Ladislav Dzurenda, Jarmila Geffertova, Vladimir Hecl[1]

Energy Characteristics of Wood-Chips Produced from *Salix Viminalis* - Clone ULV

Energijska obilježja iverja proizvedenoga od drva *Salix viminalis* – klona ULV

Original scientific paper · Izvorni znanstveni rad
Received – prispjelo: 11. 11. 2009.
Accepted – prihvaćeno: 24. 2. 2010.
*UDK: 630*831.1; 630*861.02*

ABSTRACT • *This article explores the energy characteristics of wood-chips produced from* Salix viminalis - *clone ULV, which was cultivated in an energy plantation.*
The higher heating value of wood and bark of Salix viminalis *was assessed through an experimental measurement in a special calorimeter for solid fuels, model IKA C 200. The lower heating value of wood and bark was calculated from the higher heating value* Q_s, *taking into account hydrogen* H^{daf} *and water content* W_r *in fuel samples that were assessed in a laboratory.*
The higher heating value and lower heating value of a dry Salix viminalis *wood* (Q_{SW} = 19 520 kJ/kg *and* Q_{nW} =18 044 kJ/kg) *were assessed by these analyses. The higher heating value and lower heating value of a dry Salix viminalis bark were also assessed* (Q_{SB} = 19 389 kJ/kg, *and* Q_{nB} = 17 997 kJ/kg).
The share of bark of 19.35 % was assessed in wood-chips produced from Salix viminalis - *clone ULV, in accordance with the Slovak Technical Norm STN 48 0058 for wood assortments, wood chips containing leaves, and sawdust.*
The lower heating value of wood chips produced from Salix viminalis - *clone ULV in dry state was calculated, based on the lower heating value of salix wood, the lower heating value of salix bark, and the share of bark in wood chips as a weighted average* $Q_{n\ CH}$ = 18 035 kJ/kg.

Keywords: *higher heating value, lower heating value, salix wood and bark, wood chips, energy plantations*

SAŽETAK • *U radu se prikazuju istraživanja energijskih obilježja iverja proizvedenoga od drva* Salix viminalis – *klona ULV, koje se plantažno uzgaja. Gornja ogrjevna vrijednost drva i kore određena je mjerenjem uz pomoć kalorimetra za čvrsta goriva, model IKA C 200. Donja ogrjevna vrijednost drva i kore izračunana je iz gornje ogrjevne vrijednosti* Q_s, *uzimanjem u obzir sadržaj vodika* H^{daf} *i sadržaja vode koji su određeni na uzorcima u laboratoriju.*
Provedenim analizama dobivene su gornje i donje ogrjevne vrijednosti suhog drva Salix viminalis – *klona ULV* (Q_{SW} = 19 520 kJ/kg i Q_{nW} =18 044 kJ/kg). *Također su dobivene i gornja i donja ogrjevna vrijednost kore drva* Salix viminalis – *klona ULV* (Q_{SB} = 19 389 kJ/kg, i Q_{nB} = 17 997 kJ/kg).
Određen je udjel kore u iverju proizvedenome od drva Salix viminalis – *klona ULV prema normi STN 48 0058 i iznosi 19,35 %. Donja ogrjevna vrijednost iverja proizvedenoga od drva* Salix viminalis – *klona ULV u suhom stanju izračunana je na bazi donje ogrjevne vrijednosti drva i donje ogrjevne vrijednosti kore te udjela kore u iverju, a dobivena je vrijednost* $Q_{n\ CH}$ = 18 035 kJ/kg.

Ključne riječi: *gornja ogrjevna vrijednost, donja ogrjevna vrijednost, drvo i kora* Salix viminalis – *klona ULV, drvno iverje, energijske plantaže*

[1] The authors are professor and assistants at the Faculty of Wood Sciences and Technology, Technical University in Zvolen, Republic of Slovakia.
[1] Autori su profesor i asistenti Fakulteta znanosti o drvu i drvne tehnologije Tehničkog sveučilišta u Zvolenu, Republika Slovačka.

1 INTRODUCTION
1. UVOD

Wood, and wood residues from forestry and wood processing industry, can be used as a fuel. Wood fuel has an average higher heating value, a high share of siccative combustibles and a low content of ash. It is an important renewable energy source.

Numerous plantations of short rotation coppice have been stablished in Central Europe in the last thirty years, mainly to increase production of biomass for production of energy. A minimum annual production of biomass from these plantations was 10 m^3/ha. According to several studies (Varga and Godó, 2002; Trenčiansky *et al*, 2007; Habovštiak and Daniel, 2005) the most suitable short rotation coppice for energy production in the Central Europe are acacia (*Robinia psedoacacia* L.), selected poplar clones (*Populus*), and salixes (*Salix alba* L., *Salix viminalis*).

The Grassland and Mountain Agriculture Research Institute in Banska Bystrica, Slovakia, has been cultivating short rotation coppice on low productive agricultural soils for several years. At its research station in the city of Nižna in the Orava region (North-West Slovakia), reproduction possibilites of three clones of *Salix viminalis*, ULV, ORM and RAPP, are being (have been) assessed. These three clones were originally cultivated in the Swedish University of Agricultural Sciences in Svälov.

This article presents some results of the experimental work undertaken to assess energy characteristics of wood chips produced from short rotation coppices of Salix viminalis - clone ULV that was cultivated in plantations for energy purposes. The energy characteristics assessed contain two values: the higher heating value, and the lower heating value.

2 MATERIAL AND METHODES
2. MATERIJAL I METODE

Samples of wood and bark of *Salix viminalis* – clone ULV to assess the energy characteristics were taken from wood chips produced from four-year-old plantations, Fig.1.

The higher heating value of the above mentioned samples of *Salix viminalis*, which were dried beforehand to a constant weight ($W_a = 0$ %), was assessed in a special calorimeter for solid fuels, model IKA C 200 in accordance with the Slovak Technical Norm STN 44 1352 for assessment of the higher and lower heating values of solid fuels.

Elementary analyses of wood and bark samples of *Salix viminalis*, including the assessment of share of ash in wood and bark, were undertaken by a team of experts from the Forestry Laboratory of the National Forest Centre in Zvolen, Slovakia.

The content of hydrogen in the analysed samples of wood and bark was assessed by a special analyzer, model NCS-FLASH EA 1112, produced by Thermo Finnigen.

Figure 1 Plantation of *Salix viminalis* - clone ULV
Slika 1. Plantaža stabala drva *Salix viminalis* – klona ULV

The lower heating value of wood and bark samples in dry state was calculated using the formula stated below. The inputs of the formula were: measured higher heating values of wood and bark samples, and a laboratory assessment of the contents of hydrogen and water of the same wood and bark samples.

$$Q_n = Q_s - 24.54 \cdot (W_r + 9 \cdot H^{daf}) \quad (1)$$

Q_n – lower heating value of analyzed sample in dry state / *donja ogrjevna vrijednost u suhom stanju*, kJ/kg
Q_s – higher heating value of analyzed sample in dry state / *gornja ogrjevna vrijednost u suhom stanju*, kJ/kg
W_r – water content in analyzed sample / *sadržaj vode u analiziranim uzorcima*, $W_r = 0$ %
H^{daf} – share of hydrogen in combustible substance of analyzed sample/ *udjel vodika u gorivim supstancijama analiziranih uzoraka*, %.

The share of bark in wood chips produced from Salix viminalis - clone ULV was assessed by a laboratory technique at the Faculty of Wood Sciences and Technology of the Technical Univerzity in Zvolen. The assessment was carried out in accordance with the Slovak Technical Norm STN 48 0058:2004 on assortments of wood and wood chips containing leaves, and sawdust. The share of bark was assessed using the following formula:

$$X_B = \frac{m_B}{m_{W-CH}} \cdot 100 \quad (2)$$

X_B – share of bark in wood chips / *udjel kore u drvnom iverju*, %
m_B – weight of bark in a sample of wood chips / *masa kore u uzorku iverja*, g

$m_{W\text{-}CH}$ – weight of wood in a sample of chips / *masa uzorka drvnog iverja*, g.

Based on the above specified energy characteristics of wood chips produced from Salix viminalis - clone ULV, an average energy value of the higher heating value of wood chips in dry state was calculated using the following formulas:

Higher heating value of dry wood chips:

$$Q_{S\,CH} = \left[\frac{100 - X_B}{100}\right] \cdot Q_{SW} + \frac{X_B}{100} \cdot Q_{SB} \quad (3)$$

Lower heating value of dry wood chips:

$$Q_{n.\,CH} = \left[\frac{100 - X_B}{100}\right] \cdot Q_{nW} + \frac{X_B}{100} \cdot Q_{nB} \quad (4)$$

X_B – share of bark in wood chips / *udjel kore u drvnom iverju*, %
$Q_{S\,W}$ – higher heating value of wood /*gornja ogrjevna vrijednost drva*, kJ/kg
$Q_{S\,B}$ – higher heating value of bark / *gornja ogrjevna vrijednost kore*, kJ/kg
$Q_{n\,W}$ – lower heating value of wood / *donja ogrjevna vrijednost drva*, kJ/kg
$Q_{n\,B}$ – lower heating value of bark / *donja ogrjevna vrijednost kore*, kJ/kg

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

Elementary chemical analysis of samples of wood and wood bark chips produced from Salix viminalis - clone ULV are shown in Table 1 below.

Comparative analyses of the chemical composition of juvenile wood and wood bark produced from *Salix viminalis* cultivated in an energy plantation, and the chemical composition of mature wood and bark from overmatured broadleaves trees show that the juvenile wood of *Salix viminalis* contains between 3 % and 19 % more hydrogen than is commonly found in mature broadleaves wood (Vanin, 1949; Pelerigyn, 1965; Golovkon *et al*, 1987; Marutzky and Seeger, 1999). The comparative analyses also show that the juvenile *Salix viminalis* wood contains between 140 % and 380 % more nitrogen than is commonly found in mature broadleaves wood (Vanin, 1949; Dzurenda and Banski, 2003; Mindaš and Stančíková, 2004).

The assessed higher content of nitrogen in the juvenile wood of *Salix viminalis* proves that there is a higher content of albumin in the plexus of the juvenile wood. The content of nitrogen in an immatured bark of Salix viminalis is about 121 % to 126 % higher than the common share of nitrogen in bark of older broadleaves.

Table 1 Shares of elementary *combustible* particles and ash in wood biomass (Ďurkovičová, 2009)
Tablica 1. Udjeli elementarnih tvari i pepela u drvnoj biomasi

***Salix viminalis* – clone ULV** *Salix viminalis – klon ULV*		C^{daf} %	H^{daf} %	O^{daf} %	N^{daf} %	**Ash** / *Pepeo* %
Wood / *Drvo*	Sample 1 / *uzorak 1.*	49.66	6.28	43.64	0.42	0.24
	Sample 2 / *uzorak 2.*	50. 39	6.49	42.73	0.39	0.22
	Sample 3 / *uzorak 3.*	50.29	7.28	41.66	0.77	0.25
	Averages / *srednja vrijednost*	50.11	6.68	42.68	0.53	0.24
Bark / *Kora*	Sample 1 / *uzorak 1.*	50. 21	6.27	41.81	1.71	2.76
	Sample 2 / *uzorak 2.*	50.63	6.34	41.35	1.68	2.62
	Sample 3 / *uzorak 3.*	50.40	6.30	41.58	1.72	2.84
	Averages / *srednja vrijednost*	50.41	6.30	41.58	1.70	2.74
Extended relative indeterminateness of the measurements U, % *Proširena relativna pogreška mjerenja U, %*		5	5	5	5	

Table 2 Higher heating value and lower heating value of wood and bark of *Salix viminalis* - clone UVL
Tablica 2. Gornja ogrjevna vrijednost i donja ogrjevna vrijednost drva i kore *Salix viminalis* - klona UVL

Samples / *Uzorci*	**Wood** / *Drvo*		**Bark** / *Kora*	
	Higher heating value / *Gornja ogrjevna vrijednost*	Lower heating value / *Donja ogrjevna vrijednost*	Higher heating value / *Gornja ogrjevna vrijednost*	Lower heating value / *Donja ogrjevna vrijednost*
	$Q_{S\,W}$, kJ/kg	$Q_{n\,W}$, kJ/kg	$Q_{S\,B}$, kJ/kg	$Q_{n\,B}$, kJ/kg
Sample No. 1 / *uzorak 1.*	19 587	18 200	19 428	18 044
Sample No. 2 / *uzorak 2.*	19 469	18 036	19 633	18 232
Sample No. 3 / *uzorak 3.*	19 505	17 897	19 107	17 716
Average values / *srednja vrijednost*	19 520	18 044	19 389	17 997

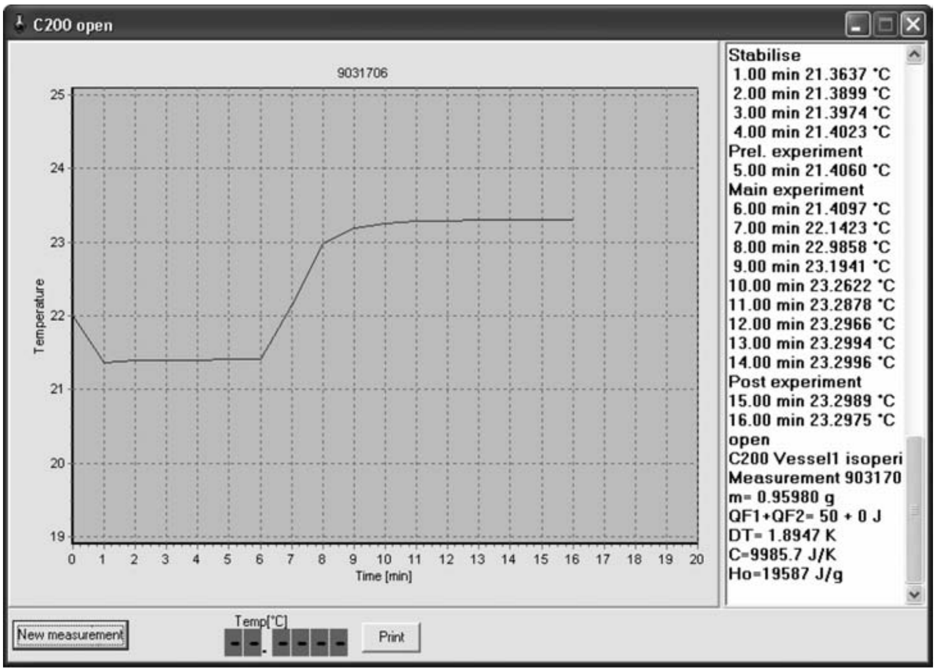

Figure 2 Equilibrium of a higher heating value of the analysed wood sample (ULVclone)
Slika 2. Ravnotežna gornja ogrjevna vrijednost analiziranih uzoraka drva klona ULV

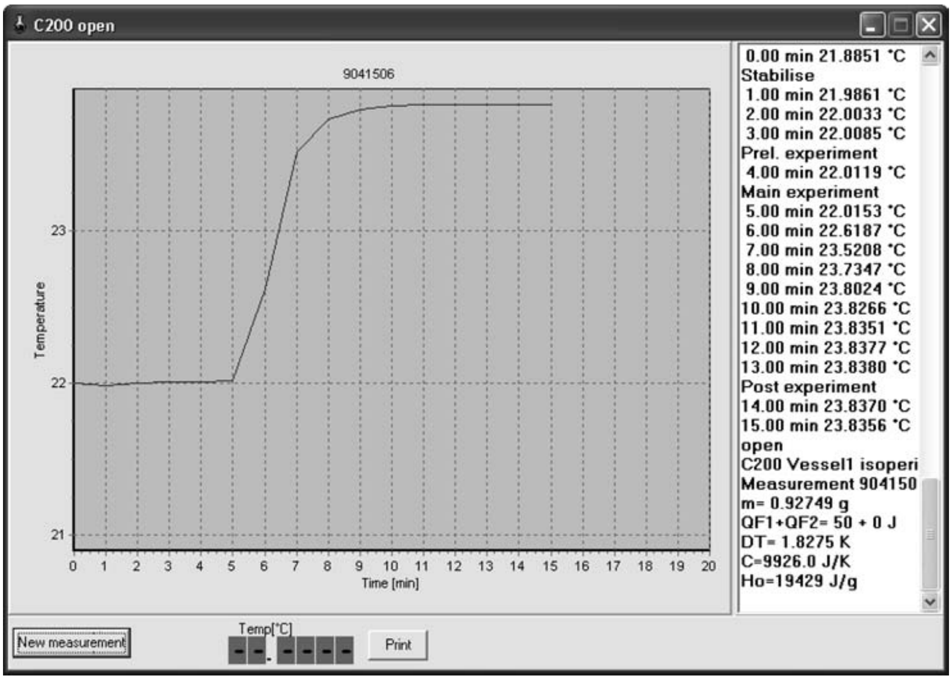

Figure 3 Equilibrium of a higher heating value of the analysed bark sample (ULV clone)
Slika 3. Ravnotežna gornja ogrjevna vrijednost analiziranih uzoraka kore klona ULV

This is caused by the presence of albumin in cambium cells, as well as by chlorophyl in the surface plexus of immature bark.

The experiments undertaken resulted in an assessment of the average share of bark X_B in the analyzed wood chips:

$$X_B = 19.35 \pm 0.65\ \%$$

The assessed value X_B does not exceed the maximum limit (X_B = 30 %) set by the Slovak Technical Norm STN 48 0058, which was endorsed in 2004. The assessed value of the bark share X_B is about 2.7 times higher than the share of bark in beech wood, about 1.7 times higher than the share of bark in oak- and poplar wood, and about 1.5 times higher than the share of bark in alder wood (Černák, 1969).

The graph in Figure 2 shows the temperature equilibrium of a higher heating value of the wood sample of *Salix viminalis* - clone ULV, measured in a calorimeter, and the graph in the Figure 3 shows the temperature equilibrium of a higher heating value of the bark sample of *Salix viminalis* - clone ULV, measured in a calorimeter.

Table 2 includes the results of measurement of the higher heating value of three samples of wood and bark of *Salix viminalis* – clone ULV, which were dried beforehand into a constant weight.

The average energy values of the higher heating value of dry wood of *Salix viminalis* - clone ULV are about 1.0 % higher than the average energy values of the higher heating value of dry bark of the same plant. This is caused by a higher share of combustible substance in the wood (lower ash content in the wood) and by a lower share of nitrogen in the wood, which is an endothermic part of the combustible substance of wood biomass.

The assessed higher heating value of Salix viminalis - clone ULV in dry state is comparable with the higher heating value of poplar published by Longauer *et al* (1987) $Q_{S\ W}$ = 19 880 kJ/kg.

The average value of the heating value of wood chips produced from *Salix viminalis* - clone ULV in dry state with the average share of bark X_B = 19.35 % is determined by the formula (4) as $Q_{n\ CH}$ = 18 035 kJ/kg.

4 CONCLUSIONS
4. ZAKLJUČCI

Based on the experiments, the following conclusion can be made: Wood chips produced from Salix viminalis - clone ULV, which was cultivated in an energy plantation, contains significantly higher shares of both hydrogen and nitrogen than is commonly found in wood biomass of matured broadleaves. The share of bark in the same wood chips was assessed as X_B = 19.35± 0.65 %.

The analyses of energy characteristics of wood chips produced from *Salix viminalis* - clone ULV show that the higher heating value of the juvenile wood of *Salix viminalis* - clone ULV in dry state is $Q_{S\ W}$ = 19 520 kJ/kg; while for dry bark of the same wood it is $Q_{S\ B}$ = 19 389 kJ/kg. The lower heating value of wood chips of *Salix viminalis* - clone ULV in dry state is $Q_{n\ CH}$ = 18 035 kJ/kg.

5 REFERENCES
5. LITERATURA

1. Černák, J., 1969: Physical nature of wood. Ružomberok: SCP. 89 p. (in Slovak)
2. Dzurenda, L.; Banski, A., 2003: Nitrogen content in individual parts of tree and concentration of NO_2 in exhaust gases made in low temperature oxidation in combusting process. In: Acta Facultatis Xylologiae. 45 (1): 7 – 14 (in Slovak).
3. Ďurkovičová, J., 2009: Protocol D-21-09: Determination of carbon, nitrogen and hydrogen shares in wood. National Forest Centre in Zvolen. p. 3 (in Slovak).
4. Golovkov, S. I.; Koperin, I. F.; Najdenov, V. I. 1987: Energetic utilization of wood waste. Moscow, p. 221 (in Russian).
5. Habovštiak, J.; Daniel, J., 2005: Cultivation of species of willow (*Salix viminalis*) for energetic purposes. In: Naše pole. 2005/5, 10 p. (in Slovak).
6. Longauer, J. ; Koska,P.; Luptak, O., 1987: Higher heating value and lower heating value of wood waste. In: VPA 5/1987, Faculty of Wood Sciences and Technology, Technical University in Zvolen, p. 61 (in Slovak).
7. Marutzky, R.; Seeger, K., 1999: Energie aus Holz und anderer Biomasse. Leinfelden-Echterdingen: DRD – Verlag Weinbrenner GmbH &Co, 430 p.
8. Mindaš, J.; Stančíková, A., 2004: Evaluation of nitrogen volume in dendromass. National Forest Centre in Zvolen. 6 p. (in Slovak).
9. Pelerygin, L. M., 1965: Theory of wood. SVTL, Bratislava, 448 p. (in Slovak).
10. Trenčiansky, M.; Lieskovský, M.; Oravec, J., 2007: Energetic evaluation of biomass National Forest Centre in Zvolen, 147 p. (in Slovak).
11. Vanin, S. I., 1949: Theory of wood. Moscow & Leningrad: Goslesbumizdat, 338 p. (in Russian).
12. Varga, L.; Godó, T., 2002: Fast-growing wood species and options for increased production of biomass for energy In: Utilisation of forest biomass for energetic purposes in conditions of Slovakia National Forest Centre in Zvolen, pp. 28-37 (in Slovak).
13. *** ISO 1928:2003 Solit mineral fuels. Determination of gross calorific value by the bomb calorimetric mothod, and calculation of net calorific value.
14. *** STN 48 0058:2004 Assortments of wood – deciduous chips and sawdust (in Slovak).

Acknowledgements
Zahvala

This study has been proceeded in the framework of the grant project No 1/0358/08 as the result of the author's research with significant help of VEGA SR Agency.

Corresponding address:

Prof. Ing. LADISLAV DZURENDA, Ph.D.

The Faculty of Wood Sciences and Technology
Technical University in Zvolen
T. G. Masaryka 24
960 53 Zvolen, Slovak Republic
E-mail: dzurenda@vsld.tuzvo.sk