The effect that co-firing pulverized coal and biomass has on the char conversion process under conditions that exist in entrained flow gasifiers is investigated in the work presented. Co-firing coal and biomass has the potential to decrease the fossil carbon footprint of power generation in a manner that will require relatively little infrastructure change and retrofitting. Before widespread adoption of this co-firing technology, it is important to understand the impact that co-firing will have on char conversion times.

Corn stover and Wyodak coal were selected as test materials in this investigation. Chars were produced by injecting pulverized the pure fuels as well as different mixture-fraction blends into a lab-scale laminar entrained flow reactor with a gas composition and temperature representative of a potential condition inside an entrained flow gasifier. Char particles were extracted from the reactor just subsequent to devolatilization using a solids sampling probe, and subjected to BET surface area measurements and thermogravimetry analysis for reactivity to CO$_2$, a primary reactant in gasifier environments.

Results indicate a significant impact of corn stover devolatilization on the devolatilization of the Wyodak coal particles. When the two fuels are co-fired, the BET specific surface area of the resulting mixed char is lower than the specific surface areas of the chars produced when the pure fuels are fired separately. A minimum in the mixed char specific surface area occurs when the corn stover is about 10-15% of the mass of the fuel blend. Possible causes for this behavior are discussed in the paper, with the primary cause being attributed to an endothermic reaction between the volatile gases of the biomass and the ambient gases, prior to devolatilization of the coal. Results also indicate that the mixed chars have a lower intrinsic reactivity to CO$_2$ than either pure fuel char. This decrease in reactivity is attributed to the reduction in coal char specific surface area. If account is made for the change in the initial specific surface area of the coal char particles, the kinetic parameters that describe the intrinsic reactivities of the
pure fuel chars to CO$_2$ can be used to adequately describe the reactivities of the mixed chars for all blends of corn stover and Wyodak coal.
I. Introduction

The use of coal is projected to increase well into the 21st century, especially in developing countries, due in large part to its abundance and low price. Some of these developing countries have already begun to feel the ill-effects of using such large quantities of coal, such as poor air quality. Nevertheless, they are unwilling to slow development, as lifting a large number of people out of poverty depends on it. Therefore, the need for a quick, economically viable method for improving the cleanliness of coal usage is direly necessary.

One such solution is co-firing biomass along with coal, in either combustors or gasifiers. This option has the potential to satisfy all of the above requirements: cleaner, economically attractive, and quick to implement. There are multiple ways in which co-firing with biomass improves the cleanliness of coal. Firstly, co-firing can reduce fossil CO$_2$ emissions. If grown, harvested, and processed responsibly, biomass can be a carbon-neutral fuel (or carbon-negative, if exhaust CO$_2$ is sequestered). Therefore, offsetting some of the coal with biomass will reduce the amount of fossil CO$_2$ released per unit of heat released. Co-firing can also reduce the emission of sulfur dioxide (SO$_2$), an important pollutant that contributes to acid rain as well as precursor to particulate matter. Biomass ash typically has a high content of alkaline minerals, which are effective at adsorbing SO$_2$ molecules [7, 8, 19]. Thus, the biomass ash acts as an in-situ scrubber, sequestering the sulfur along with the ash, and reducing the total SO$_2$ emission of the system. Finally, co-firing has the potential to reduce NO$_x$ emissions as well. The reasons for this are two-fold. Firstly, biomass has a lower nitrogen content than coal, therefore offsets NO$_x$ in much the same way that it can offset fossil CO$_2$ emissions, by simply displacing those of coal. However, biomass can also go beyond mere displacement, because a higher percentage the nitrogen in biomass forms amine radicals compared to coal, and these amine radicals can reduce NO$_x$ to N$_2$ [8, 19]. All of the above improvements apply to both gasifiers and combustors. Although NO$_x$ is
typically formed at high temperatures such as those found in combustors, autothermal gasifiers will typically have a combustion region, to provide the heat necessary to drive gasification, where NO\textsubscript{X} may be produced.

In addition, economic analyses indicate that in certain situations, co-firing coal and biomass can be quite economically feasible [16]. This significantly reduces the barriers to entry often associated with cleaner technology. However, this conclusion depends on many variables, such as the energy density of the biomass chosen, transportation costs, and more. Another factor on which the economic viability of co-firing coal and biomass depends is the ability to co-fire into existing burners or gasifiers, without the need for significant retrofitting. Concerns towards this end include how the biomass will fare with the coal feed system, as well as the whether the high ash content of many types of biomass will lead to prohibitive slagging, and how this could be ameliorated [3, 20]. The purpose of the work presented here investigates how the co-firing of biomass and coal may change the kinetics of char burnout, relative to those of the pure fuel components. Of particular interest is the search for a model that can predict the char burnout of the co-fired fuel blend using only the kinetic parameters of the pure fuels.

II. Methods

In our experimental approach, biomass and coal were milled and classified to size range of 75-106 µm using standard sieves (biomass sizes ended up being smaller than sieve size range, however, as they could not be wet-sieved, and thus some smaller particles remained in the sample). The biomass chosen for use in this investigation was corn stover, and the coal chosen was Wyodak coal, a sub-bituminous B, low-sulfur coal from Wyoming. The proximate analyses for these materials are presented in Table I. Fuel blends were then created from the two pure fuels, at several blend ratios including up to 50% biomass (by mass of the raw fuel). The pure fuels as well as the fuel blends were injected into our entrained laminar flow reactor, and char particles were extracted shortly subsequent to devolatilization
(at a residence time of nominally 30 ms in the flow reactor environment employed). The gas conditions under which devolatilization occurred were 74.6% N\textsubscript{2}, 16.3% H\textsubscript{2}O, 5.0% H\textsubscript{2}, 2.1% CO, and 2.0% CO\textsubscript{2}, with a maximum temperature of nominally 1550K. Various properties of the pure-fuel and mixed-fuel chars were then characterized: density was measured via a tap density technique, size distribution was measured via a Coulter Counter, and surface area was measured via BET tests. BET tests were performed in our pressurized thermogravimetric analyzer (PTGA) with CO\textsubscript{2} as the adsorption gas. The PTGA was then also used to perform multiple mass loss tests on each char, in conditions comprising multiple different temperatures between 800°C and 1000°C, and three different gas environments (100% CO\textsubscript{2}, 50% CO\textsubscript{2} / 50% N\textsubscript{2}, and 50% CO\textsubscript{2} / 50% CO). These mass loss tests were then used in a least squares fitting routine to find the activation energies and Arrhenius pre-factors to use in our kinetic mechanism.

We use the following five step heterogeneous reaction mechanism developed in previous work [10] to describe the gasification of char with CO\textsubscript{2}:

\begin{align}
C_f + CO_2 &\leftrightarrow C(O) + CO & \text{(R1)} \\
C_b + C(O) &\rightarrow C_f + CO & \text{(R2)} \\
C_b + C(O) + CO_2 &\rightarrow 2CO + C(O) & \text{(R3)} \\
C_f + CO &\leftrightarrow C(CO) & \text{(R4)} \\
CO + C(CO) &\rightarrow 2C_f + CO_2 & \text{(R5)}
\end{align}

In the above mechanism, \(C_f\) represents a free carbon site available for adsorption, \(C_b\) represents an underlying bulk carbon site, \(C(O)\) represents an oxygen atom adsorbed onto a carbon site, and \(C(CO)\) represents an adsorbed CO molecule. The desorption reactions, R2 and R4f, are treated as Arrhenius in form, but having distributed activation energies, which are measured via Temperature Programmed Desorption (TPD) tests. The remainder of the reactions are treated in standard Arrhenius form, and are
fit against experimental data using a least squares regression. Using this reaction mechanism, intrinsic carbon reactivity to carbon dioxide $R_{i,C}$ (in kgC/m²-s) is given by Eq. (1), where $RR_i$ stands for the rate of reaction $i$ (in kmol/m²-s).

$$R_{i,C} = \frac{\dot{M}_C (RR_2 + RR_3 - RR_{4f} + RR_{4f})}{S_g}$$  \hspace{1cm} (1)

The specific surface area of the char particle, $S_g$, must also be tracked throughout the course of gasification. We use Eq. (2) to follow the specific surface area with char conversion, where $x$ is particle conversion and $\psi$, referred to as the structural parameter, is determined by fitting surface areas measured at different extents of conversion, as described in previous work [10, 11]. This surface area model is consistent with the one developed by Bhatia and Perlmutter [4] to follow surface area during carbon conversion under chemical kinetics-controlled conditions (such as the conditions employed in our TGA tests).

$$S_g = S_{g,0} \left( \sqrt{1 - \psi \ln(1 - x)} \right)$$  \hspace{1cm} (2)

The normalized mass-loss rate, which is the value ultimately compared with our experimental data, is calculated via Eq. 3, with both intrinsic reactivity ($R_{i,c}$) and specific surface area ($S_g$) being tracked throughout the course of conversion.

$$\frac{1}{m} \frac{dm}{dt} = S_g R_{i,c}$$  \hspace{1cm} (3)

\textbf{III. Results and Discussion}

\textit{Surface Area Measurements}
The results of the BET surface area tests indicated that Wyodak Coal char and corn stover char had roughly similar specific surface areas ($m^2/g$), when devolatilized under the same conditions. The Wyodak Coal char had average surface area of approximately $375 m^2/g$, while the corn stover char had an average surface area of approximately $410 m^2/g$. The highest surface area measured was from an outlier Wyodak char sample, at $475 m^2/g$. After testing the surface areas of the two pure-fuel chars, we measured the surface at least once for each of the following fuel blends (percentage Wyodak/percentage corn stover, on a raw mass basis): 50/50, 70/30, 90/10, 95/5, 98/2, and 99/1. As noted in Fig. 1, the specific surface areas of the fuel blend chars were not representative of a simple interpolation between the values for the two pure-fuel chars, which suggests that the two fuels in the fuel blend did not devolatilize completely independently from one another. Instead of bringing the specific surface area towards the value for corn stover char, the effect of adding corn stover into Wyodak coal was actually to reduce the specific surface area. This was noticed with perhaps as little as 1% mass fraction of corn stover being added to the coal, with a significant change in surface area occurring with 2% mass fraction corn stover. The minimum surface area was observed from 5% to 10% corn stover, both of which measured approximately $160 m^2/g$. Beyond 10% corn stover, the surface area slowly rose to the value of the pure corn stover char.

We attribute the observed decrease in surface area to two things: a change in the devolatilization environment of the coal particles due to the presence of the corn stover particles, as well as the agglomeration of several particles into larger “clusters” of particles when corn stover particles are present in the fuel blend. We believe that the change in devolatilization environment of the coal particles is the primary cause of the decreased surface area, because the visible clusters are very porous, and thus diffusion of gases through the cluster is likely not significantly impeded at the high temperatures present. Therefore convection and conduction from the gas to the particle, the main modes
of heat transfer to the particle, are also relatively unimpeded. However, these clusters do ensure a close proximity of corn stover and coal particles, further enhancing the ability of the corn stover particles to change the devolatilization environment of the Wyodak coal particles.

There are two crucial traits of most biomass, including corn stover, that enable it to change the devolatilization environment for co-fired coal particles: its large volatile content, and its quicker devolatilization times than coal. It has been repeatedly observed by many researchers that biomass devolatilization occurs at earlier times than coal, when subjected to the similar conditions [6,12,13,14,17]. When co-fired directly in the same feed stream as coal, this means that the volatile gases from the biomass will be released first, and thus the ambient in which the coal particles devolatilize will now contain these volatile gases. The closer proximity of the co-fired particles, and the larger the volatile content of the biomass, the greater their ability to influence the devolatilization conditions of the coal particles. Corn stover, like most biomass, has a high volatile matter content, around 70% based on an proximate analysis. Indeed, it has been hypothesized by other researchers that the co-firing of coal and biomass in combustors may increase temperature in the proximity of the burners, compared to the coal-only case [1,5]. This is because in oxidizing conditions, the volatile gases react exothermically with the ambient, releasing heat. However, the devolatilization conditions studied in this work are reforming conditions, not oxidizing conditions. In reforming conditions, one would expect the reaction of volatile gases to result in a decrease in temperature.

To test this theory, an adiabatic flow reactor having two input streams of specified temperature, pressure and composition and a single exit stream in thermodynamic equilibrium was simulated using AspenPlus, software developed for dynamic simulation and optimization of chemical processes [2]. One input stream was assumed to have the temperature and composition of the post-flame gases established in the laminar flow reactor used when producing chars (an equilibrium mixture of H₂, CO,
H₂O, and CO₂ in N₂ at 1550 K and 1 atm) and the other stream was assumed to consist of a gas mixture containing equal mole fractions of H₂, CH₄, C₂H₄, C₆H₆, and C₆H₅O (species representative of coal and biomass volatile species), also at 1550 K and 1 atm. The relative flow rates of the two streams were varied in our simulations, which indicated that when the molar flow rate of the volatile gas stream is only 2% of the total molar flow rate entering the reactor, the temperature of the exit stream is lowered by approximately 200 K. In our flow reactor, in the immediate vicinity of the devolatilizing coal particles, the volatiles released from the corn stover particles could represent more than 2% of the gas experienced by the coal particles. Because of the magnitude of temperature change that the corn stover could potentially affect, and the fact that temperature of devolatilization has been shown to correlate with BET surface area of the char [9,18], we believe this effect to be the main cause of the observed decrease in specific surface area.

However, the aforementioned clustering is also thought to play a role in the decreased surface area. Optical photographs of these clusters are shown below, in Fig. 2. They are observed at all fuel blend mass ratios, but the effect seems to be most salient at lower mass fractions, between 5% and 30%. This seems to align with the fuel blend ratios for which the coal-to-biomass particle fraction is roughly one-to-one, since the corn stover has a lower particle apparent density (0.51 g/cm³ for corn stover compared to 0.95 g/cm³ for Wyodak coal) as well as a smaller average size (58 µm for corn stover compared to 87 µm for Wyodak coal). Between 5% and 30% corn stover by raw mass, the number of corn stover particles per Wyodak coal particle ranges from 0.33 (for the 5% corn stover blend) to 2.7 (for the 30% corn stover blend). The one-to-one particle ratio occurs between 10% and 15% corn stover in the mixture. A possible explanation for the clustering peaking around the one-to-one particle ratio is that the force holding them together is static electricity, which is generated as the two different types of particles collide. Indeed, when handled outside of the reactor, the fuel blends do behave similarly to a
substance exhibiting static electricity. Furthermore, the plastics industry has experienced problems with static electricity when attempting to blend biomass with thermoplastics in the production of wood plastic composites [15]. Since the clusters are very porous, it is unlikely that they present any significant resistance to diffusion, and thus heat transfer from the gas to the individual particles. The clusters likely would shield some of the inner particles from radiation from the walls and flame. However, radiation is a less significant mode of heat transfer than conduction and convection in our reactor, and thus the particle heating rates would likely not change by an appreciable factor. Perhaps a more important consequence of the clusters is that they ensure a close proximity between the biomass and coal particles, allowing for the biomass volatile gases to influence the surroundings in which the coal particles devolatilize to a greater extent. This may explain why the specific surface area of the fuel blend slowly climbs after 10% corn stover, even though the amount of corn stover in the blend is rising. Up until a one-to-one coal particle to corn stover particle ratio, more coal is being included into “clusters,” which provide the main mechanism for the corn stover to chemically alter the coal’s devolatilization conditions due to such close proximity. Beyond this point, corn stover particles are increasing in number but are not being incorporated into the clusters, thus they serve to simply increase the specific surface area of the fuel blend char incrementally towards the pure corn stover char value. This hypothesis is supported by the relatively linear slope of char surface area versus fraction corn stover in the blend over the range 15% corn stover to 100% corn stover.

Char Reactivity

After being subjected to surface area tests, the pure-fuel chars and fuel-blend chars were subjected to reactivity tests in our TGA. Samples of approximately 15-20 milligrams were placed in a shallow pan, and the reactor was slowly ramped to the test temperature in N₂, followed by a switch from N₂ to whichever gas condition was to be tested, at temperature. The mass loss data were then converted to a
normalized mass loss rate, \( \frac{1}{m} \cdot \frac{dm}{dt} \), and plotted versus conversion, which makes the data independent of the initial mass. It is this data that are then used to fit the kinetic parameters for the reaction mechanism, using a least squares regression that takes into account all of the reactivity data for a given fuel or fuel-blend char.

In this work, the reactivity of char to carbon dioxide (dry gasification) was studied. The kinetic parameters for the reactivity of Wyodak coal char to \( \text{CO}_2 \) (when devolatilized under the conditions of this work), as determined via the least squares fitting routine, are shown in Table II. The fits to experimental data, using the Arrhenius values from the table, are shown in Figs 3-6. The fits are quite good, accurately accounting for both changes in \( \text{CO}_2 \) concentration as well as the inhibiting effect of CO. The same procedure was also followed for corn stover char. The kinetic parameters for the corn stover char are also presented in Table II, and the fits to experimental data in Figs 7-10. Corn stover reactivity data are also fit quite well. The data indicate that the reactivity to \( \text{CO}_2 \) for Wyodak coal char and corn stover char are roughly similar, on average. Corn stover reactivity is greater than Wyodak reactivity at 1000ºC if CO is present, although corn stover and Wyodak reactivity are similar at 1000ºC if no CO is present. In addition, corn stover reactivity is greater than Wyodak reactivity at lower temperatures (800ºC, 900ºC) if no CO is present, and corn stover and Wyodak reactivity are similar at lower temperatures (950ºC, 900ºC) if CO is present. These observations are reflected in the kinetic parameters by the similar activation energies for reaction R.1f and lower activation energies of reactions R.1r for the corn stover char.

After the kinetics of the pure corn stover char and pure Wyodak char were characterized, the fuel blend chars were subjected to the same mass loss experiments. In almost all cases, the fuel blend chars exhibited lower normalized mass loss rates than either pure-fuel char. This at first may seem to present a problem, since the overall goal is to be able to predict fuel-blend reactivities from the kinetic
parameters of the two pure fuels. No interpolation of the pure-fuel kinetic parameters can be used to predict the fuel blend reactivity if they do not even bound it. However, the lower reactivities are not wholly unexpected, since the fuel blend chars did exhibit lower surface area, which appears in the equation for normalized mass loss rate. The question then becomes, if we account for the decrease in surface area caused by the co-firing of the Wyodak with corn stover, will the kinetic parameters of the pure-fuel chars then be sufficient to predict the reactivity of fuel-blend chars?

Towards this end, we modeled the reactivity of char mixtures by simulating two char samples that gasified independently, one with the kinetic parameters determined for pure Wyodak char, and one with the kinetic parameters determined for pure corn stover char. The respective masses of each char were weighted by the expected mass of the char, based on the volatile matter fraction of each fuel and the fuel blend’s raw mass ratio. For example, since the dry coal particles contain about 48% volatile matter and the biomass particles contain about 69% volatile matter, the 70% Wyodak / 30% corn stover (raw mass basis) blend would have 36.4 grams \( (70\cdot(1 - 0.48)) \) of Wyodak char for every 9.3 grams \( (30\cdot(1 -0.69)) \) of corn stover char. The only difference from the pure-fuel char simulations was that the specific surface area of the Wyodak coal char was adjusted according to the observations displayed in Fig 1. For instance, the coal char for the 70/30 blend simulation would have a surface area of approximately 190 m\(^2\)/g. The surface area of the corn stover char was left unadjusted, since the conditions in which it devolatilizes are assumed to be unaffected by the presence of the coal. The resulting model does a quite good job at fitting experimental fuel-blend reactivities to CO\(_2\) over a range of conditions, as shown in Figs 11-14. Some tests are predicted better than others, which is to be expected since significantly altering devolatilization conditions is bound to influence many intrinsic char properties besides simply surface area. However, adjusting only the specific surface area of the coal char is shown to yield a good char-CO\(_2\) burnout model when changing from two independent pure fuels
to co-fired fuels. Furthermore, the run of 85% Wyodak/15% corn stover was executed without checking for char surface area, but rather using a value for $S_{g,0}$ obtained from interpolating between the 10% and 30% points on Fig 1.

IV. Conclusions

It was observed that the direct co-firing of Wyodak coal and corn stover biomass (same feed stream) into a gasifying environment resulted in char particles that had a lower specific surface area than the char particles of either pure fuel when fired alone. This is mainly attributed to the ability for the corn stover biomass to alter the devolatilization conditions of coal particles, as it devolatilizes sooner, and ejects large quantities of volatile matter, which react endothermically with the ambient. Clustering of raw corn stover particles and coal particles (prior to devolatilization), which is observed to be most salient around a one-to-one particle ratio (10-15% corn stover raw mass fraction), is also thought to play a role. While it is unlikely that the cluster provides significant resistance to heat transfer, it likely enhances the impact of the endothermically-reacting biomass volatile gases, by keeping the coal and biomass in close proximity. The combination of these two effects is thought to produce the observed specific surface area profile in Fig 1, which shows the specific surface area of the fuel blend chars decreasing initially as the corn stover is added to the mixture, reaching a minimum between 5% and 10% corn stover (by raw mass), and then slowly rising to the value of the pure corn stover char. Because of this change in surface area, the fuel-blend chars exhibited lower reactivity to CO$_2$ than either of the two pure-fuel chars, meaning that the gasification rates alone of the two pure fuels cannot be used to predict the gasification rates of the fuel blends. However, using the kinetic parameters for the two pure fuel chars and adjusting the surface area of the coal char to match the observed values when co-fired, accurate prediction of the gasification rates in CO$_2$ of the fuel blends can be made. Note that the precise extent of decrease of surface area shown in Fig 1 is not meant to be applicable to all co-firing
scenarios. Such an effect would be highly coupled to the precise situation. The biomass species, as well as heating rate and ambient temperature, will affect the time, amount, and type of volatile gases released. The ambient temperature and gas conditions will determine how these volatile gases react. The type of coal and its proximity to biomass particles will determine how it responds to the change in conditions.
### Table I: Proximate Analyses of Wyodak Coal and Corn Stover

<table>
<thead>
<tr>
<th>Property</th>
<th>Wyodak coal</th>
<th>Corn Stover</th>
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</thead>
<tbody>
<tr>
<td>fixed carbon (wt-%)</td>
<td>35.06</td>
<td>20.0</td>
</tr>
<tr>
<td>volatile matter (wt-%)</td>
<td>33.06</td>
<td>68.9</td>
</tr>
<tr>
<td>moisture (wt-%)</td>
<td>26.30</td>
<td>~6.0</td>
</tr>
<tr>
<td>ash (wt-%)</td>
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<td>5.1</td>
</tr>
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</table>

### Table II. Kinetic Parameters for the Reactivity of Wyodak Coal Char and Corn Stover Char to Carbon Dioxide

<table>
<thead>
<tr>
<th>Reaction</th>
<th>Pre-Exponential Factor, A&lt;sup&gt;*&lt;/sup&gt;</th>
<th>Activation Energy, E (kJ/mol)</th>
<th>Std Dev σ&lt;sub&gt;E&lt;/sub&gt; (kJ/mol)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wyodak</td>
<td>Corn Stover</td>
<td>Wyodak</td>
</tr>
<tr>
<td>R.1f</td>
<td>1.52e04</td>
<td>1.63e04</td>
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<tr>
<td>R.1r</td>
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<td>R.4f</td>
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<td>2.20e-01</td>
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<td>R.5</td>
<td>3.36e06</td>
<td>3.42e08</td>
<td>266</td>
</tr>
</tbody>
</table>

<sup>*</sup> units consistent with [C(O)] and [C(CO)] in mol/cm² and [CO] and [CO₂] in mol/m³
Figure 1: Plot of specific surface area for various mass fractions of corn stover (raw basis) in Wyodak coal.
Figure 2: Optical images of raw fuel blend of 50% Wyodak coal 50% corn stover (A) and 85% Wyodak coal, 15% corn stover (B, C), showing a clustering together of coal and biomass particles
Figure 3: Calculated and experimental normalized mass rate for Wyodak coal char at 100% CO$_2$, 1 atm and selected temperatures.

Figure 4: Calculated and experimental normalized mass rate for Wyodak coal char in 50%/50% CO$_2$/CO gas environment at 1 atm and selected temperatures.
Figure 5: Calculated and experimental normalized mass rate for Wyodak coal char in selected environments containing CO$_2$ at 1273 K and 1 atm.

Figure 6: Calculated and experimental normalized mass rate for Wyodak coal char in selected environments containing CO$_2$ at 1173 K and 1 atm.
Figure 7: Calculated and experimental normalized mass rate for corn stover char in 100% CO$_2$ at 1 atm.

Figure 8: Calculated and experimental normalized mass rate for corn stover char in a 50% CO$_2$/50% CO mixture at 1 atm.
Figure 9: Calculated and experimental normalized mass rate for corn stover char in selected environments at 1273 K and 1 atm.

Figure 10: Calculated and experimental normalized mass rate for corn stover char in selected environments at 1173 K and 1 atm.
Figure 11: Experimental and predicted normalized mass loss rates for the 50%/50% coal/biomass mixed char in 100% CO$_2$ at 1 atm and selected temperatures, using the kinetic parameters of the pure fuels.

Figure 12: Experimental and predicted normalized mass loss rates for the 70%/30% coal/biomass mixed char in 100% CO$_2$ environment and 1 atm, using the kinetic parameters of the pure fuels.
Figure 13: Experimental and predicted normalized mass loss rates for the 70%/30% coal/biomass mixed char in a 50% CO$_2$, 50% CO environment at 1 atm, using the kinetic parameters of the pure fuels.

Figure 14: Experimental and predicted normalized mass loss rates for three different char mixtures and their predictions derived from pure fuel kinetic parameters.
References


