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Electrical Properties of the Sintered Biomass, Sewage Sludge and Coal Ash – Part 2

Streszczenie: *W niniejszej pracy zaprezentowano wyniki badań elektrycznych zmiennoprądowych (pomiary współczynnika strat dielektrycznych) oraz testów ciśnieniowych prowadzonych w trakcie procesu spiekania popiołów uzyskanych z wybranych paliw. Na podstawie zmian współczynnika strat dielektrycznych oraz przy założeniu modelu Arrheniusa, obliczono wartości energii aktywacji procesów zachodzących w popiołach podczas ich spiekania. Na podstawie otrzymanych wyników oraz przeprowadzonej ich analizy, stwierdzono że metoda badań procesu spiekania popiołów, oparta na pomiarach zmiennoprądowych, jest obiecująca lecz wymaga dalszych badań. (**Własności elektryczne spiekania popiołów uzyskanych z wybranych paliw część 2**)*

Abstract*, In this paper the results of both AC electrical measurements (dissipation factors) and pressure tests carried out during the sintering of some fuel ashes are presented. The activation energies of the particular sintering processes were calculated basing on the changes of dissipation factors and assumption that the relation is of Arrhenius type. The presented results give the reason for claiming that the AC electrical method of evaluation of the ash sintering process is promising but requires further study.*

Słowa kluczowe: popiół, spiekanie, współczynnik strat dielektrycznych, test ciśnieniowy
Key words: ash, sintering, dissipation factor, pressure drop test

1. Introduction

The massive built-up of ash deposits, forming as a result of physical and chemical changes, create the large exploiting problem associated with the necessity of interrupting the energy conversion for cleaning the elements of the boilers. The formation of sintered deposits are associated with the presence a low viscosity phase – liquid phase in a form of molten surface layer on ash particles- characterized by such a temperature dependent, parameters as viscosity and surface tension [1,2]. It is difficult to attain the complete and correct information on these processes, because of the type (presence of alkali metals) and microstructure (grains of different sizes and shapes) of mineral matter in ash.

The conventional method that has been used to assess the character of deposit in coal combustion systems reduces to determination of the temperature of the initial deformation, i.e. ash fusion standard temperature (AFT) that often gives misleading results and the reliability of the method is poor [3,4]. But this method is still helpful, as the temperature at which ash softens and becomes sticky, triggers the further slag formation.

The results of computer control scanning electron microscopy, thermal and electrical measurements and pressure drop test of the ash samples prepared from bituminous coal, some sewage sludge and cereal pellets are presented. The sintering tendency of the ashes was determined on the base of the chemical analysis and results of the gas pressure drop test. These data were compared with the records of AC electrical measurements . The same data were discussed in comparison to the records of DC electrical measurements that is presented in [5]. The changes of resistivity were correlated with the equilibrium phases formed during the process of ash sintering.

2. Experimental

To get ash specimens the samples of lignite coal, hard coal, biomass, sewage sludge were subjected to slow combustion process at temperature below 500ºC. The way of ash formation and testing procedure were described in part 1 [1]. The testing was realized according to a scheme presented in Fig. 1.

The ash sintering tendency was estimated using the pressure drop test, described in [6,7]. During electrical test, each sample was isothermally heated for 2 hours, at temperatures from 500ºC up to 1100ºC. The dissipation factor was measured using QuadTech 7600 Plus Precision LCR Meter.

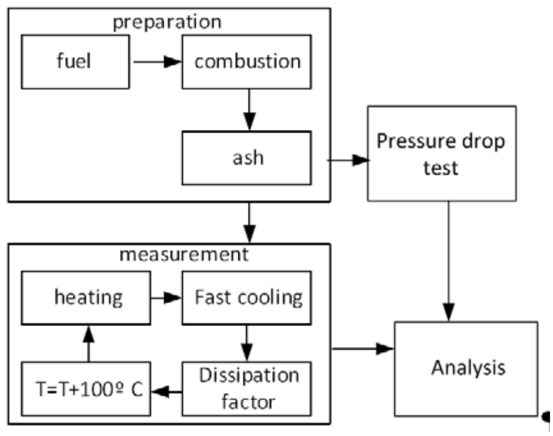

Fig. 1. The testing procedure.

The chemical analysis of ash was performed using ICP-OES technique. The composition of mineral matter in samples from various coal basins was estimated using CCSEM techniques. The CCSEM method is an automated procedure used to analyse up to 3,000 mineral grains in coal or ash particles. The mineral grains or particles are located, sized, and x-ray spectra taken. This information is further processed to classify the mineral grains or ash particles by type (major mineral present in coal or ash particle types). The area percents are converted to weight percent to determine abundance of mineral grain types found in the coal and ash particle types found in fly ash. Microbeam utilizes this information to predict the life expectancy of the system components, fireside slagging and fouling, bed agglomeration and clinkering, and the performance of air pollution control devices.

3. Results and Discussion

The ash behavior and slagging characteristics of the ash were studied by measuring mineral composition and ash fusion temperature. The abundance of the particular components in mineral matter are shown in Figure 1. As can be seen, the ash from cereal pellets, in comparison with the sewage sludge and coal, has a high content of potassium components. The sewage sludge ash contains a relatively high amount of silicon, and coal ash contains a relatively large amount of aluminum.

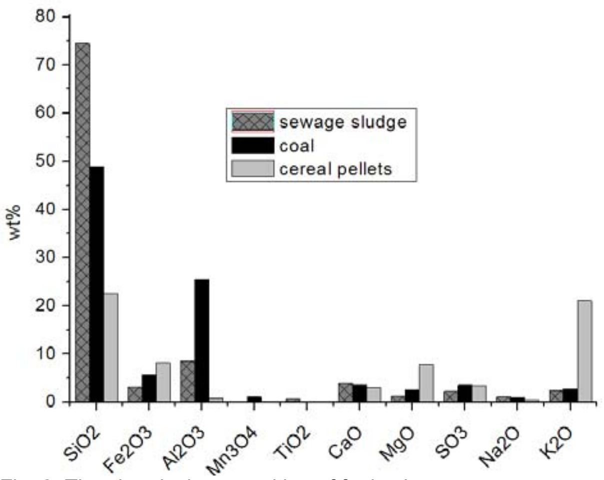

Fig. 2. The chemical composition of fuel ash.

The sintering temperature was measured according to pressure drop test method. The result as are shown in Table 1.

Table 1. Ash sample sintering temperatures T_s obtained by pressure drop test

Sintering temperature	sewage sludge	coal	Cereal pellets
°C	840	845	625

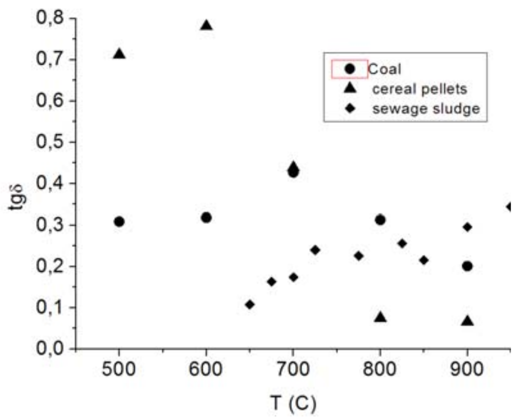

Fig. 3. The dissipation factor of the sewage sludge ash, coal ash and cereal pellet ash samples heated at temperatures in the range of 500°C ÷ 950°C

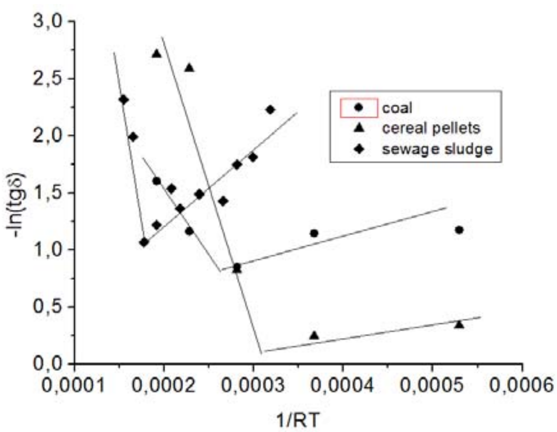

Fig. 4. The Arrhenius type relations for dissipation factor of the sewage sludge ash, coal ash and cereal pellet ash sample heated at temperatures in the range of 500°C ÷ 950°C

As can be seen in Fig.3, for cereal pellets, the significant decrease of dissipation factor occurs between about 600°C and 900°C.

The lowest sintering temperature is observed for the cereal pellets ash. This is probably the consequence of high content of potassium, magnesium and phosphorous and low content of silicon and aluminum. The sintering temperatures of coal and sewage sludge are comparable, due to the comparable amount of alkali metals in mineral matter.

The results of the AC electrical measurements are shown in Fig.3 and Fig.4.

For all the tested fuels, the two temperature regions and characteristic discontinuity points are distinguishable. These ranges of changes seems to be in a good agreement with the data collected from pressure drop test (Table 1).

To find the correlation between the resistivity changes it was assumed the simple Arrhenius type relation [6, 8]:

$$tg\delta = const \cdot e^{\frac{E}{RT}} \quad (1)$$

The results (activation energy) for samples are presented in Table 2.

Table 2. The absolute values of activation energy in kmol/kg

Temperature range	sewage sludge	coal	cereal pellets
low	100	100	100
high	50	20	20

These results suggest that during the ash sintering of selected fuels, the two main processes take place: one, in low temperature range, that needs the energy about 100 kg\J/mol to activate itself; and the second, in the high temperature range, that needs less energy – 20 kJ/mol for coal and cereal pellets and 50 kJ/mol for sewage sludge. These values suggest the occurrence of the phase transition in some components of the ash and, maybe, chemical reaction between some components. that are associated with the ash sintering process. In coal, the main components responsible for ash sintering proces, are shown in Fig.5.

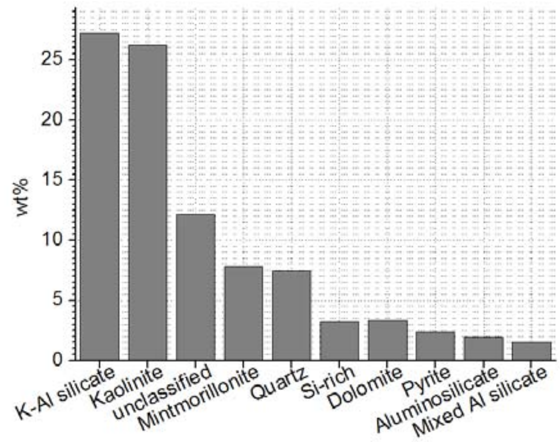

Fig. 5 The mineral matter of the coal ash

The majority (61.6%) of particles are in size of 4.6 to 22 microns. Potassium-aluminum silicate (illite) is the most abundant (27.2%) mineral identified, followed by kaolinite (26.2%), montmorillonite (7.8%), quartz (7.4%), dolomite (3.3%), silica (3.2%), iron-aluminum silicates (2.6%), and pyrite (2.4%). The total mixed layered clays accounted for 67.9 % of mineral matter found. Minor minerals (less than 2% each) account for 7.8% of the total, and the rest constitute an unclassified particles.

It is promising that the range of changes of dissipation factor, during sintering of the coal ash, sewage sludge ash and cereal pellets ash, are in a satisfactory accordance with the characteristic temperatures determined using pressure drop test (Table 1). It suggests that the dissipation factor is sensitive to phase transitions occurring during a first step of ash sintering, during the step that precedes the ash melting process. This is in a good agreement with the thermodynamic predictions for slag formation for model which assumed that 5% nonreactive particle participate in the sintering process [9-13].

Sintering phenomena are associated with the bonding or welding processes of the ash particles. The dominant sintering mechanism is viscous flow, under the influence of surface tension, when the crystalline material would behave like an amorphous one. In the first part of the presented work, It was suggested that the dissipation factor changes are associated with the occurrence of the sintering mechanism based on the surface diffusion and the viscous flow phenomena. The changes of dissipation factor during sintering process, are in a good accordance with the characteristic ranges determined with the use of pressure drop test and resistivity test [5]. The temperatures at which, the significant changes of pressure occur are in good agreement with changes of dissipation factor (derivatives). In view of these facts, one can say that electrical methods are promising as a tool for prediction of plant performance, when compared to ash fusion test, that is of poor repeatability and reproducibility. The ash fusion test has poor accuracy, because it is a subjective, wholly empirical test, based on observations rather than measurements, which gives no direct indication of the propensity of heated ash to become sticky and cause furnace slagging.

4. Conclusions

On the basis on the results presented in this work (pressure drop test, chemical and microstructural analysis, dissipation factor measurements) it can be concluded that the tendency to cause slagging/fouling during combustion of sewage sludge, coal and cereal pellets can be predicted by observing the changes of electrical properties such as resistance and dissipation factor. The data coming from electrical measurements are in good agreement with data collected from pressure drop test. It seems that resistance and dissipation factor are sensitive rather to the phase transitions in solid state than to the change of viscosity (the characteristic temperatures are lower than that obtained using standard AFT procedure).

Concluding, the electrical method is promising for slugging and fouling risk assessment but still requires further research.

Scientific work was supported by the National Centre for Research and Development, as Strategic Project PS/E/2/66420/10 "Advanced Technologies for Energy Generation: Oxy-combustion technology for PC and FBC boilers with CO_2 capture". The support is gratefully acknowledged.

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