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Reaction kinetics for biomass self-ignition at 150–230°C

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Replacing coal with pelletized biomass on pulverized-fuel CHP-plants has led to an increased fire risk in storages and processing facilities. Accurate models to predict this behavior are scarce, mainly owing to a lack of reaction kinetic data for low temperatures.

Mill fires in power plants – a case study in self-ignition

Mill fires consume fuel, may damage equipment and cause additional downtime, all detrimental to power plant operation. Fires are likely caused by settled dust beds that start to smolder. Such particle beds can easily accumulate in mills. Experience shows biomass to be more susceptible to spontaneous ignition than coal.
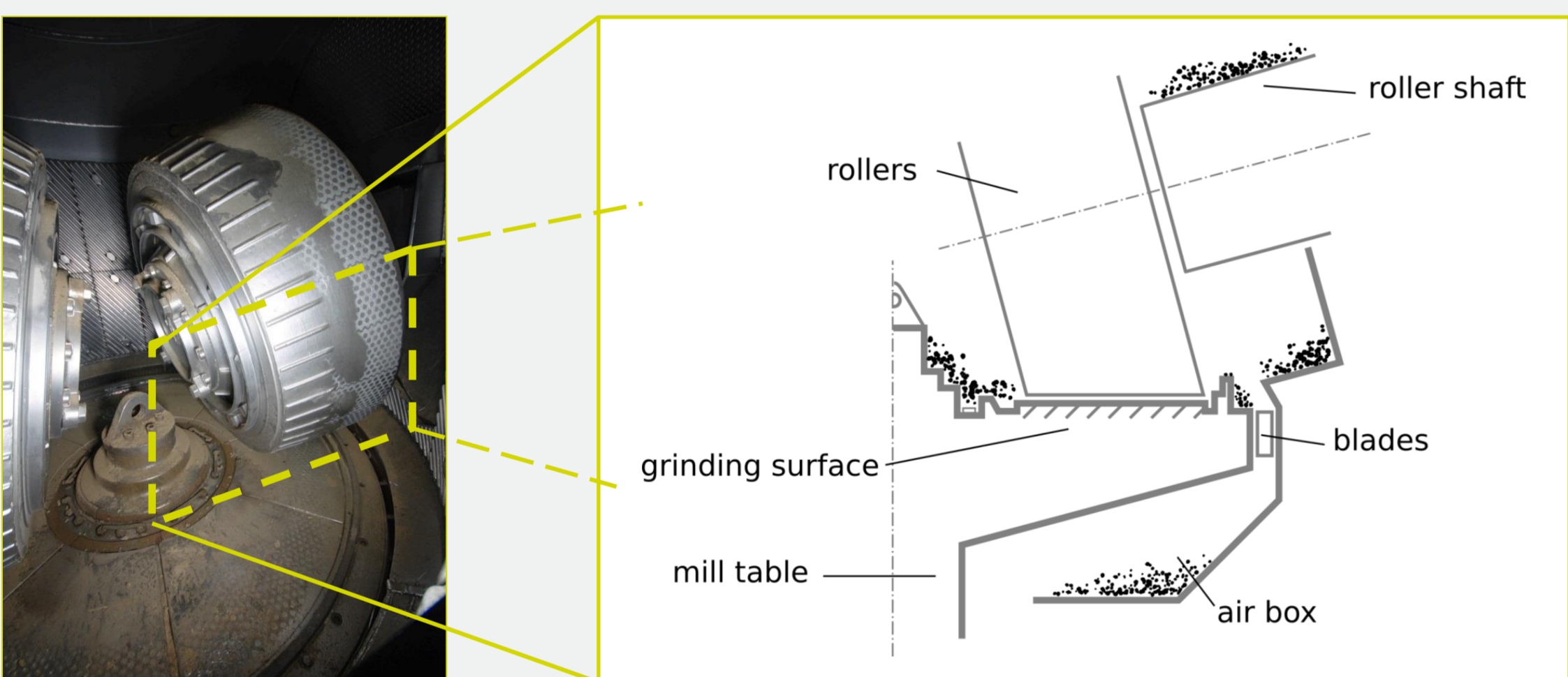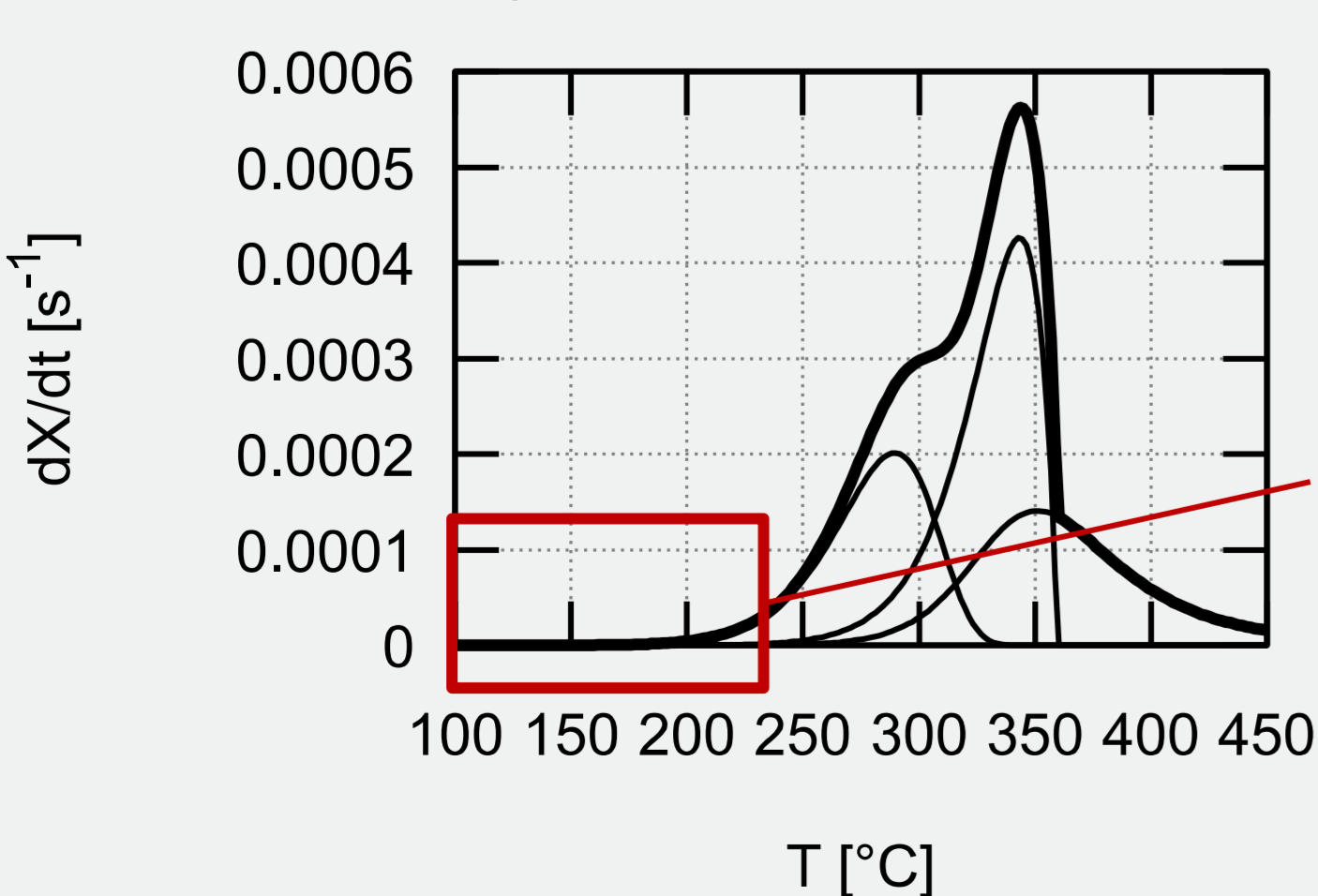
The challenge – reaction kinetic data for low temperature oxidation

Based on experiments, self-ignition is likely caused by thermal runaway of a heterogeneous oxidation reaction of the biomass. Thermal decomposition (pyrolysis) occurs simultaneously at a slightly lower rate.

Reaction kinetic data for four biomasses. Thermogravimetric analysis (TGA) was used to measure reaction rates for six isothermal holding periods between 150–230°C. Data were fitted to a scheme of one pyrolysis and one oxidation reaction, both first order in the solid. Reaction order in oxygen was fitted to the TGA-data (0.4–0.55).

Photo and schematic of a typical power plant roller mill, showing possible dust settlements. Hot air passes the mill from bottom to top, entraining fuel particles that are sufficiently fine and transporting them to the burners. Larger particles fall to the grinding table, but may also settle elsewhere. Pre-heating the transport air by heat recovery from flue gas improves plant efficiency, but also increases the risk of mill fires.

Highlights:

- Biomass reaction **kinetic data** for oxidation and pyrolysis were determined at **150–230°C** by **TGA** *(top right)*
- The data was used in a **model** combining the two reactions and heat transfer, with the aim of predicting **thermal runaway** *(middle and right)*
- The model was **validated** with lab-scale fixed bed experiments and was accurate within 15 K. *(right)*
- Production rates of CO and CO_2 could also be predicted, albeit with slightly lower accuracy. *(bottom right)*

Moving on: further developments

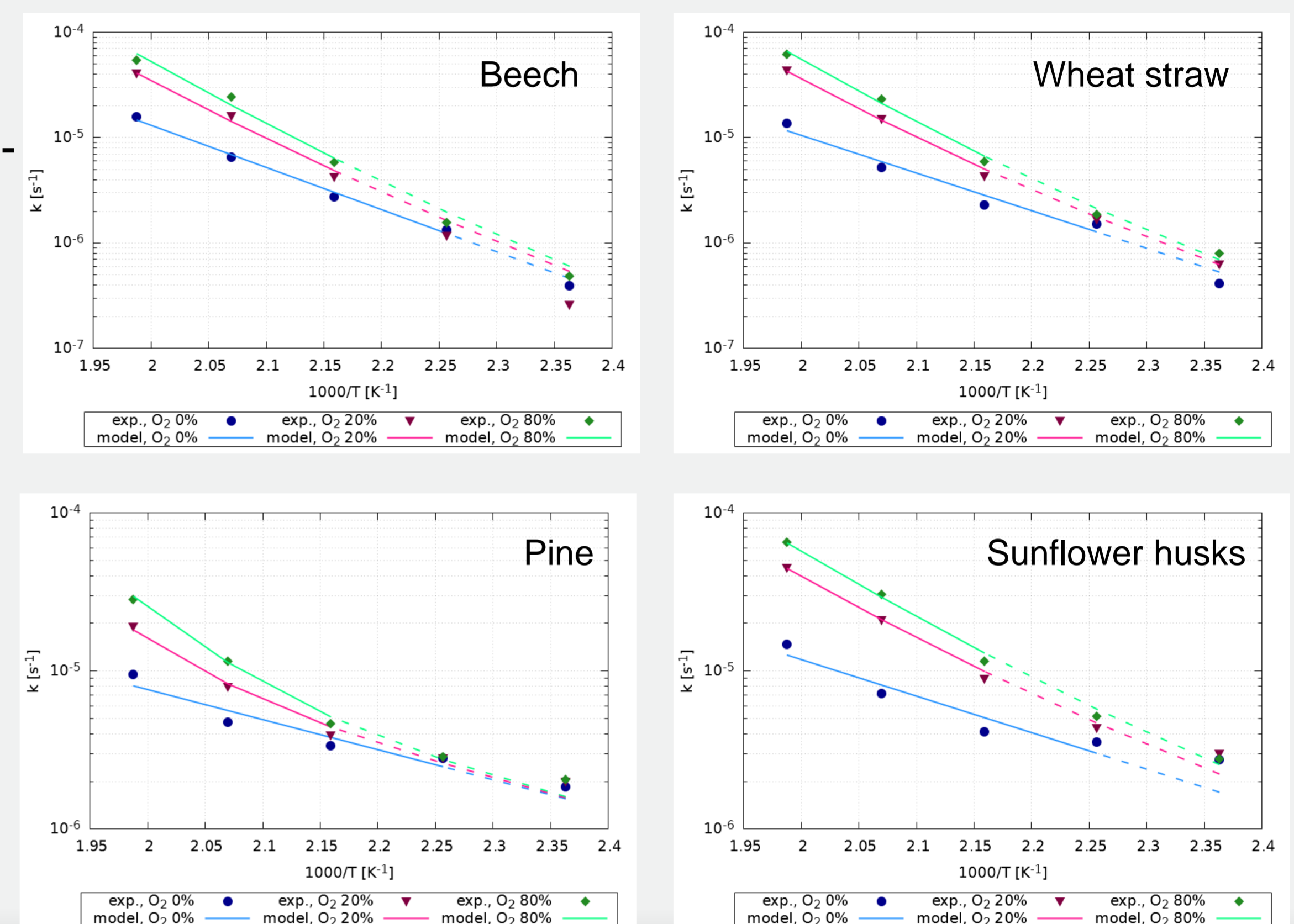The reaction model (see TGA-data top right) is currently revised. More generalized pyrolysis models exist in the literature, but these are often optimized for temperatures above 200°C.
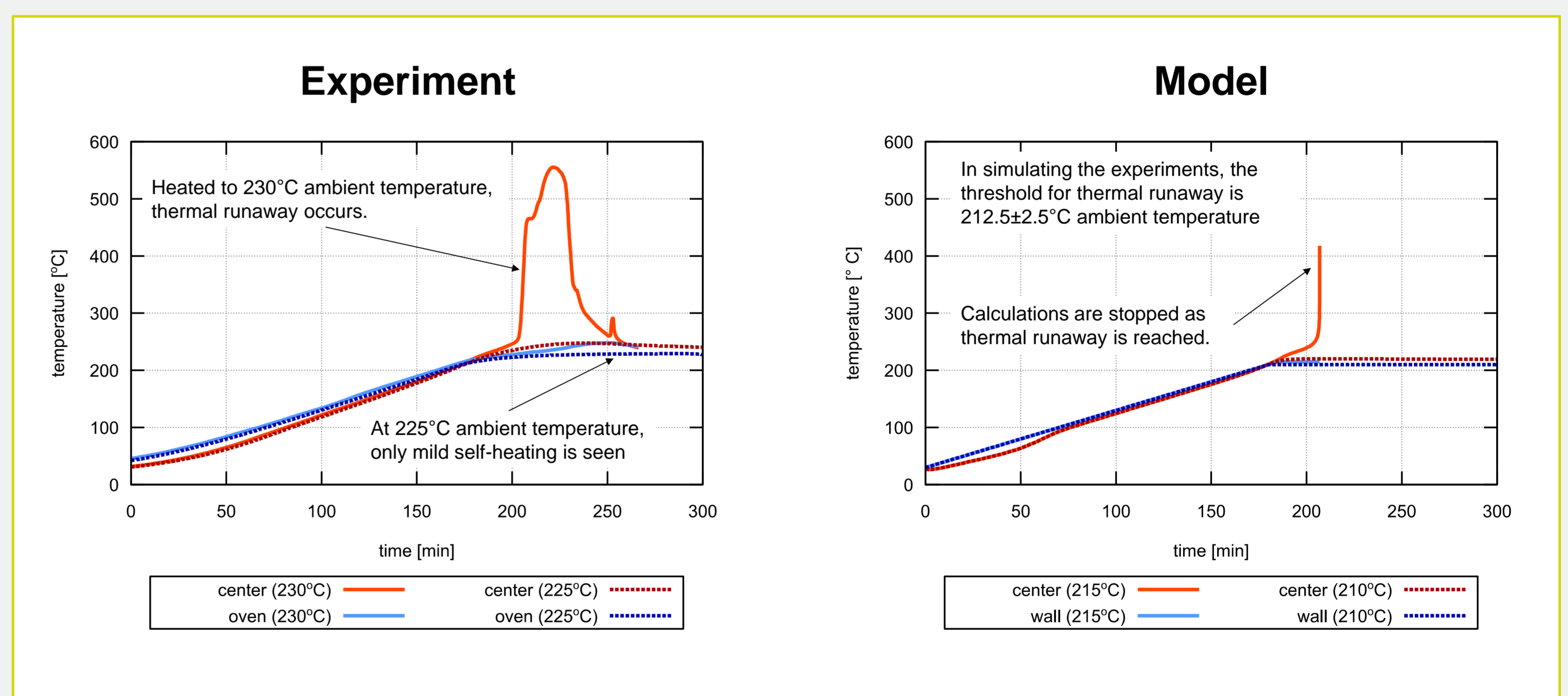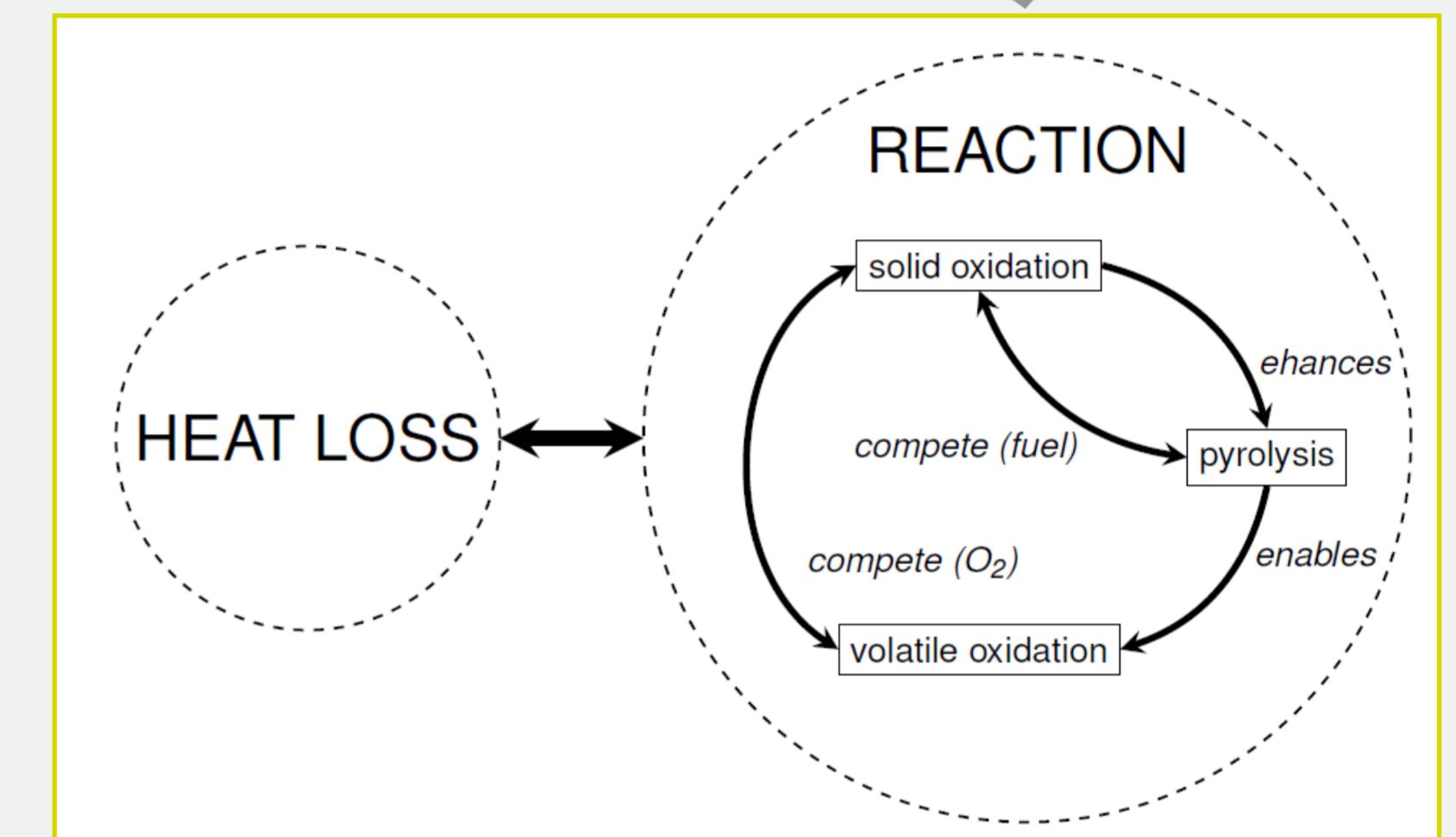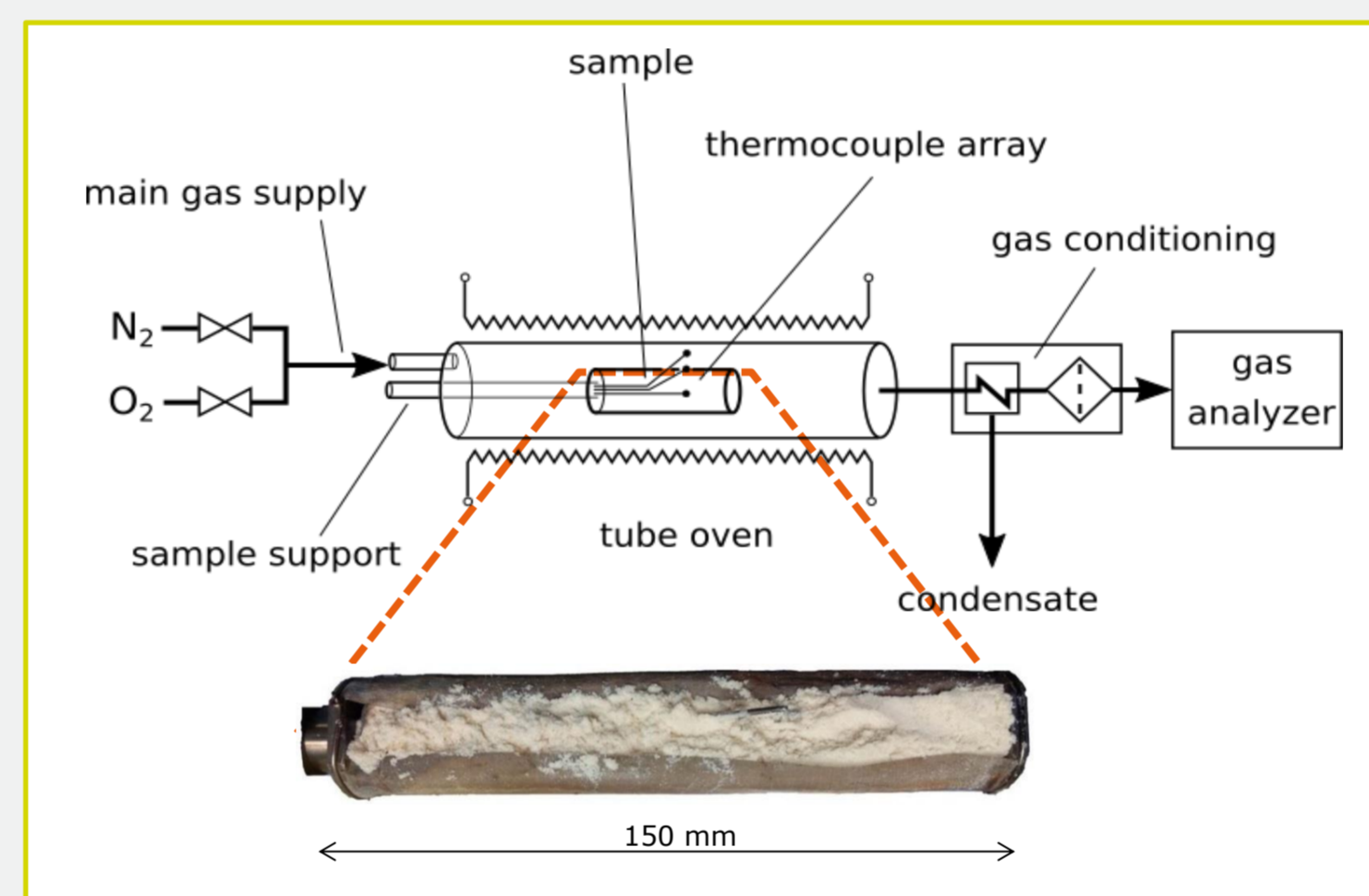

Relevant range for self-ignition
Pyrolysis conversion kinetics for pine as sum of cellulose, lignin and hemicellulose adapted from *Anca-Couce et al., Combustion and Flame 159 (2012) 1708–1719.*

Self-ignition (thermal runaway) in a lab-scale experiment and results from modelling this experiment. The experiment shown was run with 12g samples of pine, ground to 50–200 μm particle size, and heated at 1K/min to 225°C (no runaway) and 230°C (runaway), respectively. A constant gas flow of 2.5 L/min with 20% O_2 was maintained (see setup design above). An idealized 1D, time- and space discrete model was programmed to simulate this experiment. Model calculations predict a slightly lower critical temperature for thermal runaway. None of the reaction kinetic or heat transfer modelling parameters were fit to oven experiments.
Data below shows measured and modelled gas release rates of CO and CO_2 from fixed bed experiments under 20% and 0% O_2. Sample sizes 10–40 g (species dependent), heating rate 1K/min to 300°C, gas flow 2.5 L/min.