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PELLETIZATION OF INVASIVE *REYNOUTRIA JAPONICA* WITH SPRUCE SAWDUST FOR ENERGY RECOVERY

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ABSTRACT

The article focuses on processing of *Reynoutria japonica* an invasive alien species that is generally extirpated with major costs for its negative impact on biodiversity. It is the biodegradable waste that could be effectively used in energy industry. By examining first energy data (ash content, low melting temperature, nitrogen content etc.) it was found that *Reynoutria japonica* is not possible to be used separately for energy purposes. Therefore, the alternative of pelletizing six mixtures containing *Reynoutria japonica* and spruce sawdust in various content ratio was examined with the aim to produce alternative fuel pellets for automated boilers. The pelletization conditions were determined and the pellets quality was evaluated (durability, density etc.). Ash melting temperature was also evaluated. It was found none of the prepared mixtures needed an additional binder for a pelletizing process. It was assessed that the *Reynoutria japonica* input sample did not need to be dried after collection, since its moisture was sufficient for the pelletization. All samples met the parameters of the calorific value, which is greater than 10 MJ.

KEYWORDS: Waste biomass, pelletization, *Reynoutria japonica*, mechanical properties of pellets, spruce sawdust.

INTRODUCTION

The high increase in human energy consumption in the world leads to reflection on how to cover this growth trend. A major problem for global energy is the consumption of 80% of energy from fossil fuels. (Shahrukh et al. 2015). The remaining 20% of energy is spread among other sources (wind, solar, hydropower, nuclear, waste incineration and biomass burning). Biomass accounts for about 8.7% of the total consumption from renewable sources (Klessmann et al. 2011).

At present, biomass is becoming an increasingly important commodity in terms of renewable resources. Waste biomass from logging and processing of wood and forest waste (branches, bark, sawdust) has already been discussed in a number of publications (Lehtikangas 2001, Jezerska 2014, Wang et al. 2013). Biomass can be relatively easily mechanically modified and used as an alternative fuel in various mixtures for energy recovery (Kahia et al. 2017). Biomass with a lower moisture content will contain 5-10% more compact pellets than biomass with a moisture content of 15% (Mani et al. 2006). This assumption has been fulfilled for further work.

Reynoutria japonica is a dioecious plant from eastern Asia; it becomes wild very often and is classified among plants with an invasive character. In the first three years of growth of the plant, all the original growth in the area where the knotweed has taken root is gradually pushed out. *Reynoutria japonica* is on the list of dangerous invasive plant species, the list of quarantine plant pests, and the list of invasive species that affect biodiversity (GBIF 2017). Uniform legislation on similar harmful and invasive plants is still being developed in Europe (Cerny et al. 1998). At present, it grows wild on several thousand hectares of land. With great expense and effort, this plant is being destroyed (Sladky 2013). For example, annual financial losses associated with the costs of destroying invasive species within the European Union amount to EUR 12 billion, thus affecting the overall economy of the EU (Mandak 2004). Considering the difficulties connected with harvesting and the nature of the plant, it would therefore be desirable to process it along with others to readily available waste biomass. There are plenty of opportunities to use waste biomass and each technology has its strengths and weaknesses. One of them is the pelletizing process.

Pelletization is the process of efficient biomass utilization by reprocessing into solid phytofuel (biofuel) in the form of pellets. The pelletizing process allows the use of materials with a lower bulk density, and the pellets produced represent more energy per volume unit compared to untreated raw materials (Bradley 2011). It is ideal for input material with a high air volume such as biomass, when the volume changes in the process and thus saves the amount transported. The resulting product, the pellets are then impact resistant, and allow for easy handling and dosing in the combustion process (Rudolfsson et al. 2015).

The main aim of the work was to make use of the readily available waste biomass of spruce sawdust for improving energy parameters of the invasive energy plant *Reynoutria japonica*, the destruction of which is a major effort in Europe, as a renewable source of alternative fuel that could be used in the energy sector. For these purposes, six mixtures of the abovementioned feedstock were prepared in different proportions. The biochemical analysis and elemental analysis were performed on the input raw material, thus providing detailed characterization. It was further mechanically modified and then properly homogenized to provide a suitable mixture for the pelletizing process (Gil et al. 2013). The detailed description of this alternative fuel production is stated in the article. The process conditions of the process were determined and the mechanical and physical properties of the pellets were identified for all samples, including mechanical resistance of the pellets, pellet hardness, moisture resistance and density. From the energy point of view, melting temperature and ash melting temperature were evaluated. The resulting parameters can indicate how the fuel will behave in real conditions in the industry.

The article explores the potential of waste biomass (spruce sawdust) for improving energy parameters and optimizing procedural parameters of problematic *Reynoutria japonica*. It shows a new approach to the processing of traditional spruce sawdust with the problematic *Reynoutria japonica* towards the use of their energy potential. It does not promote controlled biomass cultivation for profit but tries to find solutions and evaluate waste products. The article also points to the possibility of utilizing this energy potential by using suitable additives to eliminate the problems associated with the caking resulting from implementation in industrial activities.

MATERIAL AND METHODS

The following material characteristics were performed to obtain the values of the physical properties that are important for the handling and storage of solid biomass. Crushed spruce sawdust and crushed *Reynoutria japonica* were used for pelletization in this study.

Materials

The test material was obtained from solid biomass of *Reynoutria japonica*, and spruce sawdust. Mixtures were formed from these basic raw materials, and these mixtures were used to produce pellets.

Reynoutria japonica, was collected from a locality in Jakartovice, which lies to the west of Opava. The collection took place by chopping the stem about 3 cm above the ground. In this manner, approximately 50 kg of material was collected Fig. 1.

Fig. 1: Reynoutria japonica in a period of vegetative calm.

Sawdusts are a specific type of disintegrated wood raw material that comes from wood processing. Typical is its small size - usually in mm and a high proportion of wood dust. This material is widely used for energy purposes. The spruce sawdust of up to 3 mm have been delivered in a dry state (Jezerska et al. 2016).

Methods

Elementary analysis

A basic elementary analysis of input raw materials, i.e. spruce sawdust and *Reynoutria japonica*, was determined according to CSN (Czech National Standard) ISO, valid for solid alternative fuels in the Czech Republic.

The input mixtures of the material were analyzed in IGI - VSB-TUO (Institute of Geological Engineering) laboratories, ENET laboratories and the Bulk Solids Centre.

Particle distribution

Sieve analysis determines the quantitative distribution of the particle size of the given material. This analysis indicates the size of the particles present in the sample. The analysis was performed on a Fritsch Analysette 3 Spartan vibration device. Setting - time 20 minutes with an amplitude of 1.5 mm.

Process treatment and pelletization of raw materials

All input material of spruce sawdust and *Reynoutria japonica*, was crushed in a Green Energy 9FQ hammer grinder. This crushed feedstock was further dried for 24 hours at 70°C in a Binder FED 400 dryer. Samples of the feedstock with different ratio were always homogenized in an ALBA RE 22 mixer for 25 minutes. The materials were pelletized on a KAHL 14 - 175 laboratory pelleting press with a flat die. The same single die was used in identical conditions for all the pellets.

Mechanical resistance of pellet samples

Mechanical resistance means the impact resistance to which pellets are subjected during handling. ISO 17225-6:2014 defines mechanical resistance as the degree of resistance of compacted biofuel (pellets), and the ability to maintain integrity during abrasion or impact during handling and transport. The mechanical resistance was determined according to the standard.

Hardness of pellets

The hardness of pellets is defined as the force that is required to break the pellet over time. Pellets with greater hardness are of a higher quality and have a higher bulk density, pellets with less hardness lose quality. Hardness is expressed as the mass load on the given pellet area in kilograms. The test was carried out using a KAHL ac-14 hardness tester.

Moisture resistance

Moisture resistance is the resistance of pellets to water absorption. Moisture resistance is a critical factor for storing and transporting pellets. The ability of the pellet to bind water (moisture absorption) further affects (decreases) the fuel efficiency. Depending on the moisture absorbed, pellets can break up, they may become swollen, which may lead to clogging or jamming if they are placed, for example, in a screw feeder or other closed mechanism. This resistance was expressed as the wettability index (WI), which represents the percentage of the absorbed (soaked) water by the pellet after soaking in distilled water for 30 seconds. Pellets having the lowest WI values are considered to be most resistant (Lindley and Vossoughi 2008).

Particle and bulk density of pellets

The particle and bulk density of pellets is a decisive factor mainly in the capacity of the means of transport, storage and combustion chamber space. The densities of the pellets represent the degree of densification of the material. A Mettler Toledo JEW-DNY-43 density tester was used to determine particle density of the samples. The bulk density was determined according to the standard.

Energy parameters

Important tests for commercial use in the implementation of biofuels for industry. The tests were carried out in the laboratories IGI - VSB-TUO (Institute of Geological Engineering).

Melting and ash melting temperature

The ash melting temperature is a decisive parameter that determines how fuel will behave under real conditions in industry. This analysis was determined in a Carbolite Gero CAF G5 furnace ISO 540. The temperature value output determines at what temperatures it will create unwanted inks (sticks) on the heat exchange surfaces.

Ash chemical composition

For energy use, the most problematic parameters are the ash content and its chemical composition (Na, K, Cl, N). For defining these parameters, the aqueous extract was determined from the original sample of *Reynoutria japonica*, followed by an ash extract of 1:10 ml. Analysis of the alkali content was carried out according to ISO 16995:2015 methodology.

RESULTS AND DISCUSSION

The calorific value in the *Reynoutria japonica* sample supplied was 14.22 $MJ \cdot kg^{-1}$ and 14.61 $MJ \cdot kg^{-1}$ in the dry matter. In both cases, the condition of Decree No. 415/2012 Coll., on the permissible level of pollution and its detection and implementation of some other provisions of the Act on Air Protection, which requires a calorific value in dry matter higher than 12 $MJ \cdot kg^{-1}$, is met. The results of the elementary raw materials analysis are shown in Tab. 1 and Tab. 2.

Tab. 1: Elemental analysis and calorific value of input raw materials.

Composition		*Reynoutria japonica*	Spruce sawdust
Water content in the analytical sample	(%)	-	7.48
Ash in dry matter	(%)	5.39	0.45
Volatile flammable substance in dry	(%)	80.70	89.32
Fixed carbon	(%)	13.54	10.23
Net calorific value	($J \cdot g^{-1}$)	17 347	18 611
Calorific value in dry matter	($J \cdot g^{-1}$)	14 616	17 198
Calorific value in the delivered sample	($J \cdot g^{-1}$)	14 220	15 739
C in dry matter	(%)	45.99	47.67
H in dry matter	(%)	13.25	6.86
N in dry matter	(%)	1.29	0.13
S in dry matter	(%)	< 0.01	< 0.01

Tab. 2: The properties of input raw materials.

Sample		*Reynoutria japonica*	Spruce sawdust
Moisture	(%)	14.11	8.6
Bulk density	($kg \cdot m^{-3}$)	125	148
Sample swatch	(g)	100	100

Generally, for the processing of pellets, it is suitable to use material with a wider range of particle size distribution, which by mutual wedging increases the mechanical resistance of the pellets. The results of the sieve analysis are shown in Fig. 2.

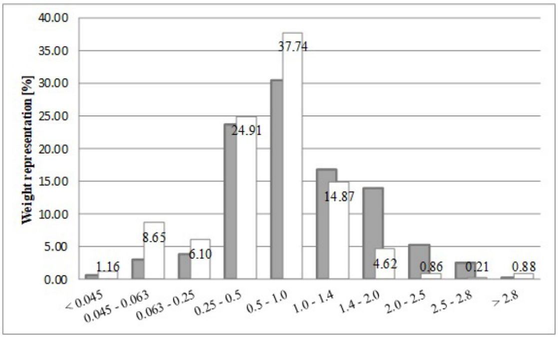

Fig. 2: Sieve analysis for sample Reynoutria japonica and spruce sawdust.
Note: *Reynoutria japonica* Spruce sawdust)

Fig. 2 shows the percentage of individual fractions. *Reynoutria japonica*, contained a larger particle size - from 1 mm, while on the contrary, spruce sawdust contained somewhat finer particles (greater proportion) - up to 1 mm. In this way, the formation of the bonds between the particles and filling the space between them occurs (Steltea et al. 2011).

Six different proportional samples of alternative fuels were made by the pelletization from the feedstock prepared in this way. During the homogenization process, the mixtures were wetted by spraying water to achieve about 15% moisture. The mixing ratio of the prepared samples is shown in Tab. 3. The first sample contains 100% *Reynoutria japonica*, the last one 100% spruce sawdust.

Tab. 3: Prepared samples

Sample	Mixing ratio (%)	
	Spruce sawdust	*Reynoutria japonica*
1	0	100
2	30	70
3	50	50
4	70	30
5	90	10
6	100	0

The determined content of lignin in the test sample was 29.32% for *Reynoutria japonica* and 23.29% for spruce sawdust. Pelletization was carried out without the addition of a binder (Sun and Cheng, 2002).

Outlet pellets of 0.6 cm in diameter and 3 cm in length are shown in Fig. 3. The pellets prepared in this way need to be allowed to cool to ensure that they have sufficient strength. Refrigeration of the pellets due to their maturation was carried out at 6°C for 60 minutes.

Fig. 3: Prepared pellets - Sample 4.

The mechanical properties of the prepared pellets were determined, including mechanical resistance, moisture resistance, hardness and densities. Fig. 4 indicating the dependence of the mechanical resistance of pellets (PDI – Pellets Durability Index) on the *Reynoutria japonica* content shows that the conditions of the standard 17225-6:2014 for mechanical resistance were met, and the percentage loss of PDI ranges on average around 99.25% with a standard deviation of 0.276. The determined mechanical resistance values (PDI) of all samples with *Reynoutria japonica* are consistent with those of other conventional energy grasses (Zajonc et al. 2012). It is possible to make a process prediction that their transport and handling will be problem-free.

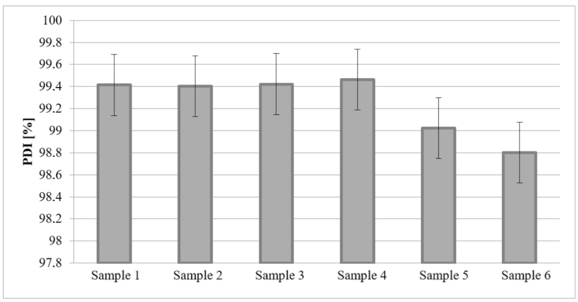

Fig. 4: Mechanical resistance of pellets with standard deviation (PDI).

In addition, water resistance Fig. 5 was found to represent the resistance of pellets to water absorption, which is a decisive factor for the storage and transport of pellets. The ability of the pellet to bind water (moisture adsorption) further influences (decreases) its fuel efficiency.

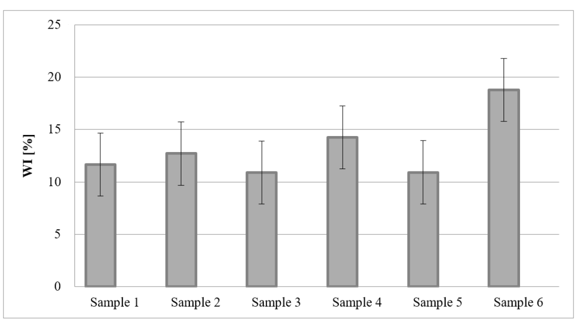

Fig. 5: Water resistance of pellets – Wettability index (WI).

It can be seen from Fig. 5 that pellets with the admixture of *Reynoutria japonica*, are significantly more resistant to moisture than pellets from spruce sawdust. *Reynoutria japonica* reduces the pellet's ability to adsorb water, which positively affects its fuel efficiency. This parameter is closely related to the content of lignin which produces a hydrophobic surface layer during pelletization. With *Reynoutria japonica*, the lignin content was about 6% higher than in the case of spruce sawdust, therefore resistance to moisture is lower and the pellets are more resistant. The resulting hardness values of the individual pellet samples are shown in Fig. 6.

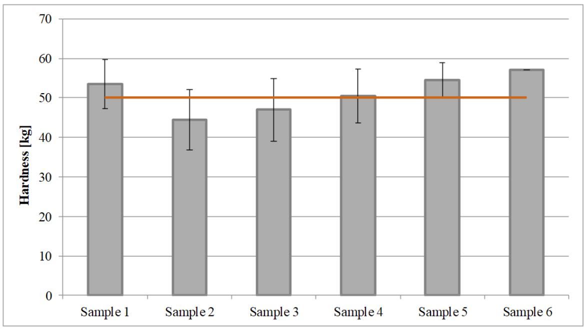

Fig. 6: The hardness of pellets with standard.
Deviation — Average hardness sample 1 - 6

It can be seen from Fig. 6 that pellets with an increasing percentage of spruce sawdust increase their hardness. We can state that the spruce sawdust contained in the pellets increases their strength. The determination of the hardness of pellets is not normative in nature and the values can therefore only be compared relatively. The measured data shows that the pellets produced have sufficient strength. Particles density values of pellets for different ratios are recorded in Fig. 7.

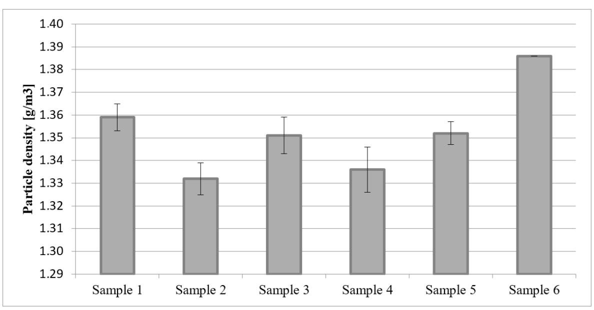

Fig. 7: Particle density of pellets with standard deviation.

Samples 1-5, including *Reynoutria japonica*, are lighter than sample 6 at the same volume (spruce sawdust alone). The resulting bulk density values of the pellet samples are shown in Fig. 8. The pellets containing solely *Reynoutria japonica* reached the highest value of bulk density. The higher the value of bulk density is, the higher their energy density becomes and the lesser transport and storage costs are. Therefore, a high bulk density is to be aspired from the economic point of view. The density values tendency of samples was similar as in case of harness of pellets (Fig. 6). By successive addition of spruce sawdust the bulk density value which indicated its minimum in case of the sample No. 2 (containing 30% of sawdust), was growing and got stabilized in the sample No. 4 (containing 70% of sawdust). The value did not alter significantly any further by subsequent addition of sawdust.

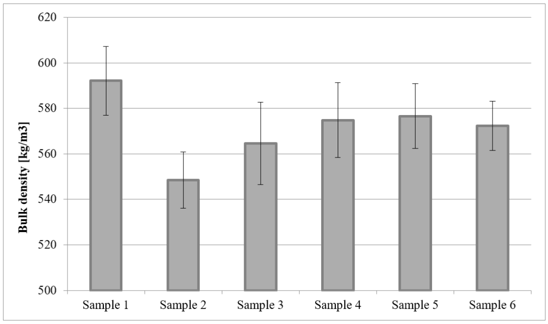

Fig. 8: Bulk density of pellets with standard deviation.

From the above results, it is clear that *Reynoutria japonica*, is able to be pelleted and, with the addition of spruce sawdust, it can probably be used as a fuel.

The final evaluation of pellets was performed in terms of energy parameters. Tab. 4 also compares the energy values of other alternative fuels (Jevic 2008)

Tab. 4: Ash melting temperature.

Type of fuel	Deformation temperature (°C)	Softening temperature °C)	Melting temperature (°C)	Flow temperature (°C)
Reynoutria japonica	700	-	-	850
Spruce sawdust*	1044	1052	1257	1267
Brown coal*	1260	1280	1360	1500
Wheat Straw*	612	767	1044	1257
Rape straw*	633	665	1452	1460

* The values of spruce sawdust, energy crops and lignite were taken from article (Jevic 2018)

The measured values show the low deformation temperature of *Reynoutria japonica* ash, starting at 700°C, that is, immediately upon insertion into the furnace. At the temperature of 813°C, the input sample begins to deform. The difference between deformation and ash flow temperatures is 150°C where the flow temperature is set at 850°C. Alkaline content is presented in Tabs. 5 and 6. Alkaline metals, especially sodium and potassium, naturally occur in the biomass at a higher concentration than in other fuels.

Tab. 5: Water extract in the dry matter of Reynoutria japonica.

Sample	pH	Conductivity	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	$(SO_4)^{2-}$
		(mS·cm^{-1})	(g·kg^{-1})	(g·kg^{-1})	(g·kg^{-1})	(g·kg^{-1})	(g·kg^{-1})	(g·kg^{-1})
Reynoutria japonica	6.71	2.14	0.0842	3.9048	0.9233	0.3056	2.0560	0.7930

Tab. 6: Water extract of Reynoutria japonica ash.

Sample	pH	Conductivity	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	$(SO_4)^{2-}$
		($mS \cdot cm^{-1}$)	($g \cdot kg^{-1}$)	($g \cdot kg^{-1}$)	($g \cdot kg^{-1}$)	($g \cdot kg^{-1}$)	($g \cdot kg^{-1}$)	($g \cdot kg^{-1}$)
Reynoutria japonica	10.50	61.4	1.692	191.667	0.8394	0.5093	36.3760	21.60

The water extract tables show an increase in alkali metal elements, as well as chlorine, determined from ash versus the original condition of *Reynoutria japonica*. Primarily, potassium and sodium concentrations increased by about 50 times in the case of K+ and 20 times in the case of Na+ (Vermont Grass Energy Partnership 2011). Problem parameters of the alkali metal content decrease the melting point and thus cause ash caking. The concentration of chlorine in ash rose by about seventeen times. The chlorine content may cause HCl and KCl to cause corrosion inside the combustion plant (Keown 2005). Alkaline earth metals have higher melting and boiling temperatures and also higher densities than alkali metals.

By operating tests, the beneficial effects of additives with a high concentration of CaO (calcium oxide) have been proven. It has also been shown that ash from spruce sawdust contains a higher percentage of calcium than pine chips, see Tab. 7 (Long 2012).

Tab. 7: Composition of ash from different types of sawdust.

Fuel	CaO	MgO	K_2O	P_2O^5
	(%)	(%)	(%)	(%)
Spruce	45.17	7.89	8.61	10.59
Pine	31.62	4.17	6.99	4.74

It can therefore be assumed that the addition of a suitable additive or spruce sawdust with a high CaO content to *Reynoutria japonica* will reduce or possibly eliminate problems with caking (Academic Pr 2015).

CONCLUSIONS

The aim of this work was the utilization of waste biomass, which is made of commonly available spruce sawdust and the invasive plant species *Reynoutria japonica*, for energy purposes. The work briefly and clearly introduces the invasive nature of this plant and presents the technology of pelleting biomass for energy purposes. The following findings were found in the production of pellets.

Pelletizing of this type of raw material does not require any additional binders. Furthermore, it was found that it was not necessary for the original sample of *Reynoutria japonica* to be dried immediately after collection, as its moisture input was sufficient for the pelletization process. During homogenization of spruce sawdust samples with *Reynoutria japonica*, the mixtures were only slightly wetted.

The collection of information on energy parameters and required standardized biofuel properties shows that the output pellets mentioned in this work meet these requirements. All the samples met the calorific value of the dry matter above 10 MJ.

The measured calorific value of 14.61 $MJ \cdot kg^{-1}$ for *Reynoutria japonica* shows the potential for using this biomass as an alternative fuel. The available scientific articles and literature for *Reynoutria japonica* indicate the calorific value in the range of 18.52 to 19.5 $MJ \cdot kg^{-1}$ (Stolarski et al. 2014). This lower, yet sufficient calorific value could be due to, for example, the harvest time.

By studying the mechanical properties of the pellets, the following results were evaluated for this work. The pellets meet the standard ISO 17225-6:2014 which gives the lowest limit of mechanical resistance.

The average hardness of the pellet samples ranged around the limit of 50 kg. By testing the hardness of the pellets, it was found that the higher proportion of spruce sawdust (wood) contained in the pellets increases their hardness. In the case of the assessment of the moisture resistance parameter (WI), the positive influence of the *Reynoutria japonica* content was observed, namely that the spruce pellets with its higher proportion absorbed less water.

Part of the work was also the primary energy evaluation of the prepared pellet samples. With the development of the use of alternative fuels and biofuels, especially of plant origin, there has been a problem with the caking of the ash of these fuels in the combustion chamber space and sticking on the heat exchange surfaces of furnaces. The problem consists in free oxides (SiO_2, CaO, Na_2O, K_2O), and chlorides. The TTP and *Reynoutria japonica* ash water extract analyses show that the parameters for combusting *Reynoutria japonica*, are not suitable. The plant has a low ash melting temperature of only 850°C, as well as a high alkali metal content in its ash that contributes to the formation of inks and sinters in furnaces. It should be noted that *Reynoutria japonica*, cannot be used separately for energy purposes. Choosing the appropriate harvest time may affect the ash content, nitrogen, chlorine, and calorific value parameters. The negative phenomenon of the formation of inks in furnaces can be eliminated by lowering the K_2O content or increasing the CaO content in the fuel. This can be achieved, for example, by mixing corresponding biomass types, such as spruce sawdust containing up to 45% of CaO, and better results for the use of *Reynoutria japonica*, in power engineering can be assumed.

It is therefore appropriate to continue to address this issue of waste biomass and the invasive species of *Reynoutria japonica*, to exploit its energy potential to ensure safe and, above all, effective disposal. Further development of the research and testing will be focused on testing suitable mixtures of fuel spruce sawdust and *Reynoutria japonica* to promote their calorific value, while appropriately selected raw materials or additives will compensate for the shortcomings of *Reynoutria japonica*.

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REFERENCES

1. Bradley, D., R. Hess, J. Jacobson, L. Ovard, 2011: The wood pellet industry and market in North America Glob. Wood Pellet Industry: Mark. Trade Study IEA, Bioenergy Task, 40 pp.
2. Cerny, Z., J., Neruda, F., Vaclavik, 1998: Invasive plants and basic ways of their disposal. Institute of Education and Education of the Ministry of Agriculture of the Czech Republic. Prague, 43 pp.

3. Commission Implementing Regulation (EU) 2016/1141 of 13 July 2016 adopting a list of invasive alien species of Union concern pursuant to Regulation (EU) No 1143/2014 of the European Parliament and of the Council.
4. Council Regulation (EC) No 139/2004 of 20 January 2004 on the control of concentrations between undertakings (the EC Merger Regulation) (Text with EEA relevance).
5. GBIF Secretariat, 2017: *Reynoutria japonica* Houtt. GBIF Backbone Taxonomy.
6. Gil, M., Schott, D., Arauzo, I., Teruel, E., 2013: Handling behavior of two milled biomass: SRF poplar and corn stover, Fuel Processing Technology 112: 76-85.
7. ISO 14780, 2017: Solid biofuels – Sample preparation.
8. ISO 1782, 2015: Solid biofuels – Determination of length and diameter of pellets.
9. ISO 17827-2, 2016: Solid biofuels – Determination of particle size distribution for uncompressed fuels - Part 2: Vibrating screen method using sieves with aperture of 3.15 mm and below.
10. ISO 17828, 2015: Solid biofuels – Determination of bulk density.
11. ISO 1783-1, 2015: Solid biofuels – Determination of mechanical durability of pellets and briquettes – Part 1: Pellets.
12. ISO 18134-3, 2015: Solid biofuels – Determination of moisture content – Oven dry method – Part 3: Moisture in general analysis sample.
13. ISO 18135, 2017: Solid Biofuels – Sampling.
14. ISO 18847, 2016: Solid biofuels – Determination of particle density of pellets and briquettes.
15. Jevic, P.; Hutla, P.; Sediva, Z., 2008: Sustainable production and quality management of solid fuels based on agro-organic products: Methodological handbook of the Czech ministry of agriculture (online). Prague Ruzyne: Research Institute of Agricultural Technology, v.v.i.
16. Jezerska, L., Zajonc, O., Rozbroj, J., Vyletelek, J., Zegzulka, J., 2014: Research on effect of spruce sawdust with added starch on flowability and pelletization of the material, IERI Procedia 8:154-163.
17. Jezerska, L., Zajonc, O., Vyletelek, J., Zegzulka, J., 2016: Mechanical material properties effect on pelletization, Wood research (2): 307 – 320.
18. Kahia, Montassar, Mohamed Kadria, Mohamed Safouane Ben Aissa, Charfeddine Lanouar, 2017: Modelling the treatment effect of renewable energy policies on economic growth: Evaluation from MENA countries, Journal of Cleaner Production 149: 845-855.
19. Keown, D. M., Favas, G., Hayashi, J., Li, Cz, 2005: Volatilisation of alkali and alkaline earth metallic species during the pyrolysis of biomass, Bioresource Technology 96(14): 1570-1577.
20. Klessmann, C., A., Held, M., Rathmann, M., Ragwitz, 2011: Status and perspectives of renewable energy policy and deployment in the European Union - What is needed to reach the 2020 targets, Energy policy 39(12): 7637-7657.
21. Lehtikangas, P., 2001: Quality properties of pelletised sawdust, logging residues and bark, Biomass and Bioenergy 20(5): 351-360.
22. Lindley, J. A., Vossoughi, M., 2008: Physical properties of biomass briquettes. Transactions of the ASAE, American Society of Agricultural Engineers 32: 2-5.
23. Long, J., Song, H., Jun, X., Sheng, S., Lun-Shi, S., Kai, X., Yay, Y, 2012: Release characteristics of alkali and alkaline earth metallic species during biomass pyrolysis and steam gasification process, Bioresource Technology 116: 278-284.
24. Mandak B., Pysek, P., Bimova, K., 2004: History of the invasion and distribution of Reynoutria taxa in the Czech Republic: a hybrid spreading faster than its parents Preslia 76: 15–64.

25. Mani, S., Tabil L. G., Sokhansanj, S., 2006: Specific energy requirement for compacting corn stover, Bioresource Technology 97(12): 1420-1426.
26. Regulation (EU) No 1143/2014 of the European Parliament and of the Council of 22 October 2014 on the prevention and management of the introduction and spread of invasive alien species
27. Rudolfsson, M., Stelte, W., Lestander, T. A., 2015: Process optimization of combined biomass torrefaction and pelletization for fuel pellet production – A parametric study, Applied Energy 140: 378-384.
28. Shahrukh, H., Oyedun, A. O., Kumar, A., Ghiasi, B., Kumar, L., Sokhansanj, S., 2015: Net energy ratio for the production of steam pretreated biomass-based pellets, Biomass and Bioenergy 80(9): 286-297.
29. Sladky, V., 2013: *Reynoutria japonica* as an energy crop. Biom.cz.
30. Steltea, W., Holmb, J. K., Sanadic, A. R., Barsbergc, S., Ahrenfeldta, J., Henriksena, U. B., 2011: Fuel pellets from biomass: The importance of the pelletizing pressure and its dependency on the processing conditions, Fuel. 90 (11): 3285-3290.
31. Stolarski, M., J.,Krzyżaniak,M., Śnieg, M., Słomińska, E., Piórkowski, M., Filipkowski, R., 2014: Thermophysical and chemical properties of perennial energy crops depending on harvest period, International Agrophysics 28(2): 201-211.
32. Sun Y, Cheng J, 2002: Hydrolysis of lignocellulose materials for ethanol production: a review, Bioresour Technol. 83(1):1-11.
33. Technical assessment of grass pellets as boiler fuel in Vermont, 2011: Vermont Grass Energy Partnership, 52 pp.
34. Tumuluru, J. S., Wright, Ch. T., Hess J. R., Kenney, K. L., 2011: A review of biomass densification systems to develop uniform feedstock commodities for bioenergy application, Biofuels, Bioproducts and Biorefining 5(6): 683 - 707.

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