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Gasification temperature measurement with flame emission spectroscopy

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HIGHLIGHTS

- Optical probe based on flame emission spectroscopy is shown to be capable of monitoring gasifier chamber temperatures.
- Spectrally derived temperatures are affected by changes in coal and oxygen flow rates and also by the presence of steam.
- The optical sensor detected gasifier burner malfunction in real time.
- OH and CH emission bands were not detectable in coal flames whereas sodium and potassium emissions were observed.

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ABSTRACT

This paper presents the results of temperature measurements inside the CanmetENERGY pilot scale entrained flow gasification facility by means of an optical sensor based on flame emission spectroscopy (FES). In the present work a cooled, purged, fibre optic probe inserted into the gasifier reactor, through an access port at one end and coupled to a small portable commercial spectrometer at the other end, collected radiation from the gasifier flame. The acquired spectra were analyzed to yield temperatures representing the reaction chamber region lying within an angle of 8.8° enclosing the central axis of the probe. In the absence of a flame when radiation was acquired only from the hot enclosure, spectrally derived temperatures were in the same range as those recorded by wall mounted thermocouples (TE). When a flame was present spectral temperatures generally differed from the TE temperatures. Analysis of the spectra after the run yielded very high temperatures during certain periods of data acquisition indicating various types of gasifier burner malfunction. The thermocouples did not record similar high temperatures during any of the gasifier burner malfunction events. Examination of the gasifier after shut down, due to failure of a thermocouple, confirmed a malfunction had occurred during the operational period. These results show that FES derived temperatures are useful for monitoring gasifier performance. The data was further analyzed to explore the usefulness of other flame spectral features such as Na and OH emission for gasifier flame diagnostics.

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1. Introduction

Gasification may be described as a means by which carbon based fuels are processed under reducing conditions at high temperature generating a gas containing a useful heating value – syngas [1]. In the type of gasifier under consideration here, an oxygen fired entrained flow gasifier, the syngas consists primarily of CO, H₂, H₂O, and CO₂. Processed syngas is commonly used as a clean fuel for power generation, a source of hydrogen for oil upgrading, and as a feedstock for chemicals production. Oxygen gasification is a well-recognized fuel conversion technology that

enables CO₂ capture and storage resulting in the potential for deep reductions in GHG emissions from the power, oil, and chemical sectors. An obvious and essential aspect of gasifier operation is performance monitoring to ensure safe conditions and satisfactory output. Temperature monitoring and control play critical roles in safe and cost effective reactor operation. Unnecessarily high temperatures lead to excessive refractory wear and low temperatures can lead to gasifier shut down due to slag tap plugging. Thermocouples are the conventional devices used for temperature measurement in entrained flow gasifiers, however, there are concerns related to their performance [2]. Flame emission spectroscopy (FES) is an alternate non-intrusive approach applicable for gasifier temperature measurement that addresses some of these concerns. The suitability of such sensors for combustion control

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is well reviewed by Docquier and Candel [3]. There is relatively little experience reported in using this technique with pressurized entrained flow gasifiers. This paper describes the application of FES for monitoring the operation of the CanmetENERGY pilot scaled pressurized entrained flow gasifier.

2. Flame emission spectroscopy (FES)

FES is a method of optical sensing based on acquiring radiation from a flame over a wide spectral region. The spectroscopy of flames is well known [4]. The advent of modern miniature spectrometers, with built-in charge coupled device (CCD) detectors during recent decades, has encouraged researchers to apply this technology to monitor the combustion performance of bench scale flames as well as large industrial scale flames [5–8]. The radiation emitted by a flame consists of different colors or wavelengths extending over a wide region. A wide band spectrometer delivers more information about the flame than that can be obtained with one or a few individual detectors and is used to obtain a more detailed flame spectral profile.

A spectral profile is a plot of the observed intensity (photon counts) of the radiation as a function of the wavelength. Hydrocarbon gas flames are known to reveal spectral lines arising from the chemiluminescence of the species OH (309 nm), CH (431 nm) and C₂ (515 nm) in the UV and visible regions. In non-luminous natural gas flames these lines are clearly visible as shown in Fig. 1. In a furnace these discrete bands are superimposed over the continuum emission from the hot walls. The relative strength of the discrete spectral lines from OH and CH radicals is useful for estimating air/fuel ratios [5–8]. Examples of spectral profiles from natural gas and coal flames collected with a UV–VIS – near IR spectrometer, at atmospheric pressure are shown in Figs. 1–3. These spectra were generated in the Canmet tunnel furnace [6]. In luminous industrial scale flames OH and CH emissions are too weak to be observed under the dominating continuous emission from the hot source. In such flames the spectral emissions from sodium and potassium present in the fuel or refractory are the prominent features over the continuum background [8].

The continuum radiation from a luminous flame may be described by the approximate form of Planck's law for a blackbody at temperature T

$$I(\lambda, T) = \frac{E_2 C_1}{\lambda^5 e^{C_2/\lambda T}} \quad (1)$$

Here $I(\lambda, T)$ is the radiation intensity (per unit area) at wavelength λ and temperature T (degrees Kelvin), E_2 is the emissivity, and the constants are $C_1 = 2hc^2$ and $C_2 = hc/k$; h is Planck's constant, c is the velocity of light and k is the Boltzmann constant.

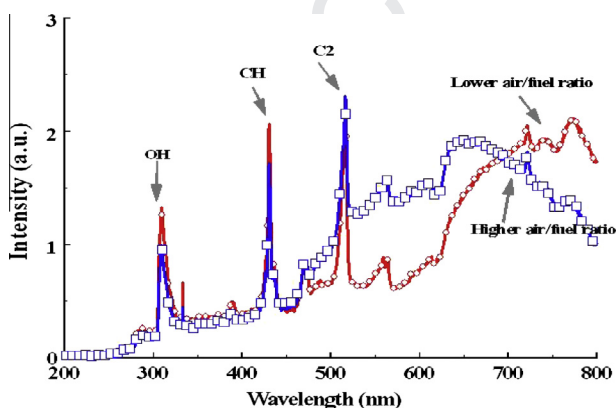


Fig. 1. Natural gas flame spectra: spectral features vary with air/fuel ratio.

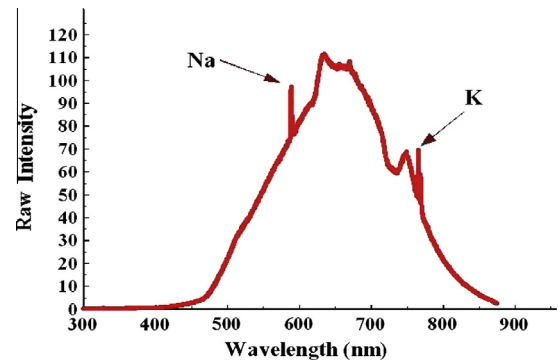


Fig. 2. Coal flame spectrum.

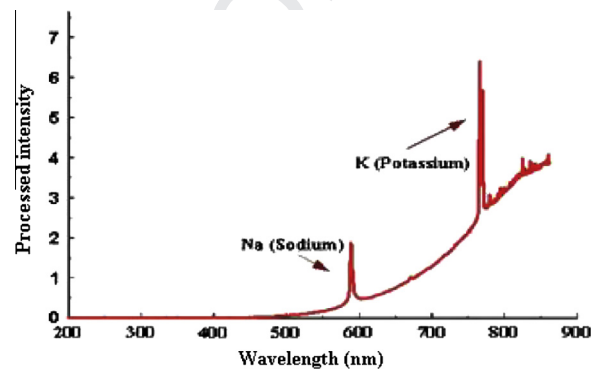


Fig. 3. Processed coal flame spectrum.

For an ideal blackbody $E_\lambda = 1$ for all wavelengths, but the combustion environment is not a perfect radiator and E_λ is less than one and may vary with wavelength. For two wavelengths which are close, E_λ may be assumed to be constant. With this assumption Eq. (1) is used to calculate the ratio of the intensities at a pair of selected wavelengths, which is solved for the temperature [9]. Two color ratio pyrometers based on this approach with single detectors sensitive to two narrow wavelength regions in the infrared are well known.

With a spectrometer such as the one in the present work, spectral intensities are measured at a large number of wavelengths. The acquired spectral profiles need to be corrected for shape changes introduced by the spectrometer sensitivity function. It is standard practice to implement this correction or calibration by using the spectrum from a blackbody reference source at a known temperature. If $I_B(\lambda, T)$ is the spectrometer measured black body spectrum at temperature T and $I_T(\lambda, T)$ is the Planck's law spectrum at the same temperature the corrected spectrum $I_C(\lambda, T)$ from a radiation source such as a flame is calculated from the raw spectrum $I_S(\lambda, T)$ as follows:

$$I_C(\lambda, T) = I_S(\lambda, T)(I_T(\lambda, T)/I_B(\lambda, T)) \quad (2)$$

In spectra of the type shown in Fig. 3 which is a corrected coal spectrum from the Canmet tunnel furnace at atmospheric pressure the region 650–710 nm is almost free from discrete spectral emission lines (e.g. Na at 589 nm) and is suitable for deriving temperatures.

When flames are turbulent and conditions change over short time intervals the acquired spectra are noisy and temperatures obtained vary with the pair of wavelengths selected. In practical two color pyrometry the average of the temperatures derived from several pairs of wavelengths is calculated. A simple method to check the assumption of constant emissivity in applying two-color

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