Energy Conversion and Management 52 (2011) 2235–2240

Contents lists available at ScienceDirect

Energy Conversion and Management

journal homepage: www.elsevier.com/locate/enconman

The investigations of temperature distributions in an opposed multi-burner gasifier

Guang-Suo Yu *, Zhuo-Yong Yan, Qin-Feng Liang, Qing-Hua Guo, Zhi-Jie Zhou

Key Laboratory of Coal Gasification of Ministry of Education, East China University of Science and Technology, Shanghai 200237, PR China

ARTICLE INFO

Article history:
Received 11 September 2009
Received in revised form 12 June 2010
Accepted 31 December 2010

Keywords:
Entrained-flow gasification
Temperature distribution
Flame

ABSTRACT

In a bench-scale opposed multi-burner (OMB) gasifier, the temperatures of gasification chamber and quench chamber are measured by thermocouples, and the temperature distributions of flame sections are reconstructed by the Filtered back-projection method. The results show that the temperature of gasification chamber increases slowly as the inserted distance increases in both diesel and coal–water slurry (CWS) tests. The syngas temperature decreases rapidly when it passes through the inlet of quench chamber. The impinging flames of diesel or CWS gasification all focus on the gasifier center due to restraining by each other, and can avoid scouring the refractory wall and prolong the lives of refractory. At the test conditions, the temperature distributions of diesel flames are 1650–2100 °C and those of CWS flames are 1500–2000 °C. The flame temperature distributions appear to be a typical simple peak. The investigations can provide some information for the industrial gasifier.

1. Introduction

There is an increasing need for energy due to global economic growth in the 21st century. Coal gasification offers one of the most versatile and clean ways to convert coal into electricity, hydrogen, and other valuable energy products. The entrained-flow gasifier has the advantages of possessing both feedstock and product flexibility, near-zero emission of pollutants, high thermal efficiency and capture of carbon dioxide, and low feedstock, operating and maintenance costs [1]. GE (Texaco), Shell, Prenflo and GSP are the well-known entrained-flow coal gasification processes in the world. In China, a new type gasifier named as opposed multi-burner (OMB) gasifier with the capacity of 1150*t* coal per day (4.0 MPa) and relative equipments were commercialized successfully in Shandong Province of China [2].

Entrained-flow gasifiers operate at high temperature (above ash slagging temperatures, generally up to 1300 °C) to ensure high carbon conversion and a syngas free of tars and phenols. However, such high temperature has an important impact on burners and refractory life [3] and need the use of sophisticated quench chamber or other equipments to cool the syngas below the ash softening temperature in order to avoid fouling and control corrosion problems. Therefore, the investigations of flame characteristics [4] and temperature distributions in the gasifier are essential to the development and optimization of these technologies.

The traditional method of measuring temperature using thermocouple with high accuracy, and has been applied in the flame temperature measurement [5,6]. But it has some limitations, only point measurement, can not simultaneously measure the flame temperature distribution. In recent years, the non-intrusive temperature measurement techniques, such as laser interferometric holography [7], photorefractive holographic interferometry [8], planar laser-induced fluorescence (PLIF) [9], coherent anti-Stokes Raman scattering spectroscopy (CARS) [10], crossed plane Rayleigh imaging [11], etc., are applied to measure the flame temperature distribution, but those methods all have two disadvantages: need expensive equipments and require large and complex optical systems. On the other hand, many researchers have been directed toward the flame temperature distribution with the charge-coupled device (CCD) camera system which is a simple, low cost monitoring system, and used the different reconstruction methods. Yan et al. [12] reconstructed the three-dimensional temperature field from two-dimensional accumulative images of the flame by the Algebraic Reconstruction technique (ART) on a burner of mixed coal and oil. Zhou et al. [13] shown the 3-D temperature distributions of combustion from the 2-D flame temperature images transformed from the color flame images by the modified Tikhonov regularization method in the pulverized-coal-fired boiler furnace of a 200 MW power generation unit. Brisley et al. [14] combined the image-processing techniques and two-color radiation thermometry to reconstruct band-limited grayscale representations of the flame and then to determine its temperature distribution. Dai and Zou [15] reconstructed the section temperature field of coal power fired boiler by reconstruction technique with the improved particle swarm optimization algorithm.

In order to provide some information for the industrial gasifier which is a quench design with special internals to reduce water carry over, a bench-scale OMB gasifier is established. Several thermocouples are used to measure the temperatures of gasification

* Corresponding author. Tel./fax: +86 21 6425 2974.
E-mail address: gsyu@ecust.edu.cn (G.-S. Yu).

0196-8904/$ - see front matter © 2011 Elsevier Ltd All rights reserved.
doi:10.1016/j.enconman.2010.12.030

chamber and quench chamber, and a flame monitoring system is installed on the top of the gasifier and used to capture the images. The temperature distributions of gasification flame sections are reconstructed by the Filtered back-projection method, and displayed by isotherm.

2. Filtered back-projection method

Fig. 1 shows the received radiation intensity $P_\theta(t)$ (projection captured by the camera) which is the integral of two dimension (2D) section function $g(x, y)$ along the straight line ($x\cos\theta + y\sin\theta = t$).

$$P_\theta(t) = \int_{AB} g(x, y) ds \tag{1}$$

Eq. (1) may be described more generally by the Radon transform

$$P_\theta(t) = \int\int_{-\infty}^{\infty} g(x, y)\delta(x\cos\theta + y\sin\theta - t)dxdy, \quad -\infty < t < \infty, \ 0 \leqslant \theta < \pi \tag{2}$$

where $\delta(x\cos\theta + y\sin\theta - t)$ is the Dirac delta function.

The Filtered back-projection algorithm based on the Projection-slice theorem will be applied to reconstruct the 2D section function from the 1D projection which is calculated by two-color method [16] from the radiative images. The Projection-slice theorem states that the 2D Fourier transform of a 2D function yields the same result as the successive execution of a Radon and a 1D Fourier transform in radial direction [17]. Consequently, the function $g(x, y)$ is reconstructed by the back projection

$$g(x, y) = \int_0^\pi Q_\theta(x\cos\theta + y\sin\theta)d\theta \tag{3}$$

where $Q_\theta(t)$ is the filtered projections and equal to:

$$Q_\theta(t) = P_\theta(t) * h(t) \tag{4}$$

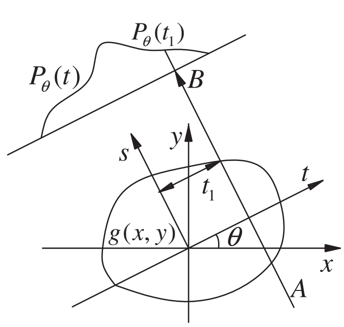

Fig. 1. Projection of $P_\theta(t)$.

where h is the filter impulse response and $*$ denotes convolution. In practice, the filter is designed directly in the frequency domain and then multiplied by the Fast Fourier Transform (*FFT*) of the projections. The projections are zero-padded to a power of 2 before filtering to prevent spatial domain aliasing and to speed up the *FFT*. For a total discrete number of M projections from a 180° arc around the burner axis, the reconstructed function can be approximated as:

$$g(x, y) = \frac{\pi}{M}\sum_{i=1}^{M} Q_{\theta_i}(x\cos\theta + y\sin\theta) \tag{5}$$

In practice, however, a sufficiently large number of projections are used to the reconstruction of the section function. For a specific case that the objects are rotational symmetry, only one projection is sufficient in order to solve the reconstruction problem. In the OMB gasifier, the fuel is atomized by the high velocity oxygen flow, so the gasification flames are turbulent and diffused. When averaged over a period of time, the flames will exhibit significant rotational symmetry.

Fig. 2 shows the flow chart of 3D reconstruction algorithm. The video signal transfers from the CCD camera to the computer and then digitizes into 8-bit two-dimensional digital images at rate of 25 frames per second. The flame images should be pre-processed by Splitting image and Median filtering. The color images are split into the three fundamental components of red, green and blue. A median filtering is applied to make the images homogeneous in color associated with shot to shot variations based on a 3 × 3 kernel with some consequent loss in spatial resolution to eliminate the image noise caused by the system. Then, the two-color method is used to calculate the projection temperature distribution. The 2D flame section is produced using the Filtered back-projection algorithm from the section projection including Hamming filter and back projection. When all 2D sections are reconstructed, the 3D distribution is formed.

3. Experimental equipment and flame monitoring system

3.1. Opposed multi-burner (OMB) gasifier

Fig. 3 shows a schematic diagram of the experimental setup and the measurement system. The unique feature of the OMB gasifier is four side-mounted burners in a down-flow reactor, which contributes to high carbon conversion. The diesel or CWS is gasified at atmospheric pressure in the presence of oxygen in the tests. Opposed turbulent flow fields are obtained by four opposed burners composed of inner and outer channels, which is shown in Fig. 4. The oxygen is fed through the outer channel of burners from oxygen cylinder, with a pressure-reducing valve to avoid pressure oscillations and achieve steady flow. The gas flow rates are controlled and measured by gas mass flowmeters (D07-9C/ZM, Beijing Sevenstar Huachuang Electronic Co., Ltd.). The diesel or CWS is fed

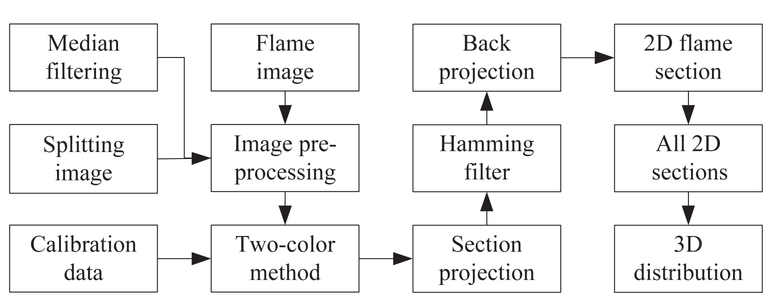

Fig. 2. Flow chart of 3D reconstruction algorithm.