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Dielectric Properties of Carbons in Blast Furnace Dust

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Abstract—**This study has presented the cavity perturbation theory applied to measurements of the dielectric properties of carbon materials contained in the blast furnace dust (BFD) at single frequency of around 2.5 GHz using a cylindrical microwave cavity at TM_{010} mode. In addition, the study shows that multimode microwave cavity system at different TM modes can be used to measure the microwave complex permittivity of these materials in the frequency *range of 2 to 8 GHz.***

Index Terms: **blast furnace dust,cavity perturbation,dielectric properties,Single mode, multiple modes.**

I. INTRODUCTION

One of the usual processes in modern blast furnace ironmaking is the injection of powdery coal. The main purpose of this is to reduce the consumption of coke (per ton) during hot metal production, which is usually referred to as coke rate. The monitoring of the combustion of injected coal is not possible as the process occurs within an extremely hot and completely closed environment. Currently, the level of combustion of the injected, pulverised coal can be obtained from indirect analysis of the particles loaded in the top gap of the furnace, and from the dust collected at the end of the process. The combustion efficiency characteristic of the furnace can be demonstrated by the quantification of the types and amounts of the different carbon materials in the blast furnace dust (BFD), especially for materials resulting from pulverised coal injection. However, such quantification is a major challenge, as the origin and the type of the resulting carbon materials cannot be identified using a chemical analysis of carbon. Although, BFD has high levels of carbonaceous material resulting from loaded coke, distinguishing between the carbonaceous materials produced from loaded coke and combustion remainders is not simple because both have the same chemical characteristics. In addition, detection of small amounts of pulverised coal injection residues in BFD is very challenging because BFD also contains a large amount of non-carbonaceous materials, such as iron ore. Thermogravimetric analysis (TGA) can be adopted for the quantitative analysis of BFD to differentiate the different types of carbon [1, 2] , but realistic alternatives are scarce.

For these reasons, in this research, microwave techniques were proposed for a simpler, more practical differentiation of carbonaceous materials in blast furnace dust based on their dielectric property measurement. The simplicity of this method also means that it could be deployed in-situ at the combustion site.

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II. METODOLOGY

Complex relative permittivity can be expressed as $\varepsilon^{'} = \varepsilon^{'} - j\varepsilon^{''}$, which can be used to present the response of materials to microwave electric field, where the real and imaginary parts demonstrates the material ability to store the electrical energy and the power loss within the material, respectively. [3].

In microwave cavity measurement method, perturbation theory is used for complex relative permittivity calculations using measured resonant frequency shift and the quality factor change when the samples are inserted in the cavity, which has high quality factor Q to obtain accurate results. [4-6].

Perturbation equations (1) and (2)for a sample inserted axially in the cylindrical cavity can be expressed using the change in the resonant frequency and quality factor to calculate the real and imaginary parts of complex permittivity values. The sample should be inserted with its length parallel to the electric filed. [7]

$$\varepsilon' - 1 = \left(\frac{f_0 - f_s}{f_0}\right)\left(\frac{2V_{eff}}{V_s}\right) \quad (1)$$

$$\varepsilon'' = \Delta\left(\frac{1}{Q}\right)\left(\frac{V_{eff}}{V_s}\right) \quad (2)$$

where f_0 and f_s are the resonant frequencies without and with sample, respectively, V_s is the sample volume within the cavity and V_{eff} is the effective cavity volume. This latter quantity is the effective space filled by the electric field energy, and for the TM_{010} mode can be shown to be about 26.9% of the cylinder volume.[7]

III. MEASUREEMENT SYSTEM & EXPERIMENTAL SETUP

Experiment procedures and setup are illustrated here, the cavity is connected to network analyser (Keysight PNA N5232A) for measuring s-parameters (S_{21}) in the frequency domain by noted the centre frequency shift and the change in the quality factor when the cavity is empty and cavity loaded with the sample.

The sample is vertically inserted in the cavity through axial hole (of diameter 5 mm) as the maximum electric field is at the axis in the case of TM_{010} mode. Here, the resonant frequency for empty cavity is 2.5GHz and shifted down to 2.45GHz for loaded cavity with sample. The cavity dimensions are radius = 46mm and hight = 40mm. the hight of the cavity carefully chosen to be not so short as to reduce the quality factor Q too much, but not too long as to allow the mode TE_{111} to interfere with the TM_{010}mode. In this experiment the used cavity is made from aluminium alloy, and due to the imperfections in the surface (such as roughness and dislocations) will increase the surface resistance and thus the quality factor will be decreased. In the TM_{010} mode, measured Q of unloaded cavity is 8000, while the "book value" is approximately 12000, The measured value of 8000 is deemed acceptable for cavity perturbation.

COMSOL simulation results for the electric (E) and the magnetic (H) fields distributions are for TM_{010} mode at frequency of 2.498 GHz shown in *Figure 1*

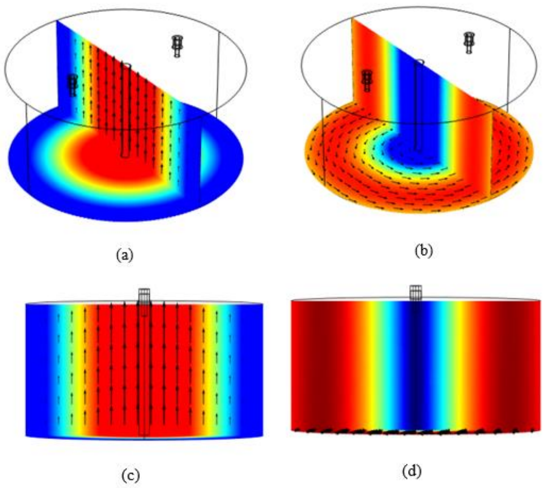

Figure 1 COMSOL simulation of the cylindrical cavity resonator TM010, showing the electric ((a)) and (c)) and magnetic ((b) and (d)) field distribution

The measurement system photograph is shown in Figure 2, it illustrates the cylindrical microwave cavity and the supporting/auxiliary systems.

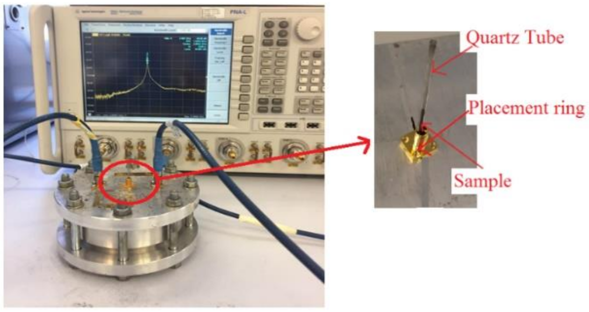

Figure 2. Photographs of the experiment set-up for cavity perturbation measurement.

A. Materials

Blast furnace dust is contained various types of carbons such as coal, char coke or partially burnt chars. Different carbon samples were measured in this study, listed in Table 1. , which were extracted from BFD. In addition, some lab-made sample were also measured, which contained coal, char and coke with different weight concentrations for imitation the components of BFD, these sample listed inTable .

Table 1. Carbon Materials Samples

Material	Label	size classification	o: c ratio	residence time
coke	coke	-	-	-
PM coal-1	coal-1	100%< 1mm	5	60ms
PM coal-2	coal-2	100%< 1mm	5	35ms
PM coal-3	coal-3	100%< 1mm	5	35ms
PM coal-4	coal-4	100%< 1mm	14	700ms
PM coal-5	coal-5	100%<1mm	5	35ms

Table 2. Lab-Made Samples

Material	Label	Description
Char 80%	Char 80%	Labe-made sample has 80% char, 10% coal, and 10% coke, by weight.
Coke 80%	Coke 80%	Labe-made sample has 10% char, 10% coal, and 80% coke, by weight.
Coal 80%	Coal 80%	Labe-made sample has 10% char, 80% coal, and 10% coke, by weight.

All measured samples were treated in the same way to have the same particle sizes. firstly, they were pulverized using a mortar and pestle, then, 63µ Lab sieve is used to make all samples to be approximately 60µm size or less. Secondly, all powdered samples were filled in quartz tubes with inner and outer diameter of 2mm and 2.4 mm respectively, Quartz was used due to its low dielectric characteristics, therefore, the effects on centre frequency and bandwidth will beminimum. Multiple samples for each material are prepared and measured to calculate the errors,

IV. RESULTS & DISCUSSTION

A. Dielectric properties of cabons in BFD

The real and imaginary values of complex permittivity of carbon contained in BFD are shown in Figure 3 and Figure 4, respectively. It is clear that. each carbon sample has different dielectric constant and loss factor even they have the same chemical structures. Coke has the highest values for both dielectric constant and dielectric loss factor at 7.25 and 3.72, and Coal-3 has value which is at least 2.5 times that of other types of coals.

As coke is generally formed by heating coal in the absence of air, the loss of the volatile components and restructuring of the carbon may increase, hence the conductivity increases due to increasing electron mobility. As temperatures continue to increase the mobility of electrons and level of free charge per unit volume increases.

Figure 5and Figure 6 present the dielectric constant and loss factor for the lab–made samples. The samples containing the highest weight concentration of coke and char have higher complex permittivity than the sample with highest weight concentration of coal.

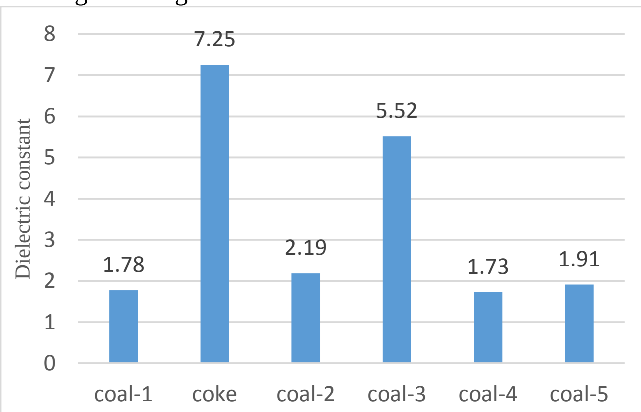

Figure 3 .Dielectric constant of different carbon samples. The typical standard error is ±0.03, which in most cases is too small to observe.

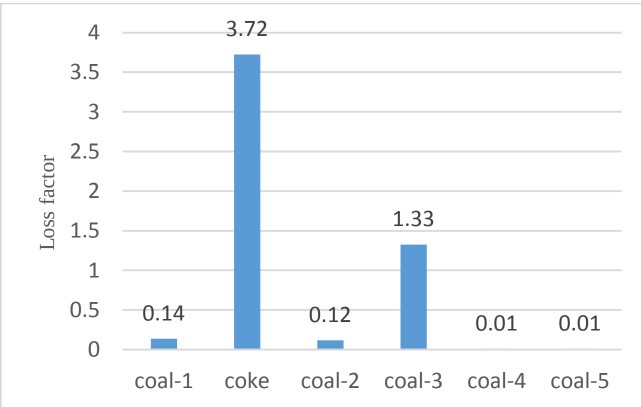

Figure 4 .Dielectric loss factor of different carbon samples. The typical standard error is ±0.03, which in most cases is too small to observe.

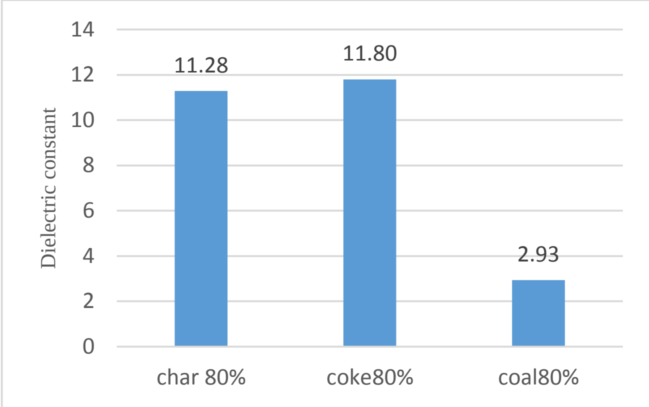

Figure 5. Dielectric constant of lab-made carbon samples. The typical standard error is ±0.01, which in most cases is too small to observe.

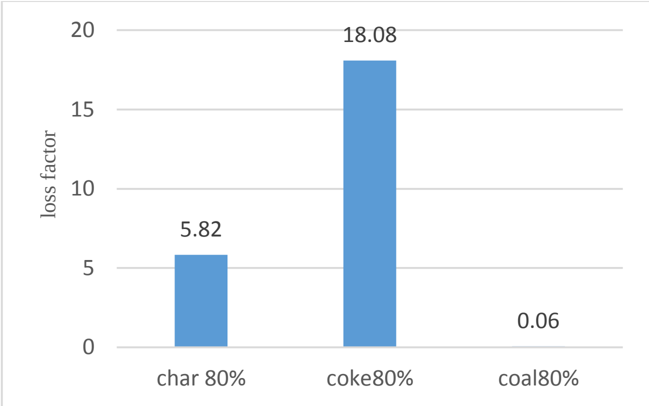

Figure 6. Dielectric loss factor of lab-made carbon samples. The typical standard error is ±0.024, which in most cases is too small to observe.

B. Multiple modes cavity system

Cylindrical microwave cavity is used to measure dielectric properties of carbon samples over range of frequencies by exciting other TM modes at different frequencies, listed in Table, which show calculated, simulated, and measured frequency for the used TM modes. all of TM modes have an electric field parallel to an axial sample. To reduce the inter-grain conductivity effects between powder particles, the samples were mixed with silica.

Table 3. Resonant frequencies (in GHz) of the various TM modes

mode	**Center Frequency**		
	Calculated	**Simulated**	**Measured**
TM_{010}	2.494	2.500	2.501
TM_{011}	4.502	4.521	4.532
TM_{020}	5.729	5.734	5.746
TM_{021}	6.843	6.875	6.891
TM_{012}	7.899	7.931	7.946

Figure 7 and *Figure 8* show the results of measurements of dielectric constant and loss factor of the carbon samples over the range of frequencies between 2 and 8 GHz range.

There are obvious differences in the dielectric constant and dielectric loss factor that depend on the type of carbons. Coke has the highest values for the TM_{010} and TM_{011} modes, and coal-3 (char) has the highest values at TM_{020} and TM_{021} modes. From Figure 7 and8 it can be seen that some modes such as TM_{010}, TM_{011} are more convenient to differentiate types of carbon.

Other coals have only slightly different dielectric behaviours, as shown inFigure 9 and Figure 10, but it is still sufficient to use these measurements to distinguish between the different types of carbon. For example, to identify these different types of carbons, the TM_{021} mode can be used sufficiently for measuring the dielectric constant and the TM_{010} mode can be also used for measuring dielectric loss factor.

The three lab-made samples that contained different weight concentrations of coal, char, and coke were also measured using multimode cavity system. From Figure 11 and Figure 12, it obvious that the TM_{021} and TM_{010} modes, alone, are sufficient to distinguish between these samples.

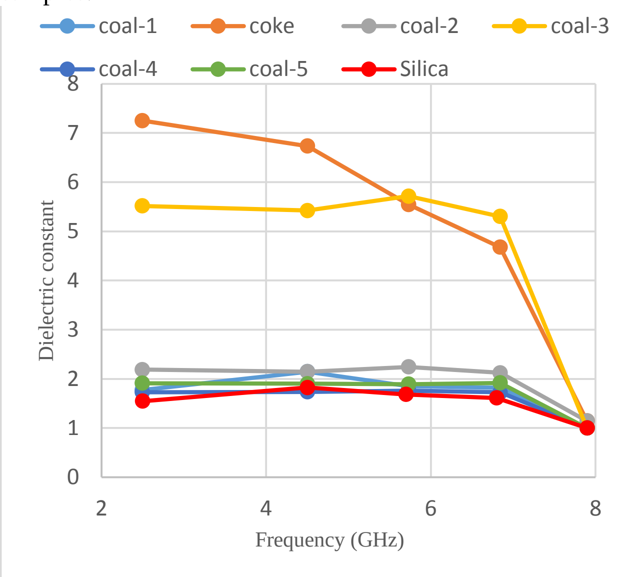

Figure 7. Real components of complex permittivity of different types of carbons

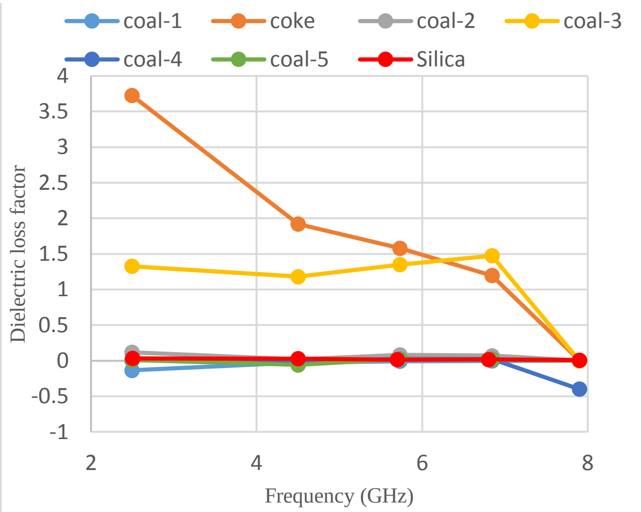

Figure 8.Imaginary components of complex permittivity of different types of carbons

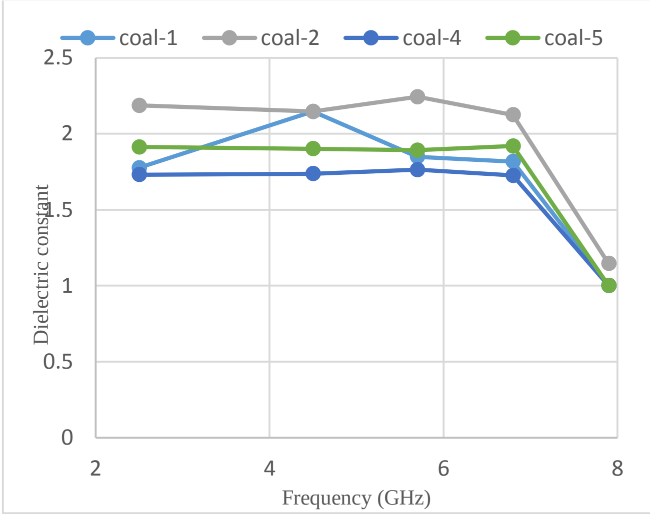

Figure 9. Real components of complex permittivity of different types of coals

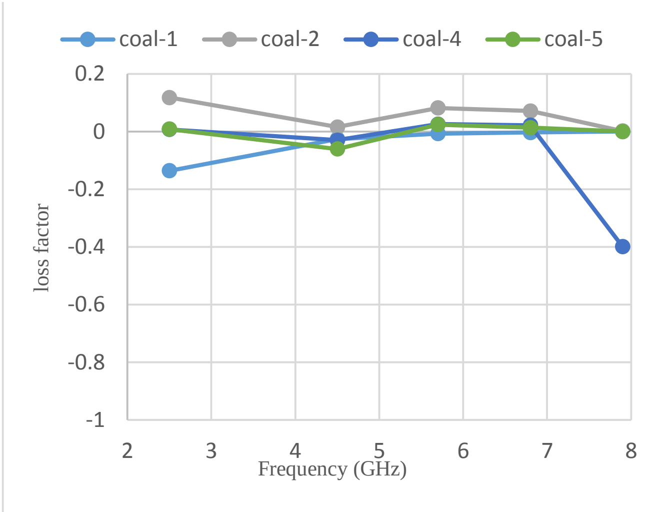

Figure 10 .Imaginary components of complex permittivity of different types of coals

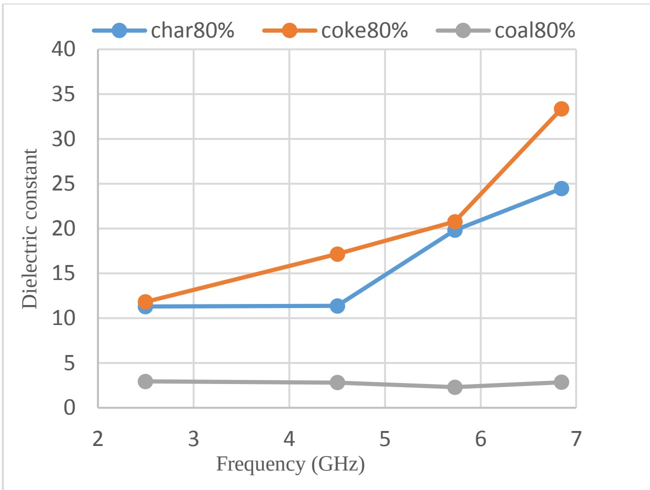

Figure 11.Real components of complex permittivity of lab-made samples

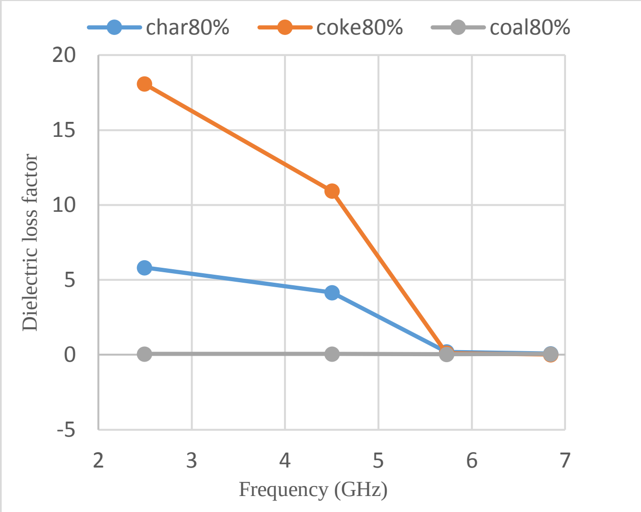

Figure 12. Imaginary components of complex permittivity of lab-made samples

V. CONCLUSION

The multimode cavity method is suitable to be used as test method for characterizing and differentiating the different forms of carbons based on the frequency dependence of their dielectric properties. Some modes are more convinced than others such as TM_{010}. generally, dielectric properties of the samples decrease as the frequency increased. finally, it can be concluded that the microwave cavity measurement method can be used effectively to differentiate carbon forms in BFD. This is a novel method of assessing this complex material and could open an important on-site characteristic for all industrial applications involving blast furnaces.

REFERENCES

[1] Ng, K., et al., Carbon type differentiation technique for diagnosing pulverised coal injection efficiency. Ironmaking & Steelmaking, 2016. **43**(3): p. 214-219.

[2] Geerdes, M., R. Chaigneau, and I. Kurunov, Modern Blast Furnace Ironmaking: An Introduction (2015). 2015: Ios Press.

[3] Al-Qodah, Z. and R. Shawabkah, Production and characterization of granular activated carbon from activated sludge. Brazilian Journal of Chemical Engineering, 2009. 26(1): p. 127-136.

[4] Stewart, M.L. and J. Stencel, Treatment of Activated Carbons for Densification. PREPRINTS OF PAPERS-AMERICAN CHEMICAL SOCIETY DIVISION FUEL CHEMISTRY, 1993. 38: p. 408-408.

[5] Ania, C., et al., Effect of microwave and conventional regeneration on the microporous and mesoporous network and on the adsorptive capacity of activated carbons. Microporous and Mesoporous Materials, 2005. 85(1): p. 7-15.

[6] Hesas, R.H., et al., Preparation and characterization of activated carbon from apple waste by microwave-assisted phosphoric acid activation: application in methylene blue adsorption. BioResources, 2013. 8(2): p. 2950-2966.

[7] Mehdizadeh, M., Microwave/RF applicators and probes: for material heating, sensing, and plasma generation. 2015: William Andrew.