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Experimental investigation of RDF combustion for the optimization of CFD simulations of oxy-fuel-fired cement kilns

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Motivation

- For the design of oxy-fuel kilns, reliable CFD simulation models of the complex combustion behaviour of refuse-derived fuels (RDF) are needed.
- RDF comprise a variety of fractions with different physical and chemical properties (see Fig. 1).
- In this study, the combustion of RDF is investigated. Five materials have been chosen to represent the different fractions of RDFs: beech wood, cardboard, cotton, polyvinylchloride (PVC) and polyethylene (PE).

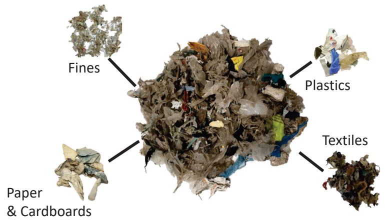

Fig. 1: Fractions contained in RDFs

Methodology

- As the size of RDF particles is in the centimeter range, the kinetic properties of the different materials as well as intra-particular transport phenomena have to be taken into account. Therefore, two different experimental setups are used:
  1. A fluidized bed reactor is used to gather data to model the intrinsic pyrolysis kinetics of the different species.
  2. A single particle reactor is used to investigate the combustion of full-scale RDF particles.

Determination of intrinsic pyrolysis kinetics

Fluidized bed reactor (FBR)[1]

- Batch-wise feeding of particle samples
  - Particle diameter ≈ 100 µm
  - Sample mass ≈ 15 mg
- *Ex-situ* measurement of the mole fractions of the released gaseous species using FTIR spectroscopy
- Experiments conducted for a temperature range between 350 °C and 800 °C

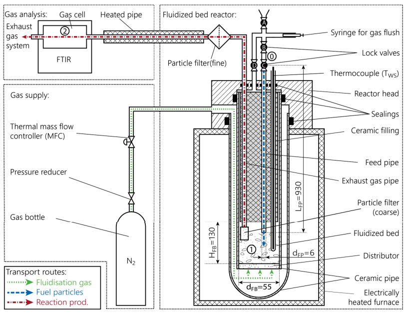

Fig. 2: Sketch of the fluidized bed reactor [1]

Modelling of experimentally determined mass release rates

- Computation of the mass flow of released species through the measurement cell
- Fitting of kinetic models suitable for CFD calculations, for example the following two-step model:

$$X = \frac{m}{m_{\mathrm{Fuel}}}$$

$$\frac{\mathrm{d}X_{\mathrm{tar}}}{\mathrm{d}t} = r_{\mathrm{prim}} \cdot f_{\mathrm{tar}} \cdot (X_\infty - X_{\mathrm{gas}}) - r_{\mathrm{sec}} \cdot X_{\mathrm{tar}}$$

$$\frac{\mathrm{d}X_{\mathrm{gas}}}{\mathrm{d}t} = r_{\mathrm{prim}} \cdot (1 - f_{\mathrm{tar}}) \cdot (X_\infty - X_{\mathrm{gas}}) + r_{\mathrm{sec}} \cdot X_{\mathrm{tar}}$$

- Signal modulation between the fluidized bed and the measurement cell taken into account by convolution of the model result.

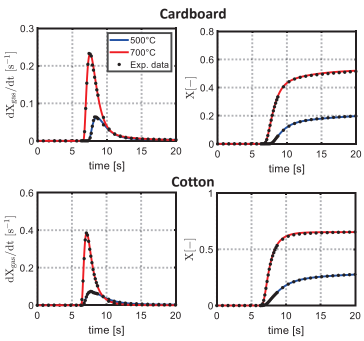

Fig. 3: Normalised mass release rates and totally released mass

Kinetic parameters

- Change of the reaction rates due to temperature is modelled using an Arrhenius equation, $r = A \cdot \exp(-E_a/RT)$

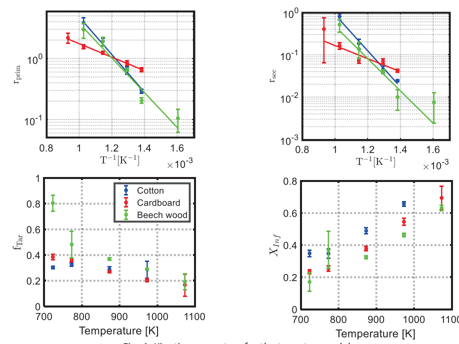

Fig. 4: Kinetic parameters for the two-step model

References

[1] Pielsticker, S., Gövert, B., Umeki, K., Kneer, R., Flash pyrolysis kinetics of extracted lignocellulosic biomass components, Frontiers in Energy Research 9 (2021).

[2] Liedmann B., Simulation der thermischen Umsetzung flugfähiger Ersatzbrennstoffe in Drehrohröfen der Zementindustrie, Dissertation, Bochum (2018)

Investigation of combustion of full-scale RDF particles

Single particle reactor[2]

- Maximum gas temperatures up to 1300 °C
- Adjustable oxygen concentration

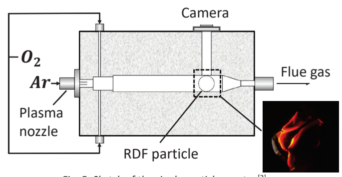

Fig. 5: Sketch of the single particle reactor [2]

Measurement of oxygen consumption and optical determination of particle conversion times

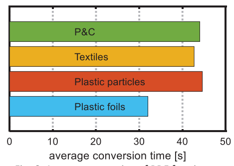

Fig. 6: Average conversion of RDF fractions (reaction conditions: 9% O_2, 1100 °C)

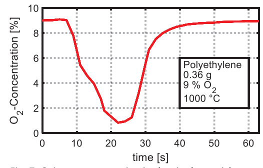

Fig. 7: Oxigen concentration in the single particle reactor during the combustion of a RDF particle

Optical determination of different reaction phases

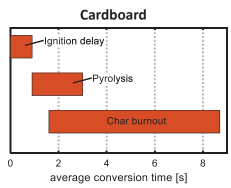

Fig. 8: Reaction phases of the combustion of a cardboard particle

- 0 – 0.9 s: Ignition delay
- 0.9 – 1.6 s: Pyrolysis and start of char burnout
- 1.6 – 3 s: Char burnout and decrease in pyrolysis
- 3 – 8 s: Char burnout

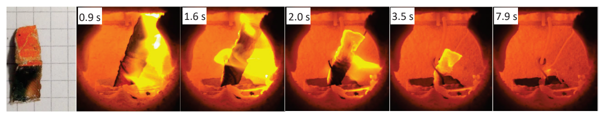

Fig. 9: Combustion of a single cardboard particle (44mg) in single particle reactor (reaction conditions: 9% O_2, 1200 °C)

Outlook

- Investigation of char burnout and gasification reactions with the FBR
- Creation and adaptation of numerical models for the combustion of a single RDF particle
- Implementation of the kinetic models in the single particle combustion models.
- Comparison of the single particle experiments with single particle simulations.
- Utilization of the RDF models to simulate the process inside the rotary kiln (see Fig. 9)

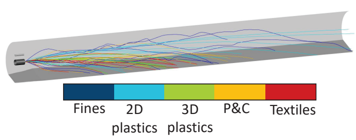

Fig 10. Flight trajectories of RDFs in a rotary cement kiln [2]

Acknowledgements

This work has been funded by the German Research Foundation (DFG) – project number 215035359 – within the framework of the CRC/Transregio 129 "Oxyflame".

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