POLITECHNIKA CZĘSTOCHOWSKA

59th International Energy Agency
Fluidized Bed Conversion Implementing Agreement

PRELIMINARY EXPERIENCE WITH A SMALL PILOT- SCALE OXYFUEL-CFB FACILITY

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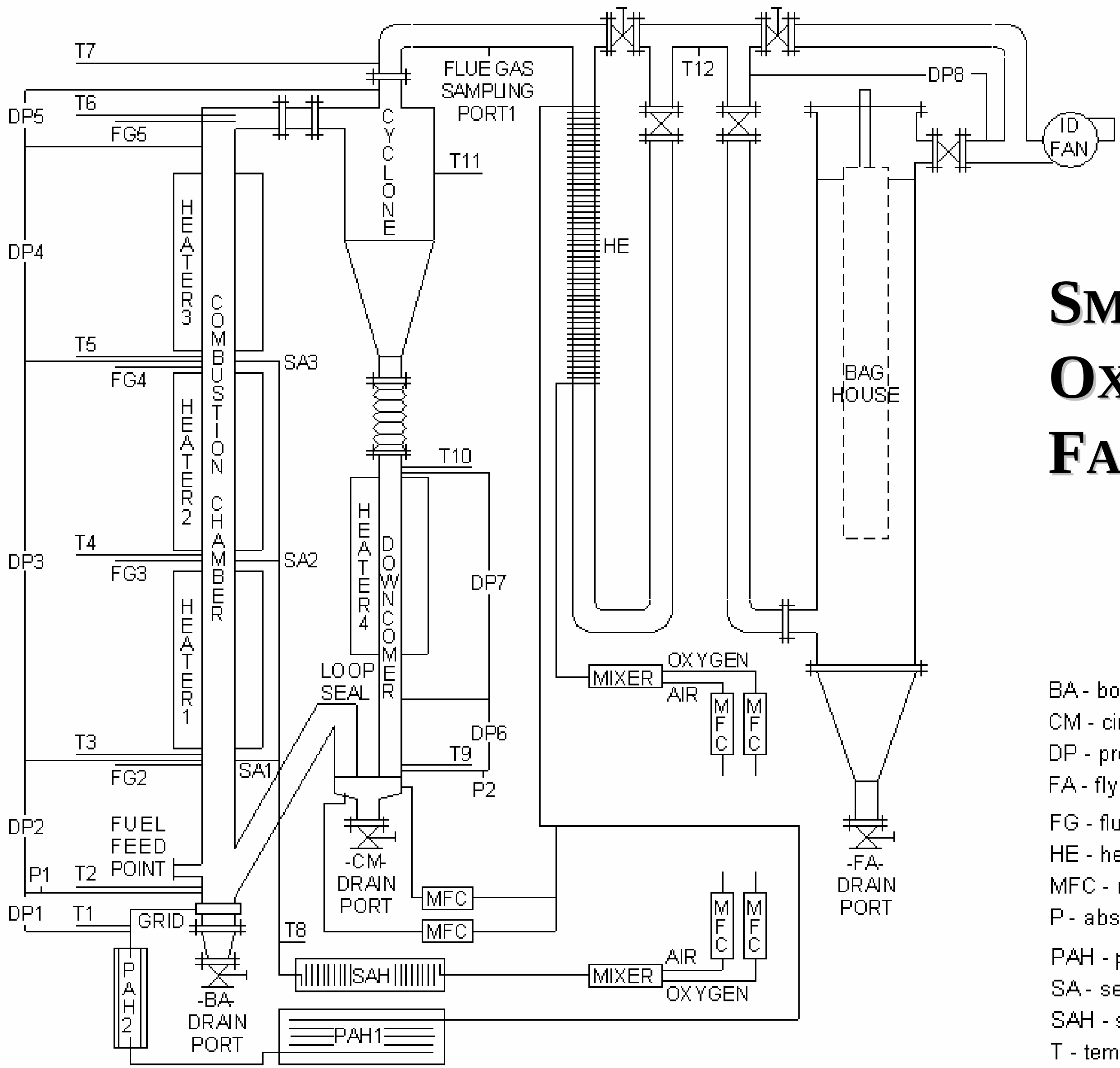


SMALL PILOT-SCALE OXYFUEL-CFB FACILITY 0,1MWth

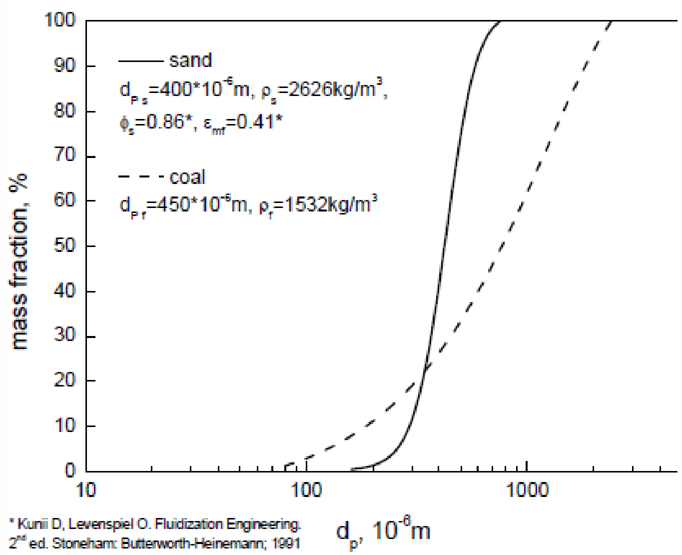
BA - bottom ash
CM - circulating material
DP - pressure drop measurement
FA - fly ash
FG - flue gas sampling
HE - heat exchanger
MFC - mass flow controller
P - absolute pressure measurement
PAH - primary air heater
SA - secondary air
SAH - secondary air heater
T - temperature measurement

ANALYSES OF SOLIDS

PROPERTIES OF FUEL

Fuel	LHV	Proximate Analysis				Ultimate Analysis				
		Moisture	VM	FC (by differ.)	Ash	C	S	H	N	O (by differ.)
	kJ/kg	%	%	%	%	%	%	%	%	%
bitumin. coal	21055	6,8	27,5	43,5	22,2	57,8	1,28	3,54	0,69	7,69

PARTICLE SIZE DISTRIBUTION OF FUEL AND BED MATERIAL



XRF ANALYSIS OF FUEL

element	fraction %
Al - aluminum	≈ 5,0
Si - silicon	9,4 ± 0,5
P - phosphorus	< 0,14 (< detect. threshold)
S - sulfur	0,53 ± 0,02
Cl - chlorine	0,087 ± 0,015
K - potassium	1,47 ± 0,07
Ca - calcium	**0,61 ± 0,03**
Ti - titanium	0,244 ± 0,007
V - vanadium	0,0047 ± 0,0007
Cr - chromium	0,013 ± 0,001
Mn - manganese	0,0266 ± 0,0014
Fe - iron	1,76 ± 0,075
Co - cobalt	0,0139 ± 0,0013
Ni - nickel	0,0025 ± 0,0003
Cu - copper	0,0011 ± 0,0002
Zn - zinc	0,0135 ± 0,0006
Sn - tin	< 0,00045 (< d. t.)
Sb - antimony	< 0,0005 (< d. t.)
Pb - lead	0,0074 ± 0,0003
Na* - sodium	0,54 ± 0,03
Mg* - magnesium	**0,53 ± 0,03**

*AAS

SCHEDULE OF INVESTIGATIONS

	Air ($21\%O_2$-$79\%N_2$)			$28\%O_2$-$72\%N_2$	$35\%O_2$-$65\%N_2$
	v=3,65m/s	v=4,25m/s	v=4,85m/s	v=4,85m/s	v=4,85m/s
λ=1,1	✓	✓	✓	✓	✓/ X
λ=1,2	✓	✓	✓	✓	✓
λ=1,3	✓	✓	✓	✓	✓

CALCULATIONS

✓ **Conversion ratio of combustible sulfur contained in fuel to SO_2**

$$CR_{S->SO2} = \frac{\dfrac{S_{fg}^{SO2}}{C_{fg}^{CO2+CO}}}{\dfrac{S_{fuel}^{comb}}{C_{fuel}}} \left[\frac{\dfrac{\mathrm{kmol_S}}{\mathrm{kmol_C}}}{\dfrac{\mathrm{kmol_S}}{\mathrm{kmol_C}}} = - \right]$$

- *Molar ratio of S (fixed in SO_2) / C (fixed in CO_2 & CO) in flue gas*

$$\frac{S_{fg}^{SO2}}{C_{fg}^{CO2+CO}} = \frac{\dfrac{[SO_2]}{10^6} \cdot \dfrac{1}{22{,}4}}{\dfrac{[CO_2] \cdot 10^4 + [CO]}{10^6} \cdot \dfrac{1}{22{,}4}} = \frac{[SO_2]}{10^4 \cdot [CO_2] + [CO]}$$

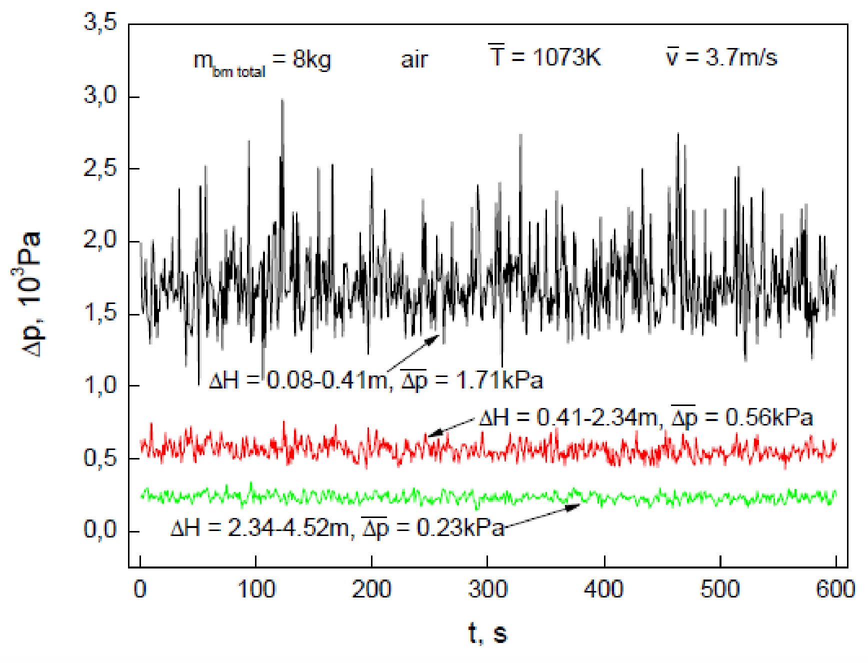
$$\left[\frac{\dfrac{m_{N\ SO2}^3}{\mathrm{m}_{N\ fg}^3} \cdot \dfrac{kmol_{SO2}}{m_{N\ SO2}^3}}{\dfrac{m_{N\ CO2}^3}{\mathrm{m}_{N\ fg}^3} \cdot \dfrac{kmol_{CO2}}{m_{N\ CO2}^3} + \dfrac{m_{N\ CO}^3}{\mathrm{m}_{N\ fg}^3} \cdot \dfrac{kmol_{CO}}{m_{N\ CO}^3}} = \frac{\dfrac{kmol_{SO2}}{m_{N\ fg}^3}}{\dfrac{kmol_{CO2}}{m_{N\ fg}^3} + \dfrac{kmol_{CO}}{m_{N\ fg}^3}} = \frac{kmol_S}{kmol_C} \right]$$

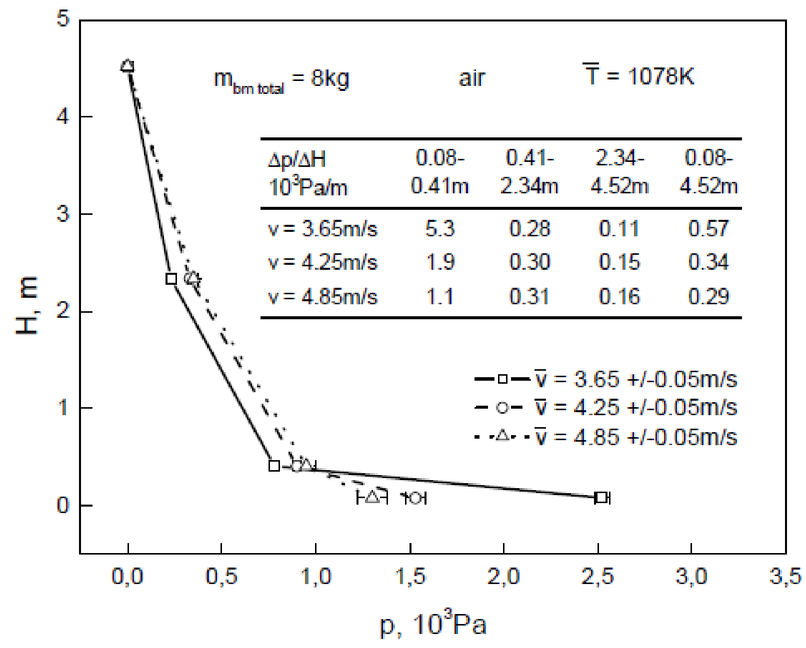
- *Molar ratio of combustible S / C in fuel*

$$\frac{S_{fuel}^{comb}}{C_{fuel}} = \frac{\dfrac{S_{fuel}^{comb}}{32}}{\dfrac{C_{fuel}}{12}} \left[\frac{\dfrac{\mathrm{kg_S}}{\mathrm{kg_{fuel}}} \cdot \dfrac{kmol_S}{kg_S}}{\dfrac{\mathrm{kg_C}}{\mathrm{kg_{fuel}}} \cdot \dfrac{kmol_C}{kg_C}} = \frac{kmol_S}{kmol_C} \right]$$

EXPERIMENTAL CONDITIONS

PRESSURE DISTRIBUTION



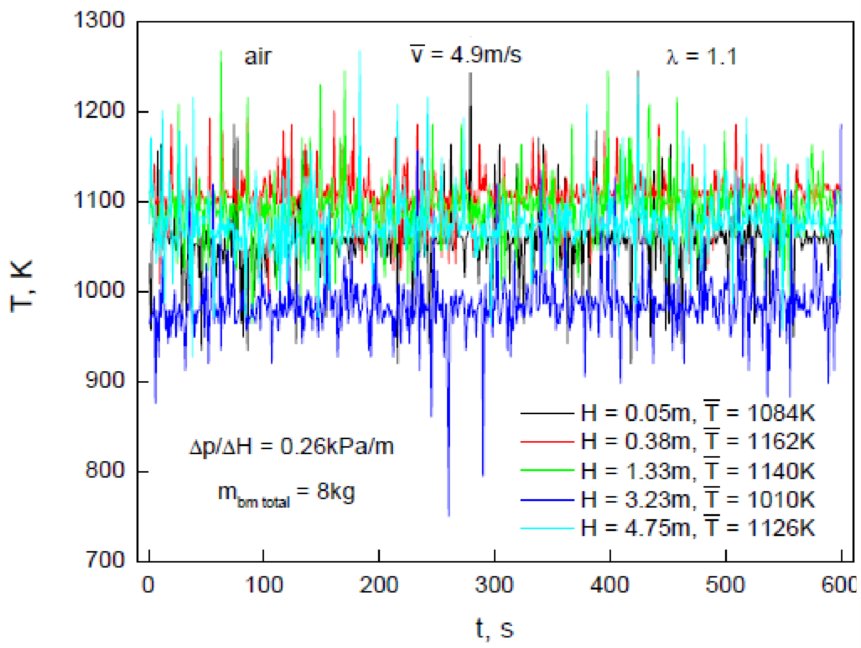


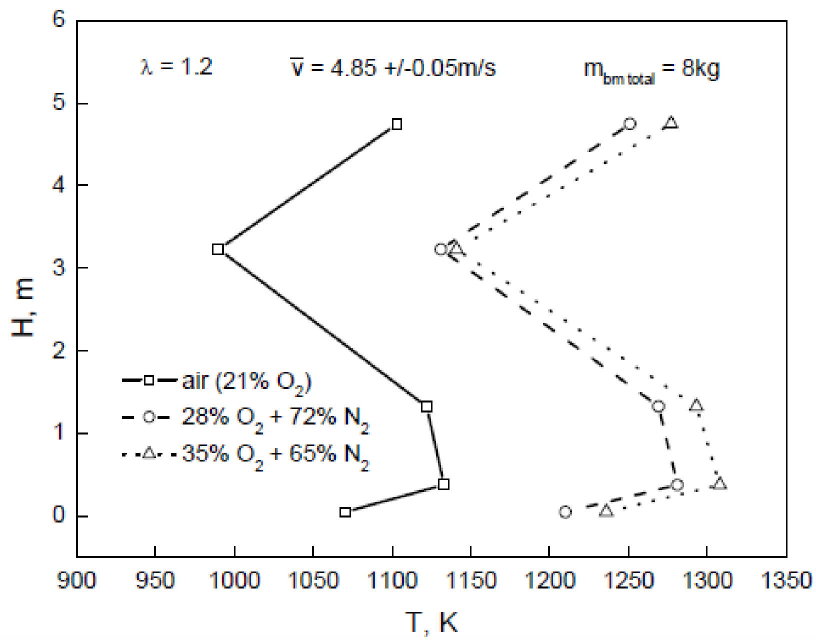
- ✓ The highest Δp & the strongest pressure fluctuations in the grid zone (dense phase)
- ✓ 3-times lower pressure drop & much lighter fluctuations in the dilute zone
- ✓ The lowest Δp & the lightest pressure fluctuations at the level of cyclone inlet

- ✓ More uniform distribution of bed material inside combustion chamber for higher gas velocity
- ✓ Declining solids concentration in the grid zone and increasing conc. in the upper part of furnace
- ✓ Higher amount of bed material in return leg (decreasing total Δp in combustion chamber)

EXPERIMENTAL CONDITIONS

TEMPERATURE DISTRIBUTION



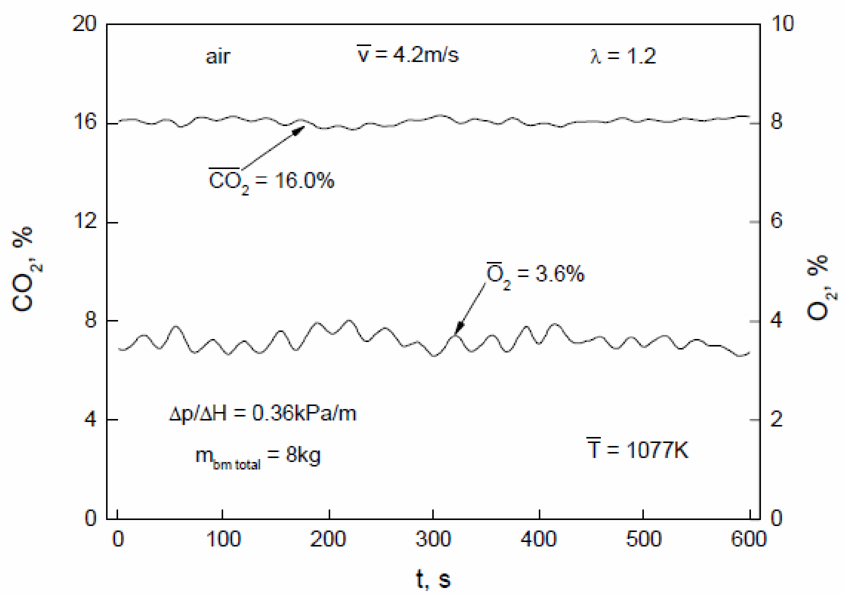


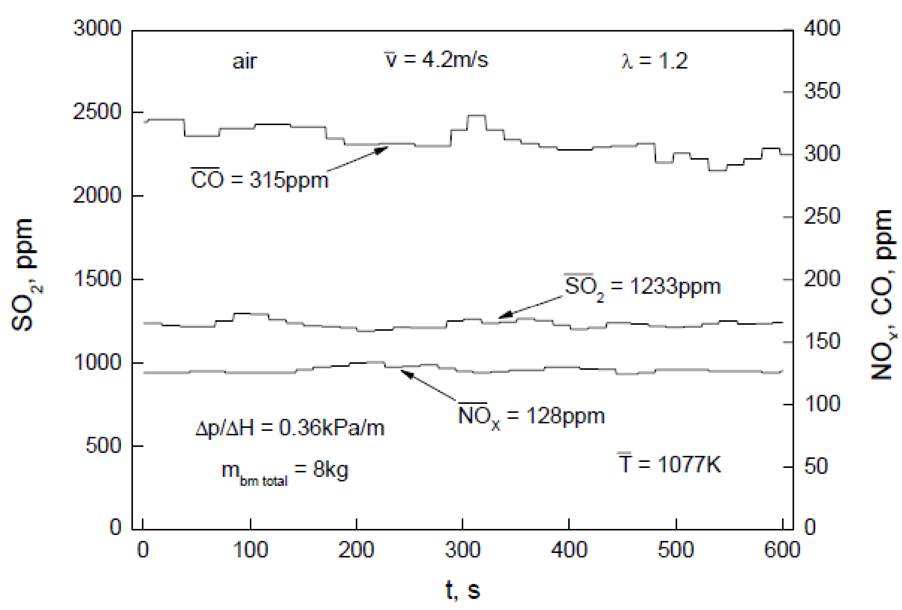
- ✓ An example of temperature oscillations measured at 5 different levels along height of combustion chamber

- ✓ Strong increase in temperature associated with elevated partial pressure of oxygen (up to 35%vol.) as a result of different chamber load
- ✓ Lighter insulation in the upper part of the furnace (enhanced heat transfer) „simulates" Wing-Walls operation in commercial CFB's

RESULTS OF INVESTIGATIONS

FLUE GAS COMPOSITION

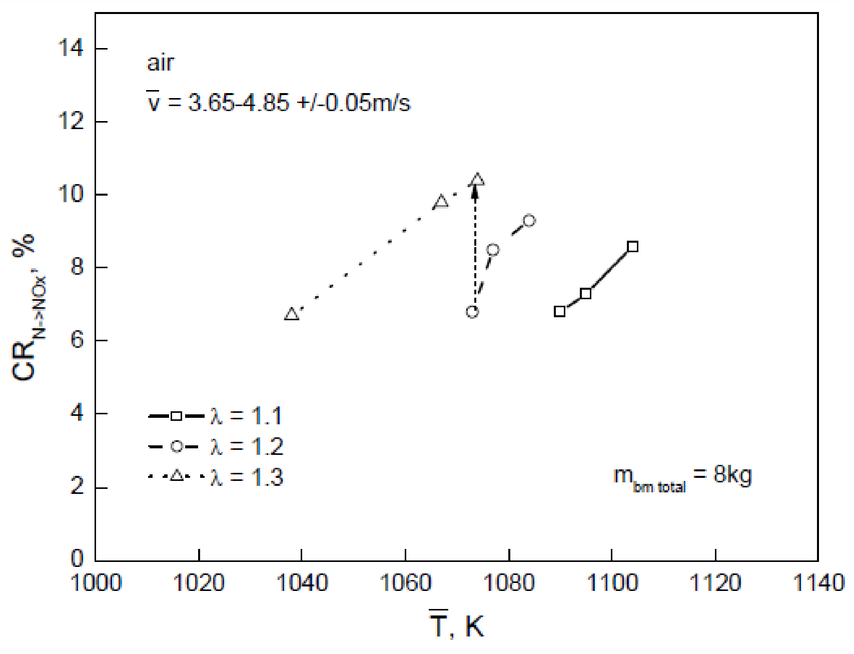


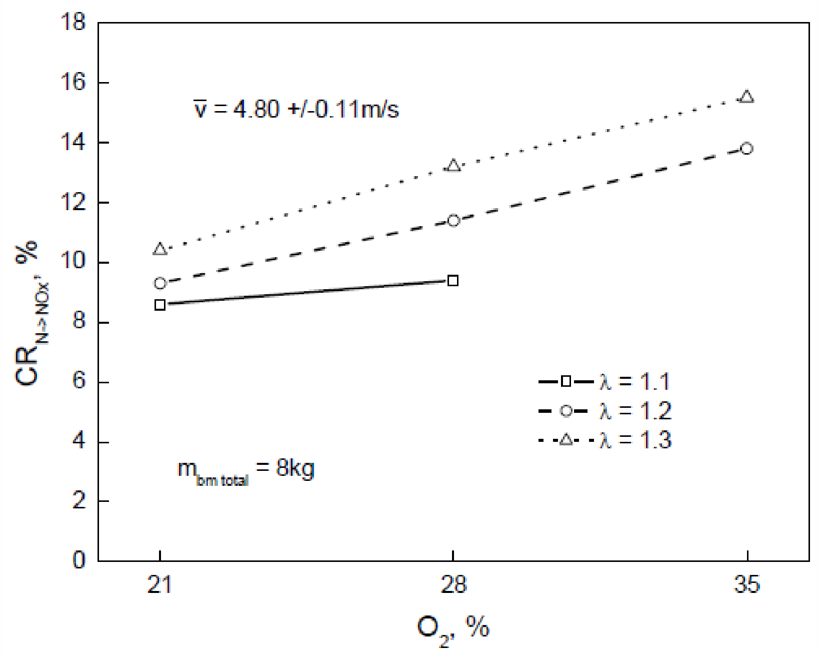


- ✓ An example of fluctuations of flue gas components concentration (CO_2, CO, NO_X, SO_2 i O_2) measured in the outlet of cyclone separator
- ✓ The results point at stable operation of OxyFuel-CFB Test Rig

RESULTS OF INVESTIGATIONS

NO_X FORMATION



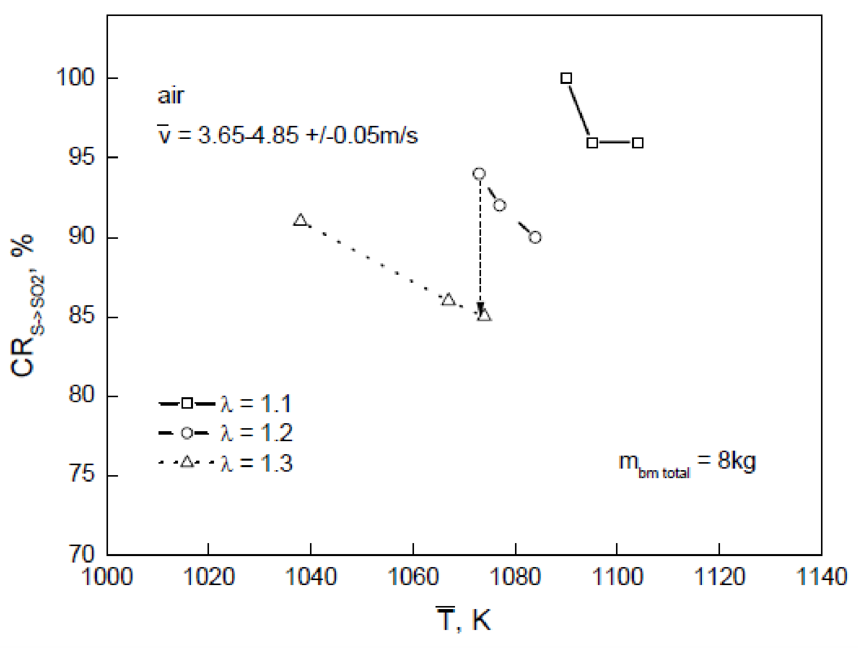


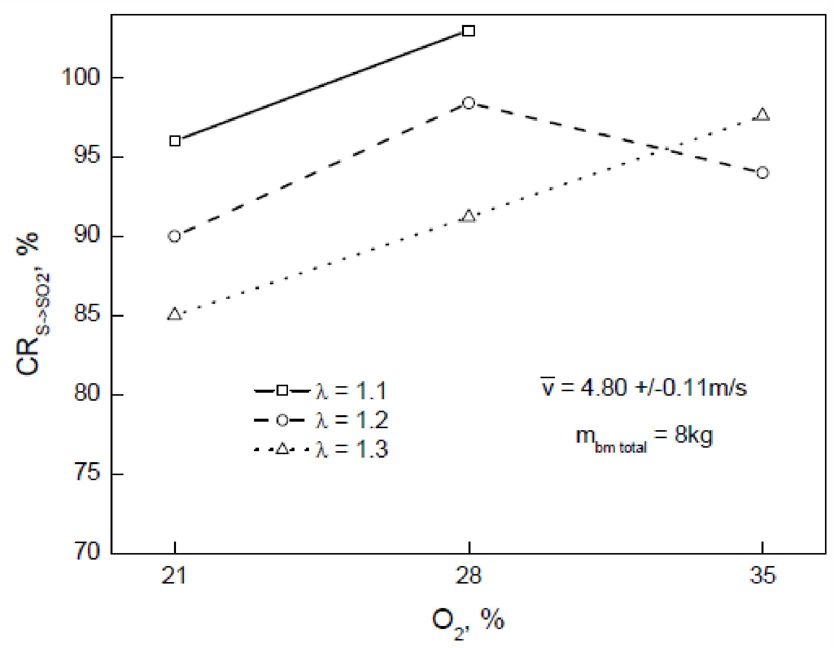
- ✓ Higher $CR_{N\text{->}NOx}$ associated with increase of temperature (regardless of λ)
- ✓ Higher (> 50%) $CR_{N\text{->}NOx}$ associated with increase of excess oxygen in reaction zone (at stable temperature)

- ✓ Higher $CR_{N\text{->}NOx}$ associated with increase of oxygen concentration in gas mixture (in parallel with increase in temperature)
- ✓ Higher $CR_{N\text{->}NOx}$ associated with increase of λ (in parallel with decrease in temperature)

RESULTS OF INVESTIGATIONS

SO_2 FORMATION



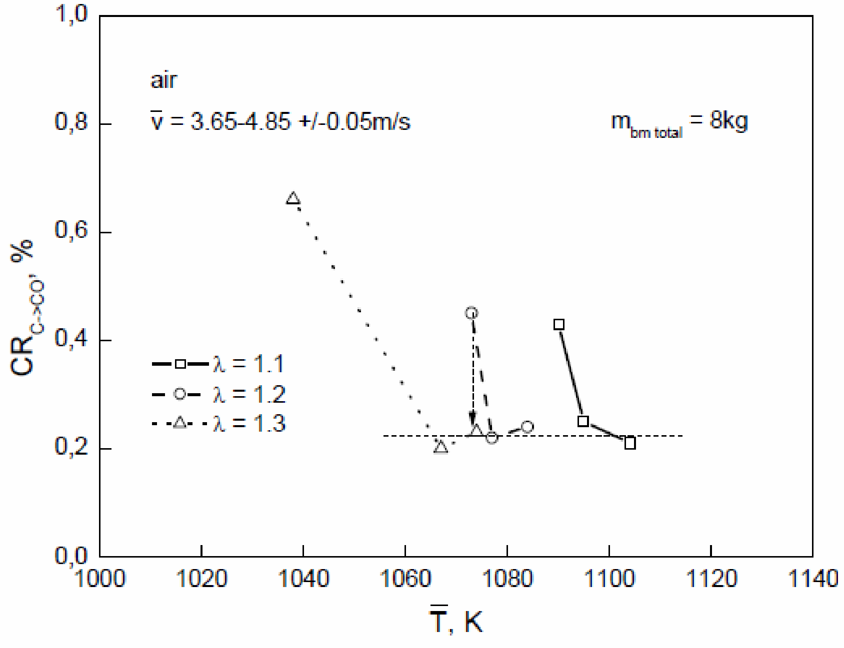


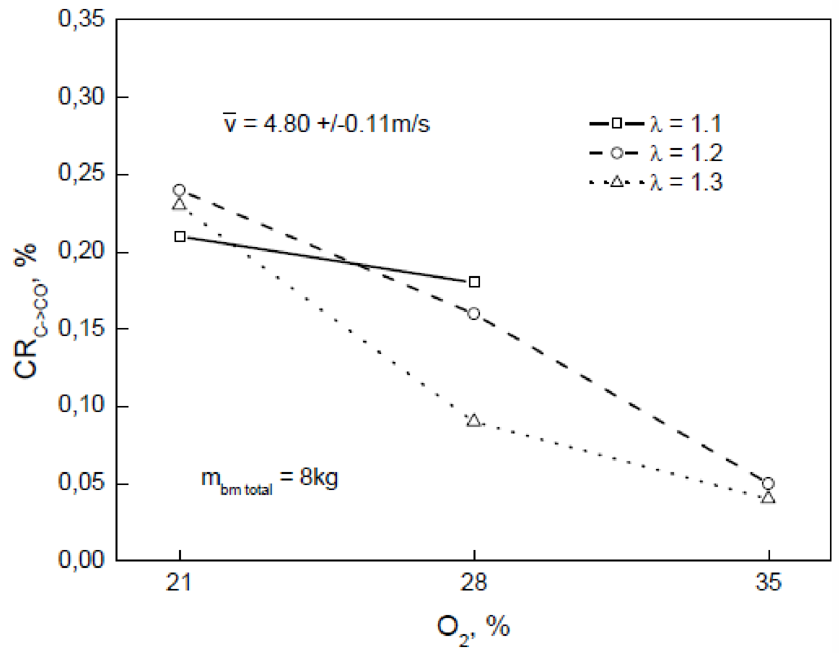
- ✓ Lower $CR_{S\text{->}SO2}$ associated with increase of temperature (regardless of λ) – effect of bonding of S with Ca & Mg contained in fuel-ash
- ✓ Lower $CR_{S\text{->}SO2}$ associated with increase of excess oxygen in reaction zone (at stable temperature) – effect of oxidation of S directly to SO_3

- ✓ Higher $CR_{S\text{->}SO2}$ in oxygen enriched environment (high temperature environment) – result of oxidation of S contained in H_2S in flue gas
- ✓ Lower $CR_{S\text{->}SO2}$ associated with increase of λ (in parallel with decrease in temperature) – effect of oxidation of S to SO_3

RESULTS OF INVESTIGATIONS

CO FORMATION





- ✓ Decline of $CR_{C\text{->}CO}$ associated with increase in temperature (regardless of λ)
- ✓ Decline of $CR_{C\text{->}CO}$ associated with increase in excess oxygen (at stable temperature)
- ✓ Minimum level of $CR_{C\text{->}CO}$ ca. 0,2% for air conditions

- ✓ Strong decline of $CR_{C\text{->}CO}$ under oxygen-enriched conditions (high temperature conditions)

MAIN CONCLUSIONS

✓ Higher conversion ratio of fuel-N to NO_X ($NO+NO_2$) associated with increase of the following parameters: oxygen concentration in gas mixture, excess oxygen in reaction zone, temperature.

✓ Higher conversion ratio of combustible S to SO_2 in oxygen-enriched environment, probably as a result of oxidation of H_2S contained in flue gas.

Lower sulfur conversion ratio associated with increase of excess oxygen or increase in temperature, probably as an effect of oxidation of S directly to SO_3 or bonding of S with Ca and Mg contained in fuel-ash, respectively.

✓ Strong decline of conversion ratio of C to CO under oxygen-enriched conditions and slight decline of carbon conversion ratio associated with increase of excess oxygen or increase in temperature.

THANK YOU
FOR YOUR ATTENTION