LATVIAN JOURNAL OF PHYSICS AND TECHNICAL SCIENCES
2013, N 4

DOI: 10.2478/lpts-2013-0024

# EFFECT OF MICROWAVE PRE-PROCESSING OF PELLETIZED BIOMASS ON ITS GASIFICATION AND COMBUSTION

I. Barmina[1], A. Līckrastiņa[1], J. Valdmanis[1], R. Valdmanis[1], M. Zaķe[1], A. Arshanitsa[2], G. Telysheva[2], V. Solodovnik[2]

[1]Institute of Physics, University of Latvia,
32 Miera Str., Salaspils, LV-2169, LATVIA,

[2]Latvian Institute of Wood Chemistry,
27 Dzerbenes Str., Riga, LV-1006, LATVIA
e-mail:mzfi@tok.sal.lv

To effectively produce clean heat energy from biomass, microwave (mw) pre-processing of its different types – pelletized wood (spruce), herbaceous biomass (reed canary grass) and their mixture (50:50) – was carried out at the 2.45 GHz frequency with different durations of biomass exposure to high-frequency oscillations. To estimate the mw pre-processing effect on the structure, composition and fuel characteristics of biomass, its thermogravimetric (TG), infrared spectroscopy (FTIR) measurements and elemental analysis were made. The pre-processing is shown to enhance the release of moisture and low-calorific volatiles and the partial destruction of biomass constituents (hemicelluloses, cellulose), promoting variations in the elemental composition and heating values of biomass. The field-enhanced variations of biomass characteristics and their influence on its gasification and combustion were studied using an integrated system of a biomass gasifier and a combustor with swirl-enhanced stabilization of the flame reaction zone. The results show that the mw pre-processing of biomass pellets provides a faster weight loss at the gasification, and, therefore, faster ignition and combustion of the activated pellets along with increased output of heat energy at their burnout.

**Key words:** *biomass pellets, pre-processing, gasification, combustion characteristics, heat energy production.*

## 1. INTRODUCTION

Different biomass types (wood, herbaceous and agriculture biomass, aquatic biomass, etc.) have been attracting attention of energy producers as renewable resources whose use would lead to significant reduction in the greenhouse carbon release and accumulation in the atmosphere. Biomass as fuel is expected to meet approximately two thirds of the renewable energy requirements by 2020 [1]. To reach this goal, different biomass types are to be converted into biofuels (biogas, bioethanol, briquettes or pellets) with improved characteristics as compared with native biomass. Different methods (physical, chemical, biological, and combined) of biomass pre-processing exist for biofuel production. The methods of plant biomass pre-processing for production of enriched renewable solid fuel can involve biomass grinding, drying, thermochemical pre-processing at 500–600 K in the absence of oxygen (torrefaction), and microwave (mw) pre-processing [2–8]. Since the 1980-es, there has been a growing interest in the mw-assisted pre-processing of lignocellulosic biomass (primarily consisting of hemicelluloses, cellulose and lignin). The effect of mw-based electromagnetic (EM) field pre-processing of biomass depends on its ability to absorb the external EM field energy and convert it into the heat due to the dissipative effects ($Q = \varepsilon''\mathbf{E}^2$) that have their origins in the response of polar molecules and ions to oscillations of the EM field [7–9]. The oscillating EM field induces vibrations of the polar molecules, which try to align themselves with the external field oscillations. In turn, these vibrations cause friction between the polar molecules and the surrounding medium accompanied by biomass heating. This phenomenon predominately occurs at mw frequencies which occupy a transitional region of the EM spectrum between infrared and radio-frequency (30 MHz to 30 GHz). At higher and lower EM frequencies, the response of the molecules to EM oscillations is not quick enough to induce resonant oscillations of the polar molecules, and the field influence on biomass heating weakens. The technology of mw pre-processing is effective for a variety of biomass types and has advantage over conventional thermal pre-processing since it can provide uniform spatial heating of biomass with a faster thermal destruction of hemicelluloses and cellulose and a faster thermochemical conversion of pre-processed biomass [8, 9]. Previous study [10] of the effect of high-frequency oscillations on the thermochemical conversion of biomass pellets has shown that applying high-frequency oscillations to the bottom part of the combustor close to the surface of a biomass layer promotes enhanced biomass gasification and mixing of the flame compounds with a more complete combustion of volatiles.

The aim of this study was to compare the effect of mw pre-processing on the main characteristics of biomass pellets for different types of biomass (spruce, reed canary grass and their mixture) and to estimate its influence on the thermo-chemical conversion of the activated biomass.

## 2. EXPERIMENTAL

Two types of biomass: spruce chips (stem wood) and herbaceous reed canary grass (R.c.g Bamse) were ground using an AGICO TSF420C hammer mill with 2 mm die holes. After conditioning up to ~12% water content, spruce sawdust (Spruce), ground R.c.g and their 50/50 mixture were pelletized using a laboratory-scale flat die pellet mill KAHL14-175.

Randomly chosen batches of each type of biomass pellets (~50 g) were pre-processed in a microwave oven ($\upsilon$ = 2.45 GHz) for 120 s and 180 s and estimated as to the influence of this processing on the elemental composition and heating values.

The processed biomass pellets and the parent sample were ground ($d \leq$ 0.05 mm) using an MM 200 ball mixer mill and then dried in the oven at 323 K. The elemental composition and ash content of the parent and pre-processed samples were determined in accordance with CEN/TS 15104:2004 and CEN/TS 14775:2004, correspondingly. The heating values were calculated taking into account the elemental composition of biomass [11]. The thermal degradation characteristics of the parent pellets were studied using a Mettler Toledo Star System TOA/SDTA 851 at the heating rate of 10 K/min, air flow rate of 50 ml/min and sample mass of 8 mg. The yields of mass and energy resulting from the mw pre-processing were calculated using the method reported in [12].

The FTIR spectra analysis of the parent and mw pre-processed biomass pellets was carried out with the use of a Perkin–Elmer Spectrum device according to the KBr pellet technique [14].

To estimate the mw pre-processing effect on the thermochemical conversion of biomass pellets, the activated batch-size biomass samples (total mass 230–250 g) were gasified and burned using a batch-size experimental laboratory-scale facility consisting of a stainless steel gasifier and water-cooled sections of the combustor [13]. To initiate gasification, propane flame flow supplied additional heat energy to the biomass at the average rate of 1 kJ/s. The primary air was supplied below the layer of biomass pellets to support their gasification, while the secondary swirling air supply to the bottom part of combustor permitted enhanced mixing of the flame compounds to complete the combustion of volatiles. The air supply into the device was controlled and measured with flow meters. Local online measurements of the flame temperature were made with Pt–Pt/Rh thermocouples. To estimate the heat production rate during the burnout of biomass samples, for cooling water the online calorimetric measurements were taken. The pellet composition was determined using a Testo-350XL gas analyzer. The design of the experimental device makes possible simple and repeatable tests for different types of pelletized and pre-processed biomass. To evaluate the composition of the volatiles released during the biomass pre-processing, the gas samples were examined by means of a Varian FTIR spectrometer. The main characteristics and heating values of the selected biomass samples are shown in Table 1.

## 3. RESULTS AND DISCUSSION

### 3.1. Effect of mw pre-processing on the structure, composition and fuel characteristics of biomass samples

The measurement results and comparison of FTIR spectra of the parent and pre-processed biomass normalized to 1510 $cm^{-1}$ (absorbance bands of aromatic units in lignin) clearly testify structural changes in the biomass at microwave impact (Fig. 1). It was shown that the mw pre-processing of biomass affects mainly the carbohydrate constituent of biomass samples. The structural transformation of the most labile hemicellulose fraction is notably pronounced.

The decrease in the absorption intensity at ~3400 $cm^{-1}$ (–OH group vibration) for all samples, and at ~1050 $cm^{-1}$ (C–O deformation in secondary alcohols and in aliphatic ethers) for R.c.g. and mixed biomass testifies a decrease in the oxygen-enriched carbohydrate content of the pre-processed biomass and a relative increase in the aromatic component.

The shifting of the absorbance maximum position from ~1735 $cm^{-1}$ to 1710–1720 $cm^{-1}$ testifies the appearance of free carboxylic groups as a result of oxidative processes. The decreasing absorbance intensity at 1250 $cm^{-1}$ (ester bonds in acetylated hemicelluloses) can be explained by deacetylation of hemicelluloses accompanied by removing the free acetic acid. The more pronounced peaks at 1600–1605 $cm^{-1}$ can be explained by the formation of new C=C bonds after dehydration and secondary condensation of hemicelluloses and cellulose constituents [14, 15].

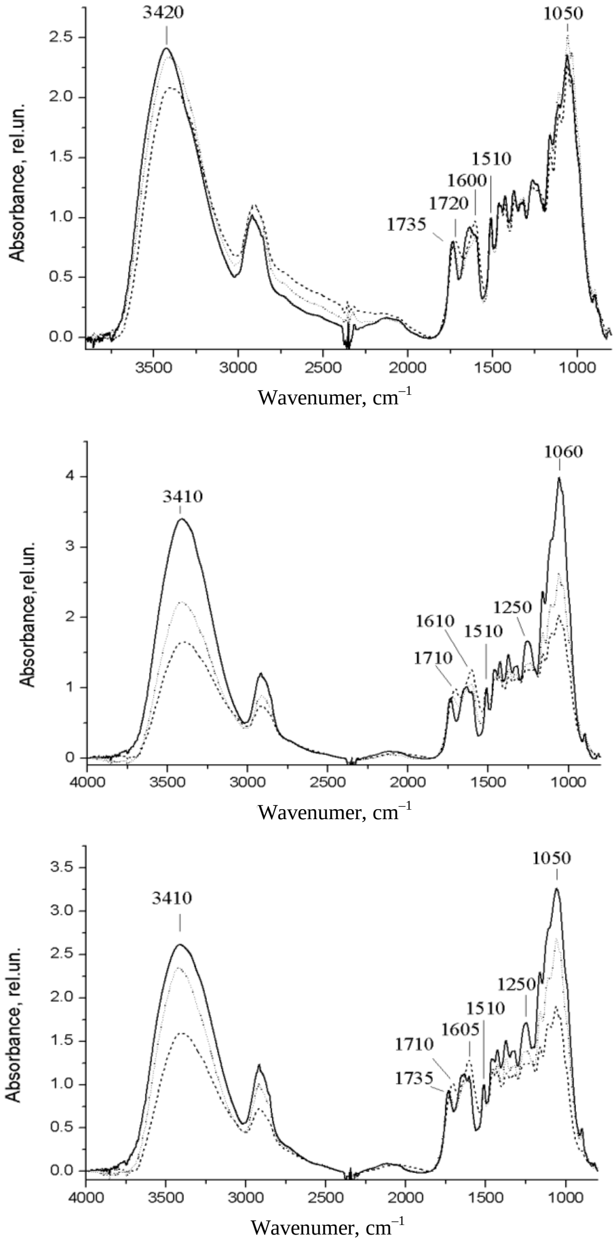


*Fig. 1.* The FTIR spectra of the samples: spruce wood (*a*), R.c.g. (*b*), spruce wood + R.c.g. (*c*) after microwave pre-treatment: 0 s – —— ; 120 s – ·-·-·-·-·; 180 s – ----.

The spruce sawdust and reed canary grass samples exhibit quite a different composition of the main constituents – the contents of hemicelluloses, cellulose and lignin of biomass for the spruce stem wood are: ~19.1%, 46.1% and 28.1%, whereas for reed canary grass – 29.7%, 42.6% and 7.6%, respectively [12, 16]. The estimation of chemical composition for the (50:50) spruce and reed canary grass mixture allows for suggestion that the content of hemicelluloses is ~24.4%, of cellulose ~42.1%, while for lignin it is ~17.9%. Coinciding with hemicelluloses in content, the above-described changes in biomass structures are enhanced in the range: spruce < R.c.g.+ spruce < R.c.g. It should be mentioned that spruce hemicelluloses consist mainly of hexoses [16], which are more stable to thermal degradation than the pentose hemicelluloses. For all samples, the extent of structural transformation of biomass is enhanced with duration of the pre-processing.

As seen from Table 1, the spruce sawdust pellets have a higher carbon and hydrogen content of biomass and thus a greater value of the highest heating value (HHV) in comparison with the R.c.g. pellets; besides, spruce sawdust pellets contain less nitrogen and ash. Therefore, adding spruce sawdust to the biomass of reed canary grass allows producing a mixture with improved characteristics relative to R.c.g. biomass – the carbon and hydrogen content as well as the HHV of the pelletized mixture increases, while the nitrogen and ash content of pellets in the produced mixture (Table 1) decreases, with direct impact on the combustion characteristics of the mixture relative to the R.c.g. characteristics.

*Table 1*

**The EM field induced characteristics of biomass at its mw-pre-processing**

| Characteristics (dry matter) | Spruce sawdust | | | Reed canary grass (Bamse) | | | Reed canary grass + spruce sawdust | | |
|---|---|---|---|---|---|---|---|---|---|
| | *t*, s | | | *t*, s | | | *t*, s | | |
| | 0 | 120 | 180 | 0 | 120 | 180 | 0 | 120 | 180 |
| C, % | 49.1 | 50.7 | 54.3 | 46.8 | 49.2 | 57.4 | 47.9 | 51.0 | 57.0 |
| H, % | 6.44 | 6.10 | 5.75 | 6.27 | 6.00 | 5.10 | 6.34 | 5.88 | 5.34 |
| N, % | 0.18 | 0.13 | 0.15 | 0.57 | 0.42 | 0.46 | 0.37 | 0.39 | 0.47 |
| O, %* | 43.9 | 42.6 | 39.3 | 43.0 | 40.8 | 33.3 | 43.5 | 40.5 | 33.6 |
| Ash, % | 0.37 | 0.44 | 0.55 | 3.39 | 3.59 | 3.78 | 1.88 | 2.21 | 3.56 |
| HHV, MJ/kg | 19.6 | 20.2 | 21.6 | 18.6 | 19.6 | 22.6 | 19.1 | 20.3 | 22.6 |
| LHV, MJ/kg | 18.2 | 18.9 | 20.4 | 17.2 | 18.9 | 21.5 | 17.7 | 19.0 | 21.5 |

*by difference

The variations in chemical composition for the selected biomass samples determine the correlating variations in the influence of mw pre-processing on the thermal decomposition of biomass. As follows from Table 1, the dominant EM field effect at mw pre-processing for all biomass samples is decrease in the oxygen content, while the carbon content and HHV of the residual biomass are increasing. The HHV increment is relatively small at the mw pre-processing for 120 s and does not exceed 3–6%, while it is more pronounced for the mw pre-processing up to $t$ = 180 s. The greatest HHV rise was found for the samples of pre-processed herbaceous biomass – R.c.g. (21%) with a higher hemicellulose and cellulose content and the lowest lignin content, whereas the lowest increase in the HHV (10%) was observed for pre-processed woody biomass – the spruce samples with the highest lignin content of biomass. The HHV increment for the mixture of spruce with R.c.g. (50:50) – by analogy with variation in the lignin content of this mixture – takes a middle position (15%). These results have confirmed those of FTIR spectra discussed above (Fig. 1). Some growth in the ash and nitrogen contents (excluding R.c.g.) of biomass as a result of mw pre-processing was also observed (Table 1).

In addition to the EM field influence on the elemental composition and heating values of biomass samples, the results of DTG differential thermal gravimetric (DTG) analysis have shown that the structural variations in pre-processed samples cause correlating variations of their thermal destruction rate (Fig. 2*a*–*c*).

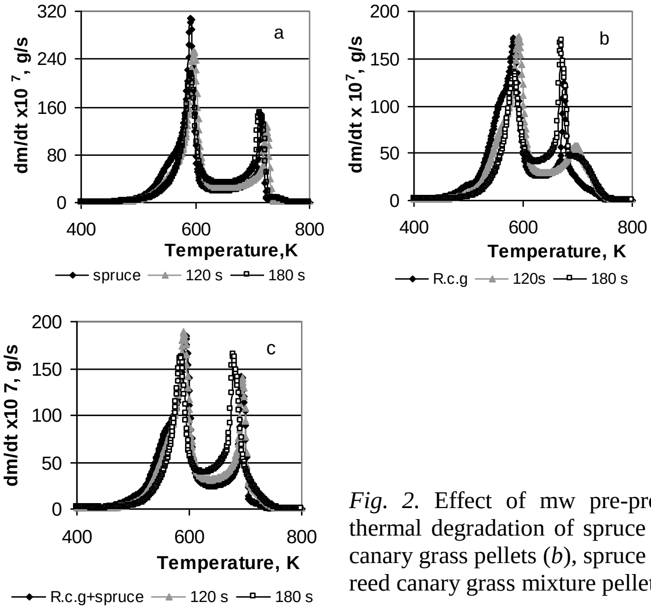


*Fig. 2.* Effect of mw pre-processing on the thermal degradation of spruce pellets (*a*), reed canary grass pellets (*b*), spruce sawdust + R.c.g. reed canary grass mixture pellets (*c*).

For all parent and pre-processed samples two distinct peaks in the temperature dependence of the biomass weight loss rates were observed. The first peak with a shoulder-like feature of the weight loss is observed at the temperatures 580–590 K, whereas the other peak is observed at around 680–710 K. Formation of these peaks is interpreted variously: with reference to [17, 18] this can be attributed to the first stage of weight loss due to the volatilization of three main constituents of biomass samples (cellulose, hemicelluloses and lignin) at $T \approx$ 580–595 K resulting in char formation [7–9] and followed by the stage of char combustion at $T \approx$ 680–720 K, while the authors of [19, 20] suggest that the first peak of weight loss is caused by the thermal decomposition of hemicelluloses and cellulose with partial decomposition of lignin and the other peak corresponds to char formation resulting from secondary condensation of the remaining lignin and combustion of char residues at $T \approx$ 650–800 K (Fig. 2*a*–*c*).

As a result of mw pre-processing, the peak value of the weight loss rate (WLR) at the primary stage of biomass thermal decomposition ($T \approx$ 520–650 K) decreases, whereas at the char conversion stage ($T \approx$ 650–800 K) it increases. For equal duration of mw pre-processing ($t$ = 180 s), the highest WLR is observed for the R.c.g sample – up to 57% as compared with approx. 30% and 50% for the spruce and mixed biomass pellets, respectively (Fig. 3*a*). The estimation of the ratio of energy and mass yields at 180 s of mw pre-processing has shown that higher ratios (1.18 and 1.14) can be obtained for mw pre-processed mixture of spruce with R.c.g and pre-processed R.c.g, respectively, in contrast to this ratio for the spruce samples (1.10), which have the highest content of lignin and the lowest content of hemicelluloses (Fig. 3*b*). This allows for the conclusion that the mw pre-processing under the considered conditions is more favourable for the spruce + R.c.g mixture providing the highest increase in the biomass energy density. Considering the results discussed above, it is seen that the biomass pre-processing predominantly activates the decomposition of hemicelluloses and less that of cellulose, yielding high calorific chars; the lignin was found to have much lower activity at mw pre-processing than carbohydrates. The data obtained are coinciding with the results reported in [7, 8, 21].

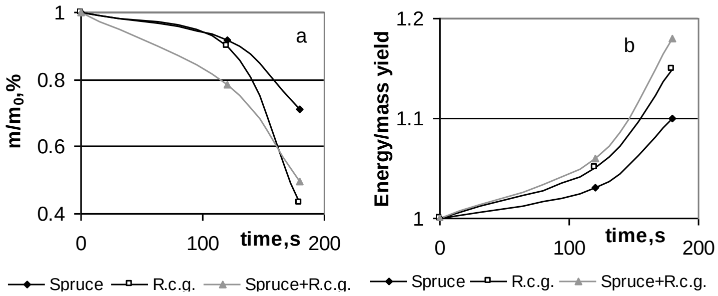


*Fig 3.* Effect of mw pre-processing on the biomass weight loss (*a*) and the energy/mass yield (*b*).

The stability of biomass samples at mw pre-processing increases in the range R.c.g. < Spruce+R.c.g. < Spruce. Obviously, the thermal stability of biomass is here to be related to the variations in the lignin and hemicelluloses content of biomass. Less stable to mw pre-processing are samples of herbaceous biomass (R.c.g) with lower lignin content (7.6%) and higher of hemicelluloses, whereas more stable are spruce samples with higher lignin content of biomass (27.5%) and lower of hemicelluloses.

The total weight loss of biomass samples at mw pre-processing is a result of complex processes, including the evaporation of physically-bonded moisture and a partial thermochemical degradation of the most labile biomass carbohydrates, which can be related to mw-heating and is accompanied by the release of volatile compounds with low heating values. FTIR composition analysis of the main fractions confirms that the mw pre-processing of biomass begins with a primary release of moisture, followed by the release of gaseous products, organic acids and aldehydes (Fig. 4*a*–*d*). In accordance with [7, 11], water at mw pre-processing can be released by two different mechanisms: the first – due to field-enhanced heating and drying of biomass pellets at $T < 400$ K, and the second – due to field-induced dehydration reactions of organic molecules at $T > 400$ K. The main absorbance of O–H bond of water molecules is detected in the range from 3000 $cm^{-1}$ to 3900 $cm^{-1}$, while the peak absorption of volatiles (organic acids and aldehydes) at the mw pre-processing of spruce and R.c.g. pellets is observed at 1736 $cm^{-1}$ (Fig. 4).

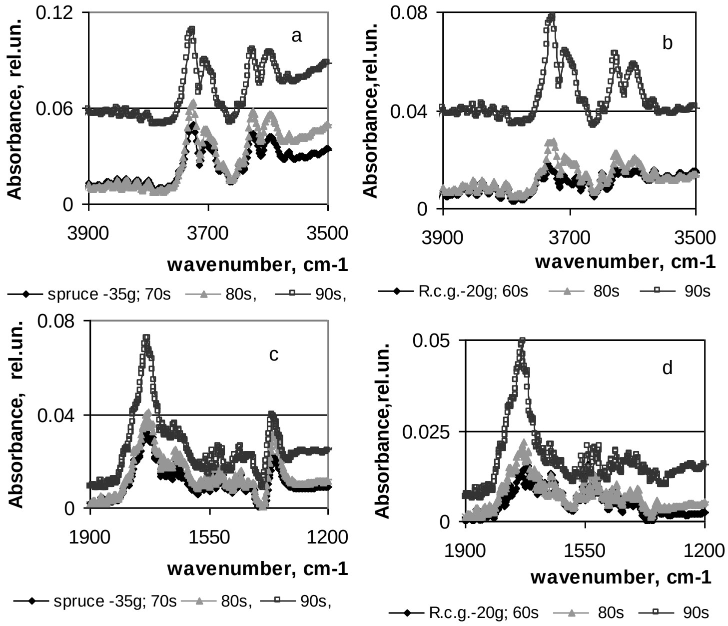


*Fig. 4.* Influence of the mw pre-processing time for spruce and reed canary grass pellets on the absorption intensity of the main volatile products: *a,b* – water, *c,d* – organic acids and aldehydes.

The thermal decomposition of spruce pellets with the higher lignin content of biomass has resulted in the formation of an absorption band at 1365 $cm^{-1}$ – obviously due to formation of $CH_4$ at thermal destruction of lignin [21]. As follows from Fig. 4, the peak values of absorption bands for all fractions released at the mw pre-processing of biomass pellets depend on its duration, which promotes the field-enhanced heating and thermal destruction of the biomass constituents (hemicelluloses, cellulose and lignin) with correlating variations of the elemental composition and heating values of biomass pellets (Table 1). In addition, the FTIR spectra of gaseous emissions from biomass during mw pre-processing confirm the structural transformation in the pre-processed biomass, proved by the FTIR spectra of solid biomass (Fig. 1).

### 3.2. Effect of mw pre-processing on gasification of biomass samples

The EM field-enhanced variations in the main characteristics and chemical composition of biomass pellets with partial destruction of hemicelluloses and cellulose at mw pre-processing exert a direct influence on the WLRs at gasification of pre-processed biomass samples, causing an enhanced mass flow of volatiles (CO, $H_2$, $C_xH_y$, etc.) at the thermochemical conversion downstream of the combustor. As seen from Fig. 5*a,c,e*, the EM field-enhanced partial destruction of cellulose and hemicelluloses at mw pre-processing promotes a faster thermal decomposition of the pre-processed samples with a higher average WLR and enhanced release of the volatiles. By analogy with the results of thermogravimetric measurements (Fig. 2) higher WLRs at biomass gasification are observed for the pre-processed pellets of the spruce sawdust + R.c.g. mixture and the R.c.g. pellets that have the highest hemicelluloses and cellulose content of biomass, whereas a weaker mw pre-processing effect on the WLR at gasification of biomass pellets is observed for the spruce sawdust pellets with the highest lignin content of biomass (Fig. 5*a–c*). At equal time of pre-processing the biomass pellets ($t$ = 180 s) and nearly equal gasification conditions ($\alpha \approx 0.5$ to 0.6) the average WLR (*dm/dt*) at gasification of the spruce sawdust and R.c.g. mixture increases from 0.11 g/s for pellets not subjected to pre-processing up to 0.13 g/s (~18%) for pre-processed pellets, with the correlating decrease in duration of the thermochemical conversion from 2300 s to 1800 s. The average WLR at gasification of the R.c.g. pellets increases from 0.15 for not processed R.c.g. pellets to 0.169 g/s for pre-processed pellets (~12.7%), while for spruce sawdust pellets the average WLR at mw pre-processing increases by approx. 7.8%.

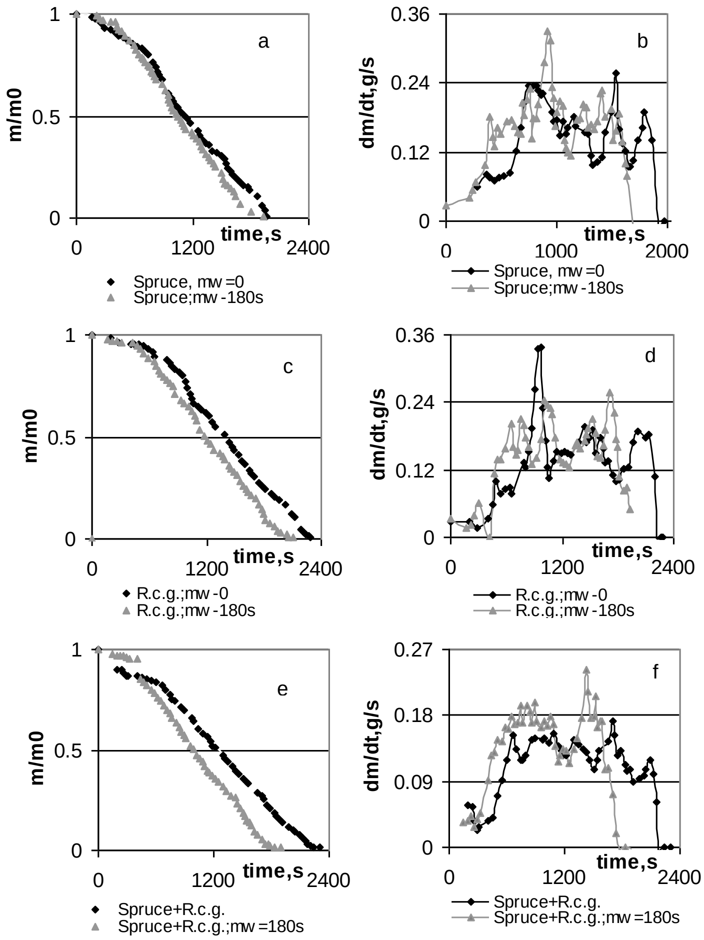


*Fig. 5.* Effect of mw pre-processing on the time-dependent variations in the weight loss and its rates: spruce sawdust (*a, b*); R.c.g. (*c, d*); spruce + R.c.g. (*e, f*).

By analogy with the formation of DTG curves (Fig. 2*a–c*), the time-dependent WLR variations at thermal decomposition of biomass pellets promote the formation of two main peaks which can be related to the primary stage of thermal decomposition of hemicelluloses and cellulose at t ≈ 1000 s and to the end stage of char conversion at 1400–1600 s (Fig. 5*b,d,f*). With nearly constant gasification conditions ($\alpha \approx 0.5$–0.6) for all pre-processed samples, the field-enhanced increase in the WLRs is observed at the primary devolatilization stage ($t \approx 500$–700 s), confirming the faster gasification of activated biomass pellets. For the activated spruce samples a slight increase in the WLR at $t \approx 900$–1000 s is observed, which can be attributed to the thermal destruction of hemicelluloses and cellulose, while the WLR at the end stage of char conversion decreases. For activated R.c.g. pellets and those of spruce sawdust + R.c.g. mixture, the WLR peaks attributable to the thermal destruction of hemicelluloses and cellulose slightly diminish and completely disappear, whereas dominating becomes the WLR increase at the char conversion stage ($t > 1200$ s). This evidences that a more effective thermal destruction of hemicelluloses and cellulose at mw pre-processing can be achieved for the spruce sawdust mixture + R.c.g. and R.c.g. pellets, while the spruce sawdust pellets with the highest lignin content are more stable and less sensitive to the field-enhanced biomass destruction at mw pre-processing (Figs. 1, 2). The mw-induced variations in the main characteristics of biomass pellets and the WLR variations at thermal decomposition for the pre-processed biomass pellets promote the correlating variations in the combustion characteristics and the formation of main products.

### 3.3. Kinetics of the EM field pre-processing effect on the combustion characteristics and composition of the products

Kinetic study of the influence exerted by mw pre-processing of biomass pellets on the combustion characteristics includes time-dependent measurements of the flame temperature, produced heat, and composition of the products at different stages of the thermo-chemical conversion of biomass pellets (Figs. 6*a*–*c*, 7*a*–*c*).

In the primary stage of thermal degradation ($t \approx 350$–600 s) of untreated pellets usually endothermic processes develop, such as biomass heating, drying and release of low calorific volatiles followed by a decrease in the flame temperature and heat power (Fig. 6 *a*–*c*) to their minimum values, which causes a delay of the ignition and combustion of volatiles.

As follows from the results of FTIR analysis, an intensive field-enhanced release of water and thermolabile carboxydrate compounds can be achieved at EM field pre-processing of biomass pellets (Fig. 4). As a result, the influence of the primary endothermic processes on the thermal degradation of biomass pellets decreases, whereas the WLR at the primary stage of biomass gasification ($t \approx 500$–700 s) (Fig. 5) increases, determining the enhanced release and ignition of the volatiles (CO, $H_2$) with a faster rise in the flame temperature and heat production to their peak values (Fig. 6 *a*–*c*). Moreover, the field-enhanced variations in the elemental composition and HHV value at mw pre-processing of biomass samples (Table 1) causes the correlating variations in the average heat power, the total amount of produced heat energy ($Q$), and the $CO_2$ volume fraction in the products at thermochemical conversion of the pre-processed biomass pellets (Table 2). Such correlation confirms that the biomass pre-processing can be employed as a tool for control of the combustion characteristics, providing enhanced combustion of the pre-processed samples along with field-enhanced heat energy production. Notice that more pronounced field-induced variations in combustion characteristics are observed for the pellets of reed canary grass and spruce sawdust + R.c.g. mixture, which have higher hemicelluloses and cellulose content of biomass, while higher stability at mw pre-processing is typical of spruce sawdust pellets with a higher lignin content (Table 2).

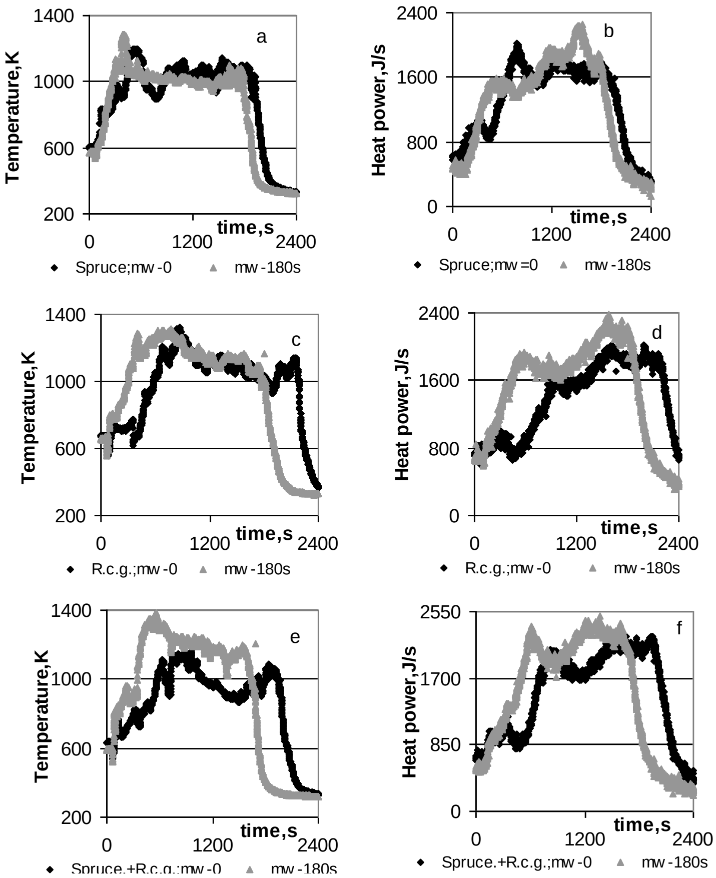


*Fig. 6.* Effect of mw pre-processing on the time-dependent variations in the flame temperature and heat production rates at different stages of biomass burnout.

By analogy with the time-dependent temperature variations in the flame reaction zone and the heat production rates, the mw pre-processing affects the composition of products mostly at the primary stage of thermochemical conversion of biomass pellets ($t < 1200$ s), when the EM field-induced impact of endothermic processes on the thermochemical conversion of biomass at mw pre-processing results in increased combustion efficiency, with a faster ignition of volatiles and a faster rise in the $CO_2$ volume fraction up to the peak value (Fig. 7*a,b*). Actually, for all activated biomass pellets the field-enhanced increase in the average values of $CO_2$ volume fraction in the products during burnout of volatiles is observed, with correlating decrease in the average values of CO mass fraction and air excess to their minimum values (Table 2), indicating that the mw pre-processing of biomass pellets provides a more complete and cleaner combustion with enhanced heat energy production.

*Table 2*

**EM field pre-processing effect on the average values of combustion characteristics**

| Characteristics | $CO_2$, % | CO, ppm | Efficiency, % | Air excess, % | *T*, K | Heat power, kJ/s | Heat energy, MJ/kg |
|---|---|---|---|---|---|---|---|
| Spruce sawdust | | | | | | | |
| *t* = 0 | 12.7 | 725.0 | 87.5 | 66.4 | 1027 | 1.66 | 11.2 |
| *t* = 180 s | 13.4 | 543.0 | 89 | 60.9 | 1033 | 1.68 | 11.7 |
| mw effect, % | 5.7 | –25.1 | 1.7 | –8.3 | 5.8 | 1.2 | 4.5 |
| Reed canary grass (Bamse) | | | | | | | |
| *t* = 0 | 9.4 | 247 | 86.1 | 103.7 | 1115 | 1.63 | 11.6 |
| *t* = 180 s | 11.1 | 192 | 87.9 | 78.7 | 1284 | 1.86 | 13.4 |
| mw effect, % | 18.1 | –22.3 | 2.09 | –24.1 | 15.2 | 14.1 | 15.5 |
| Reed canary grass + spruce sawdust | | | | | | | |
| *t* = 0 | 10.3 | 146 | 88 | 103.0 | 936 | 1.91 | 13 |
| *t* = 180 s | 11.9 | 132 | 87 | 84.7 | 1090 | 2.08 | 14.5 |
| mw effect, % | 15.2 | –9.4 | –1.1 | –18.4 | 16.5 | 8.9 | 11.5 |

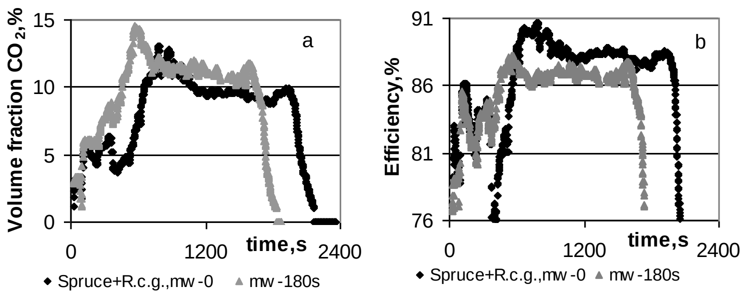


*Fig. 7.* EM field pre-processing effect on the kinetics of $CO_2$ formation (*a*) and the combustion efficiency (*b*) at thermochemical conversion of biomass samples.

## 4. CONCLUSIONS

The EM field-enhanced mw pre-processing of biomass samples contributes to complex processes of biomass drying and partial thermal destruction of hemicelluloses and cellulose with release of low-calorific volatiles and formation of new C=C bonds in the pre-processed biomass.

The biomass pre-processing leads to a decrease in the oxygen content and an increase in the carbon content of biomass, with the correlating increase in the highest heating values of pre-processed biomass pellets (to 10–21%).

The highest HHV increment has been found for R.c.g., and the lowest – for spruce pellets. A more favourable balance between yields of mass and energy is observed for the spruce + R.c.g. mixture.

The EM field-induced variations in the biomass structure and composition lead to increasing of biomass thermodegradation rate, resulting in faster ignition, faster volatization and burnout of volatiles and in higher heat energy output at combustion.

The field-induced thermal degradation at gasification of biomass samples is affected by their chemical composition (content of hemicelluloses, cellulose and lignin); the effect is stronger for R.c.g. and spruce + R.c.g. mixture, which have higher hemicelluloses and cellulose content of biomass.

The mw-induced variations of the thermal decomposition at gasification of biomass pellets promote the correlating variations in the main combustion characteristics, increasing the average values of heat power, the total produced heat energy and $CO_2$ volume fraction in the products at thermochemical conversion of pre-processed biomass pellets. Such correlation means that the pre-processing of biomass pellets can be used as a tool for control of their combustion characteristics.

*ACKNOWLEDGEMENT*

*The authors would like to acknowledge the financial support from the European Regional Development funding 2.1.1.1. ”Support to Science and Research”, Nr. 2010/0241/2DP/2.1.1.1.0/10/APIA/VIAA/006 and the financial support of Latvian Grant V7705*

REFERENCES

1. Greenhalf, C.E, Nowakowski, D.J., Bridgwater, A.V., Titiloye, J., Yates, J., Riche, A., & Shield, I. (2012). Thermochemical characterization of straws and high yielding perennial grasses. *Industrial crops and products*, *36*, 449–459.
2. Prins, M.J. (2005). *Thermodynamic analysis of biomass gasification and torrefaction.* Doctor degree thesis, Eindhoven University of Technology, 150.
3. Bergman, P.C.A., Boersma, A.R., Kiel, J.H.A., Prins, M.J., Ptasimski, K.J., & Janssen, F.J.G. (2005). *Torrefaction for entrained-flow gasification of biomass.* Energy Research Centre of the Netherlands, Report ECN –C-05-067, 50. http://www.biochar.bioenergylists.org/files/c05067.pdf.
4. McMillan, J.D. (1994). Pretreatment of lignocellulosic biomass. *In: Enzymatic Conversion of Biomass for Fuels Production* (ed-s: M.E. Himmel, J.O. Baker, R.P. Overend), 566, Ch. 15, Washington, DC: AC Ser. ACS, 292–324.
5. Zheng, Y., Pan, Z., & Zhang, R. (2009). Overview of biomass pretreatment for cellulosic ethanol production. *Intern. J. Agric&Biol. Eng*., *2* (3), 51–68.
6. Sobhy, A., & Chaouki, J. (2010). Microwave-assisted biorefinery. *Chemical Engineering Transactions*, *19*, 25–30.
7. Keshwani, D.R. (2009). Microwave pretreatment of switchgrass for bioethanol production, PhD thesis, North Carolina State University, pp. 189. http://repository.lib.ncsu.edu/ir/bitstream/1840.16/5754/1/etd.pdf.
8. Lanigan, B. (2010). Microwave processing of lignocellulosic biomass for production of fuels. Ph.D thesis, University of York, 258, http://etheses.whiterose.ac.uk/1237/1/B_Lanigan.pdf.
9. Lanigan, B., Budarin, V., Clark, J., Shuttleworth, P., Deswarte, F., & Wilson, A. (2008). Microwave processing as a green and energy efficient technology of energy and chemicals from biomass and energy crops. *Aspects of Applied Biology*, *90*, 277–282.
10. Barmina, I., Cipijs, A., Līckrastiņa, A., Valdmanis, J. Valdmanis, R., Purmalis, M., & Zake, M. (2011). Renewable Fuel Gasification and Combustion Control by Applied AC Electric Field. In: *Proceedings of 8$^{th}$ International Pamir Conference on Fundamental and Applied MHD*, 2, 843–847.
11. Friedl, A., Padouvas, E., Rotter, H., & Varmuza, K. (2005). Prediction of heating values of biomass fuel from elemental composition. *Analytica Chimia Acta*, *544*, 191–198.

12. Bridgeman, T.G., Jones, J.M., Shield, I., & Williams, P.T. (2008). Torrefaction of reed canary grass, wheat straw and willow to enhance solid fuel qualities and combustion properties. *Fuel, 87,* 844–856.
13. Barmina, I., Lickrastina, A., Purmalis, M., Zake, M., Valdmanis, R., Valdmanis, J., Arshanitsa, A., Solodovnik, V., & Telysheva, G. (2012). Effect of biomass high-frequency pre-treatment on combustion characteristics. *Chemical Engineering Transactions, 26,* 895–900.
14. Pandev, K.K. (1999). A study of chemical structure of soft- and hardwood and wood Polymers by FTIR Spectroscopy. *J. Appl. Polymer Sci., 71*, 1969–1975.
15. Hu, F., Jung, S., & Ragauskas, A. (2012). Pseudo-lignin formation and its impact on enzymatic hydrolysis. *Bioresource technology, 117,* 7–12.
16. Holkin, J. I. (1989). *The technology of hydrolysis industry*. Moscow: Wood Industry, 495 (in Russian).
17. Shen, D.K., Gu, S., Luo, K.H., Bridgwater, A.V., & Fang, M.X. (2009). Kinetic study on thermal decomposition of woods in oxidative environment. *Fuel*, *88*, 1024–1030.
18. Wang, C., Wang, F., Yang, Q., & Liang, R. (2009). Thermogravimetric studies of the behavior of wheat straw with added coal during combustion. *Biomass and Bioenergy*, *33*, 50–56.
19. Orfão, J.J.M., Antunes, F.J.A., & Figueiredo, J.I. (1999). Pyrolysis kinetics of lignocellulosic materials: three independent reaction models. *Fuel*, *78* (3), 349–358.
20. Safi, M. J., Mishra, I. M., & Prasad, B. (2004). Global degradation kinetics of pine needles in air. *Thermochim*. *Acta, 412*, 155–162.
21. Pasangulapati, V. (2012). Devolatilization Characteristics of Cellulose, Hemicellulose, Lignin and the Selected Biomass during Thermochemical Gasification: Experiment and Modelling Studies. *Thesis for the Degree of Masters of Science.* Faculty of the Graduate College of Oklahoma State University, 118.

## MIKROVIĻNU PRIEKŠAPSTRĀDES IETEKME UZ GRANULĒTAS BIOMASAS GAZIFIKĀCIJAS UN DEGŠANAS PROCESIEM

I. Barmina, A. Līckrastiņa, J. Valdmanis, R. Valdmanis, M. Zaķe,
A. Aršaņica, G. Teliševa, V. Solodovņiks

K o p s a v i l k u m s

Veikti kompleksi eksperimentālie pētījumi par mikroviļņu (2,45 GHz) priekšapstrādes ietekmi uz dažādas izcelsmes biomasas granulu (egles, miežabrāļa un to maisījumu 50:50) gazifikācijas un degšanas procesiem. Pētījumi apvieno granulētās biomasas elementārā sastāva un termogravimetriskos mērījumus, kā arī granulētās biomasas gazifikācijas un degšanas procesu kompleksu izpēti, apvienojot biomasas svara izmaiņu kinētiskos mērījumus ar degšanas zonas temperatūras, iekārtas jaudas un degšanas produktu sastāva kinētiskiem mērījumiem. Pētījumiem izmantota mazas jaudas eksperimentālā iekārta (līdz 2,5 kW), kuru veido integrēts gazifikātors un degšanas kamera. Pētījumu rezultātā konstatēts, ka mikroviļņu priekšapstrāde nodrošina intensīvāku biomasas gazifikāciju, ātrāku gaistošo savienojumu veidošanos, uzliesmošanu un pilnīgāku sadedzināšanu ar sekojošu saražotās īpatnējā siltuma enerģijas pieaugumu.

15.05.2013.