Proceedings of the

4th International Symposium on

Enhanced Landfill Mining

5 - 6 February 2018

Mechelen, Belgium

Editors

Peter Tom Jones

Lieven Machiels

KU LEUVEN

SUSTAINABLE INORGANIC MATERIALS MANAGEMENT

i-CLEANTECH VLAANDEREN enabling the future

EURELCO EUROPEAN ENHANCED LANDFILL MINING CONSORTIUM

NEW-MINE EU TRAINING NETWORK FOR RESOURCE RECOVERY THROUGH ENHANCED LANDFILL MINING

eit RawMaterials Connecting matters

DIELECTRIC PROPERTIES MEASUREMENTS OF MUNICIPAL SOLID WASTE INCINERATOR BOTTOM ASH AT HIGH TEMPERATURES

Georgia FLESOURA[1], Beatriz GARCÍA-BAÑOS[2], Jose-Manuel CATALA-CIVERA[2], Jozef VLEUGELS[1], Yiannis PONTIKES[1]

[1] KU Leuven, Department of Materials Engineering, 3001, Belgium
[2] Universitat Politecnica de Valencia, Instituto ITACA, 46022, Spain

georgia.flesoura@kuleuven.be, beagarba@upvnet.upv.es, jmcatala@dcom.upv.es, jozef.vleugels@kuleuven.be, yiannis.pontikes@kuleuven.be

Introduction

Along with recycling and landfilling, incineration is an established management strategy, allowing to recover energy while at the same time reducing the waste volume. Incineration, however, leads to the generation of municipal solid waste incinerator (MSWI) bottom ash (BA) as a major solid by-product. Bottom ash is either used in road construction or is disposed in landfills. With the aim of exploring the reuse potential of BA, the elemental composition, mineralogy, and leaching behaviour have been thoroughly studied. The dielectric properties of BA at elevated temperatures were measured as microwave thermal processing is aimed for, allowing the production of highly vitrified slag, which will be used as precursor for the synthesis of inorganic polymers.

The design of microwave processing requires knowledge of the dielectric properties of materials, since this property determines the response of being subjected to a microwave field. In general terms, the dielectric properties determine the ability of the material to absorb microwave energy and convert it into heat. These properties mainly depend on the frequency, temperature, nature, moisture content and particle size of the material. In this study, a dual single-mode microwave applicator was used both to heat the material and dynamically characterise its dielectric properties in a wide range of temperatures.[1]

Materials and methods

Background theory

In simple terms, the dielectric properties (also known as permittivity) can provide information on how the material interacts with the applied electric field. In scientific terms, the dielectric permittivity (Equation 1) is the macroscopic expression of the polarisation of solid particles, which can also include the ionic atmosphere and double layers around the particles.[2] It is a complex function, composed of a real and imaginary part. The real part, the dielectric constant (ε'), reflects the ability of the material to be polarised under the induced electric field. The most essential factor that determines the ability of the material to convert the absorbed power into heat is the dielectric loss factor, ε'' (the imaginary part).

$$\varepsilon = \varepsilon' - j\varepsilon'' \qquad (1)$$

where ε is the complex dielectric permittivity, ε' and ε'' are the dielectric constant and loss factor respectively.

Sample preparation

Wet MSWI BA samples were received from an incineration plant in the Netherlands. X-ray fluorescence data, presented in Table 1, show that the chemical composition predominantly consists of SiO^2 followed by CaO, Al_2O_3, Fe_2O_3 and minor quantities of Na_2O and MgO. Specific BA specimens were used to examine the influence of the particle size on the dielectric properties. The aim of these measurements was the dielectric characterisation of the BA and the determination of the best BA processing parameters for electromagnetic heating.

Initially, in the pursuit of obtaining the optimal BA particle size distribution, the dielectric properties of a “fine” and “coarse” grade were measured. Both samples were oven-dried at 105°C to remove moisture. The “fine BA” was initially disk milled (Fritsch Pulverisette 13) followed by attritor milling (Wiener 1S) for 8 h. The “coarse BA” was obtained by disk milling (Fritsch Pulverisette 13) only. The particle size distribution was measured by a laser diffraction particle size analyser (Beckman Coulter LS13 320). The D_{50} of the fine and coarse BA was 7.63 and 809 µm, respectively. All dielectric properties were measured on loose powder under a continuous nitrogen gas flow.

Table 1: Normalised chemical composition of BA, based on XRF data (error of semi-quantitative analysis: 10%)

Component	**SiO_2**	**CaO**	**Al_2O_3**	**Fe_2O_3**	**Na_2O**	**MgO**	**Others**
Wt%	54	15	11	8	4	2	<1

Measurement set-up

The microwave cavity that was used for the dielectric measurements is illustrated in Figure 1 and has been designed to have a high power dominant mode for heating the material and a second mode to measure the dielectric properties. The TE_{111} mode is used for heating and it has been designed to resonate near the ISM (Industrial, Scientific, Medical) frequency of 2.45 GHz, more precisely in the bandwidth of 2.2-2.6 GHz. The TM_{010} mode provides a larger frequency shift between 1.9 and 2.2 GHz and is used for measuring the dielectric properties. Different resonant frequencies have been selected to avoid interference of the two signals. The signal source for the heating mode is produced by a Vector Network Analyser (VNA) connected to an amplifier. The VNA delivers an output of 0 dBm (1 mW) up to 50dB (140 W) using an amplifier. A second VNA is used for the measuring mode.

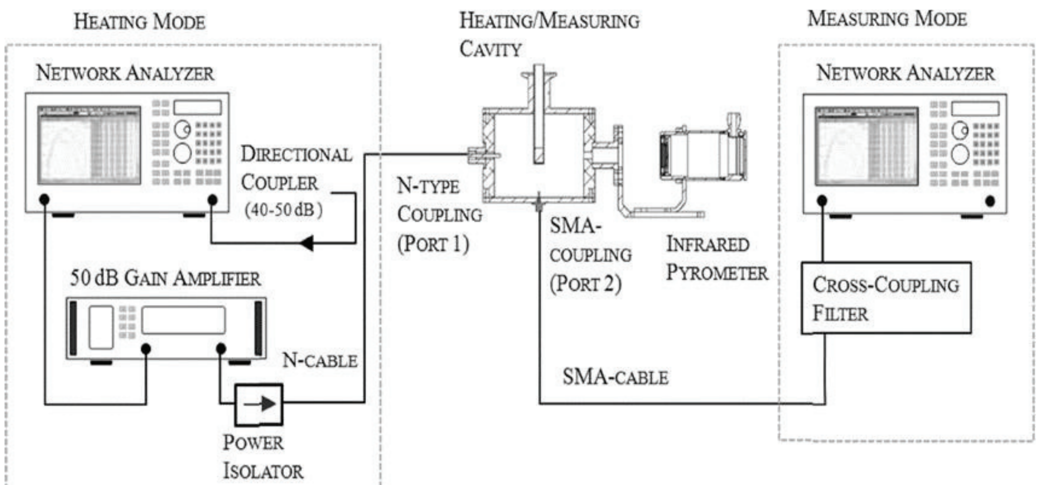

Figure 1: Schematic of the equipment to determine microwave-matter interactions. Modified from from Garcia-Banos *et al.*[3]

Results and discussion

Effect of particle size on dielectric properties

In order to examine how the BA material responds under the microwave energy, it is essential to know the heating profile and the dielectric properties. Figure 2 presents the heating profile of the fine and coarse BA under an applied power of 140 W, whereas Figure 3 depicts the measured values of the dielectric properties for both materials from room temperature up to approximately 1100°C. In Figure 3, the dielectric constant of the fine BA was higher than for the coarse BA in the 280-850°C range, as it is also depicted in the loss factor. Probably, the small particle size of the fine BA and the respective high specific surface area result in an enhanced polarisation of the induced electric charges. The fine BA powders showed accelerated heating around 250°C, accompanied by a strong increase ε' and ε'', whereas this was delayed up to 700°C for the coarse BA powder. However, for temperatures below 280°C and above 850°C, the dielectric constant of the coarse BA was higher than for the fine BA. The reason behind it needs further investigation. Although there are not so many studies on the effect of particle size on dielectric properties, some researchers have investigated this correlation for polymers and ceramic composites. Q.G. Chi *et al.*[4] studied the effect of the particle size on the dielectric properties of ceramics and concluded that the dielectric constant of the ceramic powders decreased with increasing ceramic particle size. Hsing-I-Hsiang[5] studied the effect of the $BaTiO_3$ powder size on the dielectric properties of $BaTiO_3$/polyvinylidene fluoride composites at different frequencies. At frequencies > 100 KHz, the dielectric constant of the composites increased with decreasing $BaTiO_3$ particle size. On-going work focuses on conventional thermal analysis to assess the phase transformations and elucidate how these are reflected in the material dielectric response at microwave frequencies. Simultaneously, in-depth investigation of the BA microstructure will give a better understanding of the interplay between the dielectric properties and the constituent phases.

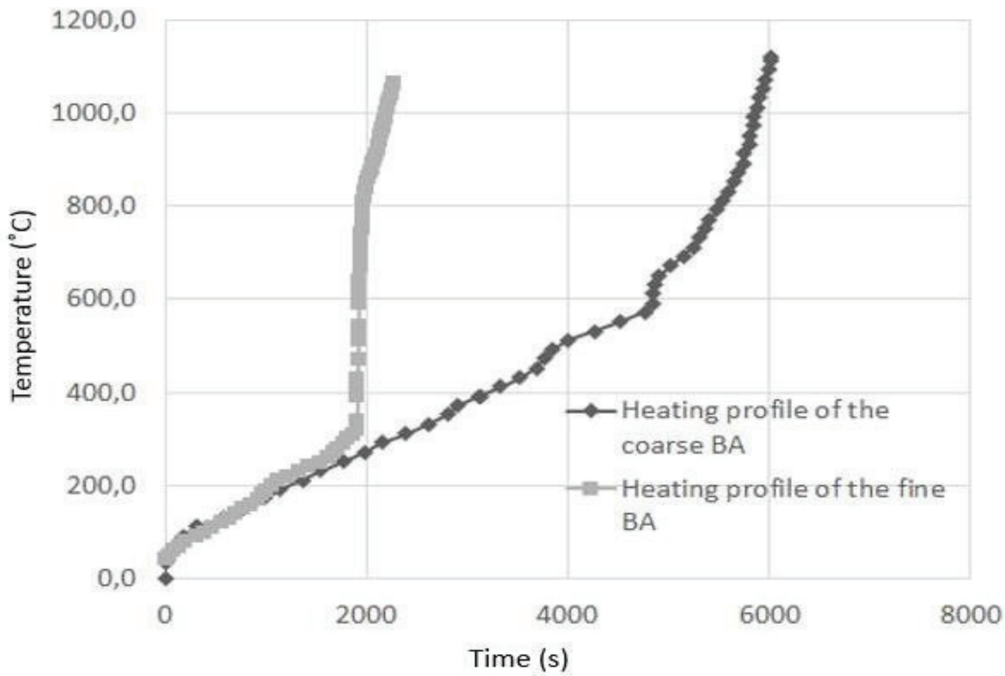

Figure 2: Heating profile of the fine and coarse BA under 140W input power

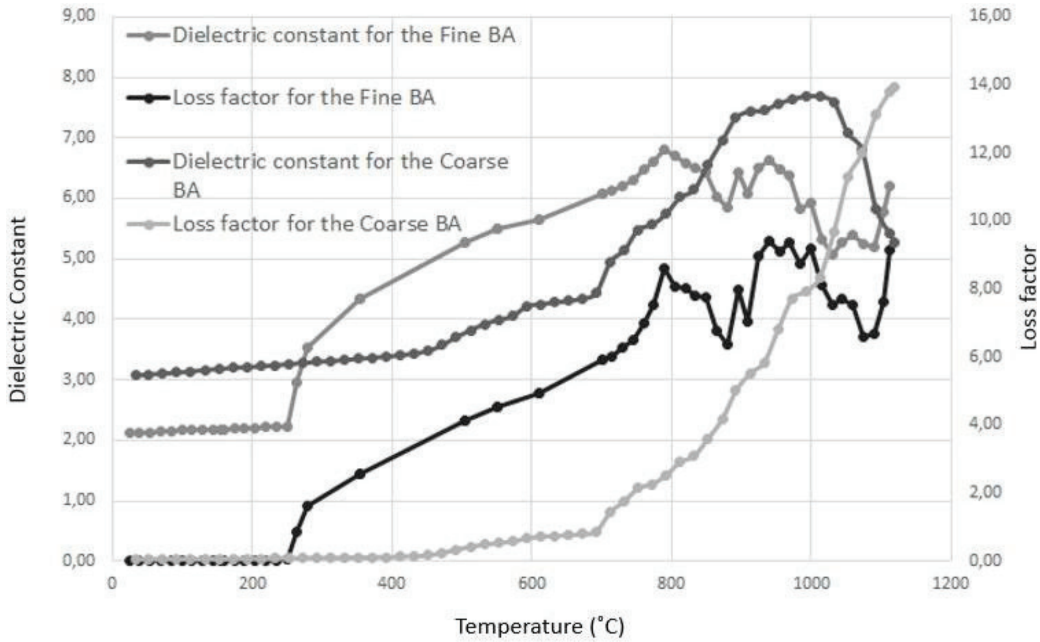

Figure 3: Dielectric properties of the fine and coarse BA during heating to 1100°C under 140W input power

Conclusions

Dynamic dielectric characterisation of BA was performed during microwave heating up to 1100°C and revealed the dielectric response of two different BA particle sizes in an electromagnetic field. The comparison shows that that the finer BA material has a higher heating rate above 250°C, due to a higher dielectric constant as well as loss factor, allowing a more efficient microwave heating process.

Acknowledgements

The research leading to these results has received funding from the European Community's Horizon 2020 Programme under Grant Agreement No. 721185 (MSCA-ETN NEW-MINE). This publication reflects only the authors' view, exempting the Community from any liability. Project website: http://new-mine.eu/

References

1. J. M. Catala-Civera, A. J. Canos, P. Plaza-Gonzalez, J. D. Gutierrez, B. Garcia-Banos, F. L. Penarand-Foix, "Dynamic Measurement of Dielectric Properties of Materials at High Temperature during Microwave Heating in a dual-mode Cylindrical Cavity", *IEEE T Microw Theory*, **63** (9) 2905-14 (2015).
2. C. Grosse, A. V. Delgado, "Dielectric dispersion in aqueous colloidal systems", *Curr Opin Colloid In,* **15** (3) 145-59 (2010).

3. B. Garcia-Banos, J. M. Catala-Civera, F. L. Penaranda-Foix, P. Plaza-Gonzalez and G. Llorens-Valles, "In Situ Monitoring of Microwave Processing of Materials at High Temperatures through Dielectric Properties Measurement", *Materials (Basel),* **9** (5) 349 (2016).
4. Q. G. Chi, J. F. Dong, G. Y. Liu, Y. Chen, X. Wang and Q. Q. Lei, "Effect of particle size on the dielectric properties of $0.5Ba(Zr_{0.2}Ti_{0.8})O_3$-0.5(Ba0.7$Ca_{0.8}$)$TiO_3$/polyvinylidene fluoride hubrid films", *Ceram Int,* **41** 15116-15121 (2015).
5. H. I Hsiang, K. Yin Lin, F. Yen and C. Hwang, "Effects of particle size of $BaTiO_3$ powder on the dielectric properties of $BaTiO_{3/}$polyvinylidene fluoride composites", *J Mater Sci,* **36** 3809-380915 (2001).