ABSTRACT
Soot is formed through solid fuel pyrolysis during wildfires, waste incineration, and aerospace applications. Solid fuel combustion is controlled by radiation feedback from the flame to the fuel surface, which induces soot formation. Pyrolysis is the process of thermal decomposition of fuels at high temperatures. The significance of pyrolysis during solid fuel combustion has motivated various studies. These studies utilize a CO2 laser to simulate thermal radiation of a flame during solid fuel combustion and study pyrolysis and soot formation from varying energy inputs. However, the presence of soot will alter the amount of laser energy reaching the surface through scattering and absorption, thus providing unknown conditions. This work’s goal is to understand the influence soot produced has on experimental conditions. In this study, a Monte Carlo Rayleigh scattering model of a CO2 laser experiment is developed to determine how much energy is reaching the surface in the presence of a soot cloud. This model can be applied to different solid fuel combustion experiments where wavelength, distance to fuel surface, and soot volume fraction vary. A more accurate correlation between heat flux and pyrolysis can be produced through this method, and in turn, a better characterization and understanding of soot formation. Understanding soot formation is crucial to working on improving the efficiency, and health and environmental effects of solid fuel combustion events and applications.

INTRODUCTION
Solid Fuel Pyrolysis

CO2 Laser Experiment
• To study the pyrolysis mechanism of solid fuels, a CO2 laser is used to mimic the thermal radiation of a flame [1-2].
• Objective: Determine influence of soot during CO2 laser induced solid fuel pyrolysis experiments.

METHODS
Monte Carlo Method
• Due to the small size parameter, Rayleigh scattering theory is used [6].
• Based on characteristic absorption and scattering lengths [Eq. 1-2] calculated from spectral properties [Fig. 3] and a random number generator, the photon bundle is either absorbed, scattered, or reaches a boundary [3-6].

Verifications
• A simplified CO2 laser experiment is simulated to determine the influence soot cloud length has on light reaching the fuel surface for varying constant volume fractions [Fig. 4].
• Verify the Monte Carlo model scatters light following the Rayleigh scattering phase function [Eq. 4].
• Verify the Monte Carlo model follows Beer’s Law [Eq. 3].

RESULTS
Phase Function Verification (2D Scattering)
• Probability scattering matrix is verified through sampling using MATLAB and an actual plot of the Rayleigh scattering phase function [Fig. 5a, 5b, Eq. 4].

Experiment Results
• As soot cloud length increases, light reaching fuel surface exponentially decays [Fig. 6].
• Data was fit to an exponential decay (Beer’s Law) and produced absorption coefficients (σ) similar to calculated inputs [Table 1].

CONCLUSION
• To better understand soot formation during solid fuel combustion, the solid fuel pyrolysis mechanism is studied.
• A Monte Carlo model was developed to determine soot influence during laser induced solid fuel pyrolysis.
• Rayleigh scattering theory was used to model the interaction between laser light and soot.
• Rayleigh scattering phase function and Beer’s Law were verified for the Monte Carlo Model.

FUTURE WORK
Monte Carlo Model
• Implement mass flux from cross flow and fuel to determine its influence of heat transfer to the fuel.
• Simulate full experiments (mass flux, boundary layer, heat transfer).

Experimentation
• Perform CO2 laser experiments in laboratory.
• Verify Monte Carlo model using CO2 laser experimental data.
• Experimentally measure soot concentrations.
• Experimentally measure light intensity through a soot cloud.

REFERENCES

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Table 1

<table>
<thead>
<tr>
<th>Constant Volume Fraction (ppm)</th>
<th>Exponential Fit</th>
<th>Fit Absorption Coefficient (10m)</th>
<th>Input Absorption Coefficient (10m)</th>
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<tr>
<td>25</td>
<td>I = 1.000 x 0.95911</td>
<td>0.0931</td>
<td>0.0931</td>
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<tr>
<td>100</td>
<td>I = 1.000 x 0.37274</td>
<td>0.3723</td>
<td>0.3724</td>
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</tbody>
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Figure 1: Combustion environment of a solid fuel sample. [1]

Figure 2: CO2 laser experiment schematic.

Figure 3: Flowchart of logic in the Monte Carlo Model.

Figure 4a (left): Results from MATLAB sampling of probability matrix.
Figure 4b (right): Rayleigh scattering phase function plotted in polar coordinates.

Figure 5a: Preliminary experiment schematic.

Figure 5b (right): Rayleigh scattering phase function plotted in polar coordinates.

Figure 6: Preliminary experiment results.

Figure 6: Preliminary experiment schematic.

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