Life cycle assessment of seawater neutralised red mud for treatment of acid mine drainage

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\textbf{A B S T R A C T}

One feature that has not been analysed in the re-use of bauxite residue (or “red mud”) is the comparison of its environmental benefits with competing products. The life cycle assessment (LCA) described in this article compares the use of seawater neutralised red mud to treat acid mine drainage (AMD) at Mount Morgan in Queensland, Australia with that of lime. The aim of the LCA is to evaluate the environmental merits of each neutralant by comparing the carbon dioxide emissions and the net energy use over their respective life cycles. Both life cycles involve the collection and processing of raw materials from Gladstone in Central Queensland, their transportation to Mount Morgan (about 150 km away) and finally their application in a wastewater treatment plant. This plant, which currently uses lime as its treatment media, increases the pH of the acidic open cut pit water to acceptable levels for discharge. The results of the analysis revealed that seawater neutralised red mud would, over the entire life cycle, generate 20% of the carbon dioxide emissions and use 44% of the electricity compared with that of lime. This amounts to a saving of about 3500 kg of carbon dioxide for every 1000 m\textsuperscript{3} of pit water treated. However, as red mud is a much weaker neutralant compared with lime on a weight basis, significantly more red mud is required to perform the same duty; as a result the fuel usage in the red mud scenario is 12 times that compared with lime, which is primarily due to increased transportation requirements for red mud. The results of a sensitivity analysis demonstrated that even if the seawater neutralised red mud neutralisation capability was half the expected value, seawater neutralised red mud would still generate only 35% of the carbon dioxide and use 44% of the electricity compared with that of lime. The fuel usage for seawater neutralised red mud would, however, be nearly 24 times greater than that for lime.

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1. Introduction

Bauxite residue (or “red mud”), a by-product from alumina refining, has properties that can assist the process of environmental remediation (Cooling and Jamieson, 2004; Jamieson et al., 2005; Komnitsas et al., 2004; Lin et al., 2004). One of the characteristics of research to date into the re-use of bauxite residue is that the environmental impacts have not always been part of the assessment process. This is not to say that the environmental issues related to red mud re-use have been neglected, but rather researchers have not taken a holistic view of the benefits and impacts of re-using red mud. In particular, life cycle assessments (LCA) have been conducted on the primary aluminium supply chain but have not been conducted extensively on red mud. If there were favourable environmental benefits of re-using red mud compared with standard practices, this may provide the catalyst for red mud re-use initiatives.

One possible re-use option for red mud is as an alternative neutralant to lime in the treatment of acid mine drainage (AMD). AMD results in the generation of sulphuric acid when water flows through the exposed sulphide rock, causing a decrease in water quality and pH.

For red mud to be an effective neutralant, it must be first neutralised using seawater to increase its acid neutralisation capacity (Hanahan et al., 2004).

The LCA described in this article compares re-using seawater neutralised red mud to treat AMD with the commonly used neutralising agent, lime. The assessment compares net energy use, fuel consumption and emission levels of carbon dioxide associated with using lime for treating AMD at the Mount Morgan Mine Site in Queensland, Australia, with that of using seawater neutralised red mud. Both LCAs involve the collection and processing of the treat-
ment media (lime or seawater neutralised red mud) from Gladstone (about 150 km south-east of Mount Morgan), the transportation of the treatment media to Mount Morgan, and finally its application in a wastewater treatment plant (WTP) installed upstream of the watercourse that flows into Dairy Creek, a tributary of the Dee River. The WTP uses the treatment media to increase the pH of the acidic open cut pit water to acceptable levels for discharge. The waste resulting from used treatment media is discharged to the base of the open cut pit.

The overall aim of this study was to compare environmental impacts over the life cycles of the different neutralants, lime and seawater neutralised red mud, in controlling acidic water discharges from the Mount Morgan pit. In particular, as carbon dioxide is generated in the production of lime, there was an expectation from the outset of this study that seawater neutralised red mud would result in a lower carbon footprint compared with lime.

2. Background

2.1. Bauxite residue (red mud)

The by-product stream from alumina production via the Bayer process is termed bauxite residue, often colloquially referred to as red mud. In its typical form, red mud is brick red in colour, caustic, about three times as dense as water and, when un-neutralised, has a high pH—typically around pH 13 (Paramguru et al., 2005). It is primarily composed of iron oxide, silica and alumina, amongst traces of other heavy metals (International Aluminium Institute, 2000). Red mud particles are quite small; typically 99% will pass through a 0.6 mm sieve and 87% through a 0.038 mm sieve (Paramguru et al., 2005).

For every t of alumina that is produced, the amount of red mud generated can vary from 0.3 to 2.5 t, depending on the characteristics of the bauxite (International Aluminium Institute, 2000). As typically 1–2 t of red mud is generated in Australia for every t of alumina produced, the amount of red mud produced is probably more than 20 million t per year based on the current annual Australia alumina production figure of 18.5 million t (ABARE, 2007). At the two Gladstone alumina refineries in Queensland, red mud is neutralised with seawater to approximately pH 8 or 9 before it is sent to a residue dam for storage. Australia is one of the top alumina producing nations in the world and the industry, over a number of years, has investigated the possible re-uses of red mud. The impetus for pursuing avenues of re-use varies, ranging from possible liabilities related to the storage of the red mud to the general burden of having to facilitate the storage (and further maintenance or extension of such facilities) of red mud.

Red mud has numerous potential physical and chemical uses, making it suitable for a variety of re-use options worldwide. The physical uses of red mud include land reclamation, construction material for road beds or as a natural marsh sediment (although the effects on ecosystems must be accounted for) (Paramguru et al., 2005). In each of these cases, a sizeable amount of red mud is treated and compacted. So far all experiments have been successful after exposure to common loads and usage (e.g. traffic on red mud road beds) (Paramguru et al., 2005).

When the chemical aspects of red mud are exploited, the amount of red mud used is considerably less than for physical uses. Un-neutralised red mud can be used as a balancer in fertilisers or acidic soils. It is also effective as a scrubbing medium for flue gases, which also contributes to reducing the pH of the red mud (Paramguru et al., 2005). Seawater neutralisation of bauxite refinery residues causes chemical changes and improves physical characteristics of the material; in post-disposal re-use, this results in an increased acid neutralisation capacity, improved soil properties and increased phosphate adsorption capacity (Hanahan et al., 2004). This property enables seawater neutralised red mud to act as a neutralant for acid mine drainage treatment. Red mud has an affinity for heavy metals, making it a candidate material for heavy metal removal from water. Commercial products have been developed from red mud for the purposes of acid sulphate soil remediation (Virotec International, 2003) and small scale sewage treatment (when combined with sand) (Bowman, 1997).

Although extensive uses for red mud have been investigated (of which many have already been pilot tested), there are limited examples of commercial-scale re-use of red mud. There is an “inherent” safety in keeping red mud stored, as the risk of misuse or environmental damage is low. However, investigations into red mud re-use continue; if red mud could be re-used, then it would create a valuable synergy between the Gladstone alumina refineries and other re-use stakeholders (Corder, 2005).

2.2. Acid mine drainage

Acid mine drainage (AMD), or acid rock drainage, is a problem that occurs for many sulphide-bearing mines. When water flows through tailings or waste dumps, the water and oxygen react with the exposed sulphides (e.g. pyrite) to produce sulphuric acid according to the reaction:

\[ \text{pyrite} + \text{oxygen} + \text{water} = \text{“yellow boy”} + \text{sulphuric acid} \]

\[ \text{FeS}_2 + 3.75\text{SO}_4 + 3.5\text{H}_2\text{O} = \text{Fe(OH)}_3 + 2\text{H}_2\text{SO}_4 \]

AMD is characterized by low pH and high concentrations of heavy metals and other toxic elements, and can severely contaminate surface and groundwater, as well as soils (Akcil and Koldas, 2006). Movement of acidic water through groundwater systems can also lead to high levels of acid in the soil, which restricts vegetative potential.

The historical mine at Mount Morgan in Queensland provides an example of an AMD problem. Mount Morgan is situated inland and is less than 40 km south-west of the Central Queensland town of Rockhampton. Mount Morgan was the location of Australia’s largest gold mine; copper was also mined at Mount Morgan until all mining activity ceased in 1981 (Department of Natural Resources and Mines, 2005). The Mount Morgan Mine has significant heritage value, but not identified as a major issue until some time in the 1990s. Currently, the open cut pit contains about 10 million m³ (or 10,000 ML) of water at a pH of 2.8 (Department of Natural Resources and Mines, 2005). The Mount Morgan Mine Site was being planned, pump-back systems were installed in the 1980s to feed back AMD seepage into the open cut pit and avoid discharge into the Dee River. In November 2003, the Department of Mines and Energy (Queensland State Government) completed the detailed rehabilitation plan for the Mount Morgan Mine Site, including strategies to combat AMD using a range of neutralising agents (including both red mud and lime) in a water treatment plant (WTP) (Unger et al., 2003).

AMD has been treated elsewhere using lime (calcium oxide) or, in some cases, magnesium oxide (Jones, 2002). Treatments can be passive or active; passive treatment tends to take the form of drains while active treatment is usually a unit process within a WTP (Department of Environmental Protection, Pennsylvania, 2005). In either case, the aim is to neutralise the water to a level suitable for discharge, however other processes are usually needed to ensure that the level of metals...
A study performed by EWL Sciences Pty Ltd showed that seawater neutralised red mud is not as effective in neutralising power compared with lime or magnesium oxide, and that, in fact, seven to eleven times more seawater neutralised red mud is required compared with lime to achieve an equivalent neutralisation (Jones, 2002).

3. Life cycle assessment methodology

3.1. Life cycle determination

In this study, life cycle assessments (LCA) were conducted for both quicklime and seawater neutralised red mud in the treatment of acid mine drainage at the Mount Morgan Mine Site. Each LCA was performed over six basic stages:

- Extraction.
- Processing.
- Fabrication.
- Transport.
- Use.
- Disposal.

The functional basis of the analyses was 1000 m$^3$ of Mount Morgan untreated acidic pit water. For both the quicklime and seawater neutralised red mud cases, it was assumed that the neutralant material, once spent (i.e. deprived of its useful reactivity), was treated and sent to open cut pit and therefore not recycled.

3.2. Quicklime scenario

Quicklime (calcium oxide) is a product formed from limestone (calcium carbonate). In this scenario, the source of the quicklime was assumed to be from an actual quicklime production plant at Gladstone, about 150 km south of Mount Morgan. The limestone for this plant is sourced from the mine, about 25 km from Gladstone. It is then transported to the production facility at Gladstone for processing in the lime.

Once at the plant, the limestone rock is screened and crushed. It is then processed through the coal-fired lime kiln to produce quicklime. The quicklime product is then transported to Mount Morgan.

The transported lime is then used in the water treatment reactor to treat the pit water. Once the reactive content of the lime has been diminished to the extent that it provides no further neutralising capability, the resulting solid waste is treated and sent to the open cut pit, ending the life cycle.

The final life cycle is shown in Fig. 1.

3.3. Red mud scenario

Defining a similar life cycle for the re-use of seawater neutralised red mud was more complicated than for quicklime. A problem occurs when attempting to define the first stage of the life cycle: should it simply be the red mud residue dam or right back to the bauxite mine?

Red mud is the by-product of the Bayer process and traditionally has had no economic value. As soon as it is being re-used, claims could be made that the red mud possesses some value as it effectively is no longer just a waste from the alumina refining process. Hence the issue of allocation arises—that is, how much of the total environmental impact of the process to that point should be attributed to alumina production and how much is attributed to the generation of red mud. The basis for selecting an allocation value is problematic, as different allocation schemes can result in significantly different results from the LCA. For example, allocation could be made on the basis of economic value, the mass proportion of the raw materials used to produce each product or by-product or based on the intent of the process (i.e. heavier allocation weightings are given to the products for which the process has been primarily designed) (Curran, 2004). The ISO 14040 standard states that when environmental impacts in an LCA need to be shared over a number of products, allocation should be avoided where possible (Standards Australia, 1998). Substitution is an alternative to allocation and there are several ways this can be done, as described in Weidema (1997).

It is feasible to consider that no environmental burden be allocated to seawater neutralised red mud from the Bayer process. In a sense, the seawater neutralised red mud is environmentally “free of charge” as it will continue to be generated as long as alumina is produced for aluminium production. This follows the allocation method based on process intent, as the primary aim of the Bayer process is to produce alumina, not red mud; this approach is consistent with similar approaches in Curran which discusses allocation issues around mine wastes (Curran, 2004, 2007). The cradle, then, would be one of the two Gladstone bauxite residue dams. In order to account for the possibility that some of the environmental burdens of alumina refining should be shared with red mud if it is being used in some beneficial manner, two red mud LCA scenarios were performed: one with the cradle at the bauxite mine (Weipa, Queensland) and the other with the cradle at the red mud dam (Gladstone, Queensland).
The full life cycle of the red mud from the bauxite mine is shown in Fig. 2. The bauxite is mined at Weipa in north Queensland and shipped to Gladstone before it is processed into alumina and red mud. This red mud is separated from the alumina mixture before being neutralised and sent for disposal in the red mud dam, the cradle for one of the LCA scenarios. Following this, seawater neutralised red mud is extracted from the dam and loaded into transporters that then take the material to Mount Morgan. As in the quicklime life cycle, the seawater neutralised red mud is used in the reactor. Once the neutralising capability of the seawater neutralised red mud has been diminished, it is disposed to the open cut pit.

3.4. Determination of key inventories

The key inventories represent the major inputs and/or outputs that are evaluated in the LCAs. The two main inventories of interest are carbon dioxide emissions and electricity usage. A third key inventory, fuel usage, was also included in the LCA. Carbon dioxide has been selected in favour of greenhouse gases as it would be the
predominant contributor to greenhouse gases. In the reporting of results, carbon dioxide has been selected as the prime inventory for comparison purposes, since both electricity and fuel contribute to carbon dioxide emissions.

3.5. Inventory calculations

The amount of neutralant required to process the functional basis of 1000 m³ of Mount Morgan pit water was calculated based on the data presented in Jones (Jones, 2002). This data indicated the neutralising strength of lime and seawater neutralised red mud in terms of a limestone equivalent. For the base case, quicklime was equivalent to 1.35 t of limestone while seawater neutralised red mud was equivalent to 0.2 t of limestone. Carbon dioxide emissions were divided into two parts: direct emissions (as a result of chemical reactions or activity related directly to the stage in question, such as transportation) and indirect emissions (as a result of using auxiliary facilities, such as electricity).

3.6. Calculation of allocation coefficient

As previously discussed in Section 3.3, the sole purpose (or intent) of refining bauxite is to produce alumina; red mud is a necessary by-product of the process and has no inherent value. Accordingly, there is then an argument that none of the environmental burdens of alumina refining should be associated with red mud and as such the base case red mud LCA in this study was performed with the cradle of the analysis at the red mud dam.

For the red mud LCA scenarios with the cradle at the bauxite mine, the inputs and outputs for the Extraction of Bauxite Ore to the Neutralisation stages were subject to allocation; the burdens attributed to generation of red mud over these stages are directly proportional to the magnitude of the allocation coefficient (which can range from 0 to 1). The selection of an allocation coefficient is always difficult because the basis on which it is chosen is always debatable. However, a few considerations of the process immediately constrain its value. Moreover, given the context of this LCA, the grade of bauxite mined will always result in, at most, an equal output of bauxite and red mud. Thus, from these constraints, the value of the allocation coefficient must be less than 0.5.

The allocation method used in this study considered the mass of red mud that was used for the remediation of AMD at Mount Morgan and compared this with the output of alumina produced over the same time period. Fig. 3 presents this schematically and supplies the equation used for the calculation of the allocation coefficient. In essence, the environmental impacts of alumina refining would be shared on a pro rata basis between red mud used for AMD and alumina produced over a given period of time.

3.7. Key assumptions

Some assumptions were made in conducting this analysis, which were considered reasonable and not likely to alter the results from the LCAs of both quicklime and red mud. The assumptions were:

- Neutralisation powers of substances remain constant with time. The magnitude of any variation was within the accuracy of this analysis.
- Reactions proceed ideally. Reaction rates were assumed constant and it was assumed there was perfect mixing in any vessels where a chemical reaction took place. This does not discount the possibility of incomplete reactions; contingencies for such situations were built into the analysis.
- Transportation costs were constant. The amount of fuel required to transport loads per kilometre remained constant throughout the study and was irrespective of factors such as distance, gradient, weather or the state of the transport vehicles.
- Power requirements when using red mud in the water treatment reactor is an additional 10% more than that required when using quicklime. Based on the estimated viscosities and percent solids of the quicklime solution and the required seawater neutralised red mud solution, the estimated increase in power requirements for using seawater neutralised red mud in the water treatment reactor (compared with lime) was calculated using a conventional dimensional analysis approach. At the base case conditions, the viscosity of seawater neutralised red mud solution was estimated to be approximately 3.3% higher than that of the quicklime solution. To achieve similar mixing and settling of the seawater neutralised red mud solution for all scenarios considered in this study, the results of this analysis indicated that an extra 10% more power would be required.

4. Life cycle inventory

4.1. Analysis structure

Three scenarios were established for the seawater neutralised red mud life cycle assessment: a base case scenario and two variations on base case scenarios. The quicklime LCA was the basis of comparison for the red mud LCAs. The neutralisation capability used in the analysis for quicklime was 1.35 t CaCO₃ equivalent (that is, 0.74 t of quicklime is equivalent to 1 t of limestone) (Jones, 2002), whilst the seawater neutralised red mud capability was 0.2 t CaCO₃ equivalent (that is, 5 t of red mud is equivalent to 1 t of limestone).
The red mud base case LCA scenario was conducted with the cradle at the red mud dam.

The variations on the base case scenario were:

1. Variation 1: Cradle at Bauxite Mine. This variation investigates the allocation of environmental burdens from the Bayer process to seawater neutralised red mud based on the calculation presented in Fig. 3.
2. Variation 2: Varied neutralisation power. This option investigates higher (0.375 t CaCO₃ equiv. and 0.3 t CaCO₃ equiv.) and lower (0.1 t CaCO₃ equiv.) neutralisation values for red mud.

4.2. Base case scenario

The results of the base case for quicklime and seawater neutralised red mud are presented in Table 1.

In short, these results indicate that over the life cycle there are significant savings in CO₂ and electricity but a higher use of fuel. This is because a significantly larger volume of red mud is required compared with that of lime to perform the same neutralising duty, thereby increasing the demand on fuel for transportation.

4.3. Cradle at bauxite mine

As discussed previously, allocation can be used to account for the additional burdens from earlier mining and processing activities associated with the re-use of seawater neutralised red mud. The calculation of the allocation coefficient was done via the use of the formula as displayed in Fig. 3 based on the annual production of alumina from Queensland Alumina Limited of just under 4 Mtpa (Corder, 2005). The calculated allocation was 0.0039, implying that the environmental burden allocated to red mud from the alumina refinery and further upstream was extremely minor. The LCA results with the cradle located at the bauxite mine and allowing for allocation are presented in Table 2.

The aim of this scenario was to determine if including allocation, that is setting the cradle at the bauxite mine, significantly affected the overall results compared with quicklime. The results of this variation show that although the inventories have increased compared with the seawater neutralised red mud base case scenario, the amount of carbon dioxide generated and the amount of electricity used is still significantly less (about 75% and 55%, respectively) compared with the quicklime life cycle (albeit the fuel usage is higher).

4.4. Varied neutralisation power

Seawater neutralised red mud is not only a less powerful neutralant compared to limestone (calcium carbonate), but the neutralisation power changes with time (Jones, 2002). As the neutralisation power of seawater neutralised red mud carries a great degree of uncertainty, a sensitivity analysis was conducted to estimate the effect on the inventories over the likely range of neutralising strengths, 0.1 t CaCO₃ equiv., 0.3 t CaCO₃ equiv. and 0.375 t CaCO₃ equiv., for red mud (Jones, 2002). These results, presented in Table 3, illustrate that the amount of carbon dioxide generated over the life cycle is naturally very dependent on the neutralisation capability of the red mud. However, at the lower level of red mud neutralisation power, the amount of carbon dioxide generated over the life cycle is still just over one third of that for lime. The fuel usage is strongly linked to neutralisation capability of the red mud, whilst the electricity usage is relatively unaffected.

5. Impact assessment and analysis

In this study, the primary yardstick used to judge the better neutralant in environmental terms was the carbon dioxide inventory. The reason for adopting this approach is that carbon dioxide is linked to global warming, as well as being indirectly related to other two inventories (i.e. fuel and electricity).

In the base case, it is clear that seawater neutralised red mud is a better option in terms of carbon dioxide and electricity compared with lime. The results indicate that approximately 80% less carbon dioxide is generated over the life cycle for seawater neutralised red mud compared with lime, whilst for electricity usage the reduction is just under 60%. However, the fuel inventory for the seawater neutralised red mud scenario is 12 times that for the lime scenario, due to the significantly greater mass of seawater neutralised red mud that is required compared with lime to perform the same neutralisation duty. In the carbon dioxide inventory of lime, a substantial amount of the carbon dioxide emissions are a result of manufacturing the quicklime. The manufacture of quicklime encompasses two processes which produce a large amount of carbon dioxide: burning coal to provide heat to the calcination reaction, as well as the calcination reaction itself (carbon dioxide is a by-product). This is illustrated in Fig. 4, while Fig. 5 shows that the main carbon dioxide contribution in the seawater neutralised red mud life cycle is from the transportation of neutralant to Mount Morgan.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Neutralant required (kg)</th>
<th>Life Cycle inventories</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CO₂ (kg)</td>
<td>Electricity (kWh)</td>
</tr>
<tr>
<td>Lime</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seawater neutralised red mud</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 t red mud = 0.1 t of limestone</td>
<td>44,594</td>
<td>1550</td>
</tr>
<tr>
<td>1 t red mud = 0.2 t of limestone (base case)</td>
<td>22,297</td>
<td>853</td>
</tr>
<tr>
<td>1 t red mud = 0.3 t of limestone</td>
<td>14,865</td>
<td>621</td>
</tr>
<tr>
<td>1 t red mud = 0.375 t of limestone</td>
<td>11,892</td>
<td>528</td>
</tr>
</tbody>
</table>

Table 2
Allocation scenario LCA Results (cradle is bauxite mine and 1 t of red mud is equiv. to 0.2 t of limestone)

Table 3
Neutralisation power scenario LCA results (cradle is red mud dam and 1 t of red mud is varied between 0.1 and 0.375 t of limestone)
5.1. Cradle at bauxite mine considerations

Even though the allocation coefficient was small, the difference in the carbon dioxide inventory between the base case scenario (cradle at red mud dam) and this scenario (cradle at the bauxite mine) was 235 kg on the basis of the functional unit of 1000 m³ of treated water. These results demonstrate that even with a justifiable allocation coefficient to account for the environment burden of the alumina refining process, 75% less carbon dioxide is generated over the life cycle for seawater neutralised red mud compared with lime, and 55% less electricity is used. Under this scenario, fuel usage for seawater neutralised red mud is 12.5 times greater than for lime, which is only a slight increase on the base case scenario.

5.2. Varied neutralisation power considerations

As mentioned previously, the neutralising capability of seawater neutralised red mud is a function of reactor time. Hence it was necessary to use an average neutralising value for the base case and Variation 1 scenarios. The value used in these scenarios was a subjectively weighted temporal average of 0.2 t CaCO₃ equiv., although the value can vary from 0.1 to 0.375 t CaCO₃ equiv. (Jones, 2002).

Although the carbon dioxide inventory decreases with increasing neutralisation power, the trend is non-linear; indeed, the additional effects of stronger neutralisation power drops off gradually. For instance, the decrease in the carbon dioxide inventory between the minimum of 0.1 t CaCO₃ equiv. to the base case, 0.2 t CaCO₃ equiv., was 697 kg (i.e. 82% decrease from 0.1 t CaCO₃ equiv. to
base case) compared with the difference between the base case and 0.3 t CaCO₃ equiv. of 232 kg (i.e. 27% decrease from base case to 0.3 t CaCO₃ equiv.). As the neutralisation power of seawater neutralised red mud decreases, this increases the mass of seawater neutralised red mud required for remediation. As a result, the main source of increase in the carbon dioxide inventory lies in the transportation of extra neutralant.

5.3. Improvements to the study

Although the results of this LCA are broadly indicative, there are several improvements that could be made to improve the accuracy of results from this study. This is especially important if further investigations into the issue of the re-use of seawater neutralised red mud are considered warranted.

Some of the key improvements are listed below:

- **Considering issues related to AMD remediation beyond the simple pH balancing.** Although increasing the pH of AMD water is an important part of remediation, there is still the issue of the high concentrations of heavy metals in the water. At Mount Morgan, there are high levels of sulphates in the water that should be considered. Sulphate removal had been considered when building the lime dosing plant currently at Mount Morgan, however this was committed to a future consideration. Seawater neutralised red mud has superior retention properties, especially for sulphates; the ability of retention improves with age (Hanahan, 2001; Jones, 2002). There is a minor risk of some leaching from the red mud, but this only occurs under certain conditions. For the purposes at hand, the risk of leaching is relatively small (Hanahan, 2001).

- **Where necessary, improve representation of processes.** Although every effort was made to use data of suitable quality to produce sufficient confidence in the LCA results, more accurate process representation would improve the credibility of the final conclusions. Areas for improvement would include better representations of the reaction kinetics, which include the mode of the reaction as well as accounting for a transient reaction rate, and transient thermal properties of fuels such as coal in the calcination process.

6. Conclusions

Significant research has been conducted in the past on the re-use potential of red mud or bauxite residue from the alumina refining process. One of these potential areas for re-use is in the treatment of AMD. There is a significant AMD problem at the Mount Morgan Mine and the synergistic benefits of reusing seawater neutralised red mud from one of the Gladstone alumina refineries to treat this problem could be substantial.

The rationale behind this study was to use LCA to compare the environmental impacts of using lime versus seawater neutralised red mud for treatment of the AMD problem at Mount Morgan in Queensland, Australia. Although re-using red mud at Mount Morgan had been investigated previously, the life cycle environmental benefits and impacts had not been considered or evaluated. In this study, the process of manufacturing and using two neutralants – lime and seawater neutralised red mud – for treatment of acidic pit waters at Mount Morgan was compared using life cycle assessment, with a focus on the inventories of carbon dioxide emissions, electricity consumption and fuel usage.

The results of this analysis indicated that seawater neutralised red mud generates about 20% of the carbon dioxide and uses about 44% of the electricity compared with lime across their respective life cycles. This amounts to a saving of about 3500 kg of carbon dioxide for every 1000 m³ of pit water treated. However, as seawater neutralised red mud on a weight basis is a much weaker neutralant compared with lime, significantly more red mud is required to perform the same duty and thus the fuel usage is 12 times that compared with lime.

Despite this study showing that there is re-use potential from an environmental point of view for seawater neutralised red mud, if serious consideration were to be given to seawater neutralised red mud re-use, then further studies involving more detailed analysis should be conducted, including investigating other management issues associated with the physical and chemical stability of red mud for long term processing requirements.

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