unibz Freie Universität Bozen
Libera Università di Bolzano
Free University of Bolzano

THESSALONIKI2021
www.thessaloniki2021.uest.gr

Bioenergy & Biofuels LAB

8 th International Conference on Sustainable Solid Waste Management

24 June 2021

Effect of char recirculation in fixed bed gasifiers: experimental and modelling analysis

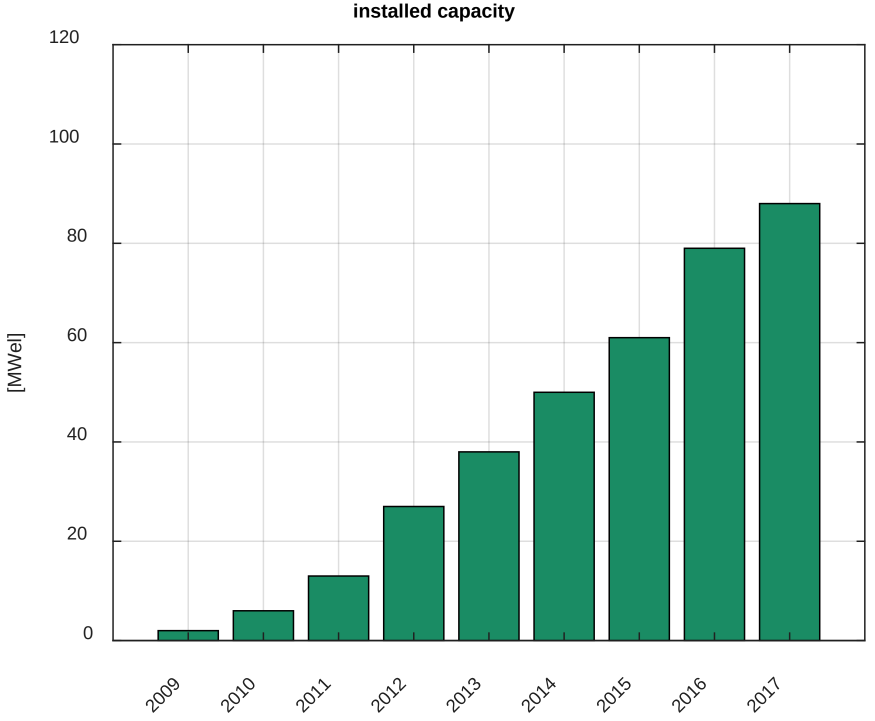
Francesco Patuzzi [1], Daniele Antolini [1], Stergios Vakalis [2], Marco Baratieri [1]

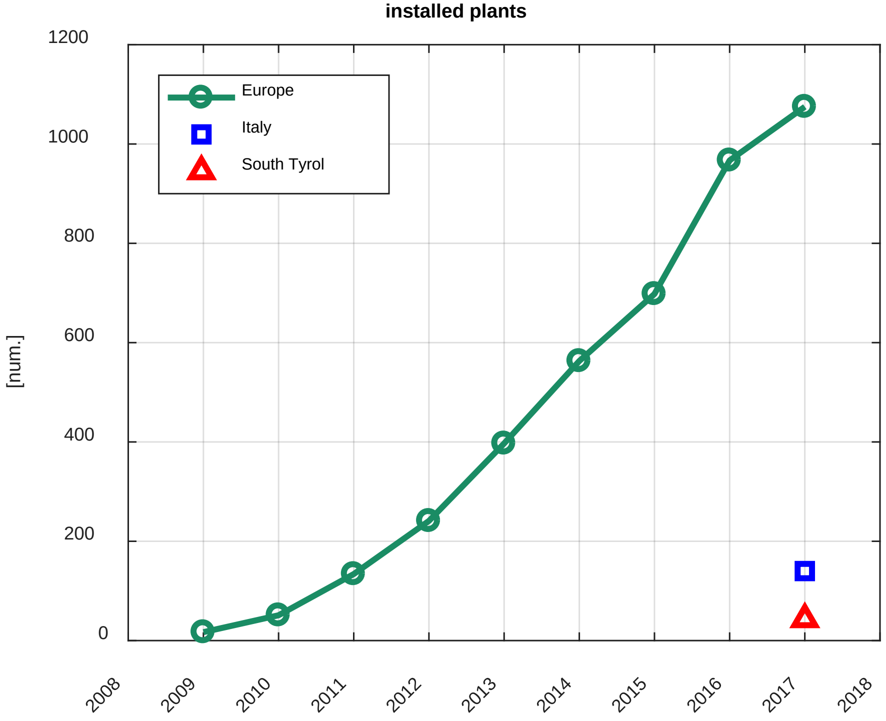
[1] Faculty of Science and Technology, Free University of Bozen-Bolzano, Italy
[2] University of the Aegean, Mytilene, Greece

Small-scale biomass gasification in EU

Size of the plants < 0.5 MW_{el}
Number of installed plants > 1000

Application: CHP (feed in tariff)
Technology: fixed bed gasifiers





Source: 2018 - IEA bioenergy Task 33

The South Tyrol (Südtirol) region

Area: 7400 km^2
Population: 511750 ab.
42% forest

46 plants in operation
~ 1300 ton/year of char
150 €/ton for disposal

Possible utilization pathways

Many possible application are reported in the literature

- for co-firing in power plants
- as soil improver
- as adsorbent
- as catalytic support

THE AIM OF THIS WORK is
to investigate the effect of
recirculating char
in fixed bed gasification systems

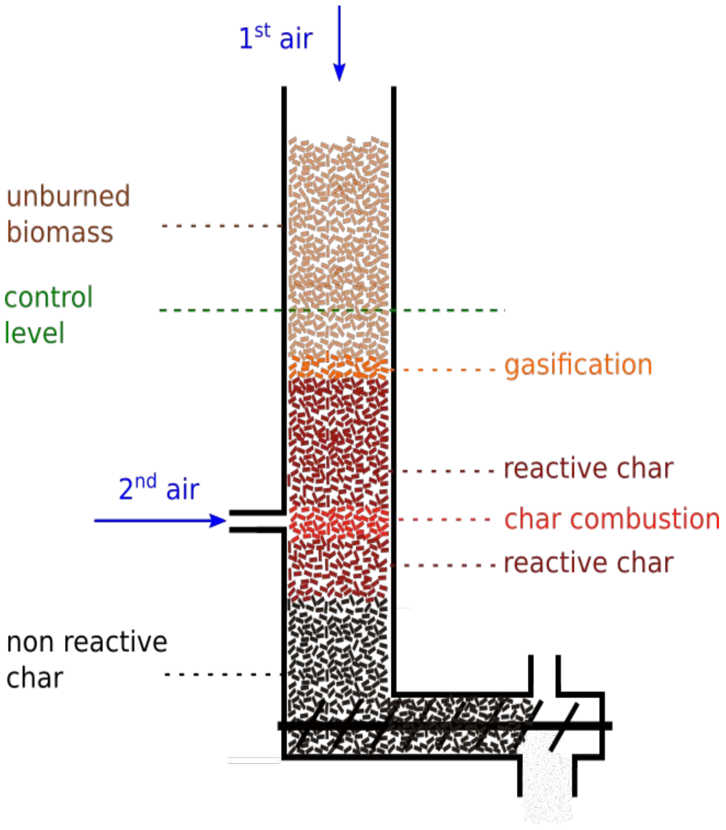
Open-top gasifier

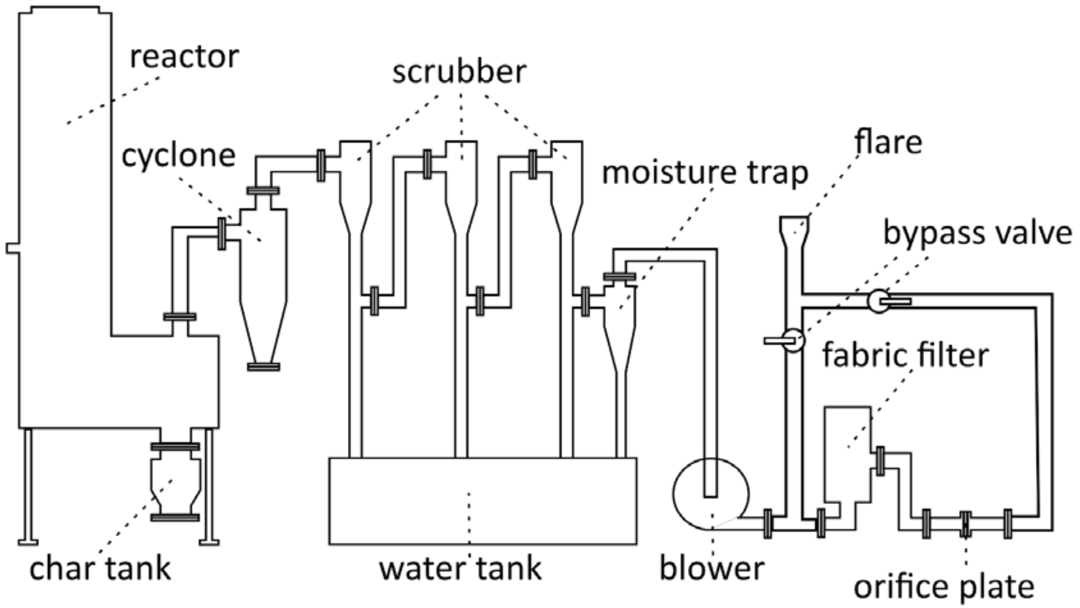
Fixed bed reactor – Nominal size: 4 kg_{biom}/h





Open-top gasifier





Measured quantities and characterized properties

- Mass IN
- Mass OUT
- Charge and discharge time

- Secondary air mass flow rate (mass flow controller)
- Producer gas flow rate (differential pressure over a calibrated orifice)
- Gas composition (microGC)

Derived quantities and process parameters

- Biomass and char mass flow rates

- Total air IN (nitrogen balance)
- Equivalence Ratio

- Energy fluxes
- Cold Gas Efficiency

Fuel characterization

Standard spruce pellet EN plus A1 – 6 mm diameter

- moisture content
- ash content
- elemental analysis C,H,N,S (Vario MACRO Cube, Elementar)
- HHV - LHV (C 200 - IKA)

Moisture	Ash	C	H	N	S	O	LHV
[%wt_{ar}]			[%wt_{dry}]				[MJ/kg_{dry}]
7.1	0.3	49.8	5.6	0.1	0.4	43.8	16.9

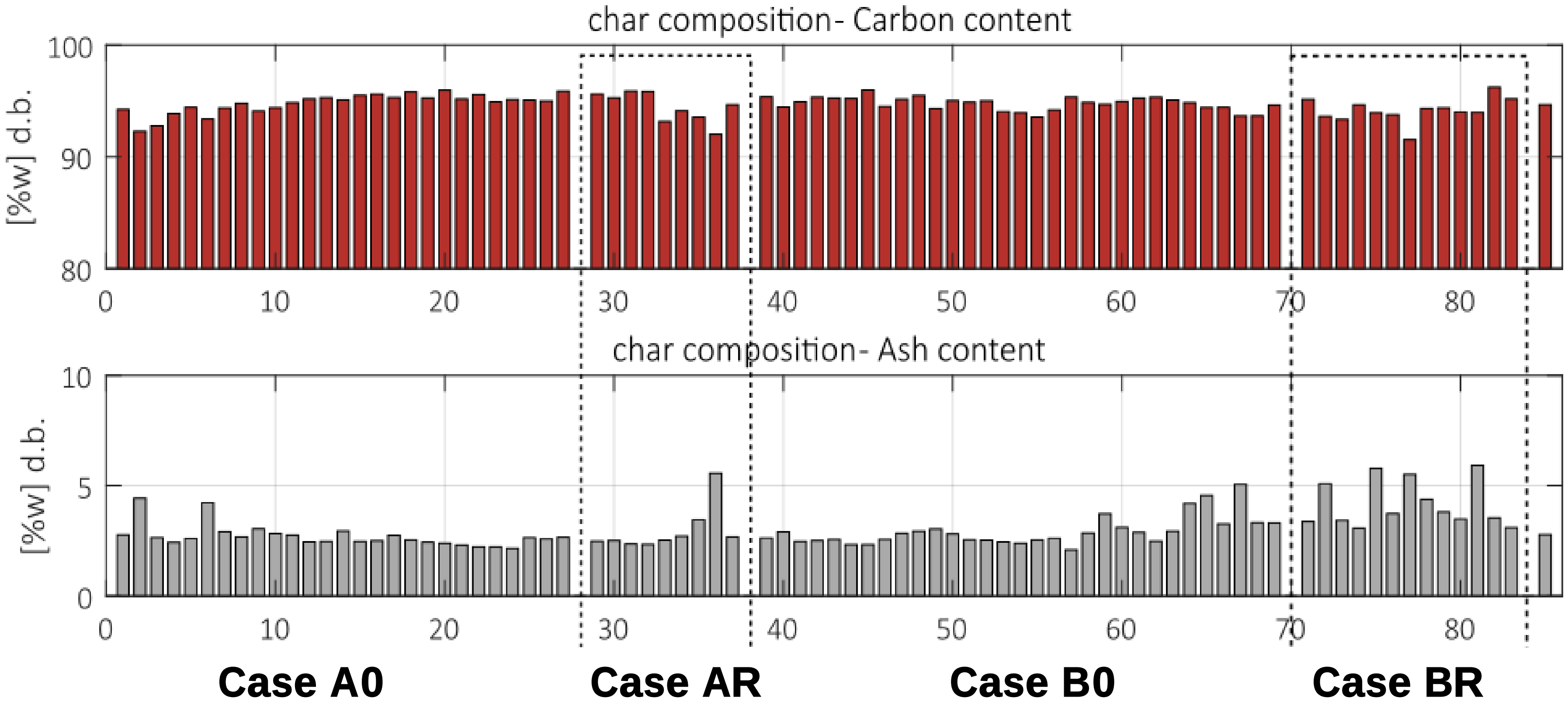
Study cases

	char yield / recirc. share [%]	2^{nd} air injected [NLPM]	Blower SP [Hz]	ER (when the fuel is only biomass) [-]
Case A	~ 10	10	40	< 0.25
Case B	~ 5	26	40	~ 0.25

Sub-cases

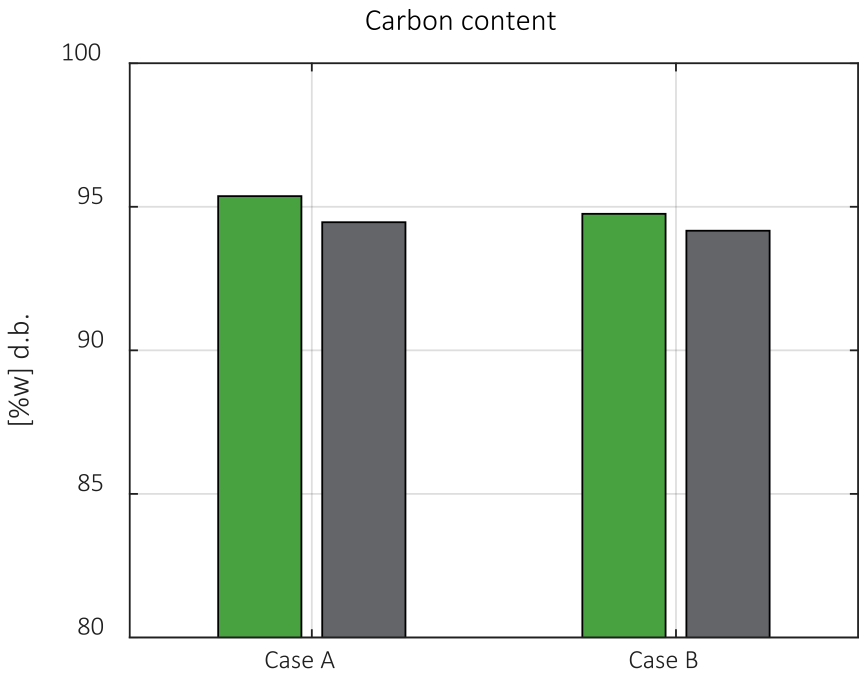
- **0:** fuel IN = standard pellet (biomass)
- **R:** fuel IN = standard pellet (biomass) + char (produced in the corresponding sub-case 0)

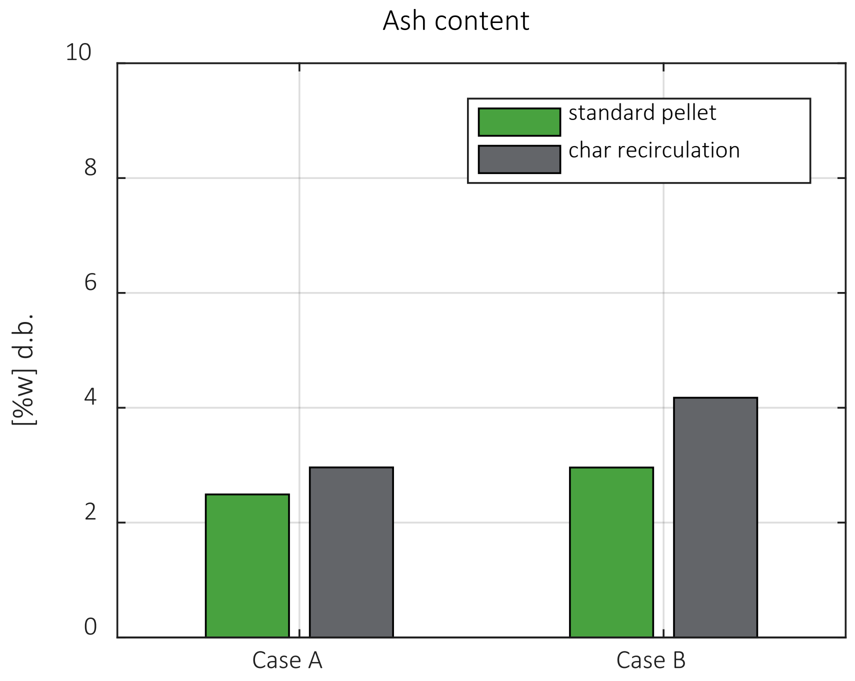
Char characterization



Char characterization

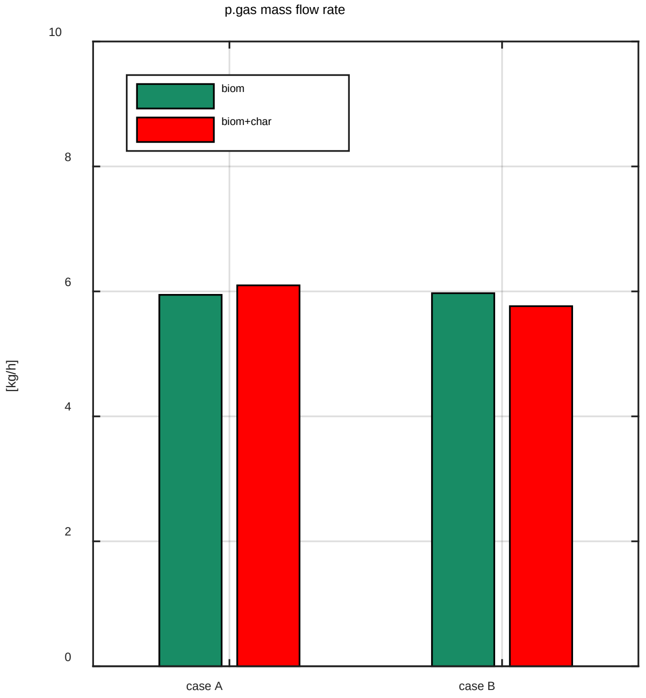
- higher ash content → higher conversion

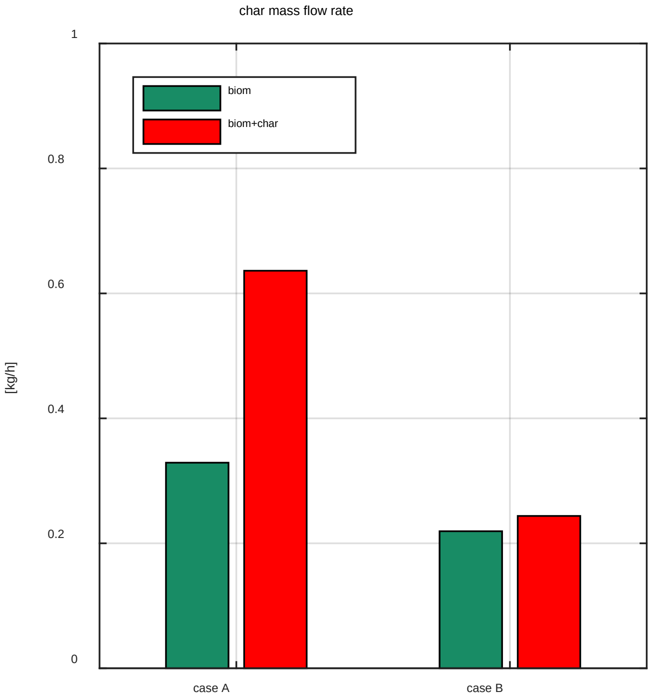




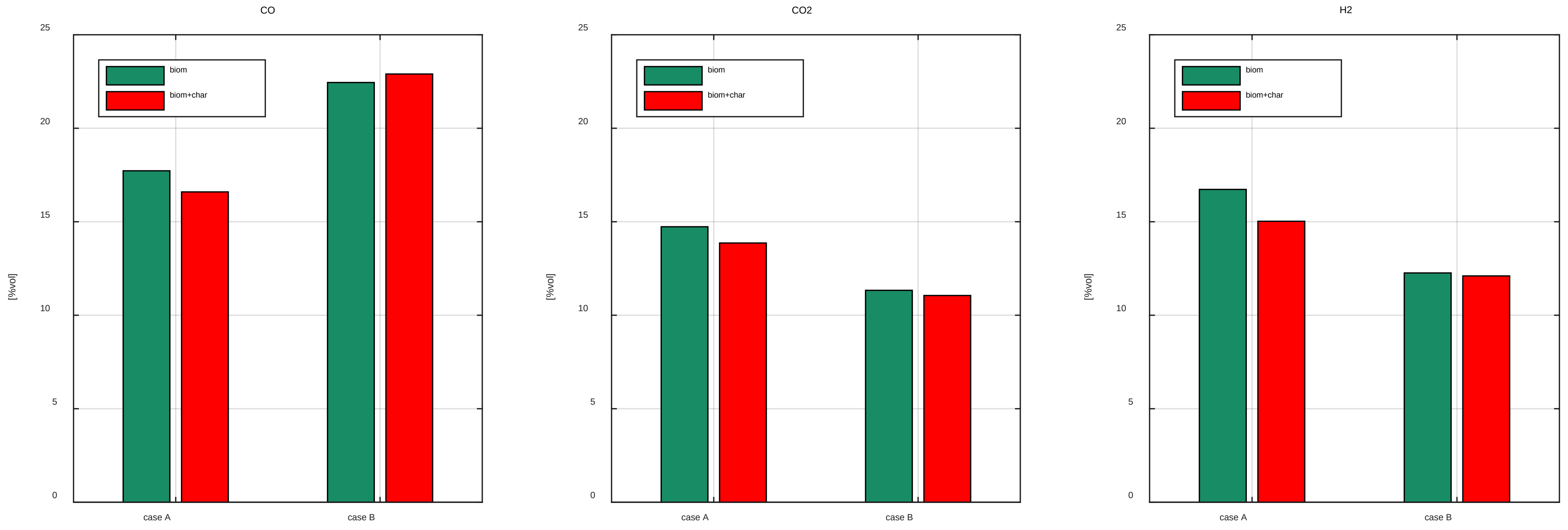
Mass flow rates

- producer gas: almost constant
- char: increases

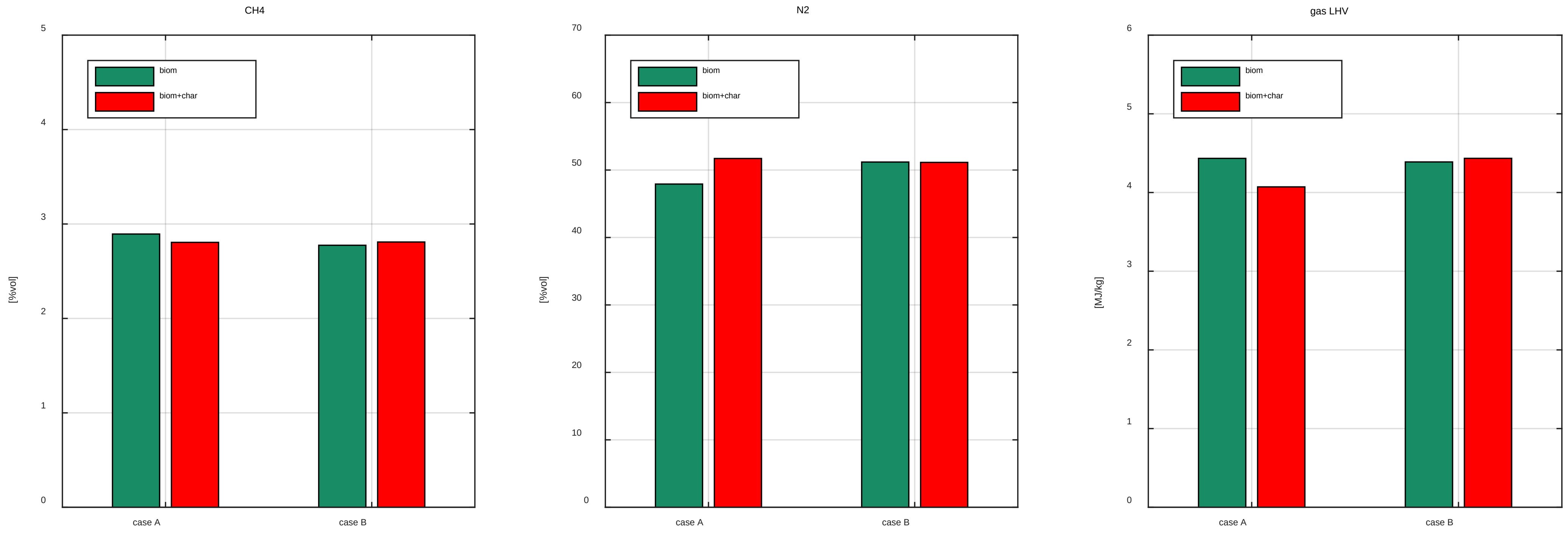




Gas composition

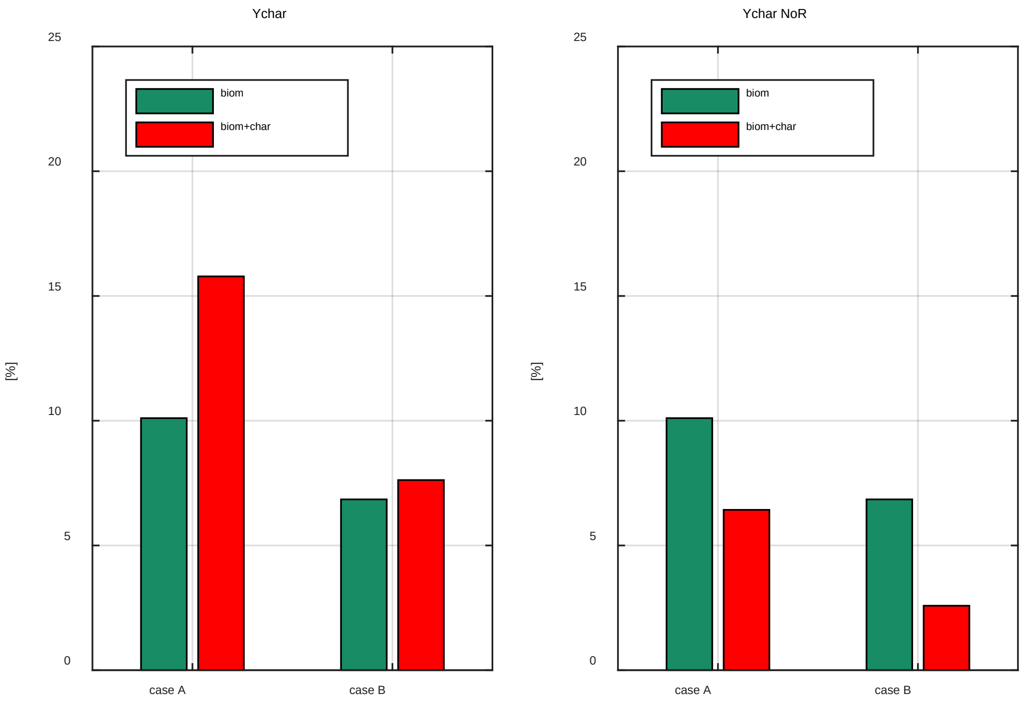


Gas composition



Overall effect of char recirculation

- Overall char yield: decreases

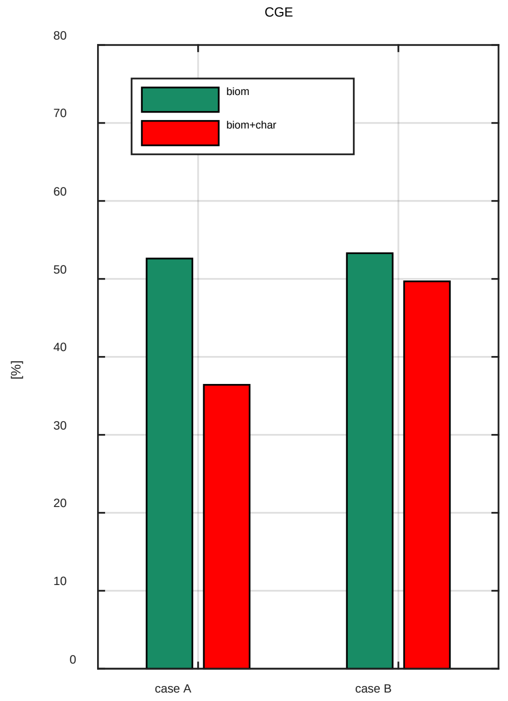


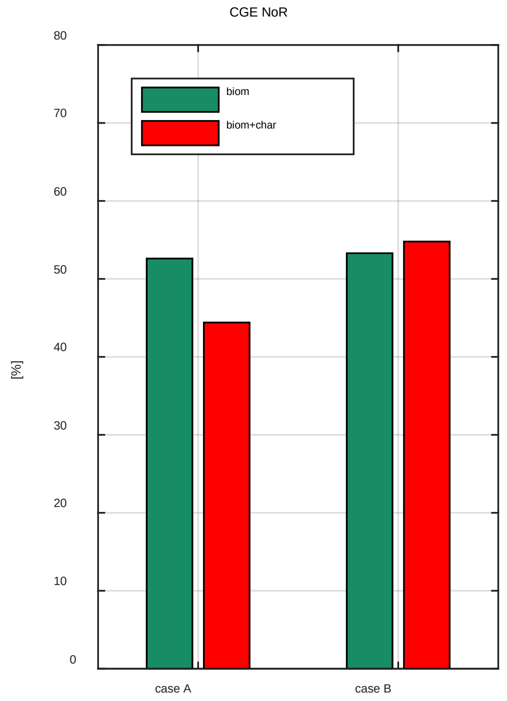
$$Y_{char} = \frac{\dot{m}_{char\ OUT}}{\dot{m}_{biom\ IN} + \dot{m}_{charIN}}$$

$$Y_{char\ NoR} = \frac{\dot{m}_{char\ OUT} - \dot{m}_{charIN}}{\dot{m}_{biom\ IN}}$$

Overall effect of char recirculation

- Overall char yield: decreases
- Overall CGE: increases in case B (process conditions better tuned up)





$$CGE = \frac{\dot{m}_{pgas} \cdot LHV_{pgas}}{\dot{m}_{biom\ IN} \cdot LHV_{biom\ IN} + \dot{m}_{charIN} \cdot LHV_{charIN}}$$

$$CGE_{NoR} = \frac{\dot{m}_{pgas} \cdot LHV_{pgas}}{\dot{m}_{biom\ IN} \cdot LHV_{biom\ IN}}$$

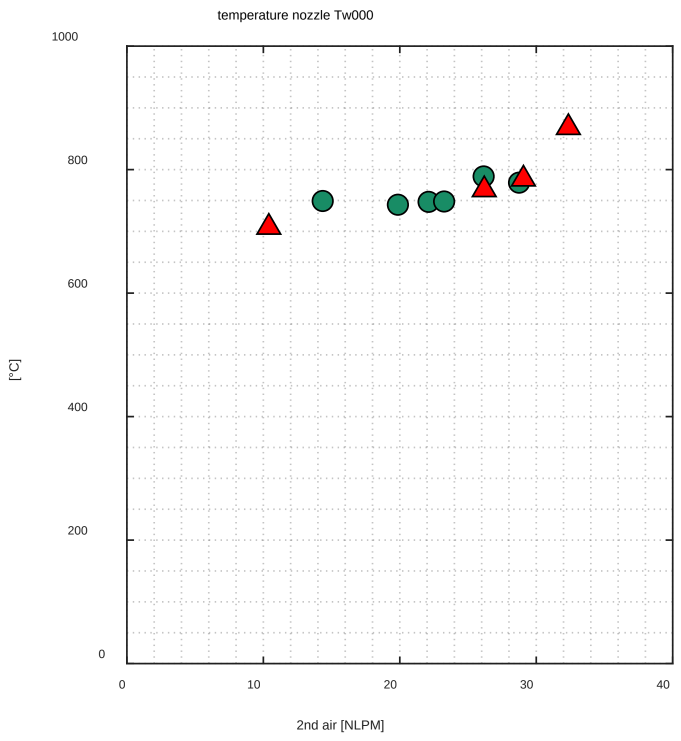
2nd air modulation

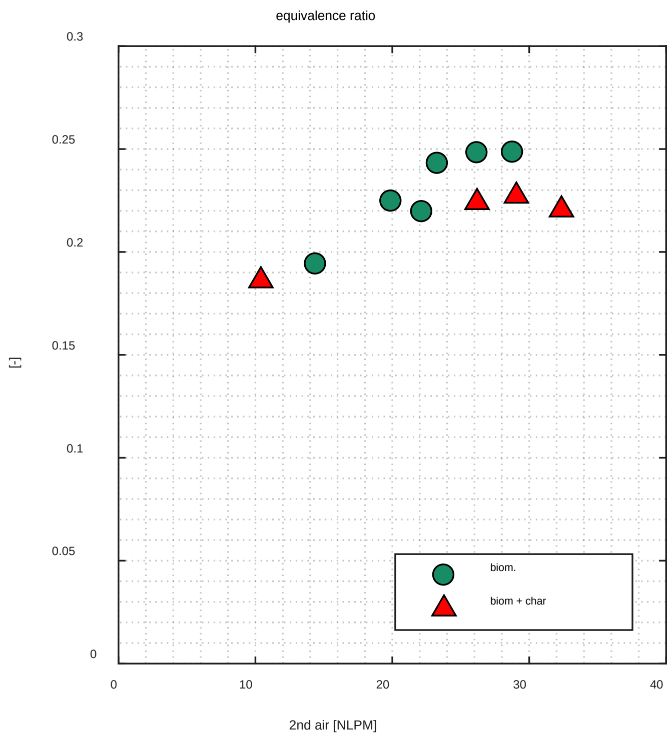
- Can the process conditions be further tuned up to optimize the process for char recirculation?

	char yield / recirc. share [%]	2nd air injected [NLPM]	Blower SP [Hz]	ER (when the fuel is only biomass) [-]
Case C	3 - 10	14 - 32	40	0.19 - 0.25

2nd air modulation

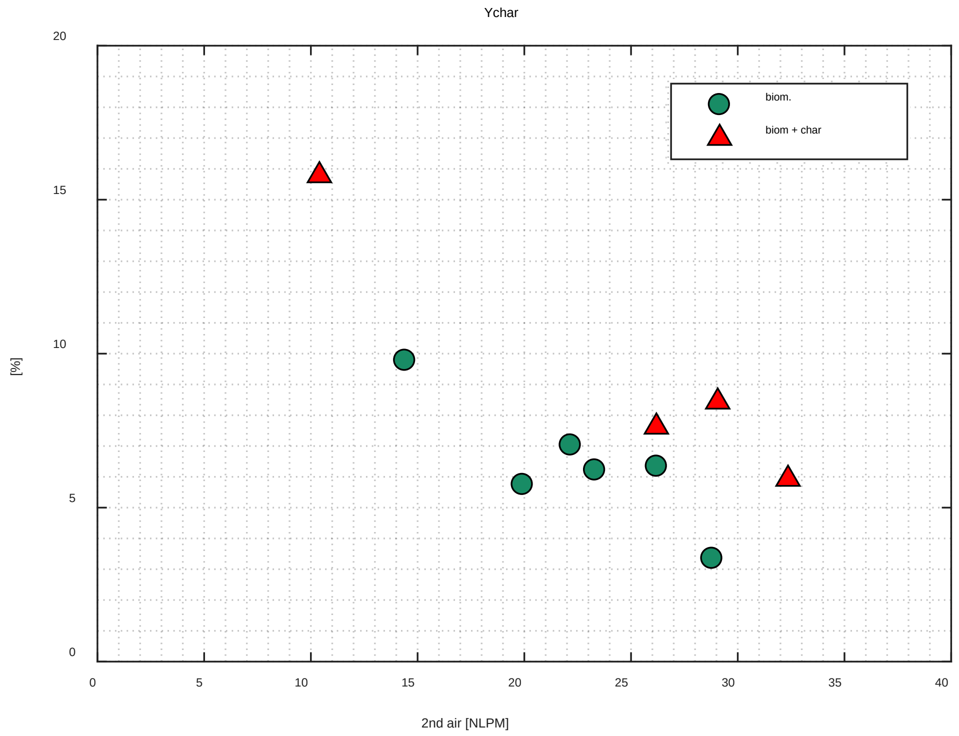
Main effects of increasing 2nd air flow rate

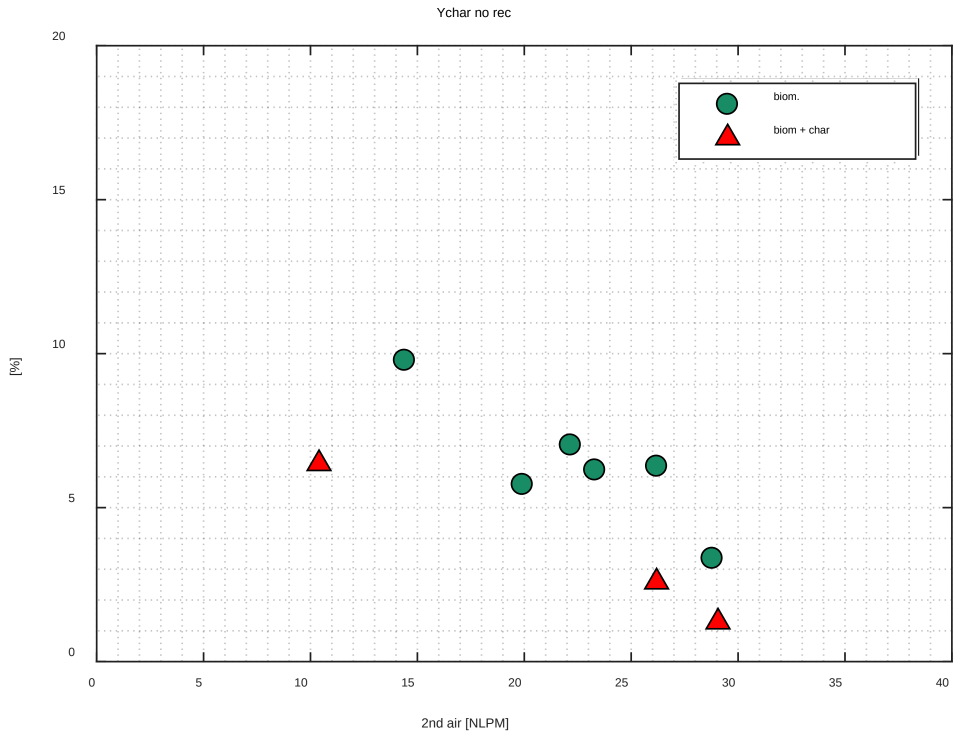




2nd air modulation

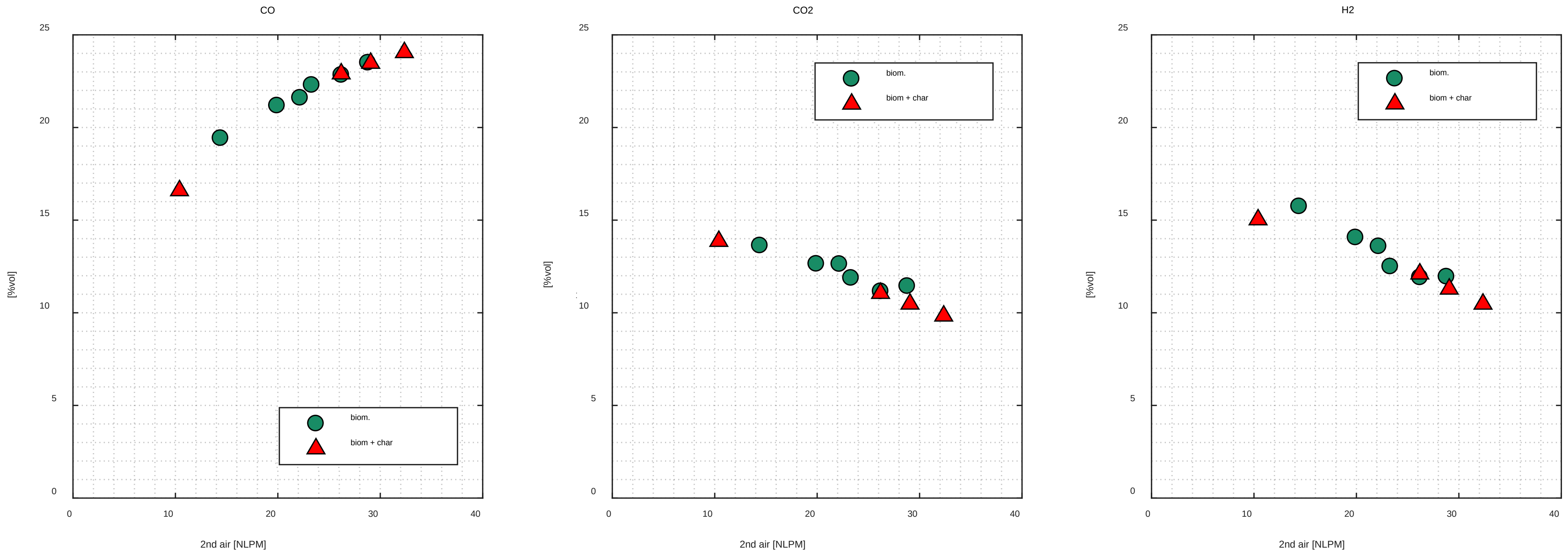
Char yield





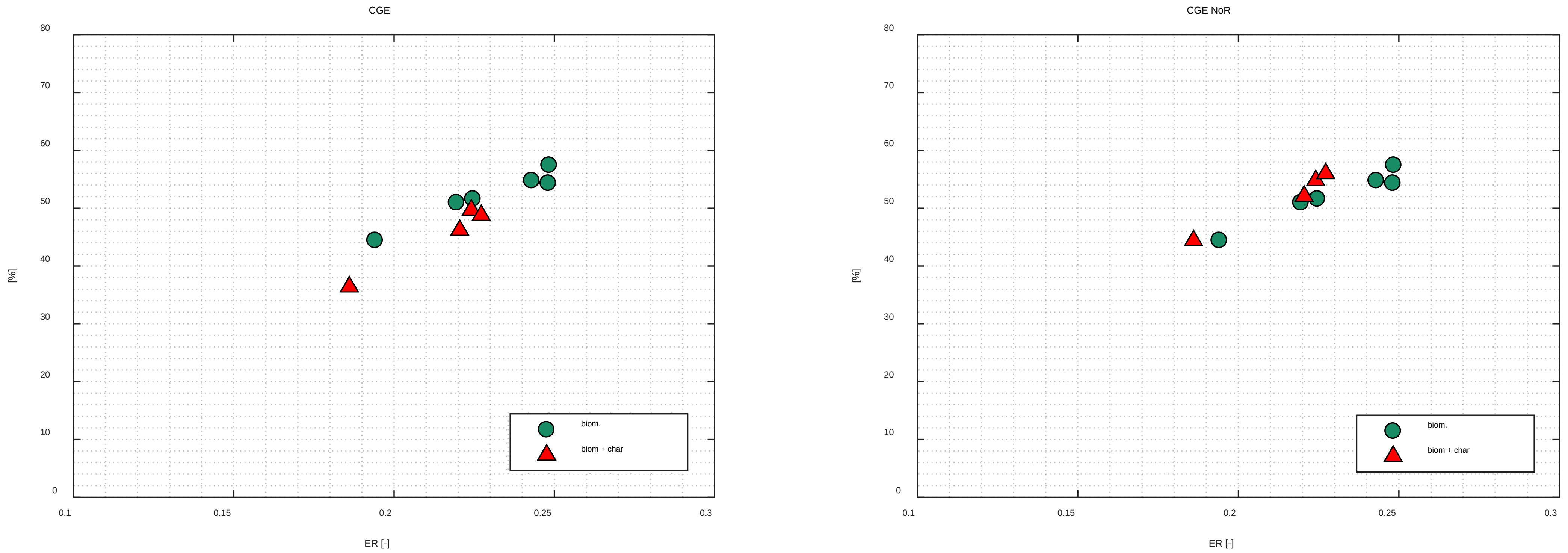
2nd air modulation

Gas composition



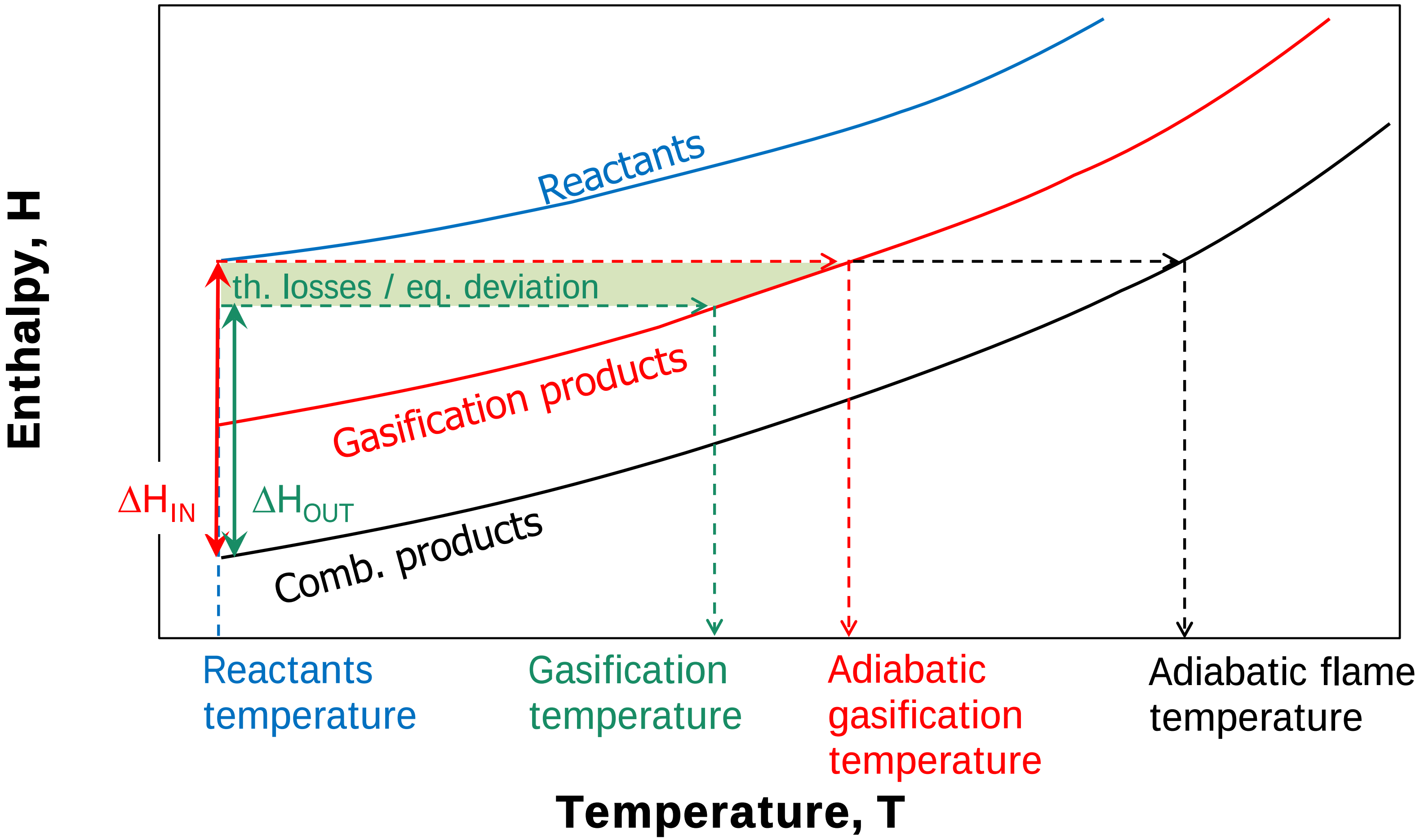
2nd air modulation

Cold gas efficiency



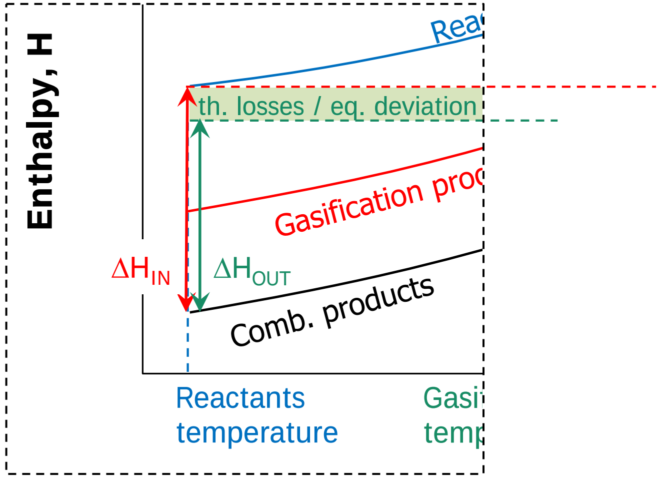
Modelling approach

- based on a **thermodynamic solid-gas equilibrium** approach (Gibbs energy minimization method)
- overcomes the issues of the classical equilibrium strategy (fixed temperature and pressure)
- introduction of an **adiabatic gasification temperature**, defined in analogy to the concept of **adiabatic flame temperature** for the combustion process.



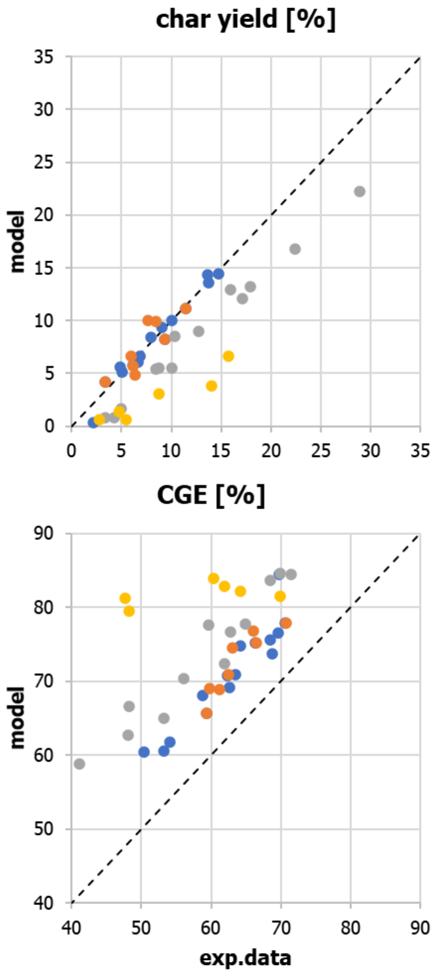
Model calibration

$$\textbf{correction} = \frac{\Delta H_{OUT}}{\Delta H_{IN}}$$



Model calibration

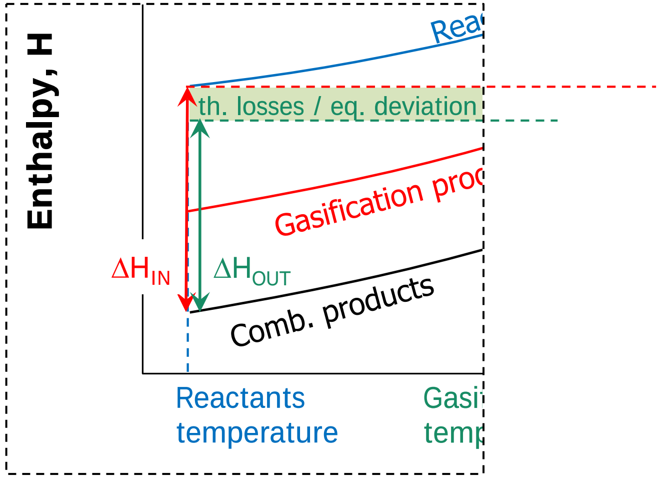
Adiabatic formulation



Four different exp. campaigns

- LOAD MODULATION (LM)
- CHAR RECIRCULATION (CR)
- TORREFIED PELLETS (TP)
- BARK AND CHIPS (BC)

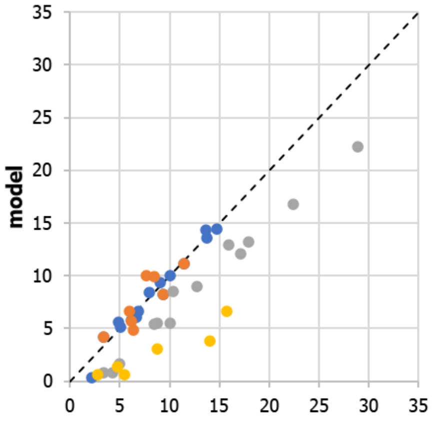
$$\text{correction} = \frac{\Delta H_{OUT}}{\Delta H_{IN}}$$



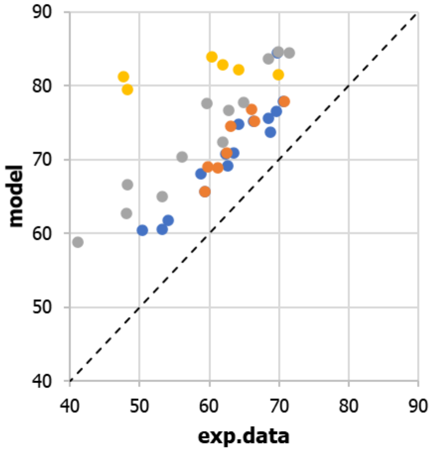
Model calibration

Adiabatic formulation

char yield [%]



CGE [%]



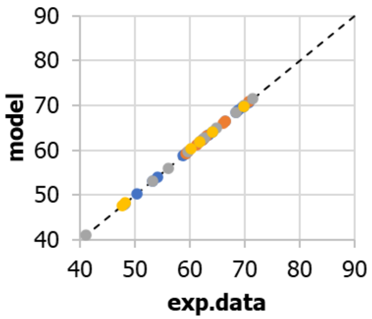
Four different exp. campaigns

- LOAD MODULATION (LM)
- CHAR RECIRCULATION (CR)
- TORREFIED PELLETS (TP)
- BARK AND CHIPS (BC)

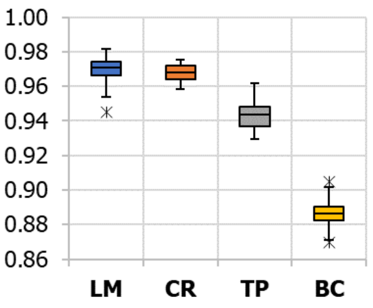
Calibration to match the experimental CGE

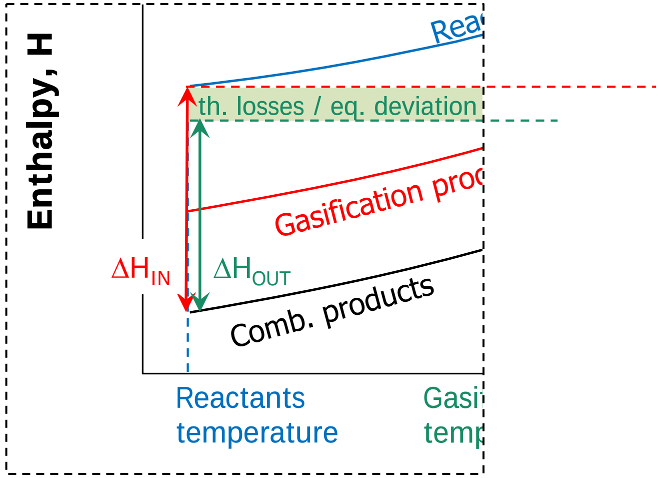
$$\text{correction} = \frac{\Delta H_{OUT}}{\Delta H_{IN}}$$

CGE [%]



correction [-]

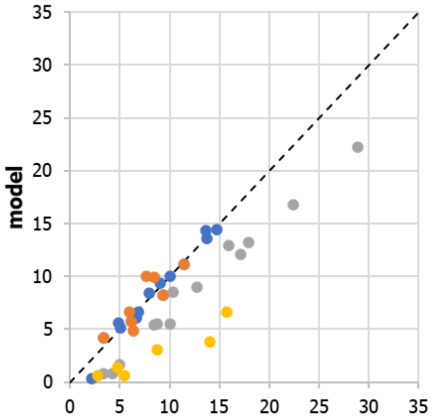




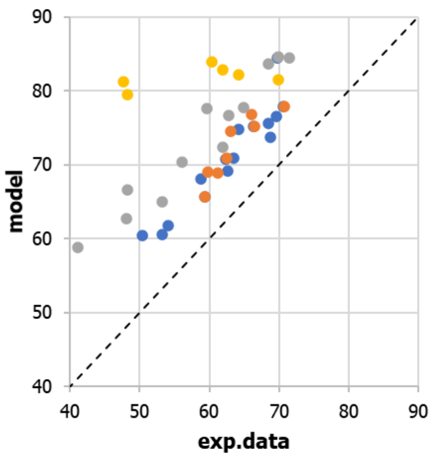
Model calibration

Adiabatic formulation

char yield [%]



CGE [%]



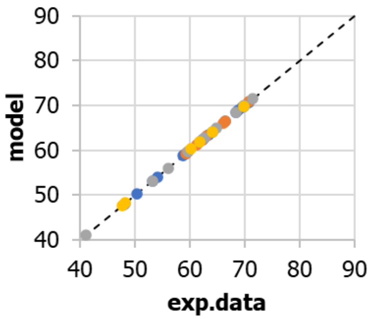
Four different exp. campaigns

- LOAD MODULATION (LM)
- CHAR RECIRCULATION (CR)
- TORREFIED PELLETS (TP)
- BARK AND CHIPS (BC)

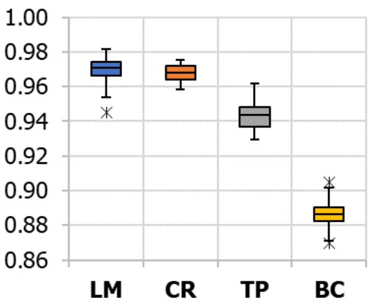
Calibration to match the experimental CGE

$$\text{correction} = \frac{\Delta H_{OUT}}{\Delta H_{IN}}$$

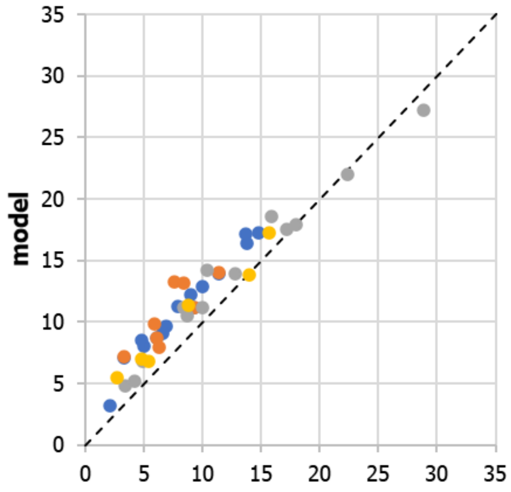
CGE [%]



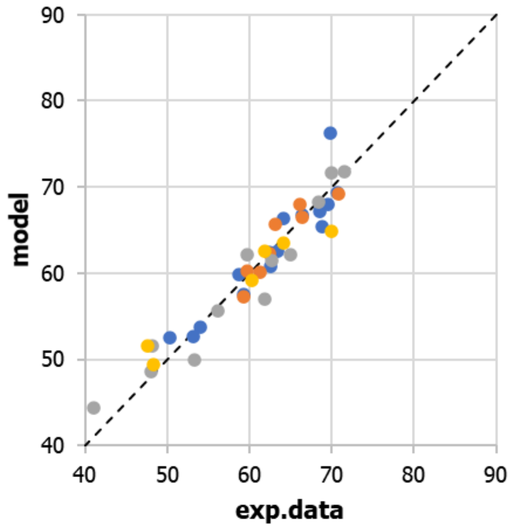
correction [-]



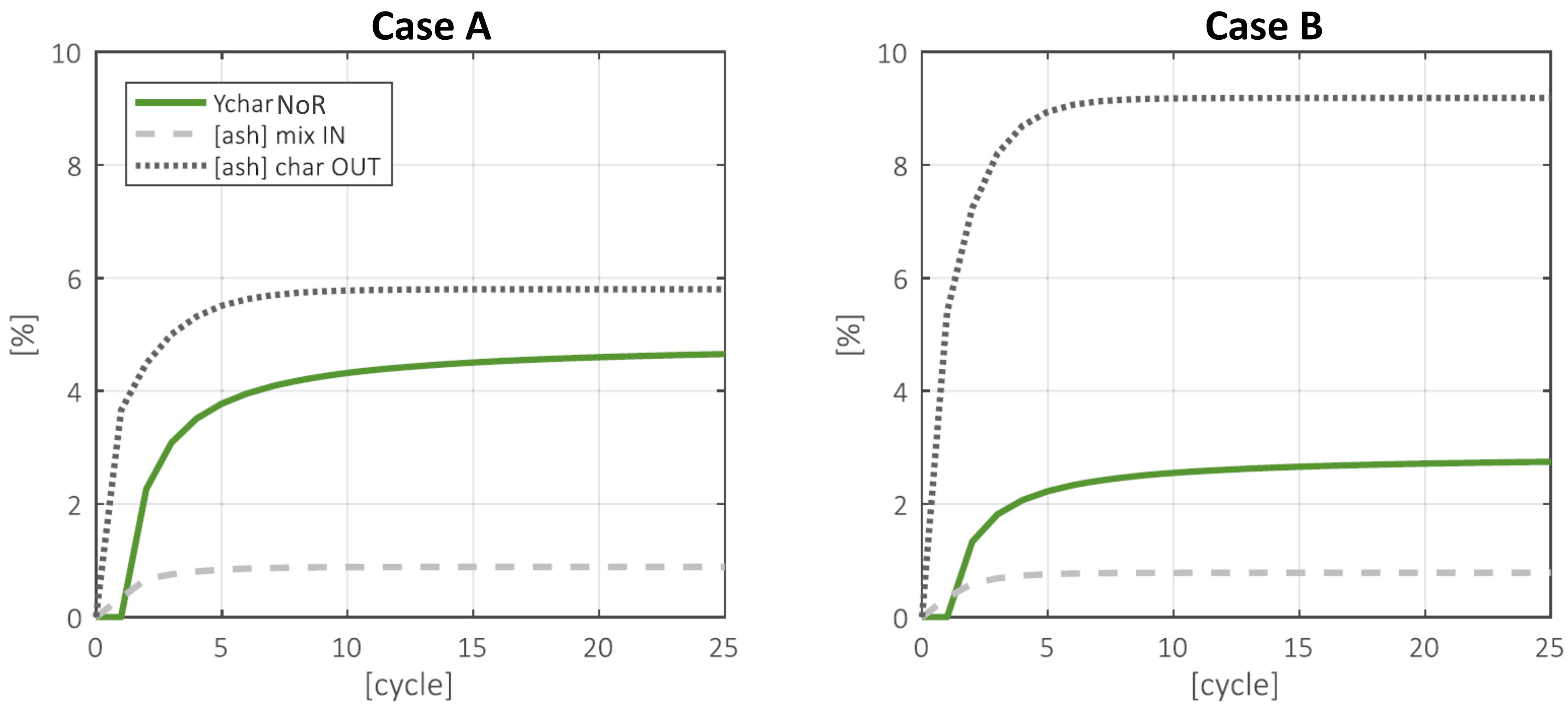
char yield [%]



CGE [%]



Long term effect of char recirculation



Conclusions

Char recirculation:

- Allows a significant reduction of the overall char yield (in the order of 40 - 60 %)
- Do not significantly impact the process if this is well tuned up
  - Gas composition and LHV remain almost constant
  - CGE slightly decreases (as per the producer gas flow rate)
  - Considering the overall effect, CGE slightly increases
- Secondary air modulation can make even more feasible char recirculation
- An asymptotic condition is reached after a certain number of recirculation cycles, as confirmed by both modelling and experimental results

Open question

- What is the effect of granulometry?
  (this worked well, but the char particles were still maintaining the original pellet shape)

Acknowledgments

This work was funded by unibz

in the frame of the project **CHAR-RCC**:

“CHAR Re-Circulation for improving the Conversion yields in fixed-bed biomass gasification systems”

Freie Universität Bozen
Libera Università di Bolzano
Free University of Bolzano

THESSALONIKI2021
www.thessaloniki2021.uest.gr

24 June 2021

Thank you very much for your kind attention!

francesco.patuzzi@unibz.it

visit us @
bnb.groups.unibz.it