Dorota NOWAK-WOŹNY, Wojciech MOROŃ, Grzegorz HRYCAJ, Wiesław RYBAK

Politechnika Wrocławska, Instytut Techniki Cieplnej i Mechaniki Płynów

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

Streszczenie: *W pracy przedstawiono wyniki badań właściwości elektrycznych (rezystywności i współczynnika strat dielektrycznych) oraz testów ciśnieniowych, prowadzonych w trakcie procesu spiekania, popiołów z osadów ściekowych, węgla kamiennego i biomasy. Na podstawie zmian rezystywności i przy założeniu modelu Arrheniusa, obliczono wartości energii aktywacji procesów spiekania. Wyniki porównano z danymi literaturowymi a także ze zmianami wartości współczynnika strat dielektrycznych (dla popiołu z węgla kamiennego). Na podstawie uzyskanych wyników stwierdzono, że metoda elektryczna oceny stopnia spiekania popiołów z badanych paliw jest obiecująca lecz wymaga dalszych badań.* ***(Właściwości elektryczne spiekanych popiołów węgla, biomasy i osadów ściekowych)***

Abstract*, In this paper there are presented the results of the electrical experiments (resistivity and dissipation factor) and pressure drop test conducted during sintering process of the biomass ash, sewage sludge ash and coal ash. The activation energies of sintering processes were calculated based on resistivity changes and assuming the Arrhenius type relation. The results were discussed with the literature data and with the changes of dissipation factor (for coal ash). On the basis of the presented study it was found that the electrical method of evaluation the sintering process is promising but requires further study.*

Słowa kluczowe: popiół węgla, spiekanie, opór elektryczny, współczynnik strat dielektrycznych
Key words: coal ash, sintering, electrical resistivity, dissipation factor

1. Introduction

The formation of sintered ash and slag deposits on heat exchange surfaces in coal, biomass or sewage sludge co-firing, is a very important problem, because the massive built-up of ash deposits force to interrupt the energy conversion for cleaning the elements of the boilers. The formation of sintered deposits is usually explained by the presence of a liquid phase or molten surface layer on ash particles. Such parameters as viscosity and surface tension (both temperature dependent) of the ash particles, govern the rate of sintering according with the model proposed by Frenkel [1] and Rassk [2]. It is very important to obtain the complete and correct information on the deposit-forming propensity of ash in different fuels. Although the conventional empirical indices relating to ash deposition are widely employed, they frequently give misleading results and their reliability is poor. Ash fusion standard temperature (AFT) systems, using digital imaging techniques, can mitigate some of the problems associated with the standard AFT test [3, 4]. The ash fusion test (AFT) is still widely used to assess the deposit characteristic of coal in the combustion systems and initial deformation temperature (IDT) is accepted as the temperature where ash softens and becomes sticky, allowing further slag formation. When all ash fusion temperatures are low, the risk of slagging is very high and readily inferred. Similarly, when all ash fusibility temperatures are high, it is easy to predict that the risk of slagging is very low. However, there are uncertainties in its use as a predictive tool for plant performance that is poor repeatability and reproducibility of ash fusion measurements. The ash fusion test has poor accuracy. 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.

In this paper are presented the results of mechanical, thermal and electrical measurements of the ash samples prepared from bituminous coal, some sewage sludge and biomass. The sintering tendency of the ashes was based on the chemical analysis. Ash Fusion Test data, and Equilibrium Phase Diagrams. It was made some correlation between the ashes sintering temperature and electrical resistivity of the samples [2, 5]. The resistivity changes were correlated with the equilibrium phases formed during heating process.

2. Experimental part

The tested samples were prepared with the ashes that were obtained in combustion process (slow combustion in temperature lower than 500 °C) of coal, sewage sludge and biomass. Then the ash were pressed to form a cylinder with a diameter equal to $3.2 \cdot 10^{-4}$ m^2 and thickness about a few millimeters. The testing was realized according to a scheme presented at Fig.1.

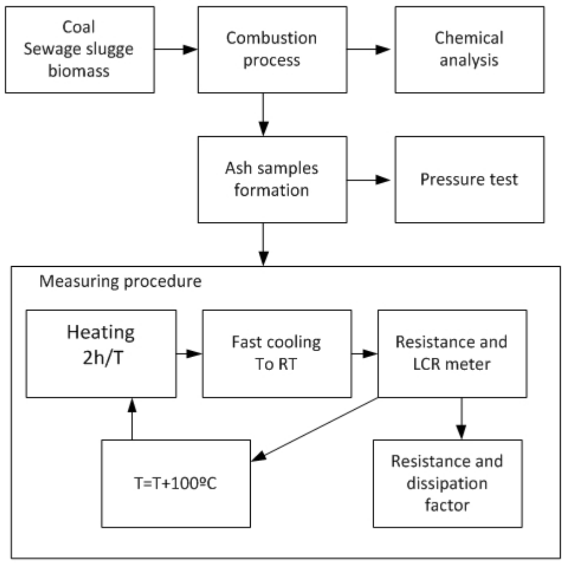

Fig.1. The testing procedure.

The ash sintering tendency was predicted by the pressure drop-based ash-sintering test, described in [6, 7]. During electrical test, each sample were isothermally heated (in CARBOLITE CFW 1200 furnace) by 2 hours, at temperatures from 500 °C up to 1100 °C. The resistance was measured by Keithley 6517B high resistance meter. The dissipation factor was measured by QuadTech 7600 Plus Precision LCR Meter. The obtained results were expressed by resistivity ρ:

(1) $$\rho = R \cdot \frac{S}{l}$$

where S is the surface of electrode and l is the thickness of the sample.

3. Results and Discussion

The ash behavior and slagging characteristics of sewage sludge ash and ash content were studied by measuring chemical composition and ash fusion temperature. The results are summarized in Table 1. From data presented in Table 1, it follows that biomass, in comparison with the sewage sludge and coal, have high content of CaO, K_2O and Na_2O components, that decrease ash fusion temperatures.

Table 1. Sample composition in wt% and sintering temperatures T_s obtained by pressure drop test

Element	Sewage Sludge ash		Coal ash		Biomass ash	
	wt%	T_s,°C	wt%	T_s,°C	wt%	T_s,°C
SiO_2	74.5		50.6		40.0	
Fe_2O_3	3.17		8.80		1.20	
Al_2O_3	8.55		24.7		4.10	
Mn_3O_4	0.05		-		-	
TiO_2	0.71		-		-	
CaO	3.94		3.70		7.30	
MgO	1.19	840	3.50	895	2.10	725
SO_3	2.24		2.30		7.00	
P_2O_5	1.80		0.25		0.92	
Na_2O	1.07		1.00		5.10	
K_2O	2.41		3.30		21.0	
BaO	0.09		-		-	
SrO	0.02		-		-	
Cl	0.03		-		9.2	
CO_2	0.14		-		-	

On the basis on the result presented in Fig.2, it was noticed three characteristic ranges of the resistivity changes:

I. from 600 °C to about 800 °C – where the resistivity for biomass and sludge decrease whereas for coal increase,

II. from about 800 °C to about 1000 °C – where the coal resistivity decrease and the biomass and sewage slugge resistivity increase,

III. above 1000 °C – where the resistivity of sewage sludge and coal increase whereas of biomass decrease.

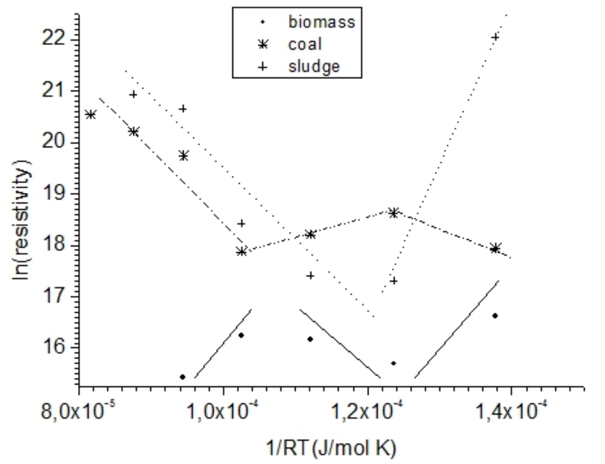

Fig.2. The resistivity of the sewage sludge ash, coal ash and biomass ash sample heated at temperatures in the range of 500 ÷ 1100 °C

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

$$\rho = \rho_0 \cdot \exp^{\frac{-E}{R \cdot T}} \tag{2}$$

where E is the activation energy of the processes occurring during the sintering and R is the gas constant.

The results of the resistivity measurement of the ash sample are shown in Figure 2. It was obtained three different values of the activation energy values:

$$E_1 = 340 \frac{kJ}{mol}, \tag{3}$$

$$E_2 = 180 \frac{kJ}{mol}, \tag{4}$$

$$E_3 = 50 \frac{kJ}{mol}. \tag{5}$$

The results (activation energy) for samples are presented in Table 2. These results suggest that during the ash sintering it occur three main processes: one that needs the energy about 340 kJ/mol to activate its, the second that needs less energy – equal 180 kJ/mol and the last that need the energy about 50 kJ/mol. For selected coal sample, it was measured the dissipation factor (Fig.3).

Table 2. The values of activation energy in kJ/mol

Temperature range	sludge	coal	biomass
600 ÷ 800 °C	340	50	60
800 ÷ 1000 °C	180	50	180
above 1000 °C	180	180	340

On the basis on the result presented in Fig.3, it was noticed the visible changes of dissipation factor, measured for 1 kHz frequency, at temperature equal to about 900 °C. This is in a good agreement with the results obtained from pressure drop method (Table 1) and from thermodynamic prediction for slag formation for model assumed that 5% nonreactive particle participate in the sintering process [9-13].

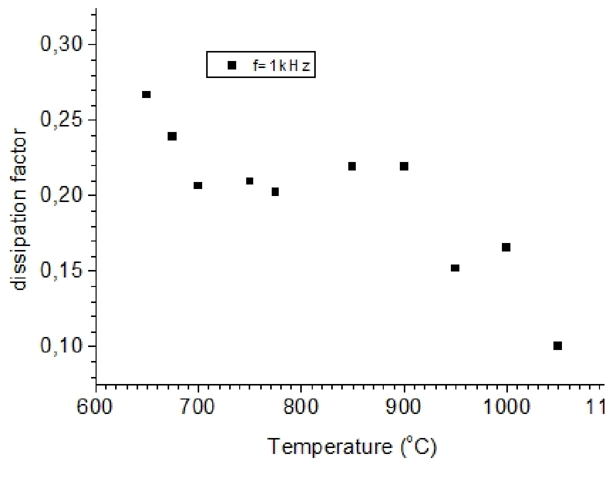

Fig.3 The dissipation factor of the coal ash sample heated at temperatures in the range of 600 ÷ 1100 °C

Sintering phenomena are associated with the bonding or welding processes of the ash particles. The particle agglomeration is closely associated with the physics and chemical processes occurred on the ash surface.

The dominant sintering mechanism is viscous flow. It was suggested that under the influence of surface tension, the crystalline material would behave like amorphous one. It was suggested that the electrical conductivity is proportional to the viscosity during temperature action. The values obtained on the basis of the electrical experiments are in good accordance with the literature data [2, 5, 7] suggesting the occurrence of the sintering mechanism based on the surface diffusion and the viscous flow phenomena.

To the identification of the processes described by the activation energy calculated on the basis of the electrical experiment and the thermodynamics calculation, the thermodynamic prediction for mineral matter transformation was made. The thermodynamic calculation was made for simple model assumed that only reactive particle participate in the sintering process [9-14].

Taking into account the thermodynamic processes occurring during annealing the samples at temperatures from 500 °C to 1100 °C, it can be stated the occurrence of the four significant ranges of change. These ranges are in some correlation with the sample's resistivity. The presented results are compared with pressure methods describing the sintering process. The sintering temperature stated by the pressure test is about 840 °C for sewage sludge ash, 895 °C for coal ash and 725 °C for biomass ash. But there are many phenomena that precede the sintering process. It is important to know that phenomena to predict the slagging tendency.

4. Conclusions

In summary, sewage sludge, coal and biomass was predicted for their tendency to cause slagging/fouling during combustion. Three different ways of predicting the slagging/fouling tendency were used: (i) the resistance test, (ii) the pressure drop technique and (iii) the thermodynamics analysis [9-14].

On the basis of the electrical measurements and thermodynamic calculation of the sewage sludge, coal and biomass ash samples, it was suggested that the electrical resistivity and dissipation factor are the promising methods of slugging and fouling risk assessment.

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.

REFERENCES

[1] Frenkel J., Viscous Flow of Crystalline Bodies Under the Action of Surface Tension, *Journ. Phys.* 9, (1945), 385-391
[2] Raask E., Sintering characteristics of coal ashes by simultaneous dilatometry-electrical conductance measurements, *Journal of Thermal Analysis*, 16 (1979), 91-102
[3] Moroń W., Rybak W., Mechanical method for determining the ash sintering temperature, *Energetyka 2002. Konferencja naukowo-techniczna. Wrocław, 6-8 listopada 2002. Wrocław: Instytut Techniki Cieplnej i Mechaniki Płynów PWroc.*, (2002) 503-508
[4] Płaza P., Ferens W., Rybak W., Pressure method for determining the ash sintering temperature, *Systems* 11 (2006), 517-524
[5] Ahn Y.C., Lee J.K., Physical, chemical and electrical analysis of aerosol particles generated from industrial plants, *Aerosol Science,* 37 (2006), 187-202.
[6] Nowak-Woźny D., Moroń W., Hrycaj G., Rybak W., Sintering tendency of some ash in correlation with electric resistivity and phase equilibrium calculations, *Archivum Combustionics*, 30 (2010), n. 2, 177-191
[7] Al-Otoom A.Y., Bryant G.W., Elliott L.K., Skifvars B.J., Hupa M., Wall T., Experimental options for determining the temperature for the onset of sintering of coal ash, *Energy Fuels,* 14 (2000), 227-233
[8] Al-Otoom A.Y., Elliott L.K., Wall T., Monghtaderi B., Measurement of the sintering kinetics of coal ash, *Energy&Fuels,* 14 (2000), 994-1001
[9] Tomeczek J., Palugniok H., Kinetics of mineral matter transformation during coal combustion, *Fuel* 81 (2002), n. 10, 1251-1258
[10] Nutalapati D., Gupta R., Moghtaderi B., Wall T., Assessing slagging and fouling during biomass combustion: A thermodynamic approach allowing for alkali/ash reactions, *Fuel processing,* 88 (2007), 1044-1052
[11] Zevenhoven-Onderwater M., Backam R., Skifvars B. J., Hupa M., The ash chemistry in fluidised bed gasification of biomass fuels. Part I: predicting the chemistry of melting ashes and ash-bed material interaction, *Fuel,* 80 (2001), 1489-1502
[12] Skifvars B. J., Backam R., Hupa M., Characterization of the sintering tendency of ten biomass ashes in FBC conditions by a laboratory test and by phase equilibrium calculations, *Fuel processing Technology,* 56 (1998), 55-67
[13] Fryda L.E., Panopoulos K.D., Kakaras E., Agglomeration in fluidised bed gasification of biomass, *Powder technology,* 181 (2008), 307-320
[14] M. Blander, Milne T.A., Dayton D.C., Backman R., Blake D., Kuhnel V., Liniak W., Nordin A., Ljung A., Equilibrium chemistry of biomass combustion: A Round-Robin set of calculations using available computer programs and databases, *Energy&Fuels,* 15 (2001), 344-349

Autorzy: *Dr inż. Dorota Nowak-Woźny, Politechnika Wrocławska, Instytut Techniki Cieplnej i Mechaniki Płynów, ul. Wyb. Wyspiańskiego 27, 50-370 Wrocław, E-mail: dorota.nowak-wozny@pwr.wroc.pl; Dr inż. Wojciech Moroń, Politechnika Wrocławska, Instytut Techniki Cieplnej i Mechaniki Płynów, ul. Wyb. Wyspiańskiego 27, 50-370 Wrocław, E-mail: wojciech.moron@pwr.wroc.pl; Mgr inż. Grzegorz Hrycaj, Politechnika Wrocławska, Instytut Techniki Cieplnej i Mechaniki Płynów, ul. Wyb. Wyspiańskiego 27, 50-370 Wrocław, E-mail: grzegorz.hrycaj@pwr.wroc.pl; Prof. dr hab. inż. Wiesław Rybak, Politechnika Wrocławska, Instytut Techniki Cieplnej i Mechaniki Płynów, ul. Wyb. Wyspiańskiego 27, 50-370 Wrocław, E-mail: wieslaw.rybak@pwr.wroc.pl.*