



# CO-COMBUSTION OF SEVERAL BIOMASS MATERIALS WITH A BITUMINOUS COAL IN A CIRCULATING FLUIDISED BED COMBUSTOR

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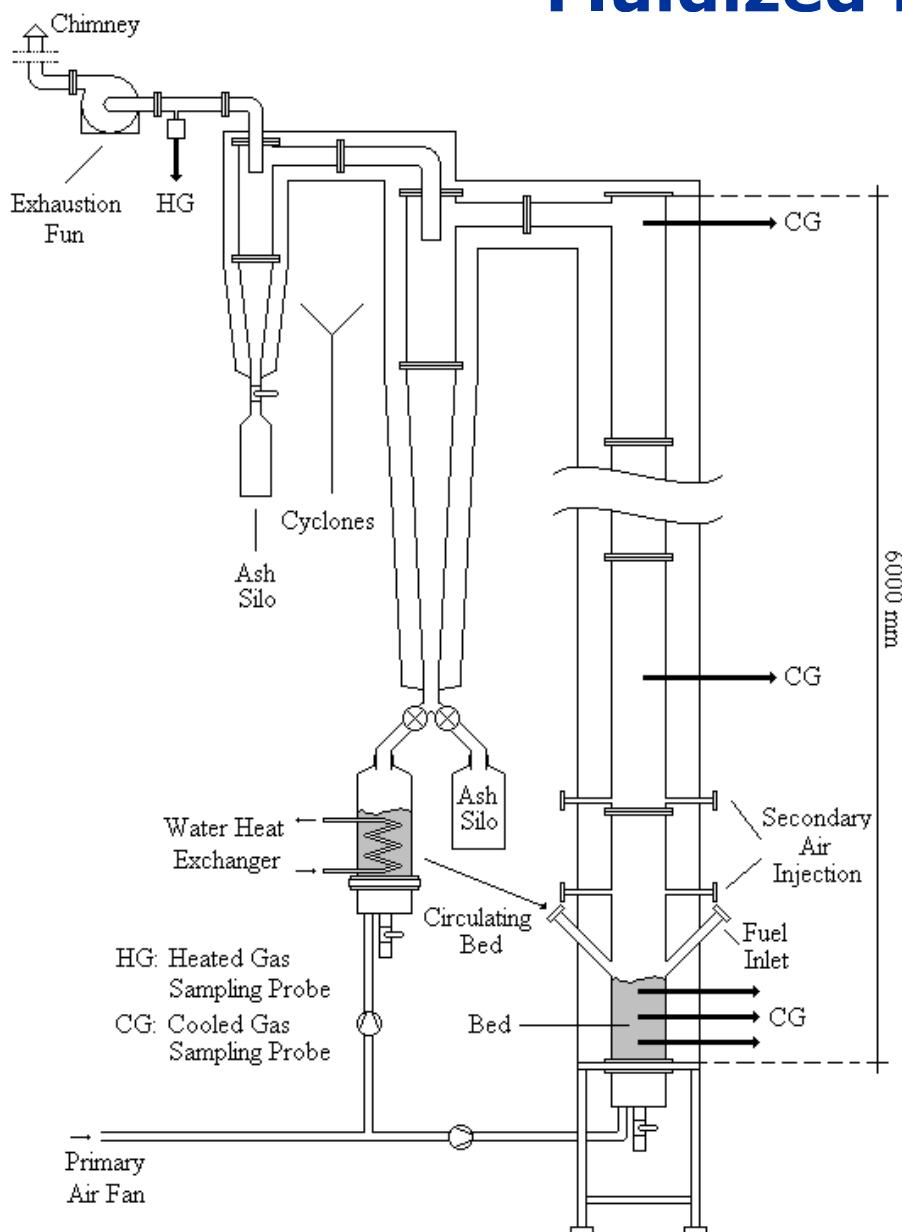
## Aim of the Work

- Monitor and study the gaseous emissions in different locations of the combustor;
- Investigate the effects of air staging in the riser;
- Achieve efficient mixing of air with volatiles for various coal/biomass ratios;
- Simultaneously achieve a reduction in the  $\text{NO}_x$  and  $\text{SO}_2$  emissions without any adverse effect on the combustion efficiency;
- Evaluation of PM, Chlorine and PCDD/F emissions during biomass co-combustion.

# Fuel Analyses – Proximate & Ultimate

<b>ar – as received basis daf – dry ash free basis</b>	<b>CC</b>	<b>MBM</b>	<b>SP</b>	<b>OC</b>	<b>WP</b>
<b>Proximate analysis (%wt)</b>					
Moisture (ar)	<b>9.3</b>	<b>3.2</b>	<b>9.1</b>	<b>7.9</b>	<b>5.8</b>
Ash (ar)	<b>12.6</b>	<b>38.5</b>	<b>6.9</b>	<b>5.3</b>	<b>0.4</b>
Volatile Matter (daf)	<b>42.3</b>	<b>90.9</b>	<b>80.9</b>	<b>81.0</b>	<b>86.8</b>
Fixed Carbon (daf)	<b>57.7</b>	<b>9.1</b>	<b>19.1</b>	<b>19.0</b>	<b>13.2</b>
<b>Ultimate analysis (%wt, daf)</b>					
C	<b>76.0</b>	<b>54.1</b>	<b>49.3</b>	<b>53.4</b>	<b>49.9</b>
H	<b>5.4</b>	<b>7.8</b>	<b>6.2</b>	<b>6.3</b>	<b>6.0</b>
N	<b>1.5</b>	<b>13.8</b>	<b>0.8</b>	<b>1.1</b>	<b>&lt;0.2</b>
S	<b>1.09</b>	<b>0.71</b>	<b>0.15</b>	<b>0.11</b>	<b>&lt;0.03</b>
Cl	<b>0.08</b>	<b>0.47</b>	<b>0.28</b>	<b>0.36</b>	<b>&lt;0.03</b>
O	<b>15.9</b>	<b>23.1</b>	<b>44.3</b>	<b>38.6</b>	<b>44.1</b>
<b>Ash analysis (g/kg, dry ash)</b>					
K	<b>20</b>	<b>7</b>	<b>158</b>	<b>305</b>	<b>182</b>
Na	<b>6.2</b>	<b>16.3</b>	<b>4.0</b>	<b>6.1</b>	<b>7.8</b>
Al	<b>102</b>	<b>2</b>	<b>2</b>	<b>4.3</b>	<b>52</b>
Fe	<b>51</b>	<b>1</b>	<b>2</b>	<b>4.3</b>	<b>10</b>
Ca	<b>18</b>	<b>347</b>	<b>44</b>	<b>54</b>	<b>138</b>
Mg	<b>15</b>	<b>6</b>	<b>10</b>	<b>41</b>	<b>44</b>
P	<b>0.9</b>	<b>130</b>	<b>13</b>	<b>26</b>	<b>13</b>
<b>LHV (MJ/kg)</b>	<b>32.1</b>	<b>23.6</b>	<b>17.8</b>	<b>20.0</b>	<b>18.5</b>

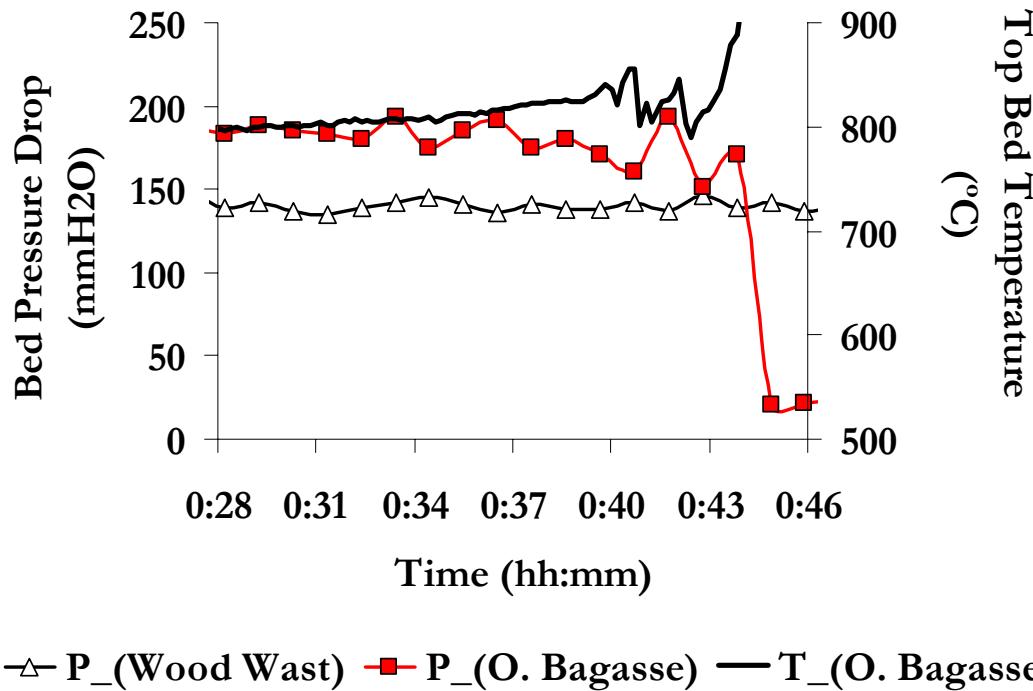
# Fluidized Bed Pilot



## Operating Conditions

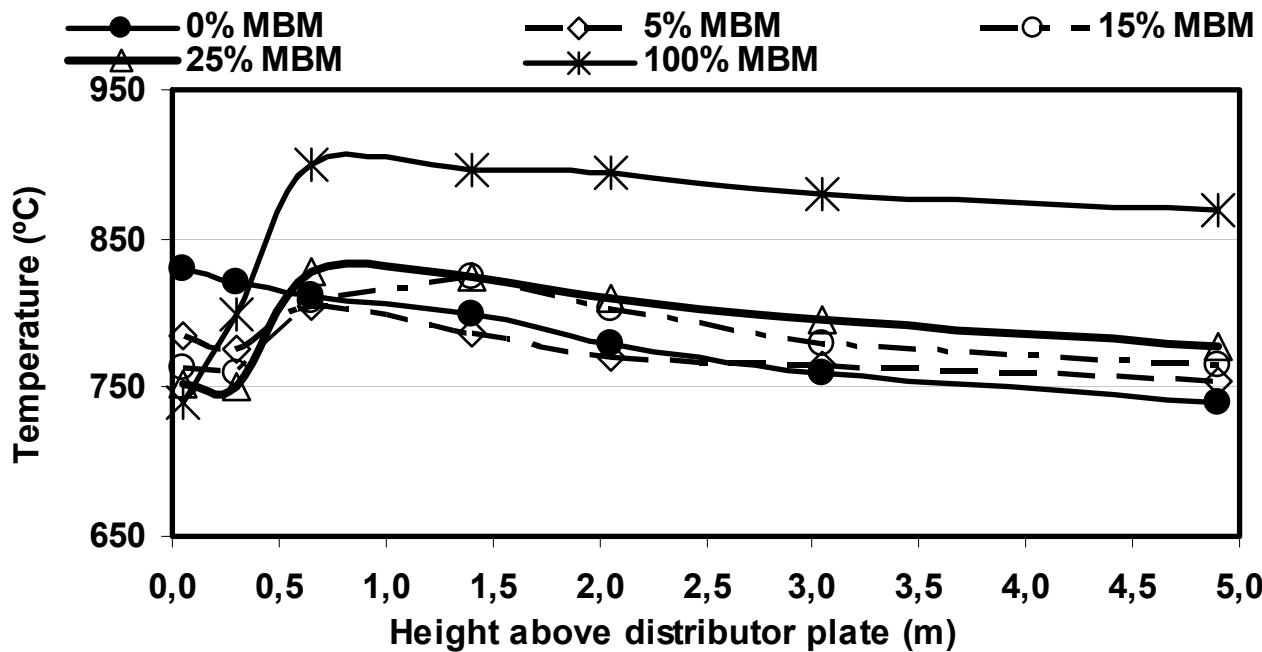
<b>Bed temperature (°C)</b>	<b>700 - 850</b>
<b>Freeboard temp. (°C)</b>	<b>800 - 950</b>
<b>Thermal Input (MJ/h)</b>	<b>300 - 400</b>
<b>Gas velocity (m/s)</b>	<b>3 - 4</b>
<b>Excess air level (%)</b>	<b>30 - 50</b>
<b>Secondary Air Level (% of total)</b>	<b>20 - 30</b>

# Pressure and Temperature Fluctuations



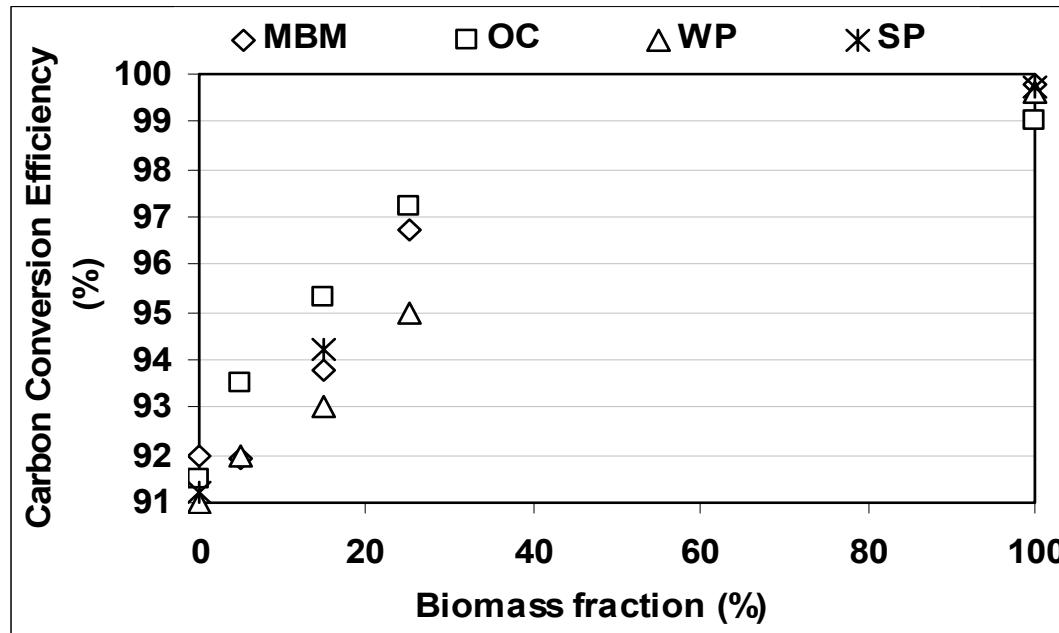
- Relatively stable fuel feed rates were achieved.
- Combustion of MBM, OC and SP => bed agglomeration problems.
- Dense bed zone  $T < 800^{\circ}\text{C}$  ( $700\text{-}770^{\circ}\text{C}$ ) => Preventing Bed agglomeration for MBM, OC and SP mono-combustion (Na, K).
- Wood pellets temperature and pressure profiles were very stable during combustion.

# Temperature Profiles – ex: MBM co-combustion



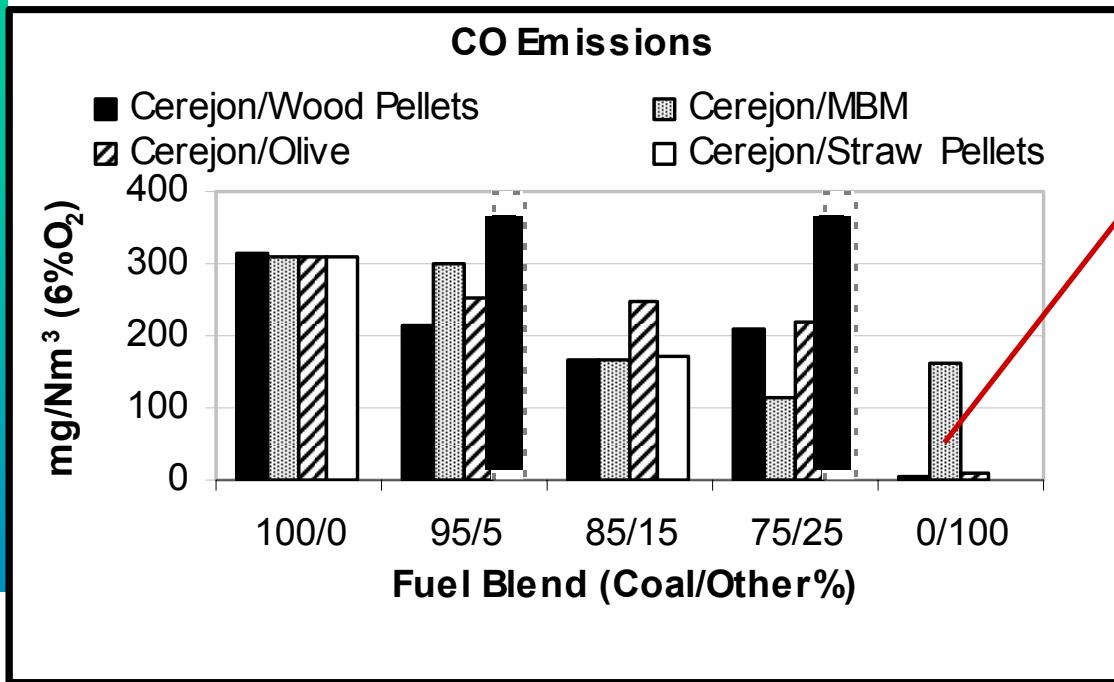
- Biomass combustion (80% VM) => higher burning rates in the Riser and higher temperatures.
- Secondary air fed in higher proportions with sufficient turbulence => low CO and VOC emissions.

# Combustion Conversion Efficiency



- Coal Conversion 90-92%; Biomass Conversion > 99%.
- Larger amounts of Coal => higher char inventory => longer burning times of solid particles; also higher carryover of solid due to attrition and less intense combustion in the riser => higher unburned carbon.
- The presence of Biomass => more intense air staging to complete volatile burning. Higher temperatures in the riser => higher oxidation rates of VM.

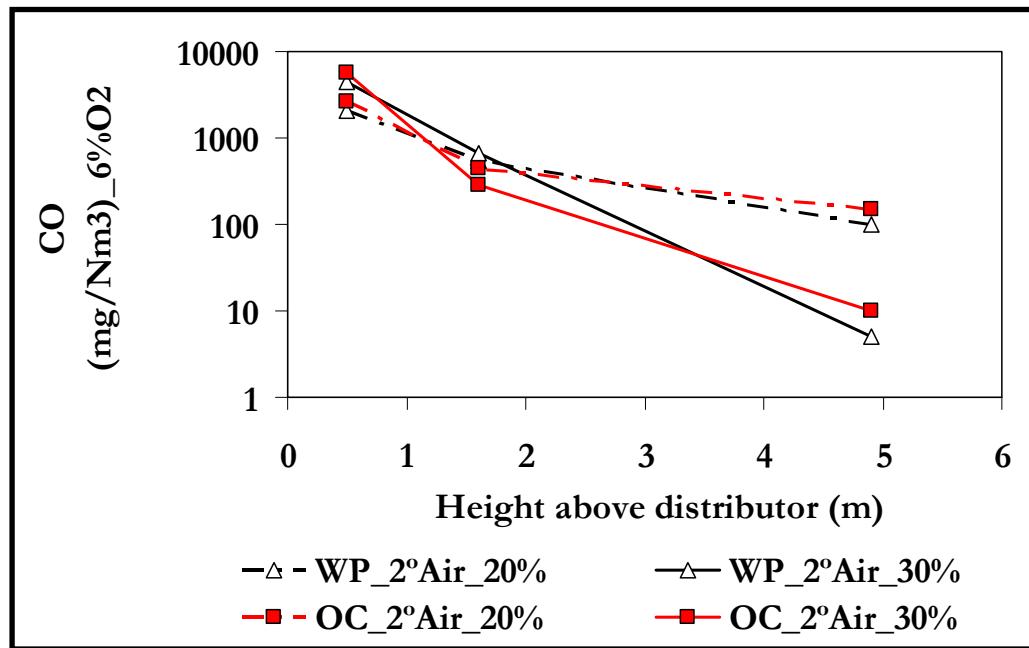
# CO Emissions



- **MBM monocombustion produced higher CO levels due to lower bed temperature that slowed down devolatilization rate and to the excessive air excess level (50%) that lowered the riser temperature and decreased the residence time.**

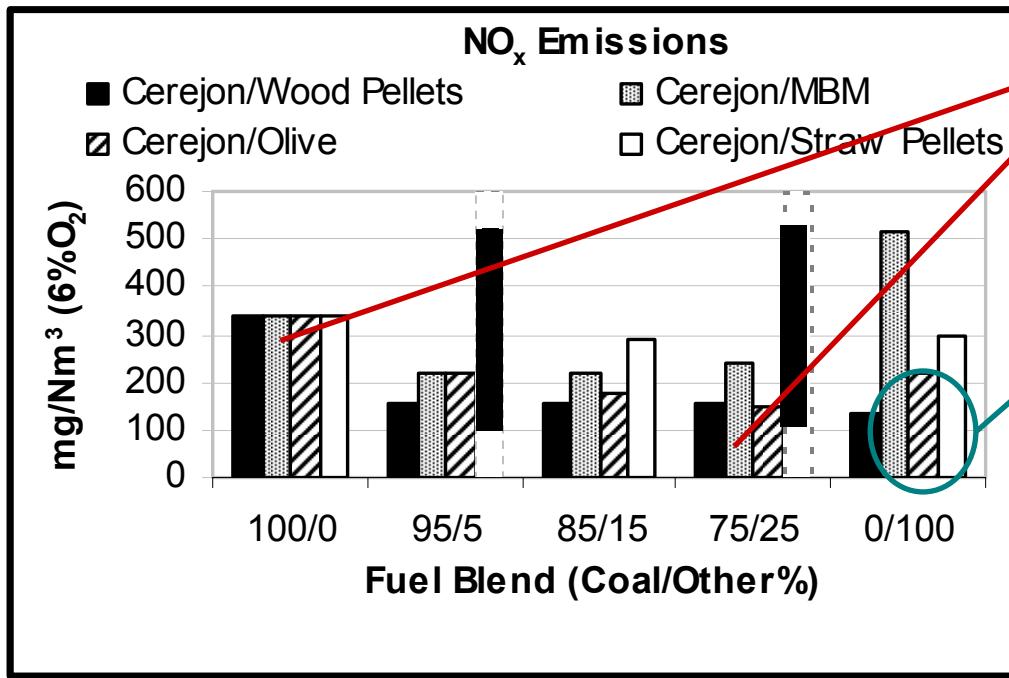
- CO decrease with increasing biomass fraction in fuel
- Bituminous coal combustion controlled by char burning producing high CO levels under reducing conditions specially in Bed and due to inefficient lateral mixing in the riser.
- With biomass burning => char inventory is reduced and higher air staging improves riser lateral mixing; also higher riser temperatures improves combustion rates of CO and VOC.

# CO Emissions – Air Staging



- Improved air staging was essential to achieve low CO and VOC emissions at the combustor exit.
- With the use of higher excess air levels, CO concentration at the top of the dense bed was greater. However, it was verified that increasing the secondary air flow rate supplied at the riser zone was essential for a good mixing degree with volatiles to ensure their complete combustion

# NO<sub>x</sub> Emissions

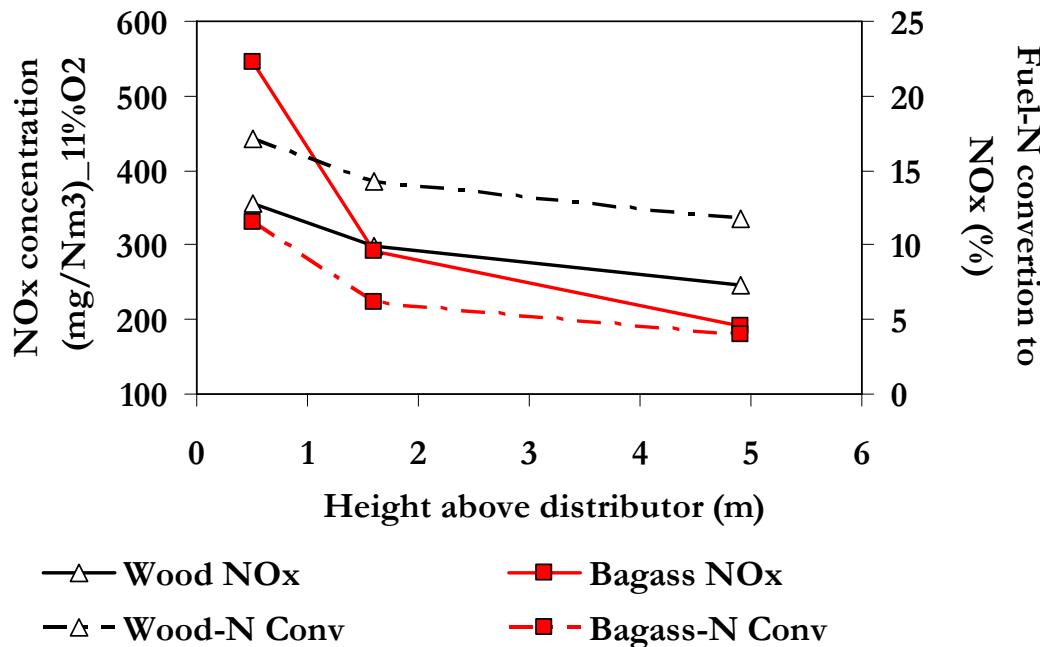


- Ex: fuel-N conversion decreased from 8 to 2 % increasing MBM from 0 to 25 %wt in the fuel mixture.

- During monocombustion of biomass fuels the fuel-N conversion to NO seems to increase probably due to higher air excess used and lower char inventory to promote NO heterogeneous reduction.

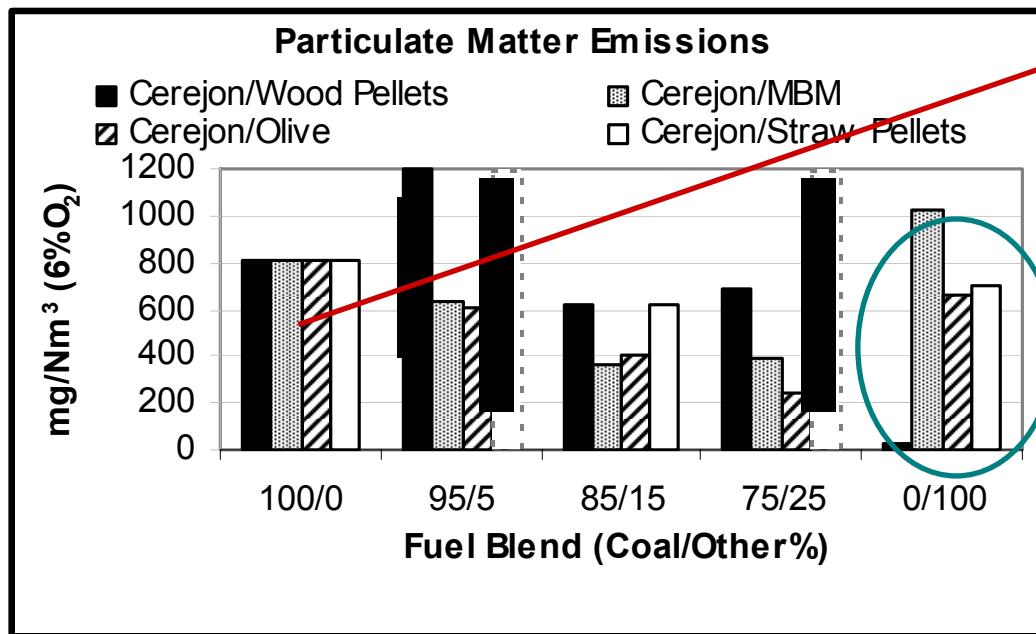
- NO<sub>x</sub> decrease during co-combustion of all biomass materials, independently of biomass N content.
- During co-combustion the fuel-N conversion to NO<sub>x</sub> decreased with the increase of biomass share in the mixture up to 25% wt.
- Biomass fuels released higher fractions of fuel-N as NH<sub>3</sub> in the riser that possibly react with NO formed, reducing it to N<sub>2</sub> through the known DeNO<sub>x</sub> mechanism.

# NO<sub>x</sub> Formation Along the Riser



- The combustor riser had a NO<sub>x</sub> reduction potential.
- Thermal DeNO<sub>x</sub> mechanism is favored by the higher riser temperatures obtained during co-combustion, as well as the greater H and OH radicals and VM supplied by biofuels that were believed to create reducing conditions for lower NO<sub>x</sub>.

# Particulate Matter Emissions

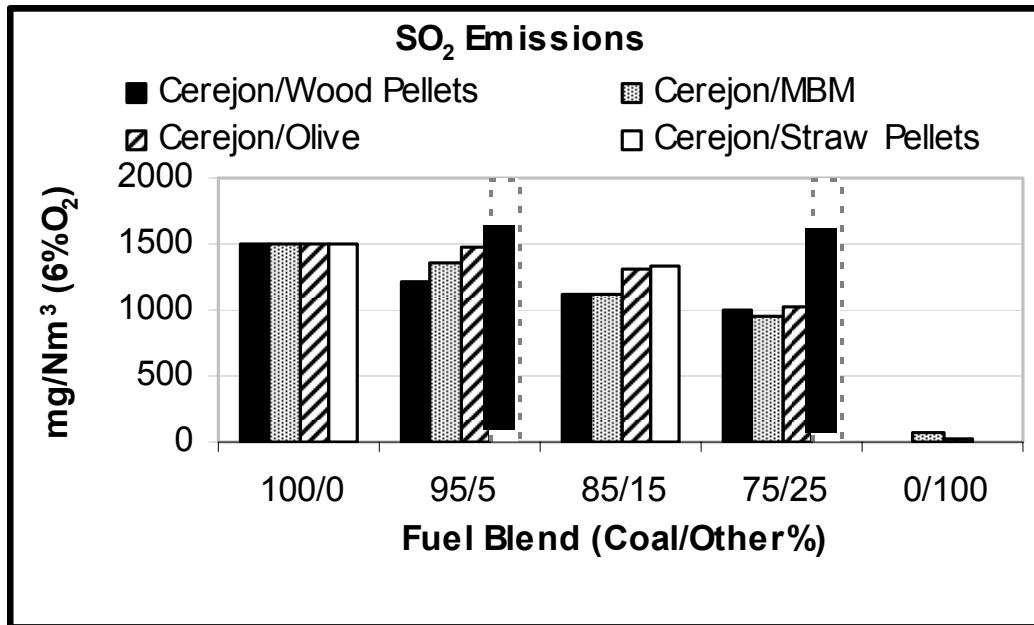


**Coal combustion:  
higher levels of  
unburned material**

**Biomass combustion  
produced a high level  
of micron-sized  
particles (<10µm)**

For particulate matter emissions, and with the exception of the wood pellets (whose ash content is 0.4%), a positive synergy was also observed for the co-combustion of all biomass fuels when compared to the mono-combustion of each material.

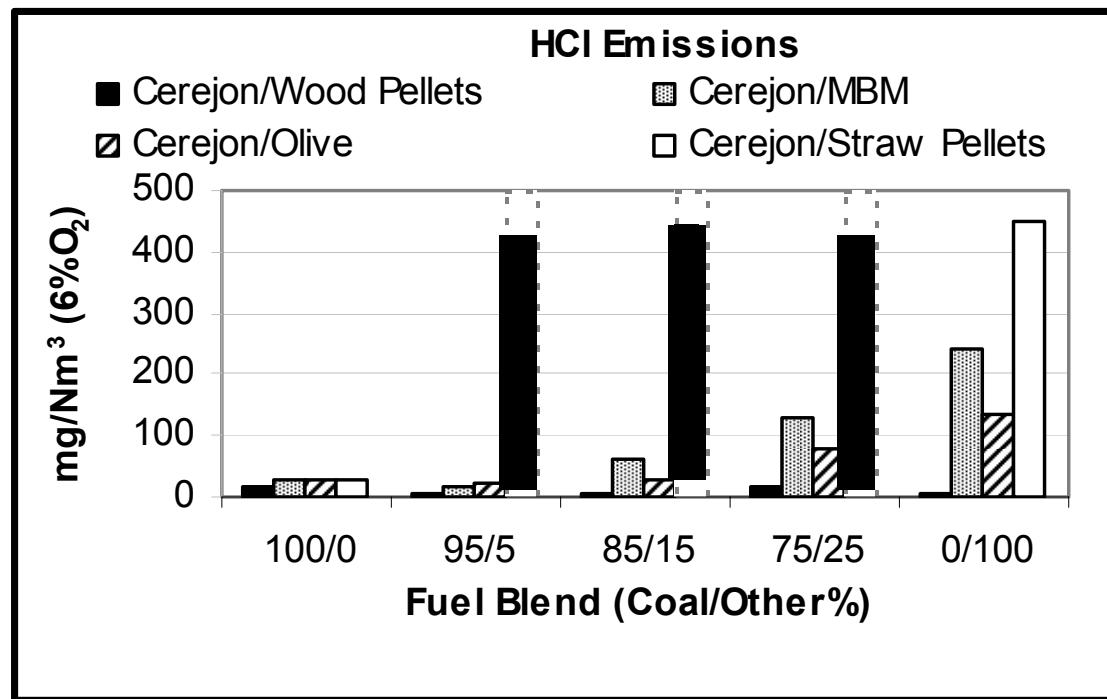
# SO<sub>2</sub> Emissions



- The S retention in MBM ashes could also be due to the reaction of S with Na which was abundantly available, thus forming  $\text{Na}_2\text{SO}_4$ .

- SO<sub>2</sub> emissions decreasing with increase of biomass fraction in fuel, i.e., with fuel-S content decrease.
- The presence of Ca in higher Ca/S amounts in the biomass ashes than in coal, also contributed for S solid retention.
- In the case of MBM most of the Ca was bonded with P; however, more than 40% of the fuel-S input was retained in the ash streams.

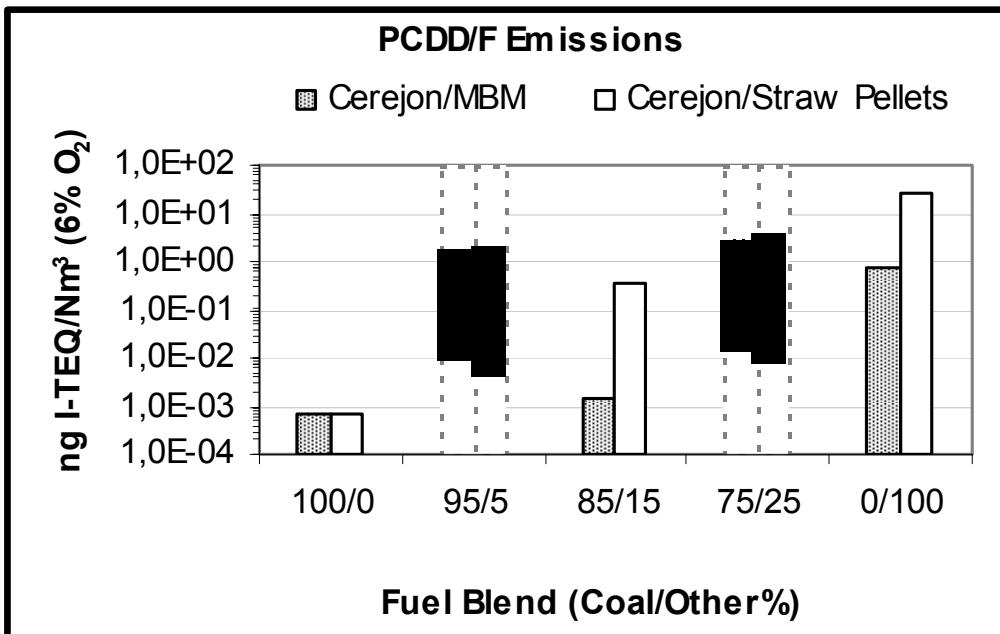
# HCl Emissions



- With exception of wood pellets (Cl content < 0.03%), the increase of biomass fraction in the fuel led to an increase of HCl emissions. The HCl emissions were higher for the mono-combustion of straw pellets, which is the case where the molar ratio Ca/(S+Cl) is the lowest, thus any retention of chlorine by calcium is much lower than for the other biomass fuels.

# PCDD/F Emissions

- Emissions of PCDD/F were only measured for the MBM and Straw Pellets campaigns and for the mixtures of 15 %wt.



- The PCDD/F emissions increased with the share of biomass in fuel for both MBM and SP.
- For the 15% wt MBM test the PCDD/F emissions were lower than expected, when compared with the mono-combustion of each fuel. Probably there is a synergy related with the high Ca/S and S/Cl molar ratios ( $n\text{Ca}/n\text{S}=2.1$ ;  $n\text{S}/n\text{Cl}=9.7$ ).

- For the co-combustion of SP, the PCDD/F emissions are higher due to the lower molar ratio of Ca/S ( $n\text{Ca}/n\text{S}=0.23$ ), although the S/Cl molar ratio ( $n\text{S}/n\text{Cl}=9.4$ ) is in the same order of magnitude as for the MBM.
- It seems that the chlorine activity was not reduced by the  $\text{SO}_2$ , thus resulting in PCDD/F emissions far above the limits allowed. In fact, the S/Cl molar ratios for these tests were always lower than 2.5, which is the minimum molar ratio necessary to minimize PCDD/F formation.

## Conclusions

- **It was demonstrated that, with controlled temperatures and air staging, the co-combustion may result in positive synergies by increasing the combustion efficiency and minimizing NO<sub>x</sub>, through the DeNO<sub>x</sub> mechanism.**
- **SO<sub>2</sub> emissions may be decreased simultaneously when low sulphur biomass is co-fired with coal, increasing also the coal-S retention in biomass ashes.**
- **For particulate matter emissions, and with the exception of the wood pellets (whose ash content is 0.4%), a positive synergy was also observed for the co-combustion of all biomass fuels when compared to the mono-combustion of each material. The coal combustion produced higher levels of unburned material and biomass combustion produced a high level of micron-sized particles (<10µm).**

## Conclusions

- When biomass has high chlorine content, the HCl emissions were found to increase with increasing fractions of biomass in fuel.
- It was shown that the co-combustion of MBM and Colombian coal could promote a significant reduction of PCDD/F formation, thus reducing the total PCDD/F formed when compared with the results of monocombustion of each fuel.
- When high chlorine and low sulphur fuel combinations were used, as in the case of straw pellets and Colombian coal, PCDD/F emissions were found to be much higher.



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Thank you for your attention