PRECIPITATION MODELLING OF WORSLEY ALUMINA (WESTERN AUSTRALIA)

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Abstract

The BRAHMA ("BHP-Billiton Refinery Alumina Hydrate Model Analysis") precipitation simulation model is used extensively at the Worsley Alumina Refinery as a tool to assist in controlling the precipitation process. It combines the method of discretised population balance with the thermodynamic based properties of the supersaturated mother liquor to simultaneously describe the reaction kinetics and the evolution of nucleating, agglomerating and growing aluminium tri-hydrate particles. The dynamic model operates in a closed loop and the precipitation circuit can be easily configured to include features like solids retention, inter-stage cooling, product and seed classification and filtration, green liquor and seed split, etc. The model provides information on the sensitivity of individual process parameters and the best combination of these process parameters to simultaneously achieve targeted yield, seed/product particle size distribution and occluded soda in product.

The model has been configured for the Worsley circuits and validated with field data over a range of operating conditions. This paper relates some of the observations from the calibration process and summarises how the model is being applied in day-to-day operation. Examples of performance improvements and enhanced understanding of the precipitation process emerging from the use of the simulation model are discussed.

Included graphs indicate that alumina trihydrate particles of diameter greater than a critical size do not take part in the agglomeration process.

A comparison is made between solid retention precipitators with natural solid density precipitators. The same agglomeration, nucleation and linear growth model parameters have been found to satisfactorily describe the performance of both types.

The model confirms the observed higher overall agglomeration constant in external airlift-agitated precipitators compared to mechanically agitated draft tube tanks. Surface activity for linear growth in mechanical agitated tanks is, however, about 30% higher.

1. Introduction

The Worsley precipitation system consists of two different types of circuits. The two circuits differ in the way the suspended in-tank solids density is achieved (solids retention and natural solid density profile), and in the number of agglomeration and growth stages. These two circuits are also interlinked via the seed recycle streams. Because of the complexity of the system, computer modelling and simulation of the total circuit is highly desirable in order to ensure consistent and adequate process parameter adjustments to control the process and maintain the quality of the final product.

At the Worsley alumina refinery the BRAHMA precipitation simulation model is being used as a powerful tool to assist in controlling the precipitation process. On a short term basis, deviation from targeted objectives in the area of yield, particle size distribution, seed balance and occluded soda are routinely analysed. The impact of the individual process parameters causing yield/production loss is quantified to direct management and operators focus.

Medium- and long-term activities include evaluation of alternative flow sheet configurations, to quantify the impact of changes in process conditions on overall precipitation performance and product quality. The model provides the required engineering and design data. Furthermore, the predicted yield benefit is used for the economic justification of the envisaged flow sheet modifications, while ensuring that product quality and operational stability will be maintained.

The model is also being used as a training tool for engineers to assess the impact and sensitivity of the various process parameters influencing the precipitation process. Important process parameters studied include seeding pattern, temperature profile over the circuit and in the seed preparation section, separation characteristics of the classification system and liquor composition.

Model output includes the complete mass balance of all streams in the circuit, occluded soda information, and particle size distribution of seed and product.

Model predictions with respect to yield and occluded soda are considered satisfactory, although ongoing effort is directed towards further improvement of accuracy of PSD and product strength predictions.

Introduction of the model in the Worsley refinery required quite some effort from the plant. The first step in utilising the model at Worsley required an extensive training of users followed by tailoring of the model to the specifics of the Worsley precipitation circuits using actual plant data and subsequent validation of the model.

In the following sections the tailoring, calibration and validation processes are described. The architecture and structure of the model and the various algorithms used to describe the precipitation kinetics and the population effects of nucleation, growth and agglomeration are outlined by "Cramer, W.J. and Visser, J., Modelling and Computer Simulation of Alumina Trihydrate Precipitation, Light Metals 1994, pp73–82".

2. Tailoring of the Model to the specifics of The Worsley Circuits

Tailoring of the model consisted of building a flow sheet representing the Worsley precipitation system by connecting the various building blocks available in the model. The building include liquor block, seed block, precipitator block, inter-stage cooler block, classifier block (gravity and hydro cyclone) and filter block. Mixer blocks and splitter blocks are used to allow multiple streams to enter or exit the various building blocks. The flow and composition of the liquor to precipitation is entered into the liquor block. This block is then connected to the relevant precipitators as feed liquor. The seed block contains the flow, solids density and PSD information of a representative sample of the seed charged. This block is used only in the initial phase to start the run. Once the system is calibrated, this seed block is disabled and the model runs in closed loop mode on its own generated seed. The complexity of the Worsley circuit requires at least 100 blocks.

The following features were configured into the Worsley precipitation flow sheet: Green liquor split over the agglomeration section, multiple inter-stage cooling steps, solids retention in precipitator tanks exhibiting classification, hydro cyclone seed and product classification, seed and product filtration, and seed wash and re-slurry.

The complete configured precipitation system is saved as a flow sheet file and can be easily retrieved and modified as applicable. The model constants used in the algorithms describing the kinetics, occluded soda, nucleation, agglomeration and separation characteristics of the classification system are also saved as a separate file (plant parameter file). This set of model constants are used in combination with the flow sheet as described above.

The user can define the display of the flow sheet information. Optional on-screen display information for a precipitator for example contains: temperature, liquor composition, linear growth rate, solids density, slurry flow, solids flow, occluded soda, PSD, SSA, etc. This information is used in an interactive way during the calibration step.

3. Calibration and Validation Steps

The kinetic and thermodynamic relations for liquor chemistry are joined by particle size calculations based on spherical crystals and surface area calculations. A seed surface activity constant (SA) is introduced to account for non-spherical particles and deviation from the standard seed used in establishing the pre-exponential constant in the kinetic equation for linear growth via batch experiments.

Batch laboratory experiments were also used initially to establish the agglomeration (Ka) and nucleation (Kn) constants, and the size above no agglomeration in the model. For the continuous crystallisation process, these constants need to be re-established, and to account also for the difference in hydrodynamics, notably in the agglomerators.

The model constants describing the separation characteristics of the hydro cyclones and the classifying precipitators are established based on samples collected from feed and discharge of these classifiers.

Finally the soda constant, Ks is established by matching the calculated occluded soda in product with the actual plant value.

4. Agglomeration Section

Description of the theoretical and experimental investigations elucidating the mechanisms involved in the complex agglomeration process is beyond the scope of this paper. The population balance technique applied to develop the mathematical description for the agglomeration system is outlined in the 1994 LM publication.

The calibration and validation results are illustrated by a number of examples in selected sections of the precipitation circuit. **Figure 1** represents three agglomerative precipitators operating in series. The liquor flow is split between the first (T301) and second (T302) tanks to control supersaturation, the seed material is added exclusively to the first tank.

Following a period of steady operation, samples of the liquor and solids were analysed. Concurrently the circuit was built inside a Brahma flowsheet and the input conditions of flowrate, temperature, residence time and seed charge entered into the model. For the calibration stage the actual seed material PSD was used as an input in the model so that the performance of the crystallisers themselves can be focused upon. Recycled seed can only be tested once the entire flowsheet has been constructed.

The liquor composition (in particular interstage alumina concentration) was adjusted in the model with the surface activity parameter to reflect actual plant conditions. Furthermore, the agglomeration and nucleation constants and the maximum size for agglomeration were adjusted to obtain the best PSD fit. These constants were derived using plant samples collected in March 2001.

Validation of the model is illustrated in this example by comparing the model predictions (using the model constants derived in March 2001) with actual plant performance in January 2002.

Figure 2 shows the evolution of the particle size distribution as sampled in the field.

Figure 3 shows the PSD predicted by the model assuming that all particles are involved in the agglomeration process irespective of size i.e there is no maximum size above which particles do not agglomerate. In this case, the mode particle size shifts with the distribution to the larger sizes, which is not a phenomenon observed in practice.

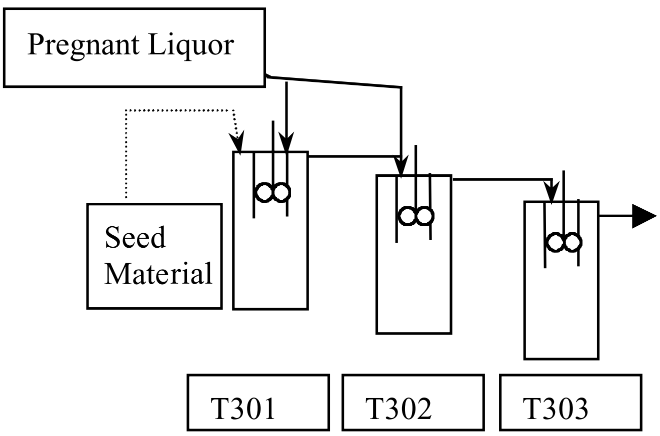

Figure 1

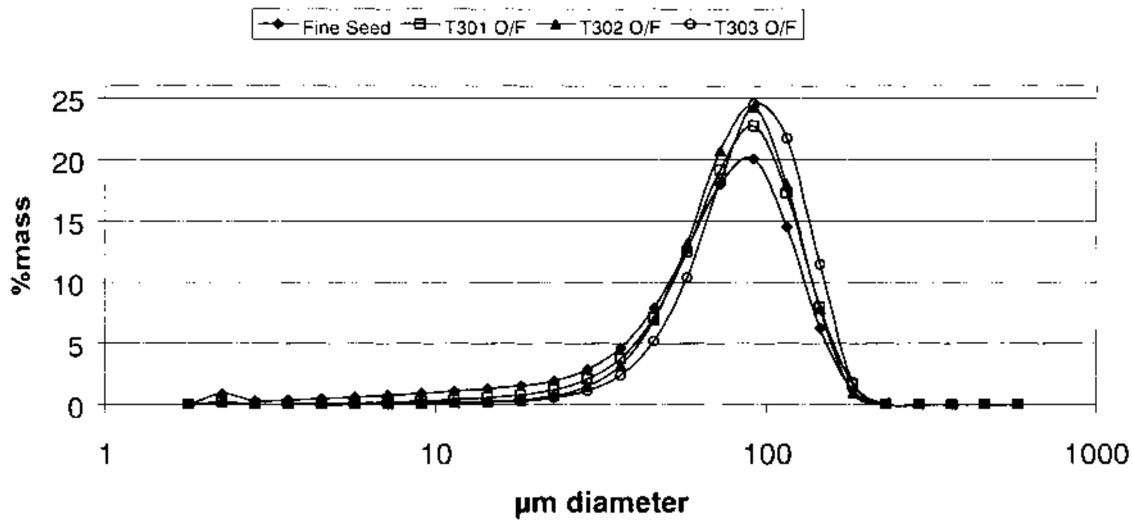

Figure 2 — PSD Evolution in Agglomerator Section-Actual Plant Data

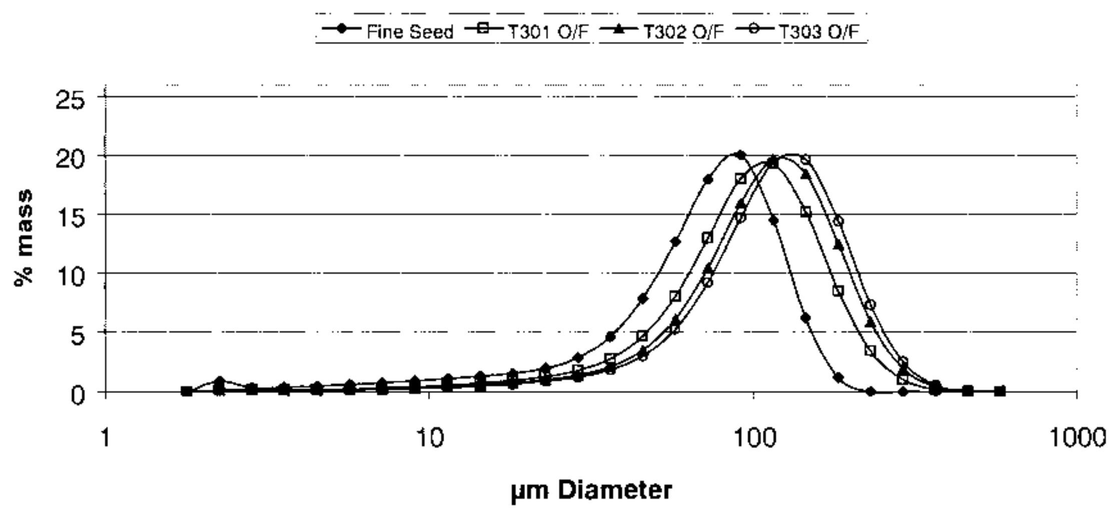

Figure 3 — PSD Simulation — No Maximum Agglomeration Size

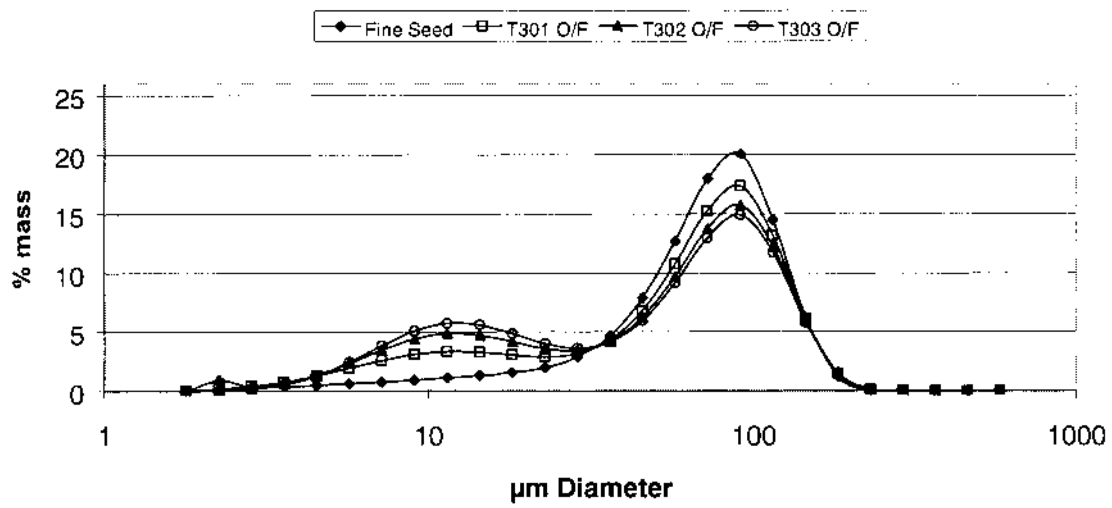

Figure 4 — PSD Simulation — Only Growth

Figure 4 shows the PSD predicted by the model in case there is no agglomeration of small particles into larger ones, just linear growth. In this circumstance the growth of the fines consumes the majority of the crystallised mass of hydrate. Again the data does not reflect what is observed in the field.

Figure 5 shows the predicted PSD using a maximum particle size of 100µm which undertakes agglomeration. The fit is within 0.8wt% of the sub-44µm fraction and 0.3wt% of the plus-150µm fraction in the discharge from the agglomeration train.

5. Hydrodynamics of Agglomeration

Worsley operates both external airlift and mechanically agitated agglomerators in the solid retention circuit which allows comparison of the hydrodynamics of the tanks. Field surveys have shown that the airlifts operate with an agglomerative pre-exponential constant (Ka) substantially higher than a mechanical agitator. The nucleation of ultrafines (or attrition) is also higher in Worsley's airlift tanks. Calculations of the power input per unit volume have indicated that the specific agitation powers are similar.

The surface activity for linear growth (Kg) in Worsley's airlifted agglomerators is about 30% lower than the mechanical agitated tanks.

6. Growth Section

Natural Solid Density (NSD) versus Solid Retention (SR) Precipitators

The residence time of the in-tank suspended solids in the SR circuit is about 80 hours compared to 35 hours in the NSD circuit. This raises the question as to whether the same model constants predict the particle size distribution at the discharge of the two circuits.

Figures 6 and **7** show that the actual and predicted cumulative size distributions are indeed accurately represented. Again, the model constants were fitted in March 2001 and these samples taken in January 2002. Figure 6 depicts the PSD in the mid-section of the circuits while the PSD represented in Figure 7 is from the back end of the circuits.

In effect, this is a test for growth dispersion. A bias in the growth of the finer PSD, notably in the SR precipitators would be highlighted by the calibration process. Within the range of plant operation, a bias has not been observed.

7. Production Reporting using the Precipitation Model

One of the first tasks with the completed and calibrated precipitation model was to begin regular comparisons to the observed conditions in the plant. During the early

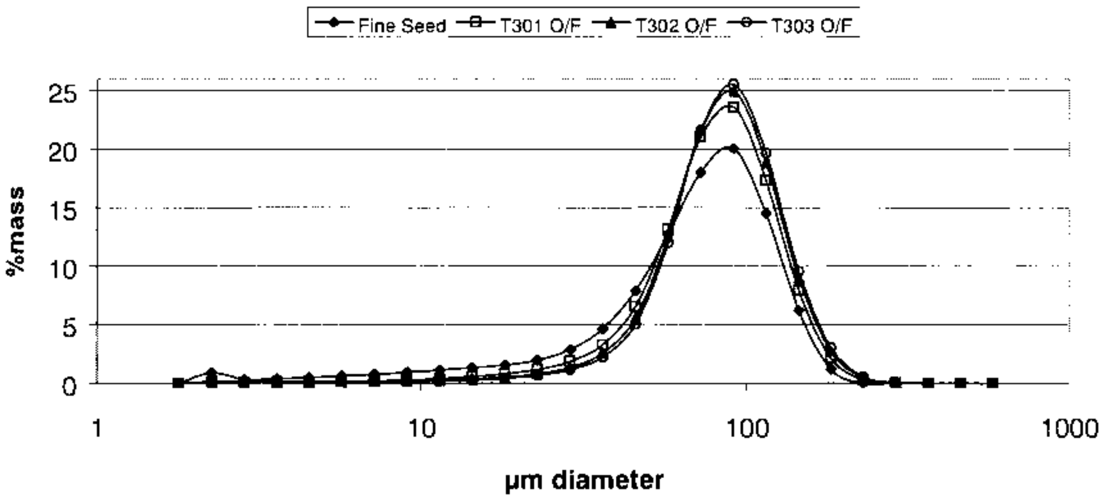

Figure 5 — PSD Simulation-Maximum Agglomeration Size 100 µm

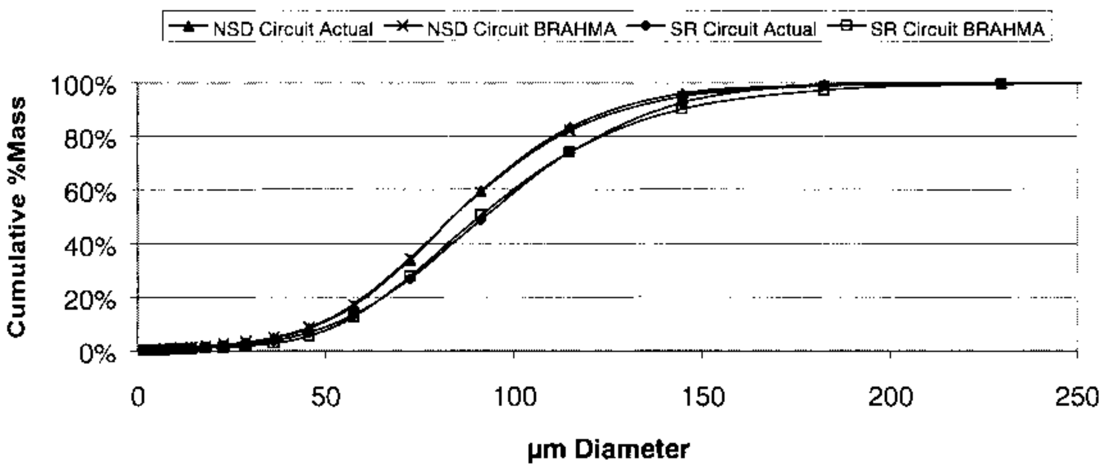

Figure 6 — Natural Solid Density vs Solid Retention Mid-Section

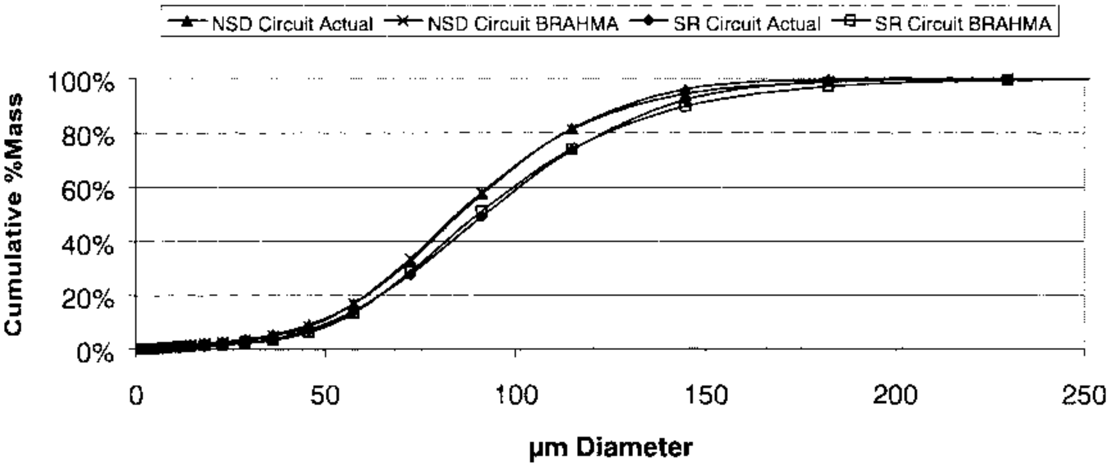

Figure 7 — Natural Solid Density vs Solid Retention BackEnd Section

stages this included resolution of deviations. Later it has led to a budget set of conditions to which plant operation can be compared.

The development of the budget case involved consideration of equipment capability, product quality and operating cost. Then, on a monthly, or as required frequency, the operating conditions are entered into the model. The budget model is then changed parameter by parameter to the current conditions and the individual impact of each parameter on liquor yield is recorded.

The major process targets include the green liquor flowrate, green liquor composition, fill temperatures, seed charge, residence time and available intank surface area.

By using this technique the budget case becomes a dynamic set of process targets, from which the effect of deviations are quantified. Action can then be taken based on the priority developed from the modelling results.

8. Ongoing and Future Development

The model has been used to generate the design and engineering data for the new precipitator circuit constructed in the recent plant expansion. The envisaged operating parameters have delivered the projected targets with respect to product quality and yield. Ongoing effort is directed towards further optimising the total precipitation system. The focus is on improving product quality consistency (occluded soda content and fines generation).

The next challenge is to incorporate BRAHMA as an on-line process control tool.

9. Conclusion

The Brahma precipitation model has been accurately calibrated and tested against reality on the Worsley circuits. It has been incorporated in production reporting, short term troubleshooting and long term planning. It is an essential training tool and a sounding board for new concepts.

During the calibration and simulation process theories of growth dispersion, maximum agglomerate size, and the effect of hydrodynamics have been studied and are now better understood.

Further development of the technology of hydrate crystallisation modelling allows Worsley to continue to improve yield, product quality, reduce costs, and form the basis for implementation of more advanced on-line process control.

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