Co-Disposal of Coarse Coal Reject with Sand Mining Reject for the Control of Metal Concentration in Runoff Water

C F Gosling[1], S J Riley[1] and C V McQuade[2]

ABSTRACT

Acid mine drainage is an unavoidable consequence of some coal mining operations. Typically runoff pH is below 3.5 and at these pH levels heavy metals are mobilised. Leachate from coal reject dumps may require collection and treatment to raise the pH and precipitate the metals before being discharged.

A bi-product of coal mining operations at Clarence Colliery is coarse washery reject. At present the coarse reject is deposited above ground and rehabilitated. Adjacent to Clarence Colliery is the Kable's Transport Pty Ltd sand mining operation. It has been proposed that co-disposal of the rejects from both operations may produce a product whose leachate has near neutral pH.

The University of Western Sydney undertook laboratory experiments to investigate the chemistry of leachate water from 22 co-disposal options. Reject material was placed in 205L drums. Each drum contained coarse reject and either sand or clay, either mixed or layered. Three control drums were used, being 100% coarse reject, 100% sand and 100% clay.

Deionised water was introduced to the co-disposed material at approximately 4mL/min for one month and the leachate tested for pH and conductivity. On two occasions samples were collected and analysed for metals concentration using Inductively Coupled Plasma Mass Spectrometry. This paper presents the results of the metals analysis, comparing the materials, quantities and modes used for co-disposal.

INTRODUCTION

Acid Mine Drainage (AMD) is produced when sulphide materials are exposed to water in oxygenated conditions. Catalysed by the bacteria *Thiobacillus ferrooxidans* (Paulin, Patterson and Hadjigeorgiou, 1994) the acid producing reactions cause a drop in pH which increases the presence of metals in leachate.

Clarence Colliery is located on the Newnes Plateau near Lithgow, (NSW) and mines about two million tonnes of thermal coal per annum. Ten percent of the washed coal is rejected, this reject is placed above ground. Tailings are extracted and blended with the washed product and sold. The coarse reject is generating acidic drainage with associated elevated levels of some heavy metals. Water treatment systems are in place at Clarence to treat the leachate to meet Environmental Protection Authority guidelines. However, they are expensive to establish and operate. An alternative long-term passive method for dealing with the reject and its bi-products is needed.

Adjacent to Clarence Colliery is Kable's Transport sand mine which produces bi-products of silts, clays and fine sand tailings. The poor structural stability of the tailings and the large voids created by the mining process cause rehabilitation difficulties for Kable's.

Disposal of coal washery reject in a manner having minimal environmental impact depends upon the mine and its location. Neutralisation using lime or fly ash additive is uneconomical for Clarence and is unlikely to provide long term prevention of acidic drainage as lime leaches out of the rejects before neutralising all the sulphides (Phipps, Fletcher and Skousen,

[1] Faculty of Engineering, University of Western Sydney, Kingswood, Australia
[2] Clarence Colliery, Lithgow, Australia

1995). A wetland treatment system may assist in neutralising some acidic leachate, but ongoing management would be required.

It has been proposed that co-disposal of the rejects from both operations may produce a product whose leachate has near neutral pH, thus limiting mobilisation of metals. Potential benefits of the co-disposal of sand mine tailings and coarse coal reject with regard to the leachate are:

1. Chemical reactions between the coarse washery rejects and sand mining tailings may reduce the acid generation. The tailings may adsorb metals.
2. Lowering infiltration rates through the reject will reduce the oxygen and water input to the dump and hence reduce AMD.

Clay layers are effective barriers for infiltration and adsorb toxic elements such as heavy metals. Al-Hashimi *et al* (1995) found that solvated elements are retained in clay barriers by adsorbtion and precipitation processes. With a geobarrier, such as clay, the reactions at the clay surface effectively raise the pH and precipitate the metals. Similar reactions can occur with sand barriers except that the interactions are related to metal complexes on the sand grains (Manahan, 1991).

This paper presents the results of a study of the metal concentration of leachate from co-disposal options in a controlled laboratory experiment. The aim is to determine the option which produces the lowest load and concentration of metals in leachate.

METHOD

Sand tailings and coarse reject can be disposed of in one of two ways, either by layering or by mixing. The coal washery reject and sand tailings product quantities and disposal options gave 22 combinations of materials for laboratory experiments, discussed in Gosling *et al* (1997). The percentage of coarse reject by weight for each of the sand and clay, and for each co-disposal method was selected to be 100%, 90%, 80%, 70%, 50%, 20% and 0%. Consideration of production rates of coal reject to sand and clay tailings lead to the higher proportion of coarse reject in the experiment. Three references, 100% of each material (coarse reject, sand and clay tailings), were used to compare the leachate metals concentration from the co-disposal options. The feasibility experiment was carried out using 205L drums. The drum and water arrangement is shown in Fig 1. Acid generation is minimised by elimination of either water or oxygen from the system. In order to assess the effectiveness of the co-disposal non-saturated conditions were used in the experiment. Details of the experiment are presented in Gosling *et al* (1997).

The experiment was monitored for one month. Daily measurements of leachate pH and conductivity were taken using portable pH and conductivity meters. Leachate samples for metals analysis were collected two weeks after the experiment commenced (15th November 1996) and at the end of the month (28th November 1996).

Leachate metals analysis was undertaken using Inductively Coupled Plasma Mass Spectrometry (Eaton *et al*, 1995). The samples were analysed for aluminium, arsenic, cadmium, cobalt, chromium, copper, iron, mercury, manganese, nickel, lead, antimony, selenium and zinc. These elements had been identified as elevated in mine water from a 1996 study by Jones and Eames (1996). The results were compared to Australian and New Zealand Environment and Conservation Council (ANZECC) (1992) guidelines for discharge into fresh waters and to metals concentration in the Wollangambe River upstream of Clarence Colliery (Tables 2 and 3). The purpose of the work was to ascertain whether there was a potential environmental issue with metals in reject leachate by an initial assessment of leachate metal concentration. It was not an extensive study.

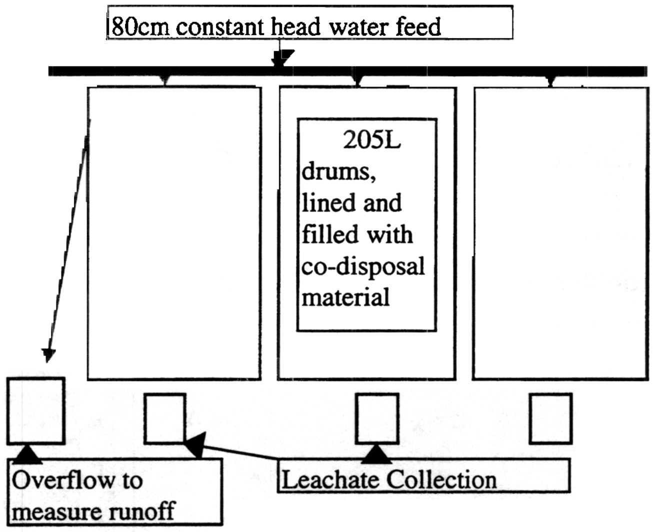

Fig. 1 - Experimental design of co-disposal feasibility experiment (Moisture not measured over time)

The metal load from each experiment was calculated by multiplying leachate volume for each 24 hour period by the metal concentration determined from statistically significant relationships between leachate conductivity and metal concentration. Thirty day total metal loads were calculated for each co-disposal option. Comparison was made between options having low 30 day load and low metal concentration to assess which option would produce leachate having minimal impact upon receiving waters. It is desired that the metal load into receiving waters be minimal. Co-disposal options having elevated leachate metal concentration would have less impact upon receiving waters if the total quantity of pollutants is low.

A means of checking for possible failure in the drum lining and contamination from the drum was undertaken by comparing iron concentration and pH (Adeloju, 1997). It is known that iron is soluble at low pH. As the pH rises the solubility decreases. Thus high concentrations of iron at high pH's would suggest contamination from failure of the liner and the steel drum. Plots of leachate pH against leachate iron concentration (Fig. 2) suggest contamination from the drum has occurred for the trials 50% coal reject mixed and layered with 50% clay. There is possible contamination in the 70% coal reject layered with 30% clay readings and for 90% coal reject layered with 10% clay on 28th November. The 50% coal reject and 50% clay drums had high iron concentration, above 7570•g/L, and high pH, above 6.0, for all samples. Seventy percent coal reject layered with 30% clay had iron concentration 12600•g/L and pH 4.9 (Table 1). While the pH is lower than 6.0, the iron concentration is high. Similar values to the 7:3 layered coal reject to clay ratio are recorded for 90% coal reject layered with 10% clay on 28th November.

Table 1: Leachate iron concentration and pH for contaminated drums

Co-Disposal Option	Date Sampled	Leachate pH	Iron Concentration (mg/L)
50% CR, 50% Clay (m)	15 November 1996	6.1	7.6
	28 November 1996	6.0	8.3
50% CR, 50% Clay (L)	15 November 1996	6.2	10.6
	28 November 1996	6.6	12.7
70% CR, 30% Clay (L)	28 November 1996	4.9	12.6
90% CR, 10% Clay (L)	28 November 1996	5.2	12.3

The plots of leachate pH against leachate iron concentration for coal reject co-disposed with sand suggest contamination has not occurred. Iron concentration was high for low pH and low for high pH (Fig. 2).

The subsequent data analysis excludes readings from 50% coal reject mixed with 50% clay and 50% coal reject layered with 50% clay.

No co-disposal option provided a leachate that satisfied all the ANZECC (1992) guidelines for direct discharge into fresh waters (Tables 2 and 3).

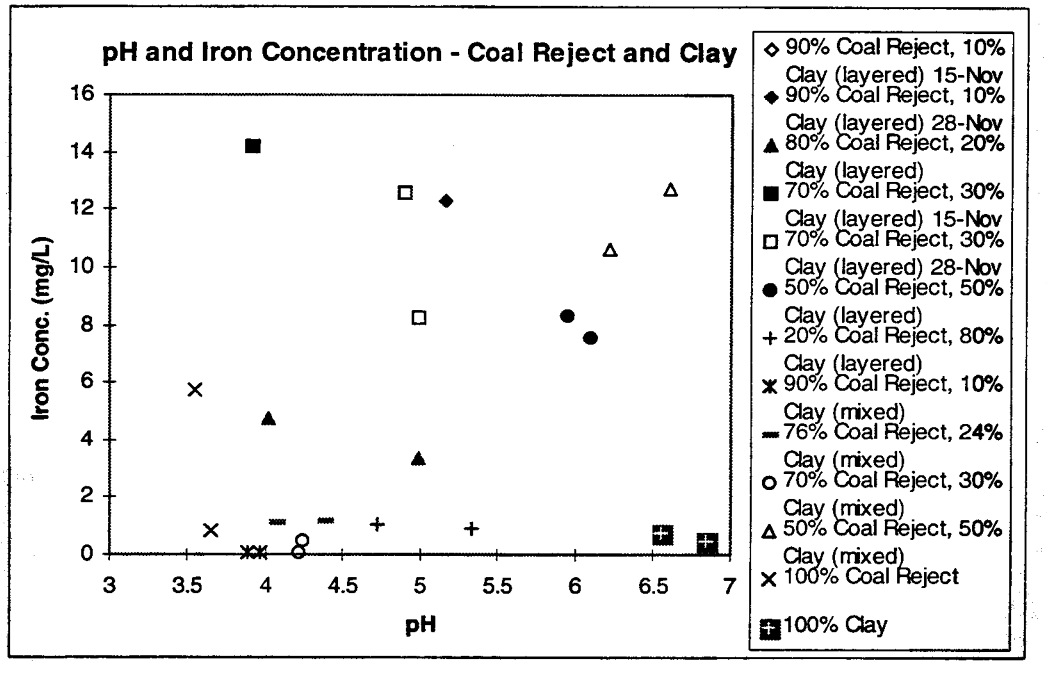

Fig 2: pH vs Iron concentration: Coal reject and clay leachate.

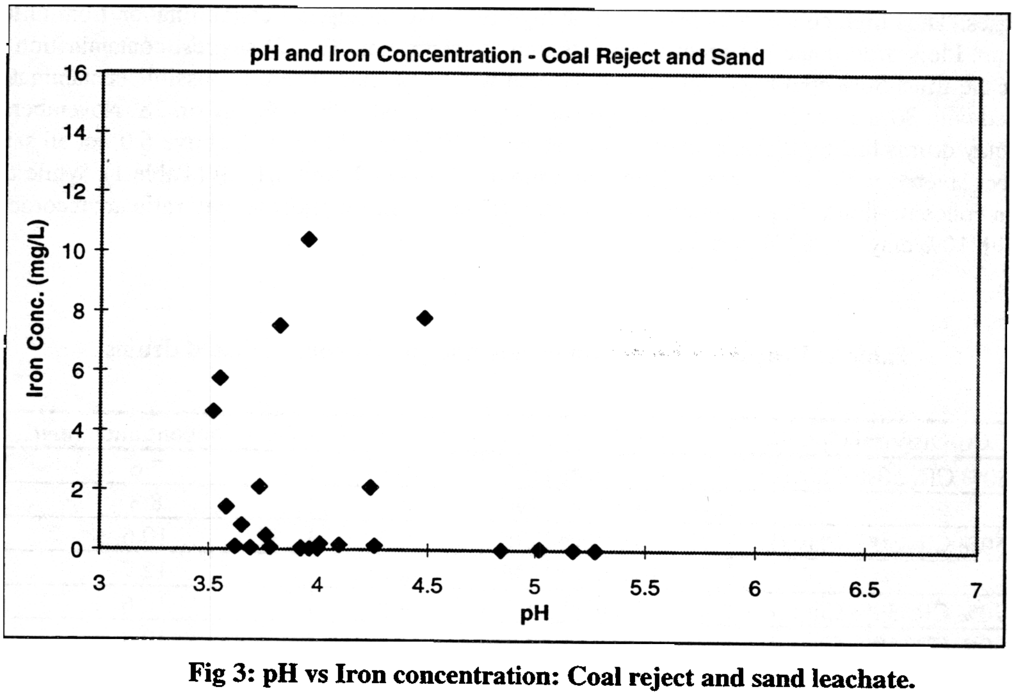

Fig 3: pH vs Iron concentration: Coal reject and sand leachate.

RESULTS

The following summarizes the results of the leachate analysis in terms of the ANZECC (1992) guidelines.

In the following analysis the metal concentration in the leachate was grouped by date and co-disposal option to establish whether or not a statistically significant relation exists between the quantity of coal reject and the leachate metals concentration, for the mixed and layered situations. This analysis may indicate a maximum percentage of coal reject that may be mixed or layered with sand or clay before ANZECC guidelines are exceeded. Consequently, optimal reject ratios may be determined.

Table 2: Coal reject and clay co-disposal, leachate metals concentration compared to ANZECC guidelines

Metal	Coal Reject and Clay												
	% Coal Reject												
	Layered							Mixed					
	100	90	80	70	50	20	0	100	90	76.3	70	50	0
Al													
As	■	■	■	■	■	■	■	■	■	■	■	■	■
Cd	■	■	■	■	■	■	■	■	■	■	■	■	■
Co							■						■
Cr	■	■	■	■	■	■	■	■	■	■	■	■	■
Cu					■		■					■	■
Fe							■		■				■
Hg	■	■	■	■	■	■	■	■	■	■	■	■	■
Mn													
Ni			■		■	■	■						■
Pb	■	■	■	■	■	■	■						■
Sb	■	■	■	■	■	■	■	■	■	■	■	■	■
Se	■	■	■	■	■	■	■			■	■	■	■
Zn						■	■					■	■

■ indicates the leachate was within ANZECC guidelines. In the case of Manganese comparison has been made with the Clean Waters Regulation 1972 - Schedule 2 (P class waters) as no value was given in the ANZECC guidelines. For cobalt comparison has been made with measured values in the Wollangambe River upstream of Clarence Colliery as no value was given in the ANZECC guidelines. Note iron contamination from the drums seems to have effected the measurements - see discussion.

Statistically significant relationships (P•0.05), exist between the leachate metals concentration and the percentage coal reject mixed with clay for aluminium, cadmium, cobalt, copper, manganese, nickel, lead and zinc (Table 4). Prior to the removal of data from 1:1 coal reject to clay a significant relationship for aluminium did not exist. For leachate cadmium and lead concentrations the relationship between leachate metals concentration and percentage coal reject changed from being statistically significant on 15th November to not showing a significant relationship on 28th November. In both cases the leachate cadmium and lead concentration for 100% clay on 28th November was much higher than those concentrations for samples on 15th November, possibly causing the reduction in the level of statistical significance.

Table 3: Coal reject and sand co-disposal, leachate metals concentration compared to ANZECC guidelines

Metal	Coal Reject and Sand													
	% Coal Reject													
	Layered							Mixed						
	100	90	80	70	50	20	0	100	90	80	70	50	20	0
Al														
As	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Cd					■	■	■					■	■	■
Co							■							■
Cr	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Cu		■	■			■	■							■
Fe	■	■	■	■	■	■	■		■					■
Hg	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Mn							■							■
Ni							■							■
Pb					■	■	■							■
Sb	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Se						■	■				■	■	■	■
Zn							■							■

■ indicates the leachate was within ANZECC guidelines. In the case of Manganese comparison has been made with the Clean Waters Regulation 1972 - Schedule 2 (P class waters) as no value was given in the ANZECC guidelines. For cobalt comparison has been made with measured values in the Wollangambe River upstream of Clarence Colliery as no value was given in the ANZECC guidelines.

Table 4: Level of significance where a statistically significant relationship between percentage coal reject and leachate metals concentration exists, coal reject and clay (Data from 1:1 coal reject to clay ratio removed)

Metal	Level of Significance			
	Coal Reject and Clay			
	Mixed		Layered	
	15/11/96	28/11/96	15/11/96	28/11/96
Al		0.01		
Cd	<0.001			
Co	<0.001	0.001	0.007	0.001
Cu	<0.001	0.003		
Fe				
Mn	0.014	0.035	0.002	0.021
Ni	<0.001	0.001	0.008	0.006
Pb	0.007			
Se				
Zn	0.021	0.024	0.007	0.015

The cadmium reading for 100% clay (Fig. 4) on 28th November appeared to be incorrect given that the reading was higher than those for 76%, 70% and 50% coal reject, and almost the same as that for 90% coal reject. Supporting the possibility of an erroneous reading is the low cadmium reading for 100% clay on 15th November, this reading being the lowest of all the cadmium readings. Removal of this value from the cadmium data did not improve the statistical significance of the relationship. Removing the sample for 100% clay increased the level significance of the relationship for selenium and zinc only, the greatest improvement being for selenium, from a level of significance of 0.041 to 0.01.

No significant relationship was found between leachate iron concentration and percentage coal reject for coal reject and clay mixed. Removal of the readings from 50% coal reject mixed with 50% clay did not improve the statistical significance of the relationship.

The leachate metals concentration increased exponentially as the relative percentage of coal reject mixed increased, except for the element aluminium where the metal concentration decreased exponentially as the percentage of coal reject mixed increased. Figs 4 and 5 show the relationship between leachate metals concentration and percentage coal reject where the level of significance was greater than 5% for cadmium (Fig. 4) and manganese (Fig. 5).

Statistically significant relationships (P•0.05), exist between the leachate metals concentration and the percentage coal reject layered with clay for cadmium, cobalt, iron, manganese, nickel and zinc (Table 4). Removal of the 100% clay sample data for the 28th November increased the level of significance for cadmium (0.299 to <0.001) and zinc only. Note that without removing the 100% clay reading a significant relationship between coal reject and metal concentration for zinc existed.

The concentration of metals in the leachate increased exponentially as the relative percentage of coal reject increased for the coal reject/tailings layered configuration.

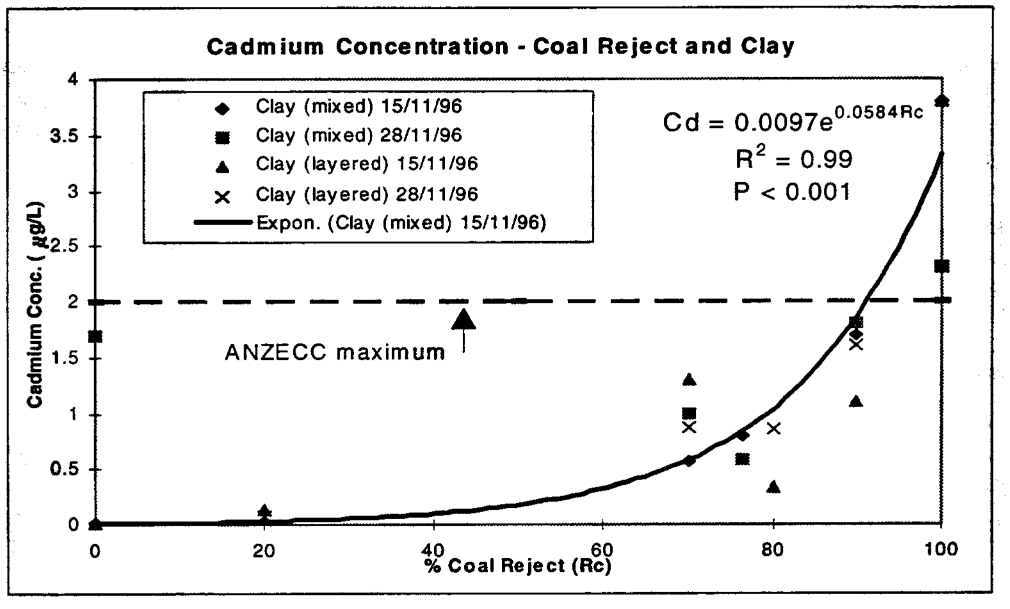

Fig 4: Cadmium concentration: Coal reject and clay leachate (Data from 1:1 coal reject and clay removed)

The leachate aluminium concentrations for coal reject layered with sand in 7:3 and 8:2 ratios are much higher than the leachate aluminium levels for other coal reject and sand layered ratios. There is probably not a drum contamination problem as there is no statistically significant relationship between the quantity of coal reject and the leachate aluminium concentration.

Statistically significant relationships (P•0.05), exist between the leachate metals concentration and the percentage coal reject layered with sand for cadmium, cobalt, copper, iron, manganese, nickel, lead, selenium and zinc (Table 5).

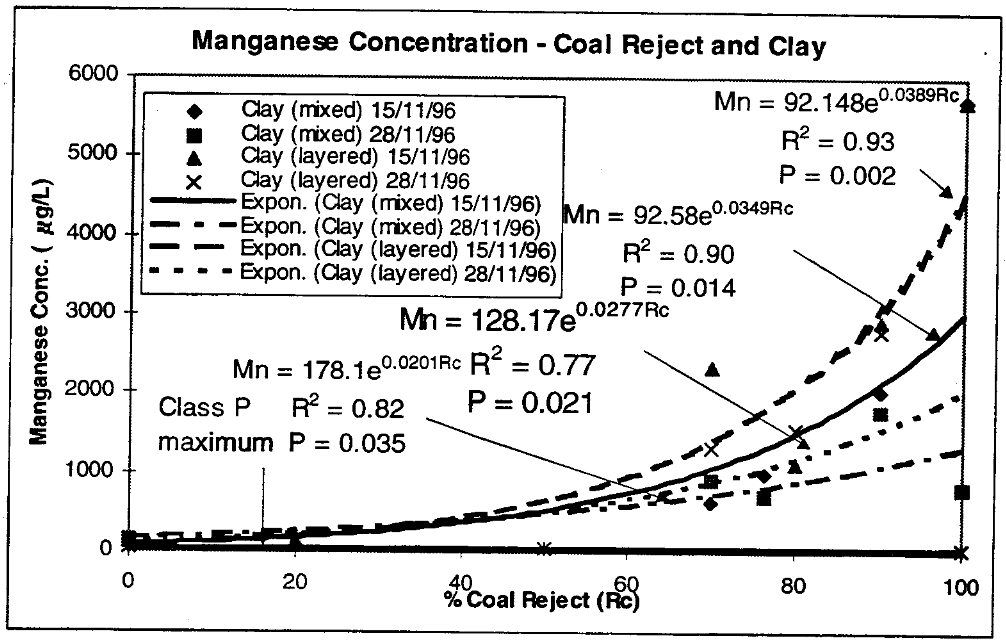

Fig 5: Manganese concentration: Coal reject and clay leachate (Data from 1:1 coal reject and clay removed)

Leachate from 90% coal reject mixed with 10% sand on the 15[th] November had much higher concentration of cadmium, cobalt and zinc than the other coal reject and sand mixed ratios. Removal of the 9:1 sample from all data sets on that date showed statistically significant relationships (P•0.05), exist between leachate metals concentration and the percentage coal reject mixed with sand for cadmium, cobalt, copper, manganese, iron, nickel and zinc (Table 5). Statistically significant relationships, (P•0.05), exist between leachate metals concentration and the percentage coal reject mixed with sand for cadmium, cobalt, copper, lead, selenium and zinc for samples collected on 28[th] November (Table 5). The leachate metals concentration increased as the percentage of coal reject mixed or layered increased for all elements.

Table 5: Level of significance where a statistically significant relationship between percentage coal reject and leachate metals concentration exists, coal reject and sand (Data from 9:1 coal reject to sand mixed ratio 15[th] November removed)

Metal	Level of Significance			
	Coal Reject and Sand			
	Mixed		Layered	
	15/11/96	28/11/96	15/11/96	28/11/96
Al				
Cd	<0.001	0.007	0.001	0.001
Co	0.001	0.018	0.001	<0.001
Cu	0.027	0.016	0.004	0.016
Fe	0.034		0.021	
Mn	<0.001		0.004	0.035
Ni	0.015		0.015	0.041
Pb	0.042		0.001	0.003
Se		0.021	0.002	0.006
Zn	0.009	0.033	0.007	0.011

Figs 6 and 7 show the relationship between leachate metals concentration and percentage coal reject where the level of significance was greater than 5% for cadmium (Fig. 6) and manganese (Fig. 7).

Statistically significant relationships between the leachate metal concentration and percentage coal reject where the trends changed between the two sampling events are shown in Table 6.

Table 6: Change in leachate metals concentration over time for coal reject and sand tailings co-disposal

Metal	Change in leachate metals concentration over time			
	Coal Reject and Clay		Coal Reject and Sand	
	Layered	Mixed	Layered	Mixed
Cd			Decreased	Decreased
Co	Increased	Decreased	Decreased	Decreased
Cu		Decreased	Decreased	Decreased
Mn	Increased	Decreased	Decreased above 90% coal reject	
Ni	Increased	Decreased	Decreased	
Pb			Decreased above 90% coal reject	
Se			Decreased	
Zn	Increased	Increased above 85% coal reject	Decreased	Decreased

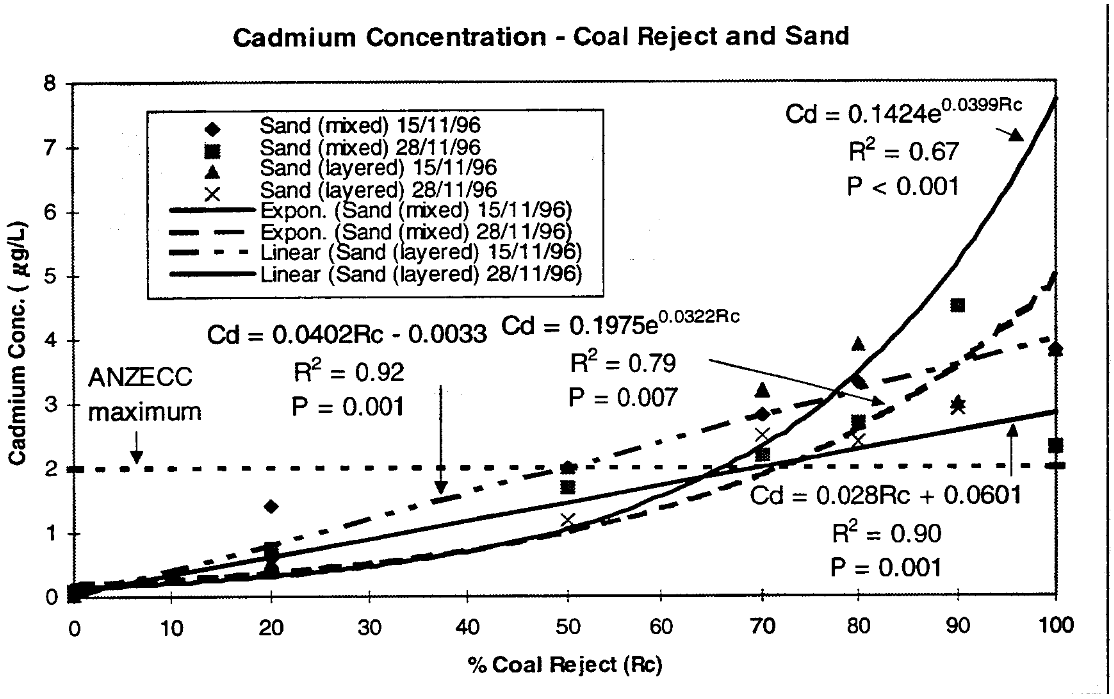

Fig 6: Cadmium concentration: Coal reject and sand leachate (Data from 9:1 coal reject to sand mixed ratio 15th November removed)

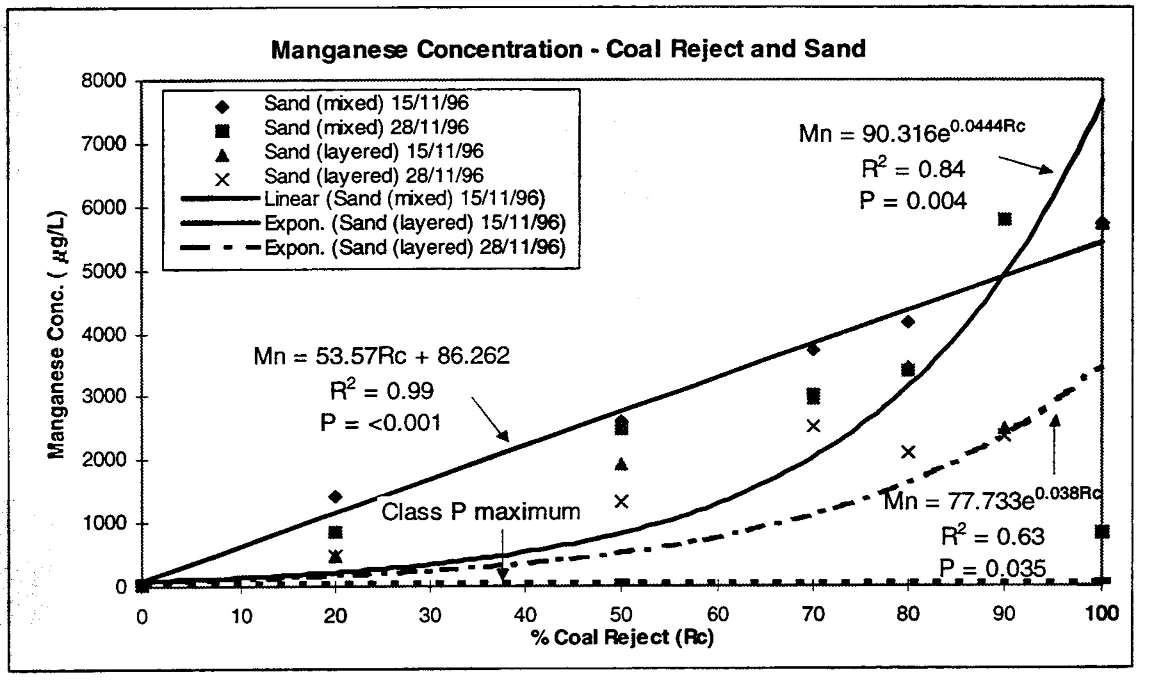

Fig 7: Manganese concentration: Coal reject and sand leachate (Data from 9:1 coal reject to sand mixed ratio 15[th] November removed)

Leachate metal load calculations for the 30 days of monitoring show coal reject and clay layered options produced the lowest total metal loads of the four co-disposal options (Table 7).

A consequence of very little of the water introduced to the coal reject and clay layered options passing through the material was the total leachate metal load was at most one tenth of the load from the three other co-disposal modes where all introduced water had passed through. Leachate from coal reject and clay layered had zinc, manganese, iron, copper, cobalt and nickel concentrations above those recommended by ANZECC Guidelines (Table 2). Compared to the 30 day total load for leachate from 100% coal reject, the total metal loads in leachate from coal reject and clay layered for these metals was reduced by two orders of magnitude except for the 7:3 coal reject to clay ratio where the load was reduced by one order of magnitude. 30 day loads for leachate from 100% sand for manganese, copper and cobalt was not found as the relationship between leachate conductivity and metal concentration for co-disposal with sand gave negative values when metal load was calculated. Consequently comparison between metal loads for leachate from 100% sand and leachate from coal reject layered with clay cannot be made for these metals. Compared to the 30 day total load for leachate from 100% clay, the total metal loads in leachate from coal reject and clay layered for zinc, manganese, iron and nickel increased by two orders of magnitude except for the 7:3 coal reject to clay ratio where the load increased by three orders of magnitude. The copper and cobalt loads for leachate from coal reject and clay layered was two orders of magnitude greater than for leachate from 100% clay, again except for the 7:3 coal reject to clay ratio where the increase was three orders of magnitude.

Table 7: Total metal loads (mg) after 30 days

Co-disposal option	Al	As	Cd	Co	Cu	Fe	Mn	Ni	Pb	Se	Zn
CR & Cl (L)											
9:1	6.9	-	0.025	3.5	0.26	87	37	8.5	-	0.056	8.5
8:2	5.2	-	0.016	0.9	0.085	56	24	2.2	-	0.033	3.3
7:3	25	-	0.1	110	5.1	460	140	300	-	0.36	110
5:5	6.4	-	0.019	0.83	0.085	68	28	2	-	0.039	3.5
2:8	10	-	0.013	0.59	0.076	120	24	1.4	-	0.063	3.8
CR & Cl (M)											
9:1	-	-	0.23	56	18	-	-	140	-	0.79	120
76:24	-	-	0.12	21	6.3	-	-	51	-	0.33	30
7:3	-	-	0.096	15	4.4	-	-	36	-	0.24	21
5:5	-	-	0.0023	0.46	0.14	-	-	1.2	-	0.0069	0.68
CR & S (L)											
9:1	81	0.052	0.45	130	58	-	440	330	0.98	2.6	280
8:2	86	0.057	0.48	140	63	-	480	350	1	3	300
7:3	59	0.038	0.33	93	43	-	320	240	0.71	1.9	200
5:5	58	0.032	0.29	81	37	-	270	210	0.64	1	180
2:8	23	0.015	0.081	21	9.5	-	58	53	0.2	0.32	58
CR & S (M)											
9:1	19	0.052	0.49	160	46	990	610	400	1.5	1.3	320
8:2	20	0.051	0.51	160	47	480	630	410	1.7	1.1	330
7:3	15	0.037	0.38	120	34	210	460	300	1.3	0.71	240
5:5	15	0.037	0.36	110	32	140	440	280	1.4	0.65	230
2:8	11	0.026	0.21	61	18	35	250	160	1	0.41	130
100% CR	88	0.066	0.56	210	11	420	500	530	1.8	3.6	280
100%Clay	0.72	-	0.001	0.043	0.0055	8.7	1.7	0.1	-	0.0069	0.27
100% Sand	18	0.016	18	-	-	-	-	3.7	0.082	0.29	25

Note: Where no load values are presented there was not a statistically significant relationship between leachate conductivity and metal concentration for leachate from the two sampling dates. 30 day loads for leachate from 100% sand for manganese, copper and cobalt was not calculated as the relationship between leachate conductivity and metal concentration for co-disposal with sand gave negative values when metal load was estimated.

DISCUSSION

No co-disposal option satisfied all the ANZECC guidelines for discharge into fresh water. Except for the elements iron and manganese, the leachate from coal reject and sand co-disposal options had higher metals concentration than leachate from coal reject and clay co-disposal. Flow monitoring of coal reject and clay layered options showed that very little of the water introduced to the material passed through to the coal reject as most water became overflow. While leachate from the layered coal reject and clay has some elevated metals concentration the low discharge volume allows for passive downstream supplementary treatment by such means as wetland filters.

Results of this study suggest that co-disposal of coarse coal washery reject from Clarence Colliery with reject from Kable's Transport sand mine is a suitable option for reducing the effects of Acid Mine Drainage. It is possible to reduce the leachate metals concentration and minimise leachate volume by layering coal reject with clay. Consideration of leachate pH, conductivity, volume and metals concentration, as well as the production rate of reject material suggest that the optimal ratio of coal reject to clay layered would be 9:1. Field trials need to be carried out to assess the long term viability of such a system.

ACKNOWLEDGMENTS

The authors acknowledge Kable's Transport Pty Ltd., Lithgow, for the supply of sand and clay reject used in the experiments.

REFERENCES

Adeloju, S, 1997. Personal Communication. Department of Chemistry, University of Western Sydney - Nepean.

Al-Hashimi, A, Evans, GJ and Cox, B 1996. Sealing and Retentive Characteristics of Ottawa Clay, in *International Journal of Environmental Studies 1996* (Overseas Publishers Association Amsterdam) 50: 91-102.

ANZECC 1992. Australia and New Zealand Environment and Conservation Council, November 1992. *Australian Water Quality Guidelines for Fresh and Marine Waters* Chapter 2 (Canberra)

Eaton, Andrew D, Clesceri, Lenore S, Greenberg, Arnold E (Eds.) 1995. *Standard Methods for the Examination of Water and Wastewater 19th Edition* Chapter 3 (APHA, AWWA, WEF, Washington DC)

Gosling, C, Riley, SJ, McQuade, CV and deGroen, MG 1997. Co-disposal of reject materials from coal and sand mining operations in the Blue Mountains - a feasibility study of the benefits. *The AusIMM Bulletin*, 4, 72-74

Jones, David R and Eames, John C January 1996. *Preliminary Assessment of Water and Sediment Quality. Final Report CET/IR 440R for Clarence Colliery Pty Ltd.* pp.12 (CSIRO Australia)

Manahan, Stanley E 1991. *Environmental Chemistry Fifth Edition* Lewis Publishers, Inc. (Michigan)

Paulin, R, Patterson, RJ and Hadjigeorgiou, J 1994. On the co-mingling of mine waste and tailings. *Proceedings of 3rd International Conference on Environmental Issues and Waste Management in Energy and Mining Production, Curtin University.* 599-606.

Phipps, Tim T, Fletcher, Jerald J and Skousen, Jeffrey G 1995. Costs for Chemical Treatment of AMD, in *Acid Mine Drainage Control & Treatment* (Eds: Jeffrey G. Skousen and Paul F. Ziemkiewicz), pp 145-171 (National Mine Land Reclamation Centre, West Virginia University).