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Fractional electric model of sintered ash from coal and biomass

Abstract. *The study of fuel ash is of great importance in the analysis processes in the light of combustion efficiency, pollution, economic use of the boiler and the wear process. In this paper are presented the results of electrical measurements (impedance analysis) of the ash samples prepared from hard coal, lignite and biomass, in terms of finding the electric model of the ash. It was obtained the same model for hard coal, lignite and biomass (wood chips) ash. The proposed model was tested by computer simulation and determined the parameters of this model were correlated.*

Streszczenie. *Badanie popiołów paliw ma olbrzymie znaczenie przy analizie procesów spalania między innymi pod kątem efektywności spalania, zanieczyszczeń, ekonomii wykorzystania kotła oraz jego procesu zużycia. W prezentowanej pracy przedstawiono analizę wyników badań elektrycznych (impedancyjnych) popiołu z węgla kamiennego, brunatnego i biomasy (zrębki drewniane), pod kątem znalezienia elektrycznego modelu zastępczego popiołu. Zaproponowano jeden model dla trzech badanych popiołów. Zaproponowany model był testowany przez symulacje komputerowe a wyznaczone parametry tego modelu zostały ze sobą skorelowane.* **(*Elektryczny model ułamkowy spiekanego popiołu z węgla i biomasy*)**

Keywords: biomass, ash, sintering, electric model, CPE fractional element.
Słowa kluczowe: biomasa, popiół, spiekanie, model elektryczny, element ułamkowy CPE.

Introduction

The complete and correct information on the deposit-forming propensity of biomass ash is very important for boilers designers and operation engineers. There are some empirical indices (ash fusion test, chemical analysis) relating to ash deposition, but they frequently give misleading results and their reliability is poor. It was also investigated the resistivity changes of the ash in the process of sintering [1-5]

The other problem is understanding how inorganic components of hard coal, lignite and biomass react, and how this affects ash behavior. An interesting problem is the behavior of the electrical properties of hard coal, lignite and biomass during ash sintering process, because the coal and biomass ash is a specific material composed of some minerals and oxides grains and during sintering process it was observed some chemical and physical processes. Some quantities characterizing such materials are capacity, resistance and inductance. Although that is, the phenomena that occur in them can not be fully expressed solely by these three measures. However, it appears that they can be successfully characterized by applying mathematical models using fractional derivatives [6].

In this paper are presented the results of impedance analysis of hard coal, lignite and biomass. The aim of this work is to build the electrical model of the hard coal, lignite and biomass ash. It is expected to receive an objective method for evaluating the slagging and fouling process. It was performed the impedance spectrometry examinations and it was found that the simplest model describing its electrical properties can be expressed as a fractional differential equation. Finding the parameters of such a model requires using identification techniques described in other work [6].

Experimental

The hard coal, lignite coal and the biomass (woody chips) ash samples were prepared during low temperature ashing (500 °C). Such samples were formed as a thin disks (1 cm in diameter and about 0.5 cm thick). To determine the equivalent electrical model of the coal and biomass sintered ash, it was examined using the impedance spectrometry method in measuring system presented in figure 1.

The impedance spectroscopy determines the linear electrical response of the tested material to stimulation with a small electromagnetic signal in a wide frequency range. This response is then analysed to obtain useful information on the physiochemical properties of the tested material [6].

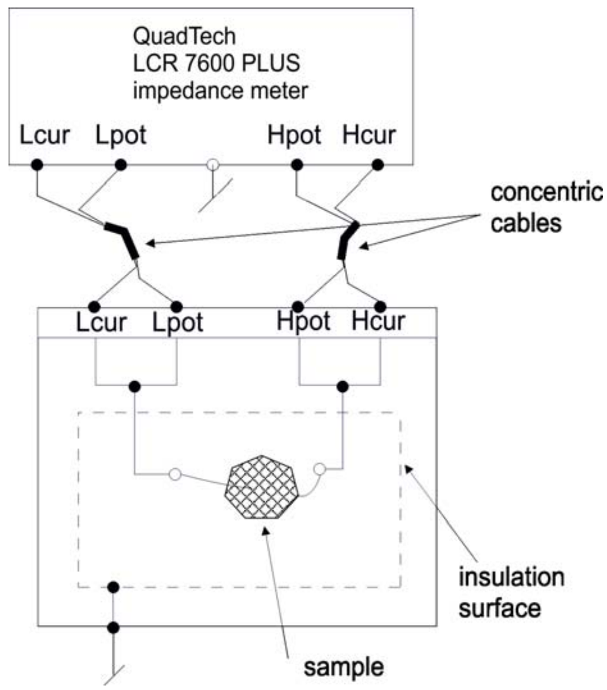

Fig.1. Measuring system

The results obtained by impedance spectroscopy are expressed by complex impedance or admittance values of the object in function of either time or frequency. These studies should take into account factors such as temperature, humidity, pressure, etc. The measurements also provide information on the geometry of the sample and the influence of both electrodes and wire connections on impedance characteristics. On the basis of the set of complex electricity values obtained as a result of the measurement, measured as a function of frequency in the range of several decades, one can make a full analysis of the dynamic properties of the measured object. These properties, in the case of systems which are linear in the frequency domain, can be described by impedance $Z(\omega)$. It can be derived from the definition of impedance $Z(\omega)$ that every measurement resolve itself into determination of the amplitude of current flowing through the object along with the phase shift between this current and applied voltage.

The sample was placed on an isolated (grounded) base, and connected to the QuadTech LCR 7600 PLUS impedance meter. The following settings were set on the meter: the level of measuring voltage V_{level} = 5 V, the error of frequency measurement was ± 0.01%. The measurement was performed in the frequency range of 500 Hz – 10^6 Hz. Results were saved directly on a PC station.

Impedance measurements of the biomass sintered (at 800 °C) ash were performed at room temperature of 25 °C.

Results and discussion

The obtained modulus of *Z*(*f*) and *Q*(*f*) results, which did not include the influence of wire resistance have been subjected to noise cancelling processing performed in the Excel and MatLab software.

The results of the materials combustion process: modulus as well as the *Q* of the tested material at a room temperature (25 °C) is shown in Figures 2-3.

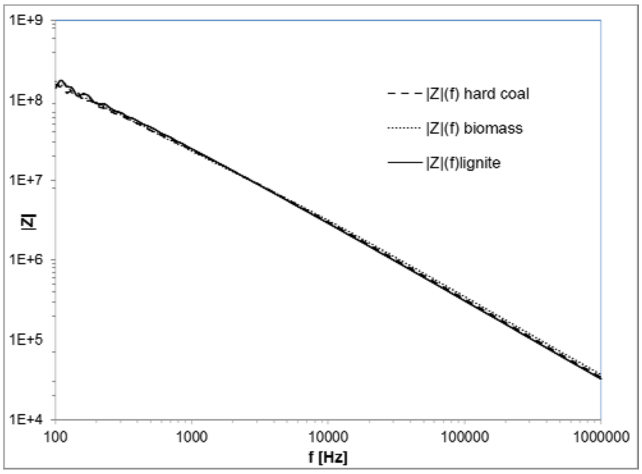

Fig.2. Dependence of modulus |Z|(f) for hard coal, lignite and biomass at 25 °C

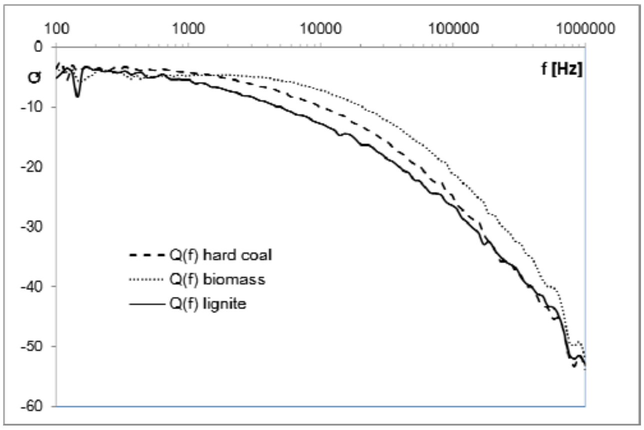

Fig.3. Dependence of Q(f) for hard coal, lignite and biomass at 25 °C

As can be seen in Figs 2 and 3, when it comes to examined parameters there is no significant difference among three products in modulus of Z and Q! Therefore we assumed one electrical model for the examined materials. Some particular chemical properties of these materials will affect for the values of some individual electrical parameters of the proposed model. A model shown in Figure 4 with R, C, CPE [6] elements was proposed to describe the electrical parameters of the tested material.

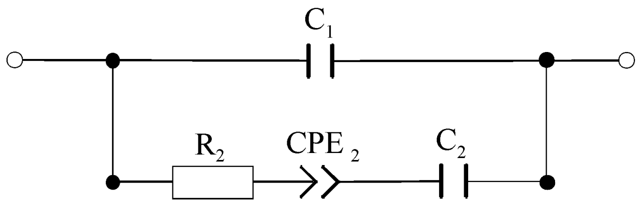

Fig.4. The equivalent circuit of the sintered hard coal, lignite and biomass at 25 °C

The interpretation of this model is difficult because of the complex composition and microstructure of pressed ash samples. The composition of hard coal, lignite and biomass ash used in this experiment, determined by the inductively coupled plasma optical emission spectrometry, are shown in Table 1.

Table 1. The composition of hard coal, lignite and biomass ash P

content\wt%	biomass	hard coal	lignite
SiO_2	21.5	40.6	32.4
Fe_2O_3	14.9	10.7	5.14
Al_2O_3	2.34	26.9	22
Mn_3O_4	0.12	0.04	0.03
TiO_2	0.65	0.91	1.48
CaO	17.3	4.81	19.1
MgO	4.06	2.32	1.67
SO_3	4.29	4.64	15.7
P_2O_5	6.39	0.71	0.17
Na_2O	0.28	6.15	1.29
K_2O	7.8	1.92	0.48
BaO	0.04	0.1	0.05
SrO	0.04	0.08	0.08

The structure of examined materials are shown in Figure 5.

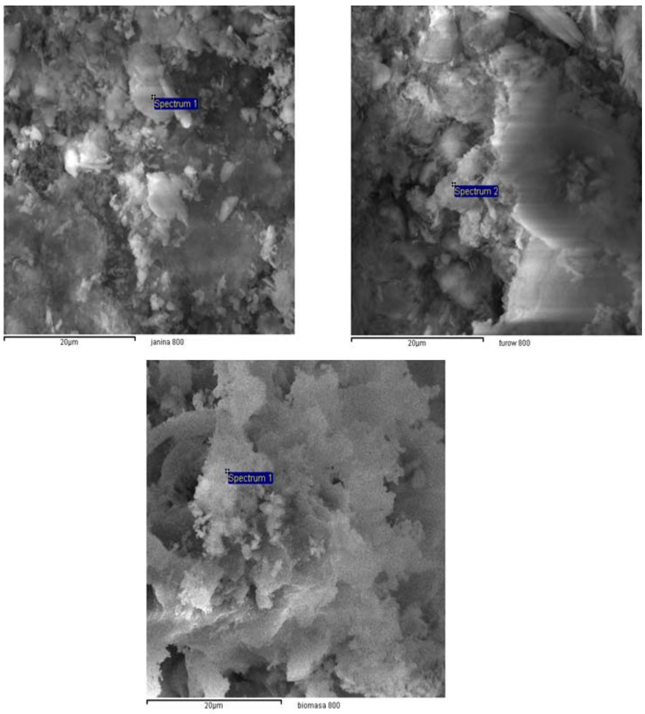

Fig.5. The microstructure of hard coal (upper left), lignite (upper right) and biomass ash, sintered at 800 °C.

Attached three photos indicate that hard coal, lignite and biomass ash sintered at 800 °C differ from each other. Biomass ash sintered particles are larger and have more irregular shape than hard coal and lignite ash particles.

The assumed model will have the same form for each of three products, only the particular parameters will change slightly. When it comes to impulse time response of the model it is expressed by a differential equation of fractional order derivative:

(1) $L(b_n D) y(t) = P(a_n D) u(t)$

where:

(2) $P(a_n D) = \left[a_1 D^{1+\varphi} + a_2 D + a_3 D^{\varphi} + 1 \right]$

(3) $L(b_n D) = \left[b_1 D^{2+\varphi} + b_2 D^2 + b_3 D^{1+\varphi} + b_4 D + b_5 D^{\varphi} \right]$

The generalized Fourier method for fractional differential equations in the definition of the integral and fractional-order derivative in the sense of Riemann-Liouville [10] was used to identify parameters of the biomass and coals products.

The results obtained after the application of this model are presented in Table 2.

Table 2. The values of resistance, capacitance and phase angle φ (nie ma w tabeli 2 phase angle) of the biomass and coals identified with the use of model.

hard coal

Temp [°C]	C1 [F]	R2 [Ω]	C2 [F]	CPE2 –T [F]	CPE2 -P
+25	4.67E-12	155490	3.72E-11	1.56E-10	0.527

biomass

Temp [°C]	C1 [F]	R2 [Ω]	C2 [F]	CPE2 –T [F]	CPE2 -P
+25	4.35E-12	20414	6.13E-12	7.04E-10	0.41669

lignite

Temp [°C]	C1 [F]	R2 [Ω]	C2 [F]	CPE2 –T [F]	CPE2 -P
+25	4.91E-12	597730	3.46E-10		0.59946

The proposed model, of which parameters are shown in Table 2, well describes the behaviour of the products in terms of electricity, what is shown in Figs 2-3. The curves marked as 'model' run closely to measured actual ones. The error of simulated model equal 11% for biomass and 12-14% for coals

Summary

The aim of this study was to investigate the electrical properties of biomass and coal ash. Based on mathematical calculations we set preliminary electric model for three tested products: hard coal, lignite and biomass.

Based on the experimental results it can be concluded that:

1. The electrical properties of these materials used in this experiment are almost similar. The modulus **Z** is the same, while the phase is slightly different .The values of the individual parameters of the proposed model was calculated for the samples subjected to the same temperature combustion. The results referred to by the proposed model correlate well with the experimental data.
2. The proposed fractional electric model of biomass and coals describes the electrical properties of the material with reasonable accuracy.
3. Using the suggested model, we can precisely control both processes occurring at the interface of the stove during the combustion of substrates and adjust parameters for the specific application in combustion systems. It should be noted that the use of identification methods, can be found a more complex alternative models, that more accurately reflect the properties of the presented material. However, in the search for complex models we have to take into account the actual properties of the object.

The proposed model will be the basis for further research and study materials behaviors simulation for a variety of signals that stimulate other points of work and working conditions at different temperatures and humidity.

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