Available online at www.sciencedirect.com

SciVerse ScienceDirect

Proceedings of the Combustion Institute 34 (2013) 2435–2443

Proceedings of the Combustion Institute

www.elsevier.com/locate/proci

Soot formation characteristics in a lab-scale turbulent pulverized coal flame with simultaneous planar measurements of laser induced incandescence of soot and Mie scattering of pulverized coal

Jun Hayashi [a,*], Nozomu Hashimoto [b], Noriaki Nakatsuka [a], Hirofumi Tsuji [b], Hiroaki Watanabe [b], Hisao Makino [b] Fumiteru Akamatsu [a]

[a] *Department of Mechanical Engineering, Osaka University, 2-1 Yamadaoka, Suita, Osaka 565-0871, Japan*
[b] *Energy Engineering Research Laboratory, Central Research Institute of Electric Power Industry (CRIEPI), 2-6-1 Nagasaka, Yokosuka, Kanagawa 240-0196, Japan*

Available online 25 October 2012

Abstract

Soot formation characteristics of a lab-scale pulverized coal flame were investigated by performing carefully controlled laser diagnostics. The spatial distributions of soot volume fraction and the pulverized coal particles were measured simultaneously by laser induced incandescence (LII) and Mie scattering imaging, respectively. In addition, the radial distributions of the soot volume fraction were compared with the OH radical fluorescence, gas temperature and oxygen concentration obtained in our previous studies [1,2]. The results indicated that the laser pulse fluence used for LII measurement should be carefully controlled to measure the soot volume fraction in pulverized coal flames. To precisely measure the soot volume fraction in pulverized coal flames using LII, it is necessary to adjust the laser pulse fluence so that it is sufficiently high to heat up all the soot particles to the sublimation temperature but also sufficiently low to avoid including a too large of a change in the morphology of the soot particles and the superposition of the LII signal from the pulverized coal particles on that from the soot particles. It was also found that the radial position of the peak LII signal intensity was located between the positions of the peak Mie scattering signal intensity and peak OH radical signal intensity. The region, in which LII signal, OH radical fluorescence and Mie scattering coexisted, expanded with increasing height above the burner port. It was also found that the soot formation in pulverized coal flames was enhanced at locations where the conditions of high temperature, low oxygen concentration and the existence of pulverized coal particles were satisfied simultaneously.

Keywords: Coal flame; Soot formation; Laser induced incandescence; Mie scattering

* Corresponding author. Fax: +81 6 6879 7254.
E-mail address: j.hayashi@mech.eng.osaka-u.ac.jp (J. Hayashi).

1540-7489/$ - see front matter © 2012 The Combustion Institute. Published by Elsevier Inc. All rights reserved.
http://dx.doi.org/10.1016/j.proci.2012.10.002

1. Introduction

Coal is recognized as an important resource for electricity production from the viewpoint of energy security since coal quarries and mines exist in various regions in the world. Most coal-fired power plants use pulverized coal combustion in which coal is pulverized into fine particles with a mass-based mean diameter of several tens of micrometers. To decrease the emission of pollutants from power plants, processes of pulverized coal combustion should be understood in detail. Pulverized coal combustion is a complicated two-phase phenomenon of many interacting processes, including coal particle dispersion into an oxidizer, devolatilization, the chemical reactions of the volatilized fuel with the oxidizer and the surface reactions of the residual char [1]. The chemical reactions in these processes are associated with soot formation. The physics that govern these processes and their interactions have not yet been understood in detail.

Although the numerical simulation of pulverized coal combustion is a useful tool for understanding the processes of pulverized coal combustion in coal-fired power plants [2–12], there is still considerable potential for improving its accuracy. Hashimoto et al. indicated that the devolatilization process is affected by the coal particle heating rate, which they estimated by performing numerical simulations [3]. To estimate the coal particle heating rate more precisely, the temperature distribution in the combustion furnace should be accurately calculated. The temperature distribution is affected by the soot formation characteristics in pulverized coal flames since there is radiation heat transfer from soot particles to the surrounding area. Soot formation, however, has not been considered in most numerical simulations of pulverized coal flames since a precise soot formation model has not yet been developed. To develop a precise soot formation model in numerical simulations, validation using experimental data is required [13]. Although the spatial distribution of the soot volume fraction is among the most valuable data for validating soot formation models, experimental results of the spatial distribution of the soot volume fraction have so far been limited to measurement results of discrete points.

Laser induced incandescence (LII) is a useful tool for measuring the soot volume fraction and its spatial distribution [e.g. 14–16]. Although LII can also be utilized to investigate two-phase combustion [17], as far as we know, reports on soot volume fraction measurement in pulverized coal flames using LII have been extremely limited. Chen et al. investigated the soot formation processes in a pulverized coal jet flame and reported that the maximum soot volume fraction in such a flame appears with the occurrence of coal pyrolysis [18]. However, since not only soot particles but also pulverized coal particles can be heated by laser irradiation to emit an LII signal in the pulverized coal flames, effects of the LII signal from pulverized coal particles requires further examination.

In this study, the two-dimensional soot volume fraction in pulverized coal flames is measured by LII while considering the effects of pulverized coal particles. To consider the existence of pulverized coal particles in the soot formation area, effects of the laser profiles (i.e., laser fluence, spatial profile of laser sheet) to LII signal are examined carefully. The signal intensity distributions of Mie scattering from the pulverized coal particles and the LII from the soot particles are compared. In addition, to examine the spatial relationship between the combustion reaction region and the existence region of pulverized coal particles, radial distributions of the LII signal intensity obtained from the current study are compared with the OH radical planar laser induced fluorescence (OH-PLIF) signal intensity obtained from the experiment by Hwang et al. [1] and the gas temperature and oxygen concentration obtained from numerical simulations by Hashimoto et al. [2].

2. Experimental apparatus and methods

Figure 1 shows a schematic illustration of the turbulent pulverized coal flame burner and the supply system. Pulverized coal particles were drawn into the main airflow and mixed with the air in an injector to form a solid–gas two-phase jet that issued from the main burner port (inner diameter: 6 mm). The pulverized coal particles were supplied and regulated by a screw feeder system. A compressor supplied the main airflow, which was controlled with a mass-flow controller. Methane was supplied to an annular slit burner (width: 0.5 mm) to ignite and stabilize the pulverized coal jet flame. The methane flow rate was maintained at the minimum value required to form a stable diffusion flame. Pulverized coal particles were supplied after forming the methane diffusion

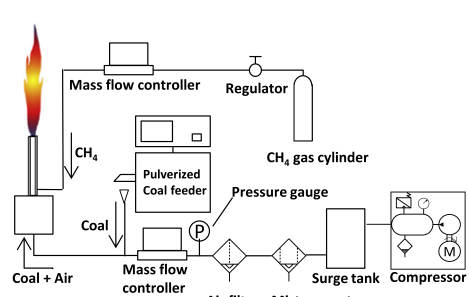

Fig. 1. A schematic diagram of the pulverized coal burner and supply system.