A novel high-heating rate, elevated pressure reactor for the thermochemical conversion of pulverized solids

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Motivation

The thermochemical conversion of pulverized solids, e.g., the conversion of alternative reducing agent in a blast furnace for ironmaking, is a complex process and depends on various factors:

• Temperature • Pressure • Heating rate • Species concentrations

High heating rates and elevated pressures are hard to achieve in lab-scale setups but it is important to understand the thermochemical conversion of solids in industrial applications like blast furnaces or dust-firing boilers.

The novel high-heating rate, elevated pressure entrained flow reactor aims to provide an experimental platform to:

- Investigate high heating rate and elevated pressure effects
- Measure thermochemical conversion rates under harsh conditions
- Evaluate novel energy carriers and processes

ARA (Alternative Redicung Agents) Reactor

ARA Reactor features:

- High temperature, high heating rate, pressurized entrained flow reactor
- Unique operation conditions
- Cyclone for particle separation
- Online gas analyzer ($CO/CO_2/O_2$)
- Gas chromatograph (GC) Discharge ionization detector (BID) system
- Particle analysis

Designed operating conditions:

- Temperature < 1800 °C
- Heating rates 10^4 – 10^6 K/s
- Pressure < 8 bar(a)
- Residence time > 50 ms, 100 - 200 ms typically
- Particle mass flow ~ 1 g/min

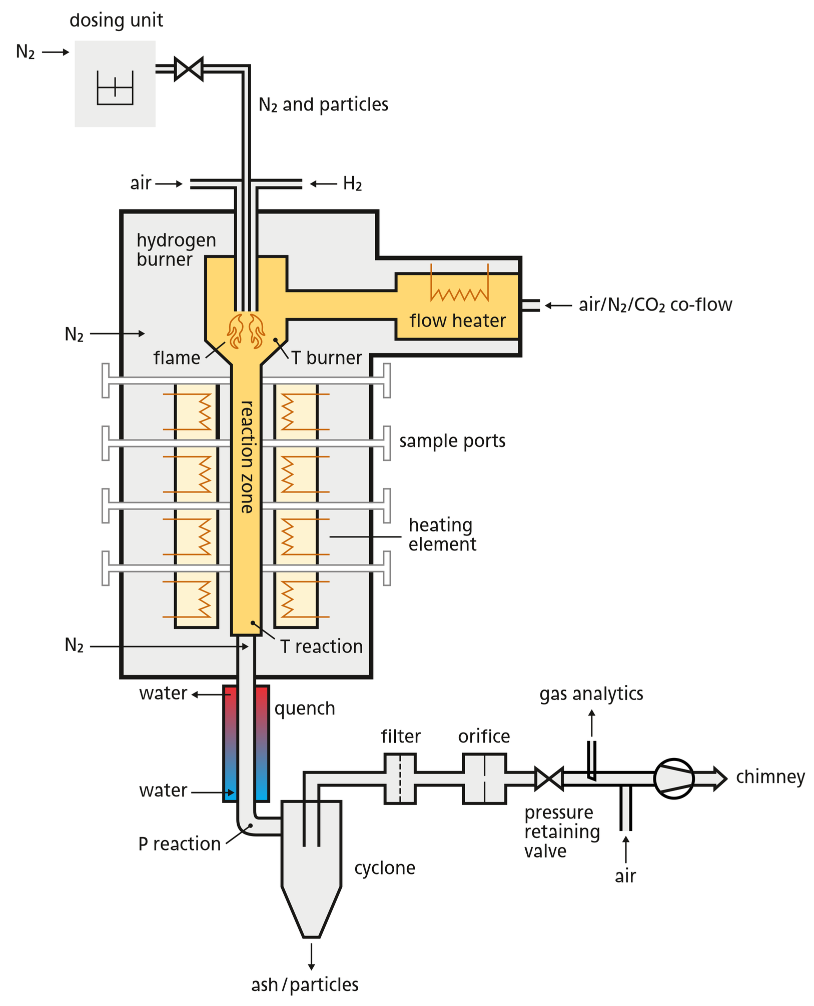

Figure 1: Schematics of novel high-heating rate, elevated pressure reactor.

Figure 2: Image of the reactor under operation at 1450 °C.

Design Validation

Validation Approach:

- Steady-state temperature and velocity fields based on experimental case
- Identification of representative particle tracks (Euler-Lagrange)
- Extraction of representative conversion conditions
- Pre-evaluation without hydrogen burner

Validation Results:

- Conversion conditions are in line with design expectations
  - Gas temperatures >1300 °C
  - Heating rates ~10^4 K/s (without burner)
  - Low slip velocities, except for the quench region
  - Gas temperatures and oxygen indicate bad mixing after injection
- Flow field needs to be optimized around the fuel injection point
  - Improved mixing between carrier gas and co-flow
  - Optimized particle tracks through reactor

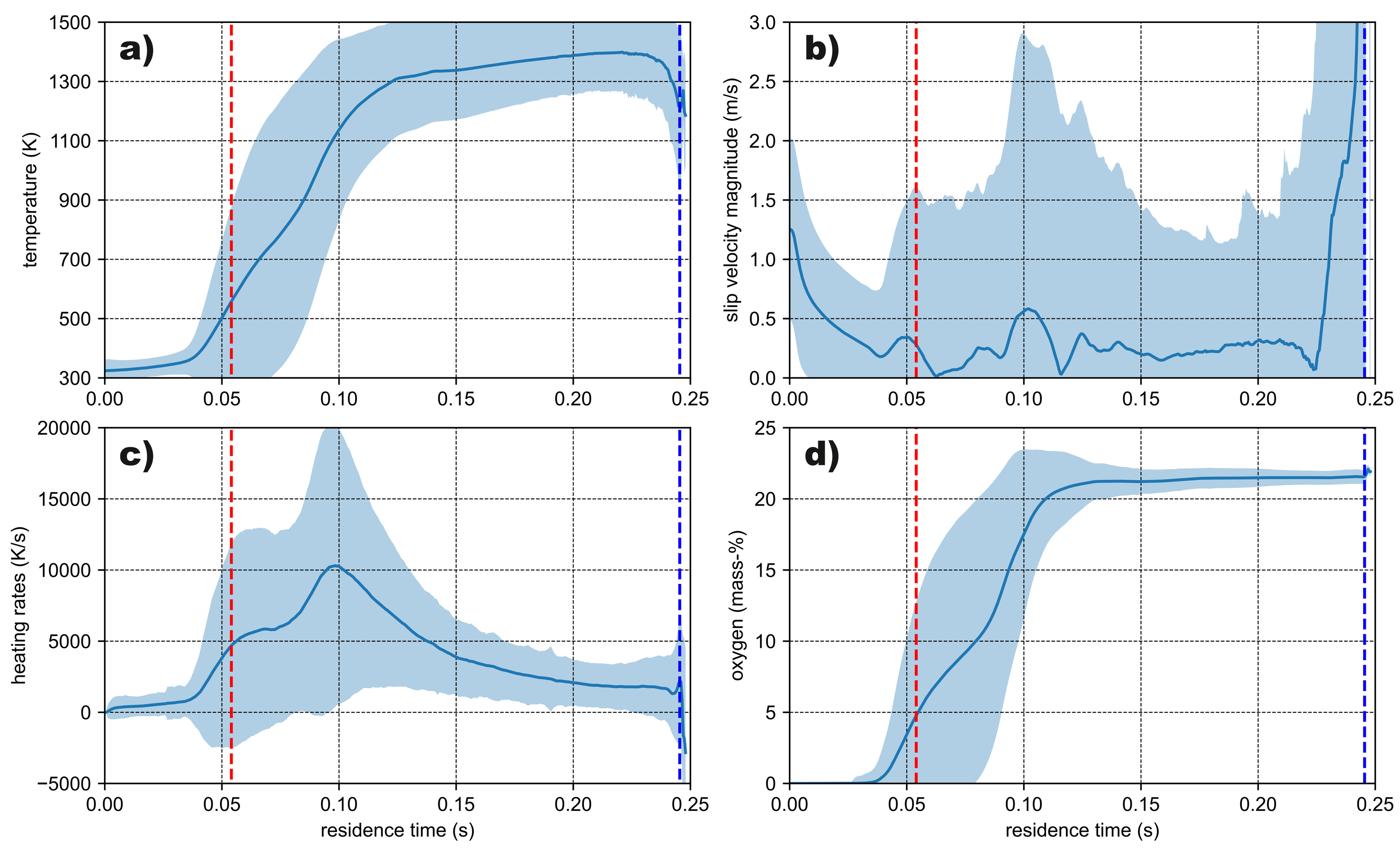

Figure 3: Extracted mean particle reaction temperatures (a), slip velocities (b), particle heating rates (c), and oxygen concentration (d).

Next Steps

Ongoing Activities:

- Final commissioning and safety certification
- Low-heating rate testing of pulverized carbon carriers
- Investigation of pressure-dependent conversion characteristic

Future Activities:

- High-heating rate experiments
- Investigation of heating rate dependency on conversion characteristics
- Detailed analytics of solid residues
- Spatially resolved CFD model for accurate evaluation of experiments

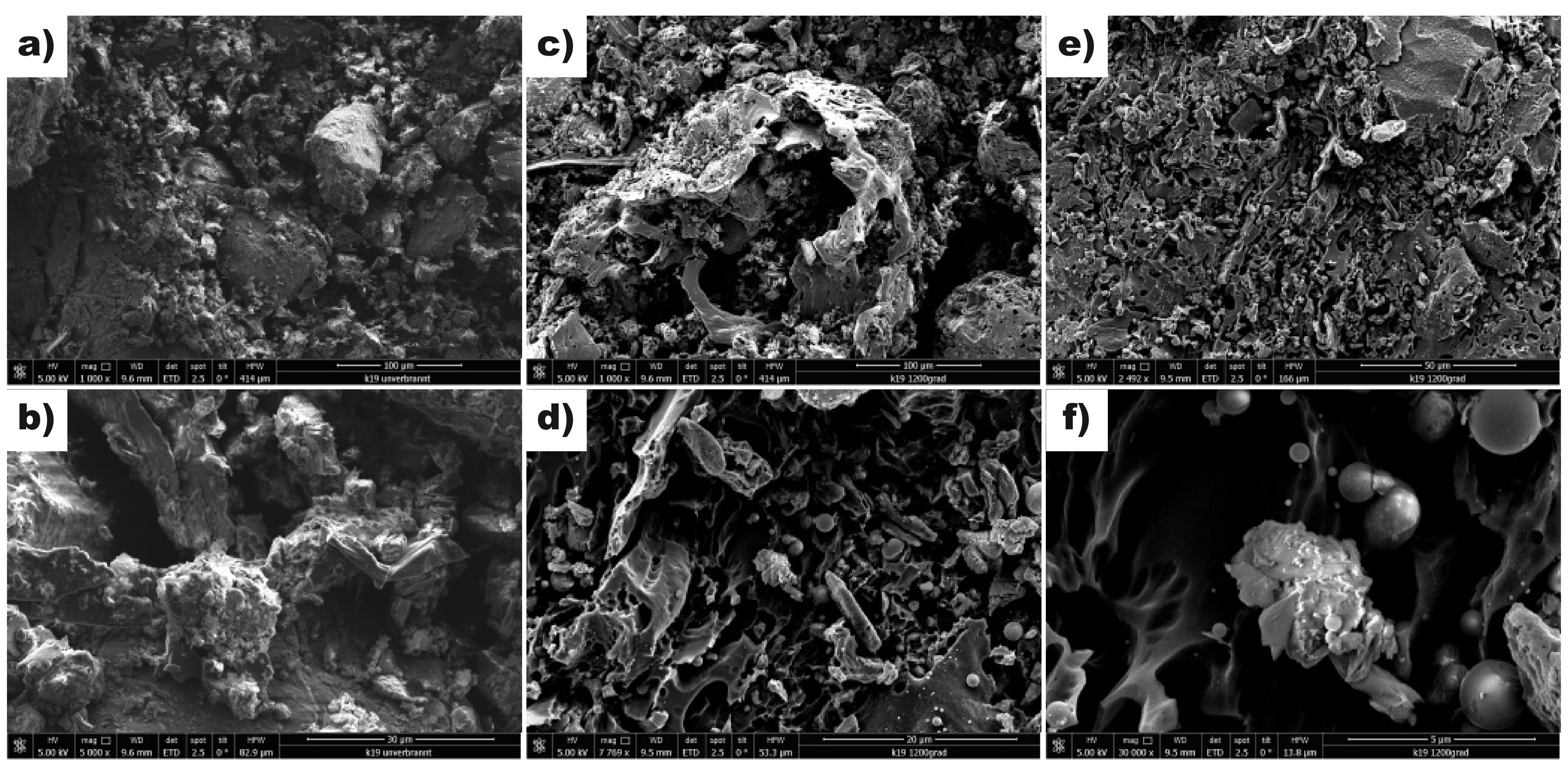

Figure 4: SEM images of virgin coal (a,b) and solid residues (c - f) from coal conversion runs at 1200 °C at various magnifications.

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