EXTRACTION KINETICS OF WEIPA MONOHYDRATE BAUXITE

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Abstract

Weipa bauxite is mainly present in pisolitic (pea-like) form and is typically ground to liberate alumina prior to high-temperature digestion. Digestion residence time is kept relatively short to minimise quartz attack.

Laboratory tests were undertaken to study the digestion kinetics. Tests using monodispersed bauxite size fractions at 10 minutes residence time showed effectively complete extraction for particles up to 850 µm diameter. Above this size, alumina extraction begins to fall away.

A simple shrinking-core extraction model was found to give an excellent fit to the experimental data. The shrinkage rate correlated strongly with the bauxite boehmite content. The model was extended to cover broader particle size distributions, which then predicted that the bauxite needs to be significantly finer than 850 µm to ensure complete extraction. Laboratory tests and plant operating data validate these predictions.

1. Introduction

Weipa bauxite, from the Cape York Peninsular in northern Australia, occurs naturally in pisolitic form. The median pisolite size (after beneficiation) is about 5 mm. About 20 to 30% of the extractable alumina in the bauxite is present as boehmite, which necessitates high temperature digestion (200–280°C).

The bauxite also contains approximately 1 to 2% quartz. This quartz undergoes caustic attack and conversion to desilication product at the high digestion temperatures, resulting in increased caustic soda consumption. By keeping digestion residence time relatively short (5–15 minutes), quartz attack and hence caustic soda consumption can be held at manageable levels. The optimum residence time represents a trade-off between the respective kinetics of alumina extraction, quartz attack and silica reprecipitation.

Quartz attack and silica precipitation kinetics have been studied and reported previously (Oku 1971, Breuer 1962). Extraction kinetics of gibbsitic bauxites up to 1.1 mm diameter have been studied by Wahnsiedler (1985). The current work studies alumina extraction kinetics for coarse particles of boehmitic Weipa bauxite.

2. Experimental

A range of monodisperse size fractions between 45 and 6700 µm were prepared from a sample of Weipa monohydrate grade bauxite. The size fractions below 425 µm were prepared by ring grinding, while those above 425 µm were prepared by crushing. Some size fractions above 1000 µm were prepared from as-received pisolites. All size fractions were separated by dry sieving and analysed for chemical composition by XRF.

Extraction kinetics were tested by gas-fired laboratory bomb digestion into plant spent liquor at 250°C. Extraction was measured based on both liquor-phase and solid-phase balances.

Samples with varying boehmite contents were prepared by dense-media separation using mixtures of tetrabromoethane and perchloroethylene.

3. Results

The first series of experimental results had been carried out some years earlier at QAL by Wehrli (1992). These are summarised below in Table 1.

Table 1 — Extraction results for different size fractions. Digest Temperature 250°C, hold time 10 minutes, target caustic = 190 g/L as Na_2CO_3, target A/C ratio 0.700 as Al_2O_3/Na_2CO_3.

Size Fraction (µm)	Extraction (%)
45–63	95.1
75–90	95.9
106–150	94.8
150–250	96.0
425–600	95.5
600–850	95.2
850–1000	93.8
1000–1400	93.4
1400–2000	90.0
2000–2800	86.8
2800–4000	78.7
4000–4750	72.6
4750–5600	72.7
5600–6700	65.5

The results in Table 1 show an upper extraction limit of about 96%, even for the finer size fractions. The extraction figures are reported as a percentage of total alumina, after allowance for kaolin content and quartz attack. The 4% unextracted alumina is assumed to be mainly due to incomplete extraction of alumina-substituted goethite.

Extraction falls away fairly rapidly for particle sizes above about 850 µm. For these larger size fractions, the unextracted residue was observed to contain coarse particles, although insufficient sample remained to permit particle size distribution measurement.

3.1 *Extraction Model*

The incomplete extraction and coarse residue observed for larger particle sizes, is suggestive of a shrinking-core mechanism for extraction. A simple shrinking-core model was proposed and tested:

$$\frac{dD}{dt} = -2kM^n \ (D > O) \tag{1}$$

where D is particle diameter, and M is the driving force for extraction and is assumed equal to $A/C_{equil} - A/C_{(t)}$. The relevant equilibrium alumina concentration was assumed to be the boehmite solubility limit. Under the experimental conditions for Table 1, an equilibrium solubility of 0.717 A/C was determined based on QAL boehmite solubility relationships.

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Using a numerical integration of Equation (1), a rate constant k was determined by non-linear regression to give a least-squares best fit to the data in Table 1. This was done assuming zero-order (n = 0), first-order (n = 1) and second-order (n = 2) kinetics. The heat-up and quench time for the bomb digests was assumed to add 1 minute to the effective digestion time. Unextractable alumina was assumed to be 4% of total available alumina. The results are shown in Figure 1.

The results show very good agreement between the experimental results and a first-order shrinking core model. A rate constant of k = 7.6 µm/s was determined.

3.2 *Effect of Digestion Time*

Two different bauxite size fractions (1400-2000 and 2000-2800 µm) were bombed for 0, 5, 10 and 20 minutes, and the resulting extractions compared to those predicted

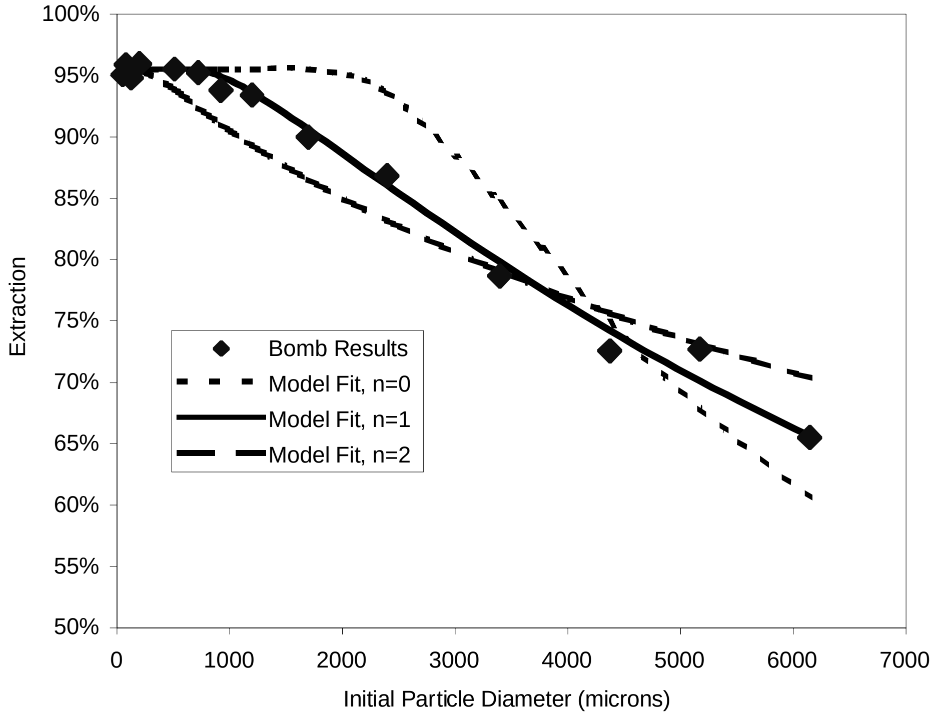

Figure 1 — Shrinking-Core Model Fit to Data in Table 1

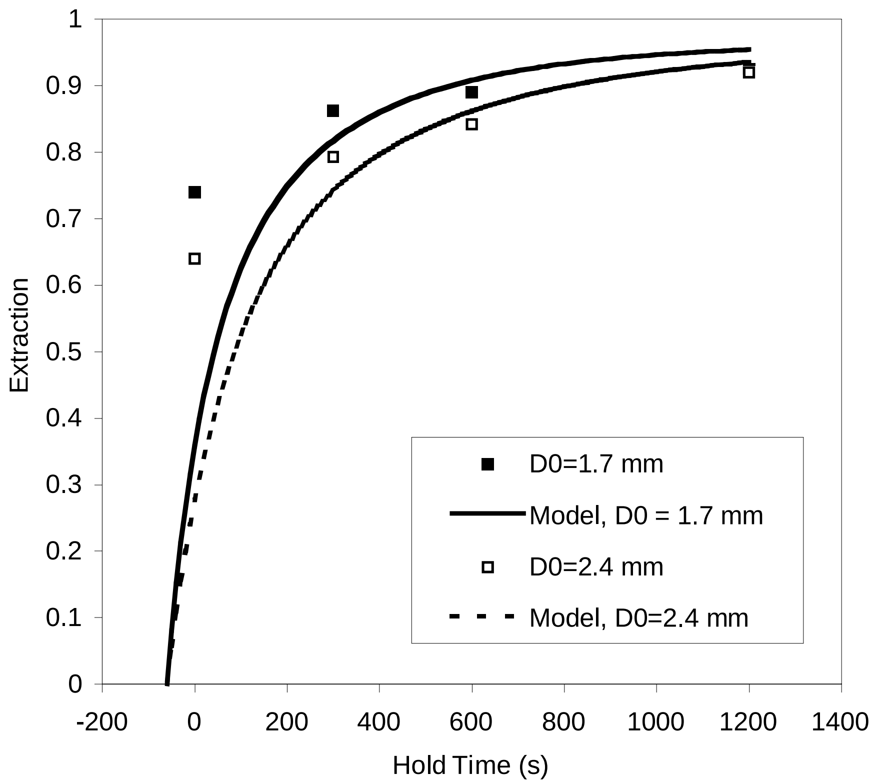

Figure 2 — Extraction versus Digestion Time

from the shrinking core kinetics. A poor fit was obtained, as shown in Figure 2.

Elemental SEM examination of the unextracted bauxite particles suggests a possible reason for the discrepancy in Figure 2. Considerable leaching of alumina is happening below the surface of the shrinking bauxite particle, as seen in Figure 3. The alumina-depleted layer is around 400 µm thick, and is believed to be due mainly to gibbsite dissolution.

A second term was added to the extraction model to represent the inside diameter of the partially leached layer:

$$D_c = D - 2\delta \quad (1)$$

Where δ is the leached layer thickness. Extraction of gibbsite within the leached layer is assumed to be effectively instantaneous, with the alumina extracted equal to the bauxite gibbsite content. Assuming a value of δ = 400 µm, and using a gibbsite content of 75% of the total alumina, the data from Table 1 was re-fitted to give a rate constant of k = 7.3 µm/s. The result is a considerably improved fit to the effect of digest time on extraction.

3.3 *Effect of Boehmite Content*

Extraction kinetics were measured for bauxite samples with a range of boehmite contents. The results are summarised in Figure 6.

The boehmite contents for the low, mid and high boehmite samples were 1%, 17% and 42% respectively, compared to 12% for the original work (all as measured by XRF using mineralogical calculations).

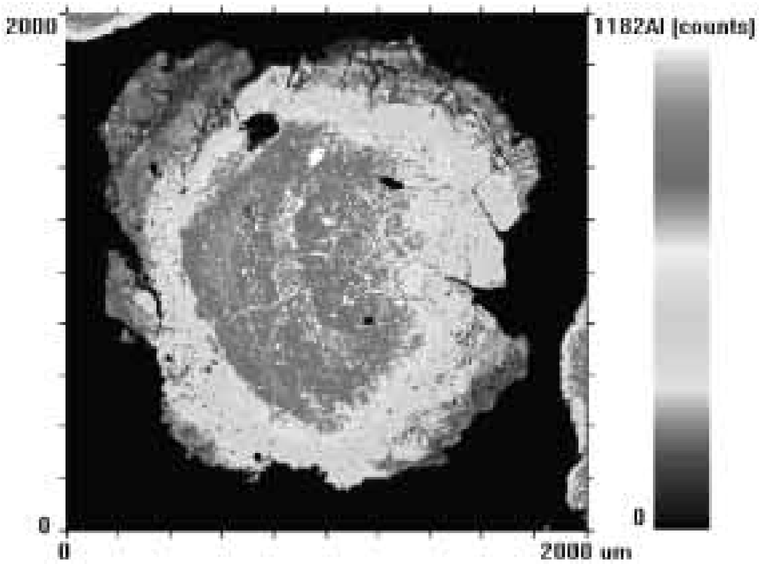

Figure 3 — Elemental SEM of Sectioned Bauxite Particle After Bomb Digestion

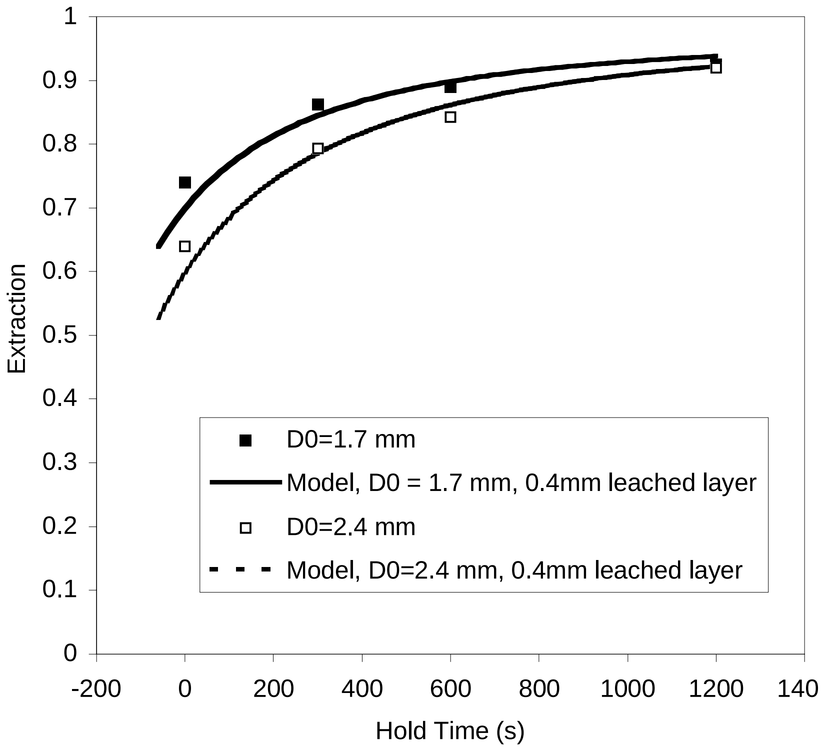

Figure 4 — Extraction Versus Time, Improved Model

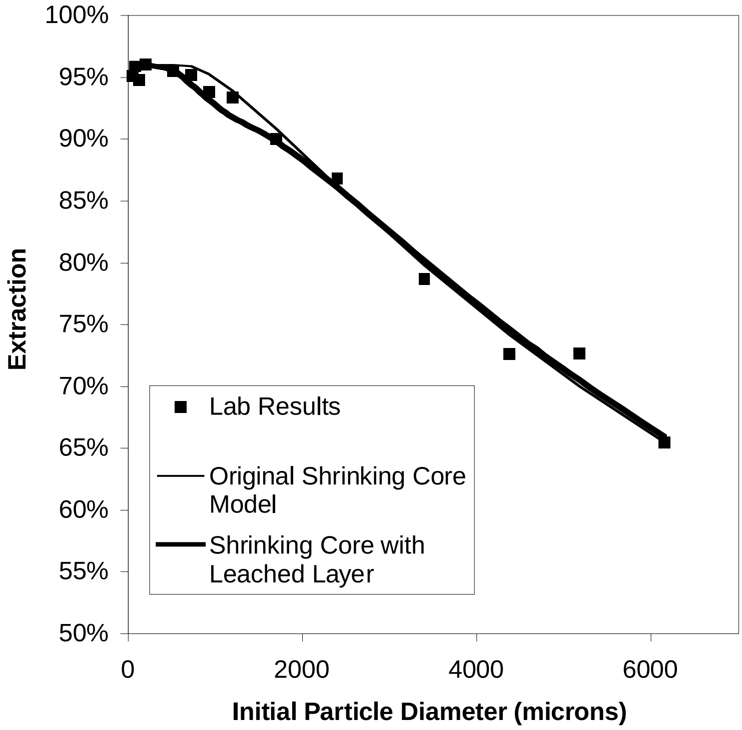

Figure 5 — Revised Shrinking-Core Fit to Data in Table 1

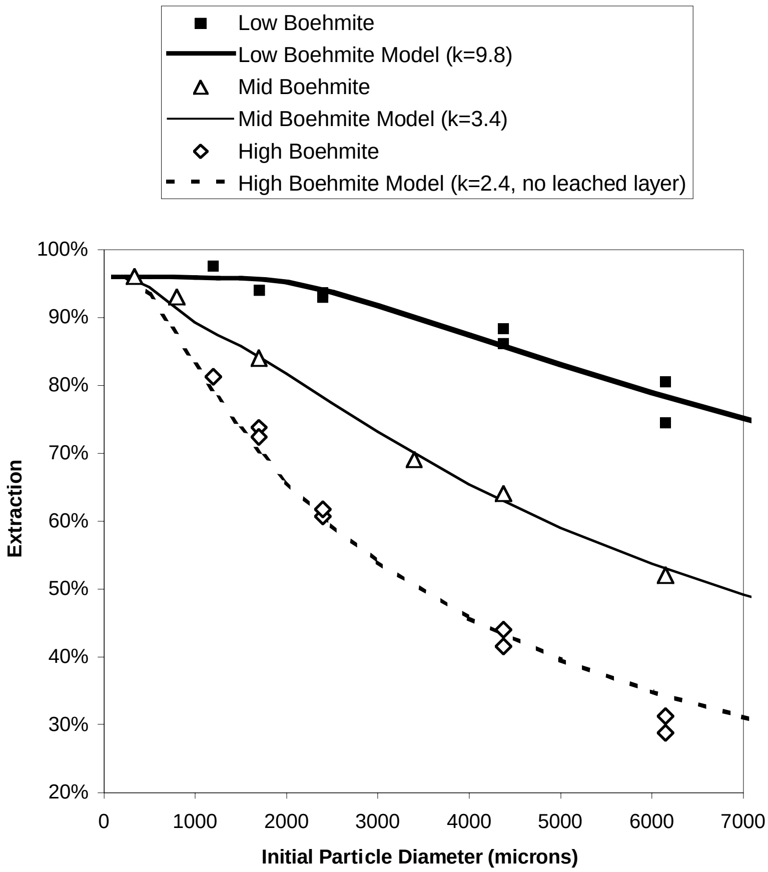

Figure 6 — Extraction versus Particle Size for Bauxites with Different Boehmite Contents

A best-fit rate constant was determined for each boehmite level. For the highest boehmite sample, the "leached layer" thickness had to be reduced significantly in order to obtain a good fit. This is not unreasonable, as the low gibbsite content (18%) will hamper the gibbsite-leaching mechanism. A reasonable fit to all data was achieved by assuming that the leached-layer thickness is proportional to the bauxite gibbsite content.

The impact of boehmite content on kinetic constant is summarised in Table 2.

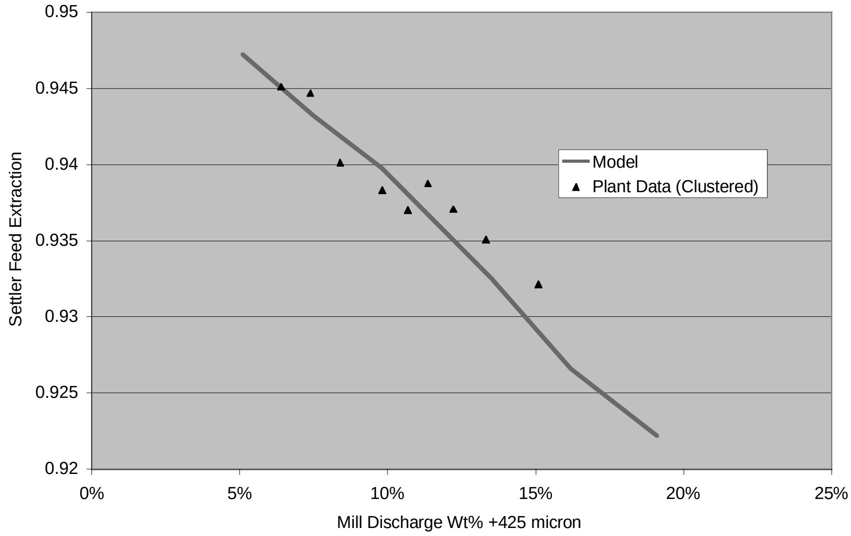

Figure 7 — Plant Digestion Extraction versus Grind

Table 2 — Influence of Boehmite Content on Extraction Kinetics

Boehmite Content	k
42%	2.17
17%	3.42
14%	5.92
12%	8.07
1%	8.33

3.4 *Particle Size Distribution Effects*

The data in Table 1 suggests that particles up to 850 µm diameter should be fully extracted under normal digestion conditions. However, the proposed extraction model implies that boehmite subsaturation is the main driving force for shrinkage of large particles. This in turn implies that the presence of fine particles (which extract rapidly to increase liquor alumina concentration) will retard the extraction rate of larger particles. The result of this “interference” is that the required particle size for complete extraction reduces from 850 µm to about 500 µm.

This interaction between fine and coarse particles was tested by preparing a mixture of 50% 5600-6700 µm particles and 50% 600-1000 µm bauxite particles. Assuming 94.5% extraction of the fine particles and 65.5% extraction of the coarse particles (from Table 1), a weighted average extraction of 80% would be expected. However, if rapid dissolution of the fine particles inhibits extraction of the coarse particles, then the shrinking-core model predicts an average extraction of 73%. This experiment was carried out and gave an extraction of 74%.

3.5 *Plant Application*

A numerical simulation of digestion under plant conditions was developed, combining the extraction kinetic model developed above, with Particle Size Distribution, residence time distribution, and particle settling effects. The alumina extraction predicted from this simulation, is compared to plant historical data from a 10-year period, in Figure 7. The plant data in this figure have been clustered using the following algorithm to reduce scatter: The 12 months having the 12 lowest +425µm values were averaged to give the first data point, then the next 12 lowest +425µm values, etc.

As a result of this analysis, bauxite grinding targets have been changed. Increased media charge and operating factor have reduced the percent +425 µm material from 13% (1996-1999 average) to 8% (2001 average). Digestion extraction has increased by 0.4% in this time, despite digestion aim safety margin being reduced by 0.01 A/C relative to the boehmite equilibrium.

4. Conclusion

The high-temperature digestion of coarse Weipa bauxite particles is governed by shrinking-core type kinetics. The diameter reduction rate is apparently first-order with respect to boehmite subsaturation. There is evidence of significant gibbsite leaching ahead of this srinking core front.

The rate constant for particle shrinkage is a strong function of boehmite content, with high boehmite levels producing lower shrinkage rates.

The presence of rapidly-extracting fine particles can interfere with extraction of coarser particles.

Acknowledgements

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