ACTIVE CONTROL OF BIOMASS COMBUSTION CHARACTERISTICS BY HIGH FREQUENCY OSCILLATIONS

Inesa Barmina, Modris Purmalis, Raimonds Valdmanis, Maija Zake
University of Latvia
mzfi@sal.lv

Abstract. The paper presents the results of an experimental study of the effect of high-frequency electromagnetic (EM) field oscillations on combustion and emission characteristics of biomass pellets with the aim to provide active control of the processes of biomass gasification and combustion. The effects of high-frequency oscillations on the combustion characteristics were studied experimentally providing complex measurements of the combustion characteristics, produced heat energy and product composition by varying the electric power and duration of biomass preprocessing by EM oscillations. It is found that high-frequency oscillations promote enhanced biomass gasification and combustion of volatiles completing the combustion of the volatiles with a correlating increase of the combustion efficiency and produced heat energy. The mechanism of high-frequency oscillations on the combustion characteristics is analyzed considering the field – enhanced variations of biomass thermal decomposition.

Keywords: renewable energy, gasification, combustion, high-frequency electromagnetic field.

Introduction

The need for active control and stabilization of the gasification and combustion processes for different biomass types produced from various harvesting and agriculture residue with diversity of their composition has led to a rapid growth in the use of different methods of combustion control and their improvement to ensure the stable thermo-chemical conversion of biomass. Recently, various methods of combustion control, such as swirl-enhanced mixing of the flame compounds, co-firing of biomass with fossil fuel, as well as electric and magnetic field effects on biomass combustion have drawn considerable attention that allows enhancing gasification and complete combustion [1-3]. In addition, the process control with plasma-assisted gasification has undergone many experimental studies confirming that the interaction of high-frequency plasma discharge with hydrocarbon fuels can be used to provide the field-enhanced thermal decomposition of biofuels and the mixing of air with produced fuel gas, so determining the enhanced combustion of volatiles, along with technological application of plasma discharge for enhanced gasification and combustion of waste [4-6]. Moreover, there is a still increasing interest in the use of high frequency EM field oscillations for biomass pre-processing that can be used to improve the gasification and combustion characteristics of biomass as well as for flame stability, depending on the frequency of EM oscillations [7-9]. Our previous research of the effect of high frequency oscillations on the thermo-chemical conversion of biomass pellets has confirmed that the application of high-frequency oscillations to the flame base, close to the surface of a biomass layer, promotes enhanced biomass gasification and mixing of the flame compounds with a more complete combustion of the volatiles [4]. The further complex experimental study of the effect of microwave pretreatment on the gasification and combustion characteristics has shown that microwave pre-treatment of biomass pellets results in faster thermal decomposition of biomass with a faster and cleaner burnout of the pre-treated biomass samples. The effect of microwave pre-treatment on thermal decomposition of biomass was accompanied by the growth of the heat energy output due to variations of the elemental composition of biomass pellets and heating values of the pre-treated samples [7]. The above experiments raised some questions in the studies of the effect of EM oscillations on the combustion characteristics. First, which mode of high-frequency oscillation application is more effective to provide field-enhanced activation of biomass gasification and combustion? Second, an option of the frequency range of EM oscillations to improve the combustion characteristics and, finally, what is the main effect of the EM field energy absorption determining the enhanced thermo chemical conversion of biomass?

The reported study is motivated by these questions. The main aim of this study is to provide and compare the field action on the thermal decomposition of biomass and on the combustion characteristics by varying the mode of EM field application and the frequency of EM field oscillations. The mechanism of EM field oscillation influence on the processes of thermo chemical conversion of biomass and on the combustion characteristics is analyzed considering the application mode and the frequency of EM oscillations.

Materials and methods

The EM field effects on the thermo-chemical conversion of batch size biomass samples (40g) was studied experimentally for wood pellets with 50.0 % carbon, 6.08 % hydrogen, 0.15 % nitrogen, 41.7 % oxygen content and the highest heating value (HHV) 19.9 $MJ \cdot kg^{-1}$ [7]. A small-scale pilot device was used to study experimentally the EM effect on the combustion characteristics at field-enhanced pre-processing of the wood pellets and at direct application of EM oscillations to the flame base (Fig. 1). An experimental study of EM field effect on the combustion characteristics and produced heat was performed for a wide range of EM field frequencies (10^6- 10^9 Hz), respectively, at: f = 2.3 MHz, f = 13.5 MHz; f = 40 MHz and f = 2.45 GHz, thus providing a comparison of the EM field effect on the combustion characteristics at biomass pretreatment with that at direct application of EM oscillations to the flame base using a single electrode configuration (Fig. 1). The experimental study of the EM field effect on the combustion characteristics was carried in a way providing online measurements of the kinetics of the product composition at different stages of wood pellet burnout along with estimation of field-induced variations of the average values of CO_2, CO, H_2, CH_4 and the produced heat (Q_{eff}). The measurements of the product composition were made using a gas analyzer "Gazohrom-3101". A heat recorder "Ultraflow" measured the produced heat energy. The flame temperature and the cooling water flow temperature were measured using thermocouples along with estimation of the field effect on the total amount of the produced heat energy and total heat loss at the thermo-chemical conversion of biomass pellets in a micro-furnace. The average power output of the device is approximately 550-850 W that means its consuming of biomass at average rate 0.026-0.05 $g \cdot s^{-1}$.

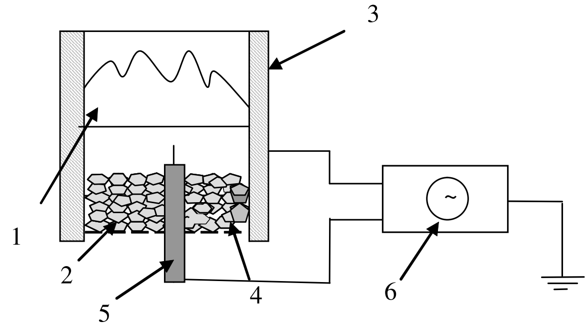

Fig. 1. **Schematic presentation of the small-scale pilot device for the experimental study of EM field effects on the combustion characteristics:** 1– micro-furnace; 2 – biomass pellets; 3 – heat surface; 4 – stainless steel mesh; 5 – axially inserted electrode; 6 – high-frequency generator

Results and discussion

The response of wood pellets to an applied EM field at pre-treatment depends on the energy dissipation effect determining the biomass heating due to the applied field, which depends on the conductivity and dielectric loss factor (ε'') of the material. The main factors determining the dielectric properties of biomass pellets can be related to the moisture content and bulk density in biomass. At a constant moisture content (8 %) and bulk density of wood pellets (≈600 $kg \cdot m^{-3}$) the dielectric properties of pellets vary with the frequency of the applied electric field due to variations of the ionic conductivity and electric polarization effects of water molecules. With reference to the data presented in [10] at low frequencies (< 10^6), biomass heating due to the field-induced mass transfer of positive and negative ions depending on the ionic conductivity dominates. As the EM field frequency increases, gradually the dissipation effect increases and the EM field energy loss due to the electric polarization of water molecules with maximum value of the dielectric loss factor and field-induced heating effect at microwave pretreatment of wood pellets (≈30 GHz) [10], resulting in the field-induced variations of the biomass structure and composition [8; 9]. As a result of the field-induced variations of the biomass structure and composition at EM field-induced pretreatment of wood pellets the variations of the combustion characteristics and composition of the products at the thermo-chemical conversion of pretreated biomass pellets were detected. As one can see from Fig. 2, for all frequencies the field-enhanced pretreatment of the wood pellets results in their enhanced thermo-chemical conversion of wood pellets promoting a decrease of the peak value of the CO mass fraction in the products with the correlating increase of the produced heat energy, whereas the heat loss due to incomplete thermo-chemical conversion of the biomass decreases (Table 1). The maximum value of the field effect on the thermo-chemical conversion of wood pellets with an increase of the volume fraction of CO_2 and correlating decrease of CO mass fraction in the products is observed at microwave pretreatment (Table 1), that is accepted as the most promising technology of biomass pretreatment.

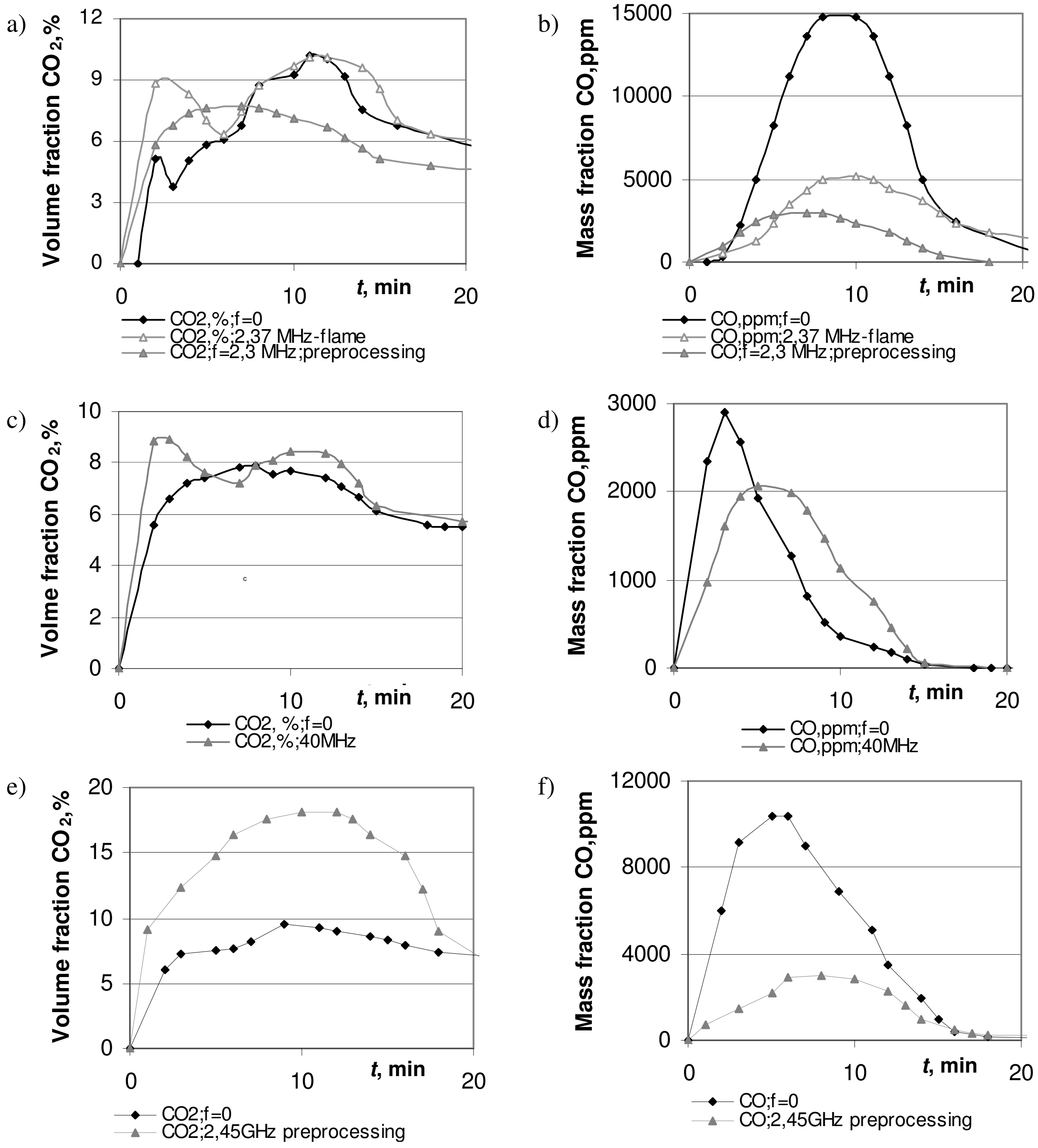

Fig. 2. **Effect of biomass preprocessing at different EM field-frequencies on the product composition (a-f) and at application of EM oscillations at the flame base (a, b)**

As follows from Table 1, the EM field-induced variations of the product composition so are observed under conditions, when the EM field oscillations are applied close to the flame base combining the field effects on the processes of biomass thermal decomposition and volatile combustion. As one can see from Table 1, with the single electrode configuration the more effective field-enhanced increase of the volume fraction of CO_2 with the correlating increase of the produced heat energy and decrease of the mass fraction of CO in the products (Fig. 2, a) is observed at low-frequency oscillations (2.5 MHz), when the field-induced heating of biomass dominates due to the ionic conductivity and field-enhanced mixing of the flow of volatiles with the air flow due to ionic wind effects developing close to the flame base. The EM field-enhanced gasification of wood pellets is observed at the formation of field-induced plasma torch discharge at the top of the single electrode, when most of the field energy is absorbed by the flame sustaining the process named as plasma gasification [11]. Under the given conditions the plasma-enhanced gasification of wood pellets is observed with the correlating increase of the volume fraction of volatiles and of the volume fraction of CO_2, while the produced heat energy at the thermo-chemical conversion of wood pellets in a micro-furnace decreases with the correlating increase of the heat loss q_3 indicating incomplete thermo-chemical conversion of the volatiles. Hence, the activation of biomass gasification at torch discharge is applicable to provide the process optimization in order to achieve complete thermo-chemical conversion of biomass.

Table 1

EM field effect on the flame composition at thermo-chemical conversion by varying the applied field frequency, time of pre-treatment (t_p), power (P_{el}) and the mode of the field application

Mode of application and frequency of EM field	dCO_2,%	dH_2,%	dCO,%	dCH_4,%	dQ_{water}, %	dQ_{eff},%	dq_3,%	P_{el}, VA	t,min
2.5.MHz-preprocessing	-0.09	-17.14	-5.57	20.60	4.2	3.8	-0.08	6.23E-07	5
2.5 MHz-flame	-0.06	-29.28	-3.85	-55.13	0.22	2.66	-0.89	6.23E-07	20
13.5 MHz preprocessing	-0.55	-44.33	-39.58	-73.76	6.19	7.16	-0.77	65.5	5
13.5 MHz Flame (torch discharge)	0.92	69.49	51.8	90.95	-0.22	-2.08	1.15	66.9	25
13.5 MHz Flame (torch discharge)	-0.36	-32.02	-12.87	-36.73	-0.69	-0.31	-0.92	5.83	24
40MHz preprocessing	-0.1	-59.98	13.62	-5.6	2.46	2.74	0.14	15	5
40 MHz-flame	-0.91	-38.17	-17.14	-46.88	0.37	2.34	-1.44	15	15
2.45 GHz-Biomass preprocessing	1.28	-69.68	-60.24	-79.36	4.35	3.82	-2.14	15	1.7

Conclusions

The paper presents the results of the complex experimental study of the EM field effect on the gasification and combustion characteristics of wood pellets under the conditions of biomass pretreatment and direct application of EM oscillations to the flame base.

1. The experimental results allow to conclude that the most intensive enhancement of thermal decomposition and combustion of volatiles at pretreatment of wood pellets can be obtained at microwave pretreatment of wood pellets, when the dissipation effect and the EM field energy loss due to electric polarization of water molecules increase, with a maximum value of the dielectric loss factor and field-induced heating effect of biomass along with the field-enhanced biomass gasification and combustion of volatiles, promoting the increase of the volume fraction of CO2 in the products and produced heat energy in the micro-furnace.
2. The field-enhanced thermal decomposition of wood pellets and the combustion of volatiles hence can be obtained, when the EM field oscillations are applied to the flame base combining the field effect on the biomass gasification due to EM energy dissipation at ionic conductivity and on the

combustion due to field-enhanced mixing of the flow of volatiles with the air in the flame reaction zone.

3. The plasma-enhanced thermal decomposition of biomass and the heat energy production in the micro-furnace are observed under the conditions of torch discharge formation at the top of the single electrode with incomplete thermo-chemical conversion of volatiles indicating that process optimization is required that is the main goal of the future research. The torch discharge increases the temperature in the burner and stimulates forming of H2. It looks like for such situation a secondary air feed is necessary, and that would enhance the oxidation of H2 and CO and result in positive heat effects.

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