BIOENERGY DOC2021 | 4TH DOCTORAL COLLOQUIUM BIOENERGY

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Julian Nix

Reduction of nitrogen oxide emissions by means of selective non catalytic reduction in a small-scale fluidized-bed combustion-system

14TH SEPTEMBER 2021, KARLSRUHE

Overview on this presentation

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1. THE PROJECT „SmartWirbelschicht“

- Motivation and goals of the project

2. INTEGRATION OF SNCR

- experimental / simulative approach and results

3. CONCLUSION AND OUTLOOK

Short introduction

Title of the Doctoral Project:	„SmartWirbelschicht“
Doctoral Student:	Julian Nix
University:	Friedrich-Alexander University Erlangen-Nürnberg
University Supervisor:	Prof. Dr.-Ing. Jürgen Karl
Funding :	BMEL, FNR — Bundesministerium für Ernährung und Landwirtschaft; FNR Fachagentur Nachwachsende Rohstoffe e.V.
Duration:	06/2019 – 05/2022

Motivation and goals of the project „SmartWirbelschicht“

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MOTIVATION – A look back on previous work at EVT

Development of a micro CHP-system combining fluidized bed combustion with a Stirling engine:

- ✓ Wide fuel range
- ✓ Prevention of slagging
- ✓ Low emissions (CO & dust – with woody fuels)
- ✓ Air pre-heating with double-walled cyclone → increase of electrical efficiency

how it started…

Upscale and field test operation of a pilot-plant

- ✓ Continous operation with several fuels (i.a. waste wood, sewage sludge)
- ✓ Detailed investigation of operation strategies and their effect on emissions

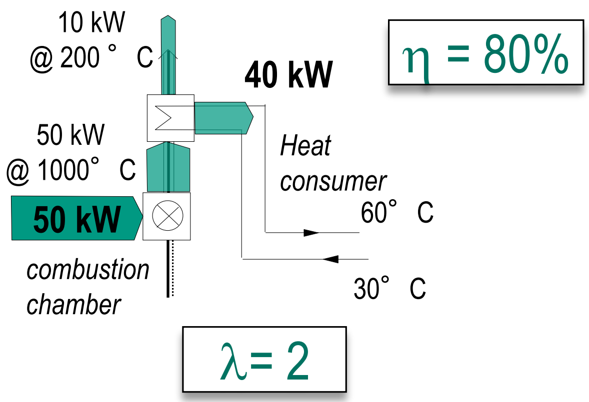
the next steps…

- ➢ Fuels with high nitrogen content e.g. hay-pellets require futher reduction measures

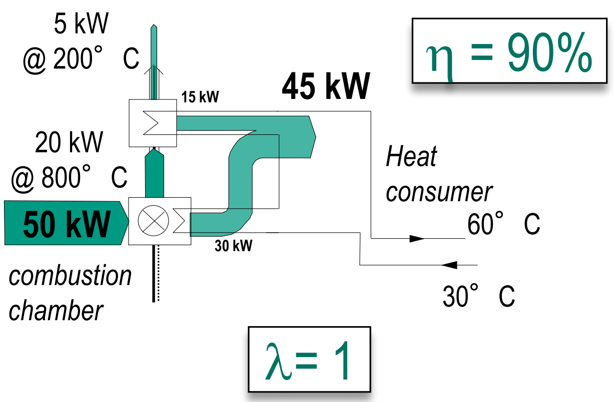
Motivation and goals of the project „SmartWirbelschicht“

MOTIVATION – fields of application (new: besides CHP)

Heat supply by a common biomass boiler



Heat supply by a cooled boiler



Motivation and goals of the project „SmartWirbelschicht“

MAIN GOALS

Identification of the „ideal application“ and acquisition of future partners

Economical- and thermodynamical evaluation of different application scenarios

- Evaluation with current customer needs/data
- Techno-economical analysis of future market potentials

eta Energieberatung

DBFZ

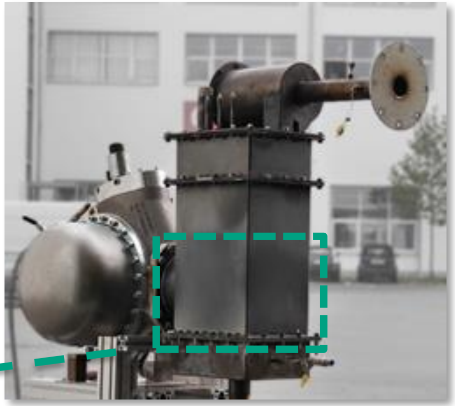
Better understanding of NO_x-formation and modification of the lab system

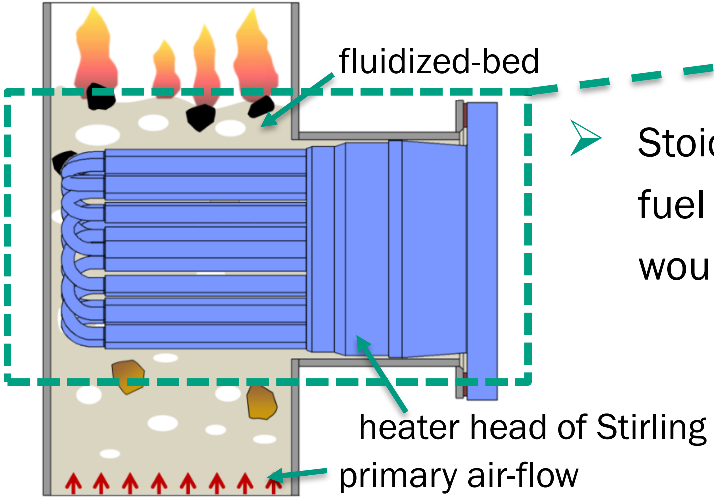
- Particle resolved simulation of fuel conversion with CPFD-software Barracuda-VR
- Gas-phase reactions including NO_x-reduction by SNCR in ANSYS Fluent
- Experimental demonstration of SNCR
- Detailed emission measurements in full- and partial-load operation

Why is SNCR the option?

Background CHP-Operation:

- Electric efficiency of the Stirling-engine strongly depends on the heat being released inside the fluidized bed





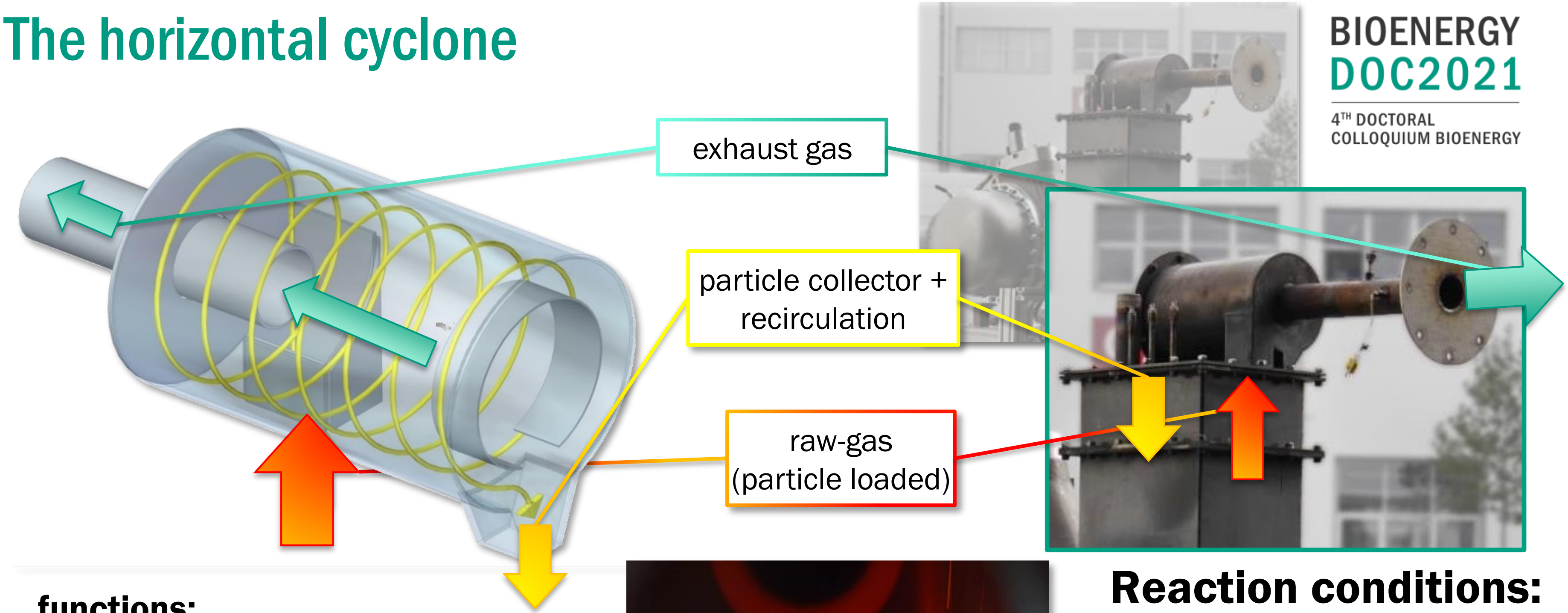
- Stoichiometric operation encourages non-ideal mixing of air and fuel and shifts heat-release towards the freeboard → air staging would even increase this effect

View inside the cyclone

Reaction conditions:

- Highly turbulent flow through the cyclone might be ideal for SNCR-application

The horizontal cyclone



functions:

- ✓ particle seperator
- ✓ thermal afterburning system
- ✓ air preheater (doubled wall)
- ➢ reduction of NO_X by SNCR?

View inside the cyclone

Reaction conditions:

- ➢ Highly turbulent flow through the cyclone might be ideal for SNCR-application

Theoretical background on SNCR operating conditions

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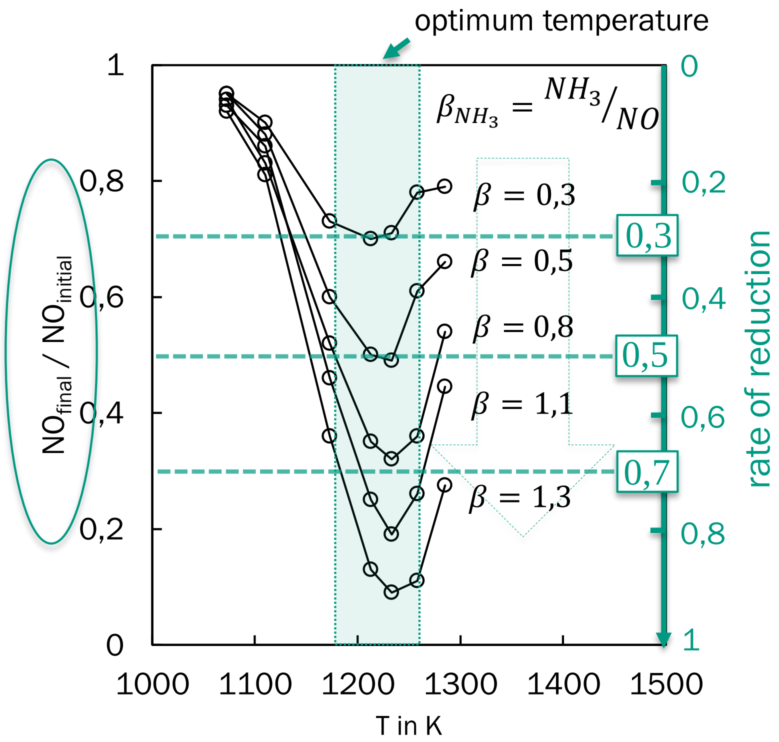


Experiments by Muzio et al. 1977
- Gas phase decomposition of nitric oxide in combustion products -
Effect of temperature on NO reductions with ammonia injection
(excess O_2: 4%; initial NO: 300 ppm)

Definition: „rate of reduction“

$$R_{Reduction} = \frac{NO_{initial} - NO_{final}}{NO_{initial}}$$

after Reduction (NO_{final})

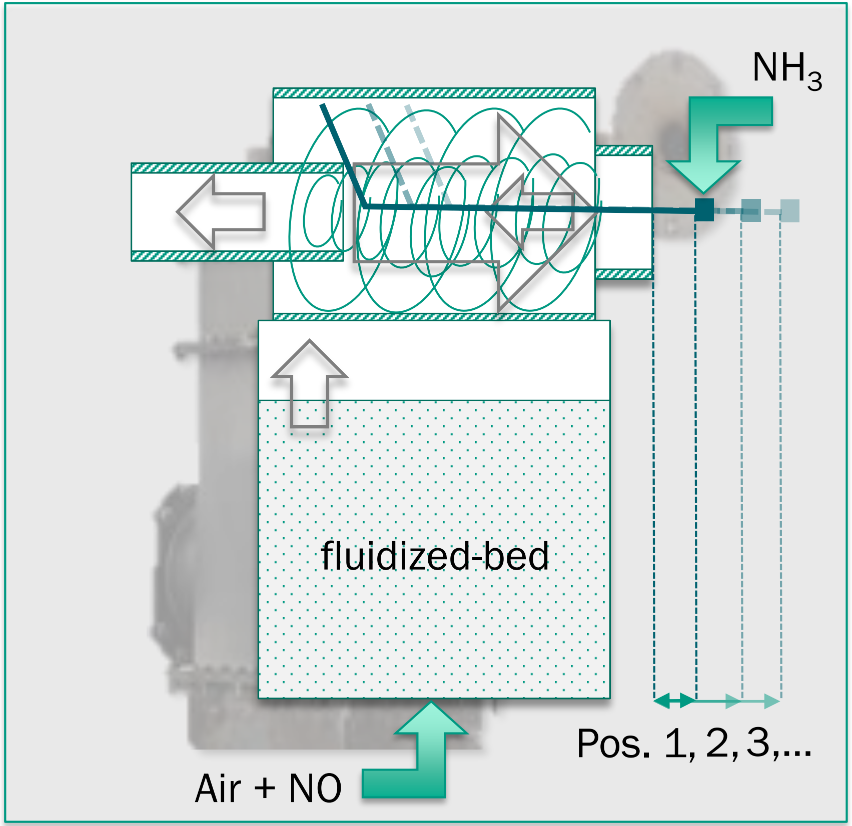
before Reduction ($NO_{initial}$)

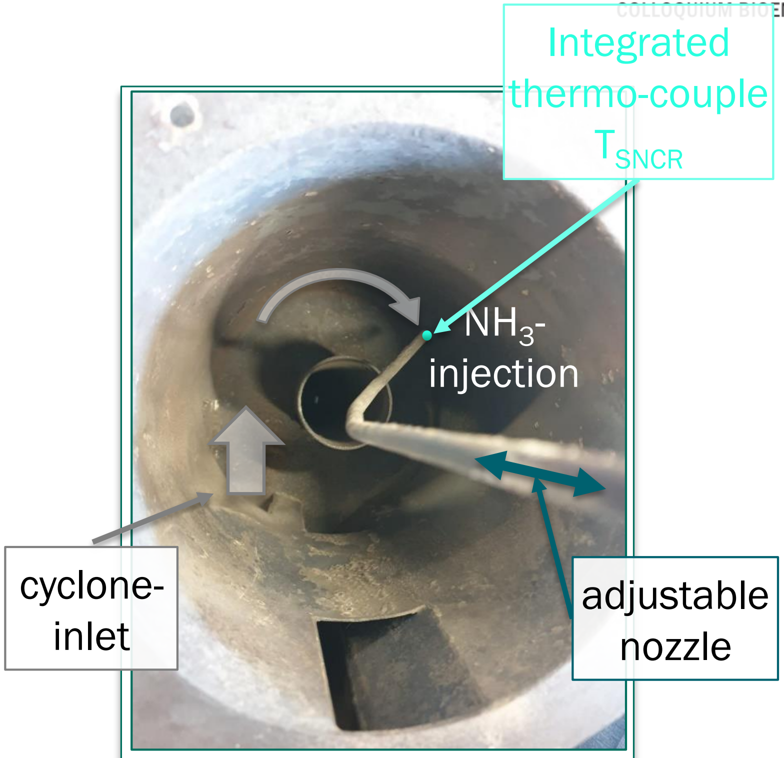
Investigation of NO-reduction by ammonia

(Muzio et al. 1977) :

- optimum temperature: 1170–1270 K or 900-1000° C
- reduction rate increases with β_{NH_3}
- complete NH_3-conversion up to $\beta_{NH_3} = 0{,}5$
- $\beta_{NH_3} > 0{,}5$: ammonia-slip

Experimental Set-Up

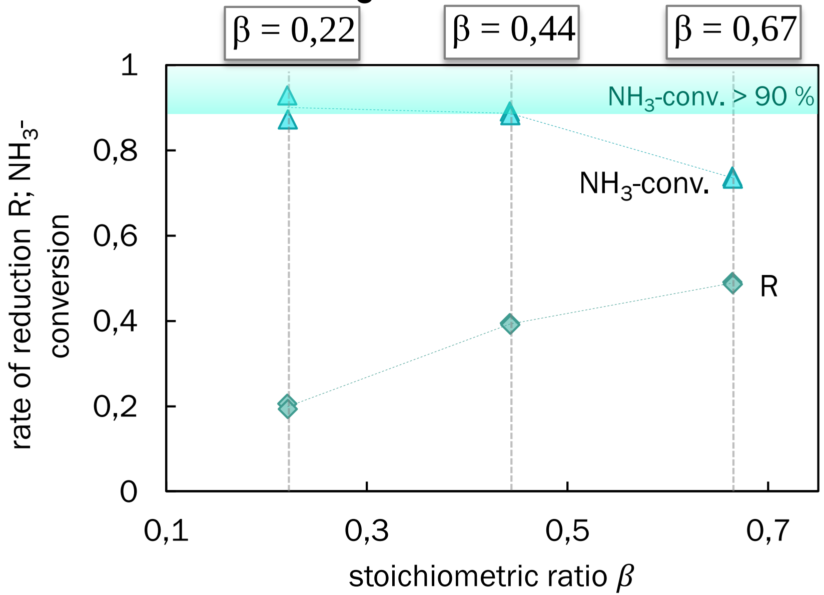




View inside the cyclone

Experimental Results

Influence of NH_3/NO-ratio on reduction rate:



- Rate of reduction R increases with stoichiometric ratio
- NH_3-conversion > 90 % up to $\beta_{NH_3} = 0{,}44$
- $\beta_{NH_3} > 0{,}5$ significant increase of ammonia slip
- ✓ **First results show good agreement with literature**
- **Next steps: investigation of optimum position + T_{SNCR} by external cooling**

Thermal input: 18 kW; λ = 1,4 – 1,6;
NO_{inital} = 300 ppm; T_{SNCR} = 880-970 °C ;
@ Postition 1; 15 min average

Experimental Results

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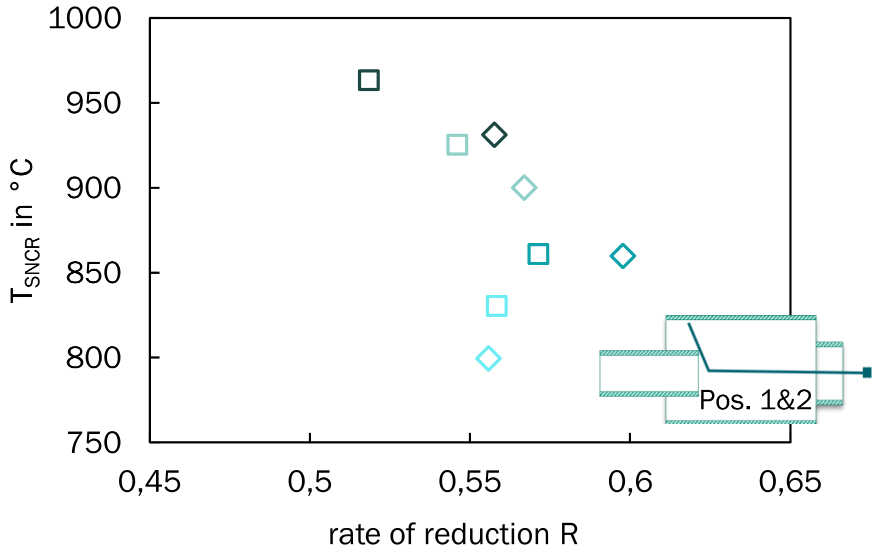
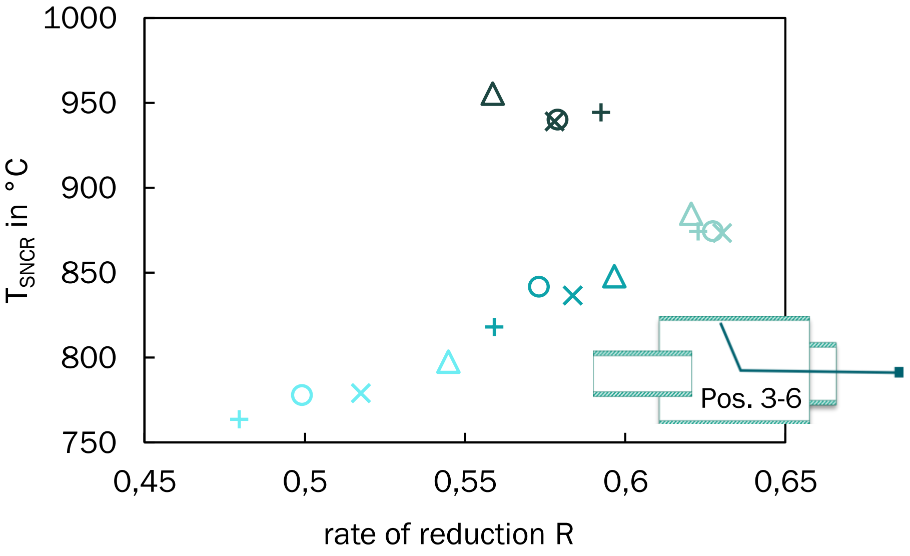
Influence of injection position and temperature on reduction rate:





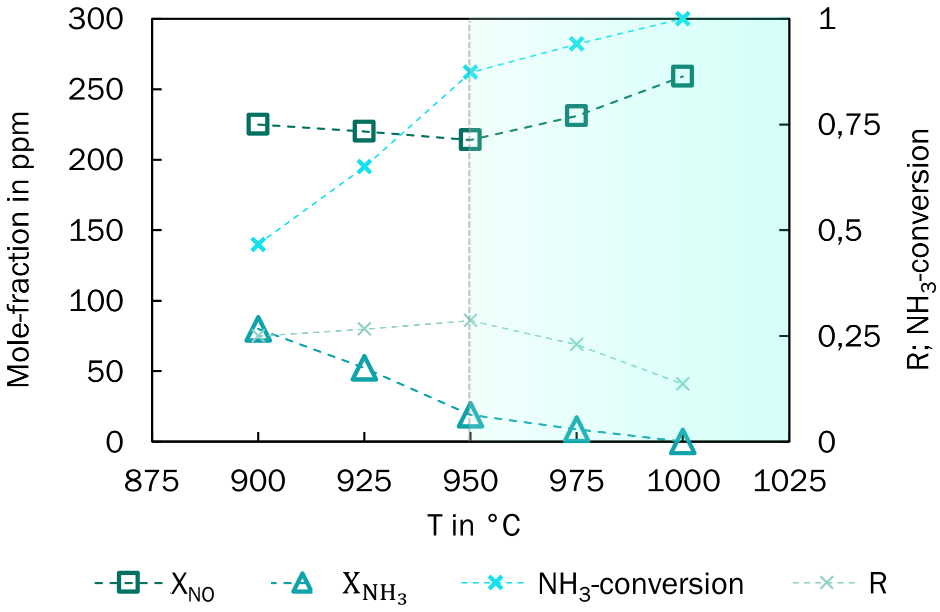
- Near Inlet zone: dominated by combustion, partial oxidation of NH_3
- Slight tendency towards optimum of reduction @ ca. 850 ° C

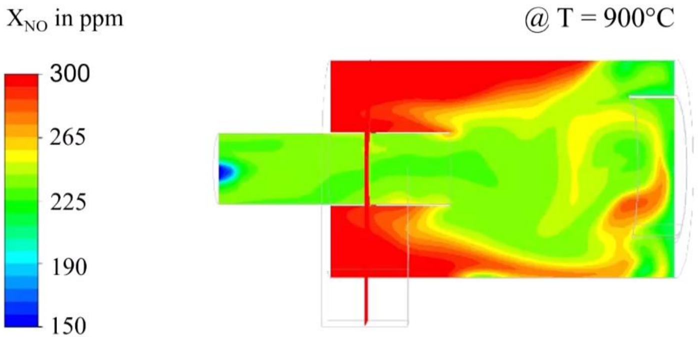
- Shift towards higher rates of reduction
- Clearly identifiable profile of T over R
- Optimum @ ca. T_{SNCR} = 870° C

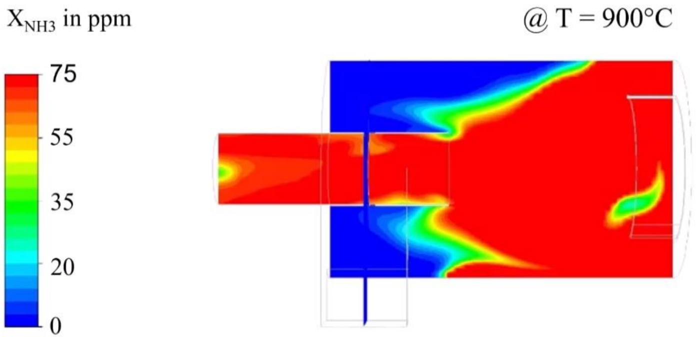
Modelling SNCR

Influence of temperature on reduction rate:

Thermal input: 18 kW; λ = 1,4; NO_{inital} = 300 ppm; β_{NH3}=0,5







- Simulation indicates optimum of R @ 950° C
- Oxidation of NH3 @ T > 950° C

Conclusion

Experiments:

- ✓ SNCR can effectively be used for the reduction of NOx in the small-scale fluidized-bed system
- ✓ Highest rates of reduction were achieved with cooled cyclone → potential for air-preheating in CHP-mode
- ✓ Optimum position + „measured“ temperature range for NH_3-injection identified
- ➢ Currently running: 36h tests with several fuels (unsteady NO_x-emissions)

SNCR -Modell

- ✓ Qualitative description of influence of Temperature on NO-reduction and NH_3-oxidation

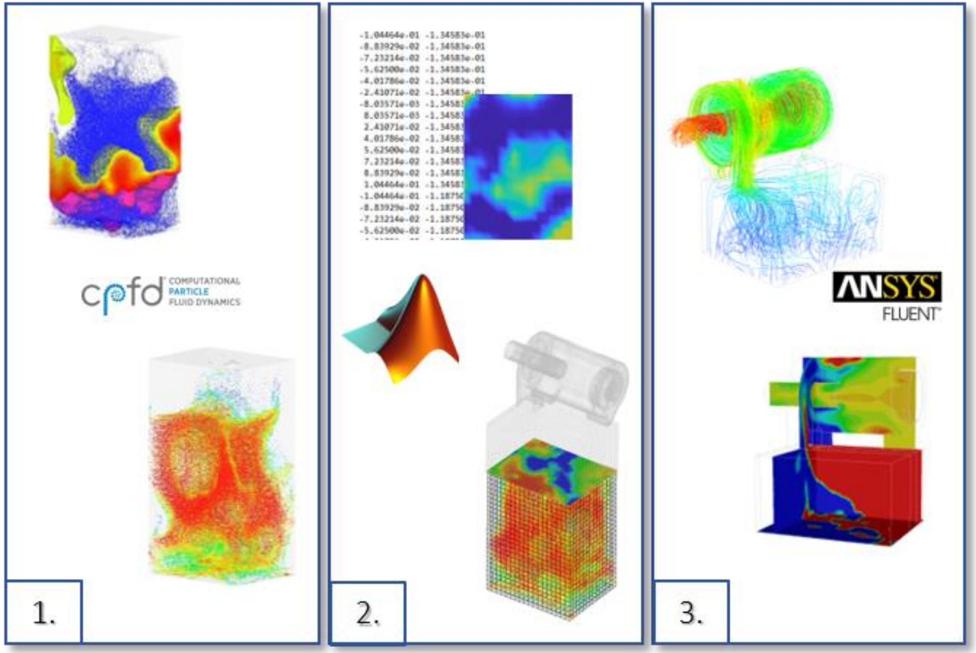
Challenges

- ➢ Validation of heat-transfer
- ➢ Influence of radiation on temperature measurements
- ➢ Prediction of size of combustion-zone inside the cyclone requires consideration of the whole system

Outlook

Coupling fuel conversion + gas phase reactions

1. Fuel Conversion and NO_x-formation in Barracuda VR
2. Data analysis and – translation in Matlab (profile-files of gas-composition, -velocity and –temperature)
3. Gas-phase reactions (combustion + SNCR in Ansys Fluent)



Benefits:

- Consideration of non-ideal mixing of air and fuel → better description of combustion-zone inside the cyclone
- Transient effects (i.a. rising gas-bubbles) can be taken into account

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