2nd Workshop

International Oxy-Combustion Research Network

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PRESENTATION - 18

Packed Bed Reactor Technology for Chemical-Looping Combustion

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Packed Bed Reactor Technology for Chemical-Looping Combustion

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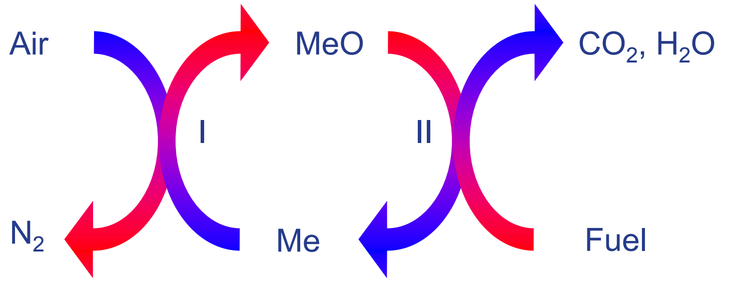
Chemical-looping Combustion



I: $4\ Me + 2\ O_2 \rightarrow 4\ MeO\ (\Delta H < 0)$

II: $4\ MeO + CH_4 \rightarrow 4\ Me + CO_2 + 2\ H_2O\ (\Delta H > 0)$

- Power production with inherent CO_2 separation
- Direct contact between air and fuel is avoided

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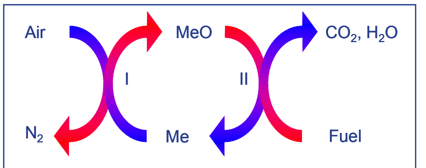
Introduction

- Chemical-looping Combustion:
  - Potential for very high CO_2 capture efficiency
  - No energy penalty for separation
  - No NO_x formation
  - Direct implementation in power plants is challenging



I: $4\ Me + 2\ O_2 \rightarrow 4\ MeO$ ($\Delta H < 0$)

II: $4\ MeO + CH_4 \rightarrow 4\ Me + CO_2 + 2\ H_2O$ ($\Delta H > 0$)

- Important research themes:
  - Oxygen carrier (MeO = NiO, Fe_2O_3, Mn_3O_4, CuO)
  - Implementation in power plant
  - Reactor concepts

Oxidizing and reducing conditions must be imposed alternately

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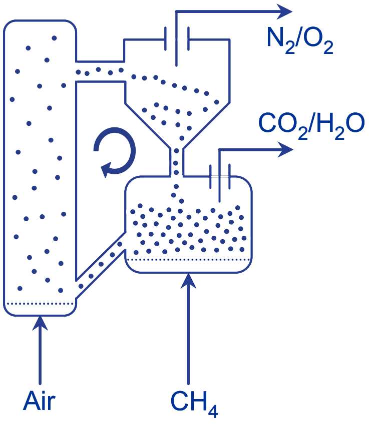
Reactor Concepts

Recirculation or stationary solids?



- Disadvantage of fluidization:
  - Recirculation of particles
  - Difficult gas-solid separation (formation of fines)
- Packed bed (membrane-assisted) CLC:
  - Stationary solids
  - Periodic switching of gas streams
  - Dynamically operated parallel reactors (gas switching system)
  - Natural gas → combined cycle!

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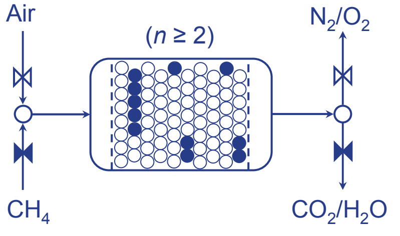
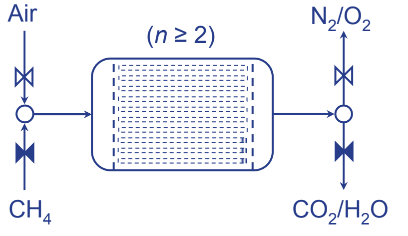
Packed Bed CLC

- Packed bed CLC (UT):



- Packed bed membrane-assisted CLC (TNO):



- Process demands:
  - ➢ Constant high-temperature air stream
  - ➢ High overall and CO_2 capture efficiency
  - ➢ Continuous operation
  - ➢ Extreme conditions (T_{out} = 1300-1500 K, p = 20-30 bar)

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Project Goal

- Evaluation of the feasibility of packed bed CLC as an alternative power production technology:
  - ➢ Can CLC be carried out using packed bed (membrane-assisted) technology?
  - ➢ How can packed bed CLC with an optimal overall energy efficiency be realized?
  - ➢ How does packed bed CLC perform, compared to fluidized bed CLC and other CO_2 capture processes?

- This presentation:
  - ➢ Modeling and experimental work on packed bed CLC.

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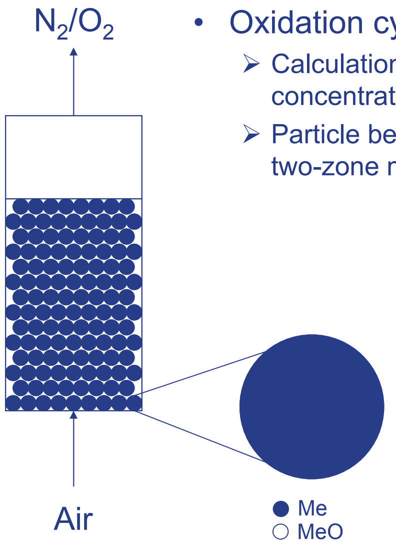
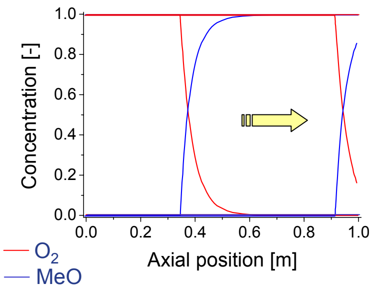
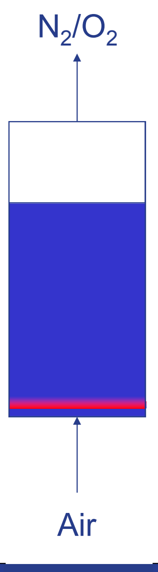
Packed Bed CLC: Oxidation



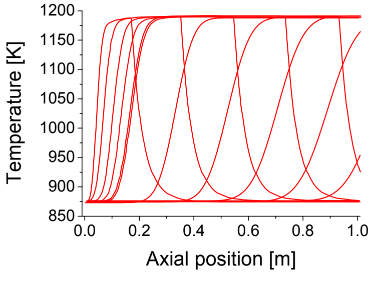
- Oxidation cycle:
  - Calculation of axial temperature and concentration profiles.
  - Particle behavior is described using a two-zone model

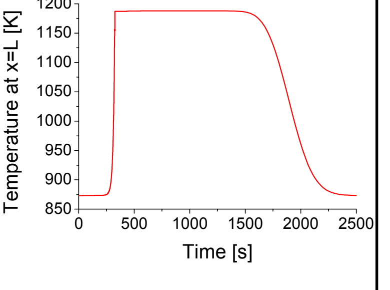


Packed Bed CLC: Oxidation



- Oxidation cycle:
  - Temperature evolution





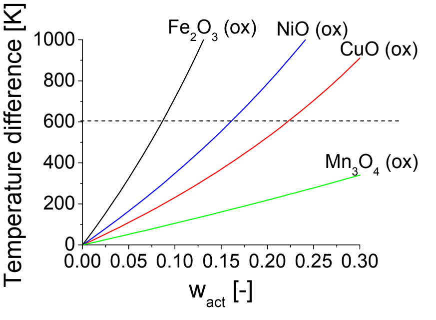
- 'No' influence of reaction kinetics or flow rate
- An air stream of high, constant temperature is produced → gas turbine

Oxygen Carrier Properties

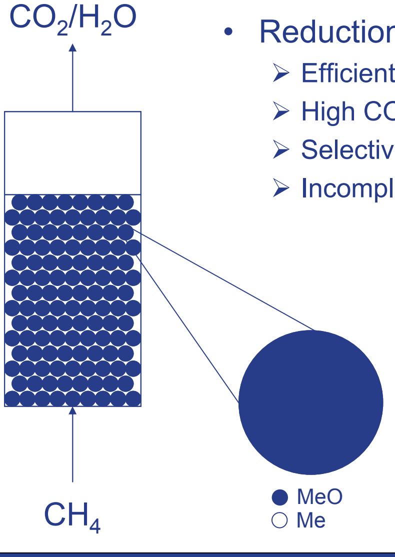
- Analytical approximation:
  - ➢ Infinitely high reaction rate
  - ➢ No influence of conduction

$$\Delta T = \frac{(-\Delta H_R)}{\frac{C_{p,s} M_{act}}{w_{act}\xi} - \frac{C_{p,g} M_{O_2}}{w_{g,O_2}^{in}}}$$

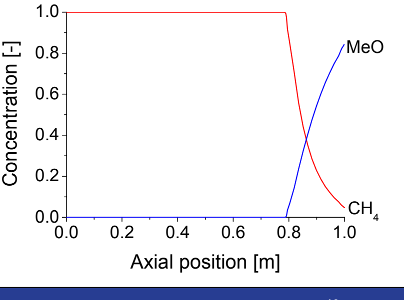
- Temperature increase can be tuned:
  - ➢ Active content
  - ➢ Support material
  - ➢ Oxygen concentration



Packed Bed CLC: Reduction

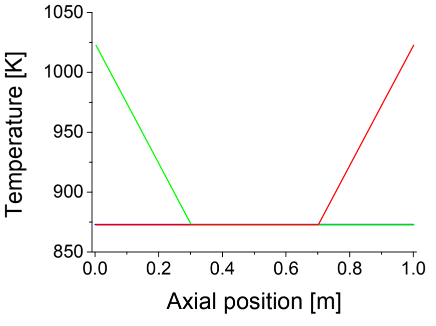


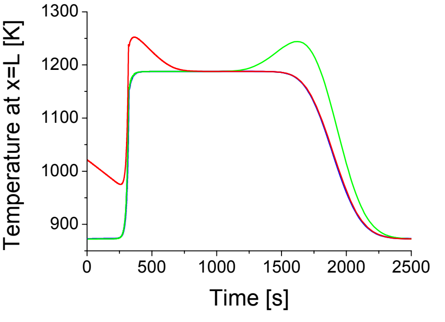
- Reduction cycle:
  - ➢ Efficient use of fuel
  - ➢ High CO_2 capture efficiency
  - ➢ Selectivity to CO_2 and H_2O
  - ➢ Incomplete regeneration of part of the bed



Packed Bed CLC: Operation

- Operation over multiple cycles:





➢ Fluidization between oxidation and reduction cycles is necessary to level off temperature profiles.

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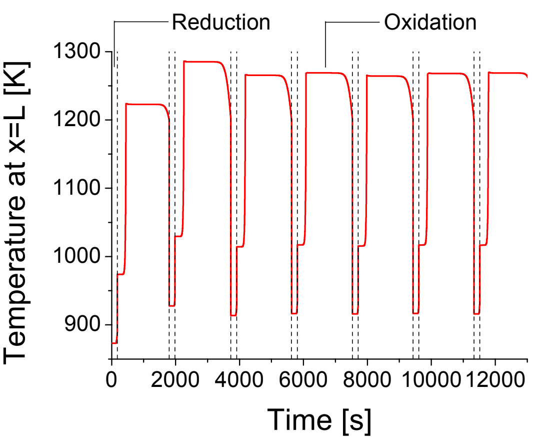
Modeling Packed Bed CLC



→ Cyclic steady state is obtained after only a few oxidation/reduction cycles.

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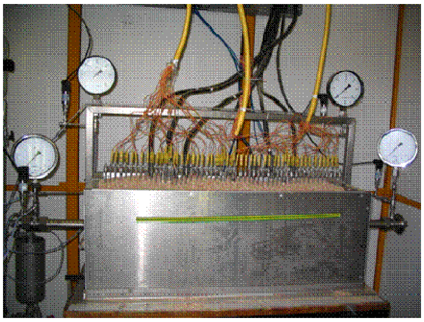
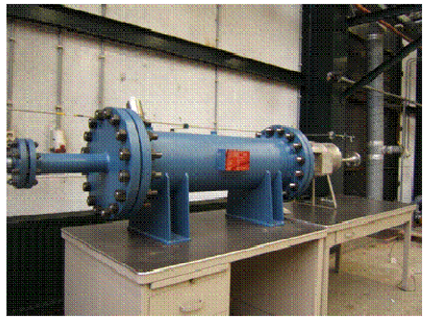
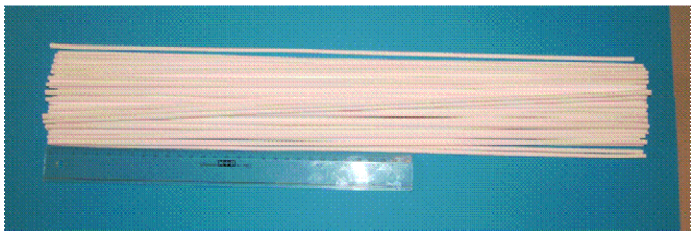
Experimental Validation

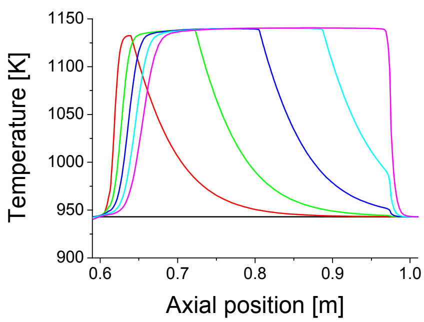




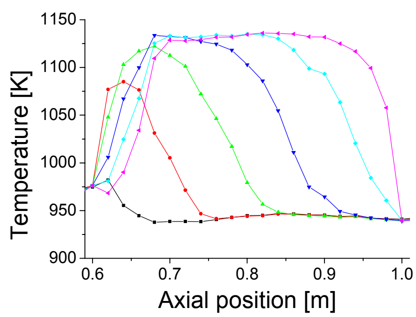


Experimental Validation

Model description



Experimental results



Oxidation reaction: (t = 0, 6, 12, 18, 24, 30 s)
(Cu/CuO, $w_{act} \approx 0.1$)

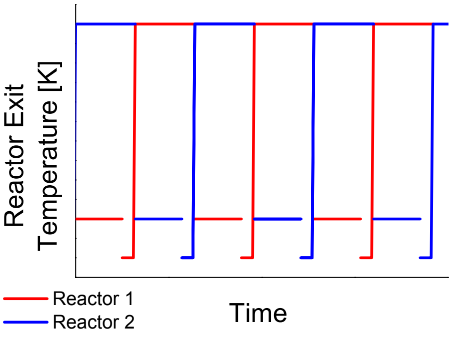
Improvements:

- Correct implementation of heat losses in the model
- Coupling of particle model and reactor model

	Model	Exp.	
ΔT_{max} [K]	195	199	➨
w_2 [cm/s]	1.53	1.58	➨
w_1 [cm/s]	0.13	0.15	➨

Implementation

- Implementation in power plant:
  - Combined cycle to maximize overall energy efficiency
- Process design:
  - Pressure drop
  - Number of reactors
  - Reactor sizing
  - Heat integration, etc.
- Important features:
  - Compact design
  - Suitable for part-load operation



Conclusions

- Packed bed (membrane-assisted) CLC is an interesting alternative power production technology:
- Process operation:
  - Oxidation cycle: generation of high temperature air stream
  - Reduction cycle: combining efficient use of fuel and high CO_2 capture efficiency
- Implementation in power plant:
  - Combined cycle
- Future work:
  - Experimental validation of packed bed CLC
  - Process design and efficiency calculations