

# Temperature-dependent electromagnetic characterisation of materials for CO<sub>2</sub> capture and utilization

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**Abstract**— CO<sub>2</sub> capture as well as H<sub>2</sub> generation are part of one of the global strategies to avoid global warming. The use of microwaves for CO<sub>2</sub> capture and H<sub>2</sub> generation by means of DRM (Dry Reforming of Methane) is one of the most promising possibilities for the use of green energy.

In order to design CO<sub>2</sub> monolithic sorbents to be heated by microwaves, a careful selection of materials must be made so that they are chemically active for the expected reaction (DRM or CO<sub>2</sub> adsorption) and that, on the other hand, their electromagnetic behaviour allows an efficient heating.

This article shows how the electromagnetic properties of different commercial and non-commercial materials have been measured for use as materials for the construction of the monoliths to be used in the microwave power applicators.

**Keywords**—CO<sub>2</sub> capture, microwave heating, electromagnetic permittivity, dielectric measurements

## I. INTRODUCTION

Global warming due to increased atmospheric CO<sub>2</sub> is evidenced by recent natural disasters. In 2021, heat waves in Sacramento caused fires, and floods hit Rhineland-Westphalia [1]. The 2015 Paris Agreement, signed by 55 countries, aims to limit global temperature rise to 1.5°C [2]. The chemical industry, responsible for 30% of industrial emissions, is crucial in this effort. Achieving net zero CO<sub>2</sub> emissions by 2050 is a key EU goal, with carbon capture, utilization and storage (CCUS) [3], and increased electricity use being

fundamental. The cement industry, for instance, emitted 2.3 Gt of CO<sub>2</sub> in 2019 [4]. Decarbonizing energy-intensive industries, especially chemicals and steel, is urgent. Power-to-X concepts and electrifying chemical processes using renewable electricity are vital steps. Process electrification involves evaluating energy use and emissions. And in the frame of this electrifying process is where microwave energy appears to help the chemical industry through microwave heating using renewable electricity, aiding in CO<sub>2</sub> capture and hydrogen generation, contributing to decarbonization and net zero emissions.

To achieve this, the first step is always to measure the permittivity of the materials to be used as sorbents and/or catalyst.

## II. MEASUREMENT METHOD AND MATERIAL SELECTION

### A. Permittivity measurement method

The permittivity of the materials gives an important information of the samples. Depending on the application of the materials, it gives the capacity of the material to store electrical energy and the capability of being heated by electromagnetic energy [5].

The objective of the paper is to characterize the proposed materials at different atmosphere (air or Nitrogen) and in a large range of temperatures. Typically, the temperatures for this application, CO<sub>2</sub> desorption takes place at temperatures between 100 to 150°C and DRM reaction occurs between 700 to 900°C. It means that, even there is a large variety of measurement methods for materials characterization, the number of possibilities is reduced when there are restrictions in the atmosphere and on the temperature [6]-[9].

Additionally, one of the main problems when measuring the permittivity at high temperatures is to guarantee the proper temperature when measuring the permittivity. This problem is solved in [10],[11]. In [10] a calorimeter is introduced that guarantees not only a proper temperature measurement but also the potential microwave effect is introduced because the sample is heated by microwave energy too. And the device also provides the facility of using different atmospheres, and even different pressures if required.

The proposed measurement method heats the sample by the TE<sub>111</sub> resonant mode and measures the permittivity by TM<sub>010</sub> resonant mode. Both resonant modes are around 2.45 GHz, even the resonant frequency changes a little bit



Fig. 1 Calorimeter used for dielectric measurements.

depending on the permittivity values, being lower frequencies when the permittivity value increases. The device is shown in Fig. 1.

### B. Material Selection

As described in the introduction section, the objective of the paper is to measure the permittivity of different materials to evaluate its capability of being heated by microwave energy.

The materials will be utilized to manufacture various monoliths, which will serve as CO<sub>2</sub> sorbents and/or catalysts within a microwave applicator. The selection of the materials is based on commercial Ni based catalyst for DRM, MOF-808 was synthesized as CO<sub>2</sub> sorbent material [12] and commercial graphitic carbon was provided by Asbury (<https://www.asbury.com/>) as microwave susceptor.

As a result, the list of the samples initially proposed is:

- 1) Comercial catalyst: Ni/CeO<sub>2</sub>/Al<sub>2</sub>O<sub>3</sub>
- 2) MOF-808
- 3) 5% Carbon + 95% MOF-808 mixture

The third sample is a mixture of MOF and carbon, prepared by ball milling. Carbon is not a CO<sub>2</sub> adsorbent, but it will be used as a microwave susceptor for MOF and other materials selected for CO<sub>2</sub> adsorption, because it is expected

that MOF will have a very low loss factor, which means that it will be difficult to be heated by microwave energy.

### III. RESULTS

Once the samples are prepared, the measurement process starts. Initially we have the results for the commercial catalyst in figs. 2 and 3. It is interesting to note that the first cycle has a different permittivity than the 2<sup>nd</sup> and 3<sup>rd</sup> cycles: this is because in the 1<sup>st</sup> cycle the water was removed, and for the following cycles the sample remains the same. And another important fact is that the loss factor is very low at lower temperatures. It means that it will be hard to use microwave energy to heat this samples unless a dopant is used.

Then the MOF was also measured, and the results are in Fig. 4 and 5. It is noticeable the same effect than in the previous catalyst: the 1<sup>st</sup> cycle eliminates the water content, and the following ones repeat the same behaviour. And, again, the loss factor is very low at lower temperatures. It is a problem when we need to heat the samples with microwave energy.

Finally, to avoid this problem, a mixture of MOF plus carbon, that is a well-known microwave absorber, is measured. The results are shown in Fig. 6 and 7.

The same behaviour is observed for the real part, when the 1<sup>st</sup> cycle is different from the following because of the water evaporation.

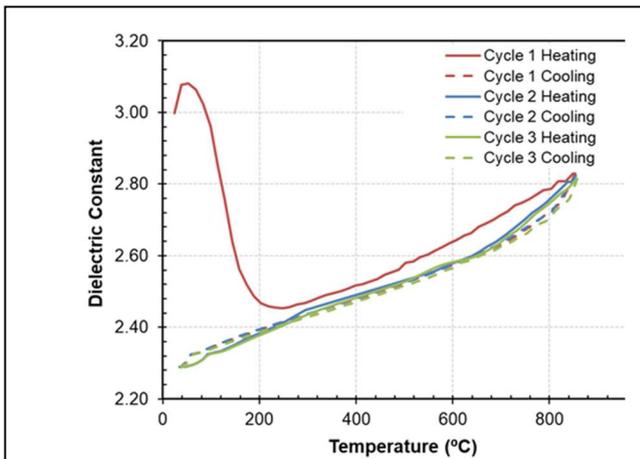


Fig. 2 Commercial catalyst permittivity: real part.

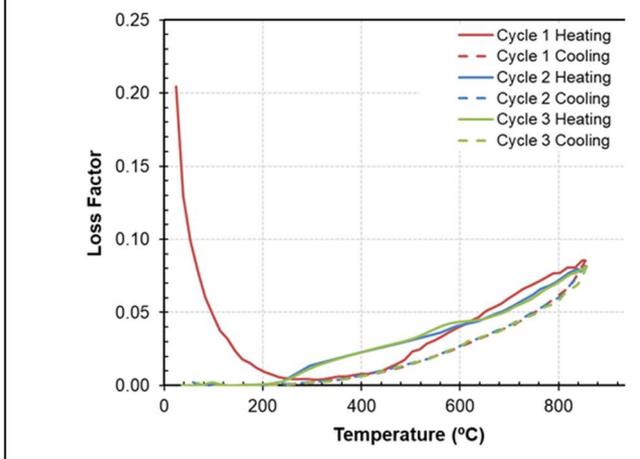


Fig. 3 Commercial catalyst permittivity: loss factor

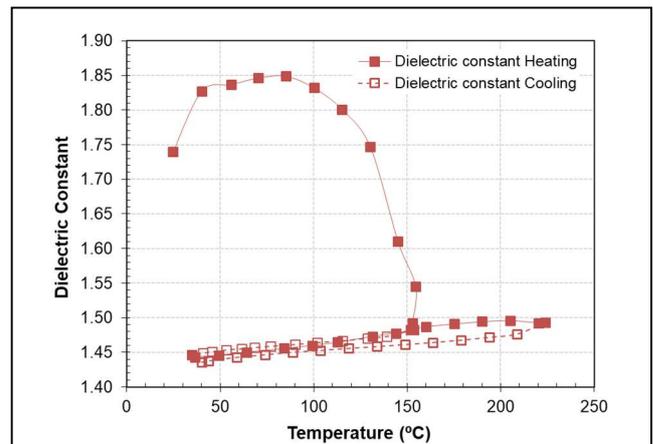


Fig. 4 MOF permittivity: real part.

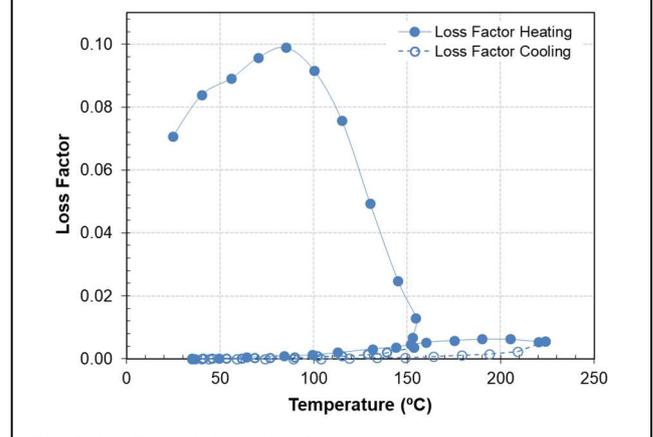


Fig. 5 MOF permittivity: loss factor

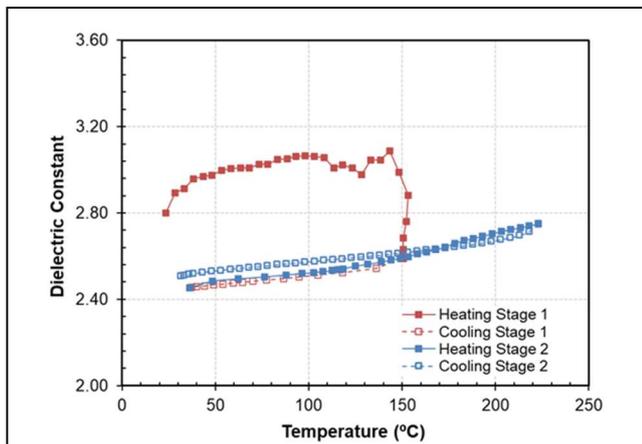


Fig. 6 95% MOF + 5% carbon permissivity: real part.

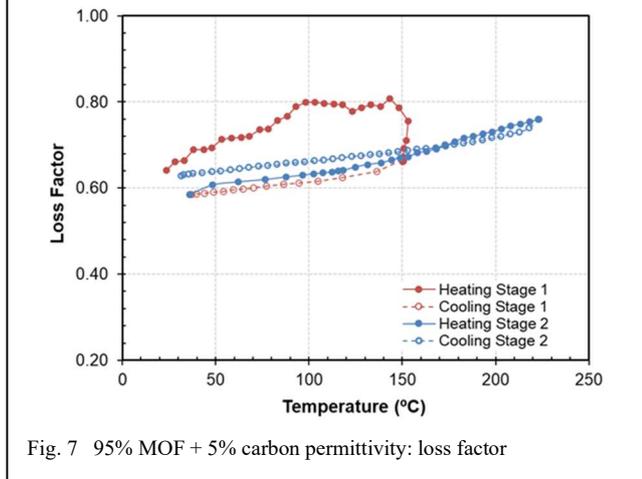


Fig. 7 95% MOF + 5% carbon permissivity: loss factor

The significant impact of adding just 5% carbon lies in how it increases the loss factor, thereby turning the sample into an effective absorber of microwave energy.

As a consequence, the use of microwave susceptors will improve the microwave energy absorption.

The following steps consist of measuring the CO<sub>2</sub> adsorption of the new sample and the design of a microwave applicator to be used with the new monoliths constructed with the new absorbers.

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