Generating Simulated Data for Spot Heating/IR Camera Analysis of Coal Slag Surfaces

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Abstract

Introduction - For combustion simulations, the wall temperature and heat transfer is an important piece of information. Coal combustion systems typically have walls that are initially a cast ceramic, but, with time, slag is deposited on the surface and coal and soot are incorporated into the slag (Figure 1). It is this slag coated ceramic that determines the rate at which heat is transferred from the wall of a combustion system. Heat is transferred to the wall by conduction. Heat conduction requires that the thermal conductivity be determined. Radiation requires that the surface emissivity be determined. The thermal conductivity of the initial cast ceramic material may be known sufficiently accurately, but the thermal conductivity of the slag coated ceramic will not be known since it is highly variable, so experiments are needed to measure it.

To solve this problem, a high-speed Infrared (IR) camera will be used to measure the temperature decay with time and position surrounding a high power Nd-YAG laser pulse which locally heats the surface of the slag coated ceramic surface (a sketch of the system is shown in Figure 2). The profile of the high powered Nd-YAG laser is Gaussian and occurs over a brief (microsecond) time frame.

Use of COMSOL Multiphysics® software - The Heat Transfer Module was used to simulate the heat conduction behavior in the surface material (Figure 3). In this simulation the ceramic is a porous material (Heat Transfer in Porous Media). A 2D gaussian function was used as the heat source, setting the heating spot in the middle of the ceramic material block to simulate the laser heat source in the experiment. Properties of the well known ceramic material were used to generate synthetic data to be analyzed in MATLAB® image analysis code, then data from slag experiments with the IR camera were applied to the same MATLAB image analysis code. COMSOL is designed to generate synthetic data in the form of a video and the surface temperature as a function of time after the laser pulse (Figure 4) at the surface of the cube.

Results - A MATLAB® image analysis code was used to analyze the pictures with time-dependent thermal behavior. This same code was used to analyze the synthetic data from COMSOL Multiphysics®. The average values of the thermal diffusivity from the synthetic data from COMSOL and values found using the MATLAB image analysis code were compared to validate the MATLAB image analysis code. Then experiments with the slag, IR camera, and Nd-YAG laser were run. The pictures taken in the experiments were studied by inserting the pictures in the MATLAB image analysis code.

Conclusion - COMSOL was an important piece of this project enabling the validation of the MATLAB image analysis code. Using the synthetic data created with the COMSOL animation, the MATLAB image analysis code was tested, validated and calibrated. Comparison shows a 1% error in the MATLAB image analysis, which was considered a reasonable value given the digitization errors in the data manipulation.

Figures used in the abstract

Figure 1: Picture of Slag in a Coal Combustion System.

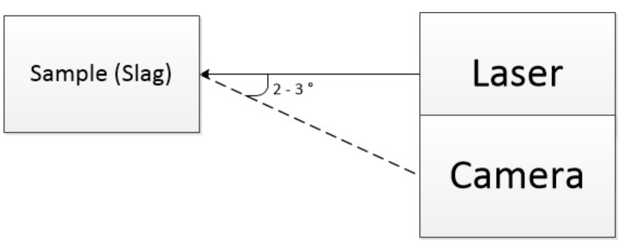

Figure 2: Schematic of Laser Heating-IR Camera Experimental Setup.

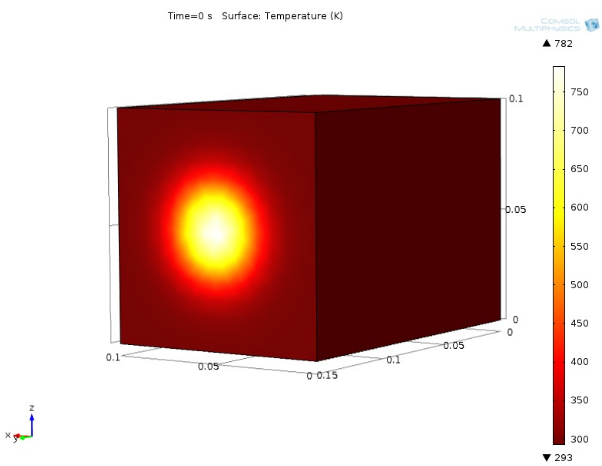

Figure 3: COMSOL Simulation of Laser Heating of Ceramic Block.

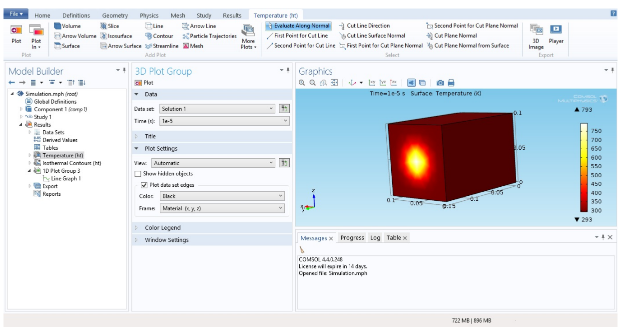

Figure 4: COMSOL Simulation Screen Shot.