

THE CHEMICAL CHARACTERISTICS OF LEACHATE FROM BLENDED BAUXITE REFINING RESIDUE

S.J. Anderson¹, P.J. Hensley² and D. Smirk³

SYNOPSIS

This paper describes a study that was undertaken to examine the quality of leachate from various blends of bauxite residue and gypsum (residue blends). The study was initiated to provide data that could be used to assess the possible environmental impact of schemes involving applications of residue blends. The study comprised a series of column leaching trials, that were conducted on five combinations of dry mixed residue and one combination of wet mixed residue. The columns were watered to simulate natural rainfall patterns for the local area, and the leachate resulting from the blended residue was analysed for alkalinity levels, salts and other possible contaminants. The results from the trials indicated that concentrations of sodium, sulphate and fluoride in the leachate were initially in the range of 85 g/l, 160 g/l and 20 mg/l, respectively, but decreased with increasing volume of leachate whereas the concentrations of aluminium and calcium remained relatively constant, at approximately 6 mg/l and 600 mg/l, respectively, throughout the trial. The results also indicated that neutralisation of the bauxite residue was successful, with the pH value of the leachate from all blends quickly tending towards a value of 7.5. Furthermore, it was demonstrated that the blended residue had a greater phosphate retention capacity than any virgin local soils.

INTRODUCTION

Alcoa of Australia is currently producing 5.5 million tonnes of alumina annually, from three refineries located at Kwinana, Pinjarra and Wagerup, in the South West of Australia, Fig. 1.

The alumina is extracted from bauxite, mined in the nearby Darling Range, using the Bayer process. The Bayer process is a caustic digestion process that dissolves alumina hydrates from the prepared bauxite ore in a sodium hydroxide solution. The undissolved solids are removed from the solution and washed repeatedly to recover the sodium hydroxide for recycling. The residue is then pumped to the residue area, where it is separated into a coarse fraction (residue sand) and a fine fraction (red mud). The residue sand is pumped to a stockpile where it rapidly drains, becoming

¹ Research Student and ² Research Fellow, Geomechanics Group, Dept. of Civil and Environmental Engineering, The University of Western Australia, Nedlands, Western Australia 6009.

³ Environmental Scientist, Alcoa of Australia Ltd, Residue Development Group, P.O. Box 252, Applecross, Western Australia 6153.

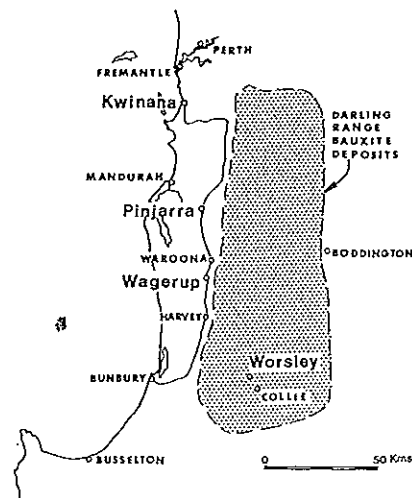
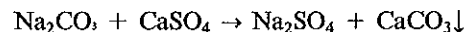


Fig. 1 Location Plan (from Glenister and Cooling, 1984)

available for future use. The red mud is thickened in a "super" thickener to about 48-50% solids (Smirk, 1990) and pumped into drying beds for storage.

The bauxite is a low grade ore by world standards, with an average recoverable alumina content of 32 percent. Therefore, for every tonne of alumina produced, approximately two tonnes of residue are generated for disposal. As a result, total residue production for the Kwinana, Pinjarra and Wagerup refineries is 11 million tonnes per year.

Bauxite residue is alkaline because the entrained moisture after washing contains sodium hydroxide. When exposed to the atmosphere, the sodium hydroxide reacts with the carbon dioxide to form sodium carbonate, which can be neutralised with gypsum (Barrow, 1982).



The major salts leached from the gypsum amended bauxite residue are sodium sulphate and calcium carbonate.

For the past 15 years, Alcoa, in conjunction with a number of research groups, has been investigating alternative uses for bauxite residue neutralised with gypsum.

This paper presents the results of a laboratory column study that was undertaken to examine the quality of effluent leached from various blends of bauxite residue sand and red mud, neutralised with gypsum. The primary aim of the study was to provide data that could be used to assess the possible impact of amended bauxite residue use on groundwater quality. In the paper, the apparatus and experimental

procedure for the column study are described, and the chemical characteristics of leachate from the residue blends are presented and discussed.

ALTERNATIVE USES OF BAUXITE REFINING RESIDUE

Barrow (1982) first suggested that alkaline bauxite residue could be neutralised with gypsum, and the residue blend used to improve the waterholding and chemical properties of sandy soils. Various field trials were conducted to test the feasibility of this suggestion during the period 1983 to 1985 (Summers *et. al.*, 1986), and the results indicated improved pasture production and greater phosphate retention in the treated soil areas.

More recently, a private company, Ecomax Waste Management Systems, in conjunction with Alcoa has been investigating the option of using residue blends in on-site septic systems. Research by Ho *et. al.* (1984) indicated that fine bauxite residue (red mud) mixed with gypsum has the ability to remove phosphorous, nitrogen and other environmental contaminants from sewage effluent. Blends containing a mixture of red mud and gypsum in local sand or residue sand, therefore have the potential to act as effective sewage filter media.

To date, two on-site septic systems have been developed which could contain bauxite residue filters. The two systems are the ECOMAX System and the BIOCYCLE System (Connor *et. al.*, 1991). The ECOMAX system, which is promoted by Ecomax Waste Management Systems (1991), consists of a conventional septic tank/leach drain or soak well system, surrounded by a filter bed. In Western Australia, filter materials consisting of red mud neutralised with waste gypsum from CSBP and Farmers Ltd, and blended with local sands or residue sand, have been approved for use in these systems (Health Department of Western Australia, 1991).

Bauxite residue blends are being considered for use in areas where conventional septic tank effluent could adversely impact the groundwater quality. It is therefore essential to confirm that the effluent originating from filter systems containing residue blends, has a significantly reduced potential to adversely affect the groundwater environment. Furthermore, it is also necessary to confirm that leachate originating from pastoral land improved with residue blends does not have significant adverse effects on groundwater quality.

APPARATUS AND PROCEDURE FOR LEACHING TRIALS

A laboratory column study was conducted to examine the characteristics of leachate from various blends of residue sand and red mud. All blends were amended with pre-determined concentrations of gypsum, to neutralise the residual alkalinity of the bauxite residue. Eighteen columns were packed with the various blends of amended soil, and watered to simulate natural rainfall patterns in the Perth area. The resulting leachate was collected and analysed for alkalinity levels, salts and other possible contaminants.

Blends of red mud and gypsum with local sand were not included in the study, as

it was considered that total residue blends would present the highest possible concentrations likely to be encountered. Results from the study could therefore be scaled down for other soil mixes.

MATERIALS

The three constituents of the residue blends were residue sand, red mud and gypsum.

Residue Sand

The residue sand was supplied by Alcoa of Australia from its Pinjarra refinery. Residue sand is the coarser fraction of bauxite residue. Smirk (1990) described the particle sizing of the sand typically as having 23% with a diameter between 20 microns and 200 microns, and 77% with a diameter greater than 200 microns. The sand consists primarily of silica (50%), iron oxide minerals (30%) and aluminium oxide minerals (10%).

Prior to use, the residue sand was oven dried at 50°C for a minimum of 72 hours. The dried sand was then placed in a rotating drum for five minutes to form a uniform mix.

Red Mud

The red mud was also provided by Alcoa of Australia from its Pinjarra refinery. Red mud is the fine fraction of bauxite residue. Estimates of the particle size distribution vary due to flocculation and cementation of the particles. One particle size distribution described by Smirk (1990) indicated that the mud has 10% of particles less than 2 microns, 67% between 2 microns and 20 microns and 23% between 20 microns and 200 microns. The mud consists primarily of naturally occurring silica (25%), iron oxide (35%), aluminium oxide (17%) and titania minerals (4%). In addition the mud contains a fraction of sodium alumina silicates (2%), that are formed by the reaction of fine silica in the bauxite with caustic soda.

Prior to use, the red mud was oven dried at 50°C for a minimum of 72 hours, before being crushed and sieved through a 1.2 mm sieve. The mud was then placed in a rotating drum for five minutes to form a uniform mix.

Gypsum

The gypsum (phosphogypsum) was supplied by CSBP and Farmers Ltd, from its Kwinana superphosphate plant. Phosphogypsum is the waste product from the phosphoric acid manufacture process. The chemical components of stockpiled gypsum are given in Table 1.

Prior to use, the gypsum was oven dried at 50°C for a minimum of 72 hours, then ground and sieved through a 1.2 mm sieve.

RESIDUE MIXES

For schemes involving the application of residue blends, it is necessary to prepare

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Table 1 Typical Components of Phosphogypsum (supplied by CSBP and Farmers Ltd).

Moisture	10 -20%
CaSO ₄ .2H ₂ O	75% minimum
SiO ₂	7.5%
Fluoride	0.6%
Aluminium	0.3%
Cadmium	0.5%
Lead	7.0 ppm

Table 2 Gravimetric Percentages of Mix Ratios.

MIX NUMBER	% RESIDUE SAND	% RED MUD	% GYPSUM
1	14.25	80.75	5
2	33.25	61.75	5
3	52.25	42.75	5
4	71.25	23.75	5
5	85.50	9.50	5
6	85.50	9.50	5

large quantities of amended bauxite residue. Preparation of the blends currently involves dry mixing, where the residue sand, red mud and gypsum are spread over a mixing area, and thoroughly blended using a rotary hoe (Anderson, 1991). However, an alternative to dry mixing is wet mixing, where the red mud and gypsum are combined in a slurry, and the excess fluid, containing salts and other possible ground-water contaminants, is decanted from the slurry before the residue sand is blended into the mixture.

The advantage of wet mixing may be an improvement in the quality of leachate originating from a wet mix. The disadvantages are the additional complexity, and hence cost, involved in wet mixing, and the necessity for dealing with the (possibly) contaminated fluid removed during the mixing procedure.

The leaching trials were conducted on five combinations of dry mixed residue sand and red mud, and one combination of wet mixed residue sand and red mud. All mixes were amended with the same percentage of waste gypsum. The gravimetric

percentages of the sand, mud and gypsum that were used in each mix are given in Table 2.

Mixes 1 to 5 were dry mixes and mix 6 was a wet mix.

Mixes 1 to 5 were selected to allow the comparison between leachate characteristics of mixes with high residue sand content, and mixes with high red mud content. Mix 6 was chosen to allow comparison between leachate characteristics of wet mixed and dry mixed residues of the same composition. It was hoped that the latter comparison would provide data that could be used to assess any advantages or disadvantages of wet mixing.

The dry mixes were prepared by blending the relevant quantities of the dried materials (residue sand, red mud and gypsum) in a rotating drum for five minutes.

The wet mix was prepared by initially combining red mud, gypsum and de-ionised water in a slurry with a moisture content of approximately 100%. Excess water from the slurry was then removed for analysis, and the residue sand was blended into the dewatered mixture by hand. The final gravimetric moisture content of the wet mix was 5.7%.

The particle size distributions for mixes 1 to 5 are shown in Fig. 2; it was assumed that mix 6 had the same particle size distribution as mix 5.

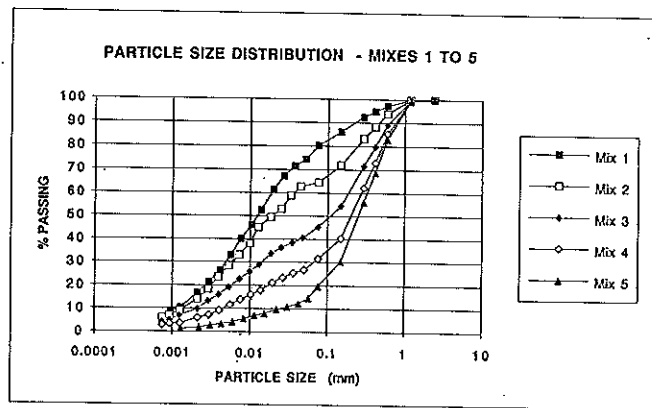


Fig. 2 Particle Size Distribution

DESCRIPTION AND PREPARATION OF APPARATUS

The leaching trials were conducted in eighteen polyvinylchloride columns. The columns were packed with the six combinations of residue blends, each mix set up in triplicate. For identification each column was labelled in the form A-B where:

A - indicated the mix in the column

and B - differentiated between columns of the same mix.

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(e.g. Column 3-1 was the first column containing mix 3)

The columns were 50 cm long with an internal diameter of 15 cm. The base of the column consisted of an end cap fitted with a 5 mm stop-cock. A three layer filter was constructed at the base of each column to prevent transportation of the finer particles with the leachate. The filter system comprised of 3 layers of filter paper overlying a dense layer of coarse silica sand. The sand had been placed on a disc of filter cloth that covered the outlet. A diagram of a column prior to packing is shown in Fig. 3.

The columns were packed in 50 mm layers to an optimum dry density of approximately 1400 kg/m^3 . In reality, some variability was noted in the achievable dry density for each mix. A dry density of about 1380 kg/m^3 was achieved in the columns packed with the mix containing the highest mud fraction (mix 1), whereas a dry density of 1560 kg/m^3 was achieved for the columns packed with the mix containing the highest sand fraction (mix 5). Furthermore, the mixes containing a high mud content had been heavily compacted, whereas the mixes with a high sand content were initially loose. As a result, the densities of the columns changed with watering, as shown by Fig. 4. It was, however, assumed that the density variation had little impact on the chemical test results.

When packed, the columns were strapped to a metal rack allowing access to the top of the column for watering, and access to the leachate collection bottles at the base of each column.

Throughout the leaching trial, the columns were stored in a temperature controlled room that was maintained around 22°C .

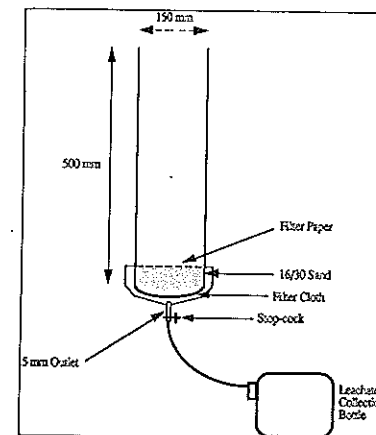


Fig. 3 Cross-section of Column.

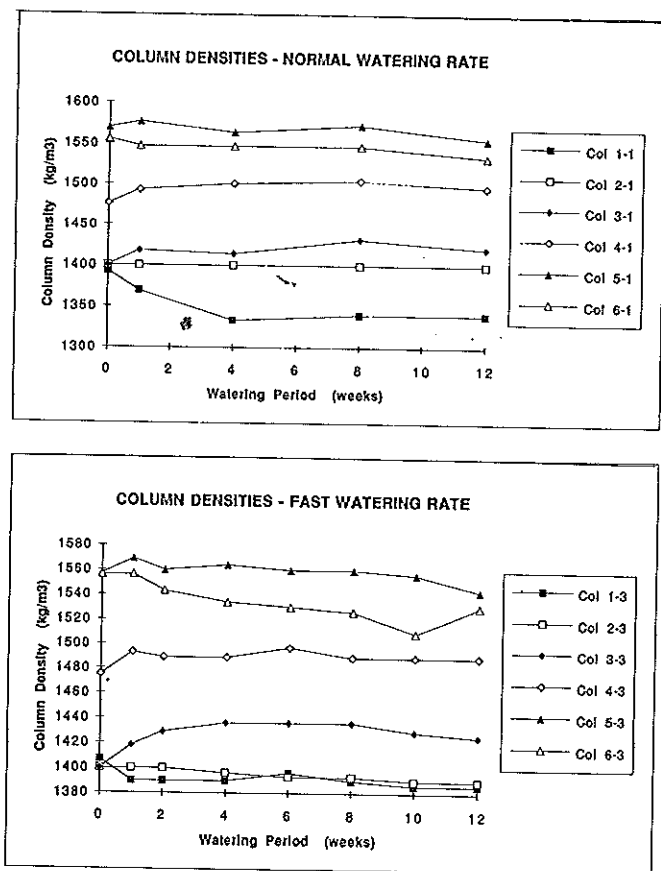


Fig. 4 Column Densities

LEACHING TRIAL PROCEDURE

The leaching trials involved watering the packed columns, collecting the leachate and submitting the leachate for analysis.

The columns were watered to simulate natural rainfall patterns in the locality of Perth, Western Australia. The monthly rainfall pattern followed that given by Ho *et al.* (1989), and is shown in Table 3.

All columns were watered with de-ionised water on a weekly basis. Columns A-1 and A-2 received the equivalent of a quarter of a months rainfall every week, which was approximately equivalent to the field operation, while columns A-3 received the equivalent of half a months rainfall every week, which was faster than the field opera-

Table 3 Average Monthly Rainfall and Equivalent Applied Volume for 150 mm Diameter Columns.

MONTH	NATURAL RAINFALL (mm/month)	EQUIVALENT VOLUME OF WATER (ml/month)
January	8	141
February	12	212
March	20	353
April	45	795
May	124	2190
June	181	3232
July	170	3073
August	133	2419
September	77	1413
October	53	971
November	20	371
December	13.5	247

Notes: (1) Columns A-2 received the equivalent of a quarter of a months rainfall once a week.
 (2) Columns A-3 received the equivalent of half a months rainfall once a week.

tion. The watering was conducted at two different rates to determine whether accelerated watering, which has the advantage of reducing the time scale of the experiment, influenced the test results.

The watering rate that simulated a quarter of a months rainfall every week was termed the 'normal' watering rate, whereas the rate that simulated half a months rainfall every week was termed the 'fast' watering rate.

The weekly application began with the simulated May rainfall. To initiate the tests, all columns received the entire April precipitation of 795 ml.

Leachate was collected and bottled on a weekly basis, prior to watering the columns. At the time of collection, the volume, temperature and pH of the leachate were measured.

Chemical analyses were conducted on all leachates collected. The leachates were analysed for sodium (Na), sulphur (S), cadmium (Cd), iron (Fe), calcium (Ca), alumi-

nium (Al), and fluoride (F). These elements were chosen for several reasons. First, the major salts leached from gypsum amended residue are sodium sulphate and calcium sulphate (Barrow, 1982). Second, iron oxide minerals and aluminium oxide minerals comprise a significant percentage of both the residue sand and the red mud. Finally, the gypsum used to neutralise the residue typically contains fractions of fluoride, aluminium and cadmium (refer to Table 1). Concentrations of these elements in the leachate may be of environmental significance if they result in unacceptable levels in groundwater.

The chemical analyses for Na, S, Cd, Fe, Ca and Al were conducted using an ICP Optical Emission Spectrometer, in the Chemical Department at the University of Western Australia. The fluoride analysis was conducted, using a fluoride electrode, by Australian Laboratory Services Pty. Ltd. (Brisbane Laboratory).

EXPERIMENTAL RESULTS

The results from the leaching trial tests are presented in this section. Only data from the columns A-1 are discussed in relation to the performance of the residue blends under a normal watering rate. The data from the columns A-2, which were also subjected to a normal watering rate, are not being presented, because the results show similar trends to those observed for the columns A-1. A full presentation of the data from all leaching trial tests is given in Anderson (1991).

LEACHATE PRODUCTION AND TEMPERATURE

The volume of leachate produced from each column was measured at the time of collection. The cumulative volume of water added to the columns, and the cumulative volume of leachate produced from the columns, is given in Fig. 5.

In all columns, the volume of leachate produced was less than the volume of water added, due to evaporative losses and moisture retention in the soil. Following the first leachate collection, the difference between the volume of water added and the volume of leachate collected in each watering period remained fairly constant. It was assumed that this difference represented losses due to evaporation. By allowing for the loss of water through evaporation prior to leachate production, an estimate of the moisture retention in each column was determined. The moisture retention estimates are given in Table 4. The estimates show that the higher the red mud content of the soil, the greater the amount of moisture retained in the soil.

Following the first leachate production, it was noted that the volume of water added to all mixes produced leachate within a period of two days; with the columns containing high contents of sand producing leachate within a few hours of watering. This suggests that all residue blends remained effective at transmitting fluid during the trial period.

The temperature of the leachate was measured at the time of collection. A range of temperatures between 17°C and 23°C was observed during the course of the experiment. Because the pH meter compensated automatically for temperature, variability

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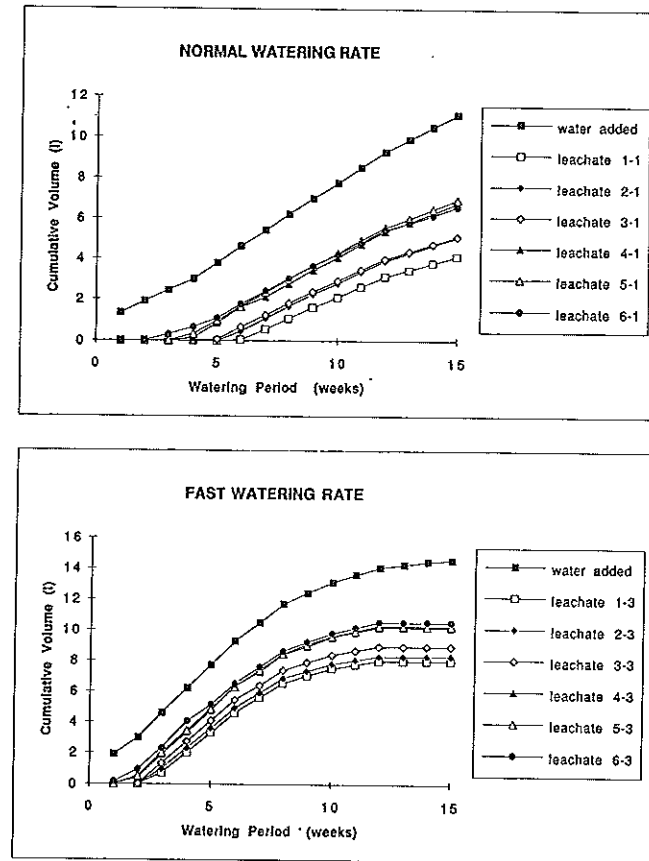


Fig. 5 Cumulative Volume of Water Added and Leachate Collected

in leachate temperature had no impact on the measured pH values.

pH of Leachate

The pH values of the leachate are presented in Fig 6.

In general, it was observed that the higher the red mud content, the higher the initial pH of the leachate. The leachate from the columns containing mix 1 (80% mud), mix 2 (62% mud) and mix 3 (43% mud) had initial pH levels between 8.5 and 9.0, whereas the leachate from the columns containing mix 5 (85% sand) and mix 6 (85% sand) had initial pH levels between 7.5 and 8.25. However, the leachate from all columns quickly moved towards an average pH of 7.5.

Table 4 Moisture Retention Estimates.

MIX NUMBER	MOISTURE RETENTION (l/kg)	
	COLUMN 1	COLUMN 3
1	0.31	0.34
2	0.30	0.31
3	0.27	0.28
4	* 0.24	0.24 ⁽¹⁾
5	0.22	0.23
6	0.17	0.17
6 ⁽²⁾	0.22	0.23

Notes: (1) The difference between the volume of water added and the volume of water collected did not become constant during this test. Thus, an average difference was used.
 (2) The values for mix 6 were adjusted to account for the fluid in the mix prior to watering.

At a normal watering rate, the leachate from mixes having a high mud content reached pH levels near 7.5 after leaching about 3 litres of water, whereas the mixes having a high sand content reached pH levels near 7.5 after leaching about 2 litres of water. At a fast watering rate, up to 8 litres was leached from the mixes having high mud contents before pH levels near 7.5 were reached. This suggests that the neutralisation of the leachate was influenced by the watering rate.

The leachate from mix 5 (dry mix) and mix 6 (wet mix) had similar pH levels. This indicates that the wet mixing procedure did little to reduce the alkalinity of mix 6. The effluent removed during the wet mixing had a pH of 8.28, indicating that the red mud was partially neutralised during mixing. However, as the mud comprised only a small fraction of the blend (9.5%), it is not surprising that the partial neutralisation of the mud did little to reduce the bulk alkalinity of mix 6.

Sodium Concentration

The sodium concentrations in the leachate from mixes 1 to 6 are presented in Figure 7. The quantity of sodium leached from each column over the test period is given in Table 5.

At the normal watering rate, the leachate from all the dry mixes (mixes 1 to 5) initially had concentrations of sodium, in the range of 60 g/l to 90 g/l. At the fast watering rate, the leachate from all the dry mixes had varying initial sodium concentrations, ranging from 43 g/l to 63 g/l. At both watering rates, the quantity of sodium leached was greater for the mixes having a high red mud content.

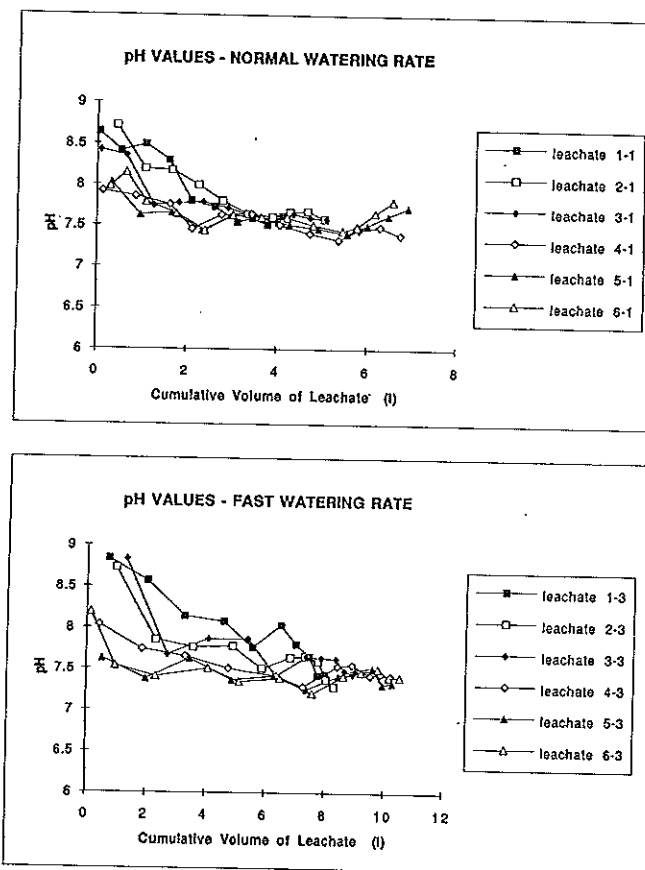


Fig. 6 pH of Leachate

The sodium concentration in the leachate from all the columns decreased rapidly. The final sodium concentrations in the leachate after one winter's rainfall (application of 8.6 litres of fluid) are given in Table 6. The data presented in this table confirm that the mixes with the highest red mud content leached fluid containing the highest concentrations of sodium.

For all the dry mixes, the columns watered at a faster rate produced leachate with a lower initial concentration of sodium. However, a greater cumulative volume of fluid was leached before the sodium concentration tapered off at a low level. This suggests that the attenuation of sodium in the leachate was affected by the watering rate. For all the mixes, the concentration of sodium in the leachate produced by the different watering rates tended towards the same value.

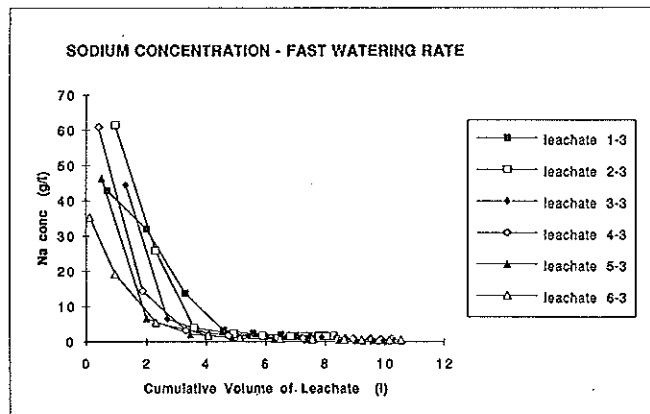
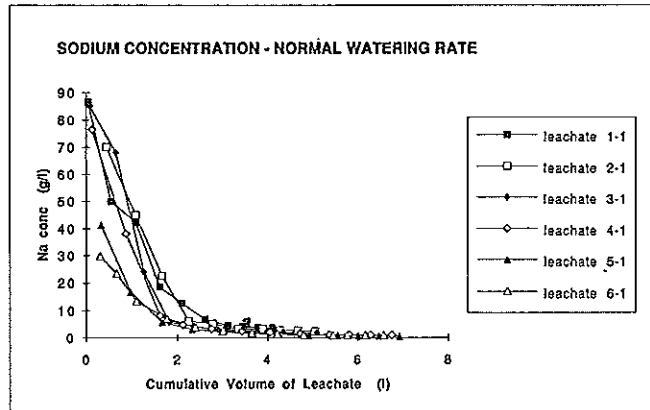


Fig. 7 Sodium Concentration of Leachate

Table 5 Quantity of Sodium Leached.

MIX NUMBER	SODIUM QUANTITY (g)	
	COLUMN 1	COLUMN 3
1	77.16	108.2
2	85.73	108.0
3	72.33	77.4
4	54.48	58.92
5	35.47	41.99
6	35.92	36.13

Table 6 Concentration of Sodium in the Leachate after One Winter's Rainfall (8.6 Litres of Watering).

MIX NUMBER	FINAL CONCENTRATION (mg/l)
1	1920
2	1600
3	1160
4	800
5	470
6	580

At both watering rates, the initial sodium concentration in the leachate from mix 6 (wet mix) was lower than the initial sodium concentration in the leachate from mix 5 (dry mix). The effluent removed during the wet mixing process had a sodium content of about 12g. However, the data presented in Table 5 indicate that the wet mix leached about the same quantity of sodium as the dry mix. Furthermore, the data given in Table 6 show that the average concentration of sodium in the leachate after one winter's rainfall (application of 8.6 litres of fluid) was marginally higher for the wet mix than the dry mix.

In general, the results indicated that the higher the red mud content, the greater the quantity of sodium produced. The results also indicated that the initial and final concentrations of sodium in the leachate were higher for the mixes with high mud contents. Furthermore, it was shown that wet mixing could result in a reduction in the initial concentration of sodium in the leachate, but not the overall quantity of sodium leached.

Sulphur and Sulphate Concentration

The leachate was analysed for sulphur content, however, the species of interest was sulphate. It was assumed that all sulphur present was in the form of sulphate. The atomic mass of sulphur is 32.1 and the atomic mass of sulphate is 96.1. The conversion from a sulphur concentration into a sulphate concentration involved multiplying the sulphur concentration by a factor of 3.0.

The sulphate concentrations in the leachate from mixes 1 to 6 are presented in Fig. 8. The quantity of sulphate leached from each column over the test period is given in Table 7.

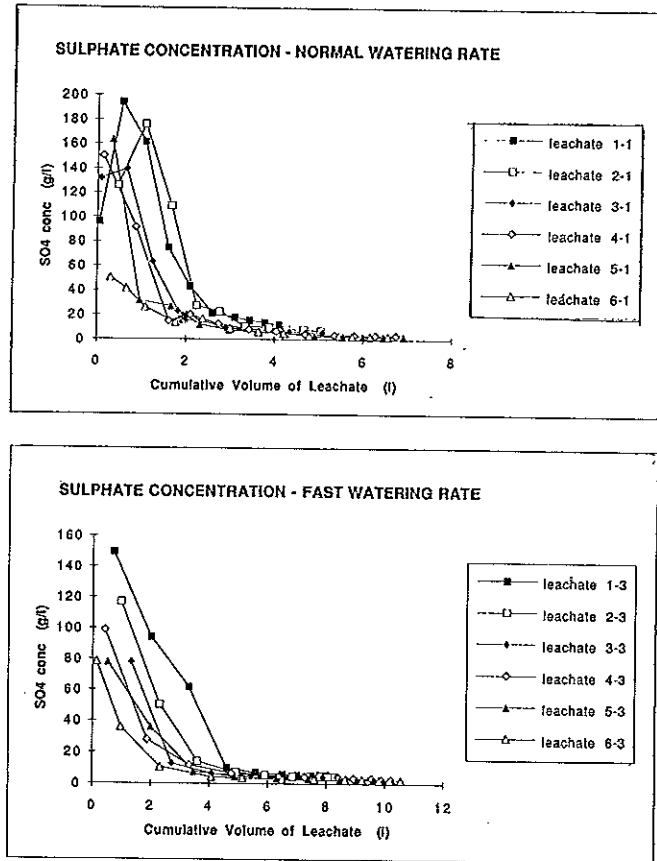


Fig. 8 Sulphate Concentration of Leachate

Table 7 Quantity of Sulphate Leached.

MIX NUMBER	SULPHATE QUANTITY (g)	
	COLUMN 1	COLUMN 3
1	281.6	341.7
2	279.7	226.2
3	170.2	151.8
4	136.4	132.2
5	120.0	129.7
6	80.8	82.1

At the normal watering rate, the concentration of sulphate in the initial leachate from the dry mixes ranged from 130 g/l to 195 g/l. At the fast watering rate, the concentration of sulphate in the initial leachate ranged from 70 g/l to 150 g/l. At both watering rates, the quantity and concentration of the sulphate leached was generally higher for the mixes having a high red mud content.

The sulphate concentrations in the leachate from the columns watered at a fast watering rate had decreased to relatively constant levels after 5 litres of leachate had been produced. The data presented in Fig. 8 suggest that the sulphate concentration in the leachate from the columns watered at a normal rate was also tending towards a constant value after 5 litres of leachate production. However, the graphs shown in Figure 8 indicate that the initial attenuation of sulphate in the leachate was dependent upon the watering rate.

The final sulphate concentrations after one winter's rainfall (application of 8.6 litres of fluid) are given in Table 8. Data presented in this table confirm that the leachate from residue blends with high red mud contents contained the highest concentrations of sulphate.

At both watering rates, the initial concentration of sulphate in the fluid leached from the wet mix (mix 6) was lower than the initial sulphate concentration in the fluid leached from the dry mix (mix 5). The effluent removed during the wet mixing process had a sulphate content of about 25g; although the data presented in Table 7 show that the wet mixing reduced the quantity of sulphate leached from the blend by about 50g. However, the data given in Table 8 indicate that wet mixing didn't reduce the level of sulphate concentration in the leachate after one winter's rainfall (application of 8.6 litres of fluid).

Table 8 Concentration of Sulphate in the Leachate after One Winter's Rainfall (8.6 Litres of Watering).

MIX NUMBER	FINAL CONCENTRATION (mg/l)
1	5580
2	4860
3	3850
4	2730
5	2220
6	2400

In general, it was observed that the mixes containing high contents of red mud leached greater quantities of sulphate. Furthermore, the results indicated that the mixes with high contents of red mud produced leachate containing high concentrations of sulphate. It was also observed that wet mixing reduced both the initial concentration of sulphate in the leachate, and the total quantity of sulphate leached. However, it was shown that the wet mixing process did not reduce the concentration of sulphate in the leachate after one winter's rainfall (application of 8.6 litres of fluid).

Calcium Concentration

The calcium concentrations in the leachate from mixes 1 to 6 are presented in Fig. 9. Table 9 presents the total quantity of calcium leached from the columns during the trial.

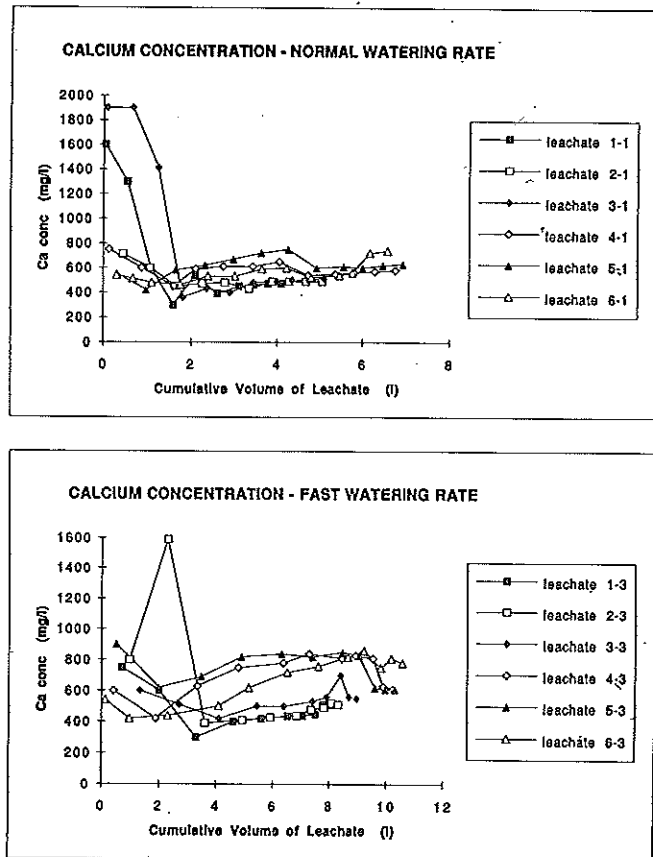


Fig. 9 Calcium Concentration of Leachate

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Table 9 Quantity of Calcium Leached.

MIX NUMBER	CALCIUM QUANTITY (g)	
	COLUMN 1	COLUMN 3
1	2.36	3.73
2	2.57	3.38
3	3.83	4.71
4	3.88	7.22
5	4.27	7.81
6	3.66	6.76

With the exception of the initial period, the calcium concentration in all leachate remained relatively constant throughout the trial; ranging from 0.3 g/l to 0.75 g/l for the normal watering rate, and from 0.4 g/l to 0.85 g/l for the fast watering rate. In general, it was observed that the higher the sand content in the mix, the higher the calcium concentration within the range specified.

Initially the calcium concentrations were as high as 1.9 g/l for some of the leachate collected. These peaks can not be explained, as there were no patterns or consistent trends regarding the size or positioning of the peaks.

Gypsum crystals were found in the leachate first produced by column 1-1 and column 4-2. The mass of the crystals were 4.87 g and 20.38 g, respectively. The presence of the crystals indicated that the solution was saturated with CaSO₄, thus giving the maximum solubility of the gypsum. The calcium concentration in leachate 1-1 was initially 1.6 g/l; this value is higher than would be anticipated for the maximum solubility of CaSO₄. The calcium concentration in leachate 4-2 was initially 0.9 g/l, which can be taken as the maximum solubility of CaSO₄ in leachate from mix 4.

The data presented in Fig. 9 and Table 9 give no clear indication that the wet mixing process was beneficial in either reducing the initial concentration of calcium in the leachate, or the quantity of calcium leached. The effluent removed during the wet mixing procedure had a calcium content of about 0.75 g.

Fluoride Concentration

The fluoride concentrations in the leachate from mixes 1 to 6 are presented in Fig. 10. Table 10 presents the total quantity of fluoride leached from each mix during the trial.

For all columns, the fluoride concentration in the leachate averaged between 10 mg/l and 20 mg/l throughout most of the test period. However, at both watering

Table 10 Quantity of Fluoride Leached.

MIX NUMBER	FLUORIDE QUANTITY (mg)	
	COLUMN 1	COLUMN 3
1	63	131
2	87	114
3	67	135
4	72	108
5	56	100
6	68	114

Table 11 Concentration of Fluoride in the Leachate after One Winter's Rainfall (8.6 Litres of Watering).

MIX NUMBER	FINAL CONCENTRATION (mg/l)
1	12.1
2	11.7
3	11.7
4	5.2
5	5.3
6	5.8

rates, there is some indication that the fluoride concentration in the fluid leached from the mixes with higher sand contents (mixes 4-6) was reducing towards the end of the trial; although it is apparent from Figure 10 that the reduction of fluoride concentration in the leachate was influenced by the watering rate. The final concentrations of fluoride in the leachate after one winter's rainfall (application of 8.6 litres of fluid) are given in Table 11.

Each column contained 475 g of gypsum, suggesting that 2.85 g of fluoride was available for leaching (refer to Table 1). However, the data presented in Table 10 show that the total quantity of fluoride leached during the trial was significantly less than this figure.

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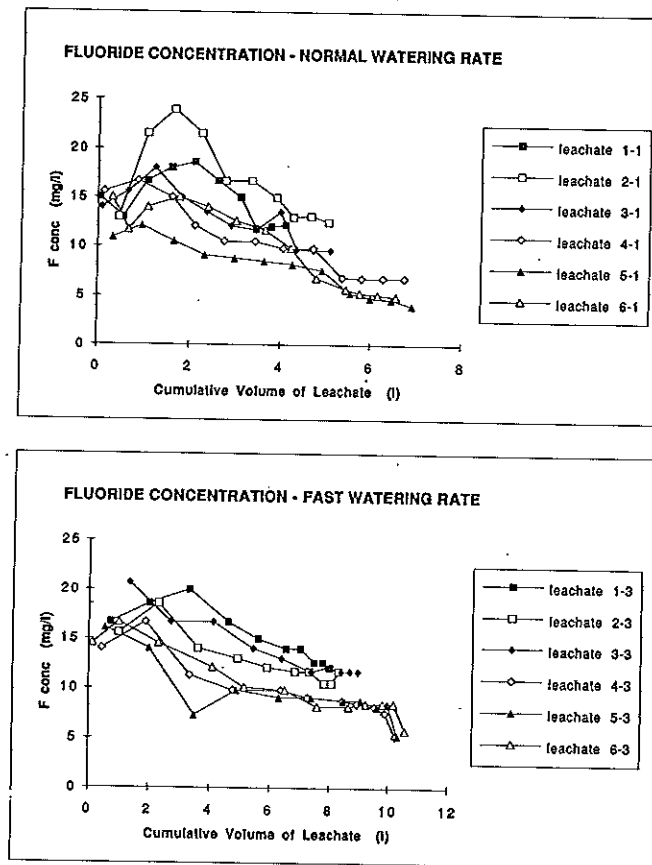


Fig. 10 Fluoride Concentration of Leachate

The data presented in Figure 10, and Tables 10 and 11, indicate that the wet mixing process was not beneficial in reducing either the concentration of fluoride in the leachate, or the quantity of fluoride leached.

Aluminium Concentration

The aluminium concentrations in the leachate from mixes 1 to 6 are presented in Fig 11.

Initially the aluminium concentration in the leachate ranged between less than 0.1 mg/l (the detection limit of the ICP Optical Emission Spectrometer) and 12.5 mg/l. However, for all columns the aluminium concentration eventually settled between 4 mg/l and 8 mg/l, with the higher concentrations of aluminium being associated with the dry mixes containing high fractions of sand.

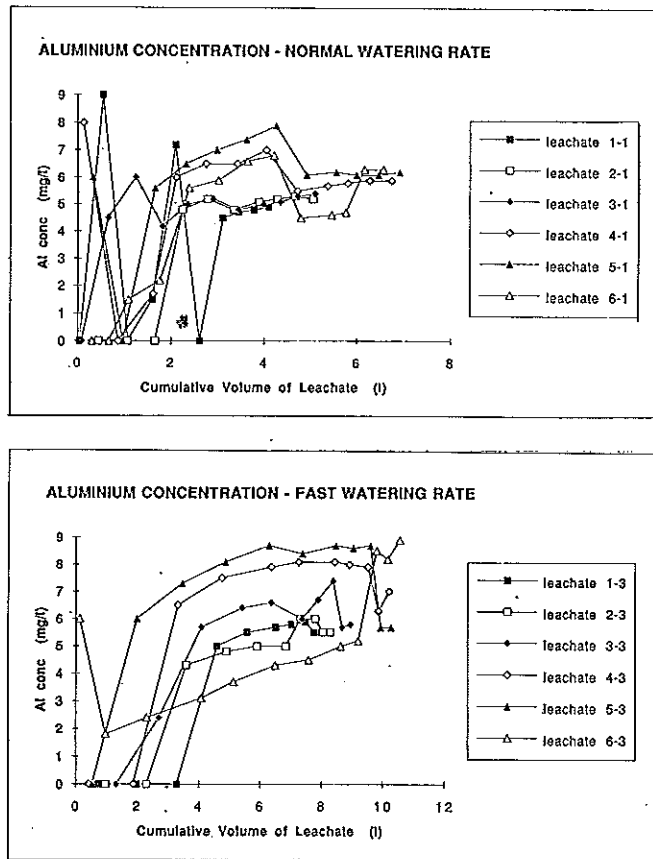


Fig. 11 Aluminium Concentration of Leachate

At the normal watering rate, the concentration of aluminium in the leachate stabilised after the production of about 3 litres of leachate. At the fast watering rate, the concentration of aluminium in the leachate stabilised after the production of about 5 litres of leachate. It therefore appears that the concentration of aluminium observed in the leachate was also dependent upon the watering rate.

There is some indication that the wet mixing process reduced the concentration of aluminium in the leachate (refer to Fig.11); although the concentration of aluminium was higher in the leachate originating from the wet mix at the end of the trial. The concentration of aluminium in the effluent removed during the mixing process was 5 mg/l.

Iron and Cadmium Concentration

The concentration of iron in the leachate was less than 0.1 mg/l; the detection limit of the ICP Optical Emission Spectrometer. In Section 2.1 it was stated that the iron oxide content in the residue sand and red mud was above 30%, thus the lack of iron in the leachate initially appears inconsistent with a chemical analysis of the residue. An explanation of this phenomenon was proposed by Ho et al. (1989). Leachate from red mud alone contains iron in the form of colloidal particles. The addition of gypsum flocculates the colloidal particles, thus preventing the transport of iron into the leachate.

The concentration of cadmium in the leachate was below the detection limit of the ICP Optical Emission Spectrometer (0.1 mg/l).

No iron or cadmium was detected in the effluent removed during the wet mixing process.

Phosphate Retention Index

The phosphate retention index (PRI) for a soil is the ratio of phosphorus adsorbed by soil to that remaining in solution under a set of standard conditions. PRI values for some of Western Australia's soils in their virgin state range from 0, for Joel sand, to 70, for Gingin red loam (McPharlin et. al. 1990).

PRI tests were conducted on the six mixes prepared for the leaching trials to determine their phosphorus retention capacity. The PRI test results are given in Table 12. The data confirm that the amended bauxite residue has a much greater phosphorus retention capacity than many native Australian soils.

The mixes with a high mud content had greater phosphorus retention capacities than the mixes with a high sand content. Results reported by McPharlin et al. (1990) indicate that higher PRI values are associated with higher percentages of iron and aluminium in virgin soils. Because the red mud contains higher quantities of iron and aluminium than the residue sand (refer to Section 2.1), it appears consistent that the high mud content samples possessed the higher PRI values.

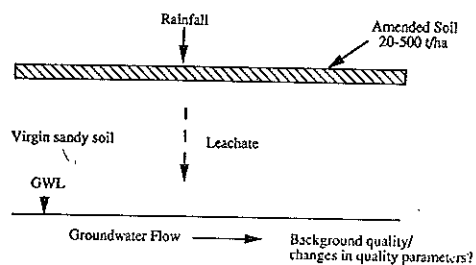
Table 12 Phosphate Retention Indices (supplied by Alcoa of Australia).

MIX NUMBER	PRI
1	> 1000
2	> 1000
3	> 1000
4	1000
5	> 1000
6	700

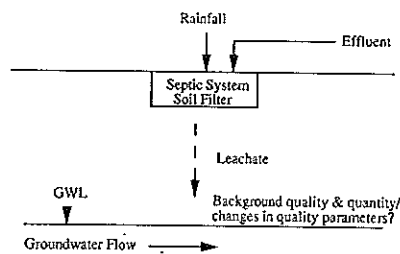
DISCUSSION

Red mud neutralised with waste gypsum and blended with local sand or residue sand, is being considered for use in areas where rainfall infiltration or effluent infiltration could impact groundwater quality. The results from the leaching trials conducted on total residue blends have provided data that could be used to assess the possible impact of amended bauxite residue on groundwater quality. Figure 12 illustrates hypothetical models where the data might be used.

Fig. 12a relates to the use of residue blends for the improvement of sandy soils for a range of agricultural and other uses. Residue is typically applied to virgin soil at a rate of 20-500 tonnes of residue/gypsum blend per hectare (Tracy *et al.* 1984). Data from the trial could be used to estimate the concentration of rainfall leachate from a representative volume of amended soil: clearly, this concentration would be lower than the concentration of leachate originating from a total residue blend.



a) Use of Residue Blends for Improvement of Sandy Soils



b) Use of Residue in a Septic Tank System

Fig. 12 Schematic Representation of Two Cases of Residue use for Leachate Transport Analysis

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Fig. 12b relates to the use of amended residue in septic tank systems. Once again, data from the trial could be used to estimate the concentration of rainfall leachate originating from a septic system containing a bauxite residue filter.

In general, results from the trial indicate that leachate originating from a residue blend with a high sand content would be expected to have a lower initial pH, and lower sodium, sulphate and fluoride concentrations, than the leachate originating from a blend with a high mud content. However, results from the study also indicate that a high sand content blend is likely to leach higher concentrations of calcium and aluminium, and have a lower moisture and phosphate retention capacity, than a high mud content blend. The study demonstrated that all blends remained effective in transmitting fluid over the period of the trial. The location and proposed use of the residue blends therefore need to be considered when selecting the optimum composition.

Data from the trial suggest that wet mixing could result in a reduction of the initial concentrations of sodium, sulphate and aluminium leached from the residue blends. However, the trial data also suggest that wet mixing was not beneficial in improving the quality of rainfall leachate from a residue blend after one winter's rainfall. Furthermore, it was observed that the wet mixed blend had a lower Phosphate Retention Index than the corresponding dry mixed blend.

The excess solution removed from the residue blend during wet mixing contained salts and other possible groundwater contaminants. In practice, this solution would have to be dealt with in a manner that did not adversely effect groundwater quality. Results from the trial therefore suggest that the wet mixing procedure does not offer significant advantages over dry mixing.

Data from the trial demonstrated that the rate of watering influenced the initial pH of the leachate, and the initial concentrations of sodium, sulphate, fluoride and aluminium in the leachate. Caution ought therefore be applied when relating data from accelerated leaching trials to the field situation; although, in all cases it was observed that the attenuation of leachate concentration was slower at the faster watering rate. This might suggest that, in reality, less fluid would have to be leached through a residue blend in order to improve its quality, than is actually suggested by an accelerated laboratory trial.

CONCLUSIONS

The work reported in this paper examined leachate quality from various bauxite residue and gypsum blends. The study was initiated to provide data that could be used to assess the possible impact of schemes involving alternative applications for bauxite residue.

The results from the study indicated that the concentrations of sodium and sulphate leached from the residue blends were initially in the range of 85 g/l and 160 g/l, respectively, but decreased rapidly with increasing cumulative volume of leachate. Furthermore, it was shown that wet mixing could result in a reduction of the initial

salt concentrations in the leachate.

The study also indicated that fluoride concentrations in the leachate were initially in the range of 20 mg/l, but demonstrated that some reduction in fluoride concentration might occur with increasing cumulative volume of leachate. However, leachate concentrations of aluminium and calcium were observed to remain relatively constant at 6 mg/l and 600 mg/l, respectively, throughout the trial.

The neutralisation of the alkaline residue with waste gypsum was shown to be successful for all the blends tested. Furthermore, the phosphate retention capacity of all blends was found to be high in comparison to the retention capacity of many virgin West Australian soils.

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