Optimization of the Control and Monitoring Strategies for Precipitation Yield and Particle Sizing using Predictive Modelling

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Abstract

The production of good quality alumina in the appropriate tonnage are two key aspects relevant for any alumina refinery. Meeting these targets are dependent on the stable operation of the precipitation circuit. The ability to maximize the precipitation yield while maintaining product sizing specifications is a key objective to improve the refinery's efficiency and cost targets. At Jamalco, the consistent production of product of the required particle size and tonnage has posed a challenge with the changes in the liquor chemistry resulting from a shift in the quality of raw materials, such as bauxite, to the process. Optimization of the various key process indicators within the precipitation circuit is an enabler to meet the refinery's customer obligations as well as its cost targets. This paper highlights the predictive tools developed using linear regression in Microsoft Excel to optimize the control and monitoring strategies used within the precipitation circuit at Jamalco. Furthermore, this paper provides a summary of the recommended model optimization steps that will be explored for future use.

Keywords: Precipitation yield, Particle size, Predictive modelling, Optimization.

1. Introduction

Jamalco, an alumina producer in Clarendon Jamaica, has a nameplate capacity of approximately 1.4 million metric tonnes per annum of sandy grade alumina utilizing the traditional Bayer process. One of the major challenges for the refinery is bridging the gap between increasing yield in the precipitation circuit and attaining the required product sizing. Literature dictates that the yield of gibbsite is largely determined by nucleation and growth of particles, while the production of coarse crystals for commercial purposes is determined by agglomeration [1]. However, the optimal conditions required for nucleation and growth typically aligned with maximizing precipitation yield do not always coincide with the optimum product size specifications or agglomeration conditions [1].

The optimization of the precipitation circuit is a key enabler in meeting the refinery's productivity and efficiency targets. The yield and strength of precipitated hydrate particles is dependent on several key process indicators such as liquor to precipitation alumina to caustic ratio, temperature profile across the circuit, seed ratio or charge, holding time, precipitation rate, and impurity levels of input seed and liquor [2].

With the changes in the bauxite feed quality to the refinery over the past 6 years, the refinery's ability to consistently meet its yield and sizing requirements has become increasingly difficult. As such, the countermeasure of crystal growth modifier, CGM, addition has become an integral part of the sizing management practice for the refinery. The coarsening effect of crystal growth modifiers on alumina trihydrate is the primary use of this product for refineries such as Jamalco, the intended purpose or result of the addition of CGM has been to improve precipitation productivity through increased seed charge and/or temperature reduction [3].

One of the major concerns for Jamalco in the refinery's sizing management program is the presence of dissolved oxalate in liquor, one of the strategies used is the addition of CGM to the circuit. The presence of the CGM results in pronounced changes in the sodium oxalate morphology by the formation of sodium oxalate clusters [3].

Linear Regression is a statistical tool used to model the relationship between two variables fitted to a linear equation, i.e., an equation in the form Y = a + bX, where Y is a dependent variable and X is an independent or explanatory variable. This is the basic concept utilized throughout this paper to predict the precipitation yield and sizing for optimization purposes. Prior to the development of the regression model, a critical step is the data cleaning process to remove outliers which can affect the model developed. Once the data clean-up process is complete, a correlation test is done using scatter plots, the CORREL function or Regression Data Analysis tool in excel to determine the correlation coefficient, which falls between -1 and 1 thus indicating an inverse and direct correlation. For multilinear regression, such as those that will be discussed, the regression data analysis tool and the CORREL function are preferred.

2. Precipitation Yield Prediction Tool and Impact

The regression data analysis tool was utilized to determine the correlation coefficients for several key process indicators such as seed specific surface area, number of precipitators in service as a measure of holding time, precipitation solids, circuit temperature amongst others with the liquor from precipitation alumina to caustic ratio. These correlation coefficients were then used to generate a singular linear equation for the prediction of the liquor from precipitation alumina to caustic ratio (LFP A/C). To facilitate optimization of this model, an error comparison was done between the LFP A/C measured by the laboratory and the predicted LFP A/C. The Solver add-in was then utilized to minimize the sum of errors while updating the model coefficients; to facilitate robustness of the model, over 300 data points were utilized for each key process indicator in this process.

To facilitate a link between the attainable agglomerated size and precipitation yield, the head tank +44 micron was incorporated in the model. The model generated was found to be in good tolerance to the actual LFP A/C ratio as shown in figure 2 and could therefore be used to predict the trend of the LFP A/C ratio in real time.

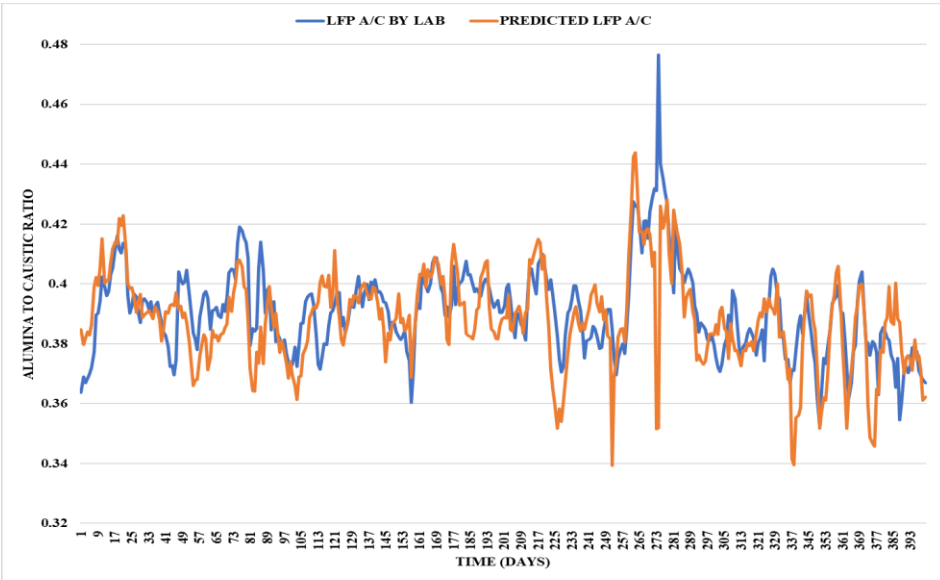
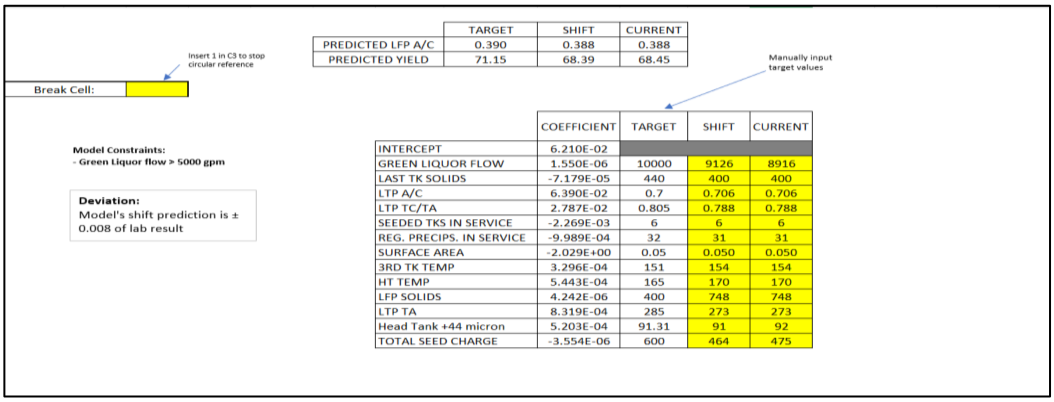


Figure 2. Comparison of the actual versus predicted LFP A/C ratio.

Model tuning is done periodically to reduce the gaps in the actual and predicted ratios attained. This prediction was further utilized to predict the current and shift precipitation yield for the refinery by pulling data directly from the Connected Plant system. The model also allows for target setting opportunities on a daily as shown in figure 3 for key process indicators to meet the appropriate yield targets.



	TARGET	SHIFT	CURRENT
PREDICTED LFP A/C	0.390	0.388	0.388
PREDICTED YIELD	71.15	68.39	68.45

	COEFFICIENT	TARGET	SHIFT	CURRENT
INTERCEPT	6.210E-02			
GREEN LIQUOR FLOW	1.550E-06	10000	9126	8916
LAST TK SOLIDS	-7.179E-05	440	400	400
LTP A/C	6.390E-02	0.7	0.706	0.706
LTP TC/TA	2.787E-02	0.805	0.788	0.788
SEEDED TKS IN SERVICE	-2.269E-03	6	6	6
REG. PRECIPS. IN SERVICE	-9.989E-04	32	31	31
SURFACE AREA	-2.029E+00	0.05	0.050	0.050
3RD TK TEMP	3.296E-04	151	154	154
HT TEMP	5.443E-04	165	170	170
LFP SOLIDS	4.242E-06	400	748	748
LTP TA	8.319E-04	285	273	273
Head Tank +44 micron	5.203E-04	91.31	91	92
TOTAL SEED CHARGE	-3.554E-06	600	464	475

Figure 3. Daily precipitation yield prediction tool.

For error minimization due to circular references, for periods where iterations are not enabled in excel, a break cell was implemented which allows the user to manually enter 1 in the designated cell to halt all circular references.

2.1 Benefits of Development and Utilization of the Yield Prediction Tool

In the absence of a simulation software such as SysCad and Aspen, this LFP A/C prediction model has given the refinery the opportunity to identify key areas for improvement with regards to the maximization of the precipitation yield. This model was used to develop the backbone of the refinery's yield improvement plan since May 2020. The yield improvement plan is a document utilized by the refinery to predict the precipitation yield based on the changes in various key process indicators; this plan also allows for users to input key enablers required to improve the key process indicators and track their progress as is needed as shown in figure 4 below.

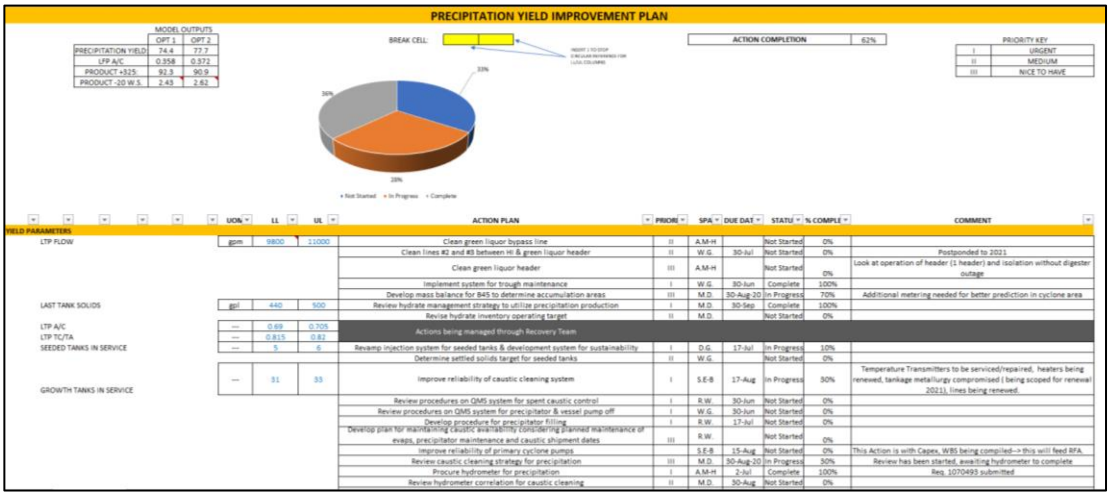


Figure 4. Snippet of precipitation yield improvement plan.

The model also generates a prediction of the product sizing attainable under these conditions. Since the implementation of the revised yield improvement plan and the predictive modelling strategy, the refinery has seen improvements in the attainable precipitation yield despite swings in the LTP A/C ratios as shown in figure 5.

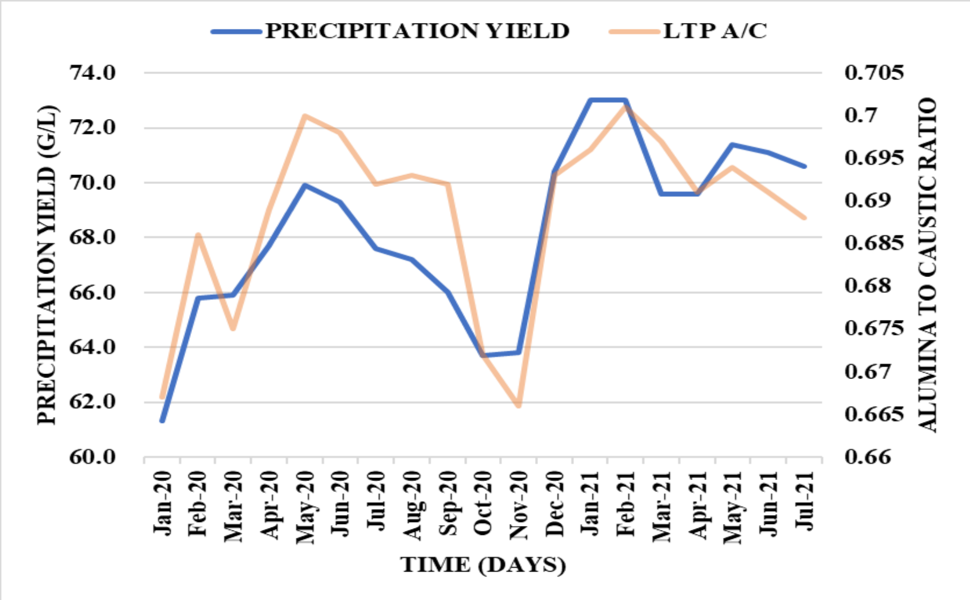


Figure 5. Precipitation yield and LTP A/C trend.

The use of predictive modelling has given the refinery the opportunity to zone into the critical areas, the maximize liquor productivity even in low feed ratio scenarios as seen in October to November 2020, resulting from instabilities associated with a plant outage. The model indicates that seed surface area, circuit temperatures, solids concentration and feed ratios and concentration are the key drivers for maximization of the precipitation yield. A critical part of this prediction process is ensuring that the optimal correlation coefficients are utilized as such, it is recommended that the model be reviewed quarterly or for any major raw material or process changes.

3. Sizing Prediction Tool

One of the key process indicators in alumina production is the hydrate strength which is critical to avoid high particle breakdown during calcination and process handling (high attrition) [2]. High attrition rates increase the potential for higher dusting and environment concerns as well as product losses [2]. Reducing attrition rates is a key focus for Jamalco, as such, several models were created to understand the major contributors to the particle sizing within the precipitation circuit.

A size reaction plan was developed which predicts the agglomerator exit size, fine seed, primary cyclone feed size, the required CGM dosage, required fine seed charge and required cyclone pressure to aid with circuit optimization. One of the most important aspects of the size reaction plan is the fine seed charge prediction as shown in figure 6 below.

This prediction plan has aided to stabilize the agglomerator size while predicting the changes required to return same to target. Increasing the seed charge leads to high fine generation, poor size control and particle breakdown in calcination [2], it is also critical to avoid over coarsening due to its yield impact and by extension the sizing impact due to circuit size cycling.

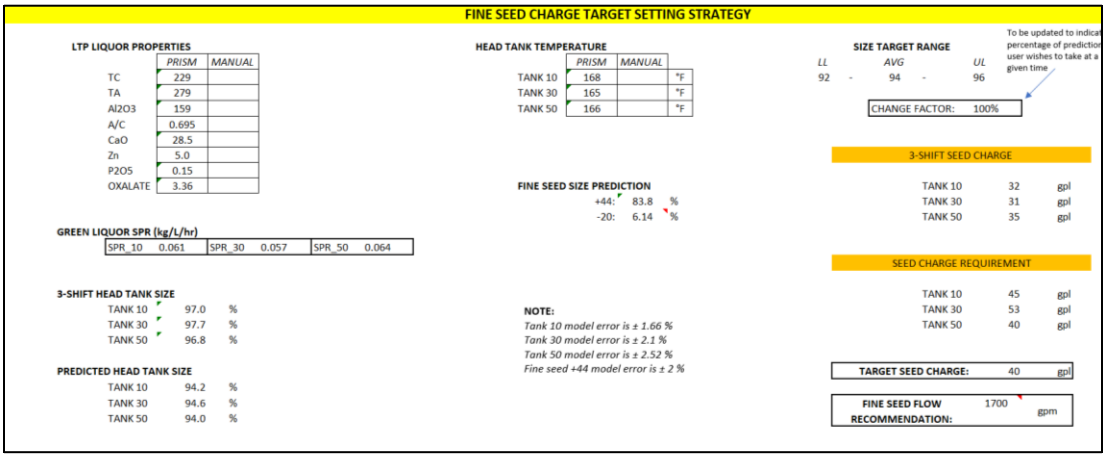


Figure 6. Fine seed charge & agglomerator size prediction model.

The model considers the feed liquor impurities as a contributor to the attainable size. A manual input section was incorporated in the prediction tool to facilitate scenario testing or target setting.

The intention is to incorporate this model into the refinery's seed ratio control program for the agglomerators for real time adjustments. The revamping of this program has already begun. The predicted size was found to be in good tolerance of the sizing attained by the laboratory as shown in Figure 7

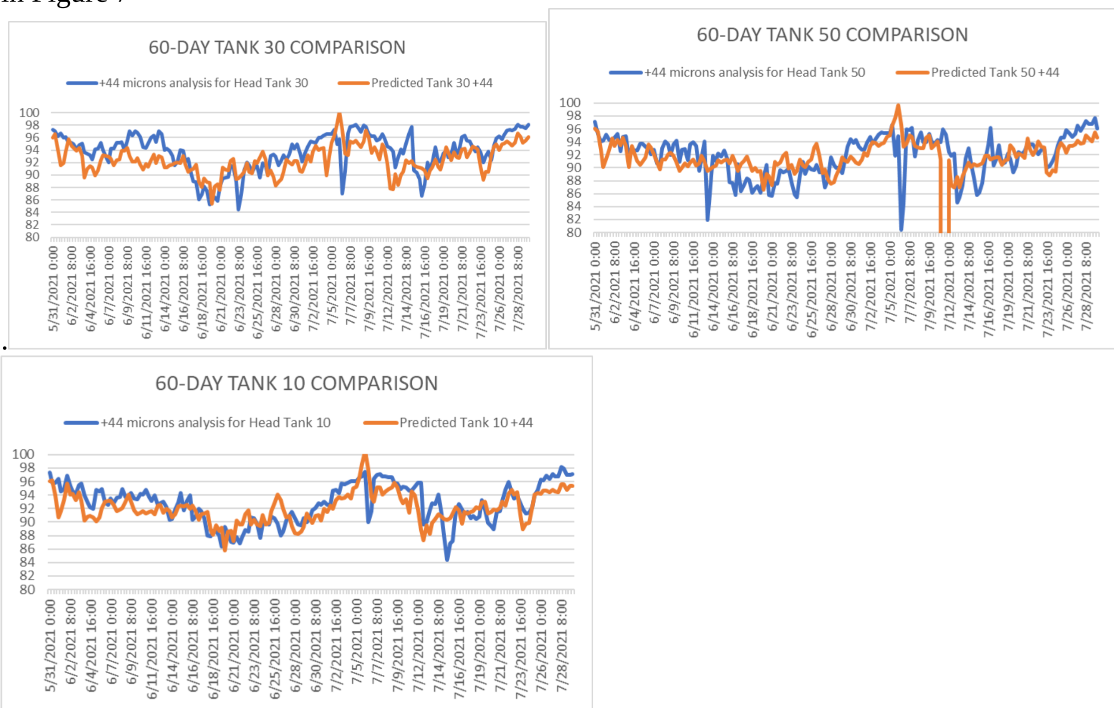


Figure 7. Model Prediction Comparison for Agglomerator Discharge Sizes

Each agglomerator size prediction has slight variations in the correlation coefficients due to process disturbances unique to each vessel. Based on the current residual life of the agglomerators within the circuit, the impact of scaling and vessel management on this prediction model has not yet been assessed.

3.1 Cyclone Performance on Sizing

The primary and secondary cyclone cluster operation at Jamalco is critical in meeting the refinery's sizing targets. Pressure target setting is a key enabler to ensure the required cyclone cut from the respective cyclones. The attainable pressure from the cyclone is heavily dependent on the internals used for the respective cyclones with the vortex finder being the most critical internal liner for sizing control.

A replicated design curve from the original equipment manufacturer manual from Krebs in conjunction with the number of cyclones in service from Connected Plant was utilized to devise a pressure target setting model for the primary and secondary cyclone clusters with an example shown in figure 8.

The model calculates the cyclone overflow and underflow rates and utilizes the design curve to predict the required pressure and the predicted cyclone cut. To optimize this model further, several key instrumentations and tracking points will be revamped.

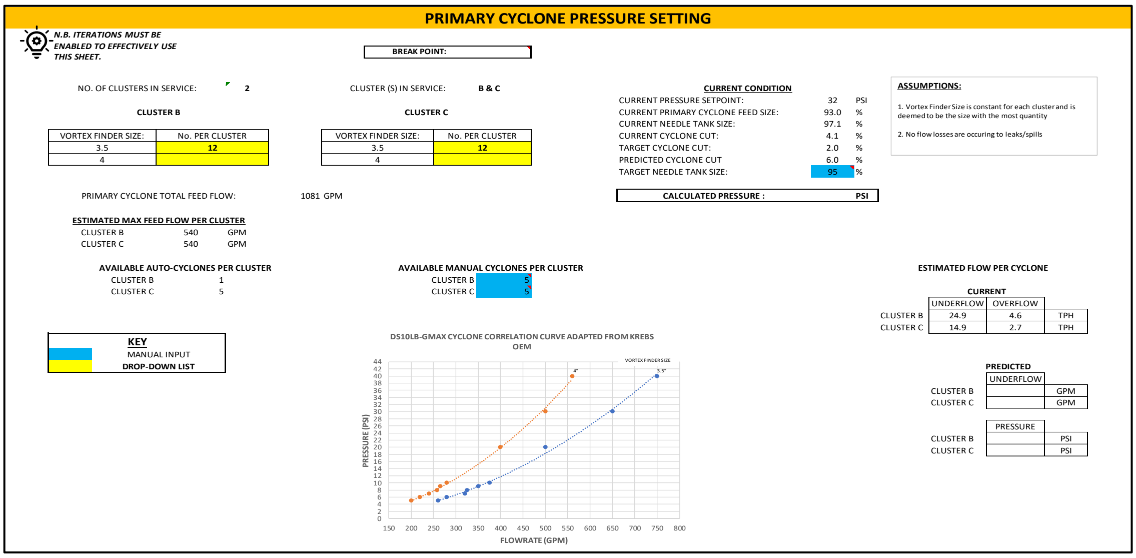


Figure 7. Primary cyclone pressure prediction sheet.

3.2 Sizing Reaction Plan Overview

It was found that two of the major contributors to the attainable sizing in product and the hydrate strength were the circuit temperatures and the fine seed charge to the circuit [2]. Higher head tank temperatures and Interstage cooler discharge temperatures were found to lead to higher attrition rates. These parameters in conjunction with the seed charge prediction, primary and secondary cyclone prediction models were utilized to generate an overarching sizing reaction plan as shown in Figure 8.

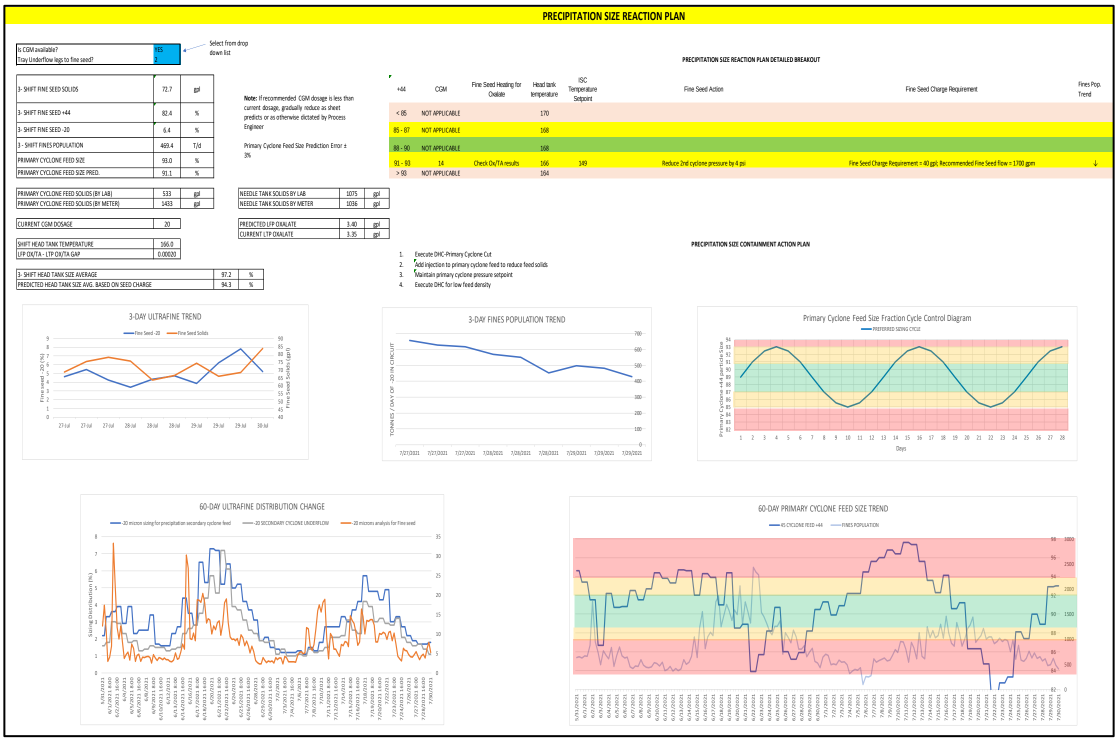


Figure 8. Sizing reaction plan overview.

It was found that size profile changes at the primary cyclone feed gives the best estimate of the sizing swings for the precipitation circuit at Jamalco, as such, the reaction plan generates actions linked to the prediction models to stabilize the sizing at this point and across the circuit. The -20-micron fraction for the fine seed, primary cyclone feed, secondary cyclone feed and fines population are closely monitored to prevent excessive fines generation within the circuit. These parameters amongst others are used to predict the required CGM dosage to be added for inhibition of secondary nucleation. The recommended plant dosage for CGM from the Supplier of ≤ 25 ppm [3] is also considered in this prediction.

The required inter-stage discharge temperature is predicted based on the attainable size and the predicted oxalate in LTP liquor to minimize the potential of fines generation due to oxalate coprecipitation and high attrition. These prediction models and the generated reaction plan provides the refinery with a quick action solution for action deployment for out-of-control scenarios.

The incorporation of over coarsening triggers using the +120 micron in the agglomerators is an improvement step that will be considered for optimization of this reaction plan.

4. Future Plans

To further optimize systems around yield and sizing control, the incorporation of the various models in the DCS with error correction, for areas such as seed charge and CGM dosage target setting, is a critical next step in the real time monitoring and control of these parameters. Revamping of key flow meters and density meters will also be brought to the fore to ensure prediction effectiveness. For cyclone optimization, the review of the vortex finder and apex liner sizes and standardization is an activity that will be continued to ensure accurate pressure predictions. In addition to the optimization of the cyclones, the utilization of this methodology will be expanded to optimize the inter-stage cooler and cooling tower performance to maximize yield and particle strength.

5. Conclusion

Linear regressions can be used to effectively develop tracking and prediction tools for the optimization of the precipitation yield and sizing for refineries in the absence of a simulation software. Due to its user interface, excel is a viable option for maintaining and generating supplemental models for refinery optimization. Baseline tools have been successfully created to support Jamalco's efficiency and quality management systems; the optimization of which will continue to be done periodically. With tools such as these, Jamalco will continue to be in alignment with its commitment to be "*The Best Alumina Producer*".

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6. References

1. Counter, JA et al., The influence of crystal growth modifying reagents on secondary nucleation of Bayer aluminum hydroxide, *Nalco Water Alumina Technical Literature*, R-857.
2. Rosalin Pradhan et al., Improvement in control strategy to maximize productivity and enhance hydrate particle strength in Bayer precipitation circuit, *Proceedings of 39th International ICSOBA Conference*, 22-24 November 2021, *TRAVAUX* 50, 205-215.
3. W.J. Roe et al., Crystal growth modification: practical and theoretical considerations for the Bayer process, *Nalco Water Alumina Technical Literature*, ADV-539.