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North Carolina A&T State University

Ignition Rate Measurement of Laser-Ignited Coals

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Introduction

Over the last several decades many experiments have been conceived to study the ignition of pulverized coal and other solid fuels. We are constructing a laser-based apparatus which offers several advantages over those currently in favor. Sieve-sized particles are dropped batch-wise into a laminar, upward-flow wind tunnel which is constructed with a quartz test section. The gas stream is not preheated. A single pulse from a Nd:YAG laser is focused through the tunnel and ignites several particles. The transparent test section and cool walls allow for application of two-color pyrometry to measure the particles' temperature history during ignition and combustion. Coals ranging in rank from lignites to low-volatile bituminous, and chars derived from these coals, will be studied in this project. For each fuel type, measurements of the ignition temperature under various experimental conditions (particle size and free-stream oxygen concentration), combined with a detailed analysis of the ignition process, will permit the determination of kinetic rate constants of ignition.

This technique offers many advantages over conventional drop-tube furnace experiments. One is the ability to directly measure ignition temperature rather than inferring it from measurements of the minimum *gas temperature* needed to induce ignition. Another advantage is the high heating rates achievable — on the order of 10^6 K/s. This is a significant improvement over experiments which rely on convective heating from a hot gas, which typically achieves heating rates of 10^4 K/s. The higher heating rate more closely simulates conditions in conventional coal combustors used for power generation.

It should be noted that single-particle behavior governs the conditions of this experiment; i.e., the particle suspension is dilute enough that particle-to-particle effects (other than radiative heat transfer) are not important. In actual combustors, particle loading, especially near the injector, is high enough that such "cooperative effects" dominate. Our approach is to gain a clear understanding of single-particle behavior with this experiment, before facing the more difficult problem encountered with cloud suspensions.

Objectives

Our objectives for this project are:

1. Construction of the laser-ignition experiment, including:
   1.1. gas delivery and regulation system;
   1.2. wind tunnel;
   1.3. exhaust system;
   1.4. laser system and beam-guiding optics;
   1.5. optical detection system; and
   1.6. data acquisition and processing;
2. Shakedown testing of the various components;
3. Ignition of coals of various rank, from lignites to low-volatile bituminous;
4. Measurement of the ignition temperatures of these fuels under various experimental conditions (particle size and free-stream oxygen concentration);
5. Extraction of ignition rate constants from temperature measurements by application of an appropriate heterogeneous-ignition analysis.

Accomplishments in This Quarter

Personnel

Two undergraduate students, Cynthia Marshall and Monique Jenkins, have been recruited to work on this project for the current academic year. Both are seniors with an interest in the thermal sciences area of mechanical engineering. Ms. Marshall is assisting the graduate student in the laboratory with experiment set-up and conduct of the experiments, while Ms. Jenkins is conducting a literature search on high-speed photography using a conventional 35-mm camera. The latter task is in preparation for the near future, when we will attempt to acquire photographs of igniting particles from this experiment.

Experiment

During this reporting period, the coal samples have all been prepared by dry sieving into the following size fractions: 53-63 μm, 64-75 μm, 76-90 μm, 91-106 μm, 107-125 μm, 126-150 μm, 151-180 μm. The coals to be used, and their ASTM rank, are:

Penn State designation	Seam name	ASTM rank
DECS-13	Sewell	medium-volatile bituminous
DECS-19	Pocahontas #3	low-volatile bituminous
DECS-23	Pittsburgh	high-volatile A bituminous
DECS-24	Illinois #6	high-volatile C bituminous
DECS-25	Pust	lignite A
DECS-26	Wyodak	subbituminous B

The experiment set-up is nearly complete, with the construction of the laser gate (used to deliver a single laser pulse to the experiment) and its controller remaining. We constructed and tested the pulsed coal feeder, set up the laser beam-steering optics, and designed and built a low-cost, rugged, photodiode detector for ignition determination. We are reserving the photomultiplier tube detector system for future use, when we begin to make temperature measurements.

Figure 1 below shows a photograph of the gas-delivery system, which regulates and blends the flows of oxygen and nitrogen to the desired concentration, and delivers it to the wind tunnel. Shown in the right side are the compressed gas cylinders and the manifolds. On the left is the control panel, with two high flow-rate and two low flow-rate flowmeters, one of each for each gas. The gases are blended and piped to the experiment in a single 3/4 inch line.

Fig. 1: Photograph of the gas-delivery system.

Figure 2 presents an overall view of the experiment including the pulsed coal feeder (with the feeder tube removed) in the upper left corner, the wind tunnel in the lower left corner, and the laser on the optical table (center right of the photograph) and the power supply underneath the table. Some accessories — laser-power meter and lenses — are on the optical table.

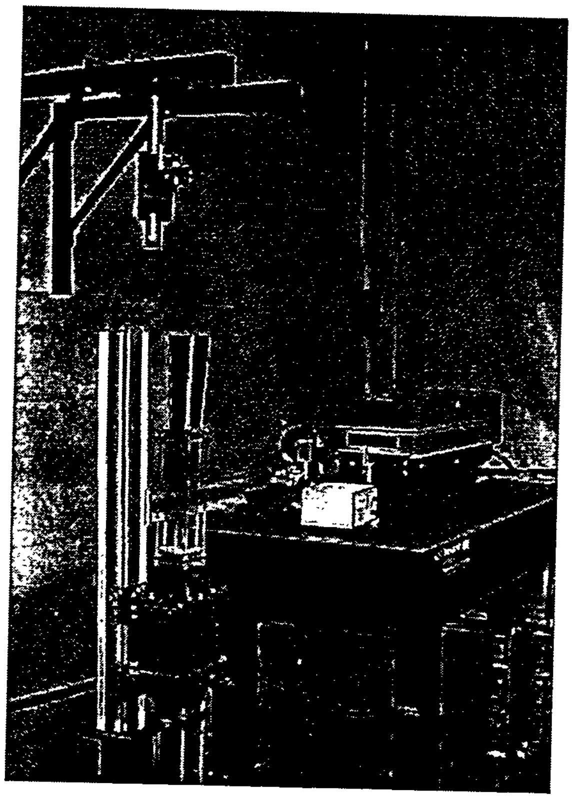
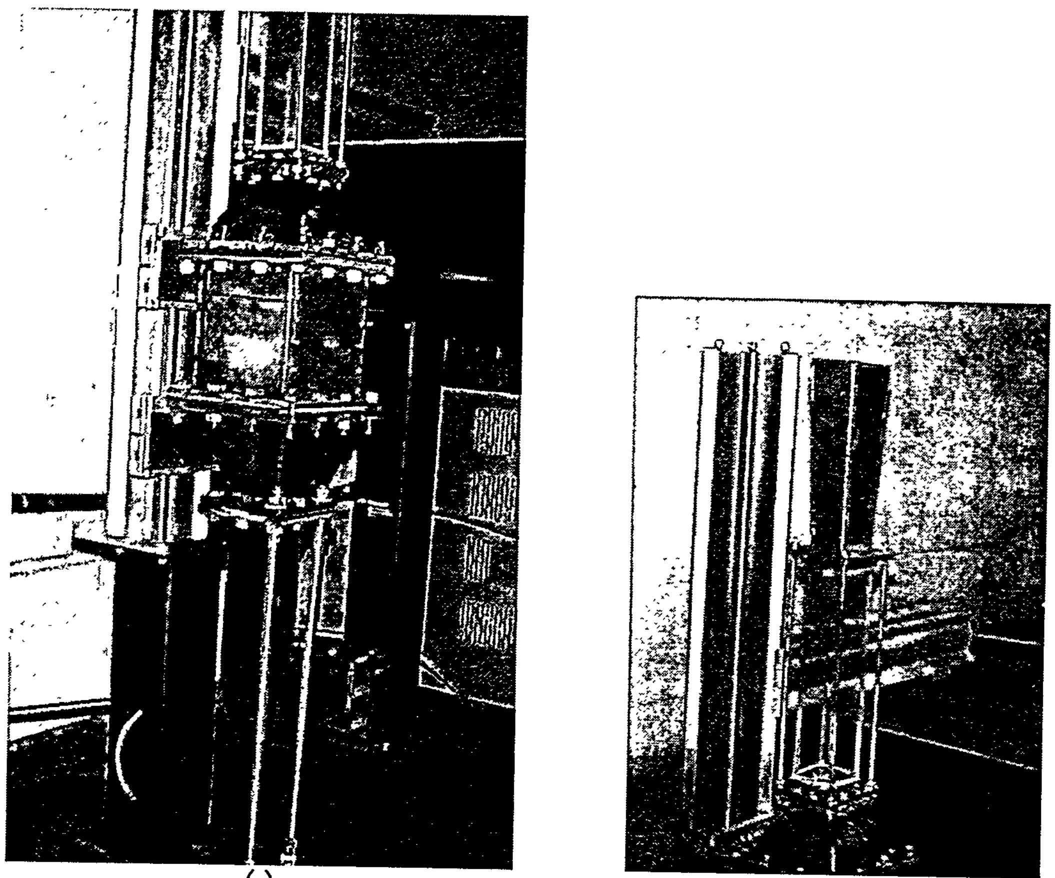


Fig. 2: Overall view of the laser ignition experiment.

Figure 3 below shows detailed views of the wind tunnel and its support structure. The lower portion of the wind tunnel (Fig. 3(a)) serves as the mating joint with the gas-delivery system, as well as the flow conditioning section. The support structure to which the wind tunnel is fastened is shown to the immediate left of the tunnel. The upper portion (Fig. 3(b)) has two parts: the transparent test section and the diffuser. Again, the support structure can be seen to the immediate left of the tunnel and, through the test section, it can be seen that the support is bolted to the optical table. Securing the support structure in this way serves to isolate any vibrations transmitted to the tunnel through the floors or walls, since the optical table incorporates vibration isolation technology.



(a) (b)

Fig. 3: (a) Lower portion of the wind tunnel. (b) Upper portion of the wind tunnel.

During the next reporting period, we will concentrate our efforts on building the laser gate and its controller. As soon as this task is complete, we will begin ignition experiments with the suite of coals listed above. Also slated to begin during the next quarter is preliminary tests to obtain high-speed photography of igniting coal particles.

Goals for Next Quarter

During the next quarter, we expect to:

1. construct the laser gate and controller;
2. begin ignition experiments; and
3. make preliminary tests for obtaining high-speed photographs.