A WATER AND MUD MANAGEMENT MODEL FOR BAUXITE RESIDUE DISPOSAL

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Abstract

After discharge into a Residue Disposal Area (RDA), bauxite residue undergoes sedimentation, consolidation and desiccation processes, with desiccation as a dominant process for thickened/pasted residue. Mud farming technology is applied to RDAs to enhance drying and drainage. For a typical RDA, bleeding water and run-off flows to a decant pond. If the decant pond volume or takeoff is too small, the drying beach would be flooded by water during wet seasons, significantly impacting on mud drying, mud farming and the subsequent storage density achieved. Drying, mud farming and water management are integrated parts for residue disposal but are addressed separately in the industry.

This paper describes a RTA model that integrates and models all of the processes for effective and efficient residue management using Goldsim. The model contains approximately 600 individual GoldSim elements for performing separate functions or calculations related to mud drying, mud farming and water balance. It is a powerful tool for residue management and its applications include: a) assisting disposal design and development of an effective residue deposition plan; b) decant ponds and pumps design via water balance modelling; and c) optimisation of mud farming operation.

1. Introduction

After discharge into a Residue Disposal Area (RDA), bauxite residue undergoes sedimentation, consolidation and desiccation processes, with desiccation as a dominant process for thickened/pasted residue in most Australian RDA sites due to climatic conditions and bauxite residue disposal methods. Mud farming technology is applied to RDAs to enhance drying and drainage. For a typical RDA, bleeding water and run-off flows to a decant pond. If the decant pond volume or takeoff is too small, the drying beach would be flooded by water during wet seasons, significantly impacting on mud drying, mud farming and the subsequent storage density achieved. Drying, mud farming and water management are integrated parts for residue disposal but are normally addressed separately in the industry by different professions.

At Rio Tinto Alcan, a single GoldSim model has been developed to integrate all of these processes for effective and efficient residue management. The model contains approximately 600 individual GoldSim elements for performing separate functions or calculations related to mud drying, mud farming and water balance.

The model was developed for effective and efficient management for both solids and liquor management. It is a powerful tool to:

Assist disposal design and development of an effective residue deposition plan, including determination of a required drying area, optimum pouring residue thickness, and drying time required for each layer to achieve a specified dry density and tonnes/ha/annum loading.

Carry out water balance modelling to assist design of decant ponds and pumps to ensure mud beach drying areas will not be flooded following large storm events and/or wet seasons.

Optimise mud farming operation, including determination of timing, frequency of farming and the type of farming required to achieve specified storage criteria.

2. Physical Processes and their governing models

The processes that tailings experience in the field after being deposited in RDAs include sedimentation, consolidation, seepage, desiccation, and rewetting after rainfalls and/or covered by liquor. Mud farming is used in the alumina industry to enhance desiccation and drainage. The importance of each of these processes for bauxite residue management depends on several factors: residue properties, disposal method, climatic and foundation conditions etc. Sedimentation and consolidation are very important for subaqueous "lagoon" disposals. Desiccation is a dominating process in sub-aerial depositions and "dry stacking" disposal systems, which are commonly practiced for bauxite residue management in Australia, and is the focus of this paper.

2.1 Sedimentation and consolidation

2.1.1 Sedimentation

Sedimentation is a process where solid particles separate from the bulk water of tailings slurry without touching one another and there are no effective stresses developed.

The sedimentation analysis is to quantify bleeding water for water balance modelling and to estimate sedimentation void ratio - the final void ratio of sedimentation phase, i.e., the void ratio at zero effective stress to be used in consolidation analysis. Sedimentation void ratios can be easily estimated by a simple column settling test method (Li, 1994).

The model adopted for sedimentation is an empirical adaption of Kynch theory, i.e., that the falling velocity of the particles is a function of the solids concentration.

It should be noted that for pasted residue, it is highly likely that the solids content at discharge points is higher than that which corresponds to the sedimentation void ratio and the residue could undergo consolidation directly without sedimentation.

2.1.2 Consolidation

During consolidation, excess pore water pressures, induced by overburden, loads and seepage forces etc, dissipate, resulting in water squeezed out of residue mass and both density and strength of the mass increased.

For "dry stacking" residue disposal systems, consolidation is not an important process in terms of residue densification. In dry stacking, a thin layer of residue is discharged at a RDA and allowed to dry out before a new layer is placed on top of the existing layer. The drying density target is so high that the residue would remain overconsolidated even at the final RDA height. Therefore, consolidation is not considered in the development of the mud management model except for the initial stage for water balance modelling.

For water balance modelling, water resulting from consolidation is considered for the early stage after deposition. The sedimentation and consolidation will only take a few days before desiccation dominates and often they exist simultaneously with the upper part undergoing sedimentation and the lower part consolidation. Considering the effective stress in a thin layer is small, the effect of consolidation can be incorporated into sedimentation effects by extending the Kynch theory for the simultaneous two processes. Another simple way is to define a settling void ratio, similar to sedimentation void ratio, and estimate its value from compressibility relationships based on the thickness of thin layers deposited.

2.2 Desiccation

Desiccation happens due to evaporation of water from the residue mass. Evaporation may be described by a two stage process, commonly done in soil physics. In the first stage, when residue is saturated and there is plenty of water supply from beneath, the actual evaporation rate from residue surface is equal to the potential evaporation rate. The evaporation is governed by climatic conditions. As evaporation continues, water supply is not adequate and desaturation occurs. The stage two begins and the actual evaporation rate decreases rapidly until the residue reaches its residual moisture content and the evaporation rate is effectively zero. In the second stage evaporation, the actual evaporation rate is governed by both climatic and residue conditions/properties such as permeability and suction in the unsaturated zone.

It shall be noted that for some tailings, especially saline tailings, thin salt crusts (<5mm) can be formed and will have significant impact on the actual evaporation (Fahey and Fujiyasu, 1994).

As the desiccation progresses, suctions will develop high enough to crack the surface. Primary cracks are formed first and followed by secondary ones, meeting these two families of cracks at almost right angles, forming columns of mostly hexagonal shape (Morris et al., 1992). Cracks can propagate in depth, reaching depths up to a couple of meters in some cases (Blight, 1997). In reality, however, for active dry stacking disposal systems, cracks will not be fully developed before a new layer of residue is deposited. Therefore, cracks are not considered in the development of the RTA Water and Mud Management model

There are a number of approaches to model desiccation process. Wilson and his colleagues developed a coupled soil and atmosphere approach (Wilson et al, 1994 and 1997). Simms and his colleagues use the approach and SoilCover software to model evaporation and drying time of thickened and pasted tailings (Simms et al, 2007; Simms et al, 2009).

Swarbrick and Fell (1992) developed test procedures and methodology to simulate tailings desiccation without cracks using the two stage evaporation model. Their approach has been adopted for the development of the RTA Water and Mud Management model.

The input data, however, is obtained mainly from laboratory tests. Field tests/trials are required to estimate the desiccation properties.

2.2.1 *Infiltration and Runoffs*

After rainfall, some rainwater will infiltrate into and be absorbed by residue whilst most will become runoff and flow to the decant pond. The infiltration and runoff data are important input parameters for desiccation and water balance modelling but little attention has been received on them for research and investigation.

A simple method for consideration of infiltration and residue surface runoff characterisation is to use an average coefficient of runoff. For example, a coefficient of 0.85 means that 85% of rainwater becomes runoff and 15% of rainwater infiltrates and is absorbed by the residue. This method is not accurate and should be only used in the conceptual study and if it has been calibrated.

A more accurate method is the AWBM (Australian Water Balance Model) method. In this method, soil and surface conditions are considered, and the catchment runoff parameters are obtained through calibration.

2.3 Mud farming

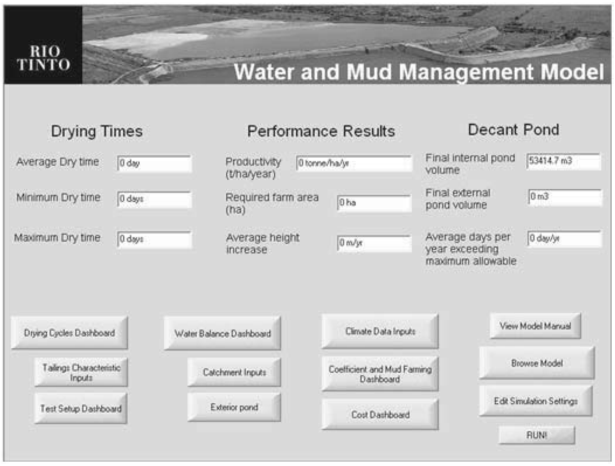
Mud farming is a process where thickened mud is distributed in layers and then turned over or ploughed to increase deposited density through the promotion of solar drying, water drainage and compaction. It has at least three advantages: increased storage efficiency, increased stack stability and improved accessibility for rehabilitation.

Although it has been successfully employed in the Australian alumina industry for more than two decades, effects of mud farming have not been quantified and no governing models have been published. In the development of the RTA model, its effects are reflected in other parameters such as drying characterisation assuming no thin crust due its breakup by farming and higher coefficient of runoff to represent better drainage conditions due to farming.

3. RTA Water and Mud Management (WMM) Model

3.1 General

The RTA WMM model has been developed using GoldSim software and all the processes described in the above section have been incorporated. The model is comprised of two basic parts, the Water Balance model and the Drying Cycles model, as shown in Figure 1.



Average Dry time: 0 day
Minimum Dry time: 0 days
Maximum Dry time: 0 days
Productivity (t/ha/year): 0 tonne/ha/yr
Required farm area (ha): 0 ha
Average height increase: 0 m/yr
Final internal pond volume: 53414.7 m3
Final external pond volume: 0 m3
Average days per year exceeding maximum allowable: 0 day/yr

Figure 1 - Dashboard of Water and Mud Management Model

The **Water Balance** part of the model provides a simulation of water balance for a residue disposal system including decant ponds and pumps. It can be used to design the sizes of ponds and pumps to ensure there are enough drying areas under different climatic conditions for the residue to achieve targeted density. It can also be utilised for day to day operations to model different scenarios for pump and decant level management. A simplified example of a typical RDA water balance system can be seen in figure 2.

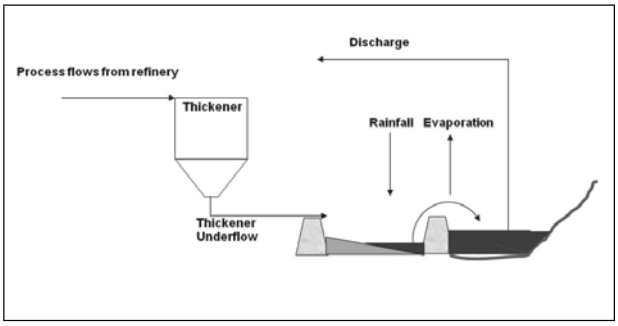


Figure 2 – A simplified RDA water balance system

The **Drying Cycles** part of the model uses two stage evaporation equations in order to simulate sedimentation and desiccation of bauxite residue for selected climatic conditions, layer thickness and tailings properties.

The simulation can be operated in two different modes, the first being to specify a dry density and allow the model to simulate drying of the tailings up until that point. This permits the user to predict the drying time that would be required to achieve a target density and assuming the production rates are known, this can then be used to predict a required area. The second mode operates in the reverse to this process. The user can define a production rate and drying area which can then be used to calculate the available drying time before a new layer must be poured. This can be used to determine what the theoretical target density should be for that setup, and can be used to test future design options or set a benchmark for expected dry densities. The integration of the daily weather data, as for the water balance model allows for the different weather scenarios to be tested and the affects of a variety of weather conditions to be observed.

3.2 Some input parameters

The RTA WMM model contains approximately 600 individual GoldSim elements and includes a lot of input parameter modules. Below is a brief description for climatic and tailings characterisation inputs.

3.2.1 Climatic inputs

The Climatic data module contains the rainfall and evaporation data used within the model. The climatic data is obtained from the Bureau of Meteorology SILO database for a selected RDA site. It provides the user with a variety of different ways to control the rainfall and evaporative conditions, with both monthly and daily data available. Daily, where available, will generally provide greater accuracy however more data is required in order to run accurate simulations and where it is not available, monthly may be used.

With both monthly and daily data, events can be defined based on different ARIs such as in 1 in 2 year, 1 in 5 years and 1 in 100 years etc.

3.2.2 Tailings Characteristics

The Tailings Characteristics module contains input data, as described by Swarbrick and Fell (1992), including

- residue initial conditions at discharge points,
- physical properties such as specific gravity and maximum dry density which could be achieved for the tailings under the simulation climatic conditions,
- Settling properties - Initial settling velocity exponent, settled height factor, settled exponent
- Desiccation properties – air dry diffusivity, diffusivity exponent and sorptivity.

4. Verification and Applications

4.1 Verification

An example was taken from Swarbrick (1992). In this example, the sedimentation and desiccation of bauxite tailings at Weipa, Queensland were simulated. Figure 2 shows the results of simulation with comparison of observed data in terms of water content. “PRED” shown in the figure is the name of the software Swarbrick developed for the simulation.

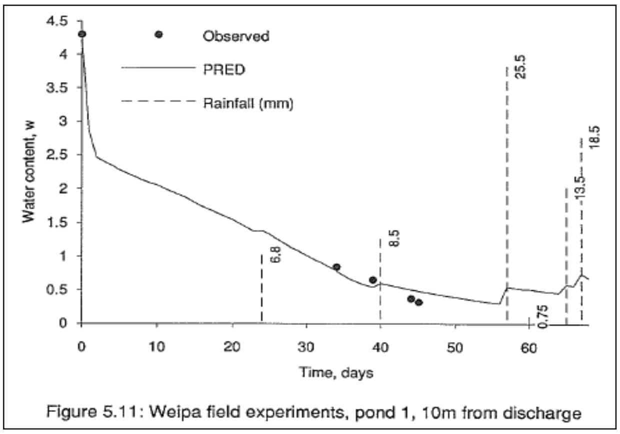


Figure 3 – Comparison of predicted and observed changes of water content with time for bauxite tailings at Weipa, Queensland (Swarbrick, 1992)

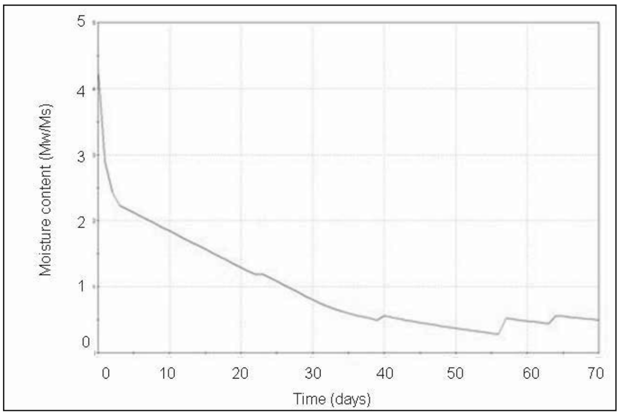


Figure 4 - RTA Model results for Bauxite tailings at Weipa, Queensland

Figure 4 shows the results using the RTA WMM model. It can be seen from the figure that the shape of the curve is much like the one shown in Figure 2.

4.2 Design for a decant pond

In this demonstration example, the purpose of the exercise is to determine if an external decant pond is required and what the storage capacity is needed. The primary point of interest is the systems effect on decant level. When decant level becomes too high, they can begin to encroach upon the area used for residue drying and mud farming. As a result of the decreased area for drying and mud farming, bauxite residue could not achieve its target densities. This decrease in dry density would result in a decrease of shear strength and increase in required storage volume, leading to more expensive wall construction, more wall raises and more expensive rehabilitation which requires more intensive capital investment.

The water balance part of RTA WMM model was used to do the exercise. A number of different propositions were investigated in the simulations including no external decant pond and construction of an external decant pond with a number of sizes in terms of storage capacity. Within these decant pond options a variety of pumping rates, and operational procedures were investigated for each. As well as this, a range of different climatic scenarios were used in order to mitigate the risk of extreme weather conditions on the decant pond options.

The primary climatic scenario for comparison was a 100 year simulation containing historical daily rainfall data for this exercise site as seen in figure 5 below. The total volume of the pond was consistently predicted by the model and this was converted to surface area and heights through the use of lookup tables of storage curves. These storage curves were used to monitor the available drying and mud farming area which in combination with the production rate was able to establish what was known as a loading factor. Loading factors are used to indicate the annual storage of dry tailings per hectare per year. Lower loading rates correlate to longer drying times and consequently, higher dry densities can be expected. Different threshold limits ranging from 15,000 – 20,000 t/ha/yr were set up to gauge the impacts of decant setups on achievable mud densities.

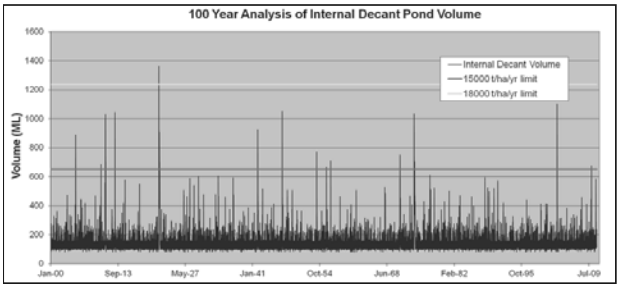


Figure 5 – Example of a 100 year analysis monitoring the internal volume against the volumetric limits of different loading factors.

Other climatic scenarios used include different ARI wet seasons. The simulation results show that there is a bottleneck for the existing return pipeline which prevents use of large decant pumps and the best option is to have an external decant pond with an appropriate size. In this case, residue will not be flooded during large storm events and storm water can be stored in the external decant pond for a period of time before it can be pumped out.

5. Summary and Recommendations

5.1 Summary

A single model has been developed to integrate sedimentation, consolidation, desiccation and infiltration for effective and efficient residue management. The model contains approximately 600 individual GoldSim elements for performing separate functions or calculations related to mud drying, mud farming and water balance.

The model is comprised of two basic parts, the water balance model and the drying cycles model:

- The Water Balance part of the model provides a simulation of water balance for a residue disposal system including decant ponds and pumps. It can be used to design the sizes of ponds and pumps to ensure there are enough drying areas under different climatic conditions for the residue to achieve targeted density. It can also be utilised for day to day operations to model different scenarios for pump and decant level management.
- The Drying Cycles part of the model uses two stage evaporation equations in order to simulate sedimentation and desiccation of bauxite residue for selected climatic conditions, layer thickness and tailings properties.
- The model has been verified using Weipa tailings for 1D sedimentation and desiccation. A demonstration example shows how to use the model for design of an external decant pond.

5.2 Recommendation

- Most input data for the desiccation process is from laboratory data and efforts should be used to obtain those parameters from fields.
- The infiltration and catchment runoff characterisation are important input parameters for desiccation and water balance modelling. However, little attention has been received on them for research and investigations. Further work should focus on obtaining this data.
- Although mud farming has been successfully employed in the Australian alumina industry for more than two decades, its effects have not been quantified and no governing models have been published. Field work is required to quantify the effects of mud farming on residue drying and drainage.

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