

ENERGETIC PROPERTIES OF GREEN WOOD CHIPS FROM *SALIX VIMINALIS* GROWN ON PLANTATIONS*

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In the present paper, energetic properties of wood chips of the species *Salix viminalis* (clones Inger, Tordis, Sven, RAPP and ORM) were determined, namely the share of bark in chips, chemical composition of combustibles of chips, ash content in dry mass of biofuel, and lower heating value. Green wood chips made of dendromass from plantations consist of juvenile wood and juvenile bark. The share of juvenile bark in green wood chips of the analyzed clones of willow is $X_B = 17.16 \pm 1.12\%$. The nitrogen content in green wood chips made of *Salix viminalis* trees grown on plantation is 3.3 times higher than the nitrogen content in the combustibles of fuelwood of *Fagus sylvatica*, which has negative impact on the production of emissions – concentration of nitrogen oxides NOx in combustion products. The share of inorganic substances determined by the form of ash content $A^d = 0.94\%$ puts the analyzed biofuel into the category of low-ash fuels. The lower heating value of green wood chips of the individual *Salix viminalis* clones analyzed in dry state is $Q_n = 18.2 \text{ MJ.kg}^{-1}$.

biofuel; green wood chips; *Salix viminalis*; combustibles; ash; lower heating value

INTRODUCTION

The wood of broad-leaved trees in dry state is, according to the European standard EN 14961-1 (2010) on solid biofuels, characterized by an average lower heating value ($Q_n^d = 18.9 \text{ MJ.kg}^{-1}$), high share of volatile combustibles, and low ash content ($A^d = 0.3\%$).

In the last three decades, significant effort has been exerted in Central Europe to increase the production of wood biomass for energy purposes by establishing numerous plantations of short rotation coppices with the production of wood biomass reaching annually at least 10 t in dry state per 1 ha.

According to Varga, Godó (2002), Jandačka et al. (2007), Trenčianský et al. (2007), Malaťák, Vaculík (2008), Čížková et al. (2010), Liebhart (2010), Varga, Bartko (2010), Otepka, Haban (2011), Spinelli et al. (2011), the most suitable short rotation coppices grown for energy purposes on Central European plantations are *Robinia pseudoacacia* L., various clones of *Populus*, *Salix alba* L., and various *Salix viminalis* clones.

According to the method of the plantations establishment and the growing period of trees, the plantations of fast-growing trees are divided into plantations

with harvest time under 5 years (mini rotation), 5–10 years (midi rotation), and 10–20 years (maxi rotation) (Simanov, 1995). The goal of the dendromass production on plantations with the 10–20-year harvest time is the production of fibre for cellulose, paper industry and plywood, feedstock for chipboards, and branches for chips for the energy sector.

Green wood chips made of dendromass from trees grown on plantations are a two-component biofuel consisting of juvenile wood and juvenile bark. The objective of the study was to determine the energetic and environmental properties of green wood chips made of *Salix viminalis*, clones Inger, Tordis, Sven, RAPP, and ORM. The following properties were investigated: share of bark in wood chips, elementary chemical composition of the combustibles of wood chips, ash content in dry mass of the biofuel, lower heating value of the biofuel, and concentration of nitrogen oxides in combustion products.

MATERIAL AND METHODS

Samples of green wood chips (juvenile wood and juvenile bark), which were used to determine the energetic properties of individual clones, were taken from

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4- and 5-year-old willow. Trees of *Salix viminalis* (clones Inger, Tordis, Sven) were acquired from a plantation near Lublica located in eastern Slovakia. Clones RAPP and ORM were acquired from the plantation of the Grassland and Mountain Agriculture Research Institute in Banská Bystrica, research station Nižná na Orave.

The share of bark in green wood chips of individual *Salix* clones was determined in a laboratory, according to the Slovak technical standard STN 48 005 8 (2004) Assortments of wood – Chips and sawdust of hardwood. The share of bark in the sample was calculated using the formula:

$$X_B = \frac{m_B}{m_{CH}} \cdot 100 \quad (\%) \quad (1)$$

where:

m_B = weight of bark in the chips sample (g)

m_{CH} = weight of the chips sample (g)

The value of expanded uncertainty of determination of bark share in green wood chips at the limit of conventional statistical certainty of 95% is quantified by the formula:

$$U_B = 2 \cdot \sqrt{u_A^2 + u_B^2} \quad (\%) \quad (2)$$

where:

u_A = standard uncertainty type A (%)

u_B = standard uncertainty type B (%)

Analysis of the biofuel combustibles – samples of juvenile wood and juvenile bark of individual clones – was carried out in the Central Forestry Laboratory of the National Forestry Institute in Zvolen. The contents of carbon C^{daf} , hydrogen H^{daf} , and nitrogen N^{daf} (%) in the combustible of juvenile wood and juvenile bark of selected clones was determined using an elemental analyzer FlashEA 1112 NC (Thermo Electron S.p.A., Rodano, Italy), Fig.1. The oxygen content in the combustible of the samples was determined with the assumption of zero sulphur content ($S^{daf} = 0$ (appearance in trace amounts)) in the dendromass and its combustibles, according to the following formula:

$$O^{daf} = 100 - C^{daf} - H^{daf} - N^{daf} \quad (\%) \quad (3)$$

where:

C^d = carbon content in the combustible of the sample (%)

H^d = hydrogen content in the combustible of the sample (%)

N^d = nitrogen content in the combustible of the sample (%)

Chemical composition of the combustible – green wood chips consisting of juvenile wood and juvenile bark was determined by a calculation based on the share of wood and bark in chips and the measured content of the individual chemical elements of the combustibles in wood and bark according to the following formulae:

$$\begin{aligned} C_{CH}^{daf} &= \left(\frac{100 - X_B}{100} \right) C_W^d + \frac{X_B}{100} C_B^{daf} \\ H_{CH}^{daf} &= \left(\frac{100 - X_B}{100} \right) H_W^{daf} + \frac{X_B}{100} H_B^{daf} \\ N_{CH}^{daf} &= \left(\frac{100 - X_B}{100} \right) N_W^{daf} + \frac{X_B}{100} N_B^{daf} \\ O_{CH}^{daf} &= \left(\frac{100 - X_B}{100} \right) O_W^{daf} + \frac{X_B}{100} O_B^{daf} \end{aligned} \quad \% \quad (4)$$

where:

C_{CH}^{daf} , H_{CH}^{daf} , N_{CH}^{daf} , O_{CH}^{daf} = carbon, hydrogen, nitrogen, and oxygen content in the combustible of chips (%)

C_W^{daf} , H_W^{daf} , N_W^{daf} , O_W^{daf} = carbon, hydrogen, nitrogen, and oxygen content in the combustible of juvenile wood (%)

C_B^{daf} , H_B^{daf} , N_B^{daf} , O_B^{daf} = carbon, hydrogen, nitrogen, and oxygen content in the combustible of juvenile bark (%)

X_B = share of bark in chips (%)

Quantification of ash content from juvenile wood and juvenile bark was carried out in a laboratory according to ISO 1171 (2010) Solid mineral fuels – Determination of ash. The ash content from the dry mass of green wood chips is determined by a calculation based on the shares of bark and wood in dendromass and the average share of ash in analyzed samples of juvenile wood and juvenile bark of green wood chips according to the formula:

$$A_{CH}^d = \left[\frac{100 - X_B}{100} \right] A_W^d + \frac{X_B}{100} A_B^d \quad (\%) \quad (5)$$

where:

A_W^d = ash content from dry mass of juvenile wood samples (%)

A_B^d = ash content from dry mass of juvenile bark samples (%)

X_B = share of bark in chips (%)

Lower heating value of juvenile wood, juvenile bark, and green wood chips from the dendromass of analyzed clones of *Salix* grown on plantations is determined on the basis of chemical composition of the combustibles and the ash content in dry mass of the biofuel according to the formula by M.I. Mendeleev (Perelygin, 1965; Golovkov et al., 1987):

$$Q_n^d = \left[339 C^{daf} + 1029.8 H^{daf} - 108.8 O^{daf} \right] \left[\frac{100 - A^d}{100} \right] \quad (\text{kJ} \cdot \text{kg}^{-1}) \quad (6)$$

where:

C^{daf} = carbon content in the combustible of biofuel (%)

H^{daf} = hydrogen content in the combustible of biofuel (%)

O^{daf} = oxygen content in the combustible of biofuel (%)

A^d = ash content in biofuel (%)

The concentration of the so-called fuel nitrogen oxides in combustion products released from the boiler into the atmosphere is described by the following equation (Dzrenda, 2004):

Table 1. Chemical composition of the combustible and the ash content of juvenile wood and juvenile bark of analyzed clones of *Salix viminalis*

Juvenile wood - a component of green wood chips made of <i>Salix viminalis</i> grown on plantations							
Clone	samples	XW ±UW	Cdaf ±UC [%]	Hdaf±UH [%]	Odaf±UO [%]	Ndaf ±UN [%]	Ad ±UA [%]
Inger	15	82.55 ± 0.88	48.85 ± 0.97	6.32 ± 0.25	44.45 ± 0.88	0.38 ± 0.02	0.61 ± 0.02
Tordis	14	84.58 ± 2.16	49.44 ± 0.98	6.26 ± 0.25	43.95 ± 0.87	0.35 ± 0.02	0.65 ± 0.03
Sven	15	82.61 ± 1.08	49.18 ± 0.91	6.36 ± 0.25	44.09 ± 0.87	0.37 ± 0.02	0.67 ± 0.04
RAPP	16	83.20 ± 1.38	49.09 ± 0.98	6.43 ± 0.25	44.16 ± 0.88	0.32 ± 0.02	0.21 ± 0.03
ORM	15	81.26 ± 1.13	49.22 ± 0.96	6.24 ± 0.25	44.02 ± 0.90	0.32 ± 0.02	0.20 ± 0.04
Average	75	82.84 ± 1.23	49.20 ± 0.96	6.32 ± 0.25	44.13 ± 0.88	0.35 ± 0.02	0.47 ± 0.03
Juvenile bark - a component of green wood chips made of <i>Salix viminalis</i> grown on plantations							
Clone	samples	XB ±UB	Cdaf ±UC [%]	Hdaf±UH [%]	Odaf±UO [%]	Ndaf ±UN [%]	Ad ±UA [%]
Inger	15	17.45 ± 0.97	49.41 ± 0.95	6.06 ± 0.23	42.75 ± 0.82	1.78 ± 0.08	3.47 ± 0.27
Tordis	14	15.42 ± 2.36	49.80 ± 0.97	6.22 ± 0.24	42.23 ± 0.82	1.75 ± 0.08	3.20 ± 0.18
Sven	15	17.39 ± 1.63	49.63 ± 0.96	6.24 ± 0.24	42.40 ± 0.82	1.73 ± 0.08	3.21 ± 0.18
RAPP	16	16.80 ± 0.65	50.19 ± 0.97	6.30 ± 0.24	42.24 ± 0.82	1.27 ± 0.07	3.24 ± 0.19
ORM	15	18.74 ± 0.59	49.39 ± 0.96	6.12 ± 0.24	42.73 ± 0.83	1.76 ± 0.08	2.93 ± 0.15
Average	75	17.16 ± 1.12	49.67 ± 0.96	6.19 ± 0.24	42.48 ± 0.82	1.66 ± 0.08	3.21 ± 0.19

$$C_{\max NO_2} = X_N \cdot \frac{3.2857 \cdot N_{CH}^{daf}}{[1.8555 \cdot C_{CH}^{daf} + 0.7905 \cdot V_{air} + (\lambda - 1) \cdot V_{air}]} \quad (\text{kg} \cdot \text{m}_n^{-3}) \quad (7)$$

where:

X_N = conversion rate of fuel nitrogen into nitrogen oxides NOx (-)

C_{CH}^{daf} = carbon content in the combustible of chips (-)

H_{CH}^{daf} = hydrogen content in the combustible of chips (-)

V_{air} = stoichiometric consumption of air for combustion of 1 kg of green wood chips ($\text{m}_n^{-3} \text{kg}^{-1}$)

λ = surplus of combustion air (-)

RESULTS

The share of bark in analyzed samples of green wood chips of the individual species is shown in Fig. 2.

The average value of the share of bark in green wood chips of analyzed clones of osier willows grown on plantations is $X_B = 17.16 \pm 1.12\%$.

The shares of juvenile wood and juvenile bark, chemical composition of the combustible, and the ash content of individual components of green wood chips of *Salix viminalis* analyzed clones are shown in Table 1.

The applied Multivariate Analysis of Variance (MANOVA) shows a significant difference in the ni-

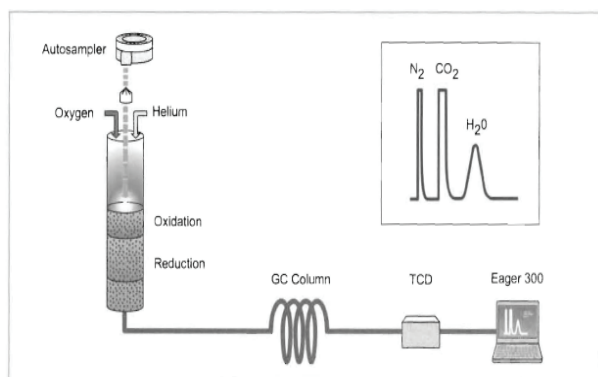


Fig. 1. Scheme of FLASH EA 1112 device

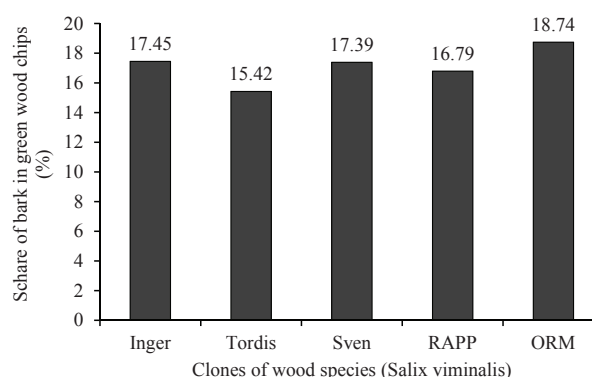


Fig. 2. Share of bark in green wood chips of analyzed clones of *Salix viminalis*

Table 2. Energetic properties of green wood chips and their components from dendromass of *Salix viminalis* grown on plantations

Component (i)	Samples	Xi	C ^{daf} [%]	H ^{daf} [%]	O ^{daf} [%]	N ^{daf} [%]	A ^d [%]	Q _n [kJ/kg]
Wood	75	82.84	49.20	6.32	44.13	0.35	0.47	18 286.8
Bark	75	17.16	49.67	6.19	42.48	1.66	3.21	17 991.0
Chips	150	100.00	49.28	6.29	43.85	0.58	0.94	18 236.1

nitrogen contents and ash content between the juvenile wood and juvenile bark in green wood chips ($P < 0.05$ for all the variables).

Average chemical composition of the combustible, ash content, and lower heating value of green wood chips and their components from dendromass of analyzed clones of *Salix viminalis* grown on plantations are shown in Table 2.

Concentration of nitrogen oxides emitted into the air by combustion products from combustion of green wood chips of *Salix viminalis* in furnaces, with surplus of combustion air $\lambda = 2.1$ and conversion rate of fuel nitrogen into nitrogen oxides X_N , is shown in Fig. 3. As reported e.g. by Guzendá, Swigon (1997) and Pleckaitine, Buinevičius (2011), the conversion rate of fuel nitrogen $X_N = 0.149 N^{-0.559}$ is an function of nitrogen conversion in fuel into oxides. Fig. 3 shows the nitrogen concentration in combustion products from combustion of wood of coniferous trees with nitrogen content in biofuel $N = 0.03\%$, fuelwood of broad-leaved trees with nitrogen content $N = 0.16\%$ and nitrogen content in green wood chips $N = 0.58\%$.

DISCUSSION

The experiments dealing with the share of bark in green wood chips show that the average share of bark in chips of the individual analyzed clones of willows grown on plantations is $X_B = 17.16 \pm 1.12\%$. The shares of bark in green wood chips of all clones were below the limit value $X_K \leq 30\%$ given by the Slovak technical standard STN 48 0058 (2004). Compared to green wood chips made of dendromass from 4- to 6-year-old trees of clones grown on plantations (Max 5, Oxford, AF 2, Monviso of wood species *Populus*), the share of bark in analyzed chips is lower by 5% (Dzurená, Zoliak, 2012).

The values of share of bark in biofuel – green wood chips made of trees grown on plantations with short harvest time are 1.5 to 2.6 times higher than the share of bark in dendromass of soft broad-leaved trees. This statement is in accordance with the knowledge of the dependence of share of bark on the diameter of trees (Pozgay et al., 1997), as well as with the knowledge of share of bark in dendromass in dependence on the age of trees as stated by Golovkov et al. (1987), Varga, Bartko (2010), Picchio et al. (2012).

From the comparison of chemical composition of green wood chips of *Salix viminalis* consisting of juvenile wood and juvenile bark with the chemical composition of fuel wood from *Fagus sylvatica* L. it follows that the combustibles of chips of willows grown on plantations differ due to noticeably higher nitrogen content – endothermic component of the biofuel combustibles. The nitrogen content in combustibles of chips of willow clones is 3.3 times higher than the nitrogen content in combustibles of beech fuel wood. This higher nitrogen content is caused by the presence of proteins and amino acids in cambial cells and chlorophyll in surface tissues of juvenile bark (Dzurená, Zoliak, 2011).

This fact is negatively reflected in the increase of emission production – concentration of nitrogen oxides NOx in combustion products released into atmosphere. Concentration of NOx in combustion products from combustion of green wood chips of fast-growing willow is 1.8 times higher than the NOx concentration from combustion of fuelwood of broad-leaved trees and 3.2 times higher than the NOx concentration from combustion of fuelwood of coniferous trees (Dzurená, 2008; Macejny, 2009).

A higher ash content in bark of the analyzed clones of *Salix viminalis* than in the wood of this species supports the known facts (Table 1). As a new fact can be considered the determination of the ash content in dry mass of green wood chips, the value for the analyzed clones of *Salix viminalis* being $A^d = 0.94\%$. This value is 2–3 times higher than the value of the ash content from wood of broad-leaved trees (Perelygin, 1965; Blažej, 1975; Golovkov et al., 1987; Simanov,

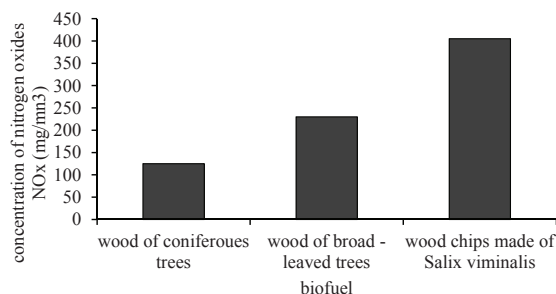


Fig. 3. Concentration of nitrogen oxides in combustion products from fuelwood of coniferous trees, broad-leaved trees, and green wood chips made of *Salix viminalis*

1995; Dzurenda, Jandačka, 2010). Despite this fact, green wood chips from willows grown on plantations belong to the group of low-ash fuels.

The lower heating value of green wood chips of analyzed clones of *Salix* in dry state, determined by formula (5), is $Q_n = 18.2 \text{ MJ.kg}^{-1}$. It is a value comparable with the lower heating values of the chips of the willow clones ORM and ULV, which have been determined from experimentally measured higher heating value reported by Dzurenda et al., 2009, 2010. This value, if compared with the lower heating value of broad-leaved trees stated in EN 14961-1 (2010), is by 3.7% lower. This difference is caused by an increased content of inorganic compounds (ash) in chips made of dendromass of fast growing trees grown on plantations, as well as by the increased nitrogen content – endothermic component of the combustibles of biofuel.

CONCLUSION

Based on the experimental research we may conclude that the green wood chips made of dendromass from osier willow clones Inger, Tordis, Sven, ULV, and ORM grown on plantations consist of juvenile wood and juvenile bark with the share of juvenile bark $X_B = 17.16 \pm 1.12\%$. The combustibles of the green wood chips differ in chemical composition from the combustibles of the fuel wood of *Fagus sylvatica* L. by a higher nitrogen content. The content of nitrogen – the endothermic component of the combustibles in the green wood chips made of trees grown on plantations – is 3.3 times higher than the nitrogen content in the combustibles of the fuel wood of European Beech. From the environmental aspect, this fact points to an increase of emission production – concentration of nitrogen oxides NO_x in combustion products.

The content of inorganic compounds in green wood chips of analyzed willow clones ($A^d = 0.94\%$) places this biofuel into the group of low-ash fuels. The average value of the ash content in the green wood chips of the analyzed clones of *Salix viminalis* is 2–3 times higher than the ash content in wood of broad-leaved trees.

The lower heating value of green wood chips of the analyzed clones of *Salix viminalis* in dry state is $Q_n = 18.2 \text{ MJ.kg}^{-1}$. Compared with the lower heating value of broad-leaved trees given in the European standard EN 14961-1 (2010), it is by 3.7% lower.

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