

Prediction of Slagging and Fouling Tendency of Biomass Co-Firing in Fluidized Bed Combustion

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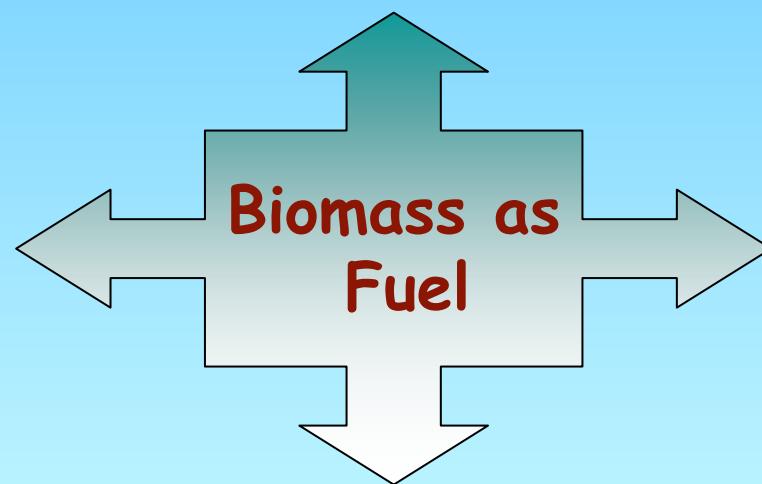


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The need to decrease greenhouse gases emissions (especially CO_2), as defined by the Kyoto Protocol

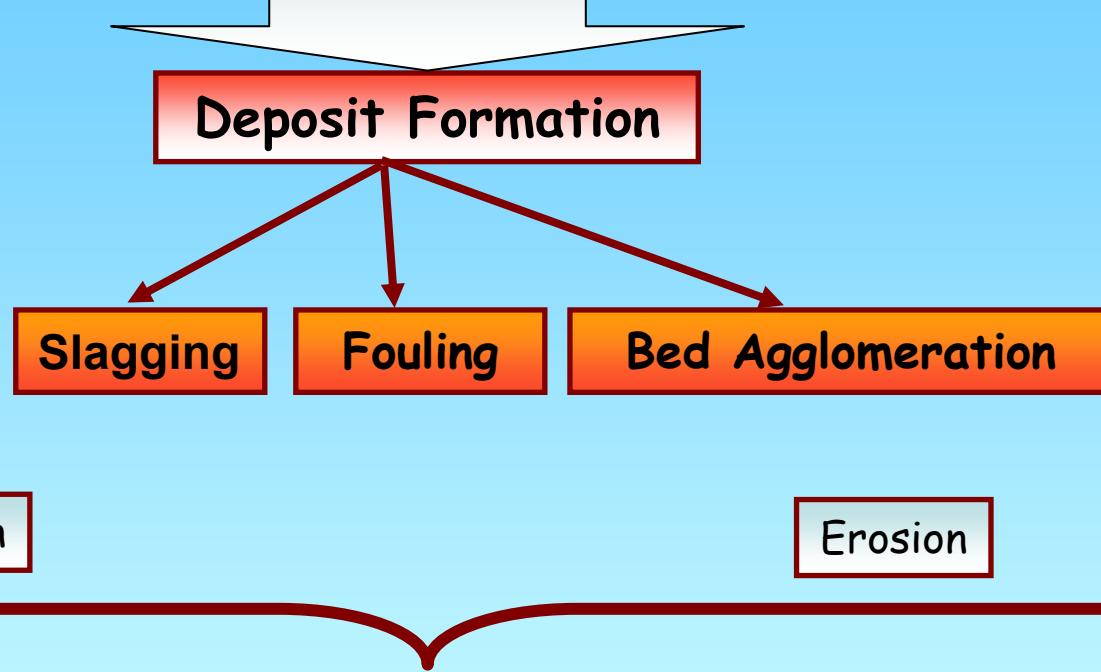
Availability of endogeneous fuel reserves at a relatively lower cost



The overdependence of those countries without adequate reserves of fossil fuels on imported energy

The recent sharp increases in fossil fuel prices

Ash Related Problems



Giving Rise to Serious Operational Problems during Combustion

Slagging

Deposit formation on heat transfer surfaces of energy conversion equipment from the adhesion of sticky of the particles especially in zones closer to flame from which the heat is mostly transferred by radiation.

Fouling

Deposit formation on the cooler surfaces of energy conversion equipment either by the adhesion of sticky particles and or condensation of particles transported by combustion gases from hot zones to cooler zones.

Bed Sintering/Agglomeration

Because of in bed sintering process, loosely bound particles become more dense, forming a compact hard mass, through the adhesion of small particles on surfaces, condensation of gaseous species and chemical reaction of gaseous alkali on the surfaces.



Continuous deposition on particles of bed material, and depending on the melting behavior of these deposits, it can occur partial melting and agglomeration.



Ash Related Problems Prediction

- ★ Slagging and fouling indices
- ★ Compression strength tests
- ★ Chemical equilibrium model calculations
- ★ Bench scale fluidized bed combustion tests

This work is the start of a global study initiated to predict ash related problems during biomass thermal conversion

How reliable is to use indices developed for coals to biomass, and specially, to biomass blends? This is the first question to be answered in this phase of the global study

The results were compared with experimental results in the work done by far

Slagging and Fouling Indices

Ash Composition Indices

$$R_{B/A} = \frac{\% (Fe_2O_3 + CaO + MgO + K_2O + Na_2O)}{\% (SiO_2 + TiO_2 + Al_2O_3)}$$

$$R_{B/A(+P)} = \frac{\% (Fe_2O_3 + CaO + MgO + K_2O + Na_2O) + (P_2O_5)}{\% (SiO_2 + TiO_2 + Al_2O_3)}$$

$$R_{B/A_{Simp.}} = \frac{\% (Fe_2O_3 + CaO + MgO)}{\% (SiO_2 + Al_2O_3)}$$

$$BAI = \frac{\% (Fe_2O_3)}{\% (K_2O + Na_2O)}$$

$$R_s = (B/A)S^d$$

$$F_u = (B/A)(Na_2O + K_2O)$$

$$S_R = \frac{SiO_2}{SiO_2 + Fe_2O_3 + CaO + MgO} \times 100$$

Evaluate

Equation

(1)

Slagging and Fouling Probability

(2)

(3)

Bed Agglomeration Probability

(4)

Slagging Probability

(5)

Fouling Probability

(6)

Slagging Probability

(7)

Ash Fusibility Indice

$$AFI = \frac{(4 \times IDT + HT)}{5}$$

Slagging Probability

Physical-chemical properties of used fuel

	Standard Method	Polish Coal	Coal Cerejon	Straw pellets	Olive Cake	Wood pellets
Moisture (a.r.,wt %)	ASTM D 3173	2.1	9.3	10.6	7.9	8.4
Ash (d.b., wt %)*	ASTM D 3174	6.2	9.2	5.8	4.9	0.4
Volatile Matter (d.b., wt %)	ISO 562	32.2	37.5	76.6	76.7	86.2
Fixed Carbon (d.b., wt %)	ASTM D 3172	54.5	49.1	18.1	18.0	13.1
Low Heating Value (d.b., KJ/kg)	ASTM D 5865	28397	27028	16590	18857	18808
Initial Deformation Temperature (°C)		1223	1202	819	751	1238
Softening Temperature (°C)	ASTM D 1857	1233	1358	1014	830	1265
Hemispherical Temperature (°C)		1251	1397	1167	1367	1282
Fluid Temperature (°C)		1284	1443	1238	1386	1291

Elemental Analysis (d.b., wt %)	Standard Method	Polish Coal	Coal Cerejon	Straw pellets	Olive Cake	Wood pellets
C		70.98	66.23	46.67	50.60	49.62
H	ASTM D 5373	4.89	5.94	6.97	6.95	6.87
N		1.22	1.39	0.73	1.09	< LQ
S	ASTM D 4239	0.51	0.65	0.14	0.11	< LQ
Cl		0.255	0.03	0.270	0.337	< LQ
P	ASTM 2795	0.012	0.006	0.080	0.140	0.004
Al		0.694	1.108	0.012	0.011	0.006
Fe		0.307	0.453	0.010	0.030	0.005
Ca		0.513	0.171	0.359	0.291	0.083
K	ASTM 3682	0.104	0.208	1.306	2.109	0.040
Na		0.045	0.011	0.029	0.054	0.002
Mg		0.222	0.132	0.077	0.085	0.020
Si		1.011	2.674	1.258	0.059	0.035

Scheme of the Pilot Fluidized Bed of INETI

According CEN/TS 14691 classification:

Herbaceous biomass →



Strawpellets

Fruit biomass →

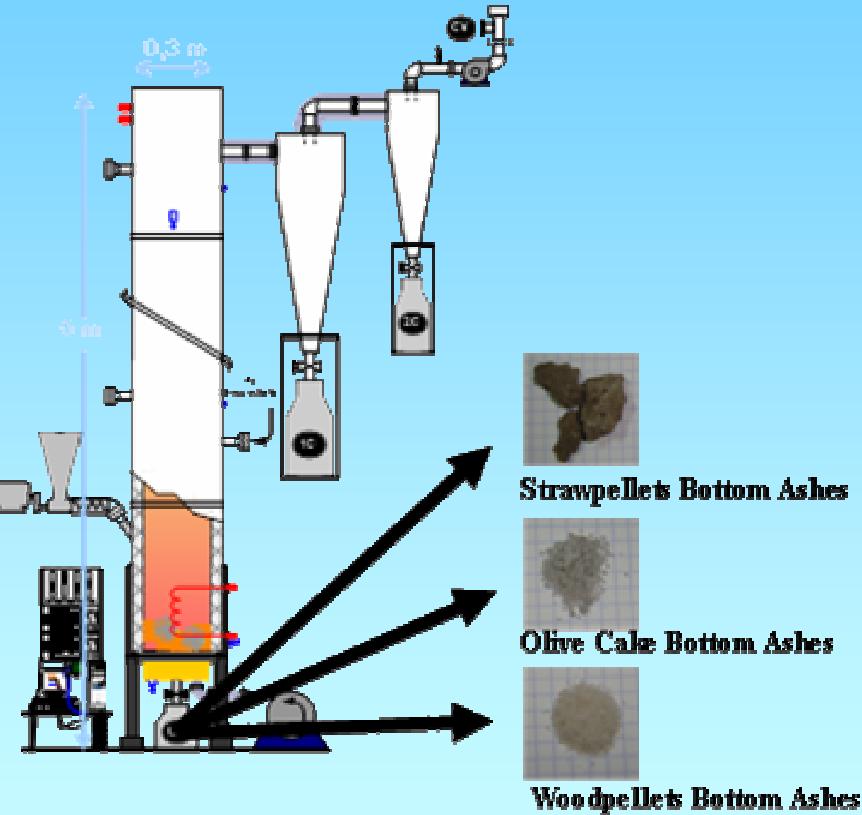


Olive Cake

Woody biomass →



Woodpellets



Combustion and co-combustion tests (with 5, 15 and 25%wt of biomass) were performed.

Combustion Conditions at the Fluidized Bed Pilot of INETI

Fuel Blend	Coal Polish (%)	Coal Cerejon (%)	Strawpellets (+ Coal Polish) (%)			Olive Cake (+ Coal Cerejon) (%)			Woodpellets (+ Coal Cerejon) (%)					
	100	100	5	15	25	100	5	15	25	100	5	15	25	100
Feed rate (kg/h)	9.56	11.45	9.77	10.4	10.6	15.7	12.4	12.9	13.9	20.3	12.4	13.4	13.8	18.3
Energy Input (MJ/h)	266	280	265	269	260	233	318	321	334	353	300	313	313	316
Bed temperature (°C)	818	850	813	813	769	701	845	840	831	766	843	842	841	831
Bed gas velocity (m/s)	1.1	0.66	1.0	1.0	0.9	0.7	0.82	0.81	0.84	1.03	0.71	0.71	0.70	0.79
Freeboard gas velocity (m/s)	1.3	0.87	1.2	1.3	1.2	1.1	0.98	1.00	1.06	1.47	0.95	1.00	1.00	1.16
Excess air (%)	35	36	31	36	31	52	40	35	35	45	37	36	36	38
Secondary air (%)	18	23	20	21	23	35	25	25	25	25	25	28	30	33
Bed height (m)	0.17	0.50	0.17	0.18	0.17	0.16	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50

In some tests (in red) the combustion temperature was reduced to prevent bed agglomeration problems.

RESULTS AND DISCUSSION

Strawpellets tests

- ❖ Slagging phenomenon was evident.
- ❖ Agglomerated particles with diameters of 5cm were observed for tests with strawpellets.
- ❖ For test involving blends with 25% of strawpellets, the temperature was maintained below 800°C to avoid the formation of agglomerates.



Olive Cake tests

- ❖ No agglomeration was detected, but it was observed that the diameter of sand particles from the fluidized bed increased, which suggested that sintering occurred without the formation of a molten phase.
- ❖ For 100% of olive cake test the temperature was maintained below 800°C.

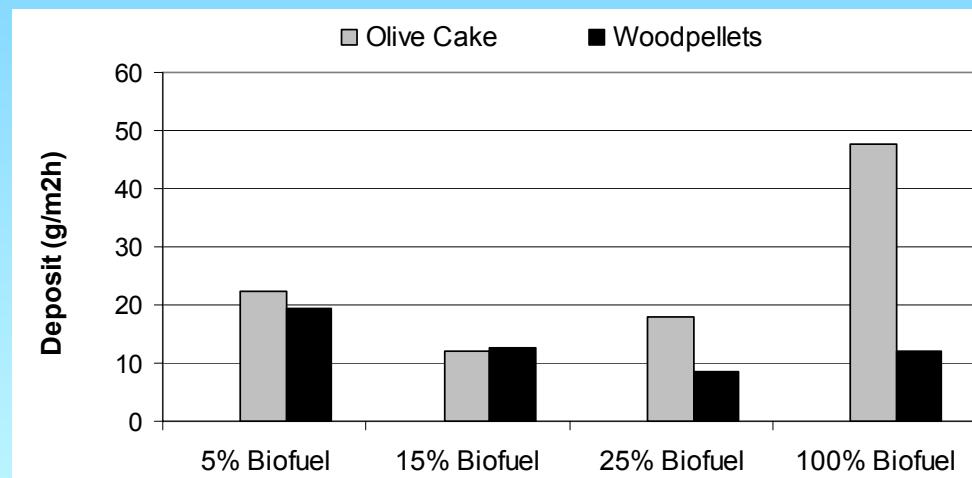


Woodpellets tests

- ❖ No slagging problem was observed.

RESULTS AND DISCUSSION

The fouling phenomenon was evaluated for different blends of olive cake and woodpellets considering the quantity of deposit collected on the fouling probe ($\text{g/m}^2\text{h}$):



- ❖ In olive cake tests the deposit quantity was much higher when 100% biomass was used as a fuel.
- ❖ In woodpellets tests the deposit quantity was almost constant (between 10-20 g/m²h).

RESULTS AND DISCUSSION

Fuel

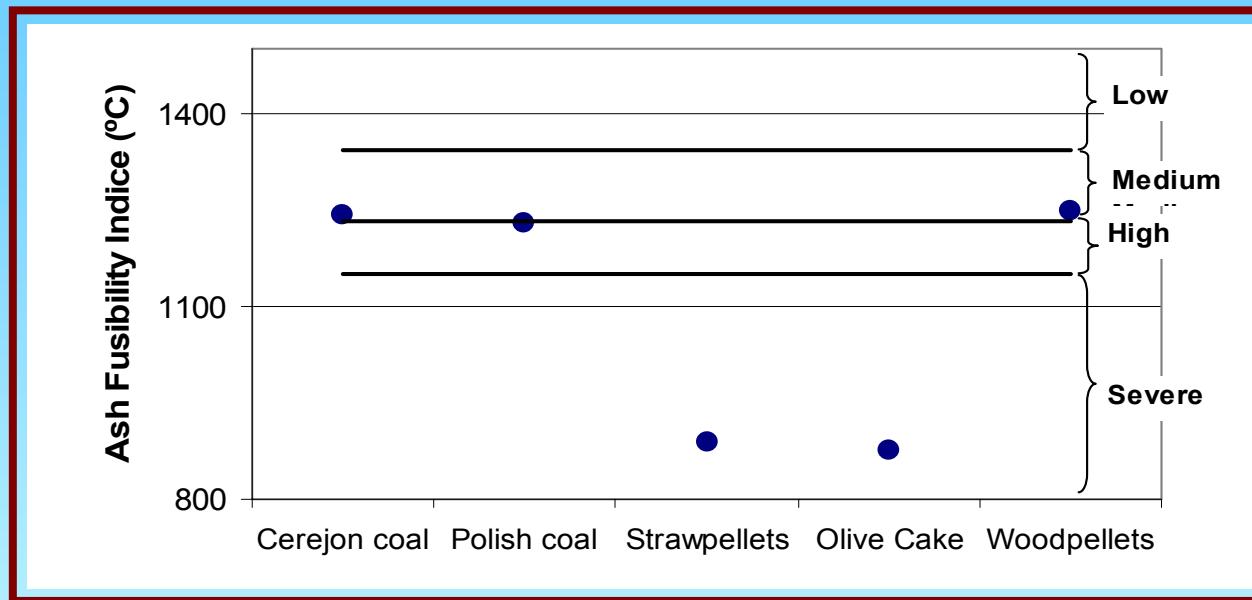
Ash Composition Indices

	$R_{b/a}$ Eq.(1)	$R_{b/a+(P)}$ Eq.(2)	$R_{b/a\,Simp}$ Eq.(3)	BAI Eq.(4)	R_s Eq.(5)	F_u Eq.(6)	S_R Eq.(7)
100% Coal Polish	Medium	Medium	Medium	Not Probable	Low	Medium	Medium
5% Strawpellets*	Medium	Medium	Medium	Not Probable	Low	High	Medium
15% Strawpellets*	Medium	Medium	Medium	Not Probable	Low	High	Medium
25% Strawpellets*	Medium	Medium	Medium	Not Probable	Low	High	Medium
100% Strawpellets	High	High	Low ??	Very Probable	Low ??	High	Medium ??
100% Coal Cerejon	Low	Low	Low	Not Probable	Low	Low	Low
5% Olive Cake*	Low	Low	Low	Not Probable	Low	Medium	Low
15% Olive Cake*	Low	Low	Low	Not Probable	Low	High	Low
25% Olive Cake*	Medium	Medium	Low	Not Probable	Low	High	Low
100% Olive Cake	Unknown **	Unknown **	Unknown **	Very Probable	High	Extremely High	Medium
100% Coal Cerejon	Low	Low	Low	Not Probable	Low	Low	Low
5% Woodpellets*	Low	Low	Low	Not Probable	Low	Medium	Low
15% Woodpellets*	Low	Low	Low	Not Probable	Low	Medium	Low
25% Woodpellets*	Medium	Medium	Medium	Not Probable	Low	High	Low
100% Woodpellets	Unknown **	Unknown **	Low	Low Probable	Low	High	Low

- ❖ The applicability of all indices should be evaluated with caution
- ❖ The indices from equation 3 and 5 should not be considered
- ❖ The BAI (eq.4) and F_u (eq.6) are coherent with the experimental results

The ash composition indices only allows rapid ideas about the slagging and fouling potentiality

RESULTS AND DISCUSSION



- ❖ The results of ash fusibility indice are in agreement with the experimental results (strawpellets and olive cake are problematic fuels).
- ❖ The evaluation of fusibility index for the different blends tested showed that the use of blends enable to mitigate the tendency to sintering of the most problematic fuels, as verified experimentally.

RESULTS AND DISCUSSION

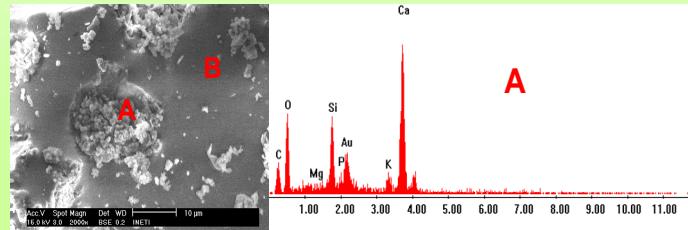
SEM/EDS analyses were performed on the bed ashes and probe deposits of the tests with 100% and 15% of biomass:

Strawpellets Tests



Bed Ashes:

- Agglomerated particles contained high quantities of Si, Ca and K (maybe calcium potassium silicates), which in function of the different proportions of $K_2O-CaO-SiO_2$ could melt or soften at low temperatures, forming ash particles with a wide range of compositions, shapes and sizes.



Fouling Probe:

- High quantities of O, S, Cl, K, Cr and minor elements such as Al, P, Mg and Ca, which may correspond to a mix of chlorinated metals and sulphates, were found.

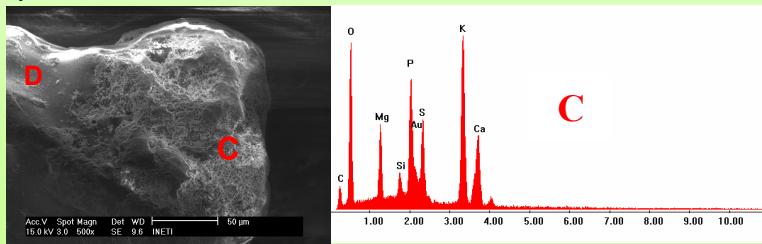
RESULTS AND DISCUSSION

Olive Cake Tests



Bed Ashes:

- Zones with Si and K (maybe potassium silicates).
- Zones with Si, K, P, Ca and Mg (maybe phosphate compounds).
- S is sometimes present (maybe sulphate compounds)



Fouling Probe:

- Unburned matter (high contents of C and O)
- Calcium sulphate crystals
- P, Cl, K, Al and Mg was also detected

CONCLUSIONS

- ❖ Woody biomass can successfully be used as biofuel without slagging and fouling problems.
- ❖ Herbaceous and fruit biomass may lead to slagging and fouling problems, however, this tendency could be mitigated through co-firing with appropriate amounts of coal (or with woody biomass).
- ❖ Not all the existent indices can be applied to biomass, but there are some indices that are coherent with the experimental results, particularly, in the case of low amounts of biomass in blends.

FUTURE WORK

- ❖ Study of blends with three types of fuels and the use of additives to reduce the slagging and fouling tendency.
- ❖ Analyze by SEM/EDS cross sections areas to evaluate the build up of **fused** layers on bed material.
- ❖ Use of software (FACTSAGE) to control and predict the slagging and fouling problems, based on fuel composition.

ACKNOWLEDGMENTS

The authors are gratefully acknowledged to financial support given by:

- ❖ 6th Framework Programme to COPOWER project: "Synergy Effects of Co-Processing of Biomass with coal and Non-Toxic Wastes for Heat and Power Generation".
- ❖ Portuguese Foundation for Science and Technology.
- ❖ Environmental Biotechnology Unity /Lisbon New University/Science and Technology Faculty (UBIA/UNL/FCT)

Thanks for your attention!