with coal), at the same time it would benefit to the land reclamation while respecting the requirements related to the protection and preservation of the environment. Biomass is a form of solar energy accumulated by plant tissues, because it is produced by the process of photosynthesis, from solar energy, CO_2 from the atmosphere and water from the soil (Stolarski et al., 2013).

Willows belong to the genus *Salix L.* Oljača et al. (2017) state that there are a large number of willow species that can have different forms, but most often it is a tree that can be over 20 m high with a diameter of up to 1 m, although they can also have the form of a ground plant or bush. Arsenov (2018) points out willows as fast-growing woody plants that are managed according to the short rotation principle, because they are characterized by high biomass productivity, enviable intensity of transpiration, well-branched and strongly developed root system and genetic variability.

Willows are known as good hyperaccumulators of heavy metals and can be used to clean up devastated habitats. The formation of energy plantations on land contaminated with heavy metals, along with the simultaneous phytoextraction of heavy metals, also provides biomass with a significant calorific value, which does not differ much from the calorific value of biomass obtained from uncontaminated habitats. Rodzkin et al. (2024) indicate the effectiveness of using fast-growing species - willows for biomass production, emphasizing that willows can be grown both on uncontaminated land and on land loaded with heavy metals, while the degree of contamination does not affect the calorific value of willows, but only on the biomass yield which depends on the type and clone of the plants and the soil contamination itself. A significant amount of certain heavy metals, in the process of phytoremediation, is stabilized in the willow roots, so that during the burning of biomass, it is not emitted into the atmosphere.

Many countries utilize woody species biomass, such as willows and poplars, for energy production, either independently in bioenergy plants or through co-firing with lignite. This process enhances the calorific value of coal, resulting in economic benefits while primarily contributing to a cleaner, more sustainable environment. Tharakan et al. (2005) state that the co-firing of coal and wood biomass, in existing energy boilers, will be the most promising method of energy production, while Tillman (2000) believes that the production of electricity by burning willow biomass in combination with other wood biomass or with coal in existing power plants, has already become the most promising commercial option. In Poland, the production of electric and thermal energy is often provided by co-firing of biomass and coal (Dzikuć and Piwowar, 2016). Backreedy et al. (2005) states that in Great Britain, in some thermal power plants, energy is produced by co-firing of biomass (in the ratio of 2-4%) and coal. Hughes (2000) states that research in thermal power plants in New York State has shown that co-firing willows with coal is technically feasible, with the costs of such capital projects being significantly lower than projects involving individual combustion of biomass, wind turbines and most other RES technologies.

The energy community treats biomass as a "carbon-free" fuel with the explanation that the amount of CO_2 that is emitted during combustion represents the same amount that it absorbs during its growth (Heller et al., 2003). Tharakan et al. (2003) point out the biomass obtained from willows as an energy source which, compared to coal, has almost no sulphur, has significantly less trace metals and, depending on the method of combustion in plants, can result in significantly lower NO_x emissions.

The aim of this paper is to determine the energy potential of willow biomass grown on contaminated land in co-firing processes with lignite in different percentage ratios.

2. MATERIAL AND METHODS

In this paper, the calorific values of three lignite samples, biomass from two willow species, and lignite-biomass mixtures with varying biomass proportions (5%, 10%, 15%, and 20%) were measured. The examined willow species: basket willow (*Salix viminalis* L.) and white willow (*S. alba* L.) - clone B-44, were grown on soil contaminated with aqueous solutions of heavy metals. The plant material (cuttings) was obtained from the mother plantation of the "Ratno Ostrvo" nursery, Public Enterprise "Vojvodina Šume," Novi Sad Forestry Unit, Kać Forest Management Unit, ensuring that the cuttings were of approximately similar morphological dimensions. The cuttings were grown in soil in 10 l bags, taken from Kolubara Mining Basin, Elektroprivreda Srbije AD, which, at the beginning of each growing season, was additionally contaminated with aqueous solutions of salts of heavy metals [$Cd(NO_3)_2$, 112,4 ppm; $CuSO_4*5H_2O$, 63,5 ppm; $K_2Cr_2O_7$, 104,0 ppm; $Na_2HAsO_4*7H_2O$, 74,9 ppm; $NiCl_2$*6H2O, 58,7 ppm; P_bNO_3, 207,2 ppm] in the concentration of 10^{-3} mol/dm^3. The experiment was set up in the nursery of the Faculty of Forestry in Belgrade. After three years, willows were cut and air-dried for two months.

The first two lignite samples (U1 and U2), sampled at two localities in the eastern part of Kolubara Mining Basin, represent mixed coal from field B/C and field E, and the current total field E, Kolubara Mining Basin. The third sample (U3) is a sample from the western part of the Kolubara basin, at the loading point Drobilana-Kalenić and represents mixed coal from the area of Tamnava western field and field G. Lignite and biomass samples were prepared by grinding in laboratory coal mills.

The calorific values of all three coal samples, both willow species, as well as their mixtures were determined without correction using the calorimeter IKA C 5003 in the laboratory of the Organizational Unit for processing (OC Prerada) within the Kolubara Mining Basin of EPS AD.

The obtained calorific values were processed using descriptive and univariate statistical methods. Descriptive statistics included the determination of the mean value, standard deviation, coefficient of variation, as well as the range of values. The significance of differences among mean values was determined by analysis of variance (ANOVA) and *post hoc* Fisher's least significant difference (LSD) test. Statistical analyzes were performed in the software program Statgraphics Centurion v. XVI.I. (2009; Statpoint Technologies, Inc., Warrenton, VA, USA).

3. RESULTS AND DISCUSSION

The mean calorific values for willow biomass obtained by air drying were 18201 kJ/kg for *Salix viminalis* and 18219 kJ/kg for *S. alba*. The first species is characterized by a minimum calorific value of 18198 kJ/kg and a maximum value of 18206 kJ/kg, while the second is characterized by a minimum value of 18213 kJ/kg and a maximum of 18224 kJ/kg. The calorific values of the biomass obtained from the researched species are characterized by a low value of the coefficient of variation (0.02-0.03%). The results of the analysis of variance (ANOVA) indicate that the mean calorific values of the biomass of the two willow species are statistically significantly different from each other (p = 0.0116) (Tab. 1). Based on the above, it can be said that there is a dependence of the calorific value of biomass and species. The obtained results are in agreement with Karampinis and Hevas (2011), who state that the calorific value of willow is 18410 kJ/kg, while Kijo-Kleczkowska et al. (2016) state the calorific value of the willow species Salix viminalis, without "dry basis" drying, amount to 16824 kJ/kg. The species *S. viminalis* is characterized by lower calorific values (18201 kJ/kg) compared to the species *S. alba* (18219 kJ/kg), which is in agreement with Urošević et al. (in press) who point out that the calorific values of basket willow and white willow, grown in an uncontaminated area, amount to 17966 kJ/kg and 18046 kJ/kg, respectively.

Table 1. *Descriptive statistics and analysis of variance (ANOVA) for calorific values of willow species*

Species	Average	Standard deviation	Coeff. of variation (%)	Minimum	Maximum	Range	ANOVA	
							F-ratio	*p*-value
S. viminalis	18201.00 b	4.36	0.02	18198.0	18206.0	8.0	19.44	**0.0116**
S. alba	18219.00 a	5.57	0.03	18213.0	18224.0	11.0		

Note: *Different letters within a column denote statistically significant differences at the 95% confidence level*

Depending on the examined coal samples, the mean calorific values of the investigated coal samples (Tab. 2) ranged from 12,138.03 kJ/kg (the lower calorific value is 7,514 kJ/kg - sample U3) to 15,946.00 kJ/kg (the lower calorific value is 9,791 kJ/kg – sample U2). The minimum value (12,070 kJ/kg) was measured for coal sample U3, and the maximum (15,978 kJ/kg) for the sample U2. In relation to the calorific value of the examined coal samples, low values of the coefficient of variation (0.25-0.49%) were established. Based on the results of the analysis of variance (ANOVA), statistically significant differences (p = 0.0000) were found between the mean calorific values of the coal samples, whereby three homogeneous groups were formed. The calorific value of coal depends on the sample, whereby the sample U2 has the highest calorific value, and the sample U3 the lowest. The lower calorific value can be explained by the presence of a larger amount of clay in the sample U3 compared to the other samples.

Table 2. *Descriptive statistics and analysis of variance (ANOVA) for calorific values of coal samples (U1–U3)*

Coal sample	Average	Standard deviation	Coeff. of variation (%)	Minimum	Maximum	Range	ANOVA	
							F-ratio	*p*-value
U1	12,975.00 b	63.24	0.49	12,905.0	13,028.0	123.0	3,902.16	**0.0000**
U2	15,946.00 a	39.40	0.25	15,902.0	15,978.0	76.0		
U3	12,138.30 c	60.70	0.50	12,070.0	12,186.0	116.0		

Note: *Different letters within a column denote statistically significant differences at the 95% confidence level*

Table 3. *Descriptive statistics and analysis of variance (ANOVA) for calorific values of coal and mixtures composed of different coal samples (U1-U3) and biomass of two willow species (G1 – Salix viminalis, G2 – S. alba) added in different percentages (B5–B20)*

Biomass and coal mixture	Average	Standard deviation	Coeff. of variation (%)	Minimum	Maximum	Range	ANOVA	
							F-ratio	*p*-value
U1G1B5	13,113.00	40.63	0.31	13,079.0	13,158.0	79.0	3,064.29	**0.0000**
U1G1B10	13,534.00	31.43	0.23	13,506.0	13,568.0	62.0		
U1G1B15	13,758.00 g	26.85	0.20	13,727.0	13,774.0	47.0		
U1G1B20	13,959.00 f	45.57	0.33	13,926.0	14,011.0	85.0		
U1G2B5	13,279.00	19.08	0.14	13,259.0	13,297.0	38.0		
U1G2B10	13,819.00 g	193.16	1.40	13,596.0	13,934.0	338.0		
U1G2B15	13,936.00 f	13.23	0.09	13,921.0	13,946.0	25.0		
U1G2B20	14,123.00 e	24.43	0.17	14,106.0	14,151.0	45.0		

Biomass and coal mixture	Average	Standard deviation	Coeff. of variation (%)	Minimum	Maximum	Range	ANOVA	
							F-ratio	*p*-value
U2G1B5	16,262.00	17.52	0.11	16,244.0	16,279.0	35.0		
U2G1B10	16,248.00 d	20.66	0.13	16,231.0	16,271.0	40.0		
U2G1B15	16,530.00 ab	15.87	0.10	16,518.0	16,548.0	30.0		
U2G1B20	16,468.00 b	26.96	0.16	16,437.0	16,486.0	49.0		
U2G2B5	16,230.00 d	24.33	0.15	16,214,0	16,258,0	44,0		
U2G2B10	16,365.00 c	19.92	0.12	16,353.0	16,388.0	35.0		
U2G2B15	16,364.00 c	30.45	0.19	16,337.0	16,397.0	60.0		
U2G2B20	16,584.00 a	19.98	0.12	16,571.0	16,607.0	36.0		
U3G1B5	12,822.00 m	23.90	0.19	12,801.0	12,848.0	47.0		
U3G1B10	13,159.00 jk	25.53	0.19	13,137.0	13,187.0	50.0		
U3G1B15	13,221.00 ij	27.73	0.21	13,204.0	13,253.0	49.0		
U3G1B20	13,502.00	25.71	0.19	13,482.0	13,531.0	49.0		
U3G2B5	12,645.00 n	22.65	0.18	12,624,0	12,669,0	45.0		
U3G2B10	12,927.00 l	22.11	0.17	12,910.0	12,952.0	42.0		
U3G2B15	12,863.00 lm	20.88	0.16	12,849.0	12,887.0	38.0		
U3G2B20	13,249.00 i	26.29	0.20	13,230.0	13,279.0	49.0		

Note: *Different letters within a column denote statistically significant differences at the 95% confidence level*

In Table 3, the mean calorific values of willow biomass and coal mixtures amounted from 13,113 kJ/kg for coal sample U1 and 5% *Salix viminalis* biomass to 16,584 kJ/kg for coal sample U2 and 20% biomass *S. alba.* The obtained calorific values of mixtures of coal and biomass samples for both types, in different percentage ratios, are characterized by low values of the coefficient of variation (0.17-1.4%). The results of the analysis of variance (ANOVA) show that the mean calorific values of biomass mixtures for two willow species in different proportions and coal samples are statistically significantly different from each other (p = 0.0000), forming 18 homogeneous groups. Based on the above, it can be said that the calorific value of the mixture depends on the species from which the biomass is obtained, the amount of added biomass and the coal sample, which is consistent with Urošević et al. (2023). The lowest mean heat value was obtained by co-firing of 5% white willow biomass and coal sample U3 (12,645 kJ/kg). The highest mean heat value obtained by co-firing of 20% of white willow biomass and coal sample U2 (16,584 kJ/kg), whereby the addition of 15% of basket willow biomass to coal sample U2 results in a similar improvement in the calorific value of coal (see homogeneous group *ab*). Also, by adding only 10% of white willow biomass to coal sample U2, a solid improvement in calorific value is obtained (see homogeneous group *c*), because by adding half as much biomass of this species to coal sample U2, only 1.3% less improvement in calorific value of coal is obtained compared to the aforementioned mixture.

Based on the differences in the calorific value of coal and biomass mixtures, added in different percentage ratios, as well as the coal samples themselves, it can be stated that the greatest increase in calorific value is achieved by adding 20% of biomass to coal. It can also be stated that the percentage of added biomass does not increase the calorific values of the examined mixtures linearly. Hence, it can be pointed out that it is more favourable, more energy efficient and more economically profitable to use a mixture of coal with lower percentage shares of biomass (5-10%). The results presented in this paper, which indicate the economic using a lower percentage of biomass in co-firing with coal, are consistent with the findings in the literature. Thus, Savolainen (2003) points out that the concept of co-firing of biomass and coal represents the possibility of replacing smaller percentages of coal with biomass - RES. Also, in accordance with Dzikuć and Piwowar (2016), the application of biomass in lower percentages (5%, 6% and 7%) in the process of co-firing with coal in thermal power plants in Poland indicates that certain countries on their path to decarbonization have started to use biomass as a substitute for a smaller portions of coal in energy production processes.

4. CONCLUSION

Based on the results of this paper, the following conclusions can be drawn:
- Biomass obtained from contaminated soils can be used for energy production;
- White willow (*Salix alba*) has a greater potential in the processes of improving the calorific value of coal compared to basket willow (*S. viminalis*).
- the Sample U2 represents coal with the highest calorific value, and the coal sample U3 is the one with the lowest calorific value.
- the calorific value of the mixture of coal and biomass depends on the type of coal and the amount of added biomass, and less on the willow species or genotype, whereby the highest calorific increase in the mixture of biomass and lignite is achieved by adding 20% of white willow biomass;
- although the differences in calorific values between the coal sample and the mixture of coal and biomass grow with the increase in the percentage of biomass in the mixture, the use of lower amounts of biomass (5–10%) is more economically justified.

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CO-FIRING OF CONTAMINATED WILLOW BIOMASS (*SALIX* L.) WITH LIGNITE IN THE ENERGY PRODUCTION PROCESS

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Summary

One of the renewable energy sources is the biomass of fast-growing deciduous trees. Willows (*Salix* L.) can be grown both on uncontaminated soil and on soil loaded with heavy metals, where the level of contamination does not affect their calorific value, but the biomass yield, which depends on the species or clone of the plants and the contamination. A significant amount of certain heavy metals, in the process of phytoremediation, is stabilized in the willow roots, so that during the burning of biomass, it is not emitted into the atmosphere. The aim of this paper is to determine the energy potential of willow biomass grown on contaminated soil in co-firing processes with lignite in different percentage ratios.

The calorific values of three lignite samples, biomass from two willow species, and lignite-biomass mixtures with varying biomass proportions (5%, 10%, 15%, and 20%) were measured. The examined species include: *Salix viminalis* L. and *S. alba* L. (clone B-44), were grown for three years on soil contaminated with aqueous solutions of heavy metals (Cd, Cu, Cr, Ni, Pb and As). Two lignite samples (U1 and U2) were sampled at two localities in the eastern part of Kolubara Mining Basin (mixed coal from field B/C and field E). The third sample (U3) is a sample from the western part of the Kolubara Basin (mixed coal from the area of Tamnava western field and field G). Calorific values of coal samples, willow species, as well as their mixtures, were measured without correction using the IKA C 5003 calorimeter. The results were processed using descriptive statistics and analysis of variance (ANOVA).

The research results show that the species *S. viminalis* is characterized by lower calorific values (18,201 kJ/kg) compared to the species *S. alba* (18,219 kJ/kg). Also, the calorific value of coal depends on the sample, whereby the sample U2 shows the highest calorific value, and the sample U3 the lowest. Finally, the calorific value of the mixture of coal and biomass depends on the species from which the biomass is obtained, the amount of added biomass and the coal sample. The highest mean heat value obtained by co-firing of 20% of white willow biomass and coal sample U2 (16,584 kJ/kg), whereby the addition of 15% of basket willow biomass to coal sample U2 results in a similar improvement in the calorific value of coal. Also, by adding only 10% of white willow biomass to the coal sample U2, a solid improvement in calorific value is obtained, because by adding half as much biomass of this species to the coal sample U2, only 1.3% less improvement in calorific value of coal is obtained. Therefore, although the differences in calorific values between the coal sample and the mixture of coal and biomass grow with the increase in the percentage of biomass in the mixture, the use of lower amounts of biomass (5–10%) is more economically justified.

KOSAGOREVANJE KONTAMINIRANE BIOMASE VRBA (*SALIX* L.) SA LIGNITOM U PROCESU PROIZVODNJE ENERGIJE

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Rezime

Jedan od obnovljivih izvora energije predstavlja biomasa brzorastućih lišćara. Vrbe (*Salix* L.) je moguće gajiti kako na nekontaminiranom zemljištu, tako i na zemljištu opterećenom teškim metalima, pri čemu nivo kontaminacije ne utiče na njihovu kalorijsku vrednost, već na prinos biomase koji zavisi od vrste ili klona biljaka i kontaminacije. Značajna količina određenih teških metala, u procesu fitoremedijacije, stabilizovana je u korenu vrba, tako da se prilikom sagorevanja biomase ne emituje u atmosferu. Cilj rada je utvrđivanje energetskog potencijala biomase vrba gajenih na kontaminiranom zemljištu u procesima kosagorevanja sa lignitom u različitim procentualnim odnosima.

Utvrđene su kalorijske vrednosti tri uzorka lignita, biomase dve vrste vrba i smeše biomase i lignita u različitim procentualnim odnosima (5, 10, 15 i 20% biomase). Ispitivane vrste, *Salix viminalis* L. i *S. alba* L. (klon B-44), gajene su tri godine na zemljištu koje je kontaminirano vodenim rastvorima teških metala (Cd, Cu, Cr, Ni, Pb i As). Dva uzorka lignita (U1 i U2) uzorkovana su na dva lokaliteta istočnog dela RB Kolubara (mešani ugalj sa polja B/C i polja E). Treći uzorak (U3) je uzorak sa zapadnog dela Kolubarskog basena (mešani ugalj sa Tamnave zapadno polje i polja G). Kalorijske vrednosti uzoraka uglja, vrsta vrba, kao i njihovih smeša, određivane su bez korekcije kalorimetrom IKA C 5003. Rezultati su obrađeni primenom deskriptivne statistike i analize varijanse (ANOVA).

Rezultati istraživanja pokazuju da vrstu *S. viminalis* karakterišu niže kalorijske vrednosti (18201 kJ/kg) u poređenju sa vrstom *S. alba* (18219 kJ/kg). Takođe, kalorijska vrednost uglja zavisi od uzorka, pri čemu uzorak U2 karakteriše najveća kalorijska vrednost, a uzorak U3 najmanja. Najzad, kalorijska vrednost smeše uglja i biomase zavisi od vrste od koje se dobija biomasa, količine dodate biomase i uzorka uglja. Najveća srednja toplotna vrednost dobijena kosagorevanjem 20% biomase bele vrbe i uzorka uglja U2 (16584 kJ/kg), pri čemu se dodatkom 15% biomase košaračke vrbe uzorku uglja U2 dobija slično poboljšanje kalorijske vrednosti uglja. Takođe, dodatkom samo 10% biomase bele vrbe uzorku uglja U2 dobija se solidno poboljšanje kalorijske vrednosti, jer se dodatkom upola manje biomase ove vrste uzorku uglja U2 dobija samo 1,3% manje poboljšanje

kalorijske vrednosti uglja. Dakle, iako razlike u kalorijskim vrednostima između uzorka uglja i smeše uglja i biomase rastu sa povećanjem procentualnog sadržaja biomase u smeši, ekonomski je opravdanija upotreba manjih količina biomase (5–10%).