Imperial College London

Coal-biomass ash deposition during deeply-staged combustion

BCURA project B78

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Background

To meet future NOx emission limits, UK power stations will need to stage combustion more deeply through the use of over-fire air. Recent combustion trials have indicated that co-firing biomass with coal can affect the sensitivity of ash deposition to changes in flame stoichiometry, with significant increases in deposit sintering and fluidity.

Coals with ultra-low sulphur contents are being chosen to meet SOx emission limits for utilities wishing to ‘opt in’ to the LCPD without installing FGD. Little is known about the interaction between the ashes from these coals and typical coals, or about the deposition potential of the resulting ash.

Project activities at Imperial

Proposed scope of activities:

- Mixtures of coal and biomass under deeply-staged combustion conditions
- Mixtures of coal and low-ash coal under normal combustion conditions

Modified scope of activities:

- Three-way mixtures of coal, low-ash coal and biomass under normal combustion conditions
- Limited three-way mixtures of coal, low-ash coal and biomass under deeply-staged combustion conditions

Literature survey

Three publications have been found that describe the deposition behaviour of Indonesian low-ash coals, two published within the last month.

These publication indicate that Indonesian low-ash coals have a high deposition propensity, and may need mineral additions to control slagging problems.

No publications have been found concerning the ash deposition behaviour of:

- Coal blends that include Indonesian low-ash coals
- Coal-biomass blends during deeply-staged combustion

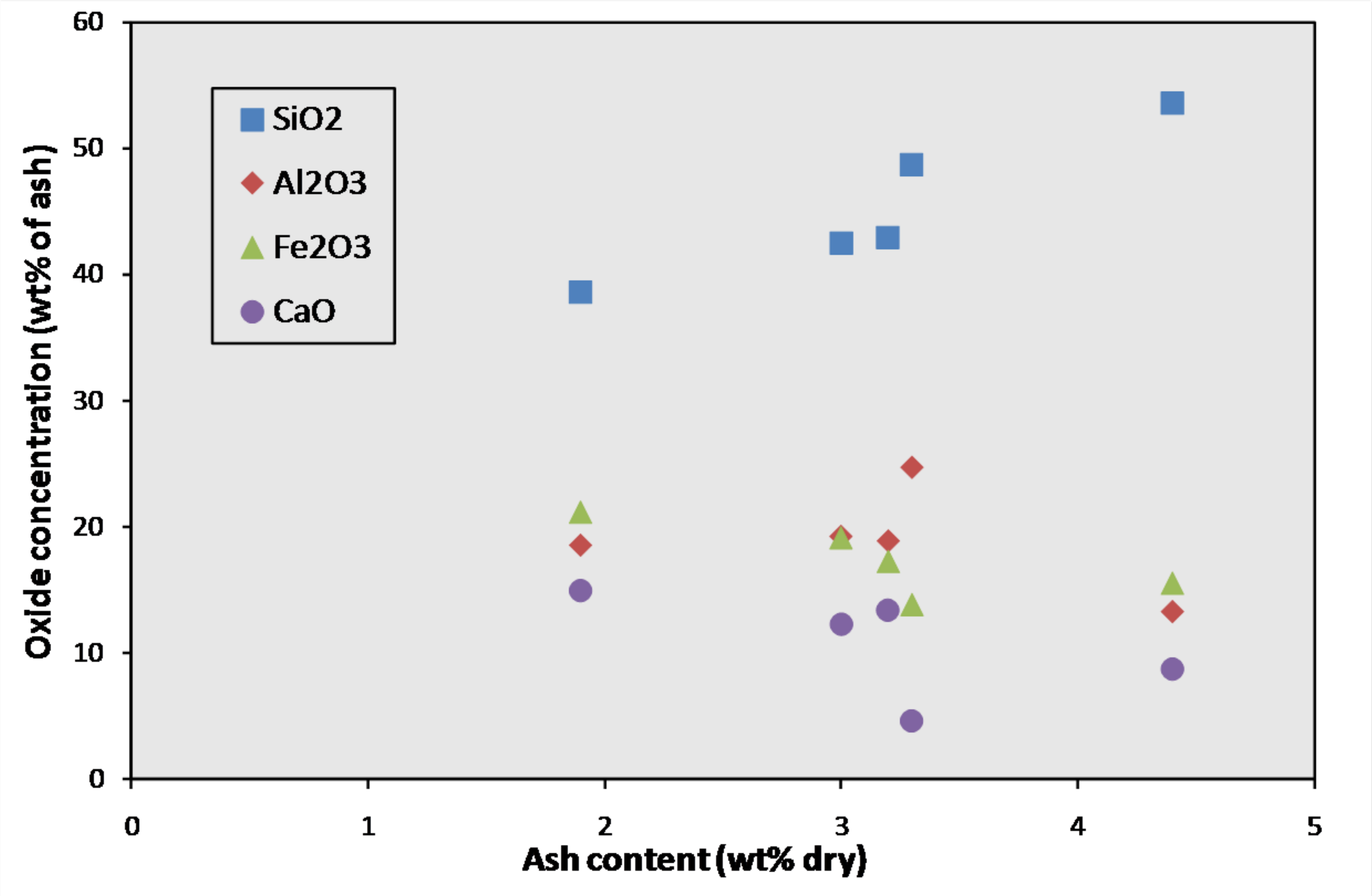
Fuels used at Imperial
Ash contents and chemistries (wt%)

	Russian coal	Low-ash coal C	Olive	Wood
Ash	*12.6*	*3.3*	*5.7*	*2.5*
SiO_2	60.1	48.7	32.1	40.7
Al_2O_3	24.0	24.7	6.6	8.1
Fe_2O_3	6.0	13.8	4.9	3.8
CaO	4.1	4.6	12.4	28.6
MgO	1.1	3.6	12.2	4.1
K_2O	3.0	2.1	18.9	6.8
Na_2O	0.4	0.6	0.4	1.1
TiO_2	1.2	1.0	0.2	1.1
MnO	0.1	0.0	0.0	3.6
P_2O_5	0.0	0.7	12.2	2.1

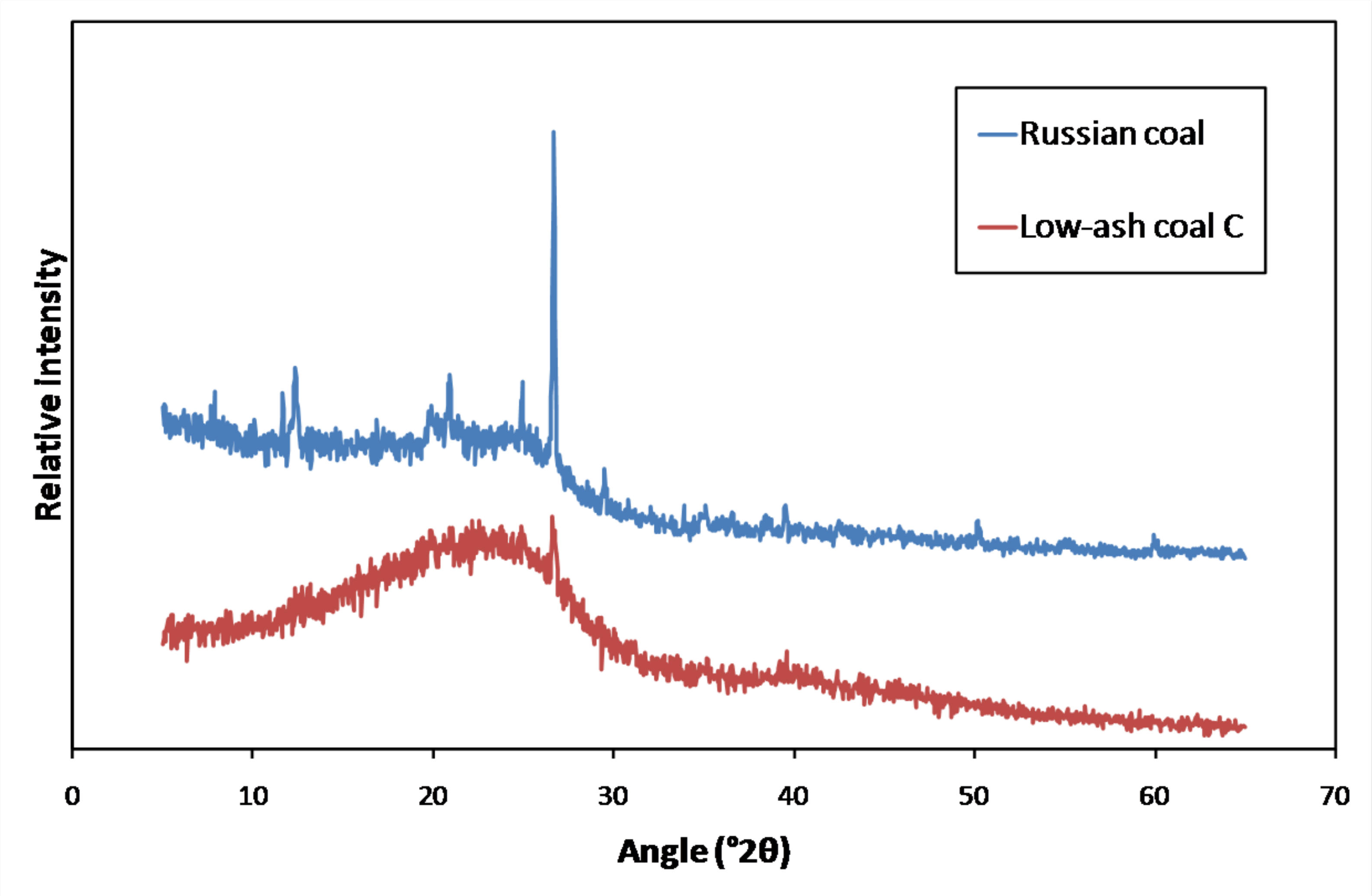
Indonesian low-ash coals
Ash contents and chemistries (wt%)

Ash	*1.9*	*3.0*	*3.2*	*3.3*	*4.4*
SiO_2	38.6	42.5	42.9	48.7	53.6
Al_2O_3	18.5	19.2	18.8	24.7	13.2
Fe_2O_3	21.1	19.1	17.2	13.8	15.5
CaO	14.9	12.3	13.4	4.6	8.8
MgO	3.8	3.0	3.2	3.6	4.9
K_2O	1.0	1.2	1.5	2.1	1.3
Na_2O	0.3	0.8	1.2	0.6	1.9
TiO_2	1.1	1.2	1.1	1.0	0.6
BaO	0.3	0.2	0.2	0.1	0.2
Mn_3O_4	0.3	0.2	0.2	0.0	0.0
P_2O_5	0.1	0.2	0.3	0.7	0.0

Ash compositions for Indonesian low-ash coals



XRD of Russian and low-ash coals



Summary of previous work on coal-biomass blends

Addition of biomass increased the ash retention index and the degree of sintering of coal ash deposits, and these effects increased with the level of biomass addition.

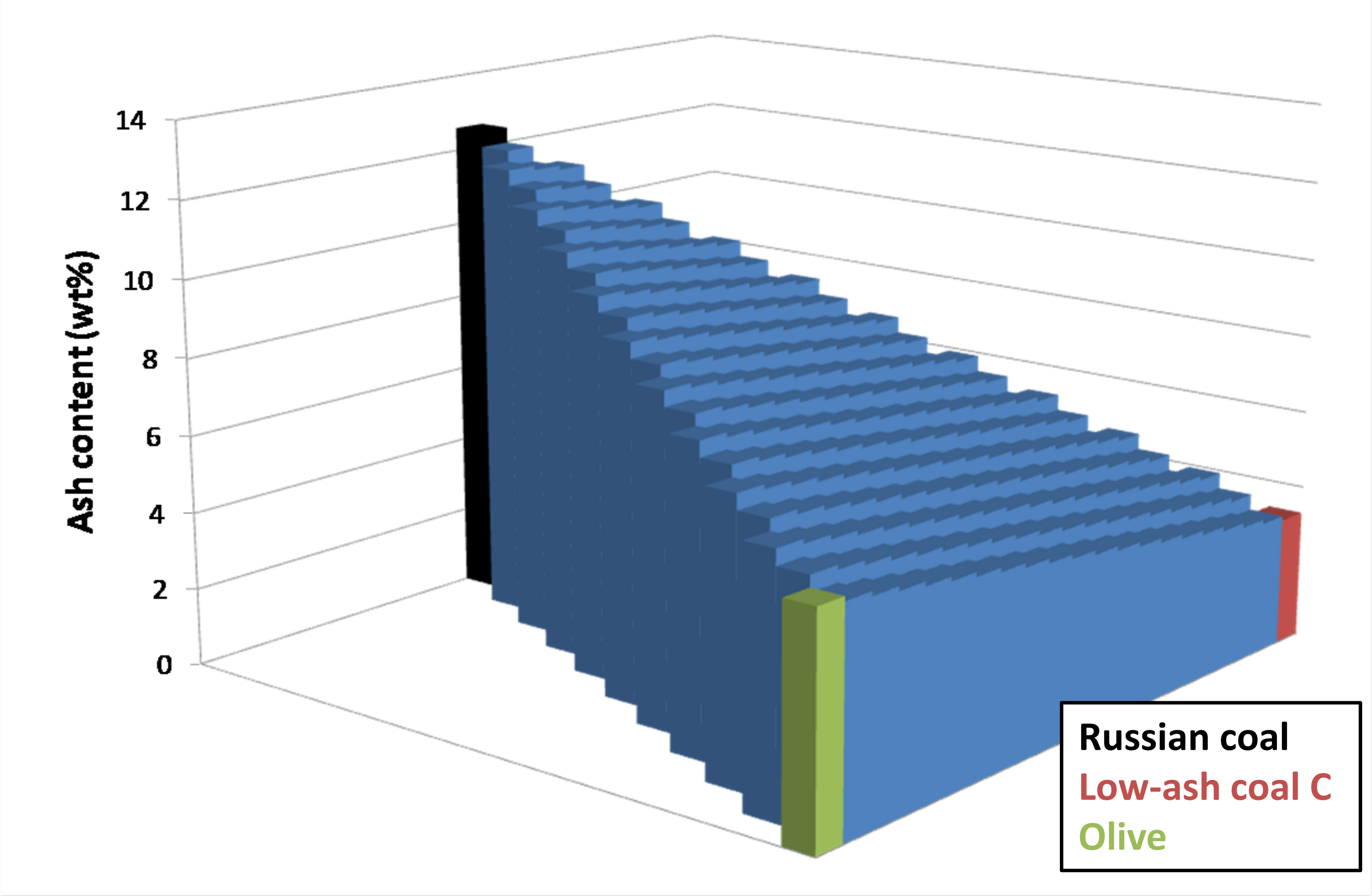
Biomasses produced increasing ash retention in the order:

processing by-products < grasses < cereals < woods

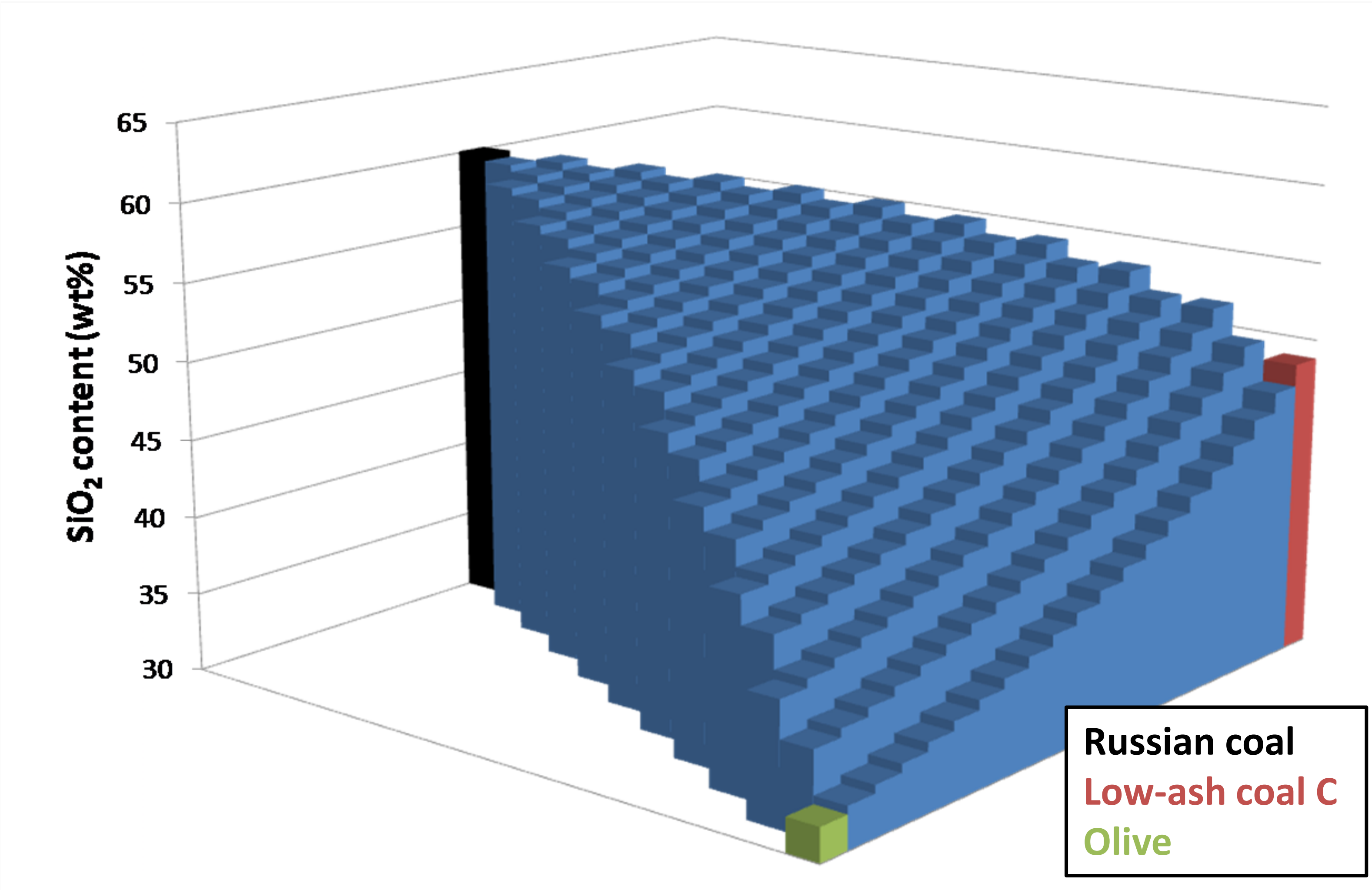
and deposit sintering decreased in the same order.

The deposition effects were smaller than calculated, probably because the vaporised alkalis from the biomass ash had only partially condensed on the deposits.

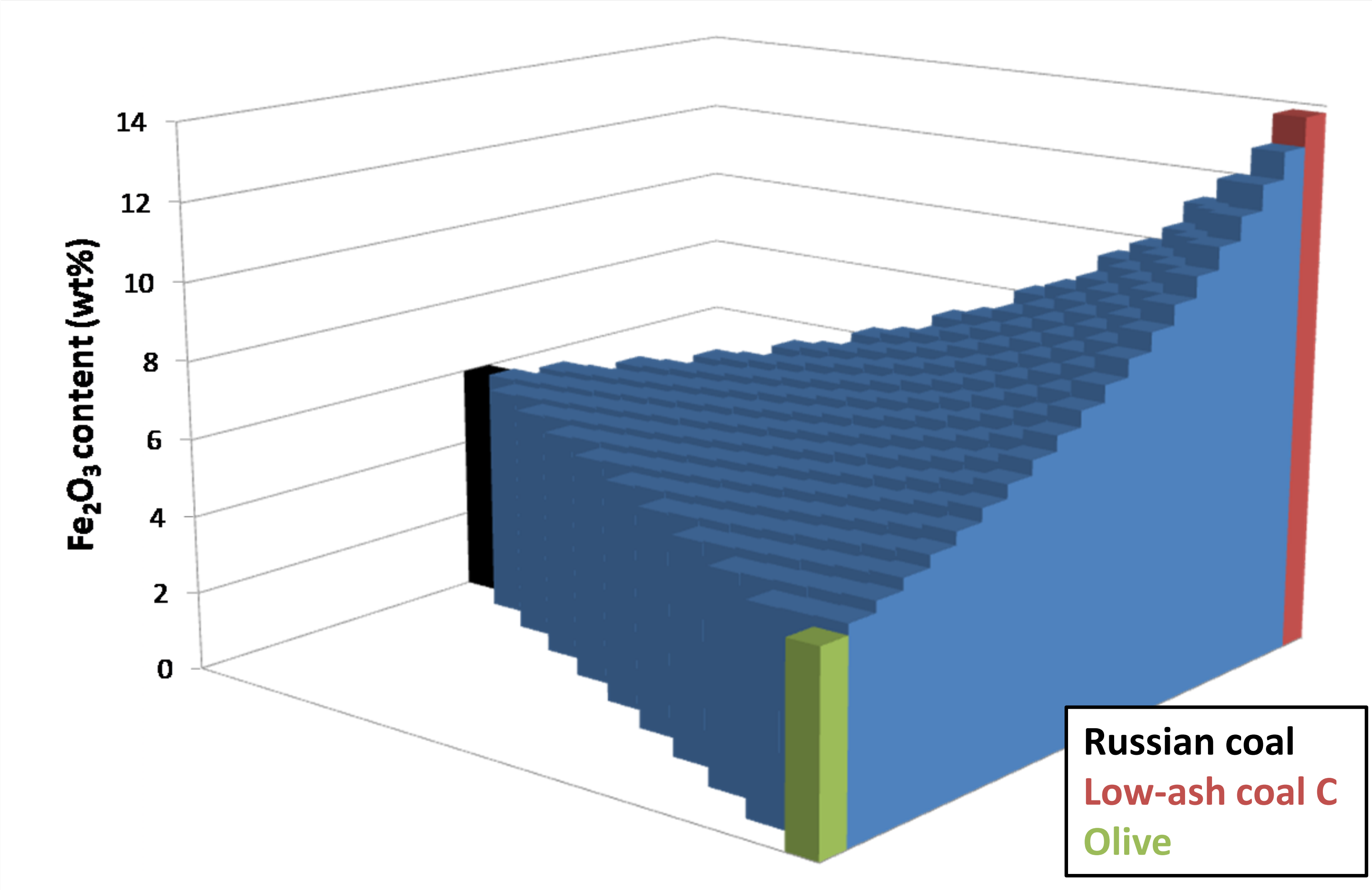
Ash content
Russian – Low-ash coal C – Olive



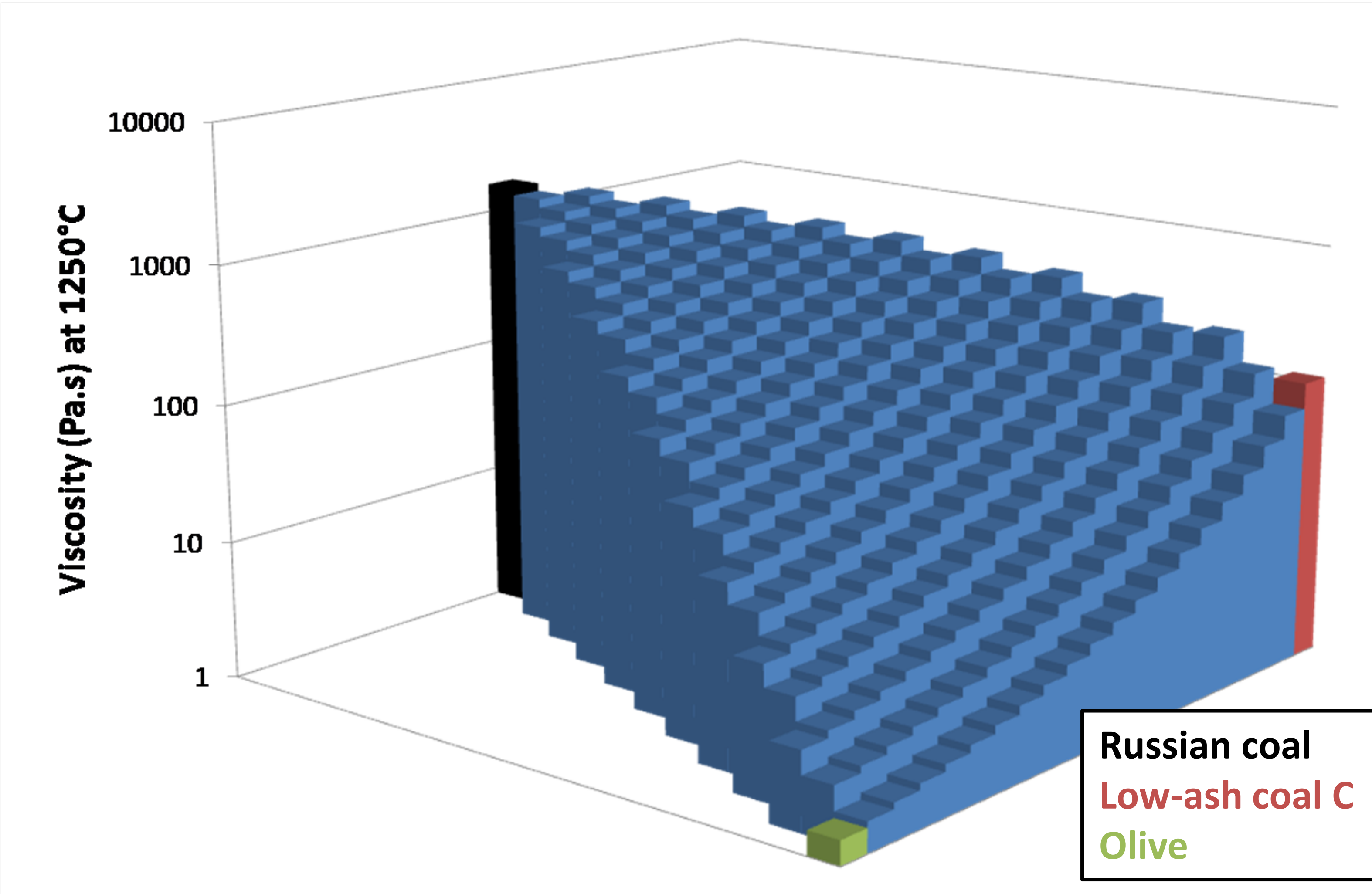
Silica content of ash
Russian – Low-ash coal C – Olive



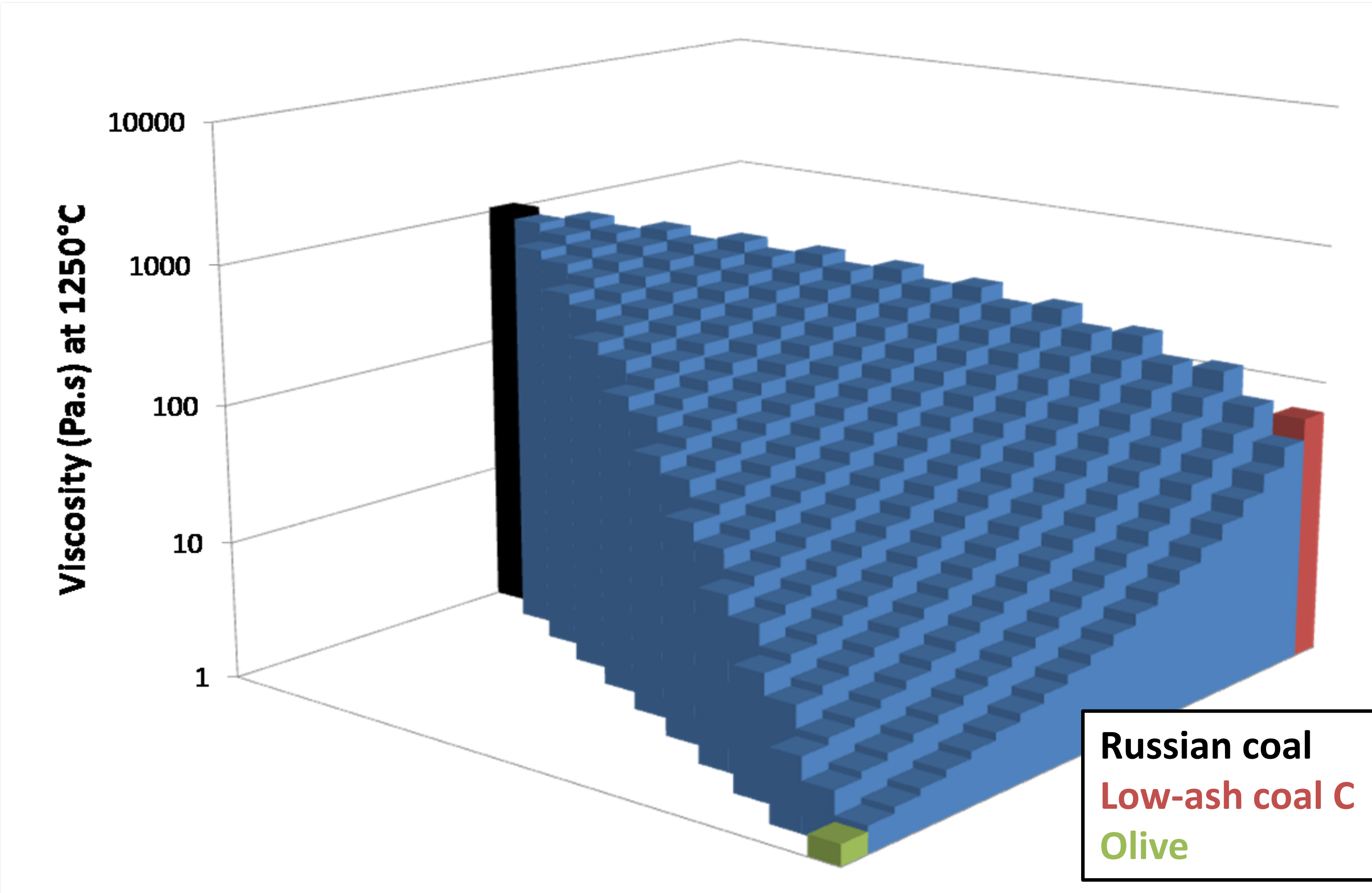
Iron oxide content of ash
Russian – Low-ash coal C – Olive



Calculated ash viscosity under 'oxidising' conditions Russian – Low-ash coal C – Olive



Calculated ash viscosity under 'reducing' conditions
Russian – Low-ash coal C – Olive

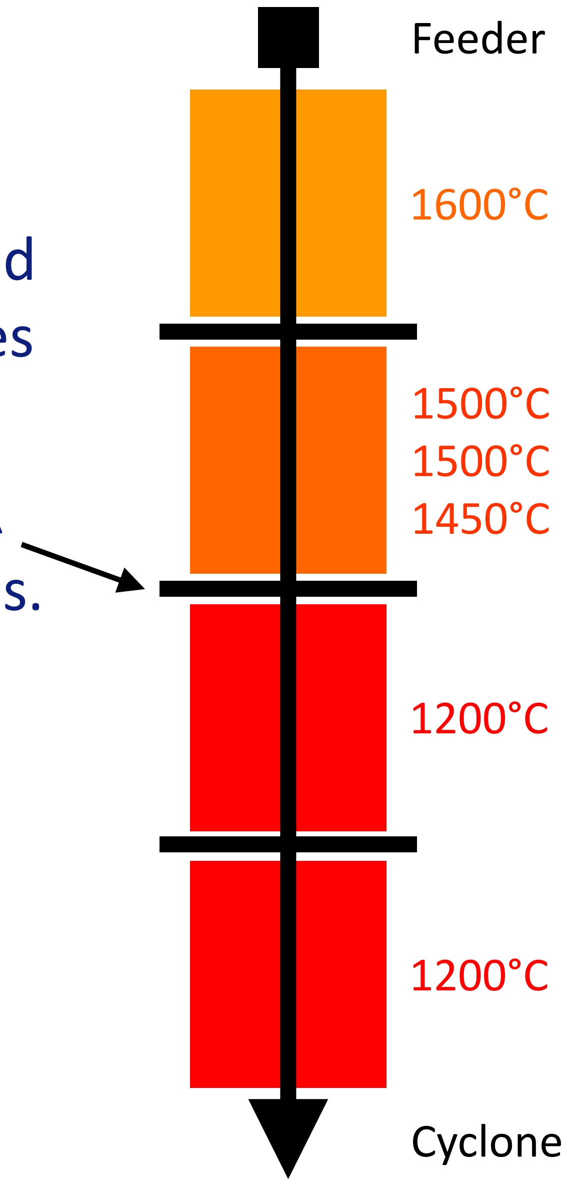


EFR deposition trials

Olive and wood were shredded to <1mm and blended, at 25 wt% of the fuel, with mixtures of Russian and low-ash coal.

The fuel blends were combusted on the EFR and deposits were collected on mullite tubes.

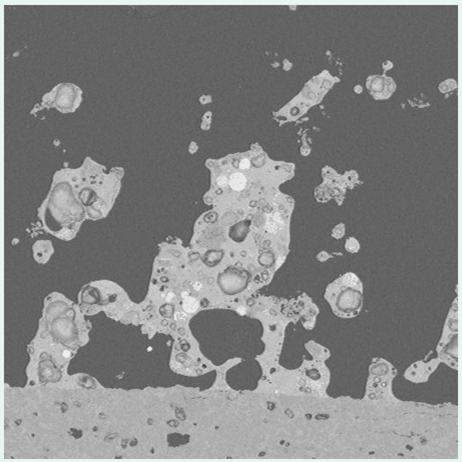
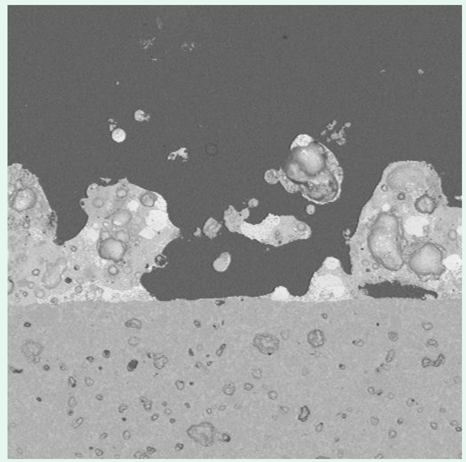
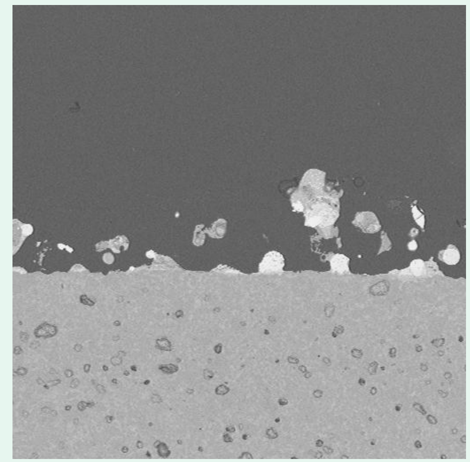
Ash retention indices were calculated, and deposits photographed. Deposit cross-sections were prepared, microstructures analysed and chemical compositions measured.



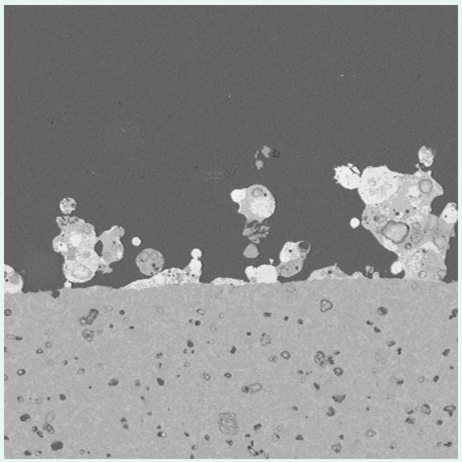
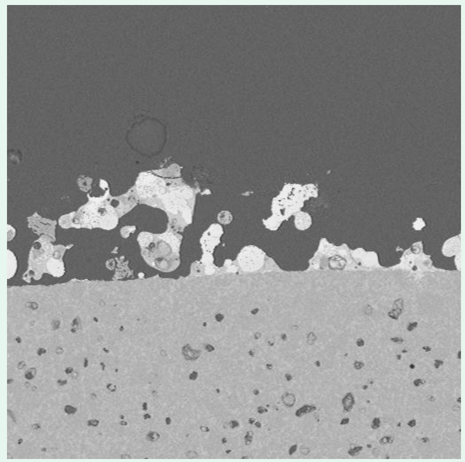
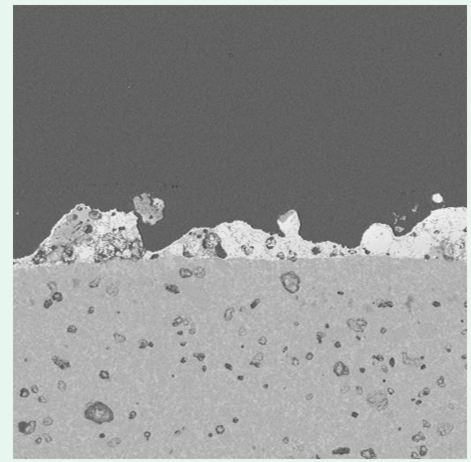
Photographs of EFR deposits
Russian – low-ash B coal blends

Proportion of coal that is low-ash (wt%)					
0	20	40	60	80	100
					

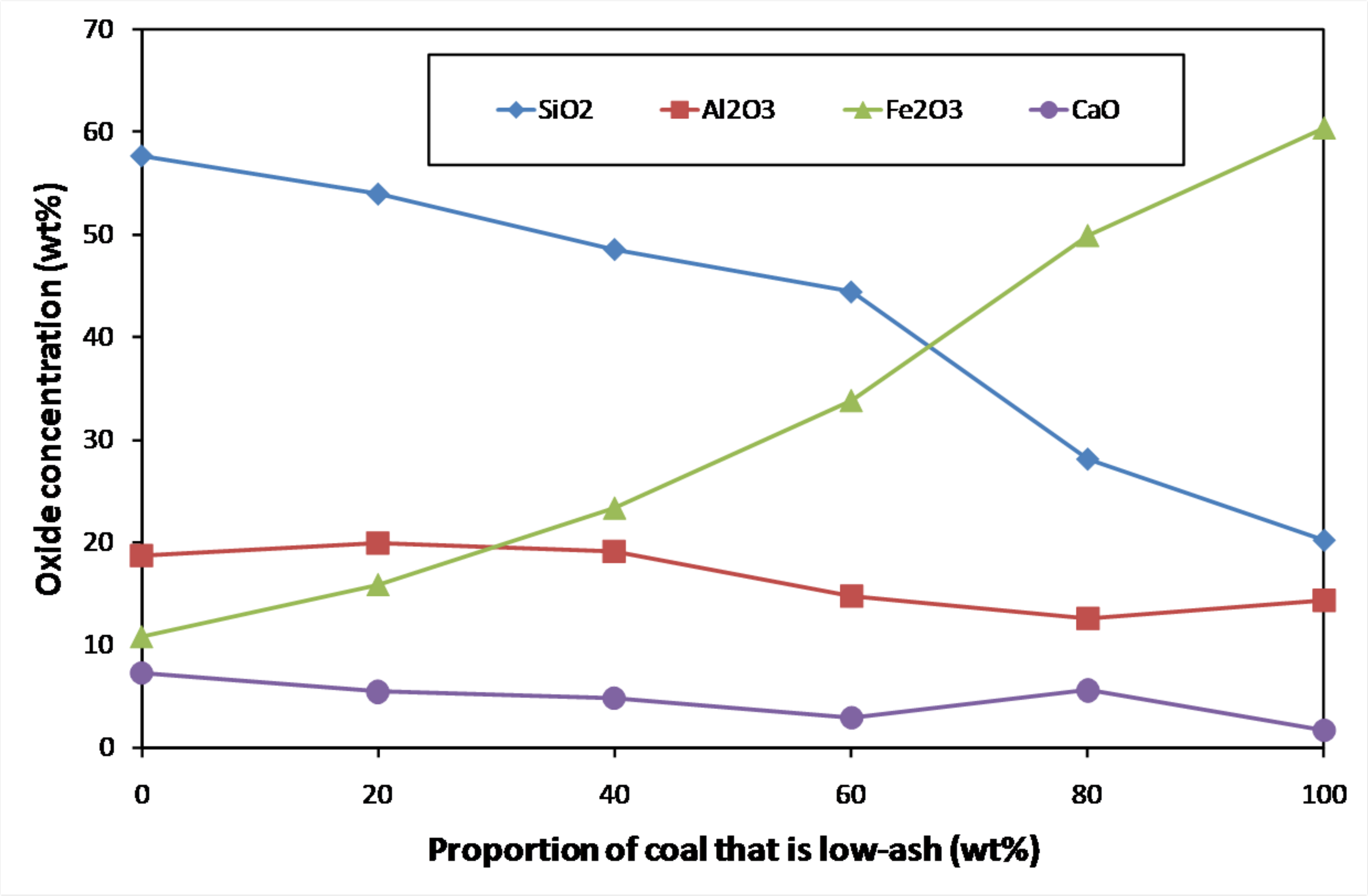
Cross-sections through EFR deposits
Russian – low-ash B coal blends 1

Proportion of coal that is low-ash (wt%)		
0	20	40
		

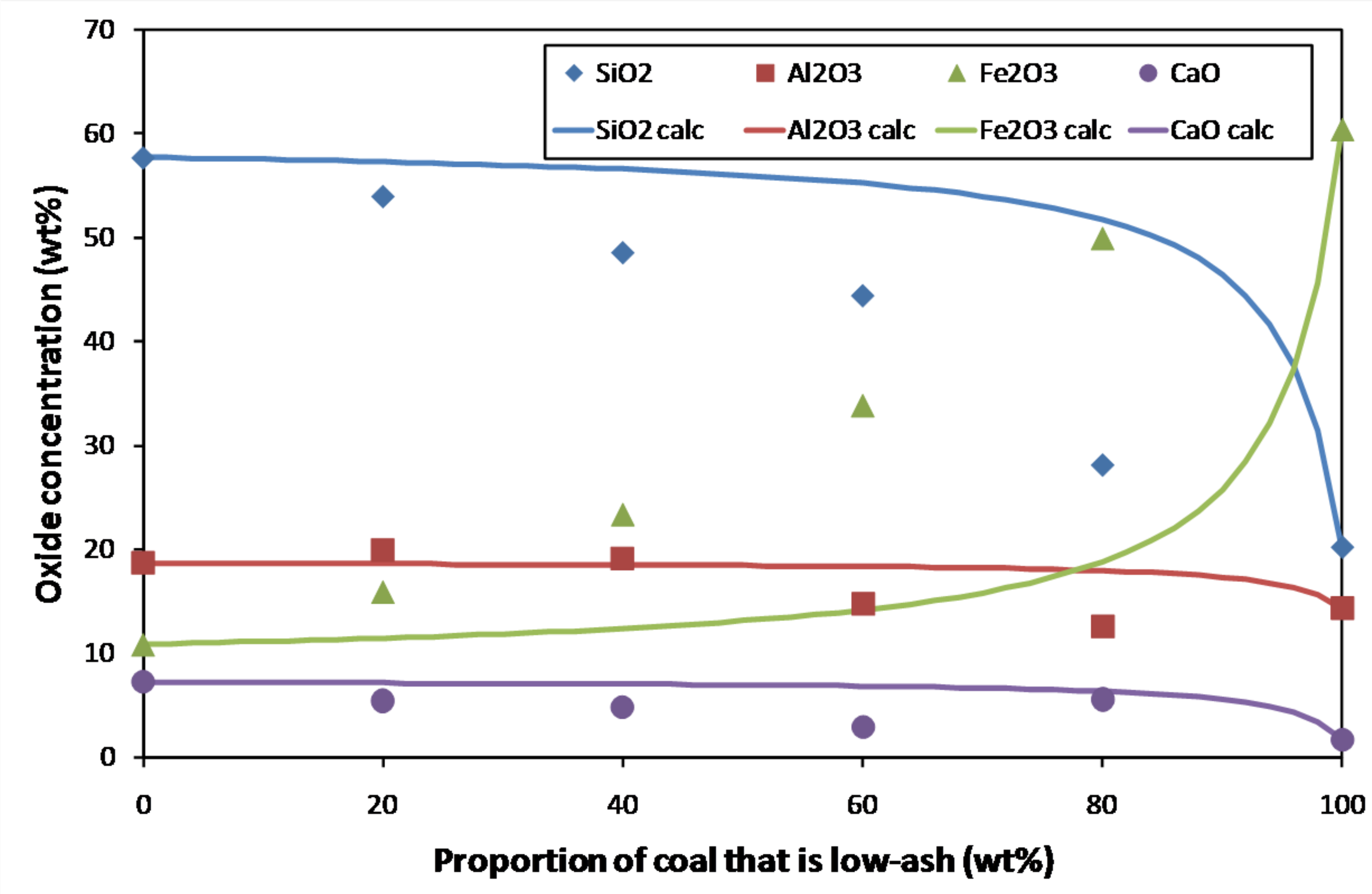
Cross-sections through EFR deposits Russian – low-ash B coal blends 2

Proportion of coal that is low-ash (wt%)		
60	80	100
		

Measured chemical compositions of probe deposits Russian – low-ash B coal blends



Calculated chemical compositions of probe deposits Russian – low-ash B coal blends



Indonesian ‘low-ash’ coal B

High-temperature ashing confirmed that the sample of Indonesian ‘low-ash’ coal B had an ash content of 11wt%, rather than the expected 1-2wt%.

The experimental samples and results obtained from mixtures involving ‘low-ash’ coal B do not contribute towards the objectives of this project.

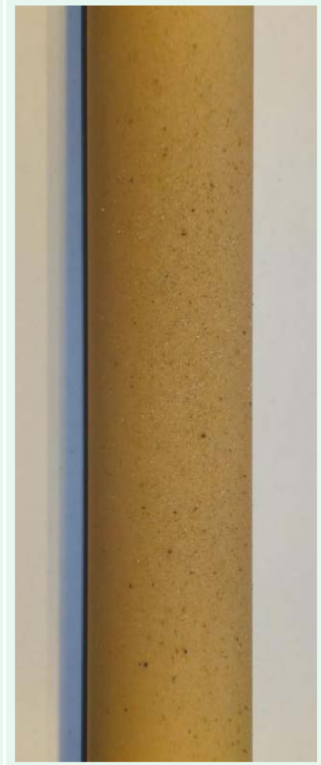
The abstract on *Ash deposition from co-firing biomass with low-sulphur coals* was withdrawn from ICCST 2007.

Experimental work and sample characterisation halted until a new sample of Indonesian low-ash coal (C) was acquired.

Run lengths (minutes) of EFR trials

Biomass added	Proportion of coal that is low-ash (wt%)				
	0	25	50	75	100
None	39	27	22	31	28
25% Olive	27	27	28	30	27
25% Wood	41	48	50	47	43

Photographs of EFR deposits
Russian – low-ash C coal blends

Proportion of coal that is low-ash (wt%)				
0	25	50	75	100
				

Photographs of EFR deposits
Russian – low-ash C coal blends with 25wt% Olive

Proportion of coal that is low-ash (wt%)				
0	25	50	75	100
				

Photographs of EFR deposits
Russian – low-ash C coal blends with 25wt% Wood

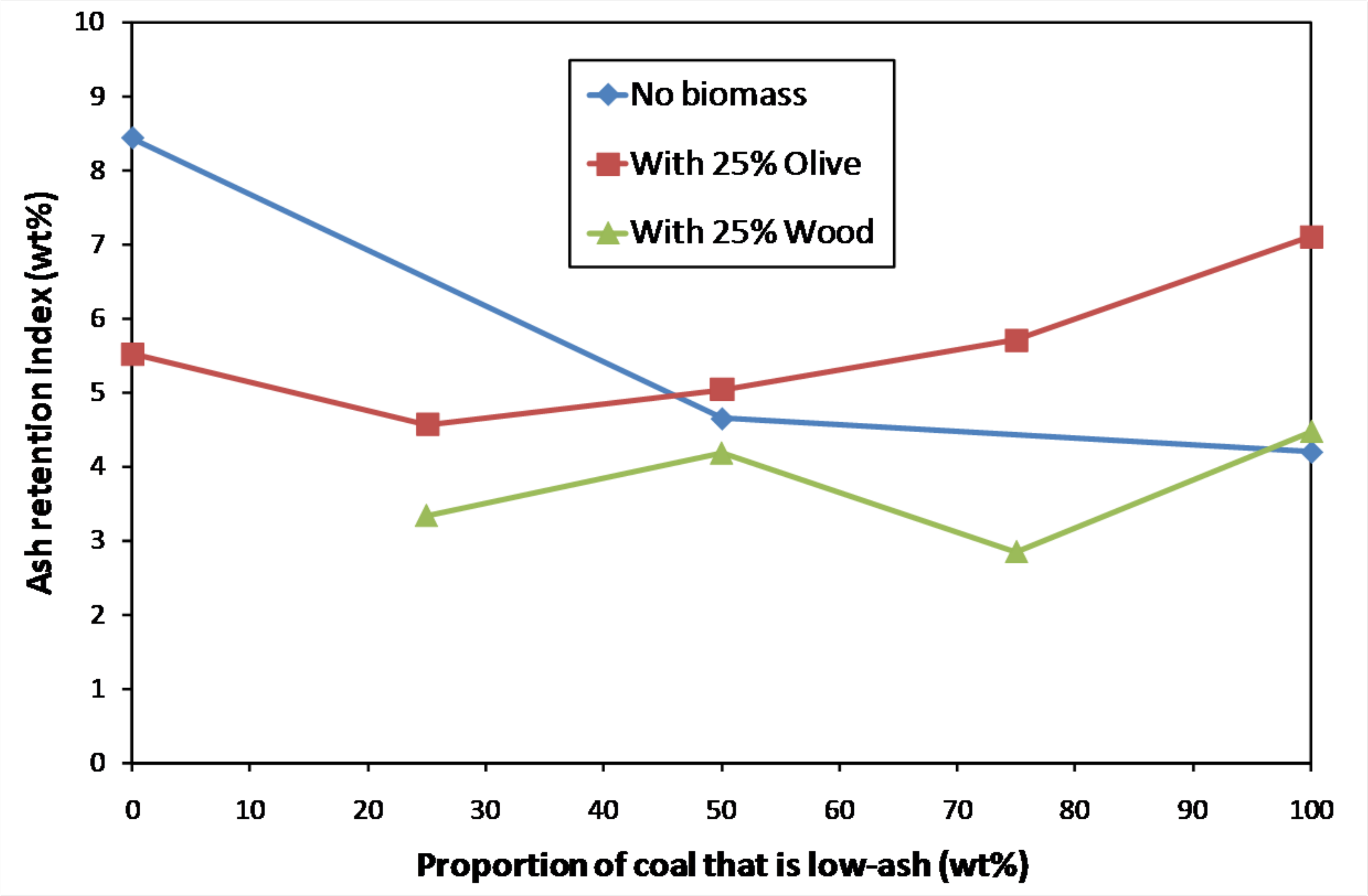
Proportion of coal that is low-ash (wt%)				
0	25	50	75	100
				

Ash retention indices for EFR trials

Biomass added	Proportion of coal that is low-ash (wt%)				
	0	25	50	75	100
None	8.4	*18.0*	4.6	*18.9*	4.2
25% Olive	5.5	4.6	5.0	5.7	7.1
25% Wood	*29.3*	3.3	4.2	2.8	4.5

Ash retention index – *the proportion (wt%) of incident ash retained on the deposition probe.*

Retention of fuel ash by probe deposit
Russian – low-ash C coal blends, with biomass



Summary of EFR deposits

As the proportion of low-ash coal increased, ash retention:

- Without biomass – did not increase significantly
- With 25wt% wood – did not increase significantly
- With 25wt% olive – increased slightly

The degree of deposit sintering appeared to increase slightly as the proportion of low-ash coal increased. Deposits with 25wt% olive were more highly-sintered than all the other deposits.

Additions of low-ash coal appear to have less impact on ash behaviour than similar (wt% fuel) biomass additions.

Ash sintering experiments

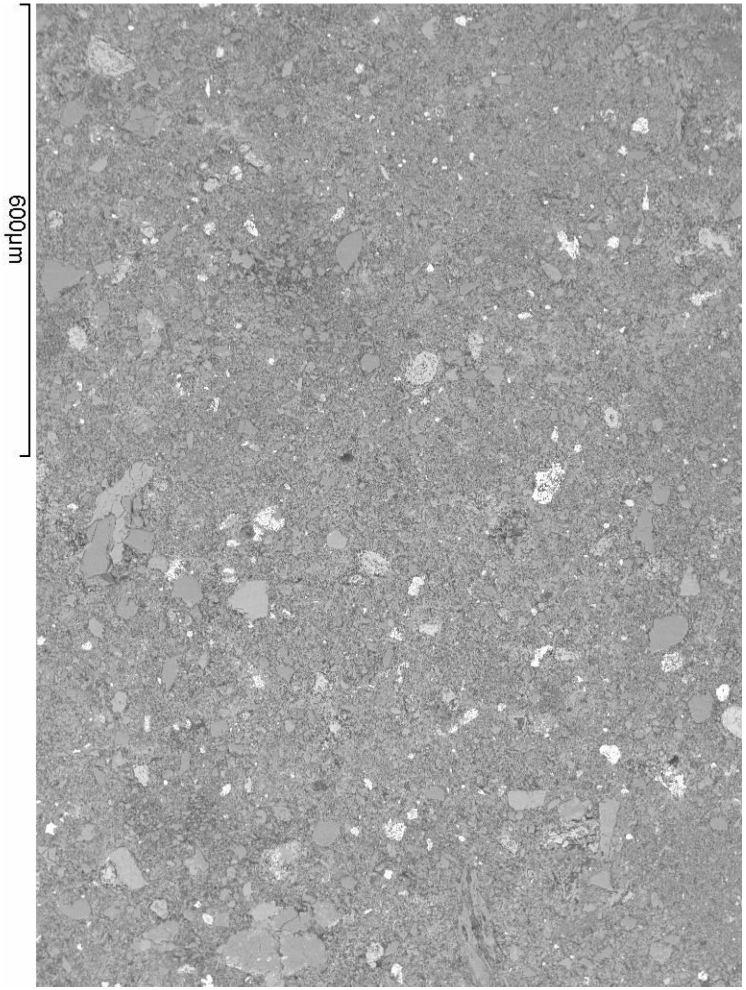
High-temperature ashes were prepared (815°C for 24hrs) from Russian coal, low-ash coal C, olive and wood.

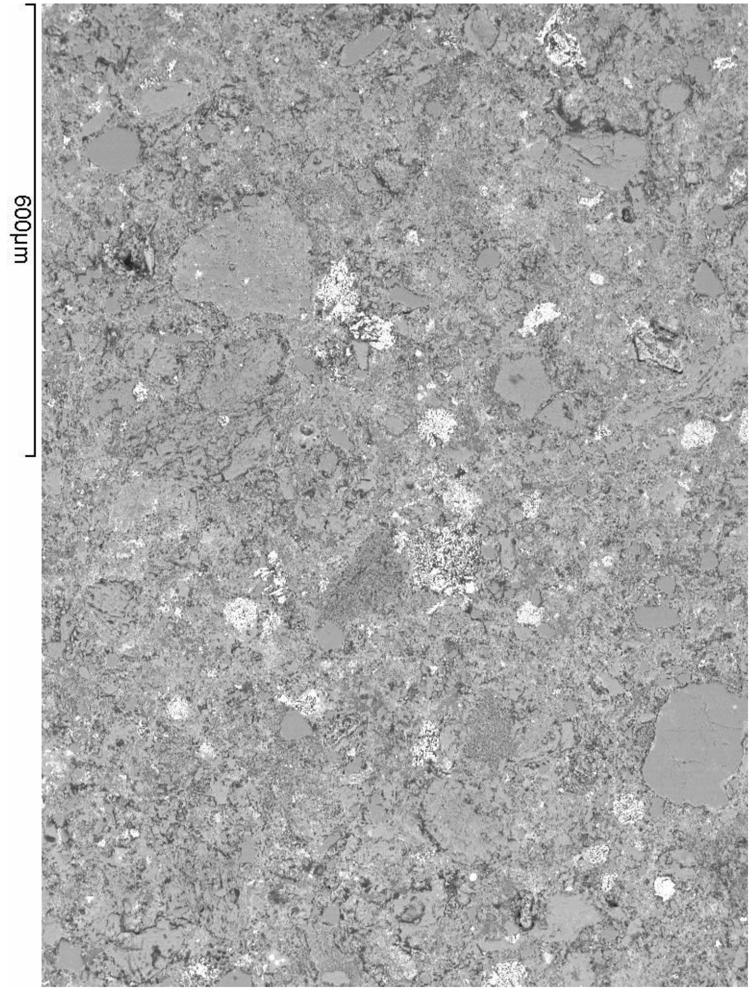
Mixtures were prepared from Russian – low-ash C coal HTA (0, 25, 50, 75 & 100wt%). Pellets were prepared from pure coal HTA mixtures, and from coal HTA mixtures with 25wt% olive HTA and 25wt% wood HTA.

Pellets were sintered (950°C for 24hrs) in air and in nitrogen. A polished cross-section was made from part of each pellet; the rest was ground for XRD analysis.

Pellets and results from sintering experiments involving 'low-ash' coal B have been discarded.

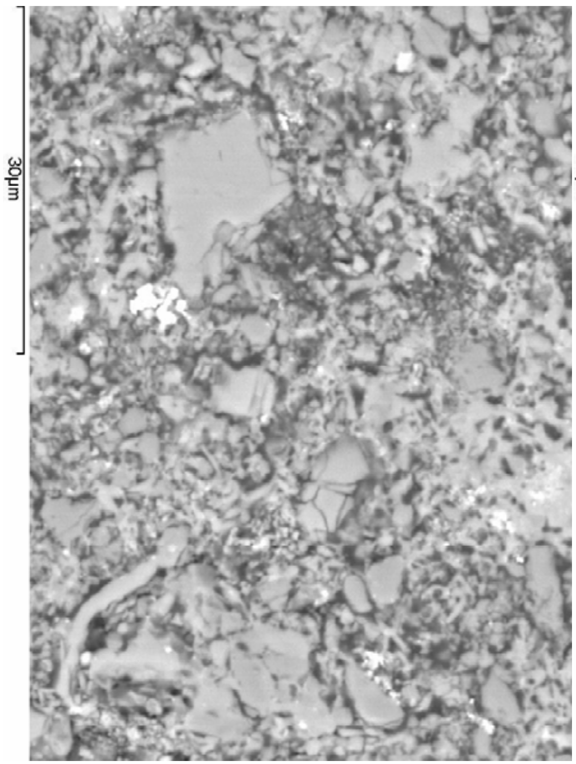
Cross-sections through heat-treated HTA pellets Russian coal and low-ash coal C (low magnification)



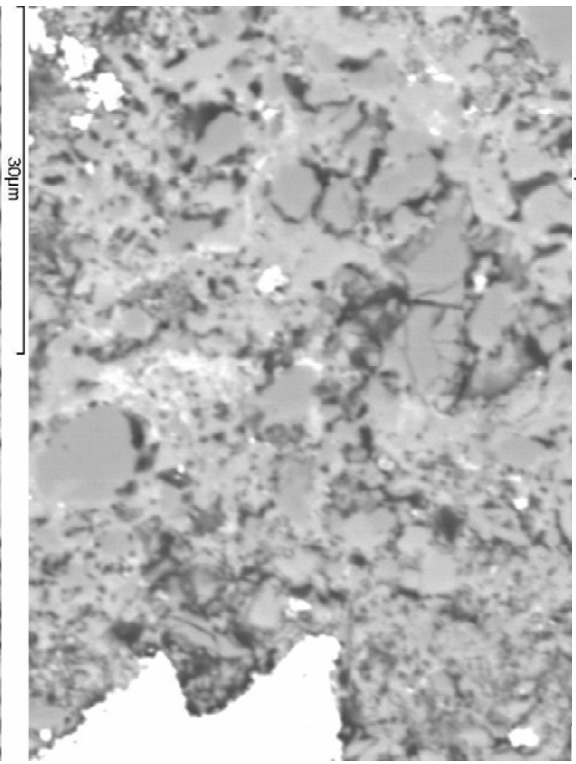


Cross-sections through heat-treated HTA pellets
Higher magnification

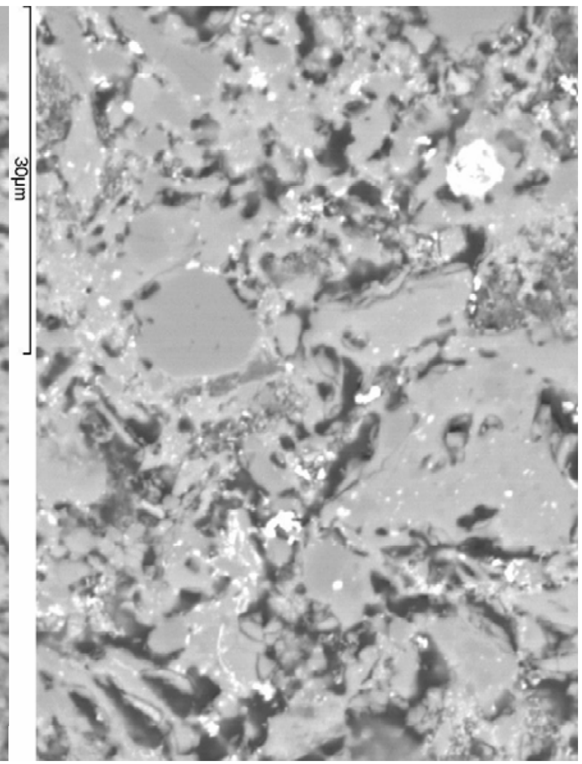
Russian coal



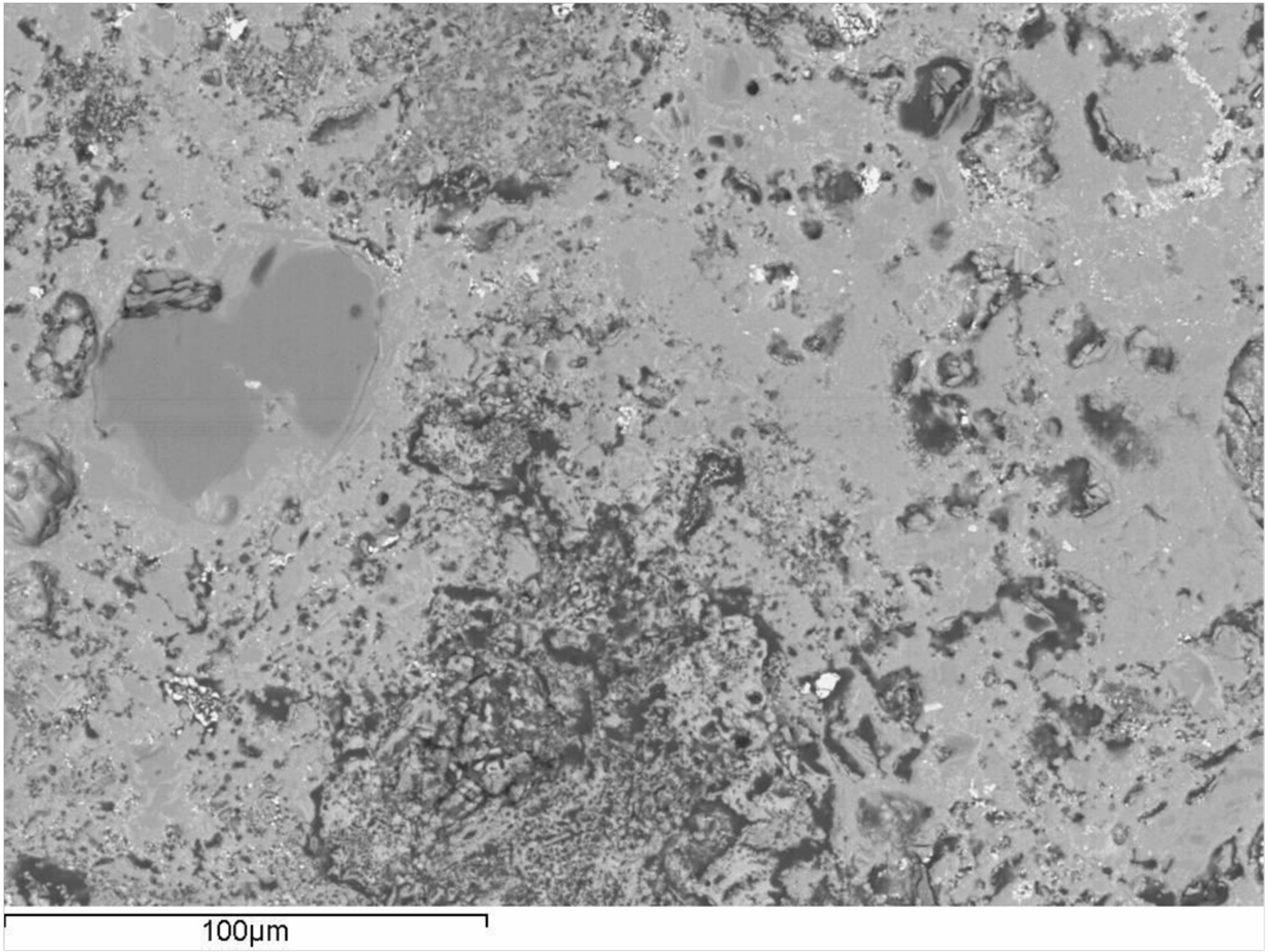
with 25wt% wood



low-ash coal C



Cross-section through heat-treated HTA pellet
Low-ash coal C with 25% Olive (mid. magnification)



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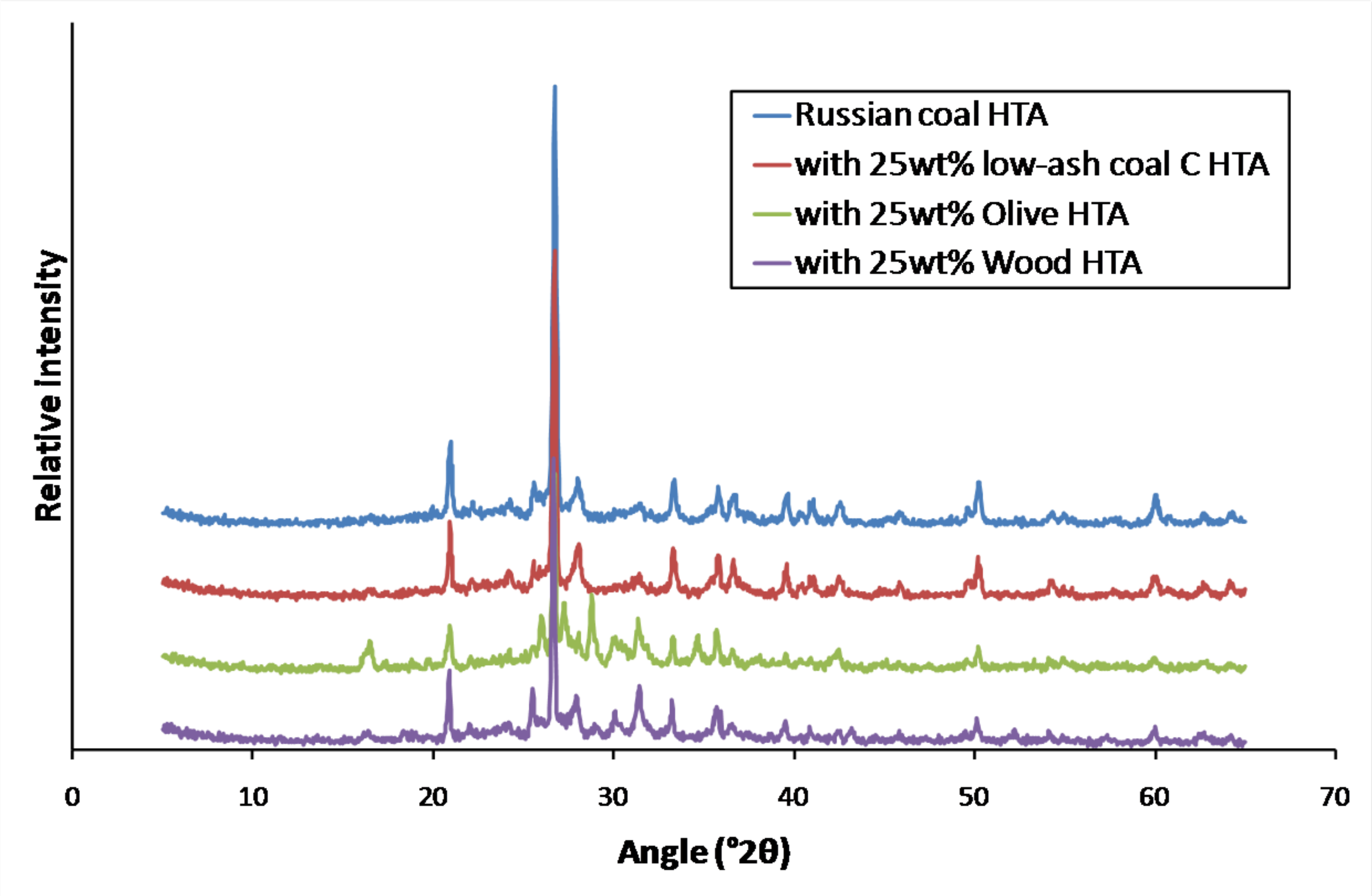
XRD spectra of sintered HTA pellets
Russian coal and 25% blends



Summary of sintering experiments

Generally, on heat-treating the HTA mixtures:

- Limited sintering occurred
- The mullite/quartz ratio increased
- Anhydrite ($CaSO_4$) disappeared

Compared to the Russian coal pellet, the 25% blend pellets:

- Showed slightly more sintering (especially the 25% olive)
- Contained the same crystalline phases, although the 25% olive contained an additional phase

No significant difference has been observed between pellets heat-treated in air and in nitrogen.

Provisional conclusions
Impact of low-ash coals

Experimental and theoretical work suggest that the addition of Indonesian low-ash coal to typical feed coal for UK power stations does not increase the proportion of ash that deposits, but may slightly increase the degree of sintering in the resulting deposit.

Additions of low-ash coal will probably have less impact on ash behaviour than similar (wt% fuel) biomass additions.

In three-way mixtures of coal, low-ash coal and biomass, the low-ash coal should be modelled as a separate component – with lower ash content than the main coal, and different ash chemistry from the biomass.

Provisional conclusions
Impact of deeply-staged combustion

Experimental work and viscosity calculations suggest that moving from oxidising to reducing conditions in the later stages of combustion would probably not significantly affect ash behaviour for mixtures of low-ash coal and biomass with typical power station feed coal.

The higher iron oxide concentrations in the ashes of low-ash coals suggest a possible impact on ash behaviour during deeply-staged combustion, but this would probably be minimised by their low ash contents and by co-firing with biomass.

Remaining activities

Complete characterisation of EFR deposits and sintered HTA pellets

Complete final report

Acknowledgements

- Dr Gerry Riley at RWE npower
- Prof. Jim Williamson at Imperial
- Funding from BCURA and BERR (views are solely those of the author)