Measurement of Monochromatic Emissivity of Cement Clinker with Various Fe$_2$O$_3$ Content at High Temperature

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An application of the optical pyrometer is studied for measuring monochromatic emissivities of cement clinker with various Fe$_2$O$_3$ content. The idea of using "brightness temperature" is introduced into the emissivity measurement. In this method, there is no need for measuring an actual temperature of sample surfaces, only with determining both brightness temperatures of a sample and a blackbody can the required emissivity be evaluated according to Wien's radiation law. In practice, the cement clinker is regarded as a greybody, the monochromatic emissivity is approximately equal to the total emissivity, so a single-colour optical pyrometer is applied for this purpose. Test measurements are carried out on 10 kinds of cement clinkers. Experimental data are treated by the least square method. As a result, the emissivity variation with temperature at a certain Fe$_2$O$_3$ content is quite well represented by $\varepsilon = a + bT$. Furthermore, this work first reported that the emissivities of cement clinker change considerably with Fe$_2$O$_3$ contents. In multiple cement production this conclusion is very important.

Keywords: monochromatic emissivity, brightness temperature, cement clinker, blackbody, radiation.

INTRODUCTION

The requirements of the accurate radiative properties of various cement clinkers in rotary kilns have been increased in connection with cement quality and energy consumption. It is essential that emissivity be properly determined for the real material being studied in order to obtain accurate temperature measurements. Direct measurement of emissivity is made calorimetrically or radiometrically. But it is difficult to make accurate measurement because of many sources of uncertainty. A major source is due to the measurement of surface temperature. Conventional thermocouples are applied for this purpose, unfortunately, they will be unstable if used at temperature above 1500 K, and some inevitable amount of heat flux transferred through thermocouple to the surroundings.

Many improvements have been made to overcome these difficulties and reduce the uncertainty in surface temperature measurement to as small a value as possible. Masada provided the transient calorimetric technique to measure the total hemispherical emissivity of metal wires and developed a method to reduce conduction heat losses through thermocouple leads (1). Cheng Shuxia analysed the effects of considerable heat losses on accurate temperature measurements (2). Redgrove presented a new method for surface temperature measurement (at temperature less than 1000°C) (3).

It is obvious that using thermocouples limits the accurate temperature measurement range and causes uncertainty of emissivity measurements. Even though some more precise and excellent equipment has been developed (4), the aim of the present work is to study a simpler, quicker and more convenient approach, which also has a sufficient accuracy for industrial usage and laboratory research. In the method both brightness temperatures of a sample and a blackbody are measured at the same actual temperature, in the same waveband and under the same viewing conditions by means of an optical pyrometer, then the sample emis-
sivity can be determined from Wien’s law. Without measuring actual temperature of sample surfaces by using thermocouples, those coincident defects may be eliminated, and the measured temperature range will extend to any desired values.

Cement clinker at high temperature is a polycrystalline material, its emissivity depends on the method of manufacture as well as the composition. In this paper the influences of Fe₂O₃ content on emissivities of cement clinkers will be reported. The conclusion is very helpful for estimating their actual temperatures in multiple cement production.

THEORETICAL BACKGROUND

The monochromatic emissivity is determined by dividing the radiance of a sample by the radiance of a blackbody at the same temperature, in the same waveband and under the same viewing condition:

\[ \varepsilon(\lambda, T) = \frac{I_A(\lambda, T)}{I_B(\lambda, T)} \]  

where \( I_A(\lambda, T) \) is the heat radiant of a real body and \( I_B(\lambda, T) \) is the heat radiant intensity of a blackbody.

For a fixed temperature \( T \) of a sample, however, there will be some lower temperature, at which a blackbody has the same radiant intensity emitted as that from the sample, a nonblackbody source. We call this a “brightness temperature” \( T_B \). It is an apparent temperature, which a blackbody would have if we assume it has the actual intensity \( I_A \), as shown in Fig.1.

In practice, the brightness \( L(\lambda, T) \) as output signal received by the detector of optical pyrometer is weaker than the actual brightness intensity. Here the detector sensitivity, absorption through windows and other influence are all taken into account in a coefficient \( A(\lambda) \), a calibration constant which depends on the wavelength but not on the temperature, then we have,

\[ L_A(\lambda, T) = A(\lambda)I_A(\lambda, T_B) = C_1\lambda^{-5}e^{-C_2/\lambda T_B} \]  
\[ L_B(\lambda, T) = A(\lambda)I_B(\lambda, T) = C_1\lambda^{-5}e^{-C_2/\lambda T} \]

combining expression (1), (3), (4):

\[ \varepsilon(\lambda, T) = \frac{e^{-C_2/\lambda T_B}}{e^{-C_2/\lambda T}} \]  

where \( T, T_B \) – the actual temperature and the brightness temperature of a sample, \( K \)

\( \lambda \) – wavelength of monochromatic emissivity, \( \mu m \)

\( \varepsilon(\lambda, T) \) – monochromatic emissivity of a sample at wavelength \( \lambda \)

\( C_2 \) – Planck’s second radiant constant, \( C_2 = 1.44 \times 10^2 \) mK

If both brightness temperature and actual temperature are known, the monochromatic emissivity can be calculated by expression (5).

EXPERIMENT

To measure the brightness temperature of the sample, as a nonblackbody source, we use a disappearing-filament optical pyrometer, once universally applied in standard laboratories for the realization of the International Temperature Scale. In this way, temperature measurements can be extended to any desired maximum temperature points. Although the accuracy of this instrument is limited by the contrast sensitivity of the human eye, the repeatability of the mean of a number of measurements by an experienced observer can be as good as \( \pm 0.5^\circ C \), hence, the accuracy attainable using a disappearing-filament pyrometer is sufficient for emissivity measurements.

In order to obtain the actual temperature of a sample, there is a need for an artificial blackbody, which is an aperture 1 mm in diameter on the surface of a large hollow sphere made of high purity synthetic sapphire with an inner diameter 60 mm. Any radiant energy entering the aperture would be completely absorbed by innerwalls of the sphere’s, it would not be reflected back out the aperture because of the multiple reflection and because of the very high absorption at each reflection. This aperture has the same character as