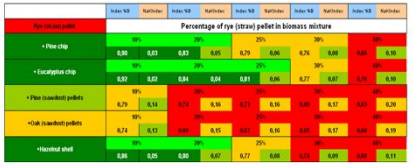
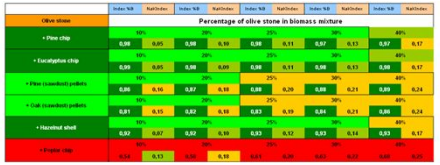
DOMOHEAT PROJECT

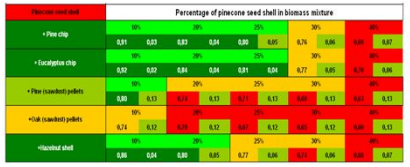
8th Coordination Meeting. Athens, Greece 2011.

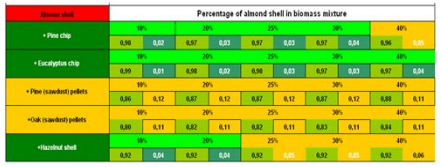
University of Vigo.

Forest Engineering group









Summary

- Domoheat #1 Slagging Indices
- Ash composition and Slagging Indices DHT#2
- Biomass mixtures:
  - Ash slagging monitoring
  - Ashes granulometry results
  - Ashes fusion temperatures

- Summary and Conclussions

Proposal of thresholds for slagging Indexs based on combustion test results (Biomasses DHT#1)

Sample	%B/ Total	Na&K in Bases
Pine chip	0,98	0,01
Eucalyptus chip	0,99	0,01
Oak chip	0,94	0,02
Poplar chip	0,49	0,08
Paulownia chip	0,82	0,26
Rye (straw) pellet	0,32	0,46
Pine (sawdust) pellets	0,85	0,13
Oak (sawdust) pellets	0,79	0,11
Pine (with bark) chips	0,80	0,26
Pinecone chips	0,76	0,18
Pinecone seed shell	0,32	0,49
Almond shell	0,93	0,10
Hazelnut shell	0,91	0,03
Olive stone	0,96	0,38
Vineshoot	0,76	0,03
Olive pruning chips	0,90	0,02

% Basic ashes Index	
> 0,8	No Slagging
0,75 - 0,8	Possible Slagging
<0,75	Slagging

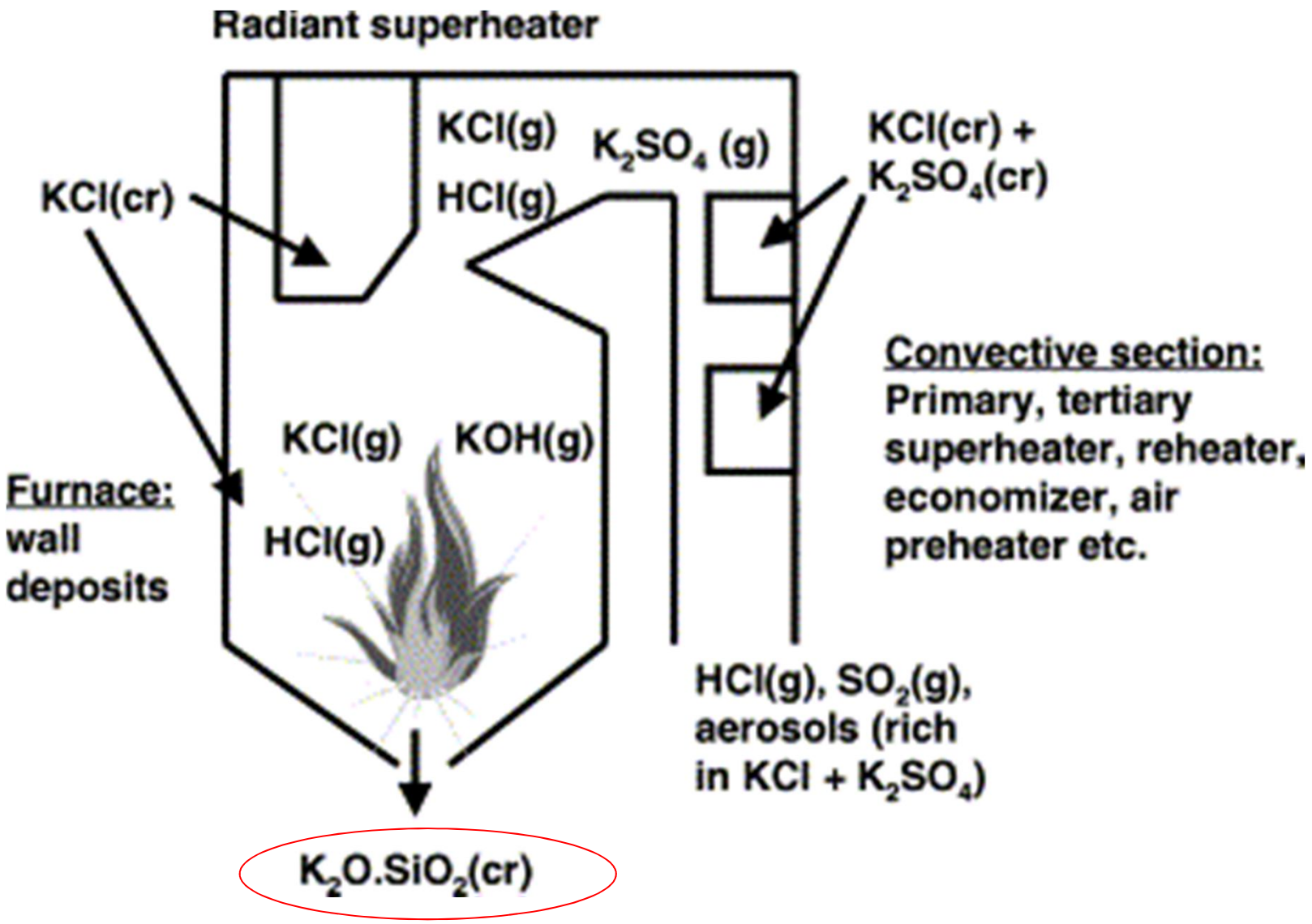
Na&K in B Index	
<0,05	No slagging
0,05-0,15	Possible slagging
0,15-0,30	Medium slagging risk
>0,30	High slagging risk

Slagging Index meaning

- 1st Index %B: High basic ash content (>80%)
  =low acid ash content =low Si level.

- 2º Index (Na2O +K2O)/B:
  Low Na &K content (<30%) in ash basic components.

  The formation of Na & K silicates is one of the main slagging & fouling mechanisms (i.e. Bapat et al., 1997, Werther et al., 2003).


Radiant superheater
KCl(g)
K_2SO_4 (g)
HCl(g)
KCl(cr)
KCl(cr) +
K_2SO_4(cr)
Convective section:
Primary, tertiary
superheater, reheater,
economizer, air
preheater etc.
KCl(g)
KOH(g)
HCl(g)
Furnace:
wall
deposits
HCl(g), SO_2(g),
aerosols (rich
in KCl + K_2SO_4)
$K_2O.SiO_2$(cr)

Domoheat biomasses #2 ash composition

ASH COMPOSITION DOMOHEAT BIOMASSES #2									
Sample	SiO2	Al2O3	TiO2	Fe2O3	CaO	MgO	Na2O	K2O	P2O5
01#2-Pine chip # 2	9.88	7.95	0.03	0.89	26.00	20.30	0.90	10.90	7.97
02#2-Eucalyptus chip #2	15.50	10.30	0.25	3.10	31.10	12.20	2.91	10.50	7.55
06#2-Rye straw pellet #2	35.30	0.84	< 0,05	0.29	20.40	2.72	2.20	21.90	3.78
07#2-Pine sawdust pellet #2	28.50	7.93	1.51	5.19	32.20	7.28	1.45	6.37	3.48
08#2-Oak pellet #2	8.55	5.94	0.34	5.22	37.90	12.60	2.24	11.60	3.89
09-Pine bark + wood chip #2	21.50	19.50	0.30	3.83	19.10	13.00	2.18	8.45	6.68
11#2-Pinecone seed shell #2	70.10	1.66	< 0,05	0.50	4.17	5.77	0.63	11.70	2.90
12#2-Almond shell #2	1.24	0.97	< 0,05	0.71	25.90	4.25	3.03	51.40	3.30
14#2-Olive stone #2	4.47	2.02	< 0,05	2.10	32.90	4.60	2.57	37.50	4.75

Slagging Indices Biomasses #2

SLAGGING INDICES			
Sample	%B	(Na+K)/B	Cl
01#2-Pine chip # 2	0.77	0.20	0.00
02#2-Eucalyptus chip #2	0.70	0.22	0.14
06#2-Rye straw pellet #2	0.53	0.51	5.23
07#2-Pine sawdust pellet #2	0.58	0.15	0.06
08#2-Oak pellet #2	0.82	0.20	0.08
09-Pine bark + wood chip #2	0.53	0.23	0.13
11#2-Pinecone seed shell #2	0.24	0.54	0.00
12#2-Almond shell #2	0.97	0.64	0.12
14#2-Olive stone #2	0.92	0.50	0.22
Proposed Index Thresholds	>0.70-0.8	<0.3	<0.2

Based on Slagging Indices, 16 Mixtures were proposed

Sample	%B Index	Na&K Index	%B Index	Na&K Index	%B Index	Na&K Index	%B Index	Na&K Index
Olive stone #2	10	%	20	%	30	%	40	%
Pine sawdust pellet #2	0.62	0.20	0.65	0.24	0.68	0.28	0.72	0.32
Oak Pellets #2	0.72	0.26	0.74	0.29	0.77	0.32	0.79	0.35
Eucalyptus chip #2	0.79	0.24	0.80	0.27	0.82	0.30	0.84	0.33
Pine chip #2	0.83	0.23	0.85	0.26	0.86	0.29	0.87	0.32
Bark + Pine Chip #2	0.57	0.27	0.61	0.31	0.65	0.34	0.69	0.36

Example of Slagging Indices calculation for olive stone

DHT#2 biomass mixtures

BIOMASS MIXTURES

SOMETIMES HARD TO AVOID FUEL STRATIFICATION

Biomass Mixtures Results:

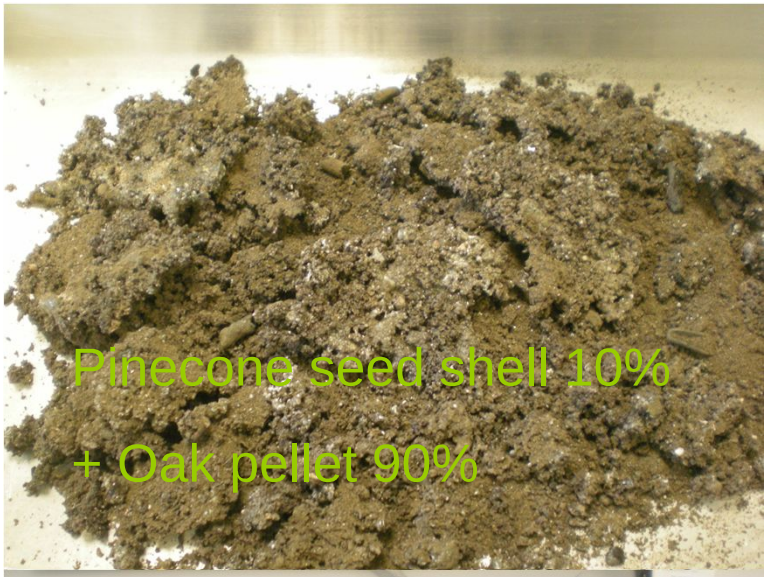
Rye straw pellet Mixtures

RYE STRAW PELLET (20%) + EUC. CHIP (80%)	**HARD SLAG**
RYE STRAW PELLET (20%) + PINE W BARK (80%)	**HARD SLAG**
RYE STRAW PELLET (40%) + OAK PELLET (60%)	**HARD SLAG**
RYE STRAW PELLET (10%) + OAK PELLET (90%)	**HARD SLAG; Small Quantity**

OAK PELLET 60% + RYE STRAW 40%

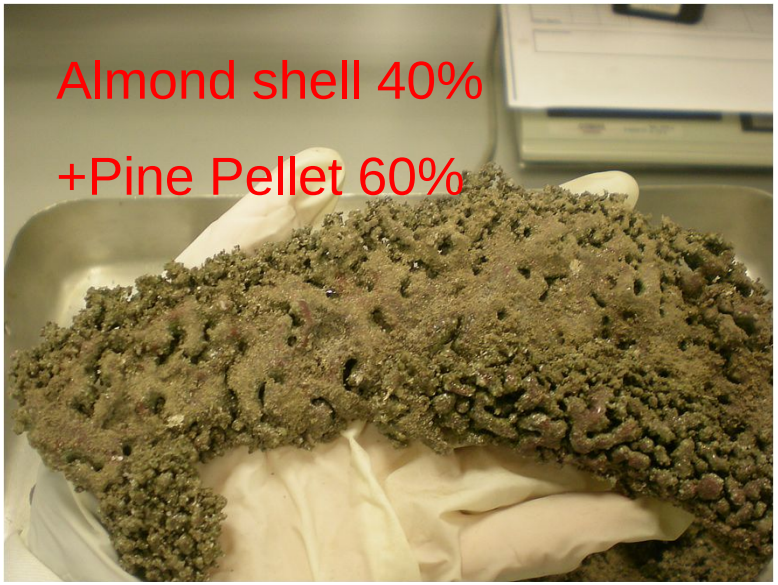
Pinecone seed shell mixtures

PINECONE SEED SHELL (10%) + OAK PELLET (90%)	**WEAK SLAG**
PINECONE SEED SHELL (25%) + EUC.CHIP (75%)	**WEAK SLAG**
PINECONE SEED SHELL (20%) + PINE CHIP (80%)	**HARD SLAG**
PINECONE SEED SHELL (40%) + OAK PELLET (60%)	**HARD SLAG**



Almond shell mixtures

ALMOND SHELL (20%) + PINE W/BARK (80%)	**WEAK SLAG**
ALMOND SHELL (20%) + PINE CHIP (80%)	**WEAK SLAG**
ALMOND SHELL (40%) + OAK PELLETS (60%)	**WEAK SLAG**
ALMOND SHELL (40%) + PINE PELLETS (60%)	**HARD SLAG**



Olive stone mixtures

OLIVE STONE (30%) + OAK PELLET (70%)	**DUST**
OLIVE STONE (30%) + PINE PELLET (70%)	
OLIVE STONE (50%) + OAK PELLET (50%)	
OLIVE STONE (20%) +PINE PELLET (80%)	

Ashes Granulommetry Results:
Domoheat#1 pure Biomasses

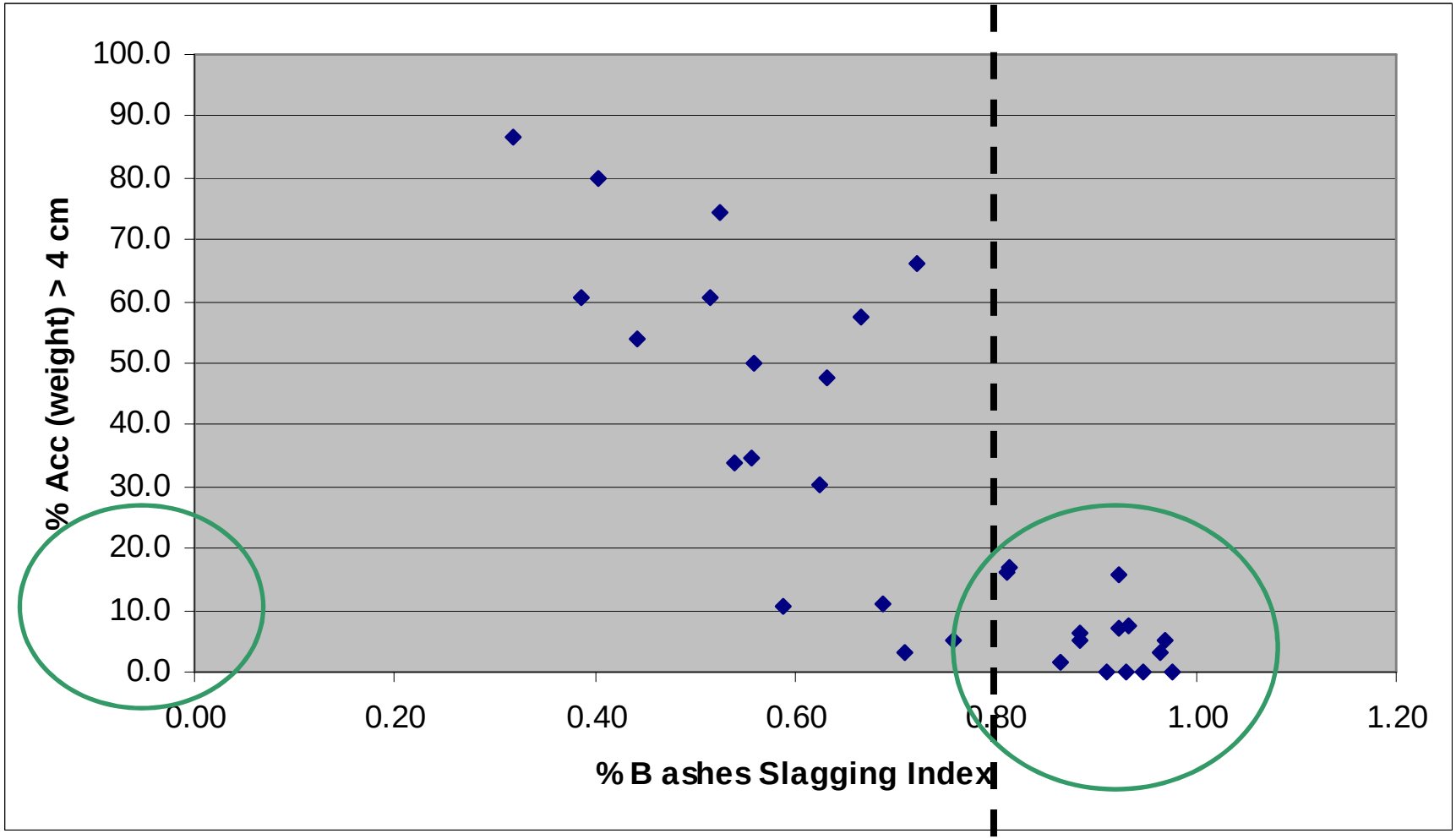
Domoheat Boiler Ash Deposit		Observed Slagging Index		% acumulated (weight)					
n	Sample	%B/Total	Na&K /B index	8	4	2	1	0.5	>0.5
1	PINE CHIP #1 #1 (AUSTRIA BOILER ASH)	0.87	0.16	0	1.7	6.5	14.7	35.9	100
2	EUCALYPTUS CHIP #1 (VIGO BOILER SLAG)	0.97	0.36	1.8	5.2	15.5	28.2	41.3	100
3	OAK CHIP #1 (VIGO BOILER ASH)	0.93	0.52	2.2	7.6	12.9	21.2	37.8	100
4	POPLAR CHIP #1 (AUSTRIA BOILER ASH)	0.59	0.14	3.9	10.6	19.3	29.2	43.9	100
5	PAULOWNIA CHIP #1 (VIGO BOILER ASH)	0.76	0.44	1.3	5.2	13.2	25.3	39.8	100
6	RYE STRAW PELLET #1 (VIGO BOILER ASH)	0.44	0.67	44	53.8	62	70.1	78	100
7	PINE (SAWDUST) PELLETS #1 (AUSTRIA BOILER ASH)	0.81	0.19	12.2	17.1	23.6	33.2	53.8	100
8	OAK (SAWDUST) PELLETS #1 (AUSTRIA BOILER ASH)	0.71	0.17	0	3.2	7.7	14	22.7	100
9	PINE WITH BARK (WINTER) #1 (VIGO BOILER ASH)	0.93	0.26	0	0	0	7.9	66	100
10	PINECONE CHIPS #1 (VIGO BOILER ASH)	0.81	0.68	8.7	16	16.8	29.8	79.3	100
11	PINECONE SEED SHELL #1 (VIGO BOILER ASH)	0.32	0.63	81.6	86.6	87.7	90.8	93.4	100
12	ALMOND SHELL CORR #1 (LEON BOILER ASH)	0.98	0.63	0	0.1	15	32.2	51.87	100
13	HAZELNUT SHELL #1 (VIGO BOILER ASH)	0.95	0.42	0	0	10.7	22.9	39.6	100
14	OLIVE STONE #1 (LEON BOILER ASH)	0.96	0.58	0	3.3	13.3	31.7	55	100
16	OLIVE PRUNING-SUMMER #1 (VIGO BOILER ASH)	0.91	0.11	0	0	16.2	25	71	100

Ashes granulommetry: results

Domoheat#2 mixtures

Domoheat Boiler Ash Deposit		Slagging Index		% acumulated (weight)			
n	Sample	%B	Na&K/B	8	4	2	1
17	17- OLIVE STONE (31%) + OAK PELLET (69%)	0.88	0.31	0.6	5	14.4	33.8
18	18- OLIVE STONE (32%) +PINE PELLET (68%)	0.52	0.24	38.6	60.8	72.9	82.8
19	19- PINECONE SEED SHELL (22%)+ PINE CHIP (78%)	0.39	0.38	50.3	60.8	72.4	83.4
20	20- PINECONE SEED SHELL (25%) + EUC.CHIP (75%)	0.65	0.27	29.5	50.1	67.9	80.7
21	21- ALMOND SHELL (18%) + PINE W/BARK (82%)	0.69	0.27	3.5	11.1	18.4	44.1
22	22- ALMOND SHELL (18%) +PINE CHIP (82%)	0.89	0.4	0.9	6.4	18.3	40.4
23	23- RYE STRAW PELLET (21%)+ EUC. CHIP (79%)	0.62	0.34	2.2	30.4	59.9	76.9
24	24- RYE STRAW (18%)+ PINE W BARK (82%)	0.54	0.37	9	33.9	61.4	80.3
25	25- OLIVE STONE (52%) + OAK PELLET (48%)	0.92	0.33	0.7	6.9	18.8	40.3
26	26- OLIVE STONE (21%) +PINE PELLET (79%)	0.56	0.24	24	34.5	41	46.3
27	27- PINECONE SEED SHELL (42%) + OAK PELLET (58%)	0.4	0.41	72.2	79.9	85.5	90.7
28	28- PINECONE SEED SHELL (11%) + OAK PELLET (89%)	0.72	0.31	51.5	66.2	75.2	82.3
29	29- ALMOND SHELL (41%) + PINE PELLETS (59%)	0.53	0.33	66.7	74.3	81.8	89.2
30	30- ALMOND SHELL (42%) + OAK PELLETS (58%)	0.92	0.24	6	15.6	26	46
31	31- RYE STRAW PELLET (41%) + OAK PELLET (59%)	0.63	0.5	36.5	47.7	54.9	92.7
32	32- RYE STRAW PELLET (10%) + OAK PELLET (90%)	0.67	0.27	26.8	57.5	73.8	82.7

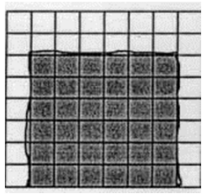
Relationship of accumulated % ashes with Slagging Index %B



Index Threshold %B> 0.8

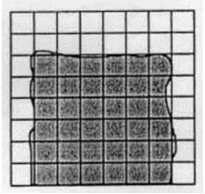
THERMAL ASH BEHAVIOUR

Deformation Temperature



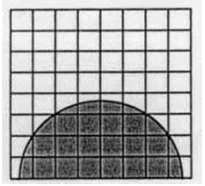
Sintering describes a process, where single ash particles stick together.
During this process the sample may change its original dimension without showing characteristics typical at the softening point.

Softening



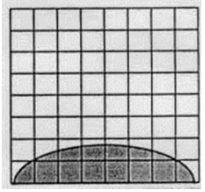
At this temperature the sample shows the first signs of softening, e.g. surface changes, the rounding of the edges are complete and the sample starts filling out the gas volume between the particles.

Hemispheric point



The hemispheric point gives the temperature, when the sample takes on the approximate form of a hemisphere. The height of the melted sample is approximate half the length of the base line.

Flowing point



At this temperature the sample has shrunk to one third of its original height.

Source: K. Reisinger, C. Haslinger, M. Herger, H. Hofbauer. Characterisation of ash behaviour. Institute of Chemical Engineering, Fuel and Environmental Technology, University of Technology Vienna, Austria.

Ash Fusion Temperatures

Domoheat #1 Boiler ashes

Number	Sample	Deformation Temp.	Sphere Temp.	Hemisphere Temp.	Flow Temp.
1	Pine chip boiler ash	1320			
2	Eucalyptus chip boiler ash	1142		1171	1209
3	Oak chip boiler ash	1136	1232	1249	1293
4	Poplar chip boiler ash	1199			
5	Paulownia chip boiler ash	1233		1274	1289
6	Rye (straw) pellet boiler ash	837	1019	1075	1215
7	Pine (sawdust) pellets boiler ash	1237		1259	1273
8	Oak (sawdust) pellets boiler ash	1182		1197	1229
11	Pinecone seed shell boiler ash	940	1117	1200	1318
12	Almond shell ash	737		773	
13	Hazelnut shell boiler ash	1059		1278	
14	Olive stone boiler ash	767			

Ash Fusion Temperatures

Domoheat #1 Laboratory Ashes (550ºC)

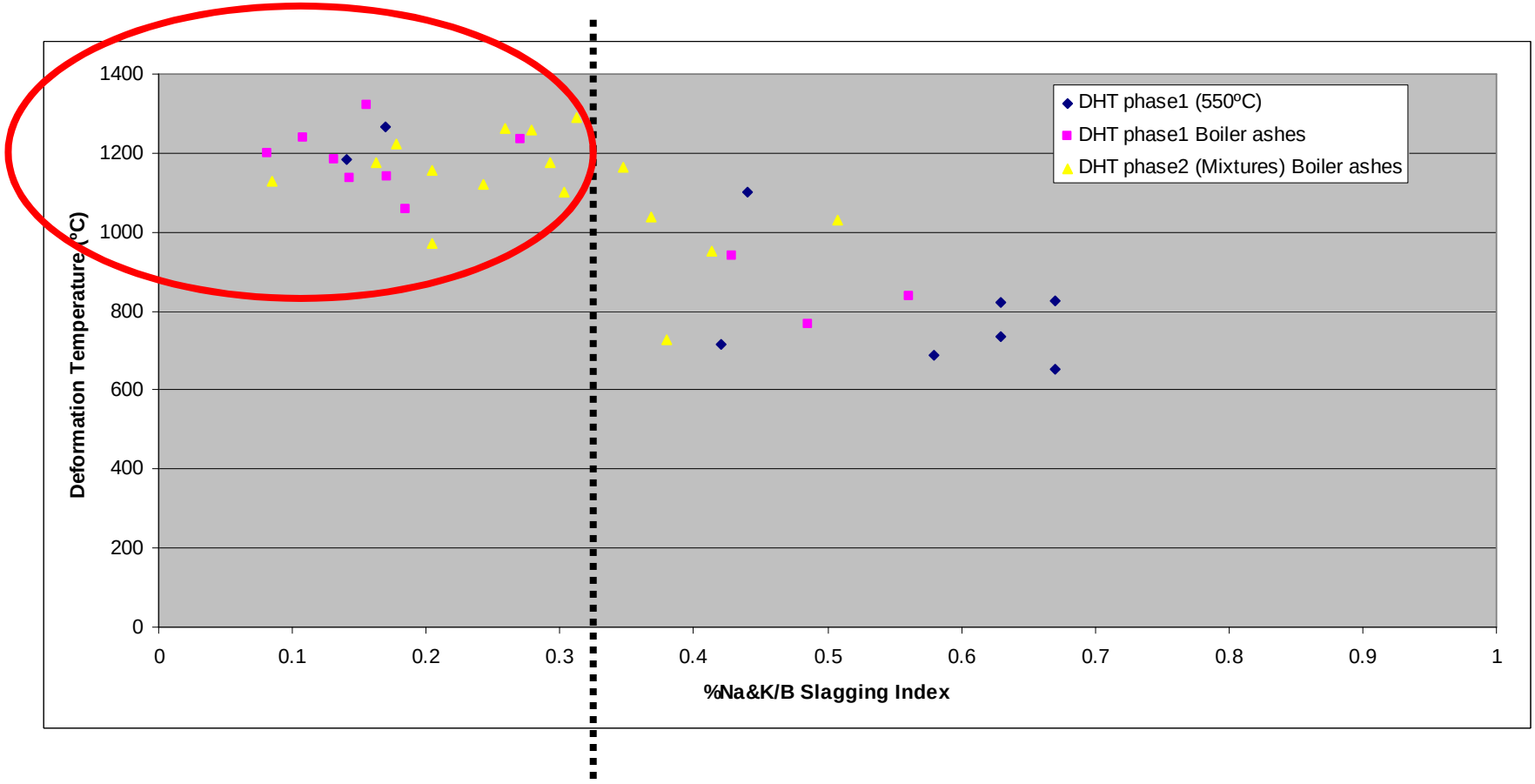
Number	Sample	Deformation Temp.	Sphere Temp.	Hemisphere Temp.	Flow Temp.
4	Poplar chip ash	1183			
5	Paulownia chip ash	1102			1264
6	Rye (straw) pellet ash	823	1012	1068	1202
		832	1019	1067	1234
		651	1007	1072	1204
11	Pinecone seed shell ash	852	1090	1153	1293
		803	1107	1184	1289
		783	1084	1135	1293
		855	1088	1148	1266
		821	1045	1114	1291
12	Almond shell ash	773		773	
		701			
13	Hazelnut shell ash	738			
		698			
		716			
14	Olive stone ash	681			
		694			
15	Vineshoot ash	1268			1297

Ash Fusion Temperatures

Domoheat #2 Mixtures -Boiler ashes

N	Sample	Deformation T	Sphere T	Hemisphere Temp.	Flow Temp.
18	OLIVE STONE (30%) + PINE PELLET (70%) H.S	1177	1198	1219	1255
19	PINECONE SEED SHELL (22%)+ PINE CHIP (78%) BOILER ASH < 0,5mm	970	1171	1183	1251
20	PINECONE SEED SHELL (25%) + EUCALYPTUS CHIP (75%) W.S	1037		1222	1287
21	ALMOND SHELL (18%) + PINE W/BARK (82%) BOILER ASH 0,25mm	1259			1283
22	ALMOND SHELL (18%) +PINE CHIP (82%) BOILER ASH < 0,5mm	1311			
24	RYE STRAW (20%)+ PINE W BARK (80%) H.S	728	1103	1130	1211
26	OLIVE STONE (21%) +PINE PELLET (79%) BOILER ASH < 0,25mm	1156			1220
27	PINECONE SEED SHELL (40%) + OAK PELLET (60%) H.S	953	1077	1136	1240
28	PINECONE SEED SHELL (11%) + OAK PELLET (89%) BOILER ASH < 0,5mm	1119			
29	ALMOND SHELL (40%) + PINE PELLETS (60%) H.S	1166		1201	1270
30	ALMOND SHELL (42%) + OAK PELLETS (58%) BOILER ASH < 0,5mm	1284			
31	RYE STRAW PELLET (41%) + OAK PELLET (59%) BOILER ASH < 0,25mm	1032			1090
32	RYE STRAW PELLET (10%)+ OAK PELLET (90%) BOILER ASH < 0,5mm	1289		1323	

Relationship of Ash Fusion temperatures with Alkali (Na&K) Slagging Index



Index threshold:

%Na&K >0.3-0.4

Summary:

General agreement of Slagging Indixes, Ashes Granulometry, Ashes Hardness characterization and Ash Fusion Temperatures

Domoheat Boiler Ash Deposit		Slagging Index		% acumulated (weight)					
n	Sample	%B	Na&K/B	8	4	2	1	Sinter Hardness	D.T (ºC)
17	17- OLIVE STONE (31%) + OAK PELLET (69%)	0.88	0.31	0.6	5	14.4	33.8	WEAK SLAG	
18	18- OLIVE STONE (32%) +PINE PELLET (68%)	0.52	0.24	38.6	60.8	72.9	82.8	HARD SLAG	<1200
19	19- PINECONE SEED SHELL (22%)+ PINE CHIP (78%)	0.39	0.38	50.3	60.8	72.4	83.4	HARD SLAG	<1000
20	20- PINECONE SEED SHELL (25%) + EUC.CHIP (75%)	0.65	0.27	29.5	50.1	67.9	80.7	WEAK SLAG	
21	21- ALMOND SHELL (18%) + PINE W/BARK (82%)	0.69	0.27	3.5	11.1	18.4	44.1	WEAK SLAG	>1200
22	22- ALMOND SHELL (18%) +PINE CHIP (82%)	0.89	0.4	0.9	6.4	18.3	40.4	WEAK SLAG	>1200
23	23- RYE STRAW PELLET (21%)+ EUC. CHIP (79%)	0.62	0.34	2.2	30.4	59.9	76.9	WEAK SLAG	>1200
24	24- RYE STRAW (18%)+ PINE W BARK (82%)	0.54	0.37	9	33.9	61.4	80.3	HARD SLAG	<1200
25	25- OLIVE STONE (52%) + OAK PELLET (48%)	0.92	0.33	0.7	6.9	18.8	40.3	WEAK SLAG	
26	26- OLIVE STONE (21%) +PINE PELLET (79%)	0.56	0.24	24	34.5	41	46.3	HARD SLAG	<1200
27	27- PINECONE SEED SHELL (42%) + OAK PELLET (58%)	0.4	0.41	72.2	79.9	85.5	90.7	HARD SLAG	<1200
28	28- PINECONE SEED SHELL (11%) + OAK PELLET (89%)	0.72	0.31	51.5	66.2	75.2	82.3	WEAK SLAG	>1200
29	29- ALMOND SHELL (41%) + PINE PELLETS (59%)	0.53	0.33	66.7	74.3	81.8	89.2	HARD SLAG	<1200
30	30- ALMOND SHELL (42%) + OAK PELLETS (58%)	0.92	0.24	6	15.6	26	46	WEAK SLAG	>1200
31	31- RYE STRAW PELLET (41%) + OAK PELLET (59%)	0.63	0.5	36.5	47.7	54.9	92.7	HARD SLAG	<1200
32	32- RYE STRAW PELLET (10%) + OAK PELLET (90%)	0.67	0.27	26.8	57.5	73.8	82.7	HARD SLAG (LITTLE QUANTITY)	>1200

Conclussions (I)

- Mixtures with Ryestraw pellet resulted in Hard slagging occurence
- For Pinecone seed shell, Hard slagging occured only for the highest percentage of mixture (40/60%) and with pine pellet.
- Almond shells mixtures gave slight slagging (with the exception of the 40/60% mixture)
- Olive stone mixtures gave no slagging problems

Conclussions (II)

Ash-based slagging indices succesfully predicted slagging ocurrence for both pure biomasses and mixtures:

- A relationship was found between % B index and ash granulommetry.
- Similarly, Na&K Slagging index showed a relationship with ash fusion temperature
- The combination of both slagging indexes showed potential for predicting slag deposit ocurrence in biomass mixtures

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