

5-26-2016

Combustion of lignin-rich residues with coal in a pilot-scale bubbling fluidized bed reactor

Roberto Solimene

Istituto di Ricerche sulla Combustione - Consiglio Nazionale delle Ricerche ,Piazzale V. Tecchio 80, 80125 Napoli, Italy, solimene@irc.cnr.it

Riccardo Chirone

Istituto di Ricerche sulla Combustione - Consiglio Nazionale delle Ricerche ,Piazzale V. Tecchio 80, 80125 Napoli, Italy

Antonio Cammarota

Istituto di Ricerche sulla Combustione - Consiglio Nazionale delle Ricerche ,Piazzale V. Tecchio 80, 80125 Napoli, Italy

Nicola Rossi

Enel Ingegneria e Ricerca S.p.A, Via Andrea Pisano 120, 56122 Pisa, Italy

Paolo Leoni

Enel Ingegneria e Ricerca S.p.A, Via Andrea Pisano 120, 56122 Pisa, Italy

See next page for additional authors

Follow this and additional works at: http://dc.engconfintl.org/fluidization_xv

 Part of the [Chemical Engineering Commons](#)

Recommended Citation

Roberto Solimene, Riccardo Chirone, Antonio Cammarota, Nicola Rossi, Paolo Leoni, and Piero Salatino, "Combustion of lignin-rich residues with coal in a pilot-scale bubbling fluidized bed reactor" in "Fluidization XV", Jamal Chaouki, Ecole Polytechnique de Montreal, Canada Franco Berruti, Wewstern University, Canada Xiaotao Bi, UBC, Canada Ray Cocco, PSRI Inc. USA Eds, ECI Symposium Series, (2016). http://dc.engconfintl.org/fluidization_xv/150

This Abstract and Presentation is brought to you for free and open access by the Proceedings at ECI Digital Archives. It has been accepted for inclusion in Fluidization XV by an authorized administrator of ECI Digital Archives. For more information, please contact franco@bepress.com.

Authors

Roberto Solimene, Riccardo Chirone, Antonio Cammarota, Nicola Rossi, Paolo Leoni, and Piero Salatino

COMBUSTION OF LIGNIN-RICH RESIDUES WITH COAL IN A PILOT-SCALE BUBBLING FLUIDIZED BED REACTOR

R. Solimene^{*}, A. Cammarota^{*}, R. Chirone^{*}, P. Leoni^{**}, N. Rossi^{**}, P. Salatino^{***}

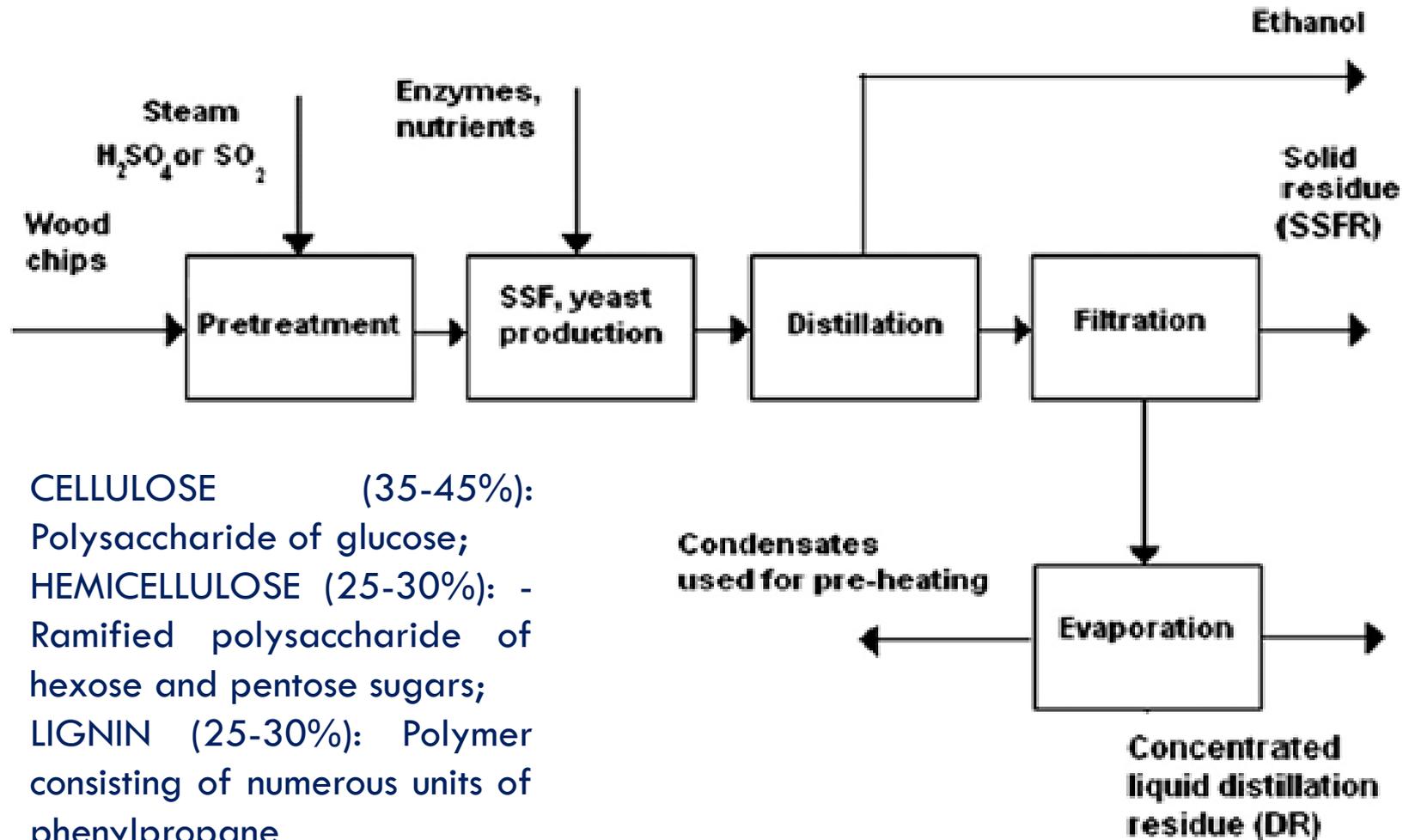
^{*} Istituto di Ricerche sulla Combustione, Consiglio Nazionale delle Ricerche, Napoli (Italy)

^{**} Enel Ingegneria e Ricerca S.p.A, Pisa (Italy)

^{***} Dipartimento di Ingegneria Chimica, dei Materiali e della Produzione Industriale, Università degli Studi di Napoli Federico II, Napoli (Italy)



2nd generation Bioethanol production



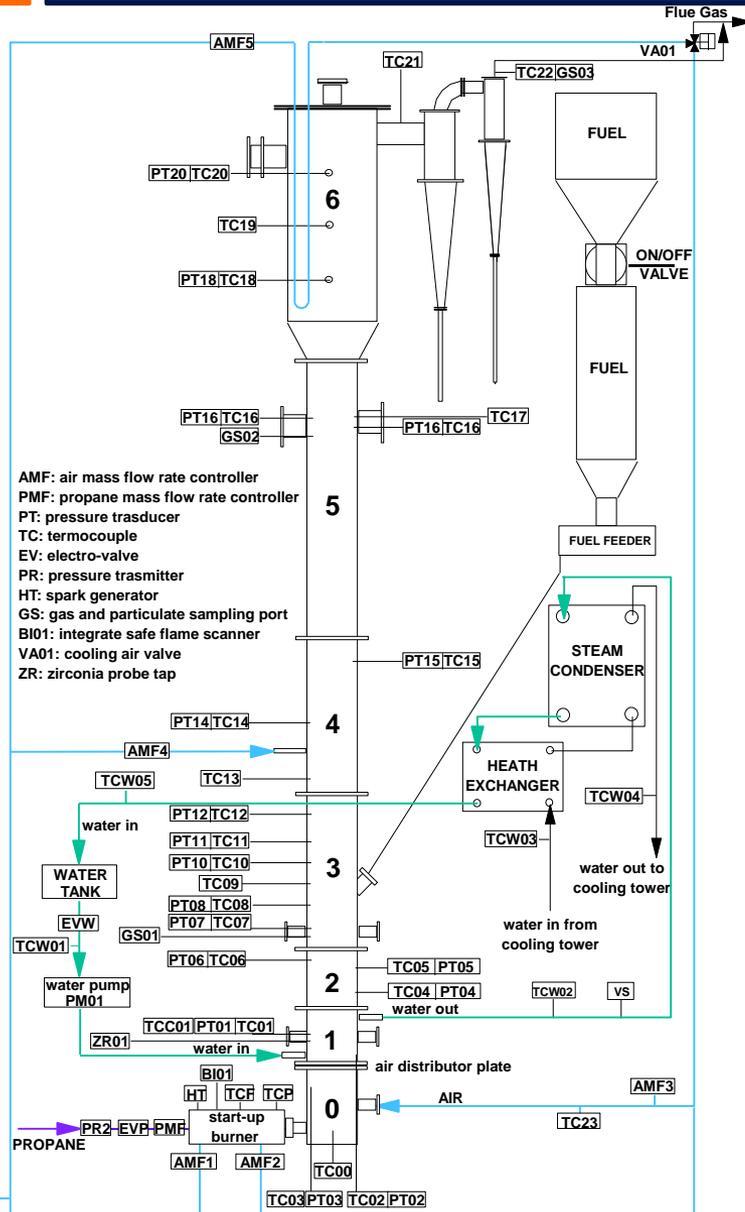
- ❖ CELLULOSE (35-45%): Polysaccharide of glucose;
- ❖ HEMICELLULOSE (25-30%): - Ramified polysaccharide of hexose and pentose sugars;
- ❖ LIGNIN (25-30%): Polymer consisting of numerous units of phenylpropane (unfermentable fraction).

Aim of the work

The aim of this work was to investigate the combustion of lignin-rich residues coming from a second-generation bioethanol production plant with coal in a pilot-scale bubbling fluidized bed combustor (FBC):

- ✓ gaseous and particulate emissions and thermal regimes during the combustion of mixtures of coal with 30%_w of lignin-rich residues varying bed temperature, excess air and fluidization velocity.
- ✓ Experiments with coal, a mixture with 40%_w of lignin-rich residues and with a mixture of coal with 20%_w of wood chips were carried out for comparison

Pilot-scale Fluidized Bed Combustor



- ✓ a circular section of 370 mm ID up to 5.05 m above gas distributor;
- ✓ the upper part of freeboard 1.85 m high enlarges to 700mm;
- ✓ two cyclones for flue gas de-dusting and particulate collection;
- ✓ a continuous over-bed belt-type feeding system;
- ✓ a propane premixed burner for the combustor start-up;
- ✓ a water-cooled external jacket (0.3 m from the distributor plate);
- ✓ an array of horizontal bayonet-type tubes whose adjustable penetration into the splash zone controls the heat removal rate;
- ✓ an air-cooled exchanger located inside the upper part of the freeboard (ID 700 mm).
- ✓ Several ports for temperature and pressure measurements
- ✓ Flue gas composition sampled at the exhaust was measured by on-line gas analyzers

Materials

Fuel	Lignin-rich residues	Colombian coal	Wood chips
LHV (as received), kJ/kg	5645	25564	8568
Proximate analysis (as received), % _w			
Moisture	60.7	10.3	45.5
Volatile matter	25.0	34.6	40.2
Fixed carbon	8.1	49.4	10.8
ash	6.1	5.7	3.5
Ultimate analysis (dry basis), % _w			
Carbon	47.0	79.3	51.3
Hydrogen	5.4	4.8	6.0
Nitrogen	1.2	1.0	1.4
Sulphur	0.1	0.7	0.2
Chlorine	0.0	0.0	0.0
ash	15.6	6.3	6.5
Oxygen (by difference)	30.6	7.9	34.6
Metal analysis (dry basis), ppm _w			
Al	3644	10140	235
Ba	57	260	4
Ca	2997	1825	3458
Fe	1674	4343	121
Mg	718	1172	736
P	691	44	125
K	3049	1209	915
Si	11170	n.a.	n.a.
Na	2561	1572	417
Sr	15	98	8
Ti	199	130	5
Zn	9	70	10
Component (dry basis), % _w			
Extractives	18.1	n.a.	n.a.
lignin	57.9	n.a.	n.a.

- ✓ All the fuels were sieved in 0.6-10mm size range.
- ✓ The mixtures of coal with lignin-rich residues or with wood chips were obtained by mixing weighed quantities of the two fuels in properly chosen vessels.
- ✓ Bed material was silica sand in the size range 0.8-1.2mm and bed inventory was kept constant at 40kg.

Operating conditions

Steady state thermal regimes, #	Fuel	Fuel mass rate, kg/h	Fuel thermal power, kW	Superficial Gas velocity @ T_{bed} (U), m/s	Excess air, %	Bed temperature (T_{bed}), °C
1	coal	11.1	71.4	1.00	34	852
2		9.3	63.6	1.00	51	849
3		11.4	80.7	0.98	14	831
4		8.8	62.3	0.97	48	818
5		12.2	86.9	1.26	32	859
6		12.2	86.9	1.32	34	908
7	Mixture with 30% _w of lignin-rich residues	13.3	66.1	0.96	45	849
8		12.3	61.1	0.99	37	837
9		12.1	60.4	0.95	58	839
10		10.5	57.2	1.00	60	849
11		17.9	88.8	1.25	34	852
12		15.0	81.8	1.31	40	902
13		28.2	147.1	2.10	29	904
14		22.3	116.3	2.03	63	863
15	Mixture with 40% _w of lignin-rich residues	17.5	85.7	1.34	33	913
16	Mixture with 20% _w of wood chips	12.1	71.1	0.94	25	856
17		11.8	69.8	0.99	36	844
18		8.6	50.9	0.98	86	831

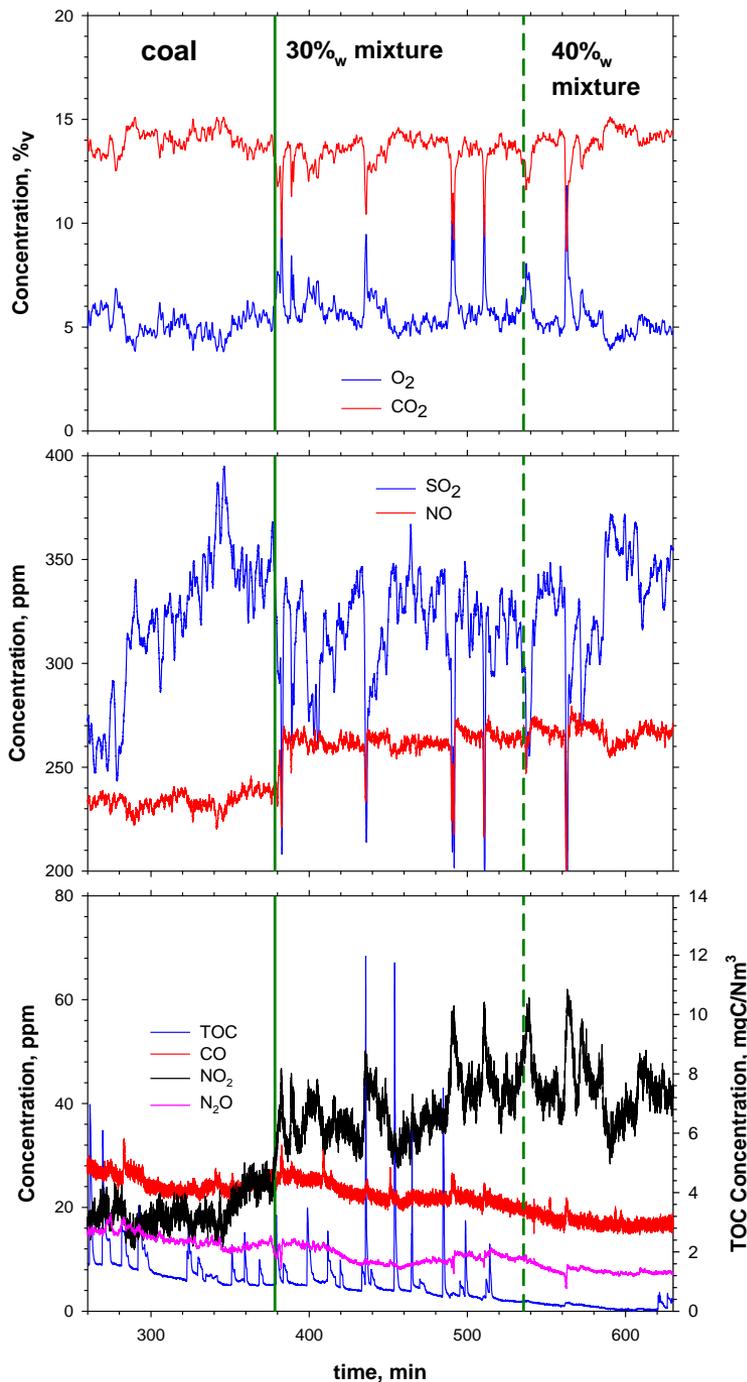
✓ The ratio between the secondary air flow rate (fuel transport air) and the primary air flow rate fed at the bottom of the bed was kept constant at a value of 20%.

✓ Excess air=14-86%

✓ $U=0.95-2.10\text{m/s}$

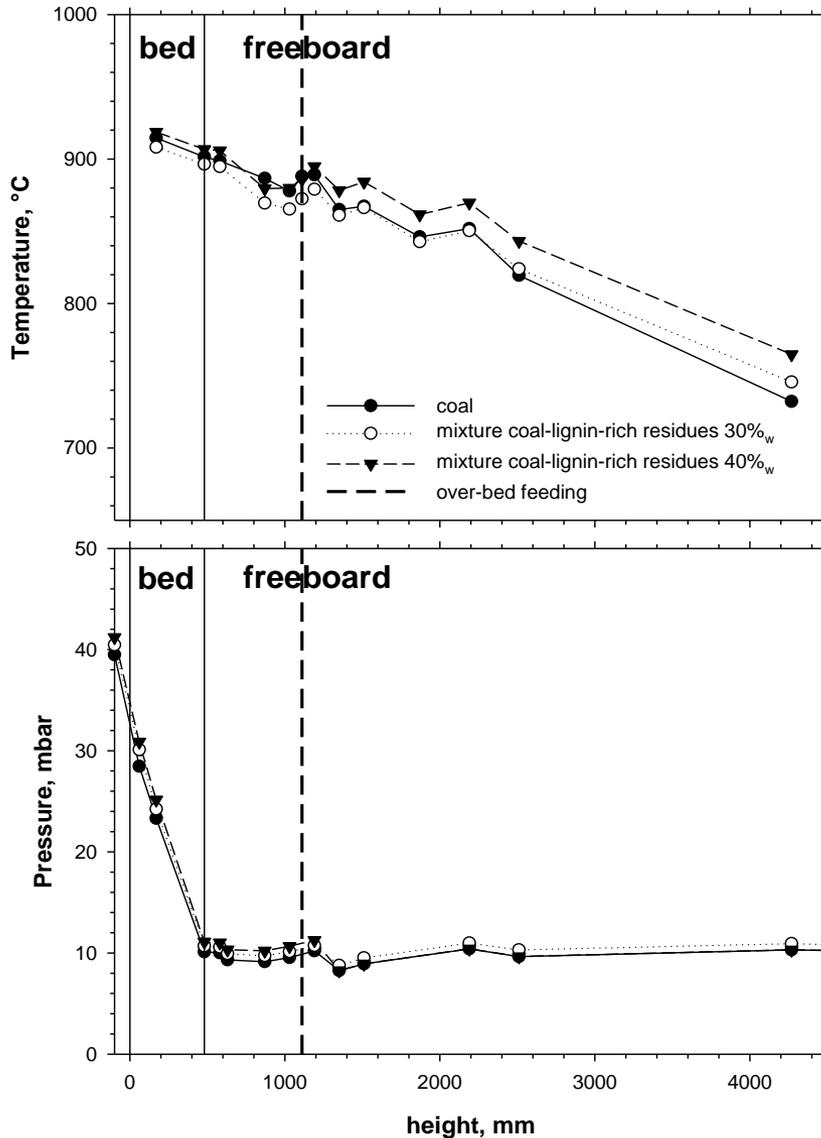
✓ $T_{bed}=830-913^{\circ}\text{C}$

Combustion regimes varying the content of lignin-rich residues fed with coal



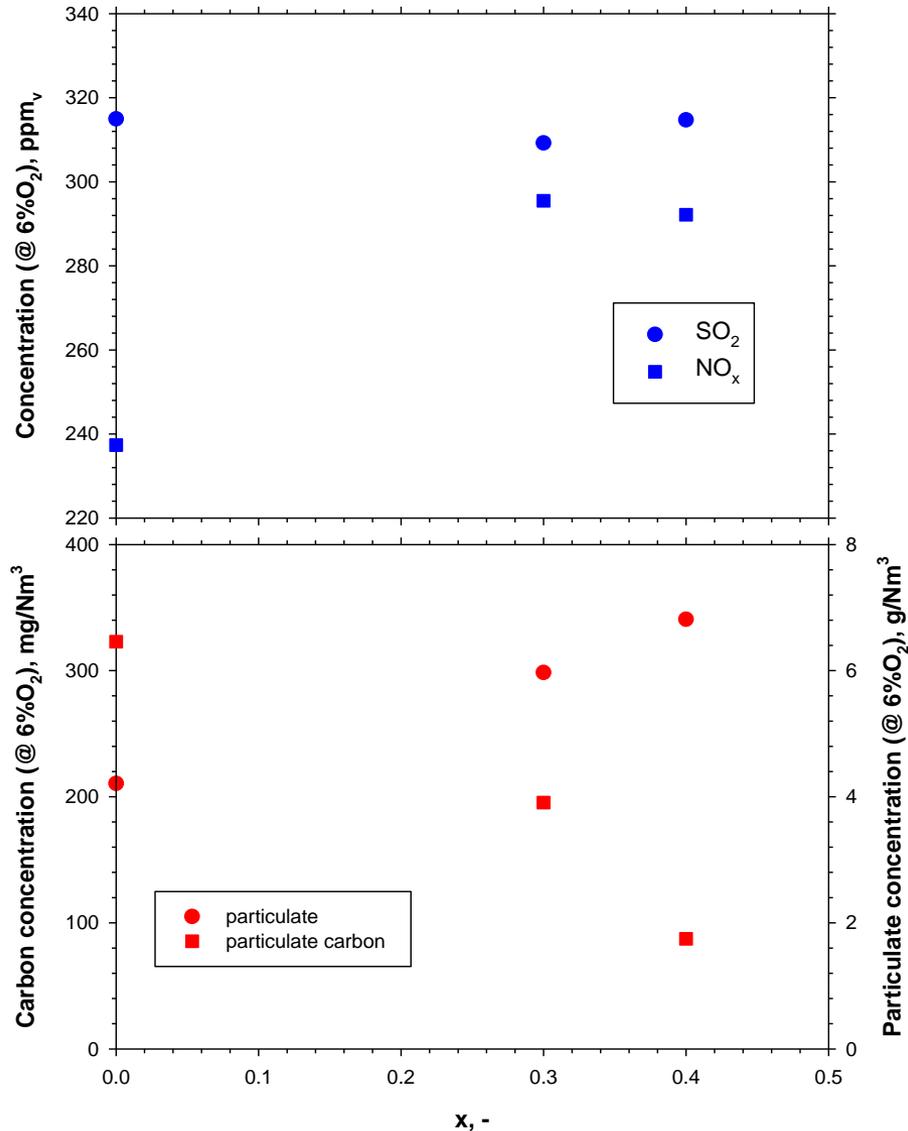
- ✓ Three steady state thermal regimes occurred in sequence feeding: 1) only coal; 2) a mixture with 30%_w of lignin-rich residues; 3) a mixture with 40%_w of lignin-rich residues
- ✓ The time-averaged oxygen concentration measured at the exhaust and bed temperature about 902-913°C were kept constant
- ✓ Sharp upward peaks in oxygen concentration time series observed when the coal was fed mixed with lignin-rich residues were due to the stickiness of lignin-rich residues that made more intermittent the falling-down of the fuel particles along the feeding ducts
- ✓ variations of SO₂ concentration were barely detectable
- ✓ NO and NO₂ concentrations rapidly increased due to the fast reaction mechanisms active in gas phase
- ✓ N₂O, CO and TOC concentrations slowly decreased probably with the establishment of different thermal regimes along the fluidization column.

Gas pressure and temperature profiles



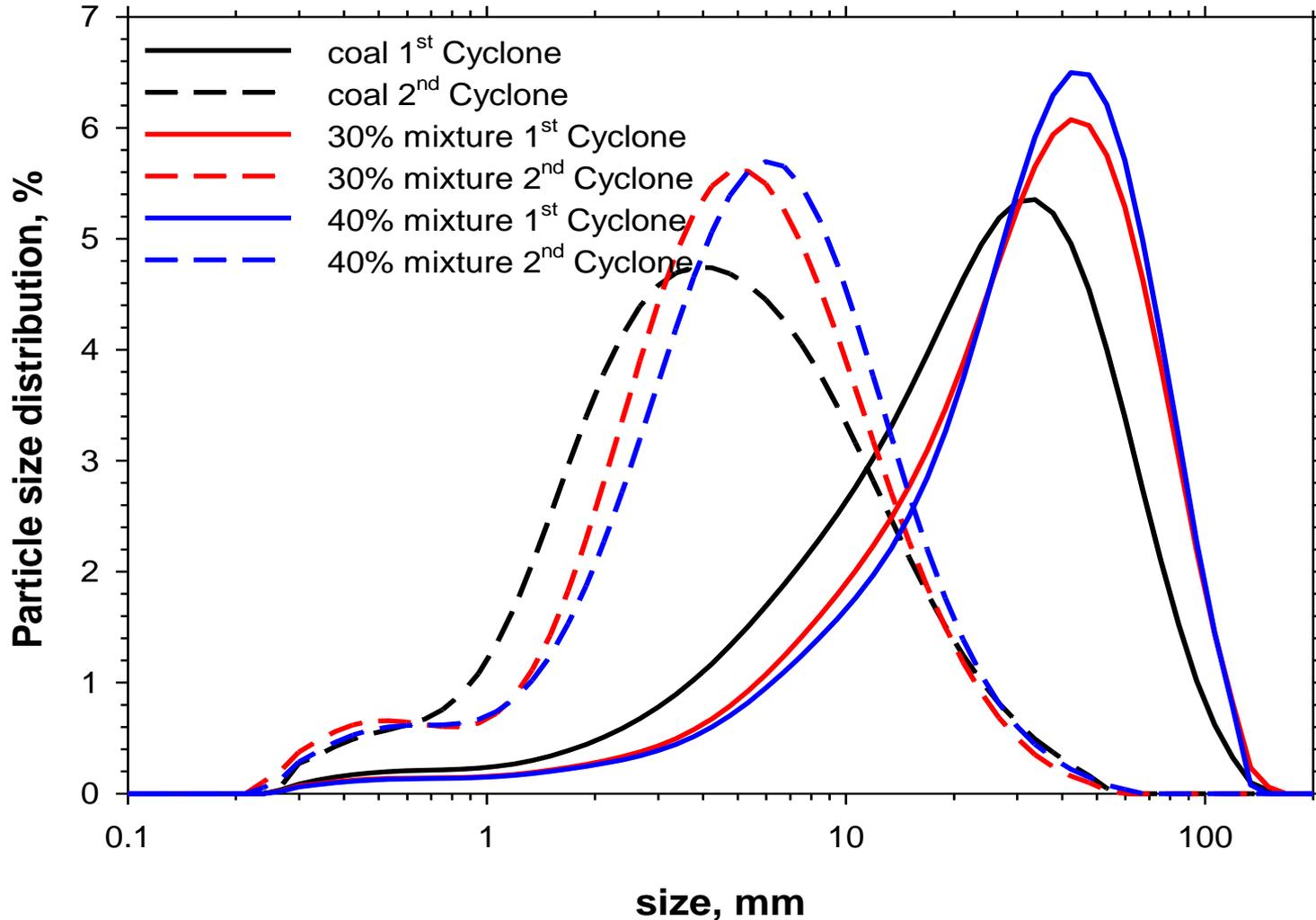
- ✓ Gas pressure profile allows to identify the height of the expanded bed and, in turn, the extension of the freeboard region;
- ✓ Temperature decreases along the fluidization column except just after the fuel feeding point where a relative maximum of temperature was observed probably related to combustion of volatile matter and/or of fine particles.
- ✓ Freeboard temperature increased with fractional content of lignin-rich residues, especially in the upper part:
 - ✓ high moisture content slows down the combustion process preventing the formation of localized hot spots and shifting the complete conversion of the gaseous species in the upper part of the freeboard.
 - ✓ increasing the volatile matter content determines less heat released inside the bed and, in turn, more heat emitted along the freeboard.

Time-averaged gaseous and particulate emissions



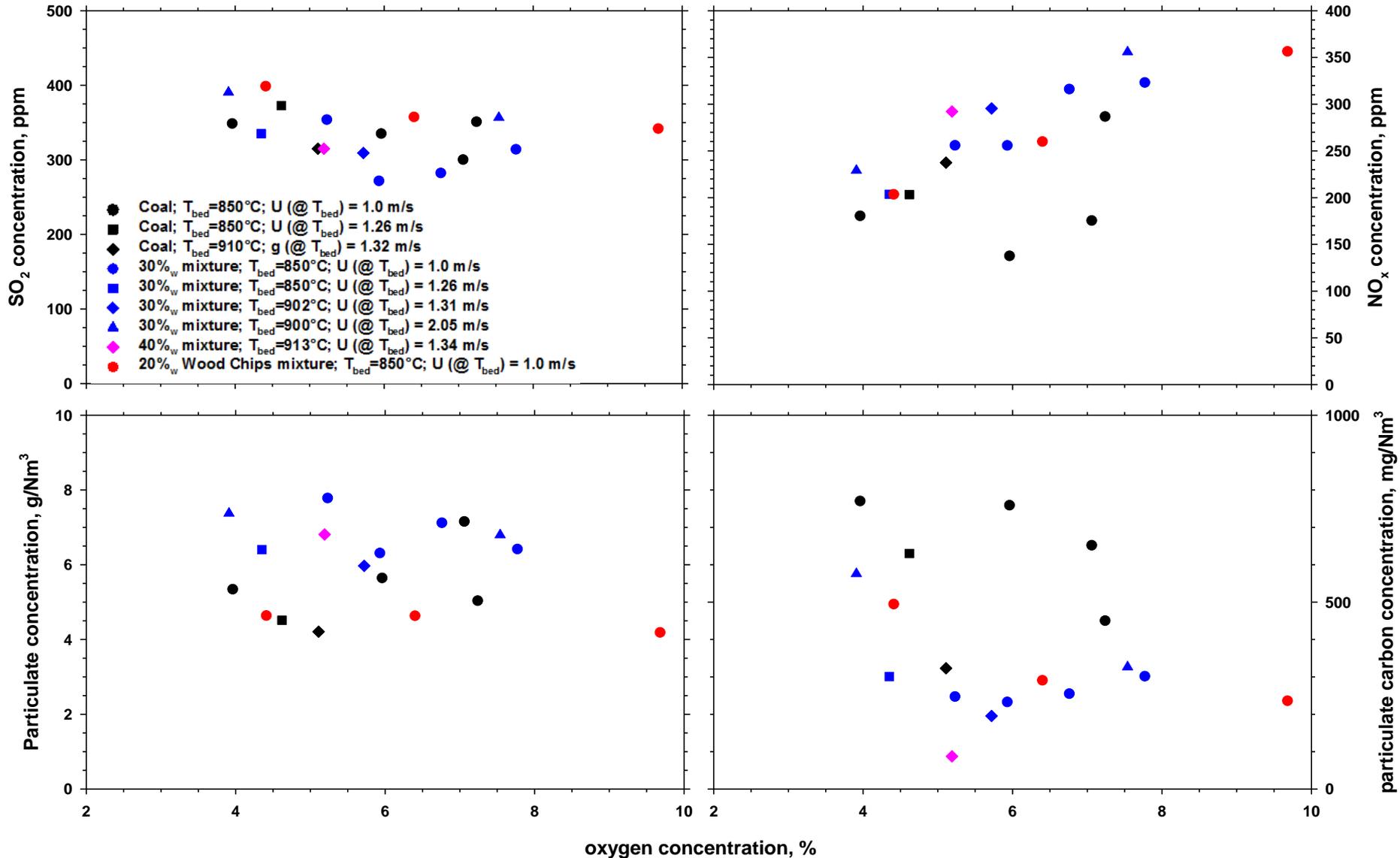
- ✓ SO₂ concentration substantially remained constant highlighting a negative synergistic effect
- ✓ NO_x and particulate concentration increased mainly due to the increase of ash and nitrogen fed with fuel
- ✓ Particulate carbon concentration decreased mainly due to the large reduction of carbon mass fraction in the fine particles collected by cyclones:
 - ✓ 7.6%_w with only coal
 - ✓ 3.2%_w with the mixture of coal with 30%_w of lignin-rich residues
 - ✓ 1.3%_w with the mixture of coal with 40%_w of lignin-rich residues

Particulate particle size distribution



- ✓ Fine carbon particles with a larger size could be characterized by a longer bed retention and a longer residence time inside the fluidization column.

Particulate and gaseous emissions



Metal enrichment in bottom bed particles

Element	Mass concentration, ppm	
	Before	after
Al	9087	9302
Ba	196	387
Ca	5209	14180
Fe	5026	56270
Mg	1436	7178
K	1459	2633
Na	1765	4500
Sr	108	1799
Ti	162	271
Zn	113	124

- ✓ Agglomerates of bottom bed particles were not observed for all the operating conditions investigated.
- ✓ Before and after the thermal regimes 13 and 14 (higher thermal power) it was observed a significant enrichment of metals like Fe, Mg, Na, Ca and K, most of them probably coming from the ash of lignin-rich residues when the apparatus was operated for long time and at high temperature.

Concluding Remarks

- 1) the gaseous emissions did not significantly change with respect to coal or to reference biomass-coal mixture at least until the mixture content of lignin-rich residues was 30-40%_w;
- 2) the particulate emissions increased when lignin-rich residues were fed with coal, but, at the same, the particulate carbon concentration was significantly reduced.
- 3) Agglomerates of bed particles were not observed, but a significant enrichment of metals like Fe, Mg, Na, Ca and K, most of them probably coming from the ash of lignin-rich residues, was observed when the FBC was operated for long time and at high temperature.

See you at the Poster!



Thanks for your kind attention