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High Temperature Monitoring of Refractory Wall Recession Using Frequency-Modulated Continuous-Wave (FM-CW) Radar Techniques

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INTRODUCTION

Furnaces are the most crucial components in the glass and metallurgical industry. Like any other components in an industry, furnaces require periodic maintenance and repair. Higher fuel consumption, low production and safety are issues that accompany delayed maintenance. As a result of the competitive market facing these industries, longer furnace lifetime with shorter maintenance downtime are increasingly required. Consequently, there is a need to know the state of a refractory wall to prevent premature or unnecessary maintenance shutdowns.

The rate of regression of a refractory lining (or wall) depends on the type of the refractory lining, the materials being melted, seepage, mechanical stresses, and temperature [1]. Moreover, the regression of a refractory lining is also not uniform throughout a furnace. Hence, more accurate measurement techniques are required to determine the local residual thickness of a refractory lining so as to utilize the refractory lining to the maximum extent possible. The use of isotope radiators, thermocouples and endoscopes has been investigated for monitoring regression in the past. These techniques are capable of providing scanned thermal images showing the profile of the refractory wall. However, these techniques can only provide relative profile information and cannot provide absolute thickness measurements [2-5]. Microwave signals can penetrate through refractory linings which are in the family of permittivity and low loss ceramics. Therefore, radar techniques are also good candidates for evaluating refractory lining/wall thickness and recession at high temperatures (such as those in running furnaces).

PROPOSED APPROACH

Microwave nondestructive evaluation techniques have evolved over the past few decades [6]. Microwave signals are able to penetrate inside of dielectric materials such as plastics and ceramics and provide information about the inner structure of these materials [6]. The primary objective of this work has been to demonstrate the potential utility of Frequency-Modulated Continuous Wave (FM-CW) radars for evaluating refractory furnace wall thickness and recession. This radar technique is a well-established microwave method for distance measurement and remote sensing [7], and was thus adopted for refractory wall thickness measurement. The utility of this radar technique, for measuring refractory wall thickness at room temperature has already been successfully demonstrated [8]. The goal of this investigation was to examine the capabilities of this technique at high temperatures similar to those experienced in a running furnace. Experiments were conducted on several types of Alumina-Zirconia-Silica (AZS) refractory bricks, commonly used in furnaces at room temperature and high temperatures, at S-band (2.6-395 GHz) and X-band (8.2-12.4 GHz), to evaluate the effect of heat on the microwave measurements (if any).

RESULTS

To accurately determine the thickness of the refractory wall, the FM-CW radar technique required an accurate relative permittivity for the refractory bricks. The dielectric properties of a material can be accurately measured using several elaborate methods including the completely-filled waveguide method [6]. Since the refractory bricks are expected to be low loss at the frequency bands used in this investigation a simpler procedure was implemented by calibrating the FM-CW radar with a refractory brick of known thickness. In this way the relative permittivity of type 315 AZS was determined to be 6.28 at S-band frequencies and 4.35 at X-band.

The FM-CW radar measurement technique provided reasonably accurate thickness measurements at room temperature [8]. Additional experiments were conducted by heating AZS bricks and measuring the thickness of the heated bricks. The first experiment was conducted on a 15.2 cm-thick type 315 AZS brick. One end was placed at the opening of a box furnace and the inside temperature was gradually increased in from room temperature to 1130°C. The X-band radar output spectrum for this setup over the entire temperature range is shown in Figure 1. The spectra show the reflection from the surface of the cold face of the brick (outside of the box furnace) and the reflection from the back of the brick (inside the box furnace) as a function of temperature. From Figure 1, the measured thickness was 15.9 cm over the entire temperature range. The same experiment was repeated with two 15.2 cm-thick type 315 AZS bricks placed one after the other. Measurements were carried out at both S-band and X-band frequencies and the results for the measurements are shown in Figures 2-3, respectively. From the S-band output spectrum, the thickness was measured to be 31.1 cm. From the X-band output spectrum, three peaks were observed, the first being the reflection from the antenna-brick interface (i.e., the cold face), the second peak from a small air gap between the two bricks (that was unintentionally formed), and the third from the back end of the brick (i.e., the hot face). From the X-band output spectrum the gap is determined to be located at 15.7 cm and the back at 30.7 cm. This air gap was detected at X-band since the range resolution at this band was finer than at S-band due to the availability of larger signal bandwidth. From these results it was observed that temperature had minimal effect on the measurement for cast 315 type AZS bricks.

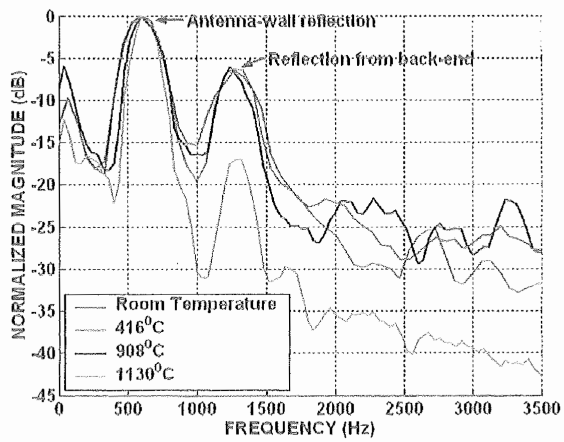

Figure 1. X-band radar output spectrum at various hot face temperatures for 15.2 cm-thick type 315 AZS brick (B = 1.5 GHz, f_m = 100 Hz).

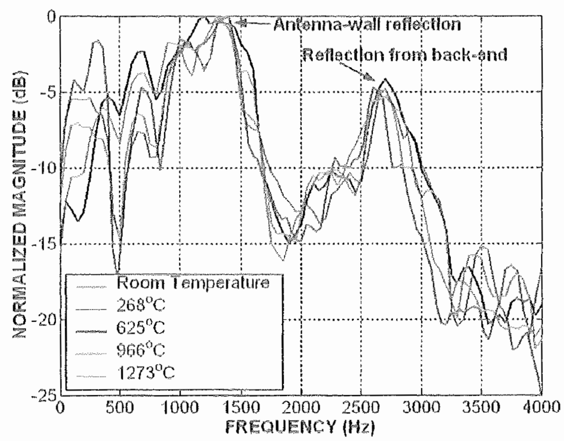

Figure 2. S-band radar output spectrum at various hot face temperatures for 30.5 cm-thick type 315 AZS brick (B = 1.2 GHz, f_m = 100 Hz).

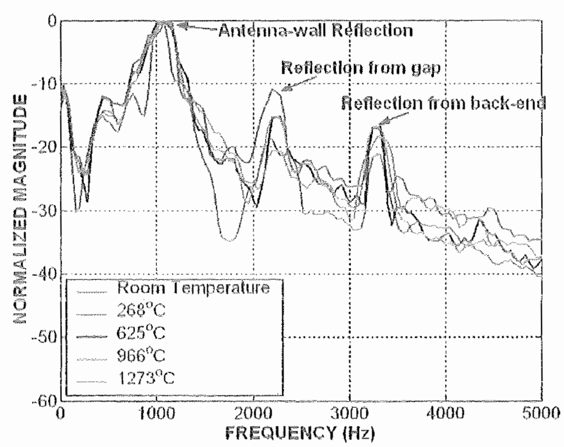

Figure 3. X-band radar output spectrum at various hot face temperatures for 30.5 cm-thick type 315 AZS brick (B = 2.5 GHz, f_m = 100 Hz).

The FM-CW radar technique showed great promise as a viable method for refractory wall thickness measurement. S-band and X-band FM-CW radars were successfully designed to demonstrate their applicability, portability and ruggedness. The technique provided good results with a high degree of accuracy. The microwave FM-CW radar technique also provided very repeatable results throughout this investigation.

In the course of this investigation it also became evident that refractory bricks containing a relatively significant amount of glass in their composition become increasingly lossy as a function of increasing temperature. This fact may limit the ability of these techniques to evaluate the thickness of thick walls without some alterations to the radar system such as an increase in the incident power level or better impedance matching of the radar antenna to that of the refractory brick. However, for thin walls, which are of the most concern, this radar system is capable of accurate measurement of the wall thickness even at high temperatures. Additionally, through the course of this investigation, it became clear that this method is capable of providing much more useful information about the structural characteristics of a wall than just its thickness. Refractory wall parameters such as lamination in a wall, planar cracks, metal and glass penetration, and porosity may also be evaluated using this method. This paper will provide a brief background on the operation of FM-CW radars and its application to refractory wall thickness measurement. Subsequently, the results of these investigations and a detailed discussion of the results will be presented.

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