

# Comparison of Waste from PF Utilities and Transitional Technologies using Australian Coal

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## ABSTRACT

Australia produces approximately 13 million tonnes per annum of pf-combustion wastes (ash) from coal-fired power stations. A small proportion is utilised but most is deposited in wet ash dams or dry repositories. The nature of this waste stream is expected to change as a consequence of constraints on the emission of carbon dioxide and the adoption of transitional power generation technologies such as fluidised bed combustion, oxy-fuel combustion and integrated gasification combined-cycle processes using slagging gasifiers. The leaching properties of the major solid waste streams from each of these (transitional) processes have been compared with those of typical fly ashes from conventional pf power stations using Australian bituminous thermal coals. Batch leaching tests were done at two liquid:solid ratios (3.5:1 and 20:1) and the results compared to similar pf ash studies. It is concluded that most trace elements were leached from the fly ash and bottom ash of FBC systems at similar concentrations to those present in equivalent leachates from ash of conventional power stations (lower concentrations of Cd, Co, Ni and Zn were leached from the waste of two FBC power stations). Trace elements were also leached in similar proportions from fly ashes derived from the same coals fired under air-fired (conventional) and oxy-fuel combustion conditions. Some of the trace elements (e.g. B, Cr, Mn, V and Zn) in the gasifier slags were not leached as readily as those in fly ash from conventional power stations; others (e.g. As and Se) were leached at similar concentrations from both types of ash materials. The significance of these findings is discussed.

## INTRODUCTION

Currently, Australia produces approximately 13 million tonnes per annum of pf-combustion by-products of which only a small proportion is utilised, most being deposited in wet ash dams or dry repositories. Due to constraints on the emission of CO<sub>2</sub> and the adoption of transitional power generation technologies (oxy-fuel pf, IGCC and FBC) the nature and amount of coal combustion products produced in Australia (and elsewhere) is likely to change significantly over time, with possibly different environmental impacts being involved.

To identify the potential changes in environmental impact from these new technologies, a study was undertaken in order to evaluate the differences between the waste products produced by transitional power generation technologies and the fly ash (and bottom ash) produced by conventional coal-fired power stations. Any differences found may indicate advantages associated with the environmentally sound disposal of the waste streams from transitional technologies, or alternatively that transitional wastes might have deleterious properties that impact adversely on the options for their disposal or use.

## **EXPERIMENTAL**

Samples of the major waste streams were obtained from either operational full-scale plants or pilot plants, as discussed more fully below. The chemical and mineralogical compositions of these samples were determined by X-ray fluorescence spectrometry (XRF) and X-ray diffractometry (XRD), with the latter using procedures described by Ward and French <sup>1</sup> to determine the amorphous content. The samples were also analysed for a number of trace elements using a variety of different techniques.

In order to evaluate the potential release of environmentally significant elements during storage or use, the samples were extracted with MilliQ water, providing data that could be compared with the results of previous leaching studies on fly ash from conventional pulverised coal fired power stations <sup>2-3</sup>. The samples (ashes or slags) were leached for three days in distilled water at liquid:solid ratios of 3.5:1 and 20:1 following the procedure described by Jankowski et al <sup>2</sup>. The leachates were then filtered through 0.22 µm Millipore cellulose acetate membrane filters. An unacidified portion of each filtrate was analysed for pH and conductivity. Another portion of each filtrate was acidified to approximately 1% v/v AR grade concentrated nitric acid and the concentrations of trace elements determined using appropriate techniques; for most elements that was ICP-AES and ICP-MS.

The following materials were investigated:

Fluidised bed combustion residues – samples of silo ash (fly ash) and bottom ash (bed material) from FBC power stations in Australia and in Japan.

Oxy-fuel combustion ashes – coal feeds and pairs of ash samples from air-fired and oxy-fuel combustion tests conducted on three Queensland coals in Japan.

IGCC slags – samples obtained from entrained-flow gasification trials completed at the Siemens' test facility in Germany on a range of Australian coals. The received slag samples were air dried before analysis and the leaching tests. As well as these samples, a gasifier slag from the Buggenum plant in The Netherlands was also included in the study.

## **RESULTS AND DISCUSSION**

The results obtained from the analyses of the transitional waste products, and also those obtained from the leach tests, are considered in this section. These are then

compared with the data obtained on fly ash from the same or similar Australian coals combusted in conventional pf-fired power stations.

## **FBC Ashes**

The mineralogy of the FBC ash samples (both fly ash or silo ash and bottom ash) is characterised by the abundance of calcium-rich phases, e.g. calcite, calcium sulphates (anhydrite and gypsum) and anorthite,  $\text{CaAl}_2\text{Si}_2\text{O}_8$  (Table 1). This is particularly so in the ash from the Japanese PFBC plant. The high calcium content is also evident in the data on the chemical composition (Table 2). Although lower proportions of Ca are found in the ashes from the Australian FBC station, compared with the ash from the Japanese station, the Ca concentrations are still higher than seen in pf ashes from Australian bituminous coals. Of the trace elements in the samples Mo and Ni tend to be lower (Table 3) than in pf ashes. The leachates are characterised by high pH and conductivity, together with elevated levels of Ca, Cr, and Pb. Si, As, Cd, and Cu values tend to be lower than in typical pf ash leachates.

The presence of high levels of Ca (as well as Ba and Sr), arising as a consequence of the addition of limestone to the bed material in FBC systems, is the major difference between ashes from FBC systems and ashes from conventional coal-fired power stations. Obviously there is a greater mass of waste ash from FBC systems per tonne of coal because limestone is added to the coal bed.

It is not evident from the data in Tables 4 and 5 that ashes from FBC are “better environmentally” than ashes from conventional pf-fired power stations. However, the greater concentrations of Ca and of the associated mineral phases indicate that FBC ashes would have greater neutralisation capacity, and therefore would be suited for backfilling at mine sites where acid mine drainage (AMD) may be a problem. Of interest is the very low concentration (below detection limit) of Mg in the leachates of the ash products from the Japanese PFBC plant. Presumably this reflects the presence of relatively insoluble magnesium carbonate.

## **Ashes from Oxy Fuel Systems**

As seen from data on relevant pairs of ash samples (Table 1), the ashes produced in the oxy-fuel tests are very similar mineralogically to the ashes from the same coals used in conventional pf power stations. Although there are no clear differences between the mineralogy of the air-fired and oxy-fuel ashes, both are distinguished from the FBC and IGCC ashes by their higher mullite contents. Iron oxide contents also tend to be slightly higher (Table 1). Although there are no consistent differences between the air and oxy-fuel fired pairs, a higher glass content is found in the ash from the air-firing of coal C, along with associated lower concentrations of quartz and mullite. There are similar but less marked differences in the pairs of ashes from coal A. The presence of sylvite (KCl) in the ashes from coal C is intriguing and is possibly related to the higher chloride and lower mineral matter in the feed coal. An unusual feature is the occurrence of minor proportions of the clay minerals illite and kaolinite, which would not have been expected to survive the temperatures typically found in pf combustion systems.

As expected, the elemental compositions of each of the paired ashes are also similar (Table 2), but with two significant differences. The concentrations of Fe and Si vary in the ash pairs of coals A and C. This may in part be the explanation for the variation in the inorganic phases seen within these two ash pairs.

The trace element concentrations are similar to those found in the FBC and IGCC ashes, apart from slightly higher levels of Pb, U, V, and Zn. The concentrations of the trace elements in each of the paired ashes are also remarkably similar (Table 3), with few exceptions, one being the high Cr, found in the oxy-fuel ash of coal C and the other high Th in the oxy-fuel ash of coal B. There is no obvious explanation for these observations.

The pH, conductivity and trace element concentrations of each of the leachates are shown in Tables 4 and 5. In comparison to the FBC and IGCC leachates, the leachates from the oxy-fuel ashes appear to have higher contents of K, Si (only in the 3.5:1 leaching tests), As, Co, Cu, Mn, Mo, Ni, Sb, Se, V and Zn with lower Pb. The concentrations of trace elements in the leachates are also generally similar in the ashes from each pair (Tables 4 & 5). However, some differences do exist: the leachates of the air-fired ashes from coal A have higher contents of K, As, Mo, V, and Zn (less pronounced or absent in the case of As, Mo, and V in the 20:1 leachate), high occurs V in the oxy-fuel leachate of coal B; high Al, Mn, Ni and Zn are noted in the oxy fuel leachate of coal C. Again, there is no obvious reason for the observed behaviour. With the above exceptions most trace elements, including the environmentally important ones such as Cd and Se, are leached in similar concentrations. The general observation is that there is little difference between the leaching behaviour of ashes obtained from conventionally fired coal and from the same coal fired in an oxy-fuel boiler. However, there were some differences observed in the analyses of individual leachates from each pair for a limited number of specific trace elements.

## **IGCC Slags**

The IGCC slags show a considerable variation in the size distribution and morphology, ranging from blocky clinker to fine beds and droplets of glass. This variation is related to factors such as the fusibility of the coal ash, the composition of the mineral matter and the temperature of gasification. All other factors being equal, it is likely that variation in the morphology (i.e. particle size and shape) will have an impact on the leaching characteristics of a particular slag.

The mineralogy of the slags is distinguished by the abundance of amorphous material, with correspondingly lower proportions of the crystalline phases. The observed mineralogical variations (Table 1) provide some evidence for the propensity of each of the coals to produce slags under the conditions of gasification, as shown by the high percentages of amorphous material present. For example, the slags from Test 104 and from Buggenum are completely amorphous. The presence of crystalline mineral phases rather than an amorphous phase is indicative of incomplete melting and subsequently poor slagging. Note also that the slags from Tests 102 and 103 contain high concentrations of carbon, which is obviously another indication of poor gasification. This is further reflected in high LOI values (Table 2).

**Table 1. Ash mineralogy by quantitative X-ray diffraction**

Phase (wt %)	Fluidised Bed Combustion						Air and Oxy-fuel pf						IGCC											
	Aus FBC			Japan PFBC			Coal A		Coal B		Coal C		T100		T101		T102		T103		T104		Bugg	
	Silo ash	Bottom ash	Fly ash	Bottom ash	Fly ash	Bottom ash	air-fired	oxy-fired	air-fired	oxy-fired	air-fired	oxy-fired	air-fired	oxy-fired	T100	T101	T102	T103	T104	T104	T104	T104	Bugg	
Quartz	25.8	30.0	3.7	9.8	3.7	9.8	12.8	10.9	3.8	3.4	3.4	7.2	8.5	0.1	1.1	0.8	0.1							
Cristobalite (?)							0.2	0.1			0.2	0.1	0.2											
Mullite	0.9	2.3	6.1				29.2	32.9	32.1	32.8		17.2	22.1			0.9	0.2							
Illite							0.8		1.7															
Kaolinite								0.7		1.3														
Anorthite	0.7	3.7	11.8	4.4										5.4	0.6									
Gehlenite			8.5	6.3																				
Merwinite			6.6	5.0																				
Melilite, sodic			5.8	5.7																				
Hematite	1.0	1.9							0.2	0.0		1.0	0.7											
Maghemite	0.7	0.6	1.0				1.0	1.5	0.7	1.7		1.1	0.9	2.8										
Magnetite	0.3	0.2							3.7	2.0		0.6	0.8	2.5	0.2	0.3								
Hercynite														0.5										
Goethite														3.2	0.2									
Periclase (?)			0.7																					
Lime			3.0	16.7																				
Portlandite			0.6	2.6																				
Calcite	1.6	0.9	3.1	43.6												0.2	0.2							
Anhydrite	0.4	1.2	7.5	5.8																				
Gypsum	3.0																							
Sylvite (KCl)												0.5	1.0											
Carbon																11.7	24.9							
Amorphous	65.5	54.8	41.6				56.0	53.8	57.8	58.9		72.4	65.9	85.5	97.9	86.1	74.6	100.0	100.0	100.0	100.0	100.0	100.0	
	99.9	99.8	100.0	99.9			100.0	99.9	100.0	100.1		100.1	100.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	

**Table 2. Major and minor element chemistry**

Sample	Fluidised Bed Combustion						Air and Oxy-fuel pf						IGCC											
	Aus FBC			Japan PFBC			Coal A		Coal B		Coal C		T100		T101		T102		T103		T104		Bugg	
	Silo ash	Bottom ash		Fly ash	Bottom ash		air-fired	oxy-fired	Air-fired	oxy-fired	air-fired	oxy-fired	air-fired	oxy-fired	air-fired	oxy-fired	air-fired	oxy-fired	air-fired	oxy-fired	air-fired	oxy-fired	air-fired	oxy-fired
wt%																								
C	8.10	0.40		4.50	3.00		0.28	0.61	0.23	0.28		0.56	0.63	1.10	1.70	11.70	21.60	0.90	1.40					
SiO <sub>2</sub>	51.8	58.8		18.8	27.6		64.1	60.9	49.5	48.8		50.6	52.5	41.5	48.2	41.6	34.8	51.1	54.5					
TiO <sub>2</sub>	0.80	0.57		0.35	0.97		1.82	1.91	2.13	2.10		1.19	1.35	0.85	1.13	1.33	1.03	1.68	1.07					
Al <sub>2</sub> O <sub>3</sub>	20.6	23.6		7.9	20.1		29.1	30.8	35.0	35.3		26.4	27.4	21.5	18.9	21.2	21.5	32.1	22.0					
Fe <sub>2</sub> O <sub>3</sub>	4.29	4.05		1.71	3.50		2.72	4.56	11.3	11.3		11.5	9.35	21.5	23.2	13.2	3.16	5.84	6.73					
CaO	3.74	6.37		46.90	32.20		0.63	0.83	1.67	1.66		2.81	2.28	9.94	4.86	7.21	12.80	7.31	14.90					
MgO	0.61	0.77		1.34	2.02		0.46	0.61	1.13	1.12		1.72	1.47	2.80	2.18	0.77	0.93	2.08	1.12					
MnO	0.05	0.04		0.04	0.05		0.04	0.08	0.19	0.18		0.06	0.07	0.12	0.09	0.08	0.03	0.03	0.05					
K <sub>2</sub> O	1.20	1.66		0.53	0.43		0.55	0.41	0.44	0.45		1.49	1.71	0.48	0.45	0.22	0.47	0.60	0.78					
Na <sub>2</sub> O	0.23	0.09		0.72	0.95		0.17	0.16	0.14	0.10		0.79	0.55	1.51	0.58	0.06	0.72	0.96	0.22					
P <sub>2</sub> O <sub>5</sub>	0.41	0.11		0.13	0.29		0.16	0.18	0.25	0.29		0.96	0.78	0.64	0.85	1.52	1.21	0.14	0.16					
SO <sub>3</sub>	1.70	0.70		4.12	6.28		0.28	0.27	0.22	0.22		1.13	1.06	0.60	0.45	0.43	0.32	0.05	0.22					
LOI	14.0	2.50		14.8	6.00											11.7	24.9							
Total	99.4	99.3		97.3	100.4		100.0	100.7	101.9	101.6		98.6	98.5	101.4	100.9	99.3	101.9	101.9	101.8					

(nd: not determined)

**Table3. Trace element chemistry**

Sample	Fluidised Bed Combustion						Air and Oxy-fuel pf						IGCC						
	Aus FBC			Japan PFBC			Coal A		Coal B		Coal C		T100	T101	T102	T103	T104	Bugg	
	Silo ash	Bottom ash		Fly ash	Bottom ash		air-fired	oxy-fired	air-fired	oxy-fired	air-fired	oxy-fired							
mg/kg																			
As	3.02	0.63		3.9	7.6		1.4	1.8	1.6	1.7		7.6	3.7	9.3	1.4	4.8	2.2	0.8	2.7
B	320	37		120	403		30	54	110	100		1160	400	200	64	160	40	91	120
Ba	470	260		390	1500		550	460	280	300		350	370	2900	3600	2200	480	1300	840
Bi	0.2	0.2		0.2	0.9		0.48	0.47	0.34	0.37		0.48	0.37	0.79	nd	nd	nd	nd	nd
Cd	0.11	0.06		0.5	0.9		0.34	0.26	0.22	0.26		0.26	0.26	0.2	nd	0.18	0.16	nd	nd
Co	25	9		32	32		66	56	29	34		88	72	61	100	41	56	38	51
Cr	121	84		35	67		91	93	137	148		83	151	1000	780	200	190	200	93
Cu	40	20		21	94		120	110	100	100		110	240	100	71	91	53	56	29
F	970	110		244	371		210	170	120	110		660	630	200	90	220	380	90	60
Hg	0.14	<0.02		0.01	0.07		0.077	0.061	0.086	0.058		0.197	0.269	0.09	0.02	0.23	0.3	nd	nd
Mo	0.7	0.5		2.3	12		2.7	2.6	2.1	2.1		5.3	3.6	200	27	14	6	14	4
Ni	83	5		28	52		61	69	118	131		174	175	240	240	320	98	79	76
Pb	43	32		28	45		80	77	84	85		69	63	35	8	12	17	4	nd
Sb	0.37	0.26		0.6	1.9		0.79	0.66	0.32	0.35		0.87	0.68	1.9	0.4	0.5	0.6	nd	0.2
Se	1.98	<0.1		3	48		1.04	1.01	0.6	0.62		1.91	1.77	1.7	0.5	0.9	0.9	0.2	nd
Sr	680	320		540	1600		440	480	400	470		710	650	2400	2200	1400	390	1400	530
Th	16	24		7.8	27		32	24	<5	22		21	19	28	40	15	13	17	17
U	9	6		1.7	6.3		13	12	8	9		11	10	9	11	4	5	6	6
V	148	63		49	160		371	313	178	223		231	228	150	140	110	87	240	170
W	1.1	0.5		<0.1	2.2		4	5	4	4		10	6	17	13	5	4	4	5
Zn	100	86		12	46		240	190	170	130		220	270	180	75	62	130	17	10

**Table 4. Trace element chemistry of the 3.5:1 leachates**

Leach Ratio 3.5:1	Fluidised Bed Combustion						Air and Oxy-fuel pf						IGCC					
	Aus FBC			Japan PFBC			Coal A		Coal B		Coal C		T100	T101	T102	T103	T104	BUG
	Silo ash	Bottom ash		Fly ash	Bottom ash		air-fired	oxy-fired	air-fired	oxy-fired	air-fired	Oxy-fired						
pH	8.3	12.4	12.3	12.3	12.3	12.3	6.4	6.1	7.5	7.5	6.2	7.46	7.85	7.82	9.09	8.68	8.05	
Condy* mg/L	2.38	8.64	7.37	9.25			3.3	2.3	2.6	2.4	11	0.53	0.16	0.6	0.79	0.08	0.21	
B	2	<0.2	0.2	0.4	0.4		2.61	2.19	2.89	3	36.8	0.33	0.06	0.14	0.06	0.01	0.09	
Ca	624	1010	610	1386	1386		157	183	192	153	708	81	22	104	142	8	28	
Fe	<0.1	<0.1	<0.1	<0.1	<0.1		nd	nd	nd	nd	nd	0.16	0.05	0.02	0.07	0.3	0.15	
K	12	60.6	39.6	3.9	3.9		541	274	382	346	2668	1.73	0.62	1.86	2.31	0.3	0.61	
Mg	8.6	<0.1	<0.1	<0.1	<0.1		1.3	1.2	1.5	2	3	8.51	2.58	4.65	2.11	0.85	0.58	
Na	5.4	12.9	55.7	4.4	4.4		28	27	26	22	102	7.53	4.53	5.56	16.47	5.63	9.19	
SO <sub>4</sub>	1523	684	19	1578	1578		787	775	758	664	3378	201	46	255	435	18	52	
Si	<5	<5	<5	<5	<5		8.3	4	3.2	4.8	12.4	2.38	0.71	1.18	0.18	1.59	1.46	
µg/L																		
Al	265	2	973	50	50		50	148	77	48	382	129	958	552	5864	1924	126	
As	2.5	0.7	0.2	1.6	1.6		33	9	48	73	19	0.48	1.78	8.02	3.47	8.9	1.06	
Ba	77	345	37048	105	105		60	56	88	45	69	104	169	350	68	53	4	
Cd	0.65	0.44	0.13	0.11	0.11		3.5	2.1	1.7	1.8	6.6	2.96	2.8	3.04	3.14	3	2.75	
Co	1.74	1.44	0.8	1.6	1.6		49	40	3	2	100	1.33	0.64	1.27	1.48	0.41	2.08	
Cr	2.49	22.91	9	92	92		2.7	1.4	36	45	17	1.03	0.9	0.87	1	1.75	0.8	
Cu	0.41	0.88	2.16	0.86	0.86		14	4	9	6.8	26	1.44	1.13	0.81	1.8	2.42	0.9	
Li	15	44	9218	402	402		1483	1480	1903	3273	3852	57	31	42	85	9	15	
Mn	10	<0.1	<0.1	1649	1649		1916	2597	502	502	4631	240	12	29	0.39	8	0.24	
Mo	295	184	66	52	52		561	245	515	637	290	198	76	79	239	19	49	
Ni	0.7	1.5	1.4	2.7	2.7		149	129	31	31	466	30	10	21	1	14	11	
Pb	<0.1	1	8	2	2		0.01	0.02	<0.01	<0.01	<0.01	0.15	0.21	0.12	0.12	1.42	0.16	
Sb	5.52	0.01	<0.01	<0.01	<0.01		24	12	5.3	6.8	6.1	1.4	3.62	3.55	10.29	1.39	1.41	
Se	55.5	1.3	42	61	61		110	45	72	70	344	11	6	57	15	22	9	
Sr	7469	4500	>>	16109	16109		2670	4597	3216	2201	9202	2962	872	2074	522	271	74	
Th	<0.1	<0.1	0	0.02	0.02		0.03	0.02	0.05	0.03	<0.02	0.02	0	0.05	0.03	0.08	0	
U	2.6	<0.1	<0.1	0.1	0.1		0.05	0.02	0.22	0.14	0.03	0.3	0.75	0.74	0.13	0.11	0.18	
V	190	<1	<1	<1	<1		1286	300	147	326	74	-0.52	0.54	0.56	5.17	7.49	0.39	
W	22	0.5	0.2	0.15	0.15		35	9	26	52	6	0.44	2.4	1.74	8.45	0.64	1.87	
Zn	10	8.5	16	11	11		670	349	48	19	1517	11.6	5.9	9.1	8.8	9.2	2.9	

(\* mS/cm; >>: over range)



Generally, the compositions of the slags, when expressed as oxides, appear to be similar to those of ashes produced by other transitional technologies (Table 2) This may in part be a result of expressing the compositions determined by XRF in the traditional manner, as it is expected that more reduced species of some elements would in fact be present e.g. FeO rather than Fe<sub>2</sub>O<sub>3</sub>. The trace element concentrations in the slags are also similar (Table 3). However, the concentrations of some of the more volatile elements such as Bi, Cd, F and Pb tend to be lower. Cr, Mo, Ni, and Th contents tend to be higher, although the Cr may possibly represent contamination from Cr-based refractories.

The overall leachability (or solubility) of elements from the slags is lower than that for typical ashes from Australian pf-fired power stations tested in a similar way (e.g. Jankowski et al., 2006; Riley, 2007), or from the FBC or oxy-fuel fired systems in the present test program. In particular, B, Ca, K, Al, Co, Cr, Se and V are lower. This is also evident from a comparison of the conductivities of the leachates (Tables 4 & 5). The conductivities of the leachates (l:s = 20:1) from the FBC ashes range from 1.38 to 8.24 mS/cm; the conductivities of the ashes from the conventional pf and oxy-fuel tests range from 0.48 to 2.71 mS/cm, whereas the conductivities of the leachates from the IGCC slags range from 0.02 to 0.24 mS/cm. However some trace elements appear from the study to be leached from the IGCC slags at similar concentrations to those leached from conventional pf-fired power station ashes.

**Table 6. Comparison of leachates (liquid:solid = 20:1) from ashes/slags produced by conventional and transitional technologies**

	Conventional pf #	FBC	Oxy-fuel	IGCC
pH	4.4 - 12.0	8.6 – 12.3	6.3 - 7.7	7.3 - 9.8
µg/L				
As	<2 - 20	0.3 - 2.1	7 – 60	0.2 - 25
B	60 - 945	<200 - 800	460 – 7280	<10 - 40
Cd	<0.2 - 5.5	0.05 - 0.13	0.4 - 1.1	2.8 - 3.0
Co	<0.2 - 145	0.6 - 1.2	0.6 – 21	0.2 - 1.4
Cr	<1 - 48	1.8 - 37	1.3 – 13	0.5 - 0.7
Cu	<1 - 275	0.2 - 1.4	1 - 9.3	0.9 - 1.9
Mn	<0.2 - 365	<0.2 - 2118	37 – 795	0.1 - 24
Mo	5 - 275	22 – 52	92 – 224	1.5 - 50
Ni	1 - 193	0.4 – 3	5 – 99	0.5 - 12
Pb	<0.2 - 1.9	<0.2 - 8	<0.2 - 0.2	<0.2 - 0.7
Sb	<0.1 - 9	<0.1 - 2	2.0 - 6.0	0.2 - 4.2
Se	3 - 60	1 – 37	12 - 72	1 - 37
V	5.6 - 70	<5 - 125	56 - 285	<5 - 9
Zn	< 1 - 1900	8 – 11	10 - 290	3 - 12

(# data extracted from Riley<sup>3</sup>)

## CONCLUDING REMARKS

The aim of this study was provide a comparison of the leachability of trace elements from the fly ash of conventional coal-fired power stations and major waste streams (ash or slags) of transitional technologies such FBC, coal-fired oxy-fuel stations and IGCC systems.

It is instructive to compare the results of this study for a number of the “environmentally significant” trace elements to those of an earlier study<sup>3</sup> in which results were given for trace elements in leachates (l:s ratios of 20:1) of fly ashes from conventional pf-fired power stations in Australia. In Table 6, the ranges are listed and compared with the ranges of a number of trace elements of the ashes or slags (from the transitional technologies) studied in this work.

It is apparent from the summary data that generally:

- Most trace elements leach from the fly ash and bottom ash of FBC systems at similar concentrations to those present in the leachate of ash from conventional power stations (i.e. using coal fired as pulverised fuel in air), although there are possibly some exceptions.
- Lower concentrations of Cd, Co, Ni and Zn were found in the leachates of the ash from the Australian and Japanese FBC power stations.
- Trace elements are leached in similar concentrations from fly ash from coal fired in conventional and oxy-fuel combustion conditions; indeed there does not appear to be any significant differences in the leaching behaviour of trace elements in the ashes from the different systems.
- Some of the trace elements in the gasifier slags do not leach as readily as those in the fly ash from conventional power stations; these trace elements are B, Cr, Mn, V and Zn and possibly Co and Cu. However, there does not appear to be any change in the leachability of the other trace elements, including As and Se. IGCC slag obviously has a larger particle size than pf ash, and the smaller surface area of the IGCC slags impacts upon their leachability. Although it is sometimes claimed that slag from IGCC plants “is environmentally benign and can be safely landfilled”, care must obviously be taken with its disposal as there are still trace elements that can be leached.

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