Acid Gas Control under Air and Oxy-fuel Firing Conditions

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Economic low carbon power Production and Emissions Control for Future and Flexible Biomass Co-fired Power Stations

Outline

- Motivation
- Introduction
- Methodology
- Results
- Conclusion

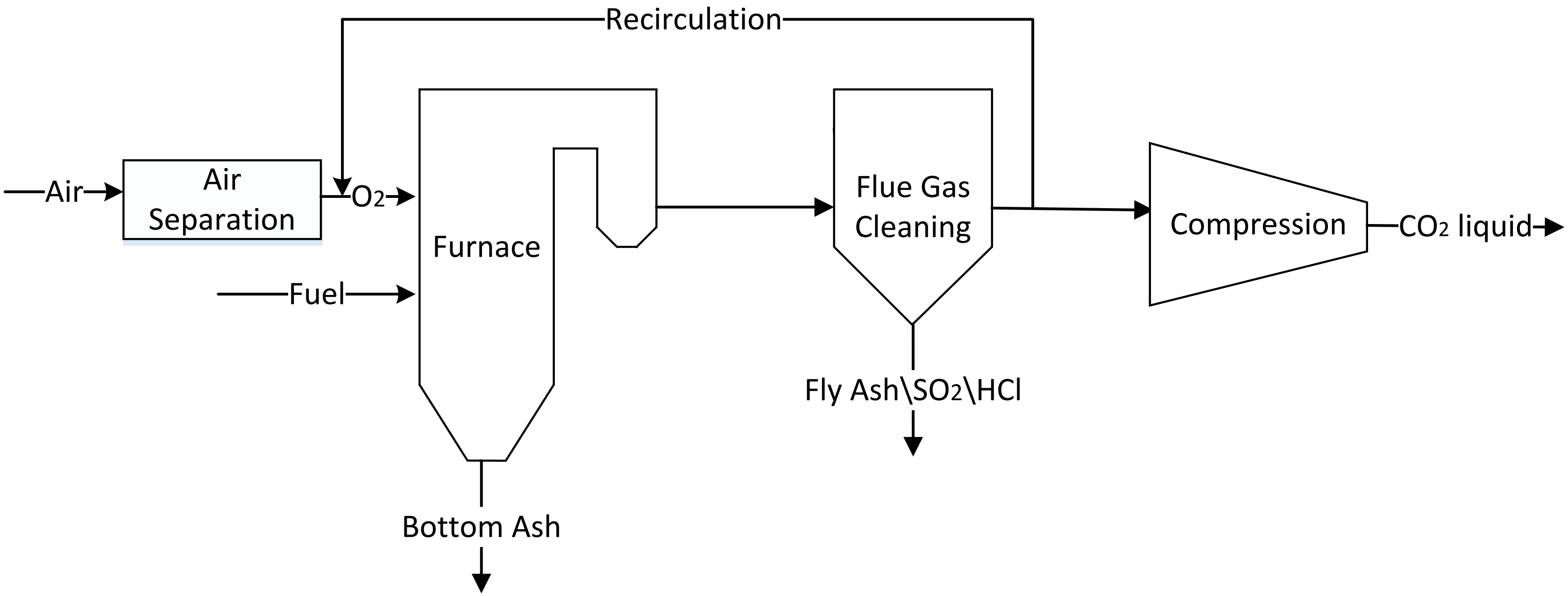
BiOxySorb Project

- Carbon-intensity reduction in coal power plants
  - Biomass co-combustion
  - Oxy-fuel combustion
  - Biomass co-combustion in oxy-fuel mode
- Emission Control
  - Dry sorbent injection
  - Biomass co-combustion

Biomass Co-combustion

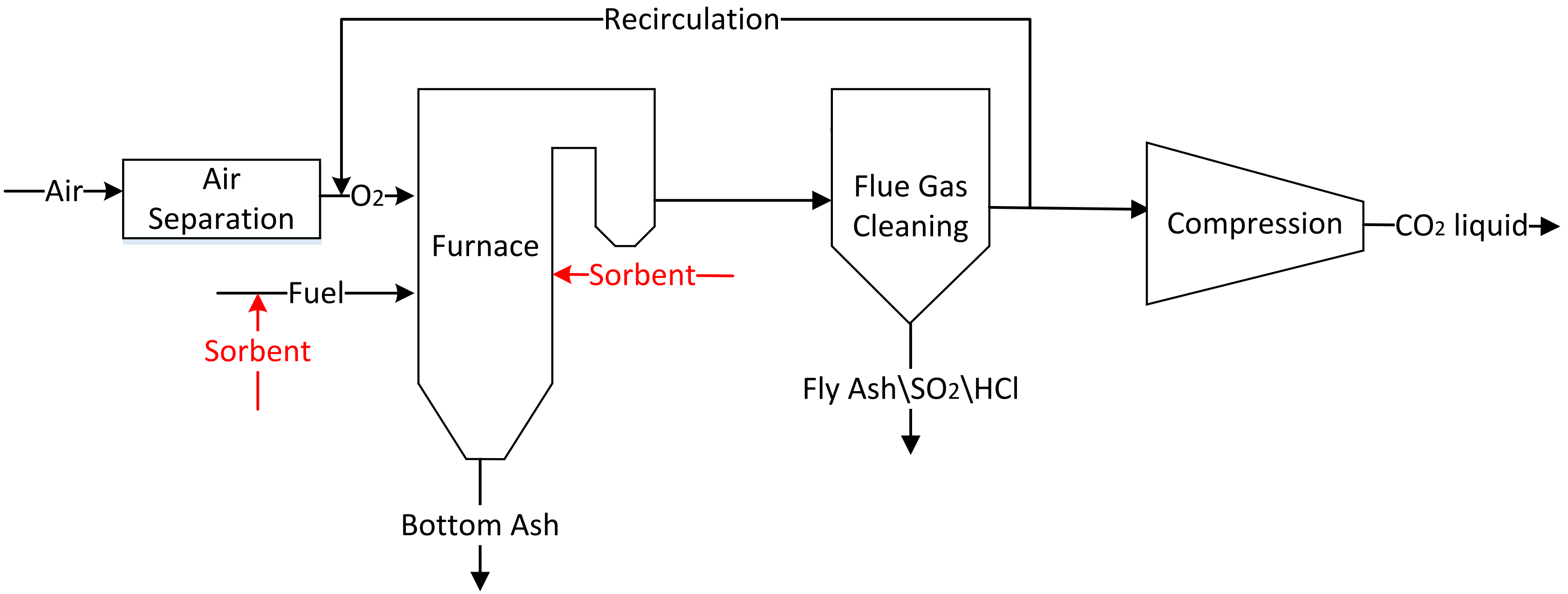
- 1st and 2nd generation of biomasses
- Emission reduction by different shares of biomass co-combustion with more than 10% co-firing share on thermal basis
- Biomass co-combustion in oxy-fuel conditions

Oxy-fuel Process



- Recirculation of flue gas in oxy-fuel technology for carbon capture and storage
- Separation of airborne N_2 in oxy-fuel and consequently 3-4 times higher acid gases concentration

Dry Sorbent Injection (DSI)



Calcination

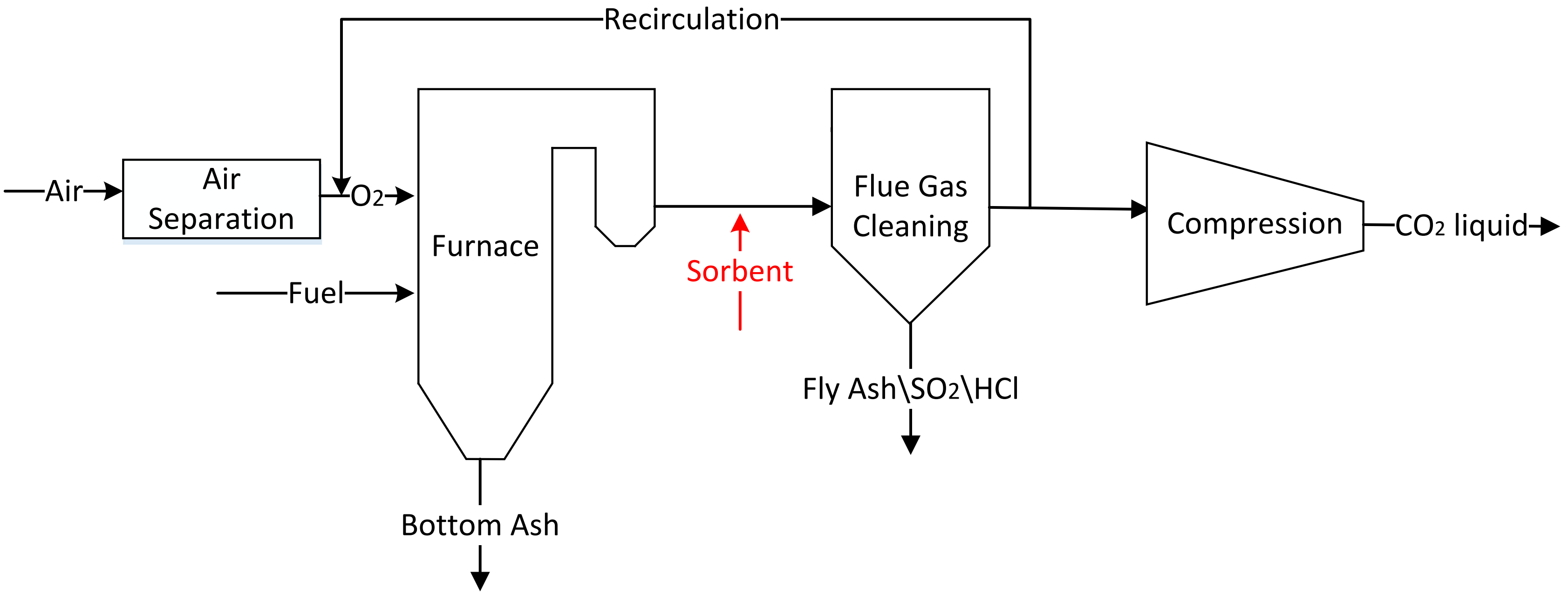
$CaCO_3 \rightarrow CaO + CO_2$ (above T=650-850°C)

$Ca(OH)_2 \rightarrow CaO + H_2O$

Desulphurization

$CaO + SO_2 + 0.5\ O_2 \rightarrow CaSO_4$ (unstable above ~T=1200°C)

Dry Sorbent Injection (DSI)



Direct Desulphurization

$$Ca(OH)_2 + 2HCl \rightarrow CaCl_2 + 2H_2O$$

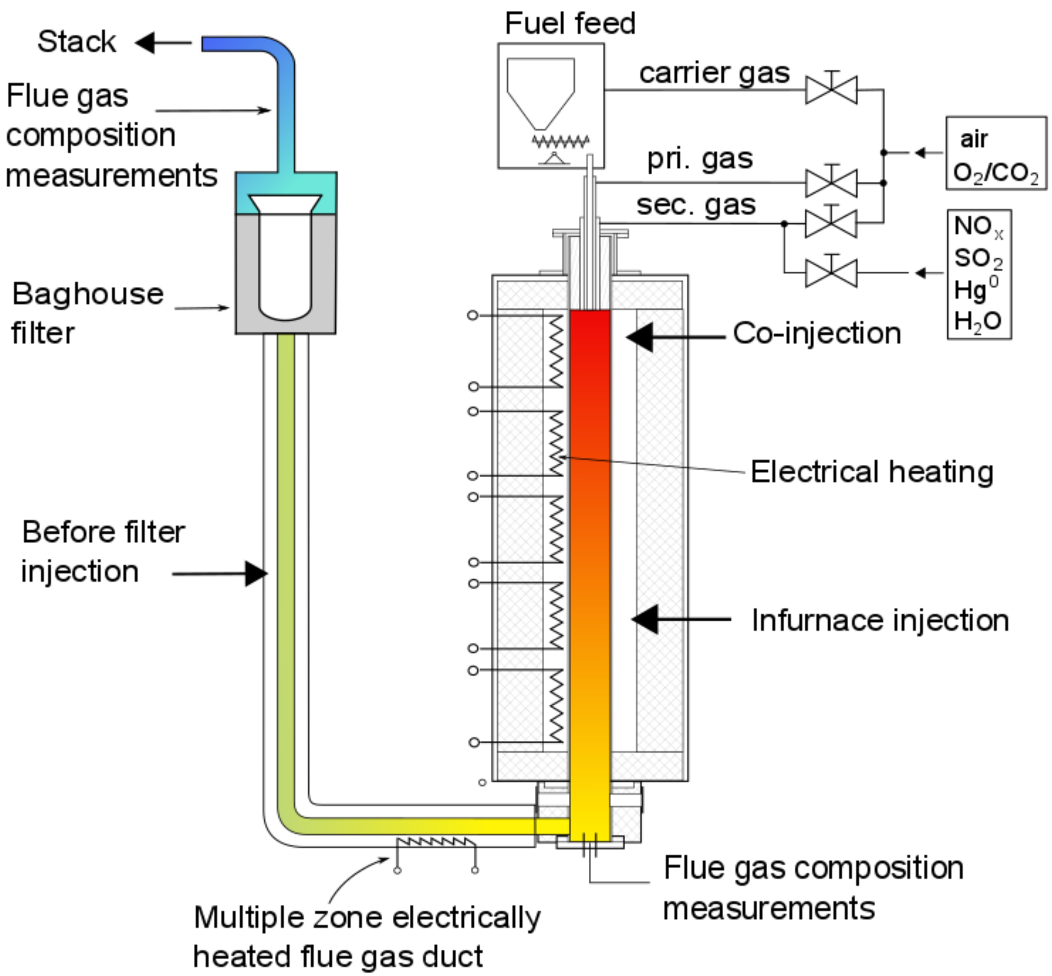
$$Ca(OH)_2 + SO_3 \rightarrow CaSO_4 + H_2O$$

(Below the calcination temperature)

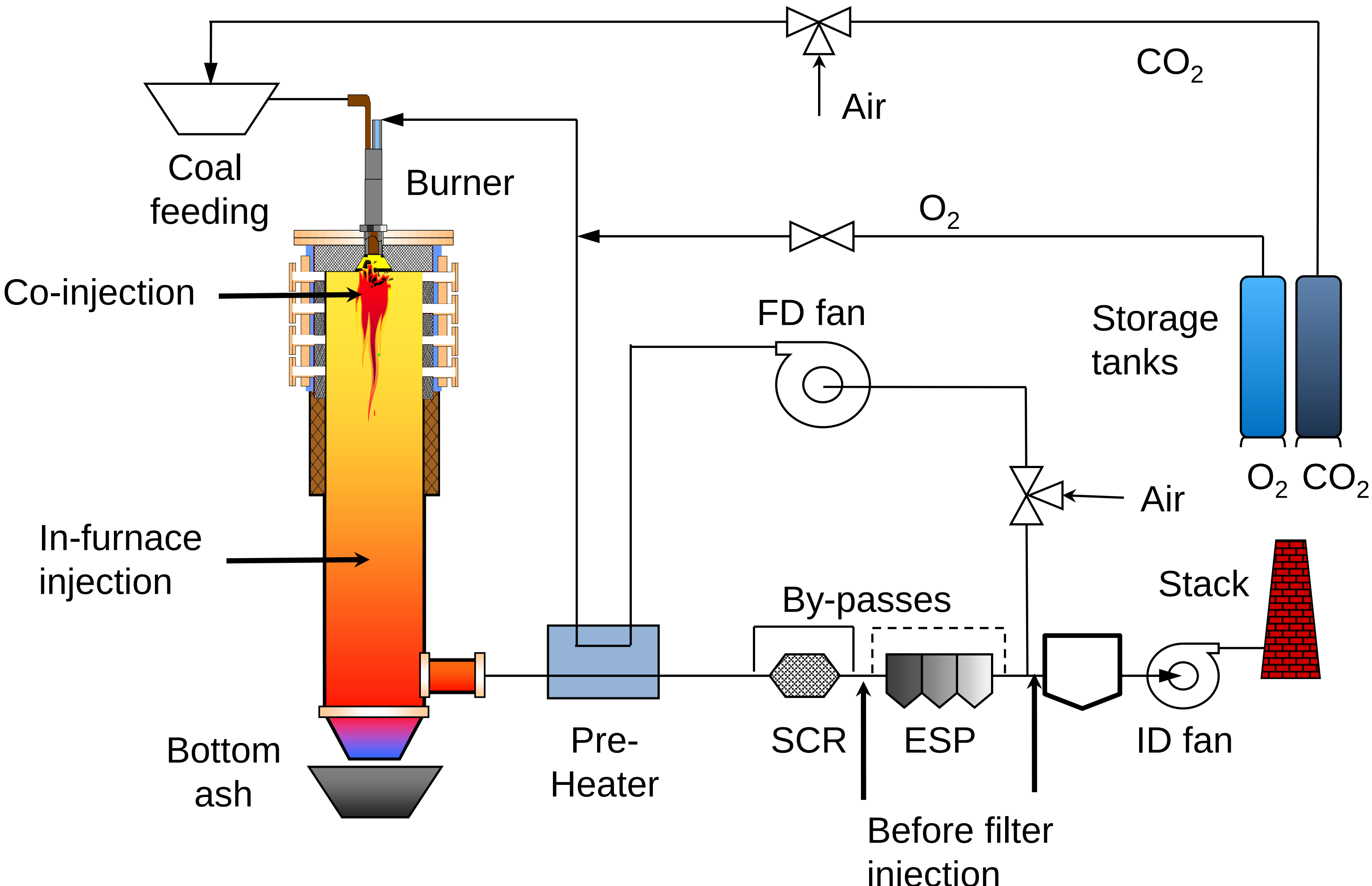
$$Ca(OH)_2 + SO_2 \rightarrow CaSO_3 + H_2O$$

Methodology

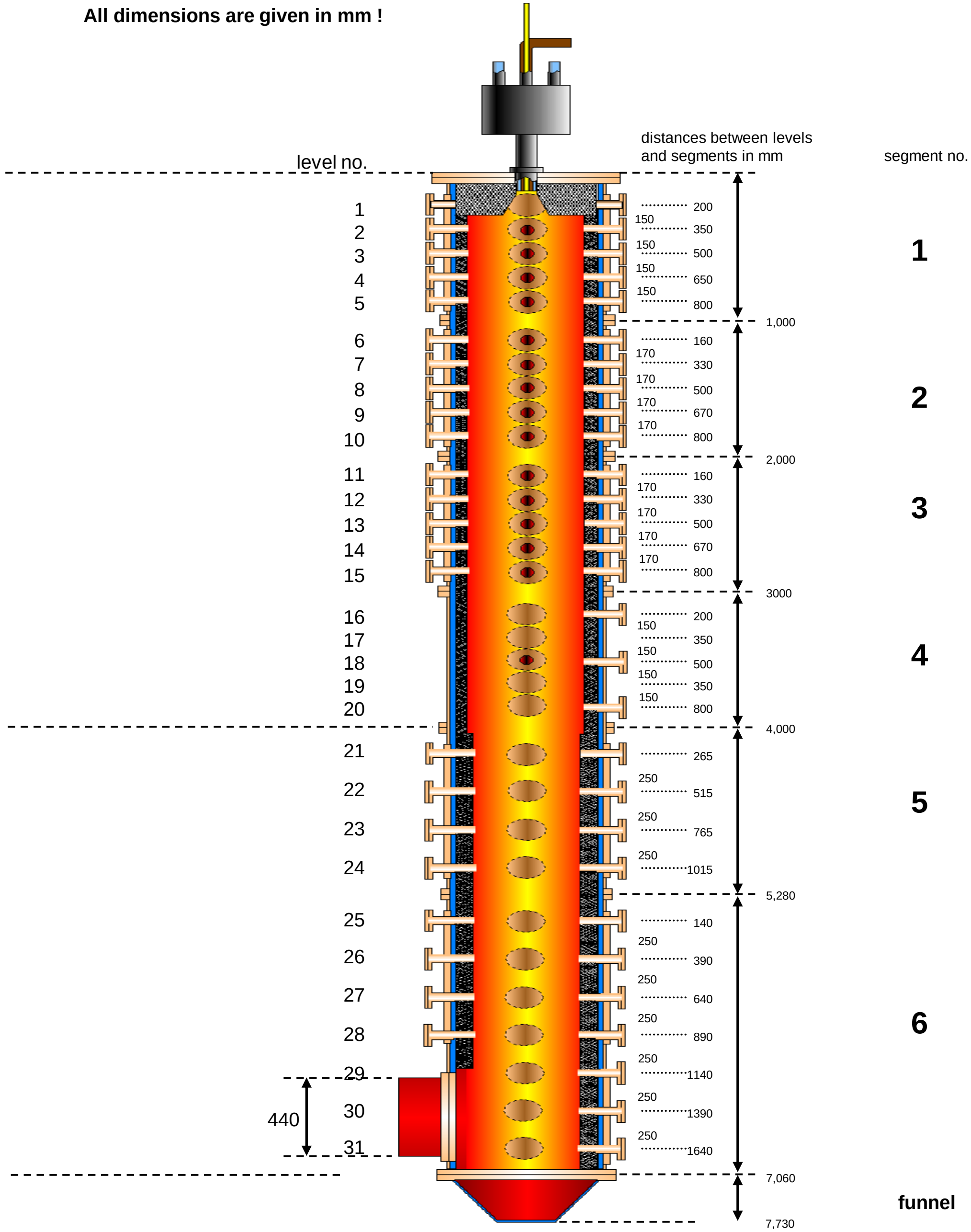
20 kW combustion rig (BTS)



500 kW combustion rig (KSVA)



All dimensions are given in mm !



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Experimental Plan (Air and Oxy-fuel)

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- **20 kW combustion rig (small scale)**
  - **Sorbent injection**
    - Different injection locations (co-injection, in-furnace, before filter)
    - Different coals (U.S.2,5 & S.A.)
    - Different sorbents ($CaCO_3$, $Ca(OH)_2$, trona)
  - **Biomass co-combustion**
    - Different biomasses (Wood pellets, Torr. Wood, Torr. Straw)
    - Different thermal shares (10%, 25%, 50%)
    - With sorbent injection

- **500 kW combustion rig (large scale)**
  - **Sorbent injection**
    - Different injection locations (co-injection, in-furnace injection, before filter)
    - Different sorbents ($CaCO_3$ and $Ca(OH)_2$)
  - **Biomass co-combustion**
    - Different biomasses (Wood pellets, Torr. Poplar, Torr. Pine)

Fuel Analysis

Coal Analysis

Fuel	NCV [MJ/kg, raw]	H_2O [%, raw]	Ash [%, wf]	V [%, waf]	C_{fix} [%, waf]	C [%, waf]	S [%, waf]	H [%, waf]	N [%, waf]	O [%, waf]
U.S. coal	30.5	1.6	9.43	38.72	61.28	81.91	2.67	5.20	1.59	8.63
S.A. coal	26.8	2.84	16.06	20.77	79.23	82.76	0.68	4.45	1.73	10.38

Biomass Analysis

Fuel	NCV [MJ/kg, raw]	H_2O [%, raw]	Ash [%, wf]	V [%, waf]	C_{fix} [%, waf]	C [%, waf]	S [%, waf]	H [%, waf]	N [%, waf]	O [%, waf]
Wood pellet	17,4	7,95	1,38	79,53	20,47	51,11	0,07	4,78	0,63	43,39
Torr. wood	19,4	6,12	0,14	79,15	20,85	50,09	0,03	4,86	-	36
Torr. straw	17,5	7,89	4,36	76,17	23,83	53,15	0,09	4,89	0,52	41,32
Torr. pine	21,24	4,54	0,61	75,66	24,34	56,31	0,05	4,52	0,03	39,08
Torr. poplar	20,59	7,26	1,34	74,96	25,04	55,40	0,04	5,40	0,07	39,09

Sorbent selection

- Ca- and Na-based sorbents
- Fine limestone($CaCO_3$)
- 5 types of hydrated lime ($Ca(OH)_2$)
    - Sorbacal® H: hydrated lime
    - Sorbacal® A: fine hydrate with higher specific surface area
    - Sorbacal®SP: highly porous hydrate with high specific surface area
    - Sorbacal®SPS: Sorbacal®SP with an additive
    - Sorbacal®SPS / GL50 (80/20): mixture of 80 wt.-% Sorbacal®SPS and 20%, activated carbon
- Trona (sodium sesquicarbonate. $Na_3(HCO_3)(CO_3)\cdot 2H_2O$)

Sorbent test matrix (20 kW)

Fuel	Location	Sorbent	Air/Oxy-fuel	Target
U.S. 2,5 coal	Co-injection	Sorbacal®SPS	Air. Oxy-fuel	SO_2
		Limestone		
	In-furnace	Sorbacal®A		
		Limestone		
		Sorbacal®SPS		
		Sorbacal®H	Air	
	Before filter	Sorbacal®H	Air. Oxy-fuel	SO_3. HCl
		Sorbacal®SP		
		Sorbacal®SPS		
		trona		
		Sorbacal®SPS/GL50	Air	
	Duct	Sorbacal®SPS		
50% torr wood	In-furnace	Limestone		SO_2
		Sorbacal®SPS		
	Before filter	Sorbacal®SP		SO_3. HCl
		Sorbacal®SPS	Air. Oxy-fuel	
S.A. coal	In-furnace	limestone		SO_2
		Sorbacal®SPS		
	Before filter	Sorbacal®SPS		HCl

Sorbent test matrix (500 kW)

Fuel	Location	Sorbent	Air/Oxy-fuel	Target
US2.5 coal		Sorbacal®SPS	Air. Oxy-fuel	SO_2
	Co-injection	Limestone		
		Sorbacal®A		
	In-furnace	Limestone		
		Sorbacal®SPS		
		Sorbacal®H	Air	
		Sorbacal®H	Air. Oxy-fuel	SO_3. HCl
		Sorbacal®SP		
	Before filter & ESP	Sorbacal®SPS		
		trona		
		Sorbacal®SPS/GL50	Air	
	Duct	Sorbacal®SPS		
50% torr wood	In-furnace	Limestone		SO_2
		Sorbacal®SPS		
	Before filter	Sorbacal®SP		SO_3. HCl
		Sorbacal®SPS	Air. Oxy-fuel	
SA coal	In-furnace	limestone		SO_2
		Sorbacal®SPS		
	Before filter	Sorbacal®SPS		HCl

Co-combustion test matrix

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Air	Oxy-fuel
Pure US2.5 coal	Pure US2.5 coal
10% torr. straw	
25% torr. straw	
10% wood pellets	
25% wood pellets	25% wood pellets
50% wood pellets	
	25% torr. wood
50%torr.wood	50% torr. wood

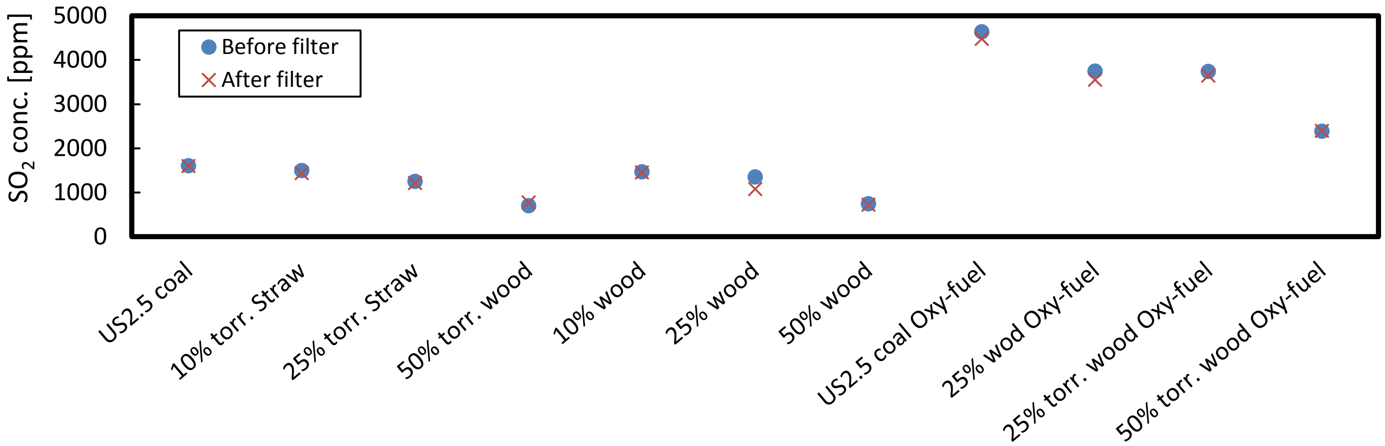
20 kW

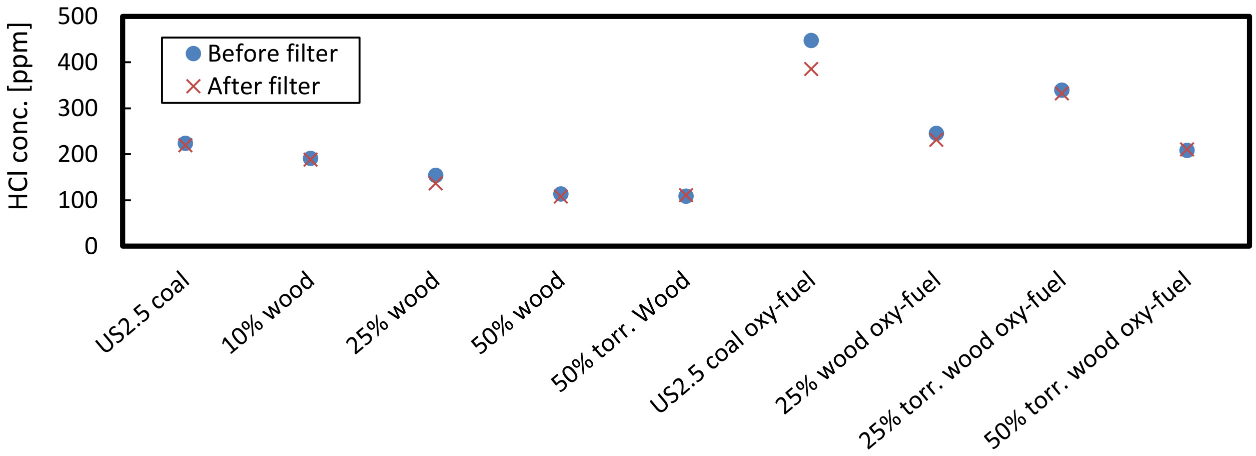
Air	Oxy-fuel
Pure US2.5 coal	Pure US2.5 coal
25% torr. pine	25% torr. pine
25% torr. poplar	
25% wood pellets	25% wood pellets

500 kW

Results

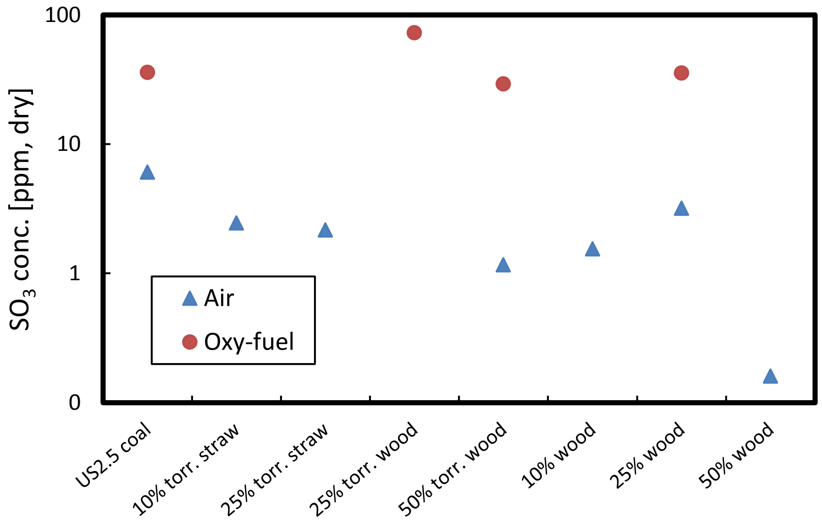
Biomass co-combustion (20 kW)





- Dilution effect of biomass co-combustion

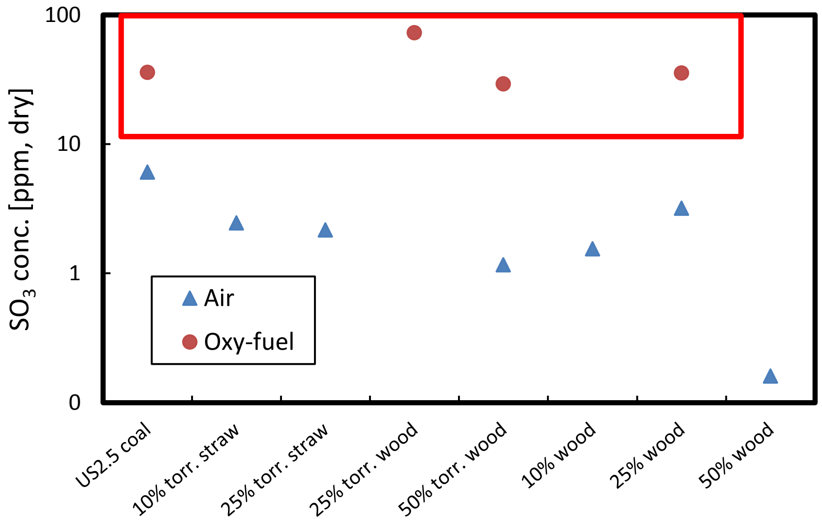
Biomass co-combustion (20 kW)

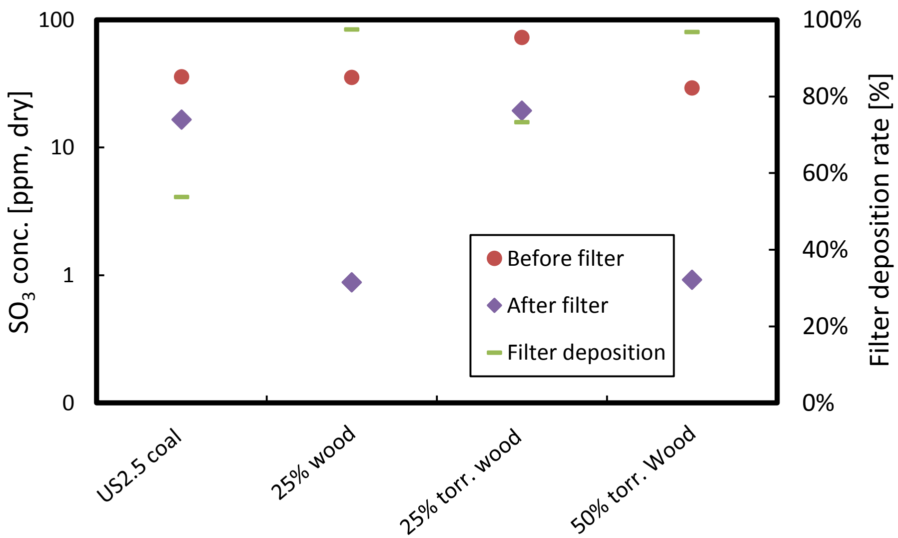


SO_3 concentrations measured before filter

- Low SO_3 concentrations under air combustion (less than 10 ppm)
- Reduced SO_3 concentration with biomass co-combustion

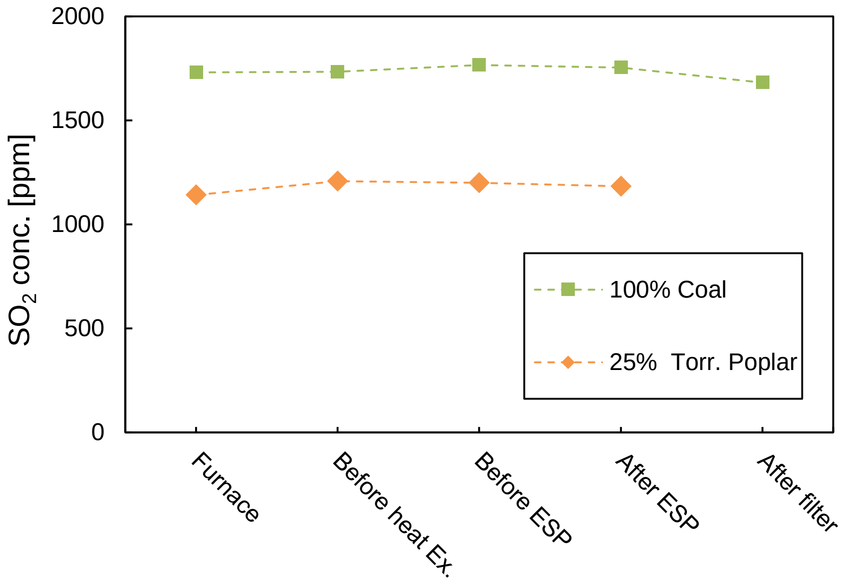
Biomass co-combustion (20 kW)



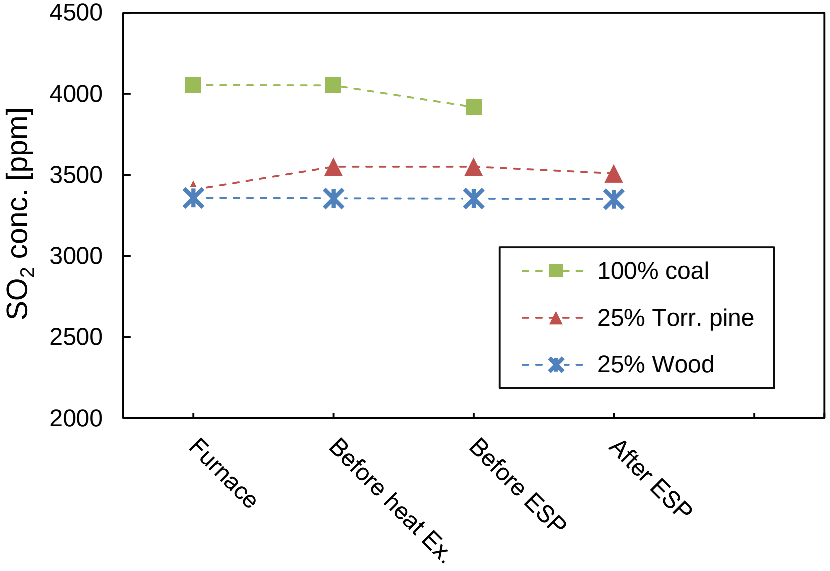


Biomass co-combustion (500 kW)

Air



Oxy-fuel



- Almost constant concentration along the flue gas duct under air and oxy-fuel combustions

DSI (Air&Oxy-fuel, 500 kW)

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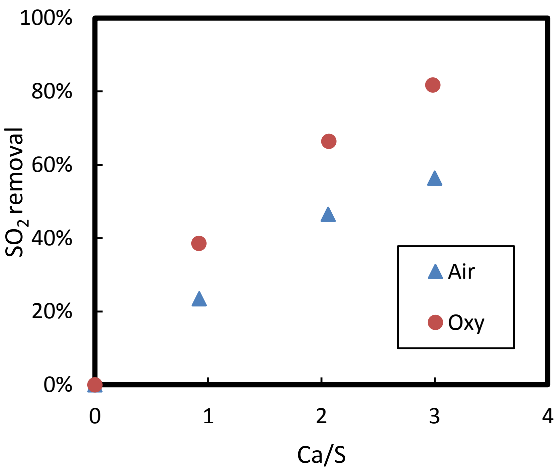
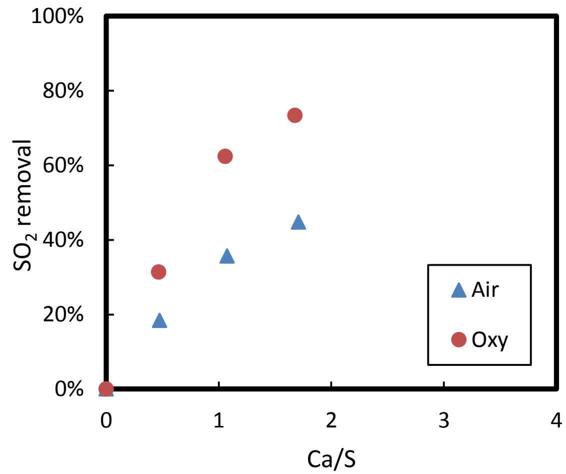
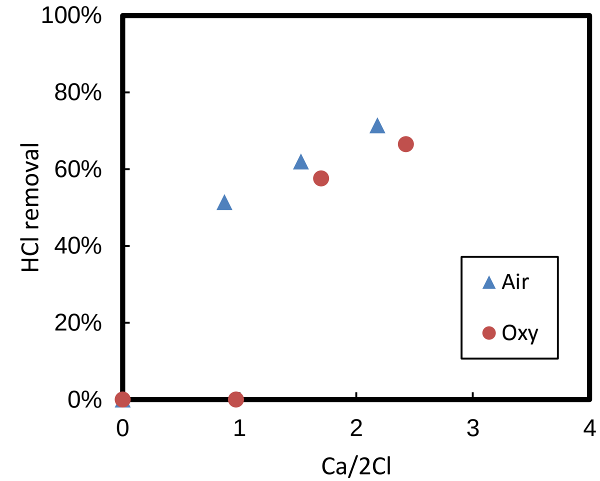
Limestone, in-furnace



Sorbacal SPS, in-furnace

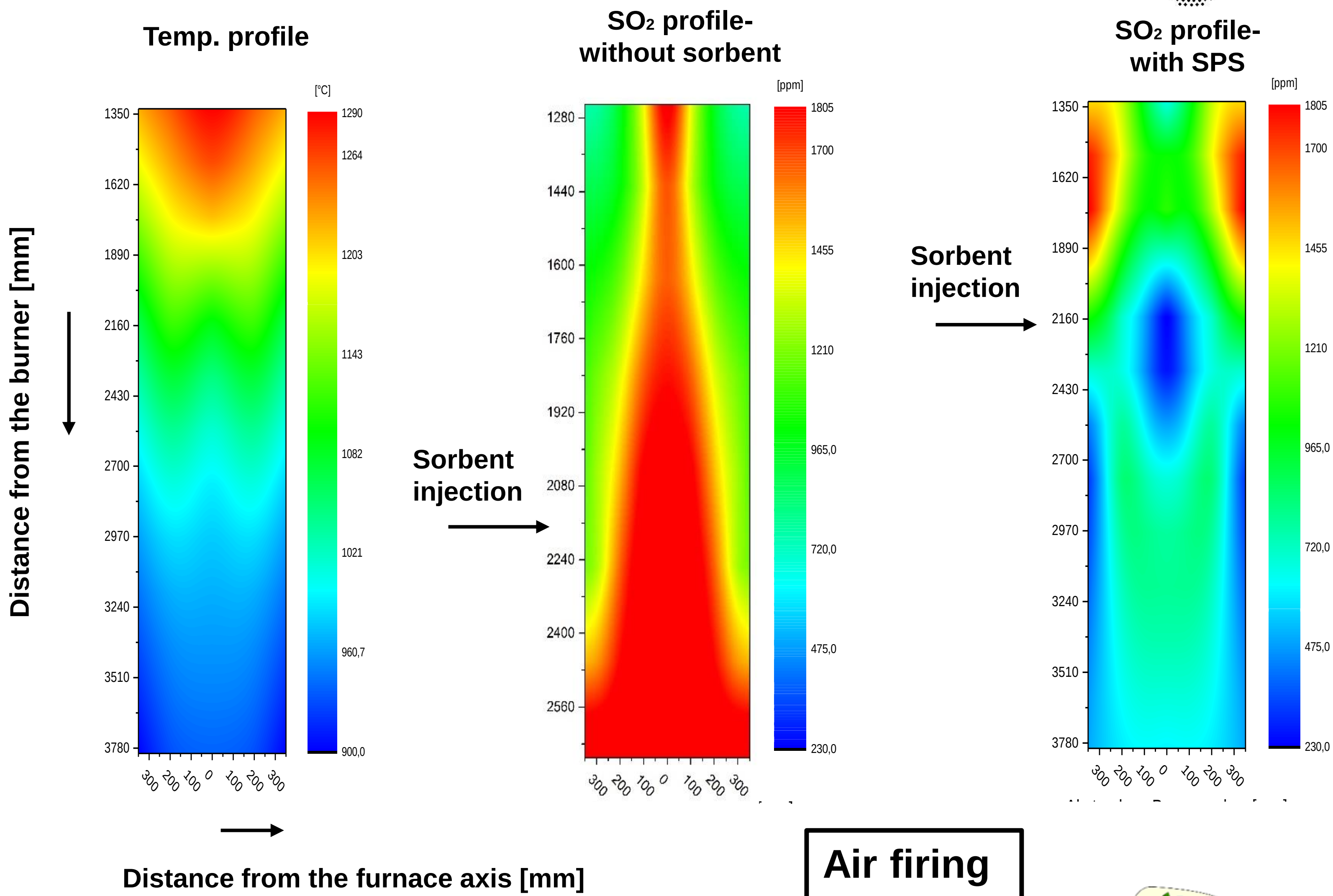


Sorbacal SPS, before E-filter



- Higher desulphurization efficiecny under oxy-fuel condition due to elevated SO_2 partial pressure
- HCl is better eliminated under air condition

Profile measurments



Air firing
U.S. coal

DSI (Sorbent performance, 20 kW)

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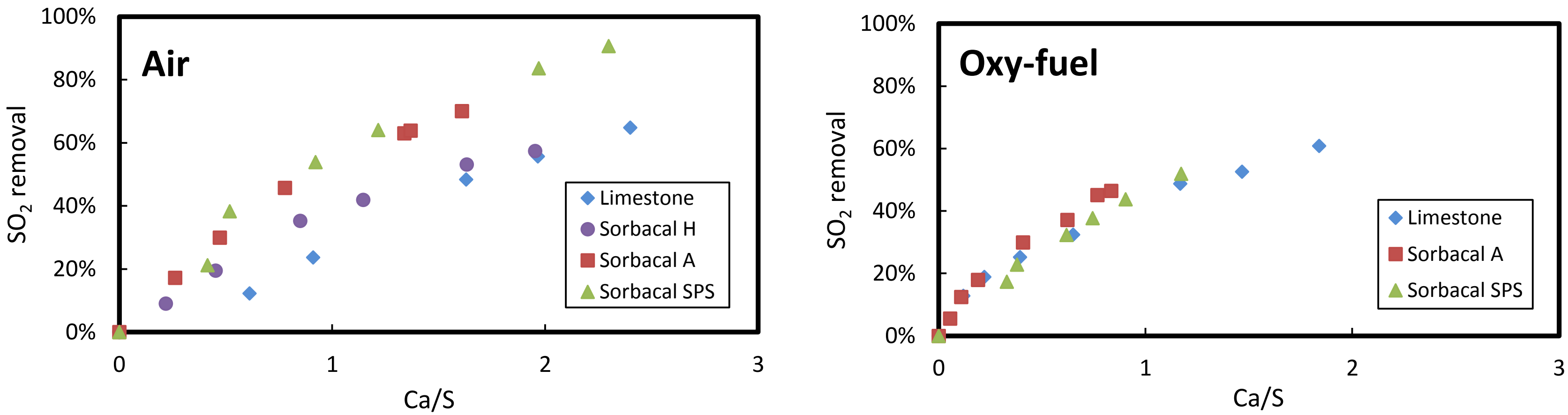
In-furnace injection 1100°C, U.S. coal



- Sorbacal SPS shows the highest desulphurization efficiecny under air condition.
- Similar sorbent performance under oxy-fuel for in-furnace DSI desulphurization

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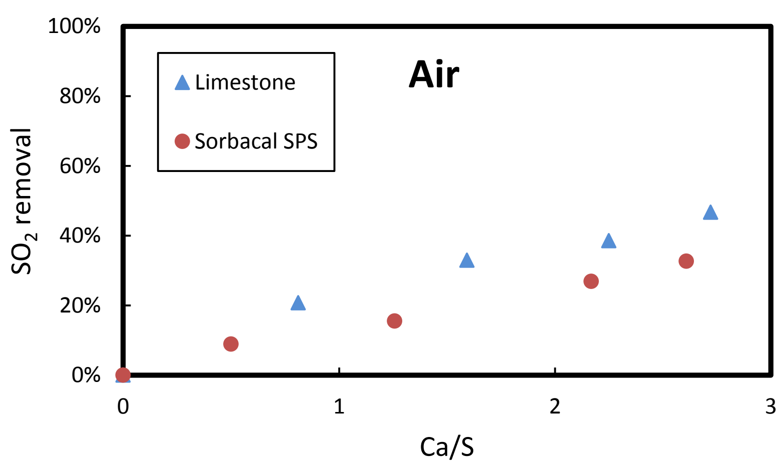
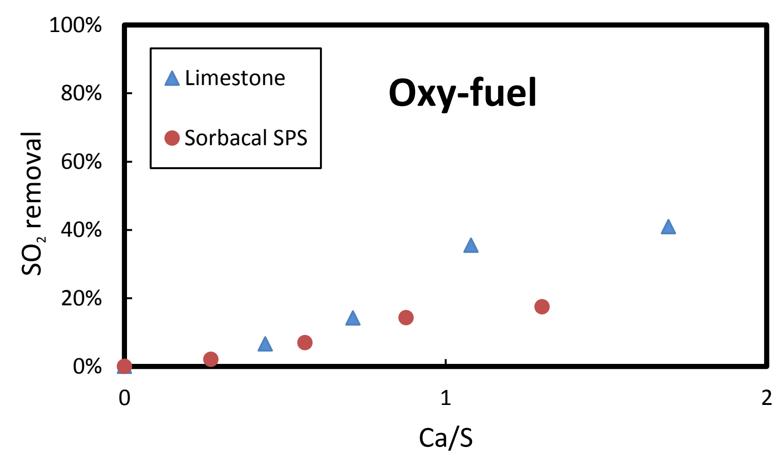
DSI (Sorbent performance, 20 kW)

Co-injection 1300°C, U.S coal





- Limestone performs better by co-injection under both combustion conditions
- SPS is more prone to sintering at high temperatures

DSI (Sorbent performance, 20 kW)

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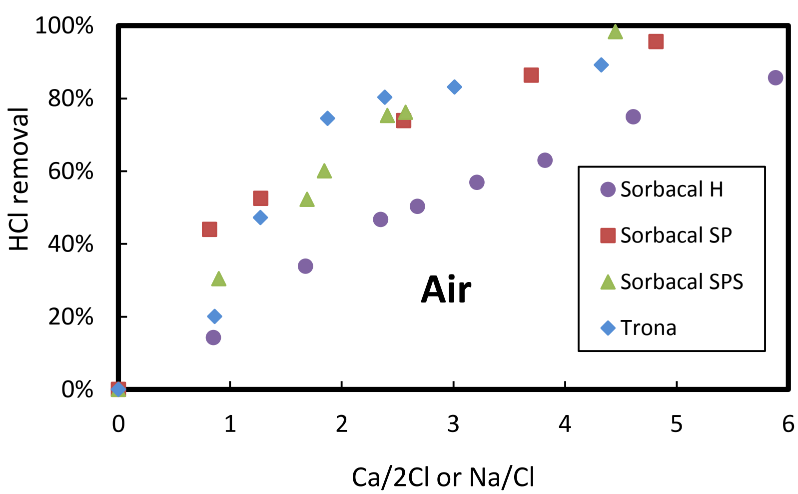
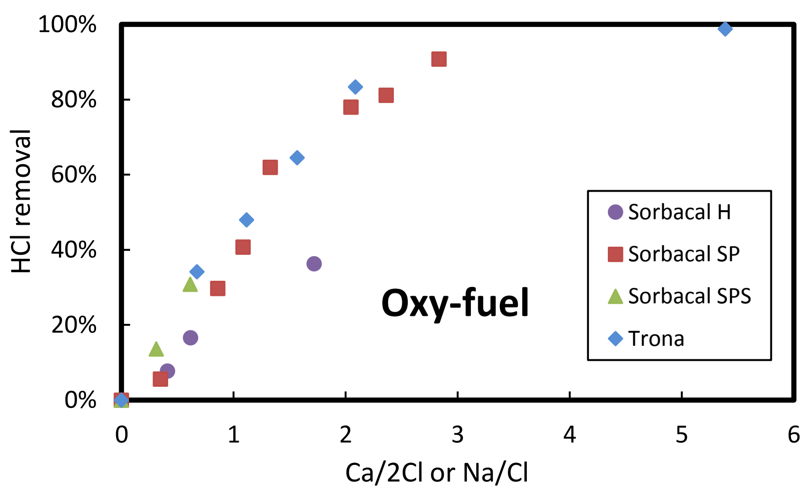
Before filter injection, 220 °C, U.S. coal





- Good degree of removal under both combustion conditions
- Lower removal efficiency with Sorbacal H under both air and oxy-fuel conditions due to less available surface area

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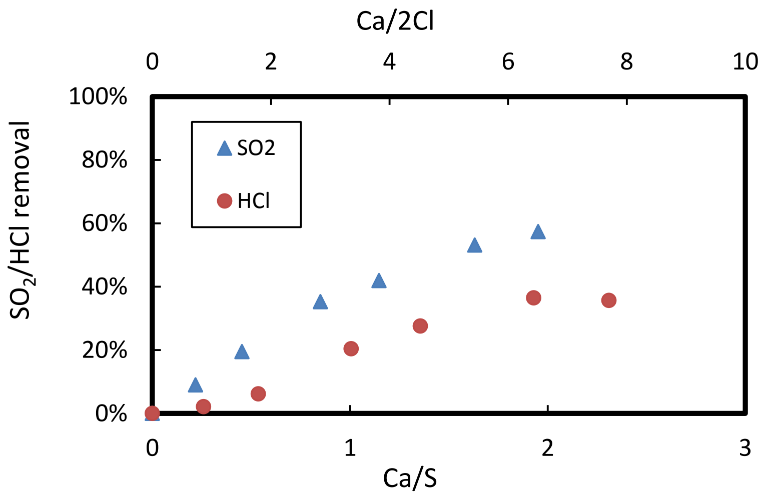
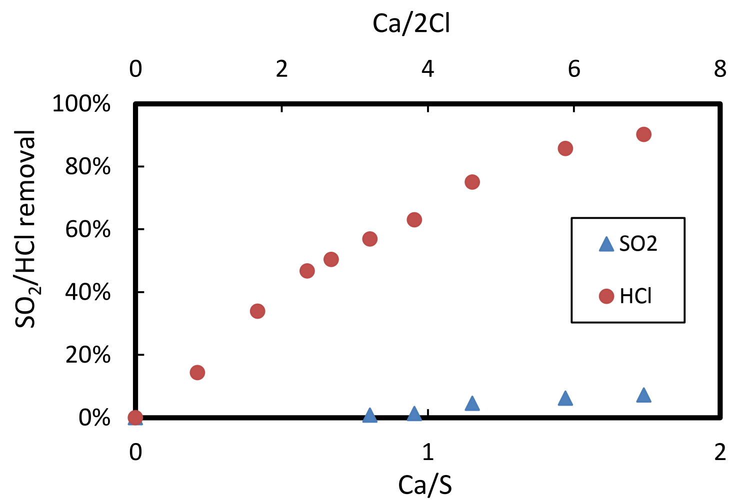
DSI (co-benefit, 20 KW)

Sorbacal H, Air, in-furnace injection, U.S. coal

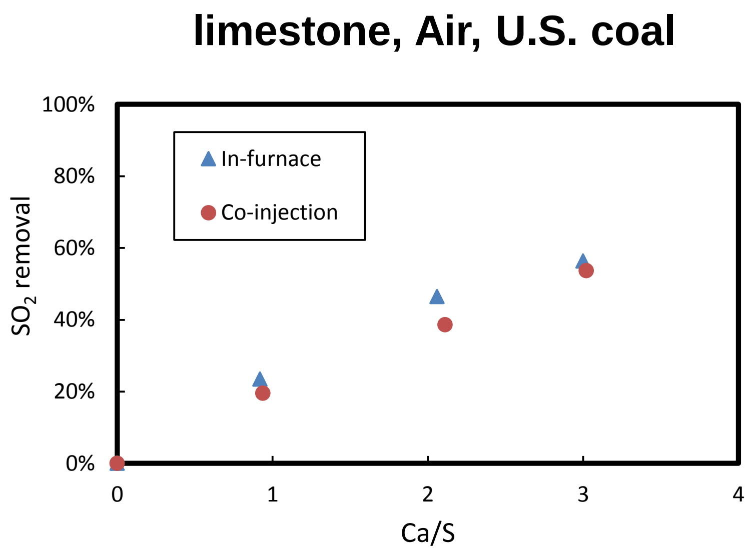


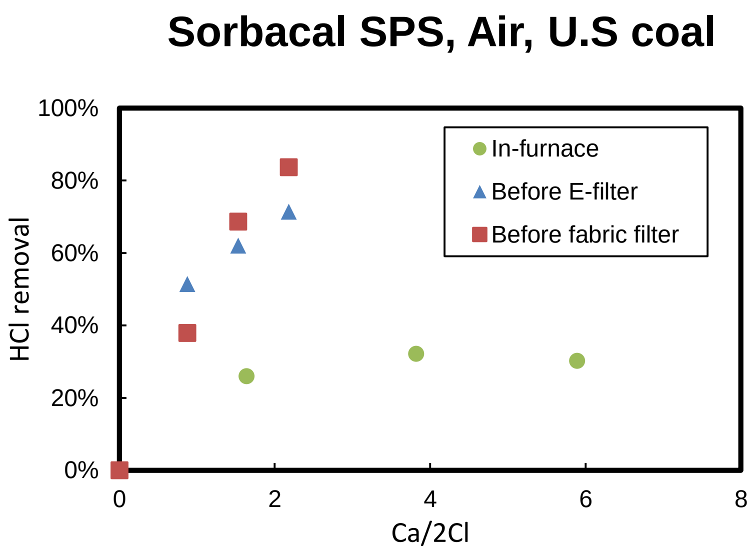
Sorbacal H, Air, before filter injection, U.S. coal



- Good degree of HCl removal by in-furnace injection
- Negligible SO_2 removal at before filter injection

DSI (injection location, 500 kW)





- Similar HCl removal behaviour for before E-filter and before fabric filter injection
- Higher desulphurization rate by in-furnace injection compared to co-injection

DSI (Coal type, 20 kW)

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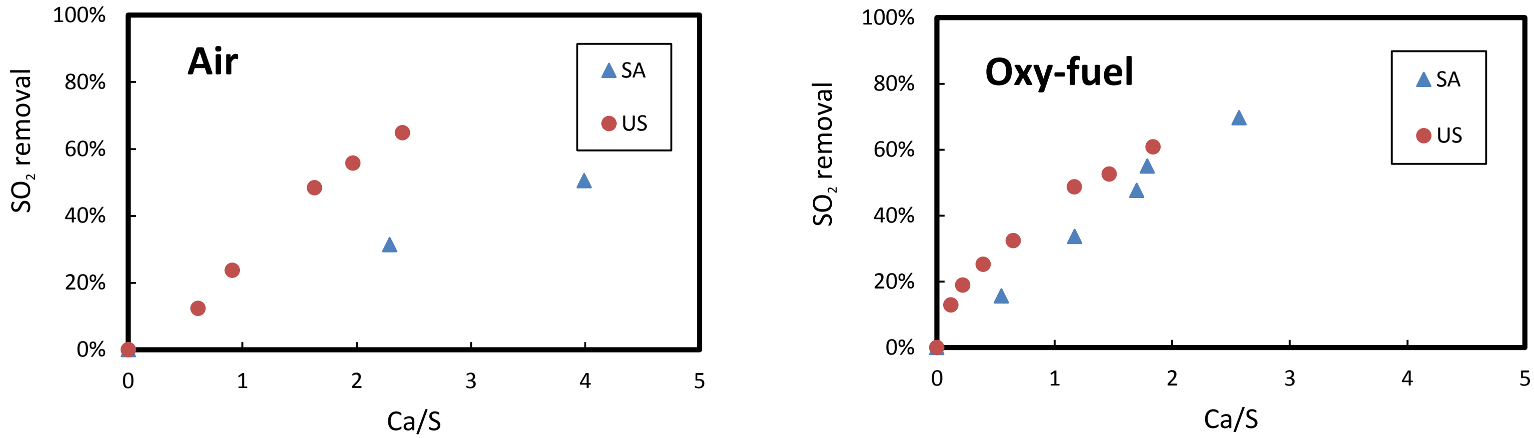
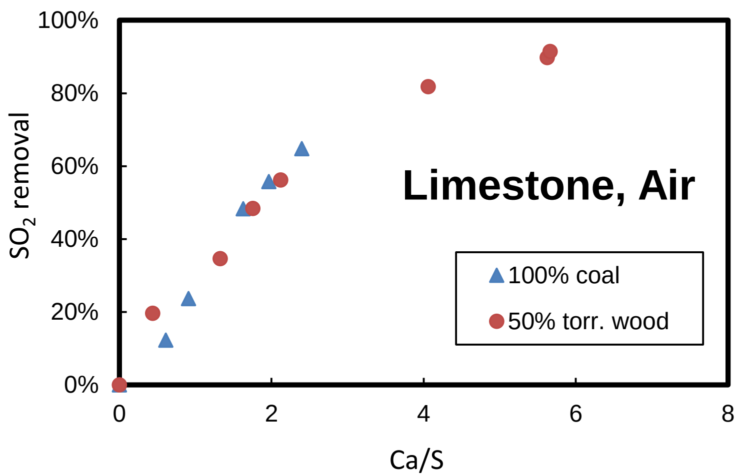
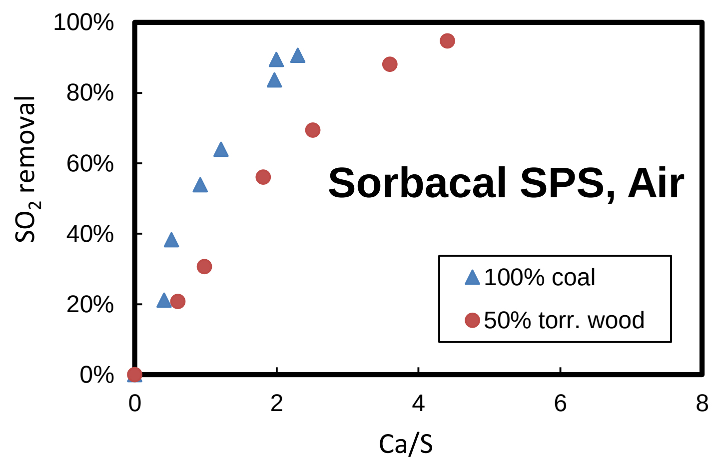
Limestone, in-furnace injection

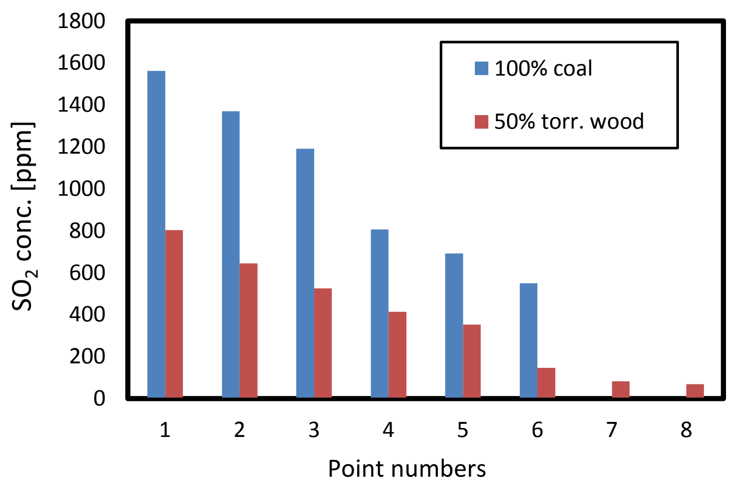


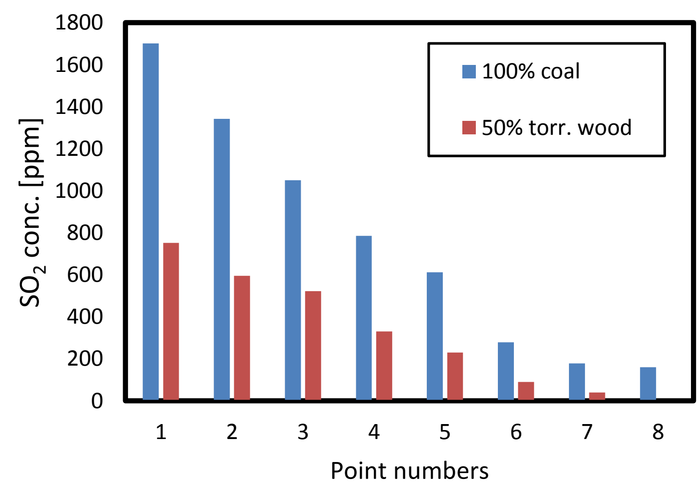
- Coal with higher sulphur content shows better removal behaviour
- Attributed to higher SO_2 concentration and more $CaSO_4$ stability

Biomass co-combustion and DSI, 20 kW



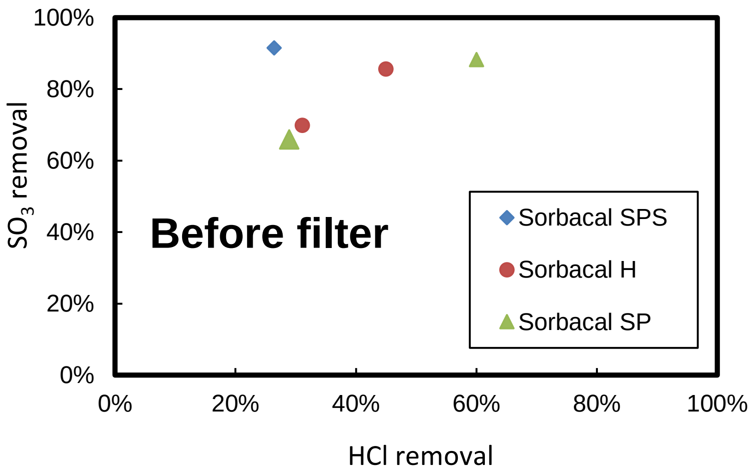




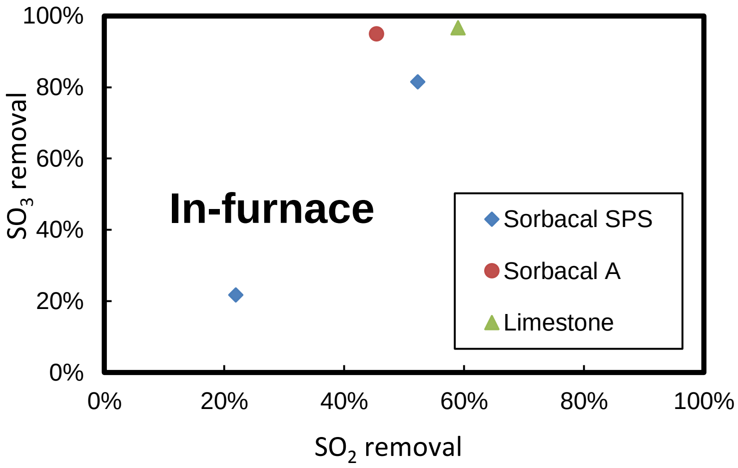


DSI (SO_3 removal, 20 KW)

Before filter, Oxy-fuel



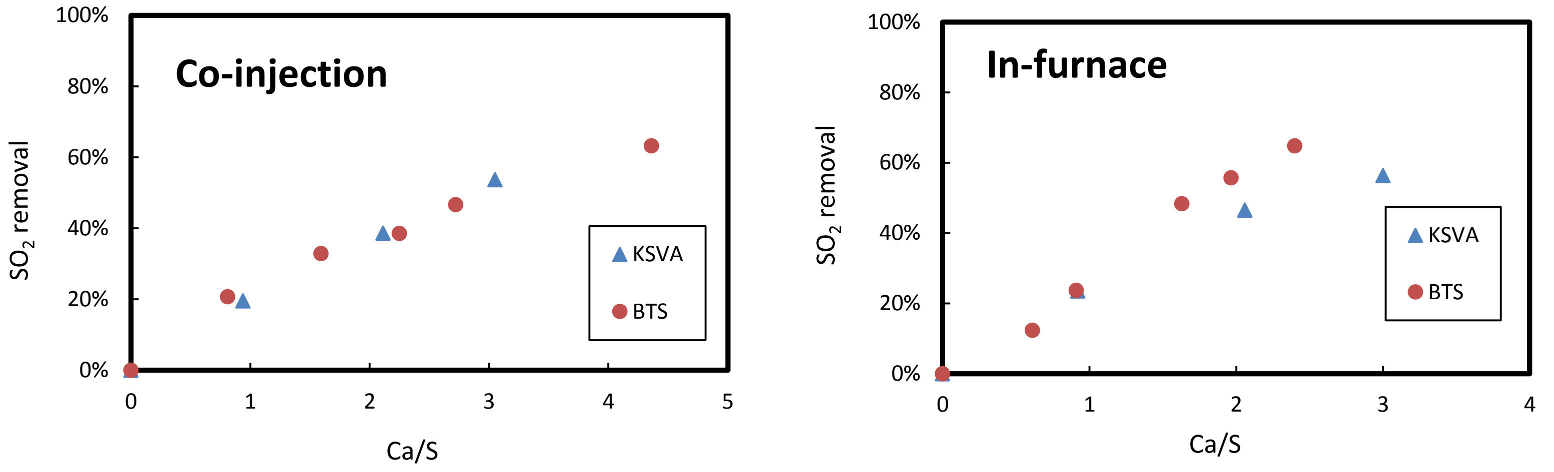
In-furnace, Oxy-fuel



- More than 80% SO_3 removal at high SO_2 capture rates
- High SO_3 removal at medium HCl removal rate

Facility scale comparison

Limestone, Air



- Similar sorbent performance at different experimental scales
- Slightly better desulphurization rate at Ca/S ratios higher than stoichiometric for 20 kW

Conclusion

- No negative impact of oxy-fuel combustion on DSI technology
- Better removal performance under oxy-fuel combustion for SO_2 control (suitable temeprature 1000°C-1100°C)
- Limestone is better for co-injection and Sorbacal SPS has better removal efficiecny by in-furnace injection.
- Decent HCl and SO_3 removal at low temperature injection
- Very low emission values by the combination of biomass co-combustion and sorbent injection
- Transferability of the results from 20 kW to 500 kW combustion rigs

Thank you for your attention

ACKNOWLEDGMENTS

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