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

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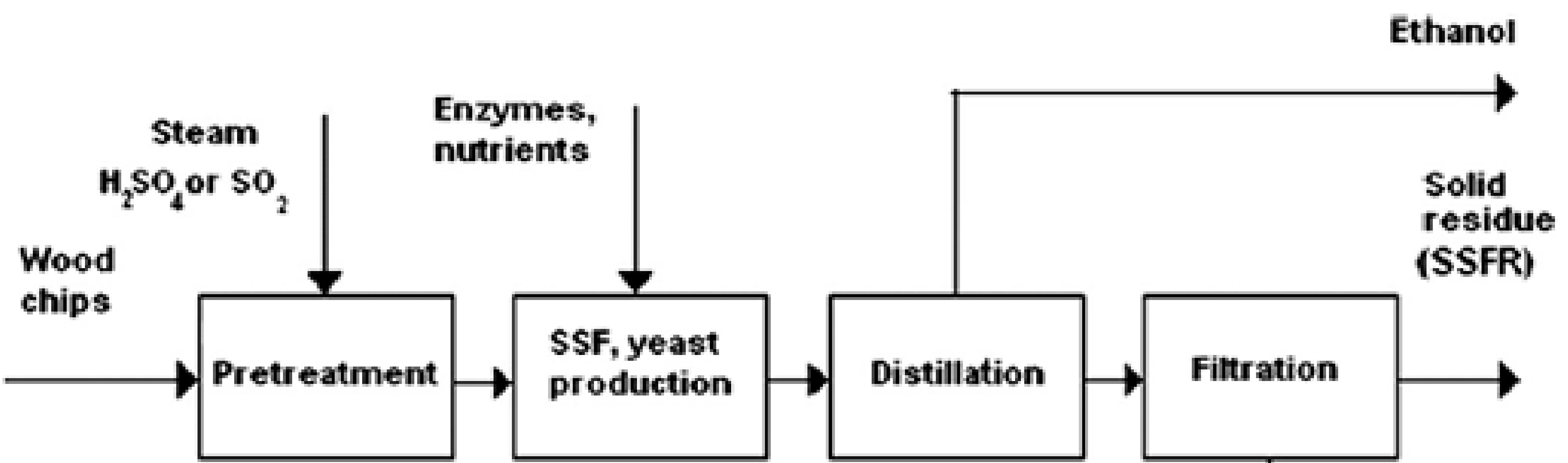
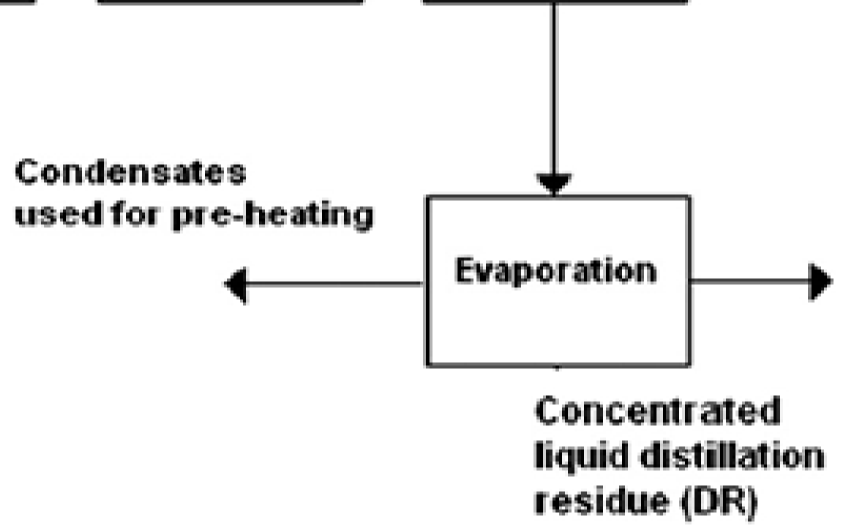
# 2nd generation Bioethanol production



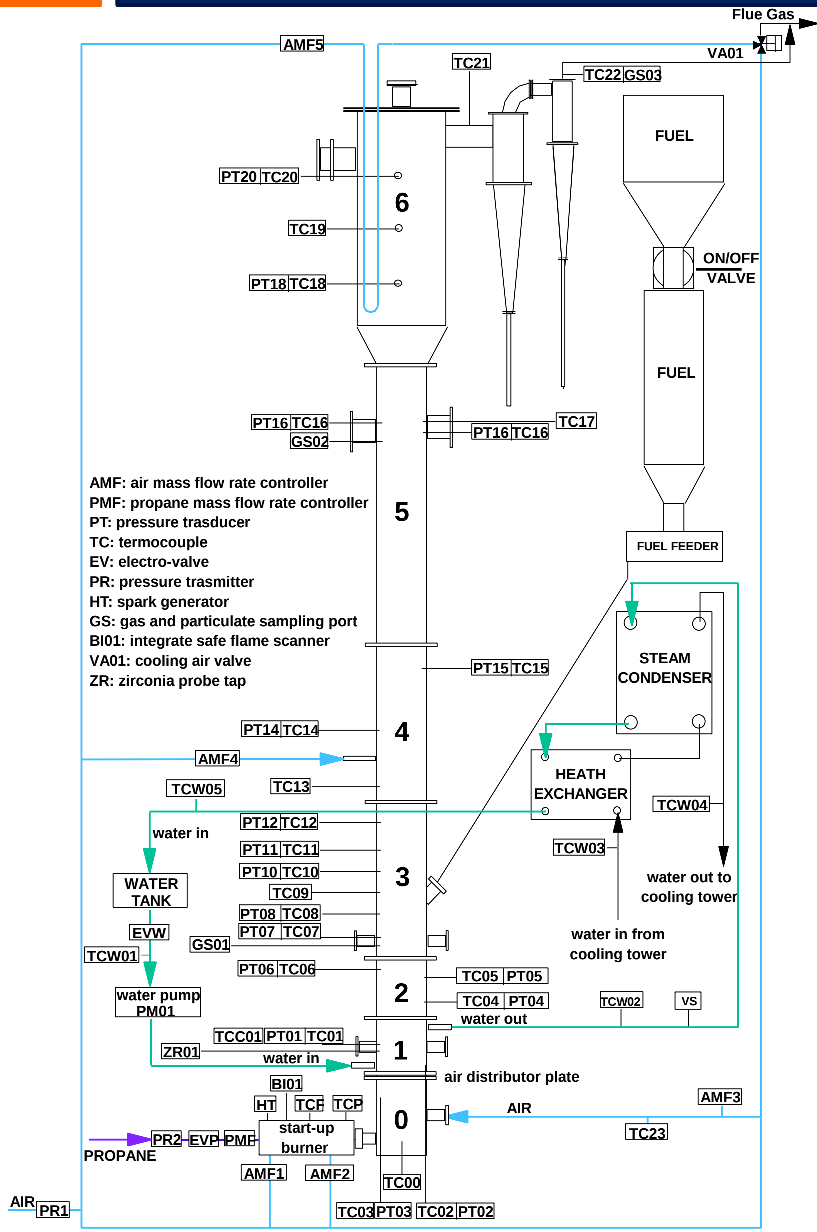

- ❖ CELLULOSE (35-45%): Polysaccharide of glucose;
- ❖ HEMICELLULOSE (25-30%): - Ramified polysaccharide of hexose and pentose sugars;
- ❖ LIGNIN (25-30%): Polymer consisting of numerous units of phenylpropane (unfermentable fraction).

# 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

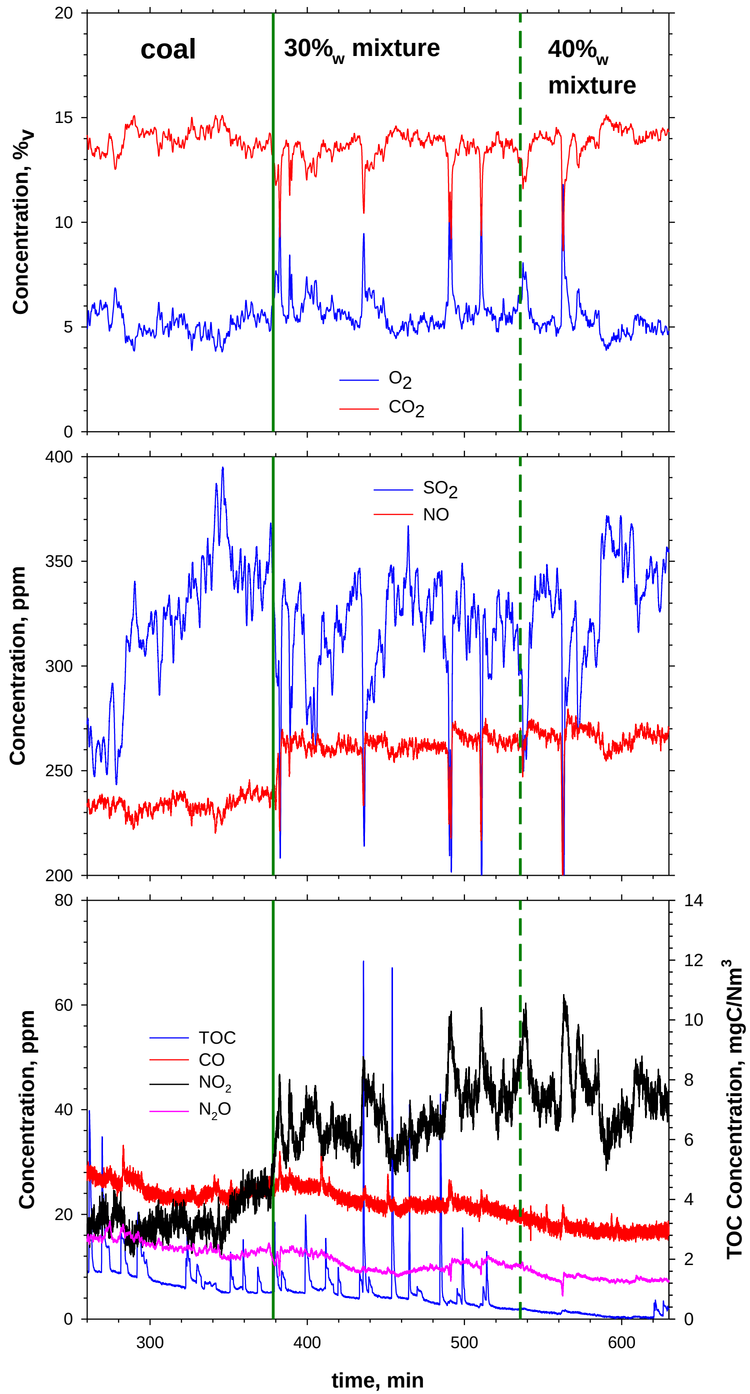
| Fuel | Lignin-rich residues | Colombian coal | Wood chips |
|---|---|---|---|
| LHV (as received), kJ/kg | 5645 | 25564 | 8568 |
| Proximate analysis (as received), $\%_w$ | | | |
| Moisture | 60.7 | 10.3 | 45.5 |
| Volatile matter | 25.0 | 34.6 | 40.2 |
| Fixed carbon | 8.1 | 49.4 | 10.8 |
| ash | 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 |

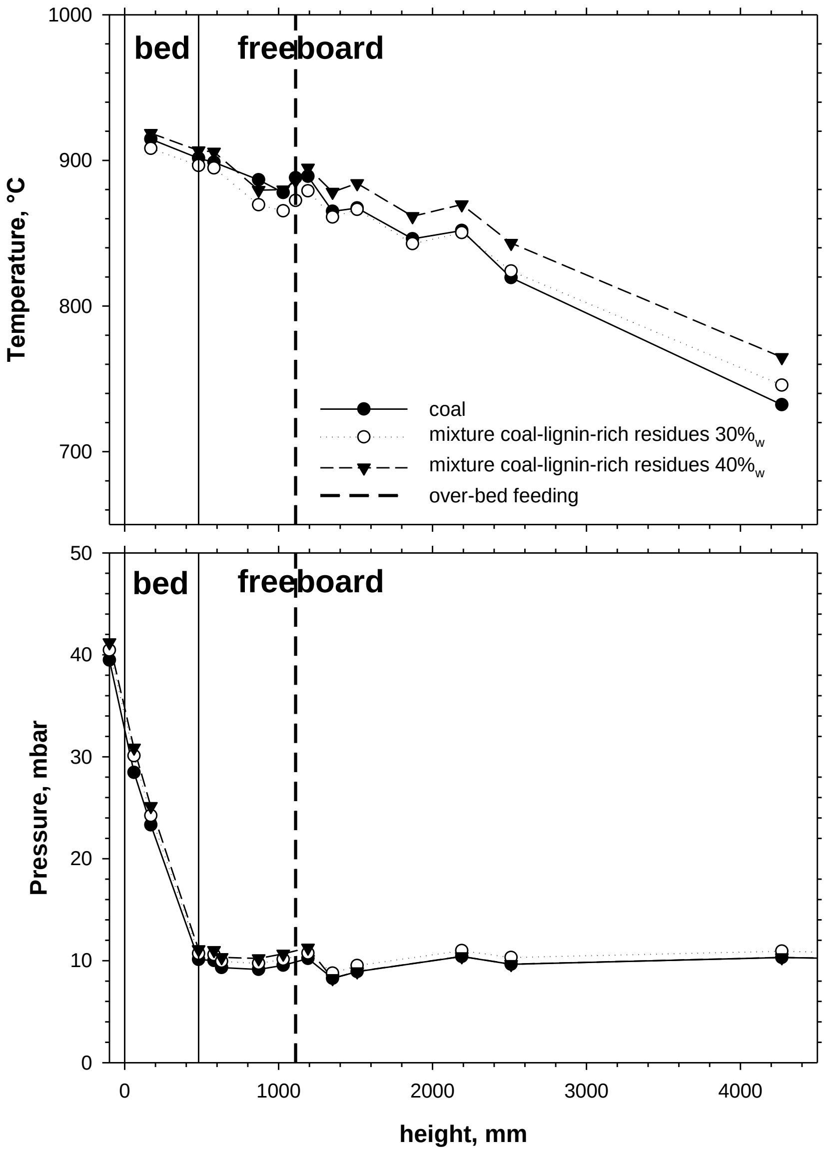
- ✓ The ratio between the secondary air flow rate (fuel transport air) and the primary air flow rate fed at the bottom of the bed was kept constant at a value of 20%.
- ✓ Excess air=14-86%
- ✓ U=0.95-2.10m/s
- ✓ $T_{bed}$=830-913°C




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

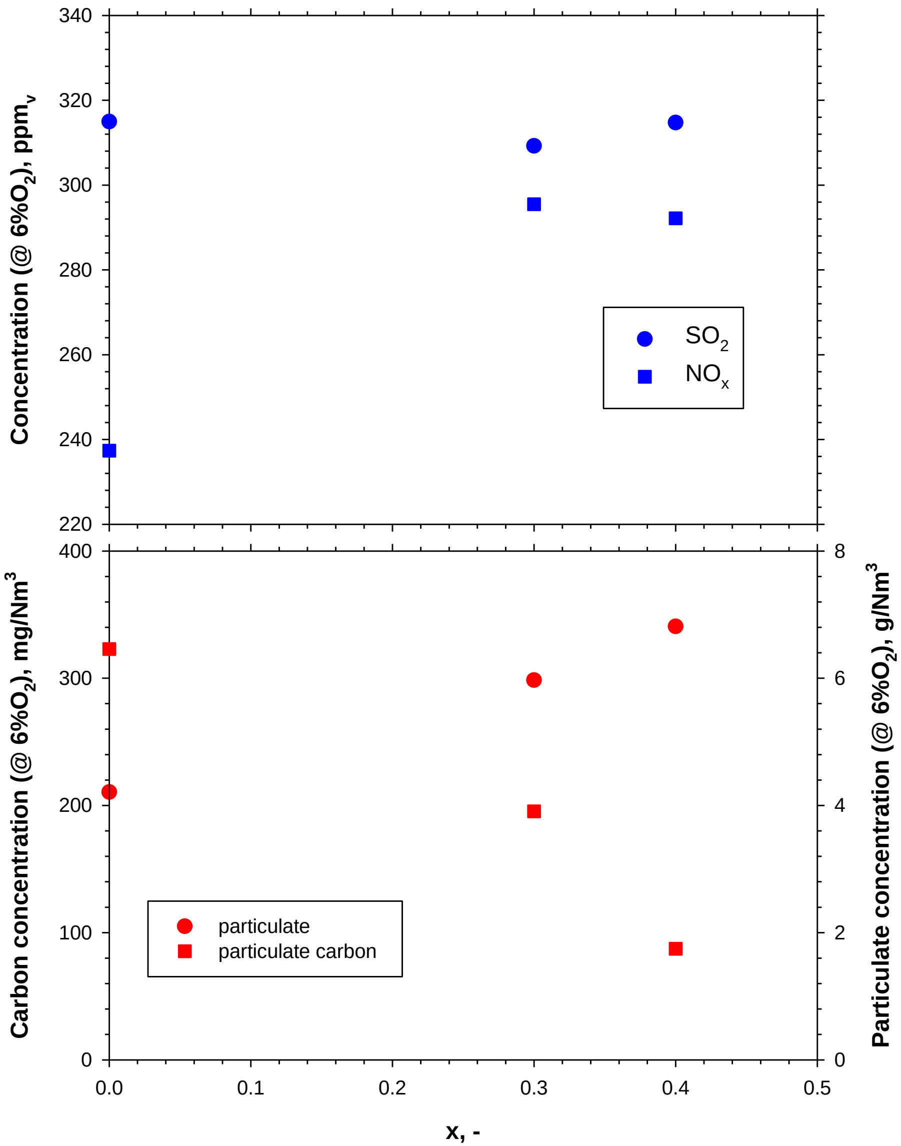
- ✓ Three steady state thermal regimes occurred in sequence feeding: 1) only coal; 2) a mixture with 30%w of lignin-rich residues; 3) a mixture with 40%w of lignin-rich residues
- ✓ The time-averaged oxygen concentration measured at the exhaust and bed temperature about 902-913°C were kept constant
- ✓ 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 $SO_2$ concentration were barely detectable
- ✓ NO and $NO_2$ concentrations rapidly increased due to the fast reaction mechanisms active in gas phase
- ✓ $N_2O$, CO and TOC concentrations slowly decreased probably with the establishment of different thermal regimes along the fluidization column.

# Gas pressure and temperature profiles



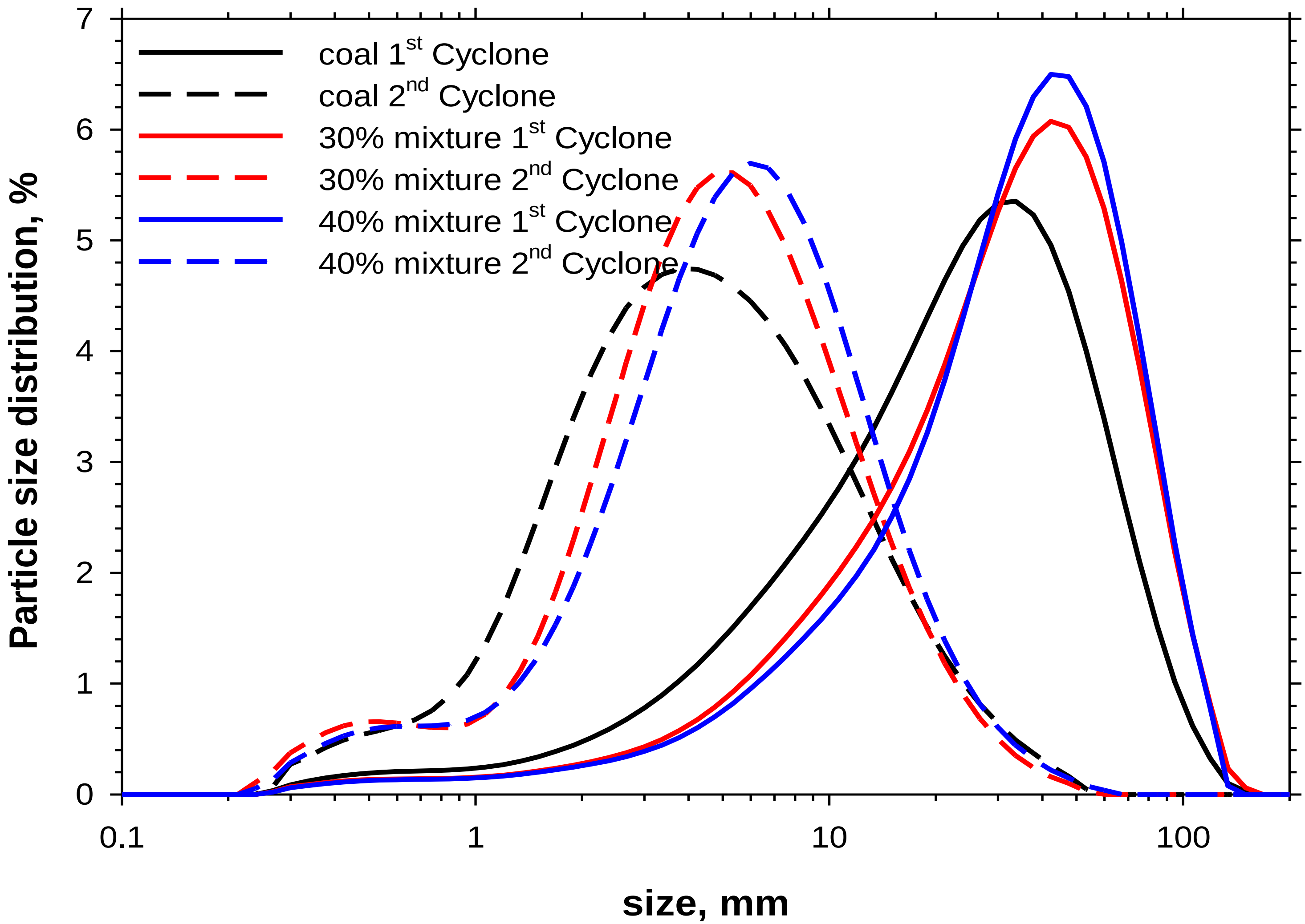

- ✓ Gas pressure profile allows to identify the height of the expanded bed and, in turn, the extension of the freeboard region;
- ✓ Temperature decreases along the fluidization column except just after the fuel feeding point where a relative maximum of temperature was observed probably related to combustion 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



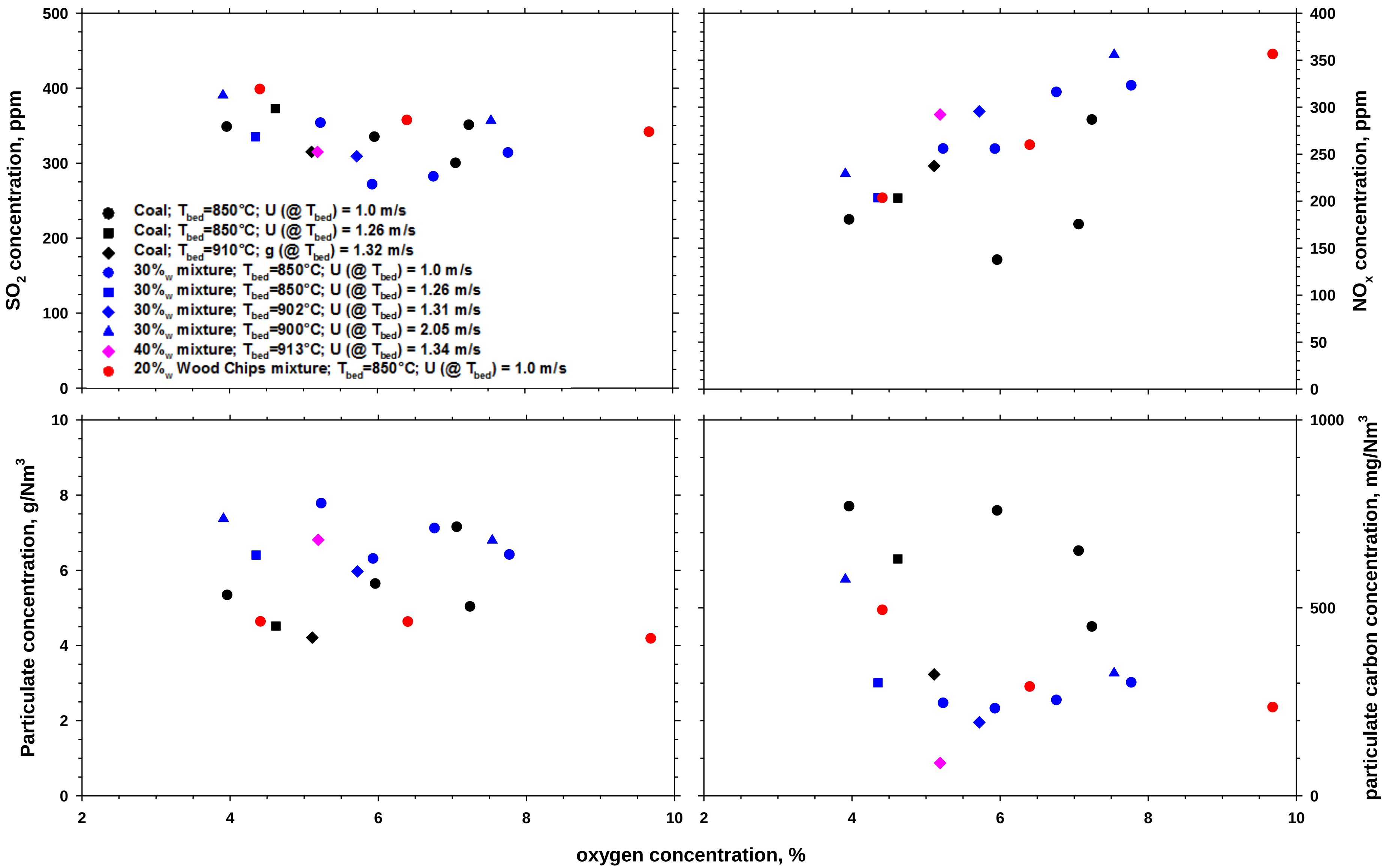

- ✓ $SO_2$ concentration substantially remained constant highlighting a negative synergistic effect
- ✓ $NO_x$ and particulate concentration increased mainly due to the increase of ash and nitrogen fed with fuel
- ✓ Particulate carbon concentration decreased mainly due to the large reduction of carbon 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