Physics-Based Modeling Enhanced by Multistep Pyrolysis Kinetics for Wildland Fires

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Current physics-based models for wildland fires rely on overly simplistic kinetics schemes, often limited to single step Arrhenius reactions, to represent the thermal pyrolysis of fuels [1–4]. However, recent thermogravimetric analysis (TGA) studies of various plant species commonly involved in wildland fires [5,6] have revealed the inadequacy of these approaches. They fail to replicate the multiple pyrolysis peaks observed in the derivative mass loss data of the TGA experiments, indicating that they do not correctly capture the complex pyrolytic behavior of wildland fuels. Accurately representing the pyrolysis chemical kinetics is essential for properly calculating fire spread via physics-based models, where major physiochemical processes, such as pyrolysis, combustion, thermal radiation etc, are included. The flammable gases released in the pyrolysis process directly influence the flaming combustion in fires.

The main objective of this work is to evaluate the impact of improving the pyrolysis kinetics schemes via multiple reactions in the physics-based modeling of wildland fires. To this end, two multistep Arrhenius type pyrolysis schemes are considered: One is attributed to Dietenberger et al. [7] and the other is developed in our group based on the TGA experiments by Amini et al. [5]. While the first scheme groups the vegetation composition into several components including lipids, digestives (glucose, fructose, and protein), hemicellulose (xylan and pectin), glucan (cellulose and starch), phenolic (lignin and tannins), and inert (silicate and mineral) and assigns one pyrolysis reaction for each group, the second scheme is not component based. First, the results of these two schemes are compared with each other and with experimental data from a TGA setup. Next, each scheme is separately incorporated into a physics-based modeling framework. The enhanced model is then used to simulate fire spread over a conifer needle fuel bed, previously studied experimentally. A comparative study is conducted between the physics-based modeling results using the two multistep pyrolysis schemes, a single-step pyrolysis scheme, and the experimental data. The study findings are then presented.

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