Center of Research & Technology Hellas
Institute of Solid Fuel Technology & Applications
(CERTH / ISFTA)

"Investigations on the operating performance and ash toxicity of CFBC with imported coals"

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Scope

Aim

To examine the reliability, operating performance and ash toxicity of a 1.2MW_{th} CFBC installation, when applying micro-combustion of coal using the fine tuned air control along the riser to decrease NO_x emissions

Objectives

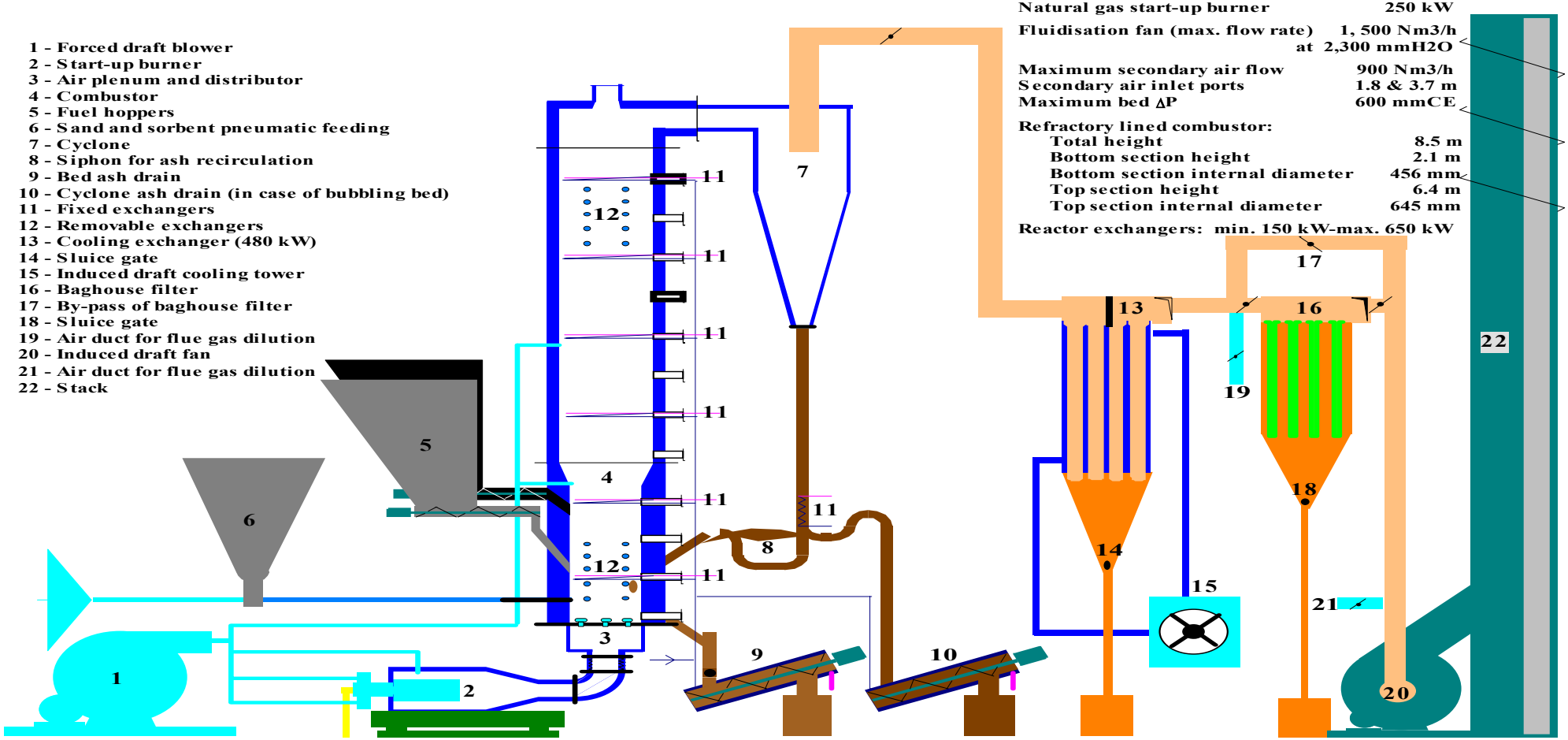
- to develop a new process based on fine control of oxygen in CFB boilers in order to reduce NO_x emissions (200mg/m_N^3, Directive 2001/80/EC)
- to investigate the physico-chemical characteristics of the solid residues
- to examine the leaching behavior of various toxic trace elements contained in the ashes
- the toxicological effect of the liquid samples obtained from the leaching test

CFBC Boiler Configuration

1 - Forced draft blower
2 - Start-up burner
3 - Air plenum and distributor
4 - Combustor
5 - Fuel hoppers
6 - Sand and sorbent pneumatic feeding
7 - Cyclone
8 - Siphon for ash recirculation
9 - Bed ash drain
10 - Cyclone ash drain (in case of bubbling bed)
11 - Fixed exchangers
12 - Removable exchangers
13 - Cooling exchanger (480 kW)
14 - Sluice gate
15 - Induced draft cooling tower
16 - Baghouse filter
17 - By-pass of baghouse filter
18 - Sluice gate
19 - Air duct for flue gas dilution
20 - Induced draft fan
21 - Air duct for flue gas dilution
22 - Stack

Main characteristics of the 1.2 MWth pilot

Natural gas start-up burner	250 kW
Fluidisation fan (max. flow rate)	1, 500 Nm3/h at 2,300 mmH2O
Maximum secondary air flow	900 Nm3/h
Secondary air inlet ports	1.8 & 3.7 m
Maximum bed ΔP	600 mmCE
Refractory lined combustor:	
Total height	8.5 m
Bottom section height	2.1 m
Bottom section internal diameter	456 mm
Top section height	6.4 m
Top section internal diameter	645 mm
Reactor exchangers:	min. 150 kW-max. 650 kW



Materials

- **Two different types of coal:**

✓ South-African (Kromdraï coal)

- moisture ~ 5%
- ash content ~15%
- volatile content ~23%
- low calorific value ~26600J/g
- N (% dry) 1.6%

✓ Colombian coal (La Loma)

- moisture ~ 12%
- low ash content ~6%
- volatile content ~36%
- low calorific value ~28300J/g
- N (% dry) 1.4%

Materials

- **Three different tests:**

	Primary air flow rate ($m_N^3.h^{-1}$)	Secondary air flow rate ($m_N^3.h^{-1}$)				
		1.9 m	*2.6m*	*3.9m*	*5.5 m*	*7 m*
Test I – Standard conditions	700	700	-	-	-	-
Test II – Multi air staging 1	600	360	40	300	50	50
Test III– Multi air staging 2	600	480	50	210	30	30

- **Fifteen different ash samples:**

✓ South-African coal combustion tests
- baghouse filter ashes (SF1, SF2, SF3)
- cooling exchanger ashes (SE1, SE2, SE3)
- bed ash drain ashes (SB1, SB2, SB3)

✓ Colombian coal combustion tests
- baghouse filter ashes (CF1, CF2, CF3)
- cooling exchanger ashes (CE1, CE2, CE3)

Experimental

- **Operational data collection**

  - temperature
  - pressure
  - heat transfer profiles
  - flow rates
  - combustion efficiency
  - flue gas analysis (CO, O_2, SO_2, NO_X, N_2O)

- **Concentrations of CO, O_2, SO_2, NO_x, N_2O:**

✓ South-African coal combustion tests
- 1600mm from the grid
- 4200mm from the grid
- 7100mm from the grid

✓ Colombian coal combustion tests
- 1600mm from the grid
- 2600mm from the grid
- 4200mm from the grid
- 7100mm from the grid

Experimental

- **Ash Characterization**

  - Particle size distribution
  - Heavy metal analysis (ICP-AES, FAAS)
  - Mercury analysis (AAS, EPA Method 7471A)
  - Mineralogy (XRD)

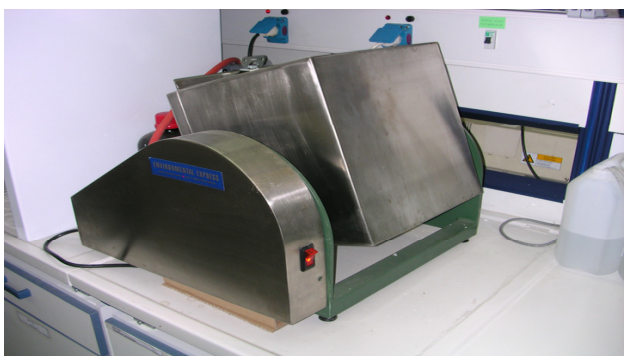
- **Toxicity Characteristic Leaching Procedure (EPA Method 1311)**

  - Environmental Express Agitator (USA)
  - Extraction fluid: acetic acid solution: pH = 2.88±0.05
  - Liquid to solid ratio, L/S = 20/1
  - 30 ±2rpm for 18h
  - Chemical analysis of leachates (ICP-AES, FAAS)
  - Mercury analysis (AAS, EPA Method 7470A)

Experimental

- **Microtox Toxicity test**
  - Microtox 500 Analyzer, AZUR Environmental
  - Microtox test is based on the reduction in bioluminescence of the marine bacterium *Vibrio Fischeri*
  - The toxic effect of the leachates on *Vibrio Fischeri* is evaluated following the:
    - ✓Microtox 82% Screening test, with a 82% concentration of the liquid sample

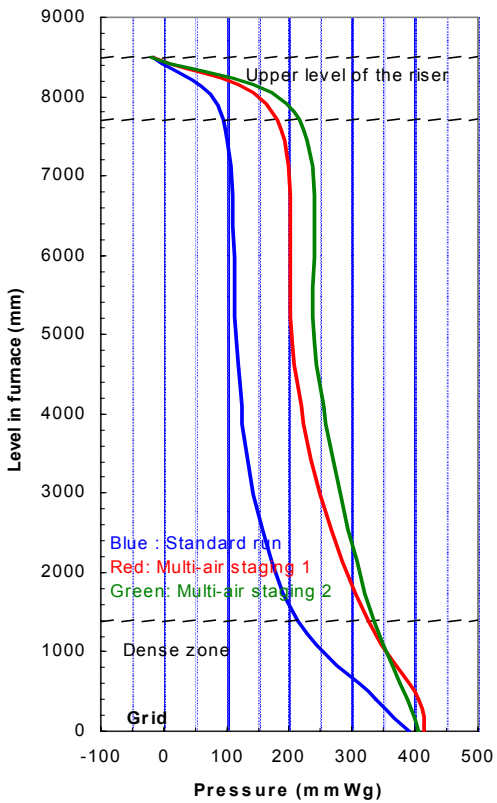
Microtox 500 Analyzer



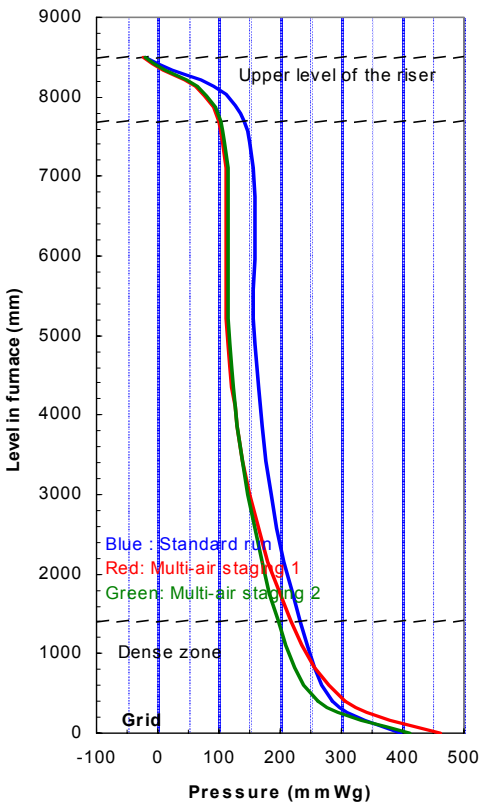
Environmental Express Agitator

Operational data of the CFB boiler

- **Axial pressure profiles**



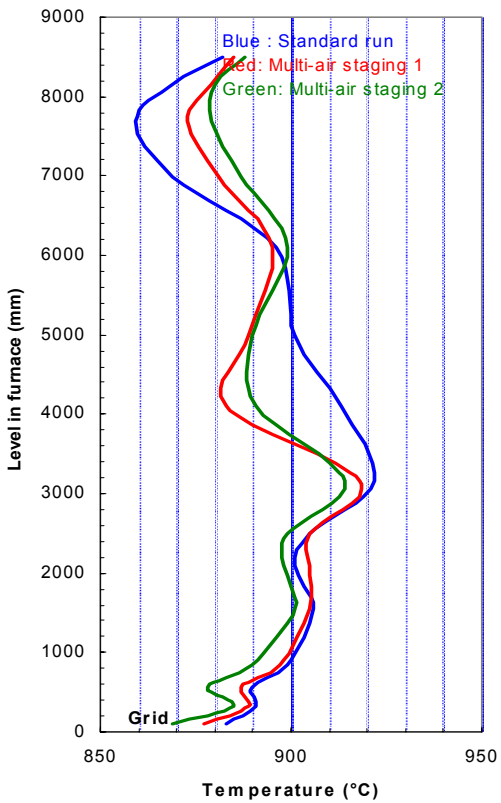
South-African coal



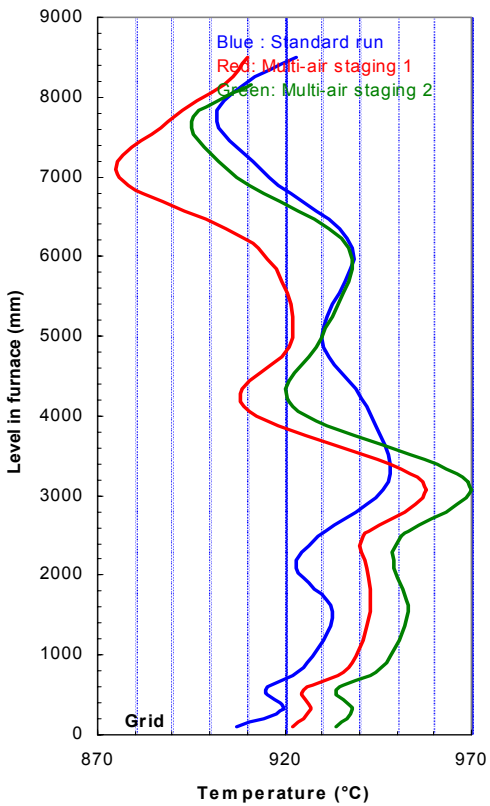
Colombian coal

Operational data of the CFB boiler

- **Temperature profiles**



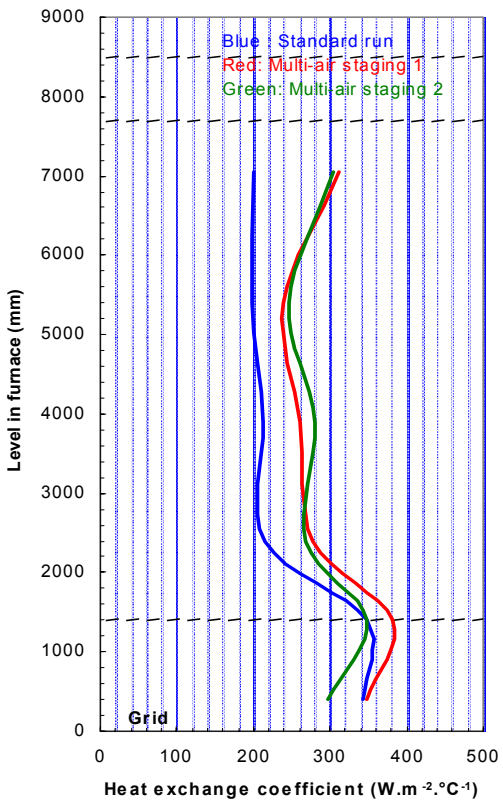
South-African coal



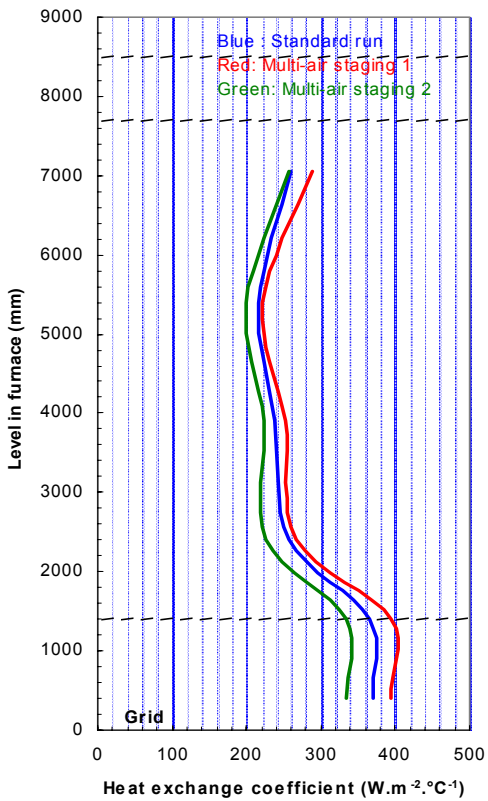
Colombian coal

Operational data of the CFB boiler

- **Heat exchange profiles**



South-African coal



Colombian coal

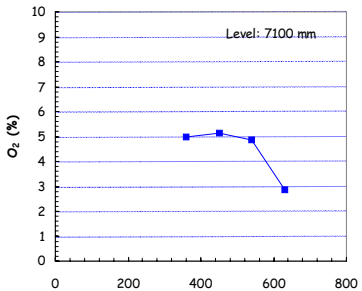
Flue gas concentrations

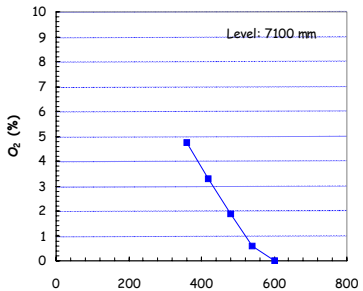
Test	South-African coal			Colombian coal		
	Test I	Test II	Test III	Test I	Test II	Test III
Riser mean temperature	894	892	892	927	918	932
O_2 in flue gas (%)	3.87	3.90	3.89	3.87	3.92	3.96
CO (mg/m_N^3, 6%O_2)	130	126	120	58	65	56
SO_2 (mg/m_N^3, 6%O_2)	192	205	170	172	536	510
NO_X (mg/m_N^3, 6%O_2)	**262**	**183**	**185**	**512**	**283**	**345**
N_2O (mg/m_N^3, 6%O_2)	165	108	160	36	16	10
Ca/S	3.24	2.98	2.74	5.5	6.5	6.0
Combustion Efficiency	0.950	0.943	0.945	0.988	0.990	0.989
NO_X variation (%)[1]	-	**-30.2**	**-29.4**	-	**-44.7**	**-32.6**
N_2O variation (%)[1]	-	**-34.5**	**-3.0**	-	**-55.6**	**-72.2**

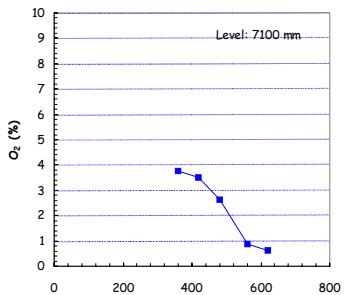
O_2 concentration profiles – South African coal

Standard conditions | **Multi air staging 1 conditions** | **Multi air staging 2 conditions**

7100 mm







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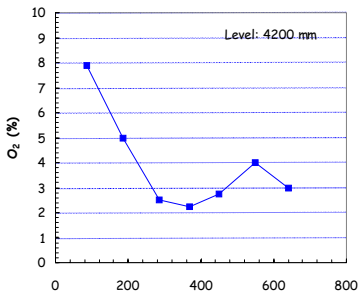

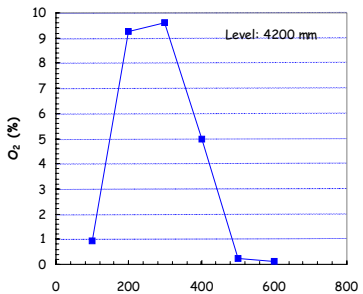

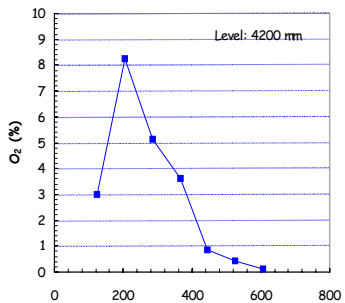

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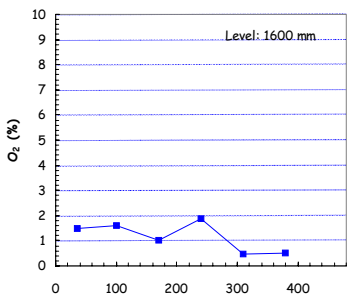
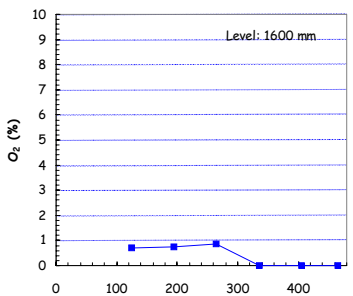
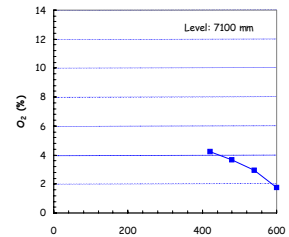


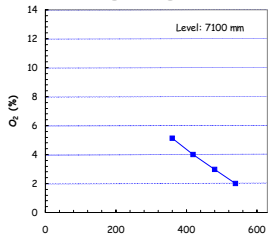


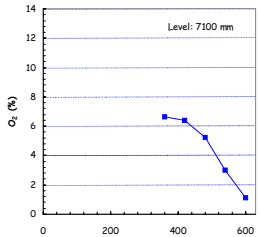
O_2 concentration profiles – Colombian coal

Standard conditions | **Multi air staging 1 conditions** | **Multi air staging 2 conditions**

7100 mm







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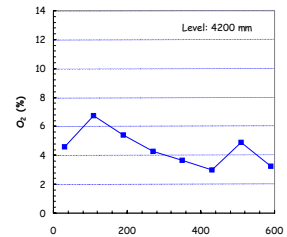

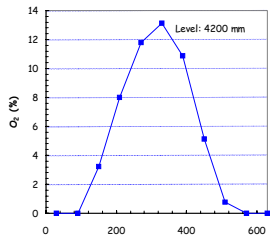

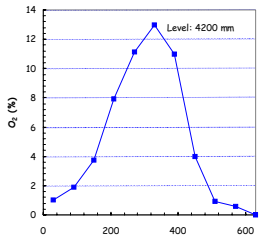

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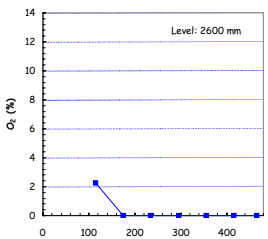

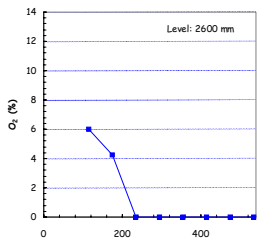

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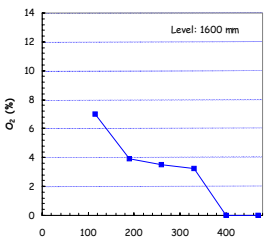
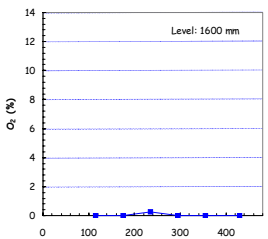
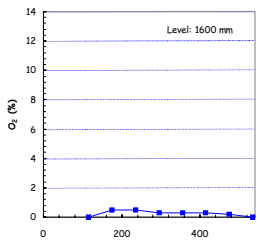


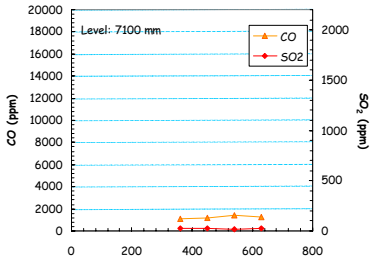


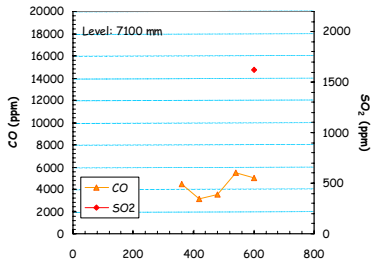


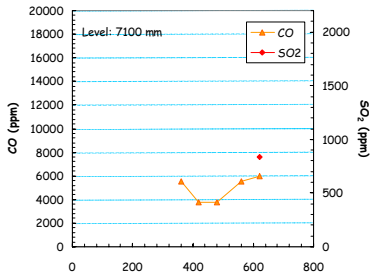
CO-SO_2 concentration profiles – South African coal

Standard conditions | **Multi air staging 1 conditions** | **Multi air staging 2 conditions**

7100 mm







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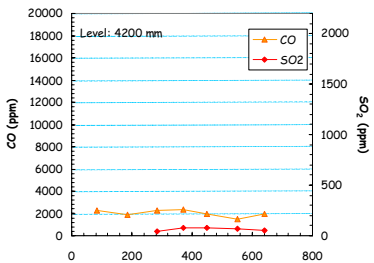

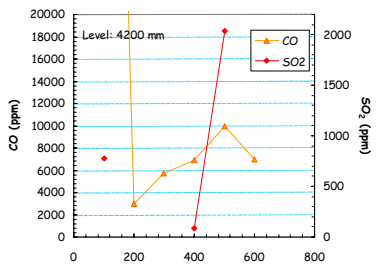

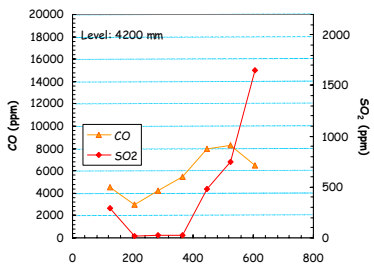

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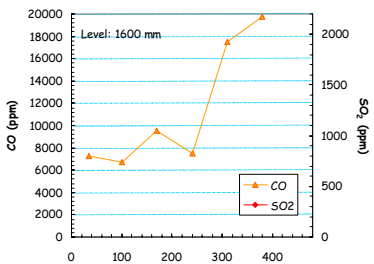
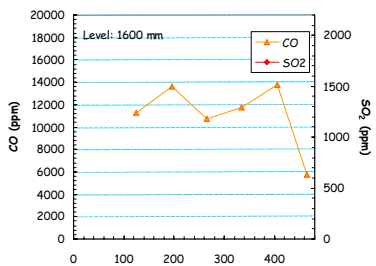
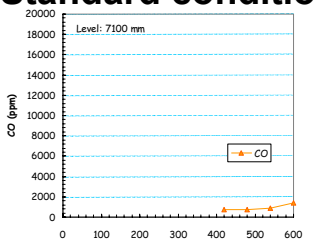


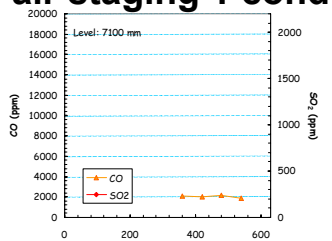


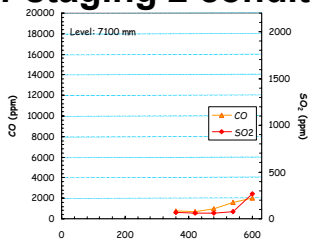
CO-SO_2 concentration profiles – Colombian coal

Standard conditions | **Multi air staging 1 conditions** | **Multi air staging 2 conditions**

7100 mm







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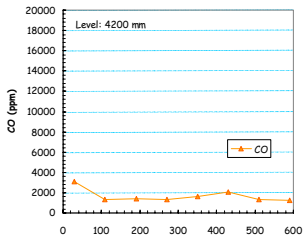
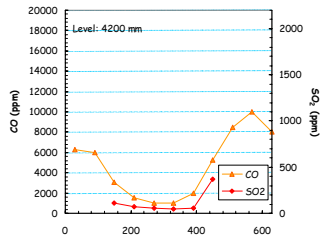
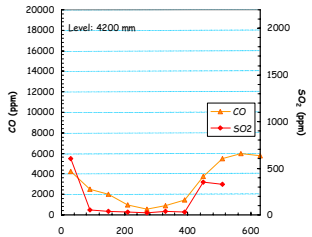
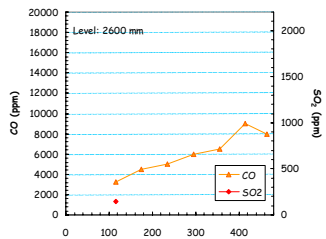
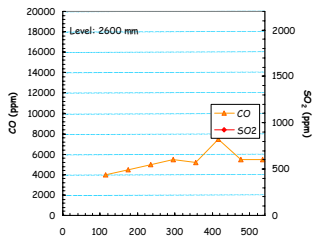






2600 mm





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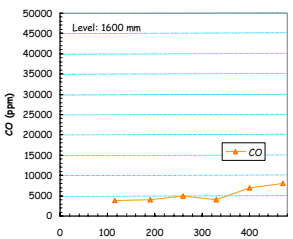

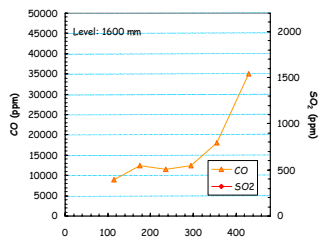

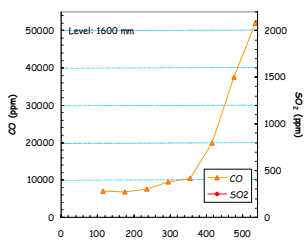

NO-N_2O concentration profiles – South African coal

Standard conditions | **Multi air staging 1 conditions** | **Multi air staging 2 conditions**

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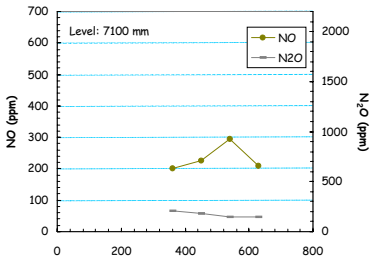

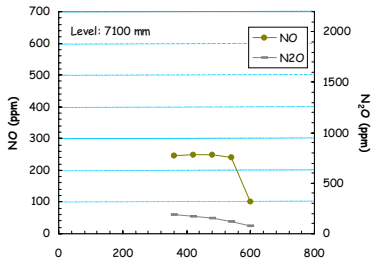

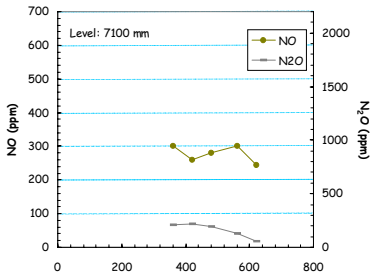

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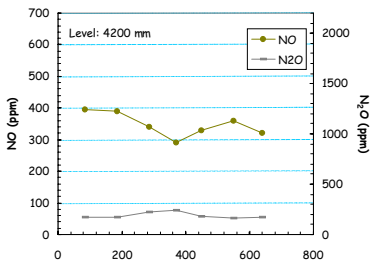

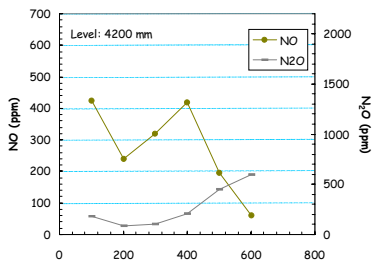

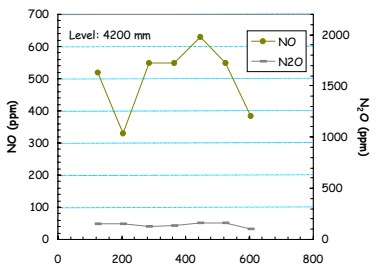

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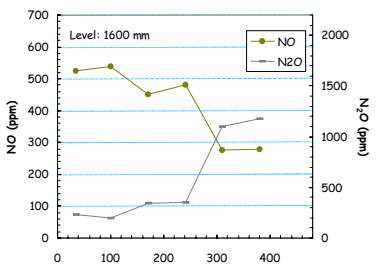
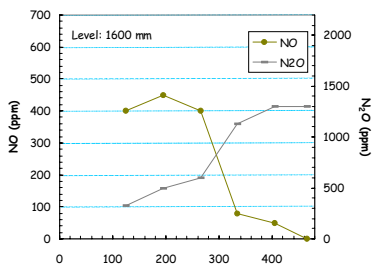
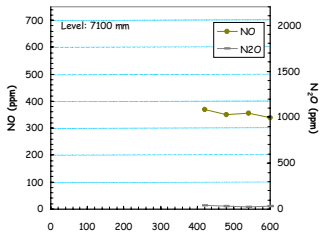


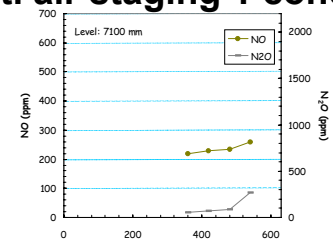


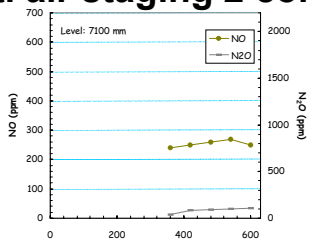
NO-N_2O concentration profiles – Colombian coal

Standard conditions | **Multi air staging 1 conditions** | **Multi air staging 2 conditions**

7100 mm







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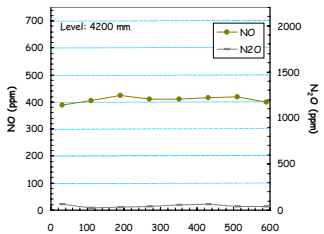

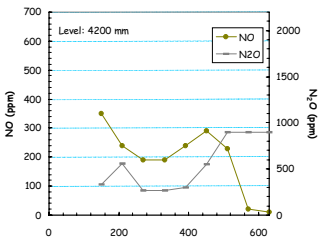

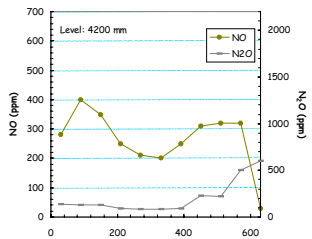

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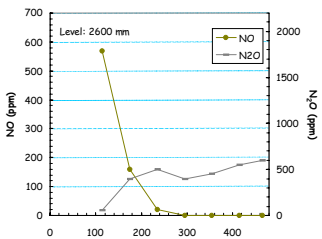

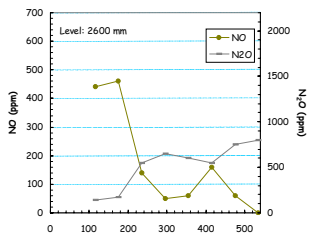

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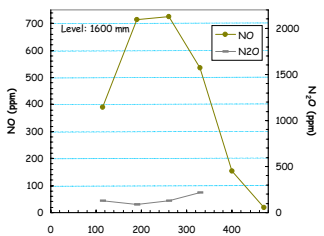
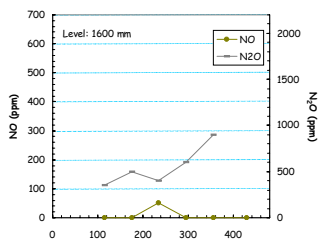
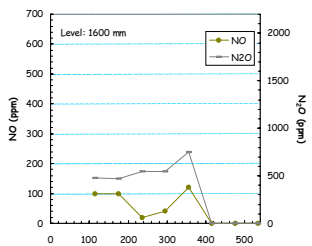
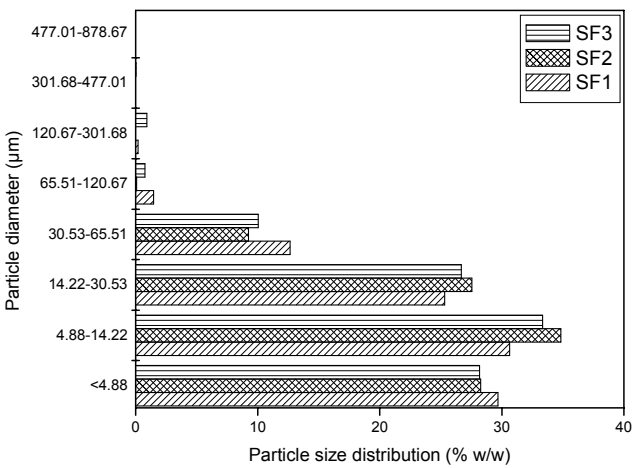




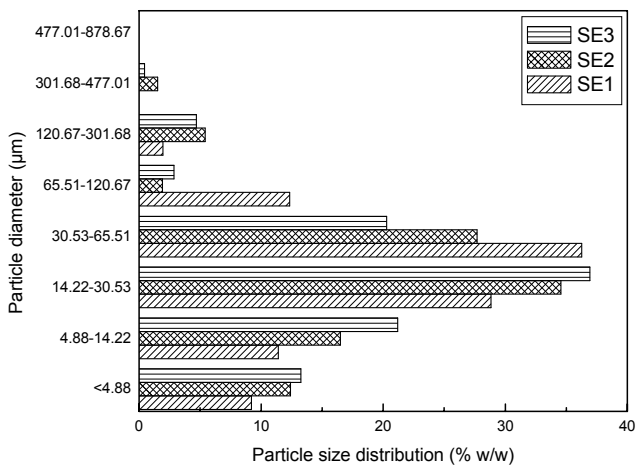


Particle Size Distribution

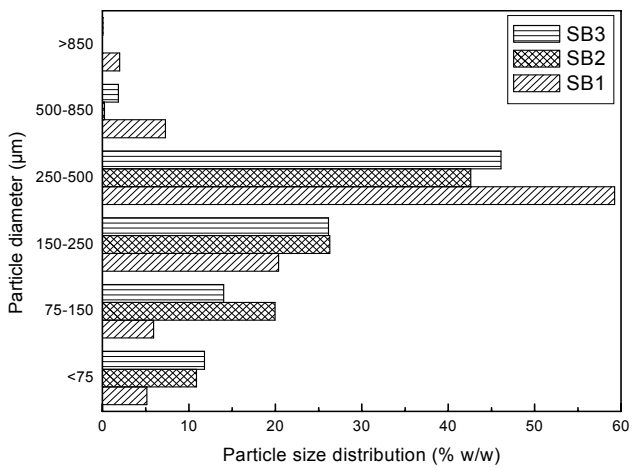
- **South-African samples**



Baghouse filter ashes



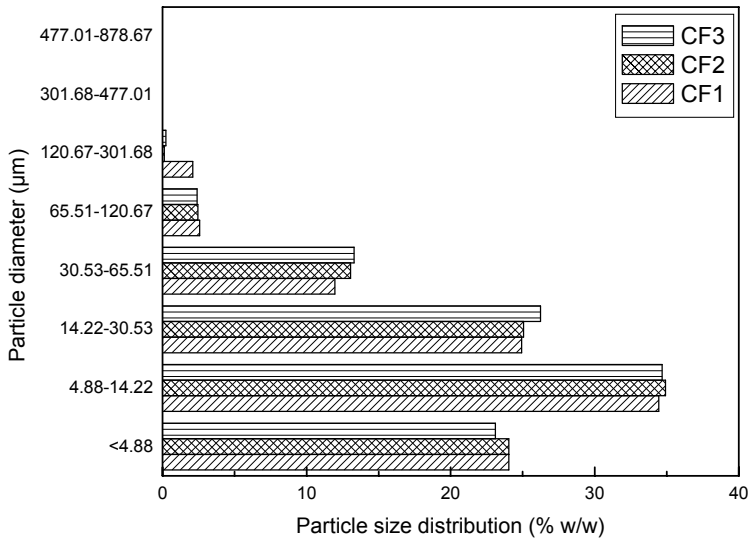
Cooling exchanger ashes



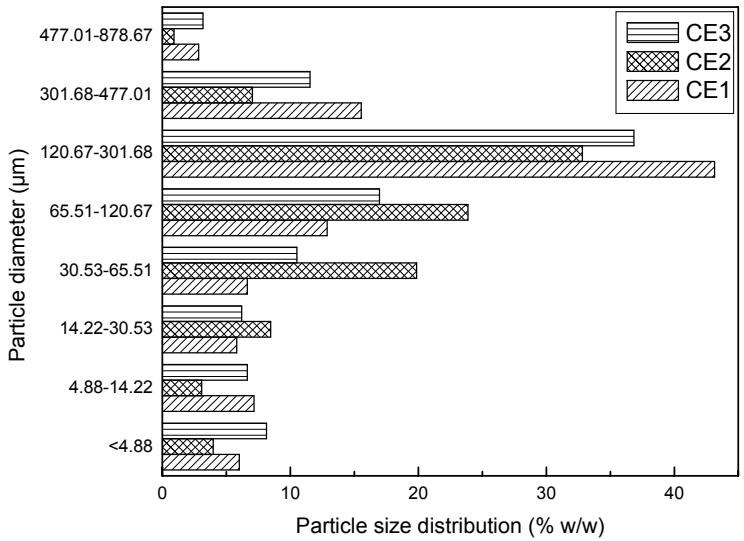
Bed ashes

Particle Size Distribution

- **Colombian samples**



Baghouse filter ashes



Cooling exchanger ashes

Chemical Analysis

- **South-African samples**

Samples (μg/g)	SF1	SE1	SB1	SF2	SE2	SB2	SF3	SE3	SB3
As	ND	ND	ND	ND	ND	ND	ND	ND	ND
Cd	0.78	ND	ND	0.39	ND	ND	ND	ND	ND
Co	15.6	8.9	ND	14.6	8.5	3.3	15.1	7.7	2.8
Cr	132	91	41	128	97	90	155	110	127
Cu	69	44	17	69	41	22	65	52	34
Hg	0.29	0.13	0.18	0.32	0.23	0.21	0.29	0.14	0.18
Ni	52	38	22	44	34	33	70	49	44
Pb	ND	ND	ND	ND	ND	ND	ND	ND	ND
Sn	ND	ND	ND	ND	ND	ND	ND	ND	ND
Zn	77	61	40	64	61	66	72	71	116
pH	11.91	12.25	11.78	11.94	12.21	12.22	11.87	12.18	12.16

Chemical Analysis

- **Colombian samples**

Samples (μg/g)	CF1	CE1	CF2	CE2	CF3	CE3
As	13	40	20	80	27	87
Cd	ND	ND	0.80	ND	0.80	ND
Co	ND	ND	80	67	ND	66.7
Cr	120	60	100	ND	173	33
Cu	53	80	80	53	80	47
Hg	0.084	0.06	0.16	0.07	0.121	0.071
Ni	153	126	173	323	1687	1133
Pb	200	933	427	733	327	226
Sn	65	493	69	584	299	159
Zn	113	200	100	133	107	133
pH	12.12	11.97	12.04	12.01	12.04	12.03

Mineralogical Analysis

- **South-African samples**

Samples	SF1	SE1	SB1	SF2	SE2	SB2	SF3	SE3	SB3
Quartz	++	+++	+++	++	+++	+++	+++	+++	+++
Anhydrite	+++	++		+++	++		++	++	+
Lime	++	+		++	+	+	++	+	+
Rutile					++				
Gehlenite						+			
Calcium Aluminum Silicate						+			
Iron Sulfite									+

Mineralogical Analysis

- **Colombian samples**

Samples	CF1	CE1	CF2	CE2	CF3	CE3
Quartz	+++	+++	+++	+++	+++	+++
Portlandite	+	+	+	+	+	+
Anhydrite	++	+	++		++	
Lime	+	+	+++	+	+++	+
Gehlenite		+		+		+
Calcium Silicate Hydrate	+					

Chemical Analysis of TCLP leachates

- **South-African samples**

Samples (mg/l)	SF1	SE1	SB1	SF2	SE2	SB2	SF3	SE3	SB3	EPA max
Ca	2577	3001	1160	2943	3400	3289	2583	3017	2984	
Cd	ND	ND	ND	ND	ND	ND	ND	ND	ND	1
Cr	0.005	0.005	0.04	0.02	0.04	0.003	0.12	0.02	0.002	5
Cu	ND	ND	0.123	ND	ND	ND	ND	ND	ND	15
Hg	0.00038	0.00018	0.00022	0.0003	0.00015	0.00027	0.00025	0.00011	0.00013	0.2
Ni	0.03	ND	0.1	0.05	ND	ND	0.12	ND	0.06	5[a]
Pb	ND	ND	ND	ND	ND	ND	ND	ND	ND	5
Zn	0.28	0.2	0.22	0.08	0.12	0.1	0.22	0.03	0.03	25
pH	6.93	12.23	4.7	6.09	12.15	12.17	5.23	11.81	7.95	

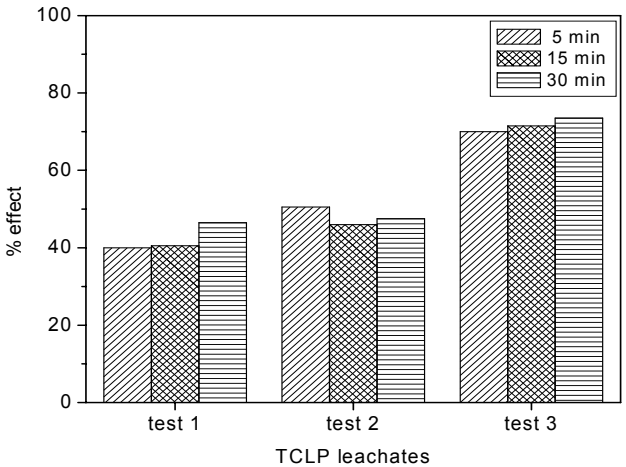
Chemical Analysis of TCLP leachates

- **Colombian samples**

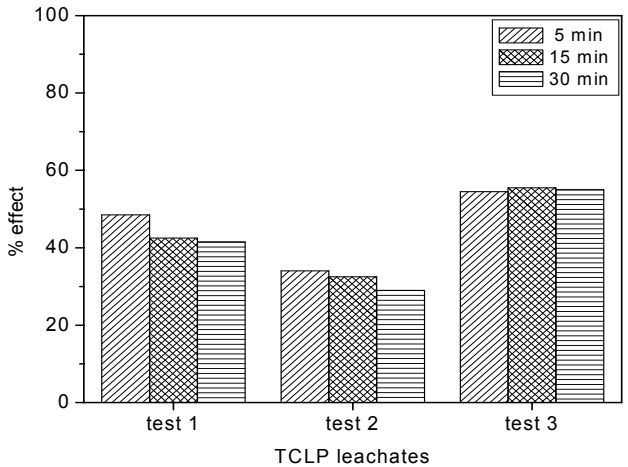
Samples (mg/l)	CF1	CE1	CF2	CE2	CF3	CE3	EPA max
As	ND	0.033	ND	ND	ND	ND	5
Ca	2960	3080	3170	2740	3110	2620	
Cd	ND	ND	ND	ND	ND	ND	1
Cr	0.18	0.09	0.15	ND	0.26	0.05	5
Cu	ND	ND	ND	ND	ND	ND	15
Hg	0.00018	0.00024	0.00024	0.00025	0.00012	0.00019	0.2
Ni	ND	ND	ND	0.075	0.01	ND	5[a]
Pb	0.01	ND	0.012	ND	0.035	ND	5
Zn	0.05	0.07	0.08	0.07	0.07	0.07	25
pH	11.93	12.04	11.98	12.01	11.96	11.99	

Microtox Toxicity test

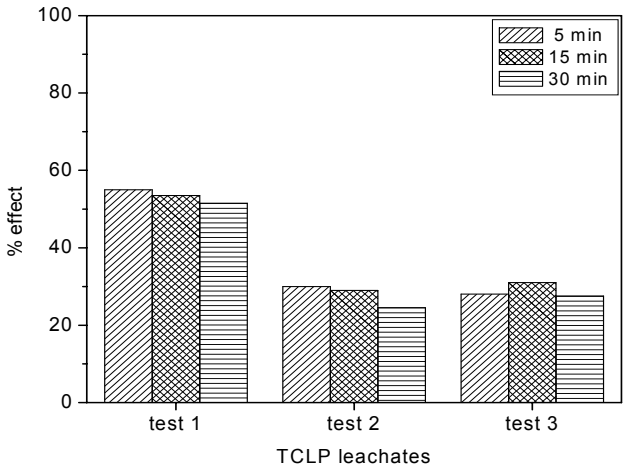
- **South-African samples**



Baghouse filter ashes



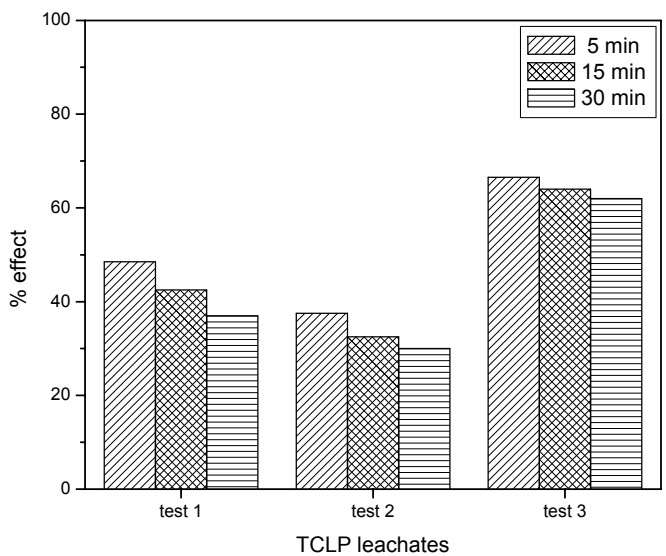
Cooling exchanger ashes



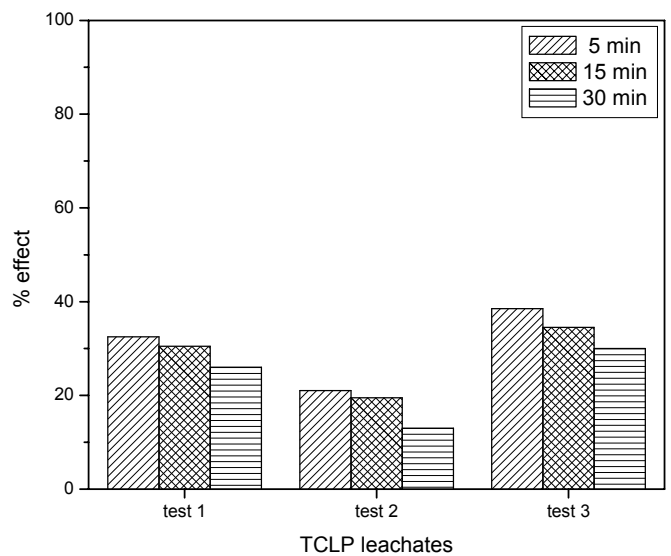
Bed ashes

Microtox Toxicity test

- **Colombian samples**



Baghouse filter ashes



Cooling exchanger ashes

Conclusions I

- Multi air staging process favours significant NO_x reduction, being 30% for South African coal and ranged from 32 to 45% for Colombian coal.
- NO_X emissions below 200 mg/m_N^3 were achieved for South African coal, while best performance for Colombian coal has been 280 mg/m_N^3.
- N_2O emissions reduction between 3 and 34 % for South African coal and from 55 to 72% for Colombian coal.
- A positive effect was measured on SO_2 emissions for South African coal, but a huge detrimental impact was observed for Colombian coal.
- CO emissions and combustion efficiency were maintained constant in both cases.

Conclusions II

- Chemical analysis and PSD showed that heavy metals are mostly concentrated in the fly ash samples due to their lower particle sizes.
- Toxic trace elements are mostly concentrated in the baghouse filter fly ash particles (smaller particle size → larger specific surfaces).
- All ash samples passed the TCLP leaching test - Higher concentrations of metals were detected in fly ash compared to the bed ash leachates.
- Baghouse filter ash leachates caused the higher toxic effects.
- Apart from the bed ash samples collected from the airstaged combustion tests of South African coal and the cooling exchanger ash samples collected from combustion tests I and II of Colombian coal, all other solid residues and especially the baghouse filter ashes should be characterised as ecotoxic and properly treated prior to landfill.