

EXPERIMENTS AND COMPUTATIONAL MODELING OF PULVERIZED-COAL IGNITION

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Abstract

Under typical conditions of pulverized-coal combustion, which is characterized by fine particles heated at very high rates, there is currently a lack of certainty regarding the ignition mechanism of bituminous and lower rank coals. It is unclear whether ignition occurs first at the particle-oxygen interface (heterogeneous ignition) or if it occurs in the gas phase due to ignition of the devolatilization products (homogeneous ignition). Furthermore, there have been no previous studies aimed at determining the dependence of the ignition mechanism on variations in experimental conditions, such as particle size, oxygen concentration, and heating rate. Finally, there is a need to improve current mathematical models of ignition to realistically and accurately depict the particle-to-particle variations that exist within a coal sample. Such a model is needed to extract useful reaction parameters from ignition studies, and to interpret ignition data in a more meaningful way.

We propose to examine fundamental aspects of coal ignition through (1) experiments to determine the ignition mechanism of various coals by direct observation, and (2) modeling of the ignition process to derive rate constants and to provide a more insightful interpretation of data from ignition experiments.

We propose to use a novel laser-based ignition experiment to achieve our objectives. The heating source will be a pulsed, carbon-dioxide (CO_2) laser in which both the pulse energy and pulse duration are independently variable, allowing for a wide range of heating rates and particle temperatures — both of which are decoupled from each other and from the particle size. This level of control over the experimental conditions is truly novel in ignition and combustion experiments. Laser-ignition experiments also offer the distinct advantage of easy optical access to the particles because of the absence of a furnace or radiating walls, and thus permit direct observation and particle temperature measurement. The ignition mechanism of different coals under various experimental conditions can therefore be easily determined by direct observation with high-speed photography. The ignition rate-constants, when the ignition occurs heterogeneously, and the particle heating rates will both be determined from analyses based on direct, particle-temperature measurements using two-color pyrometry.

For the modeling portion of this study we will complete the development of the Distributed Activation Energy Model of Ignition (DAEMI), which simulates the conventional drop-tube furnace ignition experiment. The DAEMI accounts for particle-to-particle variations in reactivity

by having a single preexponential factor and a Gaussian distribution of activation energies among the particles. Previous results show that the model captures the key experimental observations, and that adjustments to the model parameters permit a good fit to experimental data. We will complete the model by (1) examining the effects of other variations in physical parameters on the model, (2) applying the model to published results in order to extract reaction parameters, and (3) extending the model for application to laser-based ignition studies, such as our own.

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Executive Summary

During the past reporting period, we have recruited an undergraduate Research Assistant for work on this project during the summer. Mr. Antwone Ross, currently a rising senior undergraduate student at North Carolina A&T State University, will be responsible for installing two laser systems to be used for this project.

We have also been acquiring parts and supplies to service two laser systems and a computer for use on this project. One laser is a CO₂-gas laser, which has been on loan from the Federal Energy Technology Center in Morgantown, WV, since 1996. A second laser, a Nd:YAG solid-state laser, was acquired as excess property from Sandia National Laboratories in 1996. Each system has unique characteristics which we will exploit in controlling the particle heating rate for ignition

studies. Finally, we have upgraded an obsolete 80486 PC-compatible computer to a Pentium-level computer for use as data acquisition for this experiment, and for data processing and analysis.

Introduction

The ignition of pulverized coal has been the subject of research for nearly 150 years, with the initial motivation being the avoidance of coal-dust explosions in mines. In more recent times, due to the world's increased reliance on coal for power generation and the need to maximize energy-conversion efficiency, research has shifted to understanding the fundamental mechanism of coal ignition and measuring its kinetic rates. The importance of ignition to coal-flame stability is obvious — the more easily a particular coal ignites after injection into a boiler furnace, the better its flame-stability characteristics. A less obvious ramification of the ignition process is its role in establishing extended, fuel-rich zones in coal flames which are responsible for the destruction of NO_x and its conversion to benign N₂. Certainly, the ignition process is inextricably linked to the formation of this NO_x-reduction zone, and the ignition behavior of coals and coal blends will strongly affect the ease and extent of formation of this zone. This connection is deserving of further study and its understanding is the goal toward which we hope to apply the results of this proposed study. Specifically, we propose to examine fundamental aspects of coal ignition through (1) experiments to elucidate the ignition behavior of coals, and (2) modeling of the process to derive accurate and useful rate constants, and to provide a more insightful interpretation of data from ignition experiments.

Objectives

Our objectives for this project are to:

1. develop a novel experimental facility with extensive optical-diagnostic capabilities to study coal ignition;
2. determine the ignition mechanism of coals under simulated combustion conditions by direct observation with high-speed photography;
3. examine the effects of various experimental conditions, including coal rank, particle size, oxygen concentration and heating rate, on the ignition mechanism; and
4. measure the ignition rate constants of various coals.

5. modify our existing ignition model to examine the effect of particle-size distribution on the ignition behavior;
6. incorporate, if necessary, a size distribution into the model;
7. apply the model to extract ignition rate constants from previously published data from conventional experiments;
8. modify the model and apply it to our laser-based ignition studies for determination of ignition rate constants.

Results from This Reporting Period and Discussion

Personnel

Mr. Antwone Ross, currently a rising senior undergraduate students at North Carolina A&T State University, will be working on this project during the summer. His main responsibility will be to service and install two laser systems to be used for this project, as described below. It is expected that Mr. Ross will continue to work on this project during the 1997-98 academic year on a part-time basis.

Experiment

During the past reporting period, we have been acquiring parts and supplies to service two laser systems and a computer for use on this project. One laser is a CO₂-gas laser, which has been on loan from the Federal Energy Technology Center in Morgantown, WV, since 1996. A second laser, a Nd:YAG solid-state laser, was acquired as excess property from Sandia National Laboratories in 1996. Each system has unique characteristics which will exploit in controlling the particle heating rate for ignition studies. Finally, we have upgraded an obsolete 80486 PC-compatible computer to a Pentium-level computer for use as data acquisition for this experiment, and for data processing and analysis.

Goals for Next Quarter

During the next reporting period, we will set up the two laser systems and determine their state of usefulness. Furthermore, we will begin to develop schemes for high-speed photography to examine pulverized-coal ignition *in situ*.