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Pyrolysis of Firwood (*Abies bornmülleriana Mattf.*) Sawdust: Characterization of Bio-Oil and Bio-Char

Piroliza jelove (*Abies bornmülleriana* Mattf.) piljevine: karakterizacija bioulja i biougljena

ABSTRACT • *This paper describes the research of slow pyrolysis of firwood (Abies bornmülleriana Mattf.) sawdust by using fixed-bed reactor. The effect of temperature ranging between 350 and 600 °C on gas, liquid and solid products was examined. The maximum bio-oil yield of 45.9 % was obtained at the final pyrolysis temperature of 500 °C. The elemental analysis and heating value of bio-oil and bio-char were determined, and then the chemical composition of the bio-oil was investigated using chromatographic and spectroscopic techniques such as Gas Chromatography–Mass Spectrometry (GC/MS) and Proton Nuclear Magnetic Resonance (¹H-NMR). The liquid product was mainly composed of phenolics, including 2-methoxy-phenol, 2-methyl-phenol, phenol, as well as aldeyhdes, acids, esters, alcohols and ketones. The chemical characterization has shown that the bio-oil obtained from residues of forestry production, such as firwood sawdust, can be used as an environmental feedstock, which is an ideal candidate for alternative fuels. Moreover the bio-char can be used as an energy source and active carbon.*

Keywords: *Bio-oil, Fir wood, GC/MS,¹H-NMR, Pyrolysis*

SAŽETAK • *U radu je opisano istraživanje spore pirolize jelove (Abies bornmülleriana Mattf.) piljevine uz primjenu fiksnog reaktora. Analiziran je učinak temperature u rasponu od 350 do 600 °C na plinovite, tekuće i krute proizvode pirolize. Maksimalni prinos bioulja od 45,9 % dobiven je na konačnoj temperaturi pirolize od 500 °C. Napravljena je elementarna analiza i određena ogrjevna vrijednost bioulja i biougljena, a zatim je ispitan kemijski sastav bioulja uz pomoć kromatografskih i spektroskopskih tehnika kao što su plinska kromatografija i masena spektrometrija (GC/MS) te protonska nuklearna magnetska rezonancija (¹H-NMR). Tekući proizvodi pirolize sastavljeni su uglavnom od fenola, uključujući 2-metoksi-fenol, 2-metil-fenol, fenol, kao i od aldehida, kiselina, estera, alkohola i ketona. Kemijska su svojstva pokazala da je bioulje dobiveno od ostataka proizvodnje u šumarstvu, poput jelove piljevine, raspoloživa sirovina iz okoliša koja je idealna za alternativna goriva. Osim toga, biougljen se može koristiti kao izvor energije i kao aktivni ugljen.*

Ključne riječi: *bioulje, jelovina, GC/MS, ¹H-NMR, piroliza*

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1 INTRODUCTION
1. UVOD

Renewable energy is of growing importance in satisfying environmental concerns over fossil fuel usage. Wood and other forms of biomass, including energy crops and agricultural and forestry wastes, are some of the main renewable energy resources available. This growing interest also resulted in intensive research of thermal conversion techniques for biomass, consisting of combustion, gasification and pyrolysis (Bridgwater, 2003; Janse*et al.,* 2000). Pyrolysis is an attractive technology for converting biomass into gases, liquids (bio-oil), and char at relatively low temperature ranging between 300 and 600 °C in the absence of oxygen (Murata *et al.,* 2012; Bu *et al.,* 2011).

Bio-oil is referred to by many names such as pyrolysis oil, bio-crude-oil, bio-fuel-oil, wood liquids, wood oil, liquid smoke, wood distillates, pyroligneous tar, and pyroligneous acid. The bio-oil is usually dark brown and free flowing with a distinctive smoky smell. Bio-oil is a mixture of about 200 types of major and minor organic compounds and can be used for the production of chemicals and substituted for fuel–oils in many stationary applications for heat or electricity generation. The gas products can be used in engines and turbines for power generation. Bio-char can also be used as a fuel (Bridgwater, 2004; Uzun and Sarıoğlu, 2009; Enginar*et al.,* 2009; Özcimen and Ersoy-Mericboyu, 2010).

As a clean fuel, bio oil has a number of practical advantages including the following:
- it is renewable and locally produced from organic waste,
- it can be stored and transported similarly to petroleum-based products,
- it is a neutral greenhouse gas and can generate carbon dioxide,
- it generates lower NOx emissions than light fuel oil in gas turbines and diesel fuel in stationary diesel engines (Sadaka, 2009).

Numerous researchers have investigated various pyrolysis processes that were developed to maximize the formation of liquid products used as fuels or chemical feedstock. Şensöz (2003) pyrolyzed pine bark (*Pinusbrutia*Ten.) in an externally heated fixed-bed reactor at 300 °C and 500 °C with heating rates of 7 and 40 °C/min. The product yields were significantly influenced by the process conditions. The bio-oil was obtained at 450 °C, at which the liquid product yield was maximum. In addition, the solid and liquid products were analyzed to determine their elemental composition and calorific value. Chemical fractionation of bio-oil showed that only low quantities of hydrocarbons were present, while oxygenated and polar fractions dominated (Şensöz, 2003). Ingram *et al.* (2008) have investigated pyrolysis of pinewood, pine bark, oak wood and oak bark in a continuous auger reactor. They found that the yield of bio-oil from pine was 40 to 55 % at 450 °C (Ingram *et al.,* 2008). Wangand co-workers produced bio-oil from pine wood sawdust at differ-

ent temperature ranges and analyzed the fuel properties of bio-oil. They reported that the degradation of hemicellulose started at 200 to 300 °C, forming many sorts of liquid products, such as saccharide, furan, carboxylic acid, ketone and aldehyde, with the occurrence of dehydration, decarboxylation and decarbonylation, while cellulose remained unimpaired in its polymerized structure. Cellulose was substantially decomposed at 300 to 50 °C, leading to a great increase in the yields of liquid and gaseous products, and simultaneously the solid residue became aromatized, which was characteristic of a concentrated lignin structure. The residue was largely decomposed to numerous guaiacols and phenols at 450 to 700 °C (Wang *et al.,* 2009).

In this work, fir wood sawdust (*Abiesbornmülleriana*Mattf.) was pyrolyzed at various temperatures, using a fixed bed type reactor. The aim of this study was to elucidate the effect of temperature during slow pyrolysis on yields of the bio-oil, gas and bio-char. The chemical properties of bio-oil were characterized by GC/MS, ^{1}H-NMR and elemental analysis. Also, the characterization of bio-char was performed in terms of its elemental composition and Fourier transform infrared spectroscopy (FT-IR).

2 MATERIAL AND METHODS
2. MATERIJAL I METODE

2.1 Materials and sample preparation
2.1. Materijali i priprema uzoraka

Fir wood (*Abiesbornmülleriana*Mattf.) was used in this study as the raw lignocellulosic biomass, which is one of the widespread and abundant species in the northwestern and Marmara regions of Turkey. Fir wood is an important commercial wood; it can be used for furniture and building materials, which produces large amounts of sawdust and wood residues every year. The raw sawdust sample supplied by the Department of Furniture and Decoration at Karabük University was ground and sieved to less than 1 mm, and it was then dried for 12 hours at 100 to 105 °C prior to use as a pyrolysis sample.

The proximate analysis was performed according to the ASTM standard test methods for measuring moisture contents, combustible matter and ash contents, and namely ASTM D 4442-92, ASTM E897-88 and ASTM D-1102-84, respectively. The chemical composition of feedstock was determined according to Wise and John, 1952, Rowell *et al.* 2005 and TAPPI standards (T-257, T-222, T-204). The ultimate analysis was conducted using an elemental analyzer (LECO CHNS-932). The oxygen content of the biomass was found by the difference. The H/C and O/C molar ratios were calculated from elemental composition. The HHV of the fir wood sawdust was calculated based on Dulong formula (Wang *et al.,* 2007)

2.2 Thermal analysis
2.2. Toplinska analiza

The thermal decomposition of raw material was examined by using a thermogravimetric analyzer (Per-
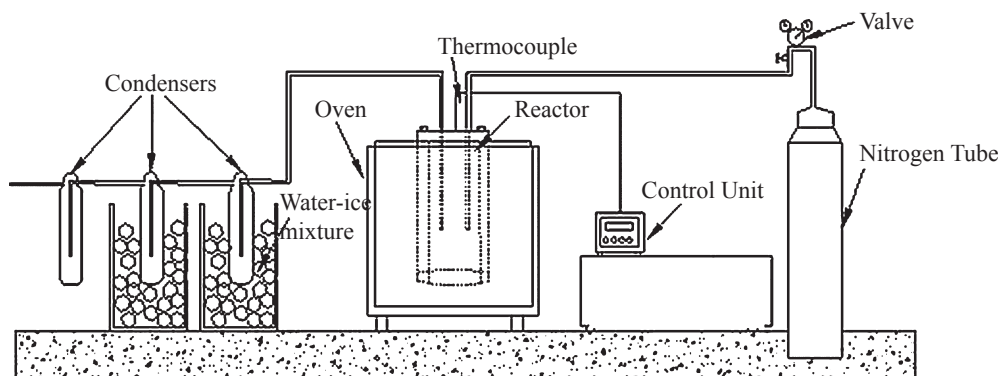
Figure 1 Schematic diagram of pyrolysis apparatus
Slika 1. Shematski prikaz uređaja za pirolizu

kin Elmer Pyris 1). For the TGA experiment, approximately15 mg of sample was used with a 10 °C/min. heating rate. Nitrogen was used as the carrier gas, with a flow rate of 25 ml/min. After that, the sample was heated from 25 °C to 600 °C.

2.3 Pyrolysis
2.3. Piroliza

Pyrolysis experiments were performed in a fixed-bed reactor under a nitrogen atmosphere. The reactor has a steel cylinder with an internal diameter of 6 cm and a height of 21 cm. A schematic diagram of pyrolysis apparatus is shown in Figure 1. During the experiments, heating rate and pyrolysis temperatures were controlled with a PID (Proportional–Integral–Derivative) controller. The temperature was measured every minute in the reactor using a type K thermocouple. In the pyrolysis experiment, a sample of 50 g was weighed and placed into the reactor, which was heated by an electric furnace. The temperature was increased from room temperature to 350, 400, 450, 500, 550 and 600 °C, while the heating rates were increased 15 °C/min. Experimental apparatus was held at an adjusted temperature either for a minimum of 30 min or until no further significant release of gas was observed. A condenser was connected to the output of the reactor and the liquid was condensed in a collector to be weighed. The bio-char collected in the reactor was weighed at the end of the experiment. The gas yield was calculated by taking the difference. Experiments were repeated at least three times within the experimental error of less than ±0.5 %.

2.4 Characterizations
2.4. Karakterizacija

Liquid products were extracted with an equal quantity of diethyl ether. The diethyl ether extracts were analyzed by instrumental techniques such as Elemental, GC/MS and ^{1}H-NMR. The carbon, hydrogen and nitrogen contents of bio-oils were determined using a LECO CHNS-932 Elemental Analyzer. The oxygen content of bio-oils was found by the difference. The chemical composition of the liquid product was analyzed by GC/MS (Agilent 6890). A capillary column (HP-5, 30m×0.25mm i.d.×0.25 μm) was employed to separate organic mixtures. Diethyl ether was used as solvent to dilute the dehydrated liquid product to a concentration appropriate for analysis. Helium was used as carrier gas at constant flow of 1.2 mL. The GC oven temperature was programmed to start at 40 °C, held for 10 min, then raised at a rate of 2 °C to 170 °C, held for 5 min, then raised to 250 °C at a rate of 8 °C held for 15 min, then raised to 300 °C at a rate of 15 °C, and held at this final temperature for 10 min. The injector temperature was 250 °C with split mode. The end of the column was directly introduced into the ion source of Agilent 5973 series mass selective detector operated with electron impact ionization mode. G1035A software with a NIST library was used as data acquisition system. The ^{1}H-NMR spectrum of the bio-oil was obtained at an H frequency of 300 MHz using a BrukerUltrashield instrument. The bio-oil sample was dissolved in $CDCl_3$.

The bio-char was characterized by elemental analysis, using a LECO CHNS-932 Elemental Analyzer. Dulong formula was used to determine the HHV of the liquid and solid products (Wang *et al.,* 2007). Functional group chemical analysis of the bio-char was carried out using Fourier transform infrared (FT-IR) spectrometry (Nicolet iS10FT-IR spectrum instrument).

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

3.1 Characteristics of fir wood sawdust
3.1. Obilježja jelove piljevine

The main characteristics of the biomass (fir wood sawdust) are listed in Table 1. The dry wood sample contained 0.36 % ash. Elemental analysis showed that it contained 46.99 % C, 6.37 % H, and 46.64 % O_2 (in mass percent, dry basis).

3.2 TGA analysis of fir wood sawdust
3.2. TGA analiza jelove piljevine

Thermogravimetric (TG) and derived thermogravimetric (DTG) curves of fir wood sawdust are shown in Figure 2. According to Figure 2, the moisture was removed from the raw material up to 100 °C and the main decompositions of fir wood started around 250 °C with a sharp incline to 600 °C. Wörmeyer *et al.,* 2011 reported that the rapid weight loss between 200 and 600 °C is due to the breakup of inter-unit linkages

Table1 Main characteristics of fir wood sawdust
Tablica 1. Glavna obilježja jelove piljevine

Characteristics / *Obilježje*	Method / *Metoda*	Value / *Vrijednost*
Moisture content, % / *sadržaj vode, %*	ASTM D-4442-92	6.81
Proximate analysis[a], % / *neposredna analiza, %*		
Volatiles / *hlapljive tvari*	ASTM E-897-88	78.32
Ash / *pepeo*	ASTM D-1102-84	0.36
Fixed carbon / *fiksni ugljik*	Calculated from difference / *izračunano iz razlike*	14.51
Ultimate analysis[a], % / Konačna analiza, %		
Carbon / *ugljik*		46.99
Hydrogen / *vodik*		6.37
Oxygen / *kisik*	Calculated from difference / *izračunano iz razlike*	46.64
H/C molar ratio / *H/C molarni omjer*		1.61
O/C molar ratio / *O/C molarni omjer*		0.74
Component analysis[a], % / *Analiza sastavnica, %*		
α-cellulose / *α-celuloza*	Rowell *et al.*, 2005	43.53
Holocellulose / *holoceluloza*	Wise and John,1952	73.70
Lignin / *lignin*	TAPPI T 222 om-02	30.33
Extractive / *ekstraktivi*	TAPPI T 204 cm-97	2.69
HHV[b] , MJ/kg	Calculated from Dulong Formula	16.65

[a]Weight percentage on dry basis / *postotak na bazi suhe tvar* /[b](HHV) calculated by the Dulong Formula, that is, HHV (MJ/kg) = 0.338C+1.428(H-O/8)+0.095S

and evaporation of monomeric phenol units (Wörmeyer*et al.,* 2011). Thermogravimetric analysis (TGA) has been widely used, because it is an easy technique to evaluate pyrolysis of wood and other lignocellulosic biomass. Similar trend was observed in previous studies (Yang *et al.,* 2007; Ertaş and Alma, 2010; Wagenaar *et al.,* 1993).

3.3 Product yields
3.3. Udjeli proizvoda pirolize

Pyrolysis of fir wood sawdust was carried out in the temperature range of 350 to 600 °C at intervals of 15 °C, and each yield of pyrolytic products (bio-oil, gas and bio-char) is shown in Figure 3. These experiments revealed that the quantitative composition of pyrolysis products was clearly affected by the temperature. At 350 °C, the solid product (bio-char) yield reached its highest value (38.8 %). Since increasing the pyrolysis temperature decreases char yield, the char yield decreased down to 26.5 % at 600 °C. The bio-oil yield was 39.9 % at the pyrolysis temperature of 350 °C.The yield of bio-oil was maximized at approximately 46 % at 500 °C, and at the final temperature of 600 °C, the bio-oil yield was decreased to 44.8 %. This was
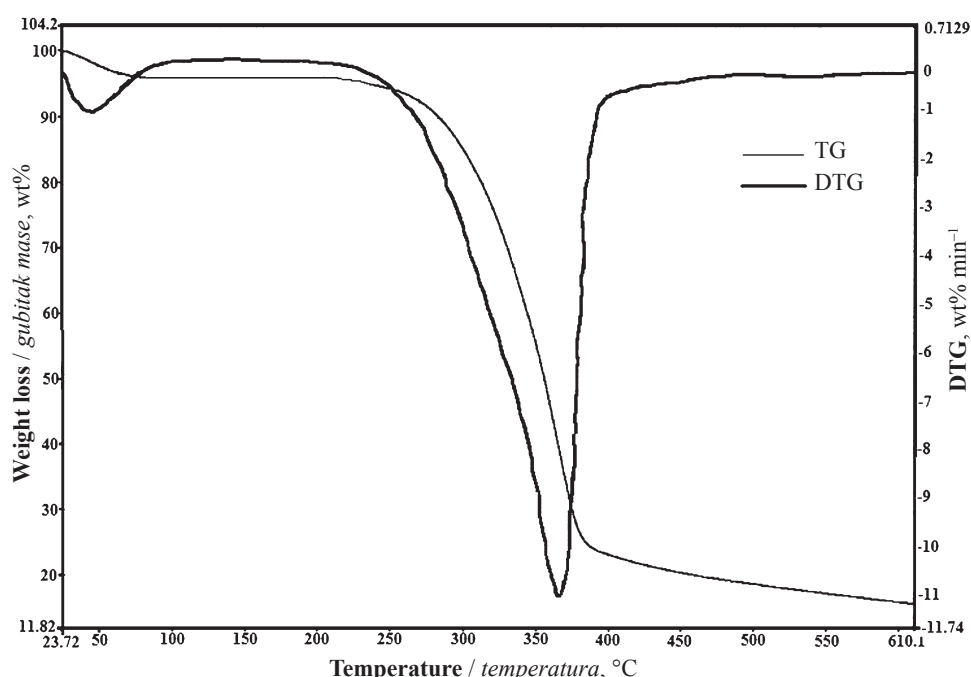

Figure 2 TG and DTG curves of fir wood under nitrogen atmosphere
Slika 2. TG I DTG krivulje jelove piljevine u atmosferi dušika
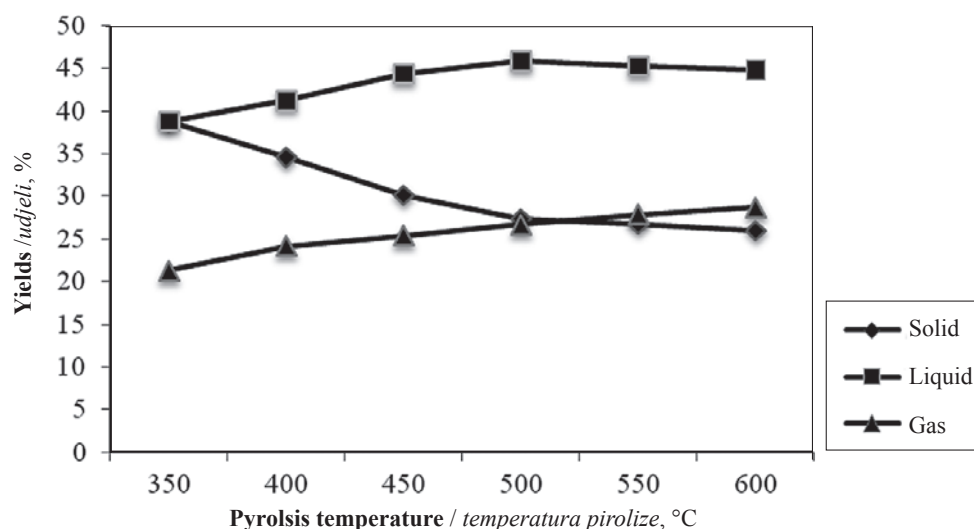
Figure 3 Yields of pyrolysis products
Slika 3. Udjeli proizvoda pirolize

due to the secondary reactions of the heavy-molecular-weight compounds in the pyrolysis vapors, which is known to become active at temperatures over 500 °C (Fagbemi*et al.,* 2001). As reported in previous studies, pyrolysis temperature plays an important role on the yields of pyrolysis products (Chen *et al.,* 2008;Heo*et al.,* 2010; Lee *et al.,*2005; Duman*et al.,* 2011; Özbay, 2012).

3.4 Characterization of bio-oil
3.4. Karakterizacija bioulja

The bio-oil selected for the characterization was obtained at the pyrolysis conditions that gave the maximum bio-oil yield. The elemental composition, H/C and O/C molar ratio and HHV of bio-oil are listed in Table 2.

As it shown in Table 2, the oxygen content was lower in bio-oil than in raw material. Since the decrease in oxygen content of the bio-oil (31.23 %) compared to the original feedstock (46.64 %) is significant, it can be used as the transport fuel. Furthermore, comparison of H/C ratios with conventional fuels indicates that H/C ratios of the bio-oil obtained in this study are less than those of light and heavy petroleum products. The higher heating value, calculated by Dulong formula, was 25.12 MJ/kg. The heating value of the bio-oil was higher than that of the raw material (16.65 MJ/kg). It can be seen that a significant decrease in the oxygen content resulted in an increase in the heating value. Results were in accordance with the previous studies reported in literature (Pütün*et al.,*2005; Sheng and Azevedo, 2005).

Biomass pyrolysis vapors consist of volatile compounds and non-volatile oligomers. GC/MS was only able to determine the volatile organic compounds. In the research, the ion chromatogram was obtained from the pyrolysis of the fir wood sawdust. A total of 32 major compounds were identified as given in Table 3. The GC/MS chromatogram of the bio-oil is illustrated in Figure 4. The compounds identified in bio-oil are also listed in Table 3. As shown in Table 3, the bio-oil was mainly composed of phenolics, including 2-methoxy-phenol, 2-methyl-phenol, 4-methyl-phenol, 4-ethyl-2-methoxy-phenol, 2-methoxy-4-vinyl-phenol, 2,6-dimethyl-phenol, 3-methyl-phenol,phenol and 2-methoxy-4-(2-propenyl)-phenol, 2-methoxy-4-(1-propenyl)-phenol, 2-methoxy-4-propenyl-phenol as well as aldeyhdes, acids, esters, alcohols and ketones. Phenols and methoxy group are generally considered as the pyrolysis products of lignin, while hemicelluloses can be decomposed to acetic acid andaldehydes such as furfural, and cellulose can be decomposed to ketones, aldehydes and furans (**Özbay***et al,* 2013, Pütün*et al.,* 2005; Ren *et al.,* 2012; Heigenmoser*et al.,* 2013; Özçifçi and Özbay, 2013).

Phenols derived from biomass pyrolysis oils are valuable chemicals and can be used as intermediates in the synthesis of pharmaceuticals, for the production of adhesives and the synthesis of specialty polymers, while furfural is a useful organic reagent for the production of medicines, resins, food additives, fuel additives and other special chemicals (Žilnik and Jazbinšek, 2012; Shen *et al.,* 2010; Shen and Gu, 2009). The

Table 2 Elemental composition of bio-oil[b]
Tablica 2. Elementarni sastav bioulja

Component *Komponenta*	C %	H %	O[a] %	H/C	O/C	HHV MJ/kg
Value / *vrijednost*	61.93	6.84	31.23	1.31	0.37	25.12

[a] By difference, [b]obtained at 500 °C (HHV) calculated by the Dulong Formula, that is, HHV (MJ/kg) = 0.338C+1.428(H-O/8)+0.095S
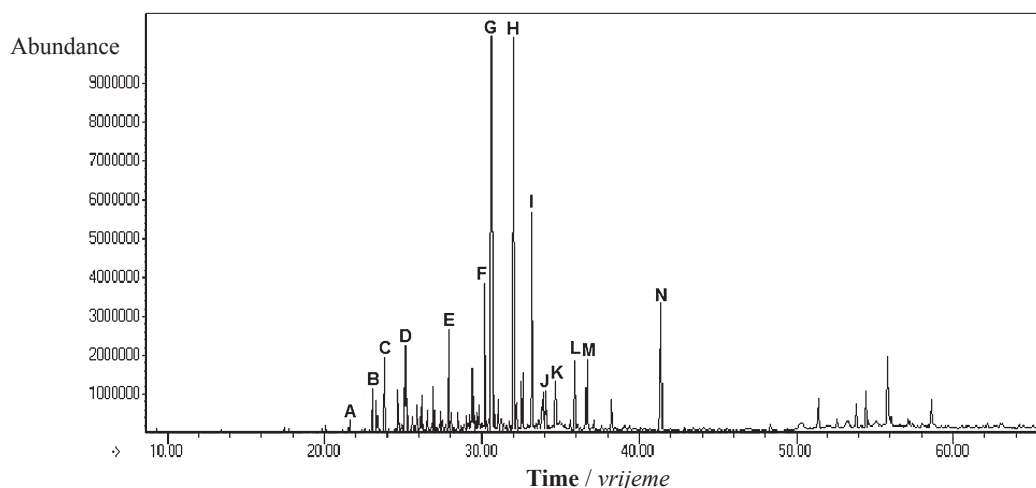
A: 2-cyclopenten-1-one, **B:** 2-methyl-2-cyclopenten-1-one, **C:** furfural **D:** 2-furanmethanol, **E:** 1,2-cyclopentenedione, **F:** 2-hydroxy-3-methyl-2-cyclopenten-1-on, **G:** 2-methoxy-phenol, **H:** 4-methyl-phenol, **I:** 4-ethyl-2-methoxy-phenol, **J:** 2-methoxy-4-(2-propenyl)-phenol, **K:** 3-methyl-phenol, **L:** 2-methoxy-4-(2-propenyl)-phenol, **M:** 2-methoxy-4-vinyl-phenol, **N:** 2-methoxy-4-propenyl-phenol

Figure 4 GC/MS chromatogram of bio-oil
Slika 4. GC/MS kromatogram bioulja

chemical composition of bio-oil was matched with previous GC/MS studies (Lu *et al.,* 2011; Beis*et al.,* 2002, Acıkgoz and Kockar, 2009; Liaw*et al.,* 2012; Luo *et al.,* 2004; Bu *et al.,* 2011).

The ^{1}H-NMR spectrum of the bio-oil is given in Figure 5. It can be seen that the bands between 6.5 and 9 ppm were assigned to aromatic structures. Resonances between 5 and 6.5 ppm indicate that the aromatic species were largely phenolic compounds. Aromatic ring-joining methylene protons were observed in the bio-oil and their characteristic peaks were in the resonances ranging between 3.3-4.5 ppm. The results showed that larger proportions of aliphatic structural units existed in the bio-oil from the pyrolysis of fir wood. These findings are consistent with the results of GC/MS analysis. Onay (2007) noticed that the bio-oils mainly contain aliphatic protons at carbon atoms bonded to other aliphatic carbon atoms (Onay, 2007). The products found in the bio-oil

correspond well to the literature data (Demiral and Ayan, 2011; Lu *et al.,* 2010).

3.5 Characterization of bio-char
3.5. Karakterizacija biouglljena

Elemental composition and an HHV value of the bio-char are presented in Table 4. As shown in Table 4, the bio-char, obtained from pyrolysis of fir wood sawdust, consisted of 77.28 % carbon and 18.81 % oxygen. It has an HHV of 28.35 MJ/kg. An H/C molar ratio of 0.60 and an O/C molar ratio of 0.18 were found. The elemental compositions of the bio-char were found to be better than that of the original feedstock since their carbon content was the highest. This carbon-rich product shows potential as an alternative solid fuel in the form of briquettes and pellets (Kim *et al.*, 2011).

Figure 6 shows the FT-IR spectra of both raw material and bio-char. Changes in functional groups of
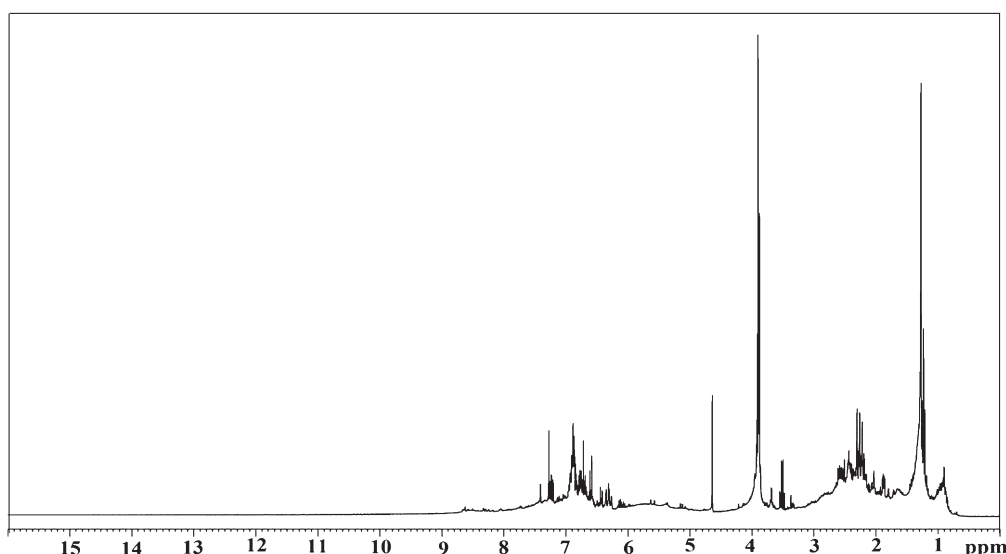

Figure 5 ^{1}H-NMR spectrum of bio-oil
Slika 5. ^{1}H-NMR spektar bioulja

Table 3 Main organic components of bio-oils[a] with GC/MS analysis
Tablica 3. Glavne organske komponente bioulja[a] dobivene GC/MS analizom

No	RT (min)	Name of compounds / *Naziv komponente*	Area / *Područje* %	Category / *Kategorija*
1	23.02	2-cyclopenten-1-one	1.38	Ketone
2	23.31	2-methyl-2-cyclopenten-1-one	0.84	Ketone
3	25.13	furfural	2.06	Aldehyde
4	25.85	1-(2-furanyl)-ethanone	0.62	Ketone
5	26.21	3-methyl-2-cyclopenten-1-one	0.96	Ketone
6	26.52	2,3-dimethyl-2-cyclopenten-1-one	0.43	Ketone
7	27.40	butanoic acid	0.56	Acid
8	27.89	2-furanmethanol	2.78	Alcohol
9	29.42	1,2-cyclopentenedione	1.55	Ketone
10	29.68	2-hydroxy-3,4-dimethyl-2-cyclopenten-1-one	0.38	Ketone
11	29.83	3,4-dimethoxytoluene	0.59	Benzene
12	30.18	2-hydroxy-3-methyl-2-cyclopenten-1-one	3.96	Ketone
13	30.62	2-methoxy-phenol	11.82	Phenol
14	30.77	2-methoxy-3- methyl-phenol	0.69	Phenol
15	31.06	3-ethyl-2-hydroxy-2-cyclopenten-1-one	0.80	Ketone
16	32.00	4-methyl-phenol	13.06	Phenol
17	32.15	ethanone	0.73	Ketone
18	32.23	maltol	0.70	Alcohol
19	32.50	2-methyl-phenol	1.50	Phenol
20	32.59	phenol	2.25	Phenol
21	33.18	4-ethyl-2-methoxy-phenol	7.12	Phenol
22	33.87	2,6-dimethyl-phenol	1.07	Phenol
23	33.94	4-methyl-phenol	1.36	Phenol
24	34.10	3-methyl-phenol	1.53	Phenol
25	34.66	2-methoxy-4-(1-propenyl)-phenol	1.67	Phenol
26	35.94	2-methoxy-4-(2-propenyl)-phenol	3.35	Phenol
27	36.67	2-methoxy-4-vinyl-phenol	3.11	Phenol
28	38.28	2-methoxy-4-propenyl-phenol	1.63	Phenol
29	41.38	2-methoxy-4-propenyl-phenol	8.52	Phenol
30	51.39	4-hydroxy-3-methoxy-benzaldehyde	3.01	Aldehyde
31	55.81	1,2-benzenediol	4.81	Phenol
32	58.57	4-methyl 1,2-benzenediol	2.72	Phenol
Total / *Ukupno*			87.56	

[a]obtained at 500 °C / *dobiveno pri 500 °C*

Table 4 Elemental composition of bio-char[b]
Tablica 4. Elementarni sastav biougljena[b]

Component *Komponenta*	C %	H %	O[a] %	H/C	O/C	HHV[c] MJ/kg
Value *Vrijednost*	77.28	3.91	18.81	0.60	0.18	28.35

[a] by difference, [b]obtained at 500 °C; [c]HHV calculated by Dulong Formula, that is, HHV (MJ/kg) = 0.338C+1.428(H-O/8)+0.095S

bio-char were determined when FT-IR spectra of bio-char and raw material were compared. FT-IR spectrum of the bio-char was simplified. In FT-IR spectrum of raw material, the O-H stretching vibration band observed between 3600 and 3200 1/cm, the C-H stretching vibration band observed between 2935 and 2885 1/cm and the C=O stretching vibration band observed between 1740 and 1700 1/cm were not found in the bio-char obtained from the pyrolysis of fir wood saw-

dust. The bio-char loses both hydroxyl and aliphatic groups and the aromatic character increases quite rapidly above 450 °C (Sharma *et al.,* 2004).

4 CONCLUSIONS
4. ZAKLJUČAK

In this paper, the fir wood sawdust was pyrolyzed to convert into bio-oil and bio-char using a fixed-bed reactor at different pyrolysis temperatures, and their chemical properties were characterized. The yields of pyrolytic products distribution, bio-oil, bio-char and gases, was significantly influenced by pyrolysis temperatures. The maximum bio-oil yield of 45.9 wt% was obtained at the final pyrolysis temperature of 500 °C. The bio-oil derived from fir wood sawdust consisted of about 32 major compounds, including phenols, organic acids, aldehydes, ketones and alcohols. The chemical properties have shown that the bio-oil obtained from fir wood sawdust could be use as a feedstock, and that it was an ideal candidate for alternative fuels. Moreover, the bio-char can be used as an energy source and active carbon.
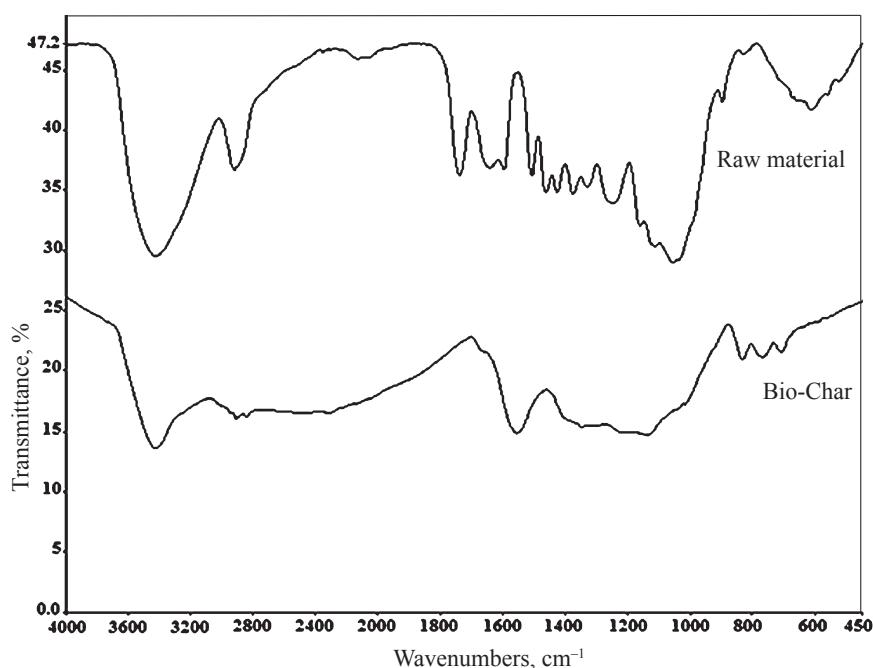
Figure 6 FTIR spectra of raw material and bio-char
Slika 6. FTIR spektar sirovine i biougljena

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