

ELECTRIC FIELD CONTROL OF BIOMASS GASIFICATION

Inesa Barmina, Antons Kolmickovs, Raimonds Valdmanis, Sergejs Vostrikovs, Maija Zake

Institute of Physics

antons.kolmickovs@gmail.com

Abstract. The aim of this study is to investigate the DC electric field effect on biomass gasification to provide effective control of processes developing at thermal decomposition of pelletized renewable fuels under oxygen rich conditions ($\alpha \approx 0.06-0.12$) and controllable production of combustible volatiles (CO , H_2), which can be used as a fuel for energy production. Experimental investigations of the DC electric field effect on the biomass thermal decomposition in a batch-size pilot gasifier were carried out using a single electrode configuration and a fixed air supply ($\sim 0.32 \text{ g}\cdot\text{s}^{-1}$). The bias voltage of an electrode, which is axially inserted through a biomass layer, can be varied from $U = 0$ to $U = +2.4 \text{ kV}$, whereas the current in the space between the electrodes is limited to 2 mA. The results of complex spectral measurements and analysis of the produced gas composition evidence the field-enhanced thermal decomposition of biomass with the field-enhanced production of the axial flow of main gasification products CO , H_2 , CH_4 and unsaturated hydrocarbons (C_2H_2 , C_2H_4 , etc.). The field-enhanced variations of the composition of the produced gas and heat effects are analyzed considering the field effect on the operation conditions of the biomass gasification.

Keywords: wood, biomass, gasification, electrodynamic control.

Introduction

The use of fossil fuels for heat and energy production has a relation to global warming due to increasing accumulation of carbon dioxide in the Earth's atmosphere. Renewable fuels have lower heating values compared to fossil fuel, dissimilar structure and wide-range variations of the moisture content and chemical composition that can cause variations of the combustion characteristics. The possibility of using waste biomass and agricultural residues in the energy production process is driving for further development of the technologies.

Nowadays, industry already uses a biomass gasification technology in the biogas plants for the electricity production. Besides, the use of biomass gasification technologies for energy production may lead to problems associated with the release of unsaturated hydrocarbons, which can cause typical turbine damage [1]. Methods of biomass pretreatment have been developed, such as torrefaction, microwave treatment, etc. that reduce the release of corrosive volatiles at biomass thermal decomposition [2; 3]. However, the use of biomass pretreatment technologies raises the raw product price. Therefore, the development of new methods to control the biomass decomposition is considered as an alternative for cleaner energy production.

There are studies on alternative combustion control techniques based on the electric field-induced "ion-wind effect" in the flame [4; 5]. Experimental investigations of the DC electric field effect on the swirling flame formation and combustion of volatiles at high swirl intensity have shown that the field-enhanced mass transfer of the flame species in the field direction allows controlling the process of products' recirculation, with direct impact on the flame shape and combustion characteristics [5]. If an electric field is applied to the gasification zone of biomass pellets, it results in processes related to biomass dipole polarization [6], causing different effects, such as constant-current electro-osmotic dewatering [7], dielectric RF wood heating [8], and adhesion forces improvement.

The present investigation is focused on the improvement and control of the gasification characteristics at thermochemical conversion of biomass (wood pellets) using the DC electric field effects on the biomass gasification under oxygen-rich conditions with the aim to increase the total amount of the produced main gasification products (CO , H_2 , CH_4), reduce the by-product concentration in the gaseous phase and minimize the endothermic effect of biomass gasification.

Materials and methods

In order to investigate the DC electric field effect on the thermal decomposition of biomass pellets, an experimental batch-size biomass gasifier has been designed (Fig. 1). The gasifier consists of a water-cooled channel (1) and diagnostic sections (4, 5, 6). Discrete doses of biomass (wood) pellets with a total mass amount of $m = 115 \text{ g}$ are placed on a steel mesh at the base of the gasifier. The inner diameter of the gasifier is about $D = 60 \text{ mm}$ and the total height is $L = 330 \text{ mm}$. The propane flame

flow (2) was used to provide additional heat energy supply through the bottom biomass layer at the average rate of heat supply $P_{prop.} = 1-1.3$ kW to initiate the endothermic process of biomass thermal decomposition. To advance the biomass thermal decomposition, the axial air flow was supplied below the biomass layer through the nozzle (3) at the average rate $q_{air} = 0.3-0.6$ g·s⁻¹, producing a fuel-rich ($\alpha \approx 0.3-0.6$) axial flow of volatiles (7). This pilot device is similar to the industrial upstream gasifier with biomass oxidizing, gasification and recombination zones. The electric control of wood biomass thermal decomposition was provided using a single electrode configuration (8), with the total height $L = 245$ mm of the electrode, which was positioned axially through the biomass layer. In order to prevent the DC electric field effect on the propane flame, the lower part of the electrode (up to 150 mm) was isolated. An electric field was applied between the positively biased electrode and the grounded channel walls. The voltage U of the axially inserted electrode relative to the channel walls could be varied from +0.6 to +2.4 kV, whereas the ion current in these experiments was limited to $I = 2$ mA.

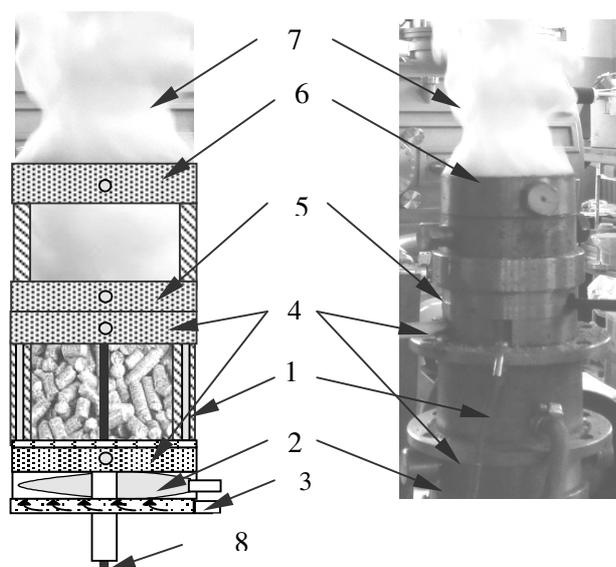


Fig. 1. **Principal schematic and digital photo of the biomass gasifier:** 1 – water-cooled channel; 2 – propane flame flow; 3 – air supply; 4, 5, 6 – diagnostics sections; 7 – axial flow of volatiles; 8 – electrode

The experimental study of the DC electric field effect on biomass gasification combines complex measurements of temperature, composition and gasification heat power, and data analysis. The propane flame and gasification product flow temperature was measured by a Pt/Pt-Rh thermocouple. An infrared FTIR spectrometer Varian 640-IR and a gas analyzer Testo 350XL (CO, H₂ and NO_x) were used to control the gas composition at biomass gasification. The infrared spectrum absorption intensities of the produced gas were measured for band absorption of components: CO (2169 cm⁻¹), CH₄ (3017 cm⁻¹), C₂H₂ (729 cm⁻¹), C₂H₄ (949 cm⁻¹) and C = O (1733 cm⁻¹). The gasification heat effect was analyzed from calorimetric measurements of the cooling water flow with online data registration using the PC-20 TR plate. The average variations of the gas composition were measured using of 3 reiterations.

Results and discussion

The process of biomass thermo-chemical conversion develops with the subsequent endothermic processes of biomass heating, drying, and thermal decomposition. The process of biomass thermal decomposition is determined by the biomass chemical composition and includes the thermal decomposition of hemicelluloses, cellulose and lignin. The complex measurements of the absorbance of the produced volatiles at biomass thermal decomposition and of the temperature of volatiles at different air supply rates and constant additional heat supply rate ($P_{prop.} = 1$ kW) revealed that, when the electric field was not applied ($I = 0$), the most intensive and stable process of biomass thermal decomposition developed at the air supply rate $q_{air} = 0.3$ g·s⁻¹ ($\alpha = 0.3$), when the most intensive increase of the absorbance of volatiles (CO, C₂H₂, C₂H₄, CH₄) was observed at a certain wave number

v , cm^{-1} (A_{ij}) indicating their concentration increase in the produced gas mixture (Fig. 2-a). As follows from Fig. 2-b, the process of biomass thermal decomposition under such conditions develops at a nearly constant temperature above the biomass layer.

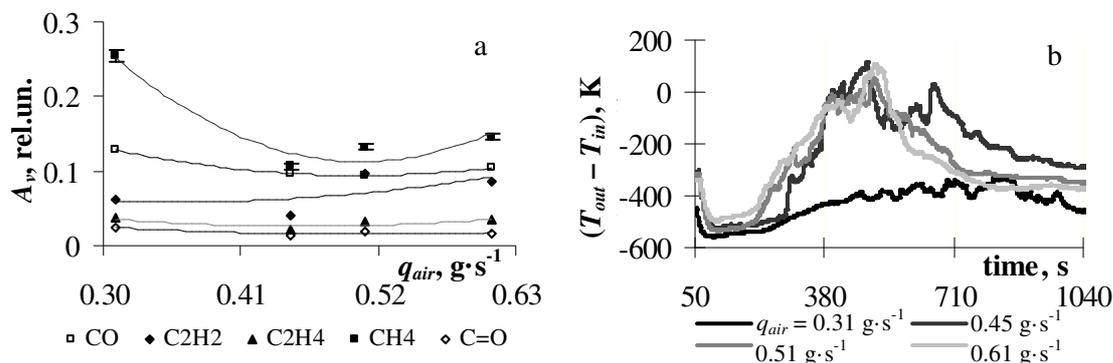


Fig. 2. Composition of the axial flow of volatiles vs. the air supply rate (a), and the time-dependent variation of the temperature difference between the outlet flow of volatiles and inlet air vs. the varying air supply rate (b)

Increasing the additional heat energy supply into the biomass layer to 1.3 kW, with the air supply rate into the biomass being constant ($0.3 \text{ g}\cdot\text{s}^{-1}$), results in a decrease of the absorbance of CO, C₂H₂, C₂H₄ and thus their concentration in the produced mixture (Fig. 3-a). This leads to a correlating increase of heat power at the thermochemical conversion of volatiles and of the average temperature difference under and above the biomass layer (Fig. 3-b), indicating a transition from the endothermic processes of biomass thermal decomposition to a regime, when the exothermic processes of thermochemical conversion of volatiles develop (Fig. 3-a). Note that a heat power peak value was observed at 1.2 kW (Fig. 3-b) and it started to decrease with the higher values of the additional heat energy supply, when the enhanced development of the endothermic processes of biomass thermal decomposition at the constant air supply rate led to an intensive heat energy consumption from the biomass gasification zone so decreasing the released heat power at biomass thermochemical conversion (Fig. 3-a, b).

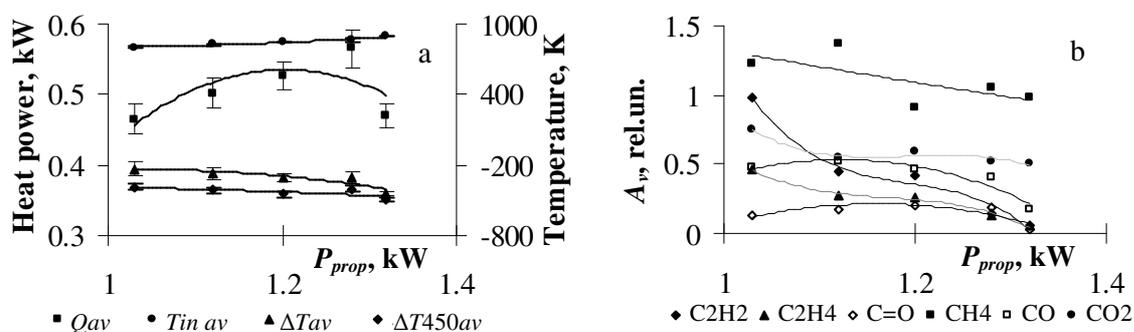


Fig. 3. Effect of additional heat energy supply into biomass on average values of heat power released at biomass gasification and on the temperature difference average value ($T_{out} - T_{in}$) (a), and concentration of volatiles represented in relative absorbance unions (b)

The enhanced transition from the thermal decomposition dominant regime to a regime, when the thermochemical conversion of volatiles dominates, was confirmed by the time-dependent measurements of the temperature difference between the inlet and outlet flows and of the absorbance of volatiles (Fig. 4-a, b). As follows from Fig. 4-a, b, increasing the additional heat supply into biomass promotes a faster thermochemical conversion of C₂H₂ with a correlating decrease of the absorbance of harmful acetylene (Fig. 4-b).

The mechanism of biomass thermal decomposition is still argued and supplemented as new information arrives. Yet, it is found that the primary endothermic processes of biomass heating and drying take place in the temperature range $T = 300\text{--}420 \text{ K}$ and, as observed at the biomass thermal

decomposition, these processes last up to 100 s. Figures 5-a, b show that with no electric field applied ($I = 0$), the processes of biomass heating and drying result in moisture release correlating with a slight decrease of the inlet air temperature and a sharp decrease of the outlet gas temperature. The next endothermic stage of the biomass thermal decomposition without electric field ($I = 0$) resulted in an outlet gas temperature decrease to ~ 400 K.

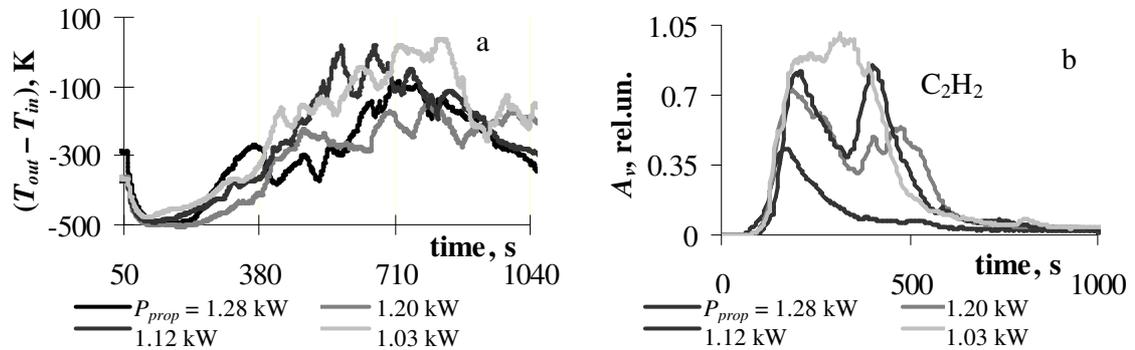


Fig. 4. Effect of additional heat energy supply on the time-dependent variation of the temperature difference between the outlet and inlet flows (a) and on the absorbance of C_2H_2 (b)

Additionally, a correlating sharp peak of the C_2H_2 and C_2H_4 absorption in the outlet gas at ~ 200 s (Fig. 6-a) were observed with a large increase of the CO and CH_4 absorption (Fig. 6-b, c). The formation of volatiles at this stage of biomass thermal decomposition cannot be attributed to the decomposition of one specific wood component (hemicelluloses, cellulose, or lignin) due to the relatively high temperature of the inlet air flow (~ 830 - 870 K), because a simultaneous thermal decomposition of these components could occur. The exothermic process of thermal decomposition of hemicelluloses, developing in the temperature range $T = 490$ - 600 K, could be the main source of C_2H_2 and C_2H_4 release due to the irregular branched chemical structure of hemicelluloses, whereas the evolution of the endothermic process of cellulose thermal decomposition ($T = 580$ - 650 K) with a pronounced heat energy absorption due to depolymerization processes could be responsible for the sharp decrease of the outlet temperature at $t > 450$ s (Fig. 5-b), which correlates with the increase of the CO absorption intensity at 500 s. Note that the time-dependent variation of the H_2 concentration shows a similar increase up to the maximum value, which was observed at $t \approx 200$ s and $t \approx 500$ s. The thermal decomposition of lignin occurs in the temperature range $T = 520$ - 800 K, producing CH_4 , the formation of which is a result of the thermal instability of the methoxy functional group.

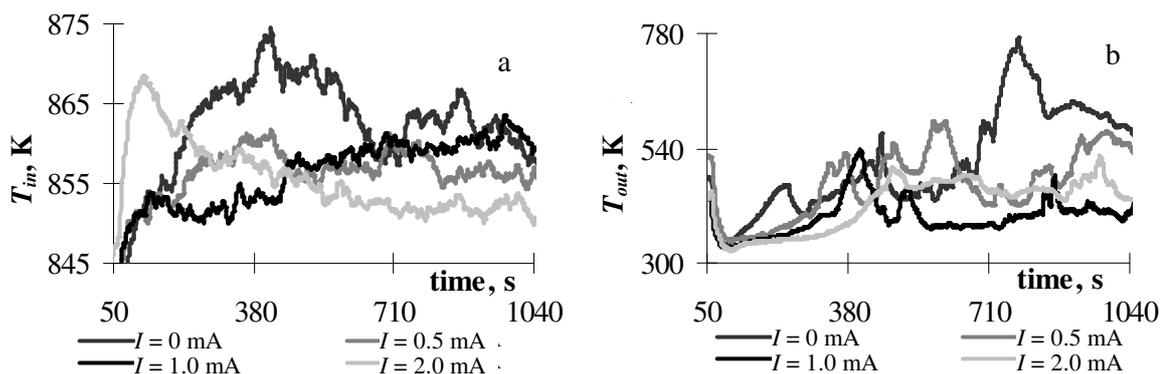


Fig. 5. Electric field effect on the time-dependent variation of the inlet (a) and outlet (b) gas temperature at thermal decomposition of wood pellets

If the electric field is applied to the biomass gasification zone, the field-induced current in the space between the electrodes testifies the influence on the time-dependent variation of the temperature and absorbance of the produced volatile compounds. The time-dependence of the inlet hot air flow temperature demonstrates a slight increase in temperature at the primary stage of biomass thermal decomposition ($t < 350$ s) along with field-induced stabilization of the inlet air temperature after $t > 350$ s (Fig. 5-a). The time-dependent variation of the outlet gas temperature testifies the electric field effect on the biomass thermal decomposition, i.e., the DC electric field influence delays the

primary endothermic effect with the enhanced biomass thermal decomposition and intensive heat energy consumption (Fig. 5-b), which is confirmed by the averages of the heat power released during the thermal decomposition of biomass pellets ($t = 50\text{-}600$ s) (Fig. 7-a). The most pronounced electric field-induced variation of the outlet gas temperature with the correlating increase in absorption peak values of C_2H_2 , C_2H_4 , CH_4 and in H_2 concentration in the flow of volatiles were observed at $I = 1.0$ mA (Fig. 6). The field-induced variation of the CO_2 absorption intensity confirms a more intensive hemicellulose thermal decarboxylation with a sharper increase in value during the first stage of biomass decomposition, when the correlating increase of the inlet air flow temperature was observed (Fig. 5-a). The field-induced increase of the nitric oxide (NO_x) average concentration is obvious (Fig. 6-d) because of the overall electric field-enhanced thermal decomposition with the enhanced release of fuel-bound nitrogen, which is proved by the composition averages (Fig. 7-b) correlating with the increase in the heat energy consumption (Fig. 7-a). The DC current increment between the electrodes is followed by a small growth of the average air temperature at the inlet (Fig. 7-a) due to the field-induced temperature increase and process stabilization at the primary stage of biomass thermal decomposition ($t < 350$ s) (Fig. 5-a, b). Moreover, the decrease of the average value of the outlet gas temperature by increasing the DC electric field-induced current in the biomass correlates with the boost of the general biomass gasification product absorption averages within 50-600 s (Fig. 7-a, b).

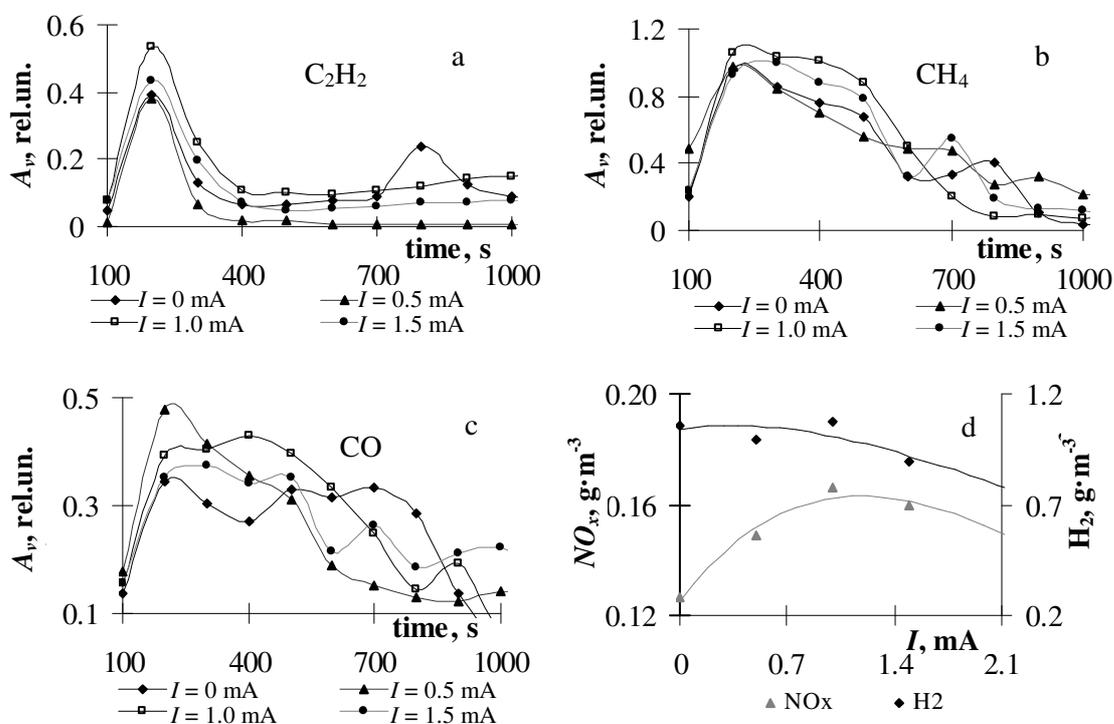


Fig. 6. Electric field-induced current effect on the formation of volatiles (a-c) and NO_x (d) at biomass thermal decomposition

In fact, the main mechanism of the field-induced current effect on biomass gasification is not still clear. However, the field-induced variations of the biomass temperature and composition allow to suggest that the electric field disturbs the balance between the endothermic and exothermic processes at biomass thermal decomposition. The overall DC electric field effect on biomass thermal decomposition could be attributed to overlapping of both field-enhanced effects: the field-induced “ion-wind” that enhances the temperature field homogenization in the biomass layer and the electric field-induced biomass interfacial polarisation assumed to force the electric field-induced mass transfer of O_2^- towards the positively polarized surfaces of biomass pellets, thus increasing the oxygen concentration close to the surface of pellets. This can lead to enhanced decarboxylation of hemicellulose and to decarbonylation of cellulose. In order to reveal the mechanism of the electric

field-induced variation on the biomass thermal decomposition, more detailed studies should be provided.

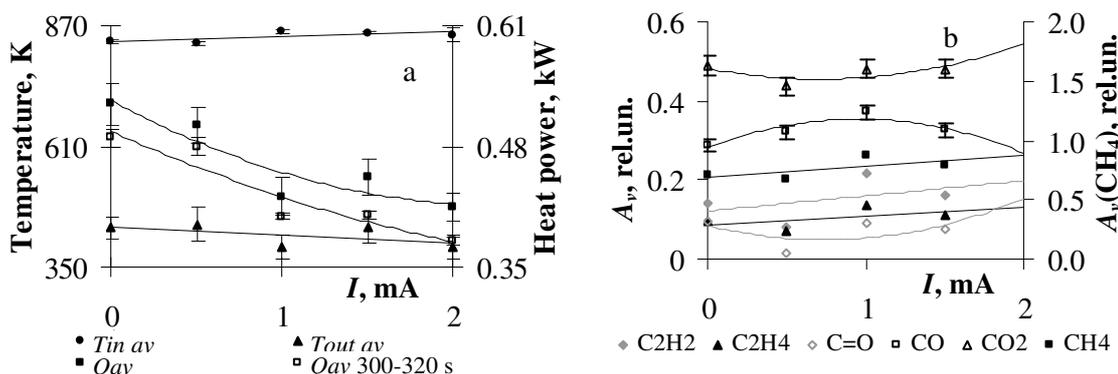


Fig. 7. Biomass thermal decomposition inlet/outlet flow temperature, produced heat power average values (a) and gasification product absorption intensity average values within 100-600 s with reference to the electric field current

Conclusions

1. Biomass thermal decomposition is a complex process the endothermic effect of which can be controlled by varying the air and heat energy supply into biomass.
2. The electric field-induced effect on biomass thermal decomposition improves the temperature homogenization; boosts the release of the main gasification product (CO by ~11-30 %, CH₄ by ~13-25 %) and enhances the heat energy consumption by ~4-21 %.
3. The mechanism of the DC electric field-induced variation of biomass thermal decomposition is suggested as overlapping of the field-induced “ion-wind” effect that enhances temperature homogenization and stabilization and of the field-induced interfacial polarisation of biomass pellets due to the field-induced mass transfer of negative oxygen ions towards the polarized surface of biomass pellets, thus increasing the oxygen concentration close to the solid interface, which might result in field-induced decarboxylation of hemicellulose and decarbonylation of cellulose.

Acknowledgment

The authors would like to acknowledge the financial support of the European Research and Development Funding, project No. 2014/0051/2DP/2.1.1.1.0/APIA/VIAA/004.

References

1. Bridgeman T.G., Jones J.M., Shield I., Williams P.T. Torrefaction of reed canary grass, wheat straw and willow to enhance solid fuel qualities and combustion properties. *Fuel*, vol. 87, 2008, pp. 844-856. DOI 10.1016/j.fuel.2007.05.041
2. Barmina I., Līckrašņa A., Valdmanis J., Valdmanis R., Zaķe M., etc. Effect of microwave pre-processing of pelletized biomass on its gasification and combustion. *Latvian Journal of Physics and Technical Sciences*, vol. 4, 2013, pp. 34-47. DOI 10.2478/lpts-2013-0024
3. Lawton J., Weinberg F., *Electrical Aspects of Combustion*, Clarendon Press, Oxford, UK, 1969.
4. Barmina I., Zaķe M., Valdmanis R. Electric Field-Induced Variations of Combustion Dynamics. *Chemical Engineering Transactions*, 2014, vol. 39, pp. 1531-1536.
5. Sugimoto H., Norimoto M. Dielectric relaxation due to interfacial polarization for heat-treated wood. *Carbon*, vol. 42, issue 1, 2004, pp. 211–218. DOI 10.1016/j.carbon.2003.10.013
6. Iwata M., Jami M.S., Sato M. Analysis of constant-current electro-osmotic dewatering of various solid-liquid systems by considering the creep deformation. *Separation and Purification Technology*, vol. 58, 2007, pp. 274–281. DOI 10.1016/j.seppur.2007.03.017
7. Helmuth Resch. High-frequency electric current for drying of wood – historical perspectives.
8. Kauman W.G. High-frequency electric current for drying of wood historical perspectives. *Maderas: Ciencia y Tecnología*, vol. 8, issue 2, 2006, pp. 67-82. ISSN 0717-3644. <http://www.scielo.cl/pdf/maderas/v8n2/art01.pdf>