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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

Experiment

During this reporting period, we have completed the installation of a new laser gate as described in our previous Technical Progress Report, and we have begun ignition experiments with four coals. The four coals we have chosen for this first study are:

Name	Rank
Wyodak - DECS 26	subbituminous B
Illinois #6 - DECS 24	high-volatile C bituminous
Pittsburgh #8 - DECS 23	high-volatile A bituminous
Sewell - DECS 13	medium-volatile bituminous

For these coals, we will determine their ignition behavior under 50, 75 and 100% oxygen concentrations, and three particle size ranges — 63-75, 106-125, and 150-180 μm in diameter will be tested. Some results will now be presented and discussed.

Figure 1 shows the results for the 106-125 μm, Pittsburgh #8 high-volatile (hv) bituminous coal. Plotted in the figure are the ignition frequency (or probability) as a function of the laser pulse energy and oxygen concentration. Each data point represents 20 attempts at ignition at the stated condition, and ignition is defined as the appearance of emitted light (as detected by a photodetector) after the first emission due to laser heating. This test method is necessary since, even under identical conditions, only some ignition attempts are successful due to the fact that there exists a distribution of reactivities among the particles within a coal sample. Thus, when the laser pulse interacts with a select few particles of such a batch, whether or not the particles ignite is given by a probability that the particles are reactive enough, under the given conditions, to ignite. This fact leads to the results shown that as laser energy is increased (so the particles are heated to higher temperatures), it is more probable (and frequent) that the select particles will ignite.

The repeated data lines for 100% oxygen concentration is meant to show the repeatability of the experiment on two separate days. As can be seen, the repeatability is excellent, which gives us confidence that our experimental procedure is well understood and reproducible.

Finally, Fig. 1 shows that as oxygen concentration is decreased (for a given coal of the same diameter), the ignition frequency curve shifts to higher laser energies with no perceivable change in the slope of the curves. This expected result can be interpreted in two ways: as oxygen concentration is decreased, (1) a higher laser energy is needed to heat the particles to higher temperatures in order to affect the same ignition frequency, or (2) a fixed laser energy will result in lower ignition frequency.

Figure 2 shows similar results for the 106-125 μm, Wyodak subbituminous B coal. Comparing the results between the Wyodak and Pittsburgh coals at the same oxygen concentration, it is clear that the Wyodak coal is more difficult to ignite; that is, its ignition reactivity is lower. Furthermore, given that the ignition frequency curve of the Wyodak at 100% oxygen concentration spans a wider range of laser pulse energy, it can be said that the Wyodak coal possesses a broader distribution of ignition reactivity compared to the Pittsburgh coal.

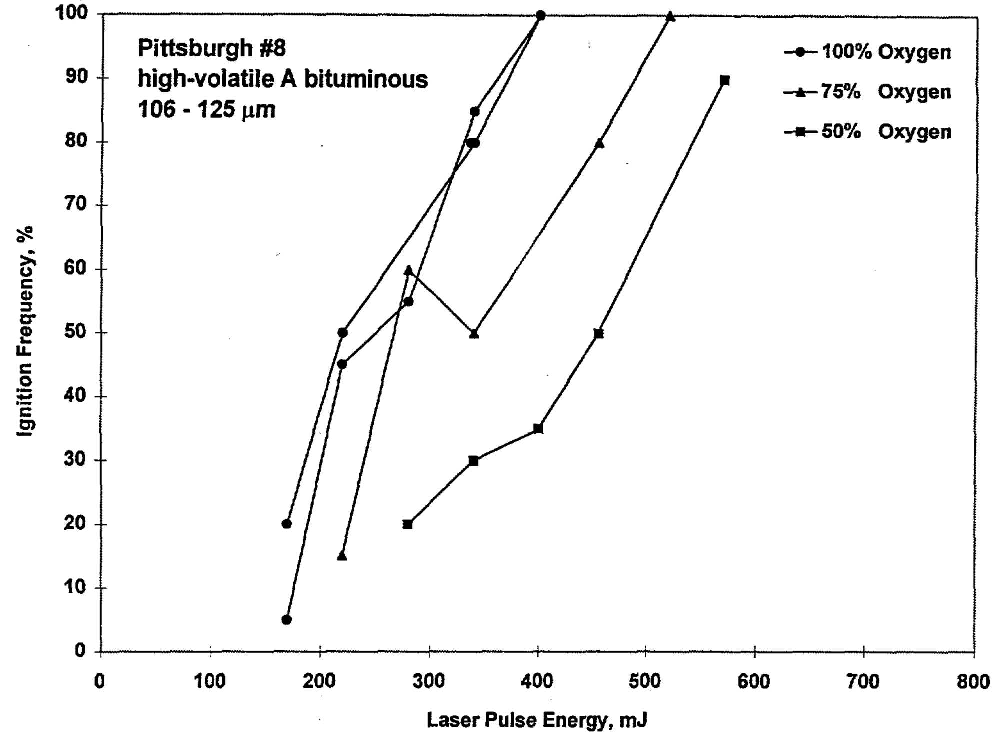

Figure 1: Ignition characteristics of Pittsburgh #8 coal.

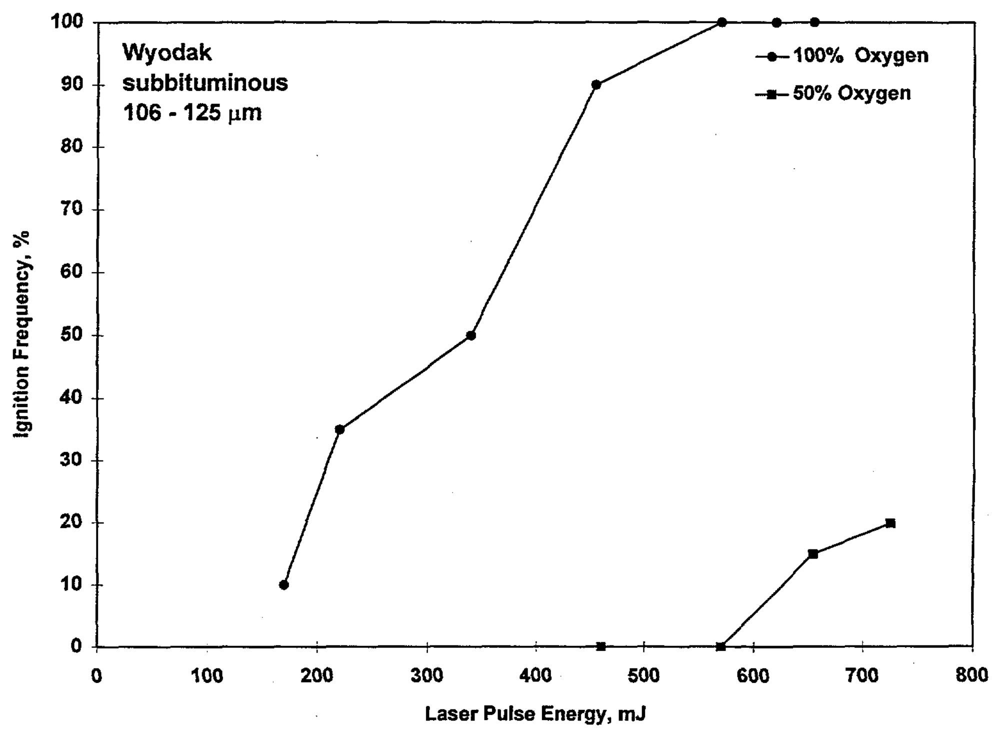

Figure 2: Ignition characteristics of Wyodak subbituminous coal.

Goals for Next Quarter

During the next quarter, we expect to:

1. complete the first set of experiments described in this report;
2. begin development of the two-color pyrometry system to measure particle temperature at ignition.