PREDICTION OF DEEP CONE SETTLER PERFORMANCE UNDER INCREASED FEED LOADS USING MULTIVARIATE MODELLING

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Abstract

Refinery expansions or a need to process lower grade bauxites will lead to larger mud loads through Clarification circuits. This can be handled either by building more process equipment or increasing the loads on existing equipment.

This work was centred on the latter alternative assessing the equipment capability and possible process risk of planned increases in average slurry flowrates and mud loadings of some forty percent. This was done before the event using proprietary statistical multivariate analysis software to model future performance based on targeted historical data correlating multiple key performance parameters.

Focusing primarily on modelling for future increased equipment loadings, this paper reviews the purpose of the work, the software methodology, its capability to produce correlated results quickly and reliably from extensive data, the analysis outcomes and also possible future work. Based on Key Performance Indicators that define Settler performance it was shown that conditions for higher rates should not differ from historical standard Settler operating conditions, and therefore they are unlikely to cause poor Settler performance.

With the methodology and philosophy of the work established, there is a brief review of trending work comparing performance of different flocculents in full-scale flocculent field trials undertaken over two years by Worsley Alumina to improve Settler performance at existing flow conditions. Multivariate statistical analysis modelling of existing operations demonstrated changes in underlying processing modes over the two years that are not evident from the data using simpler trending. Further data analysis is being undertaken to better establish the business case.

As more data becomes available from the new operating regimes it will be used with the Knowledge Extraction and Benefit Estimation components of the software to optimise overall operation of the units. It is also proposed to replicate the models developed in other areas of Clarification and the Refinery

1. Introduction

Refinery expansions or a need to process lower grade bauxites will lead to larger mud loads through Clarification circuits. This can be handled either by building more process equipment requiring additional capital, or increasing the loads on existing equipment beyond current operating experience thereby introducing a process risk.

This work was centred on the latter alternative of increased slurry flowrates and mud loadings by some forty percent. Proprietary software for multivariate statistical analysis [1,2] was used to initially validate data before proceeding to process modelling to predict the performance of Deep Cone Settlers compared with their original specification and historical operation.

As an adjunct, full-scale flocculent field trials had also been undertaken by Worsley Alumina to improve Settler performance at existing flow conditions. The opportunity was taken to use the same statistical analysis tools to compare operating performance and the effects of the changed flocculent. In this instance the software was used for initial multivariate *trending analysis* of parameters over an extended two year period thus providing rapid assessment of extensive arrays of data, followed by process modelling to a lesser extent to clarify trending validity. This highlighted the software's facility often to rapidly analyse myriad data quantitatively in a visual format to assess performance without the need to proceed immediately to modelling.

2. Initial Data Analysis for Higher Settler Feed Loads

Determination of the performance of the Deep Cone Settlers under increased loads required identification of historical periods of Settler operation where conditions of high mud loadings and feed flows had occurred. From this data further analysis of Settler performance under these conditions was conducted to identify criteria for good performance and bad performance and to allow assessment of future Settler performance under the increased loading. Performance criteria were Overflow Clarity of Settler Feed to the Green Liquor Security Filtration Facility and Underflow Slurry Density to the Clarification Washers.

The initial task was to analyse the suitability of the data. This involved objectively identifying the conditions that represented 'ideal' running conditions. The data were extracted from the Refinery Process Data Base in csv format, although a variety of other methods are available including OPC HDA. The two 1-year periods identified as most likely to have the necessary comparison data were 2005 and 2010, chosen as they represented two different operating phases of the Refinery. The objective was to identify when Settler operating conditions in this historical data were comparable to the expected future operating conditions. In particular the total feed throughput flow rate and the input mud (solids mass) were used as the measures for comparative operating conditions.

As conditions in the historical data were rarely at these elevated levels, it was decided to target slightly downgraded data with the following characteristics as the reference data for further analysis work:

Total Feed Flow:	>2000 m3/h
Mud (Feed solids)	>280 t/h per Settler

Settler data was initially extracted at 30 minute intervals across the five Settlers and was brushed for the target operating conditions. Brushing is a technique facilitating data selection directly from the visual trend or scatter plot [3].

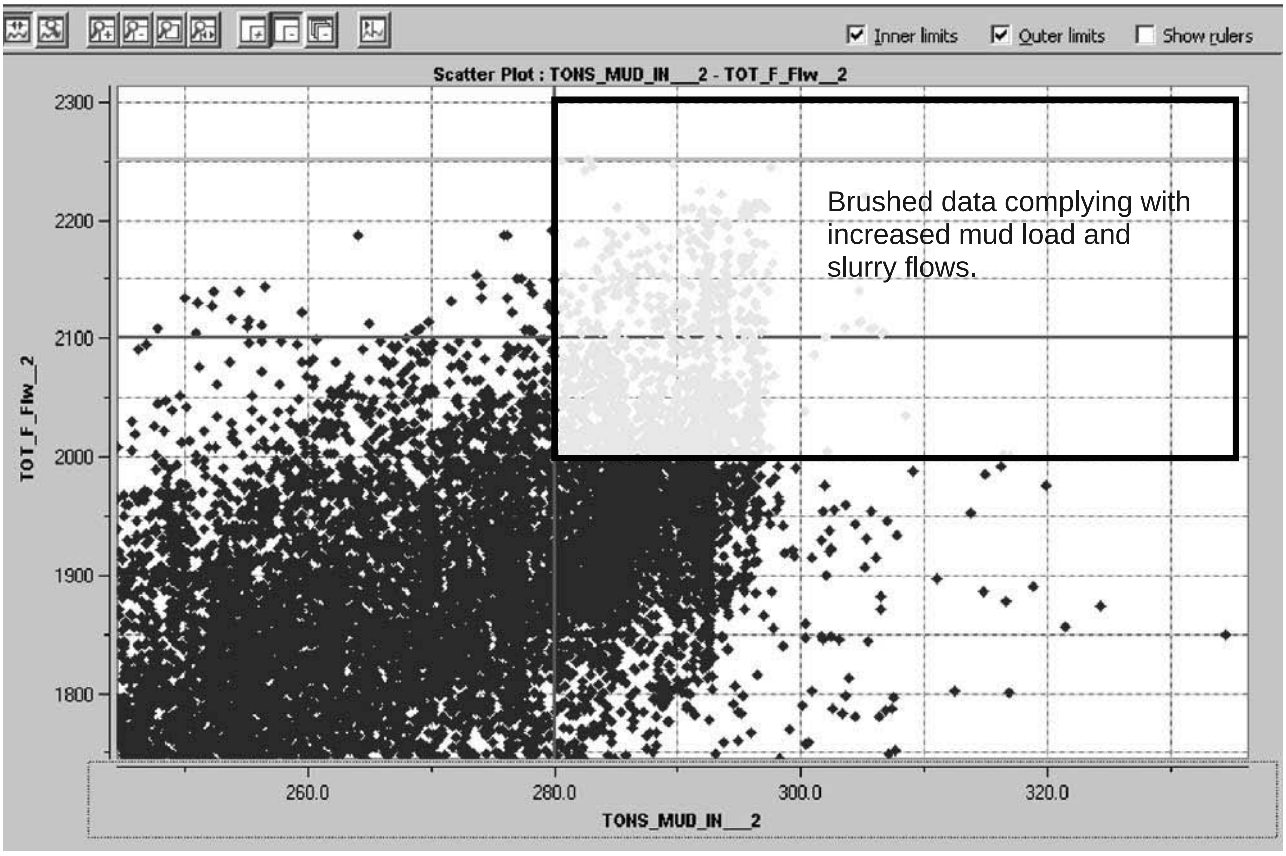

Fig 1. Scatter plot of the two KPI's brushed for the data ranges required.

This analysis delivered 12 periods of data totalling more than 70 days of operation that could be isolated for further investigation.

During these periods the required operating conditions for Overflow Liquor Turbidity and Underflow Density were maintained, which indicated the Settlers should be capable of performing adequately under the expected future operating conditions. Such periods were then subjected to a further more focused data capture using shorter 10 minute sample averaged intervals.

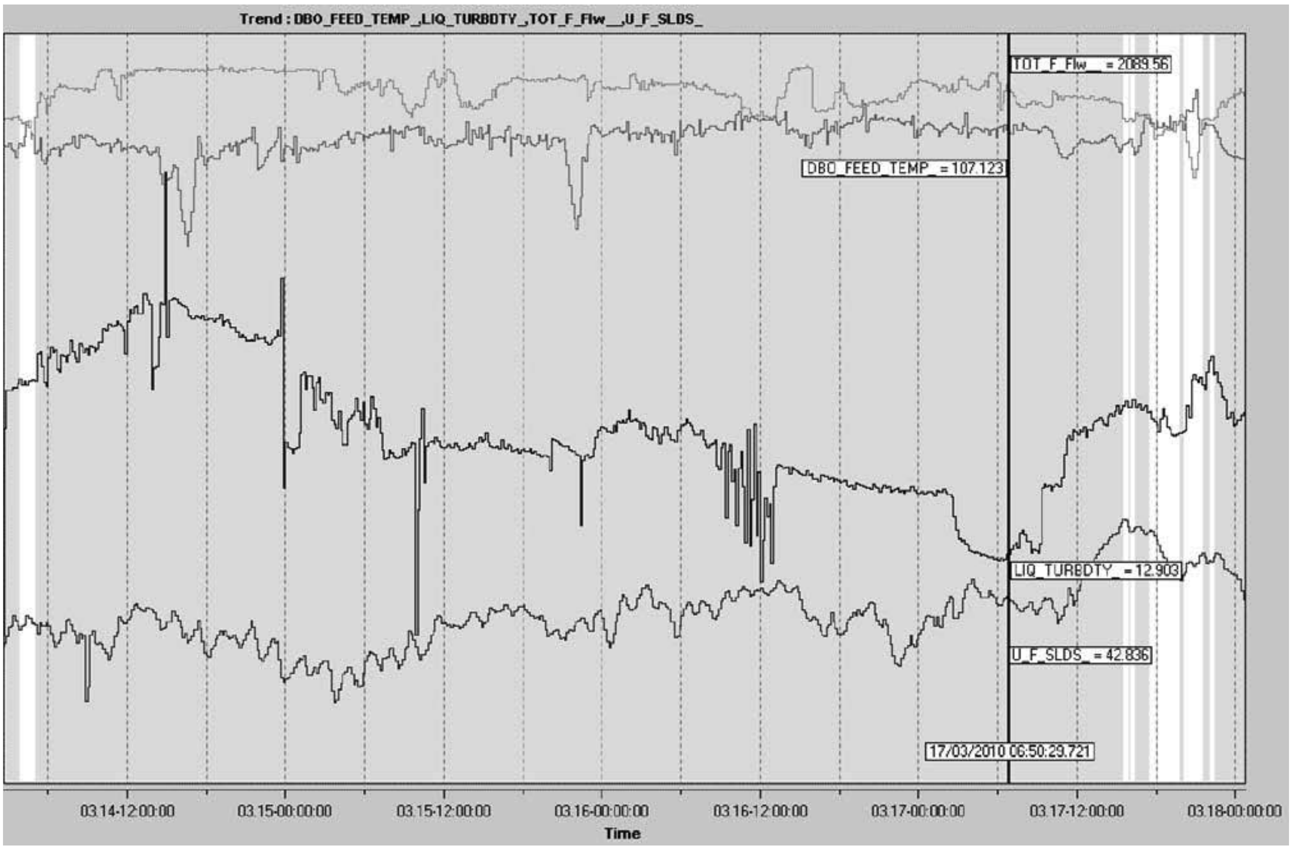

Fig 2. Brushing of KPI data set is automatically overlaid to all other data sets (greyed areas).

Grey 'brushed' areas highlight time referenced data where Settler inflow feed conditions were similar to those expected for future operations.

3. 3.0 Comparison of Settler Operating Conditions

A further analysis compared the Settler operation under these conditions of high Settler feed flow and high mud loading against the full data spread of Settler operating conditions.

The first step was to brush out non valid data (shutdowns, low Digester temperature, etc) and then build the Principal Component Analysis (PCA) model for comparison.

Shown in Figure 5 is the array of data for 5 parameters initially selected for comparison purposes from 15 parameters. Other parameters could have been included such as various Control Laboratory analyses and Mud Residence Time; even characteristics of the bauxite feed.

The purpose of this comparison was to show how the data associated with the High throughput periods, gave an adequate representation of the Settler output characteristics under standard operating conditions.

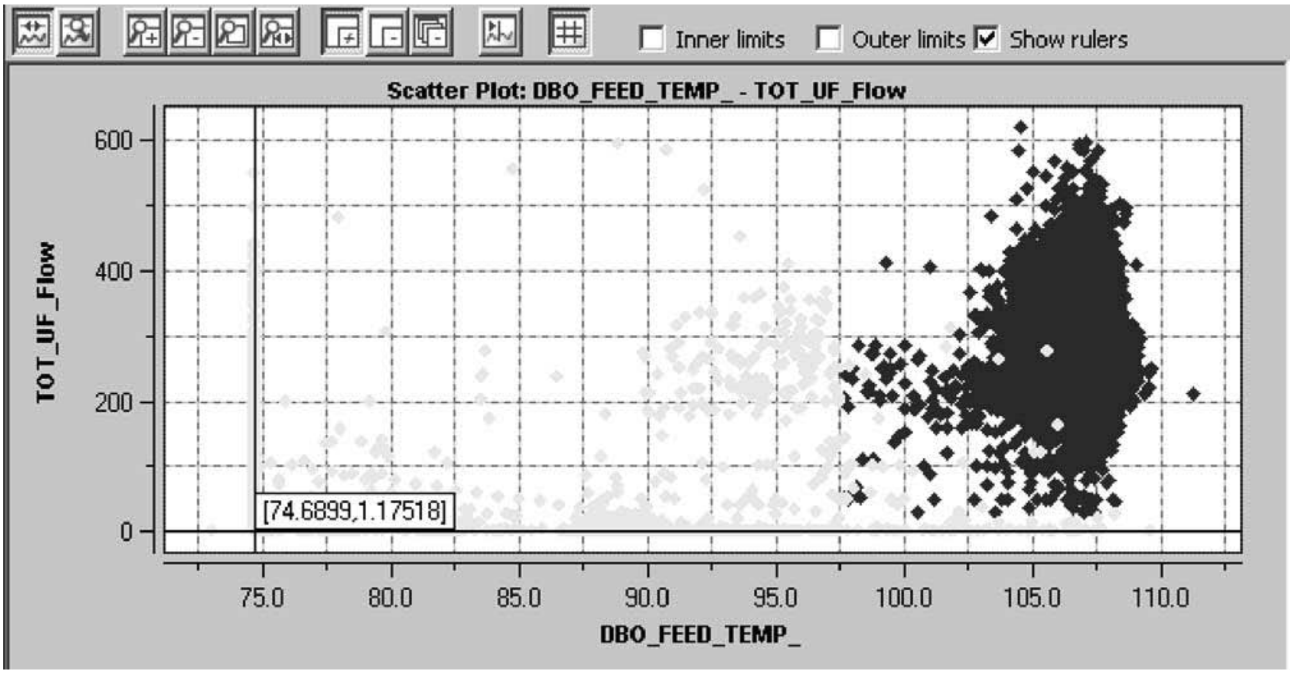

Fig 3. Elimination of low Slurry U/F Rates and low Digestion Temperature data

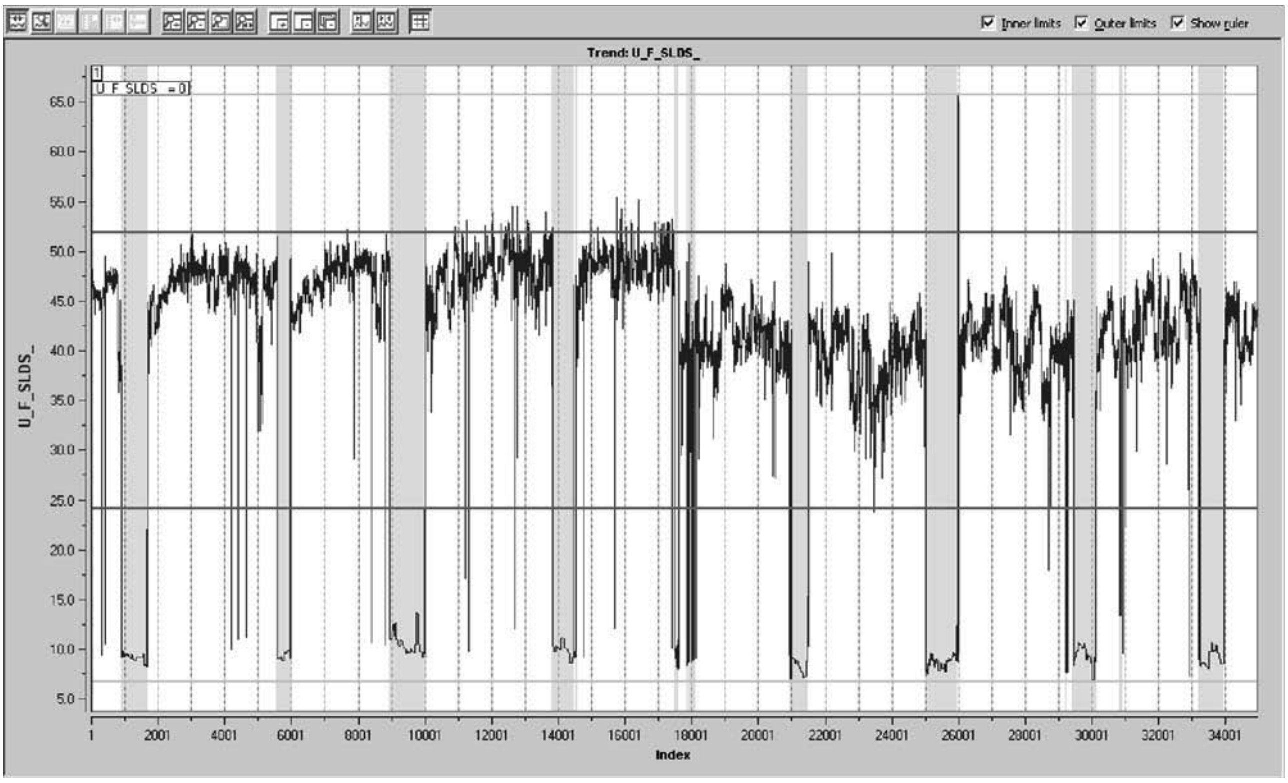

Fig 4. The above brushing overlaid against one trend – U/F Solids (greyed areas)

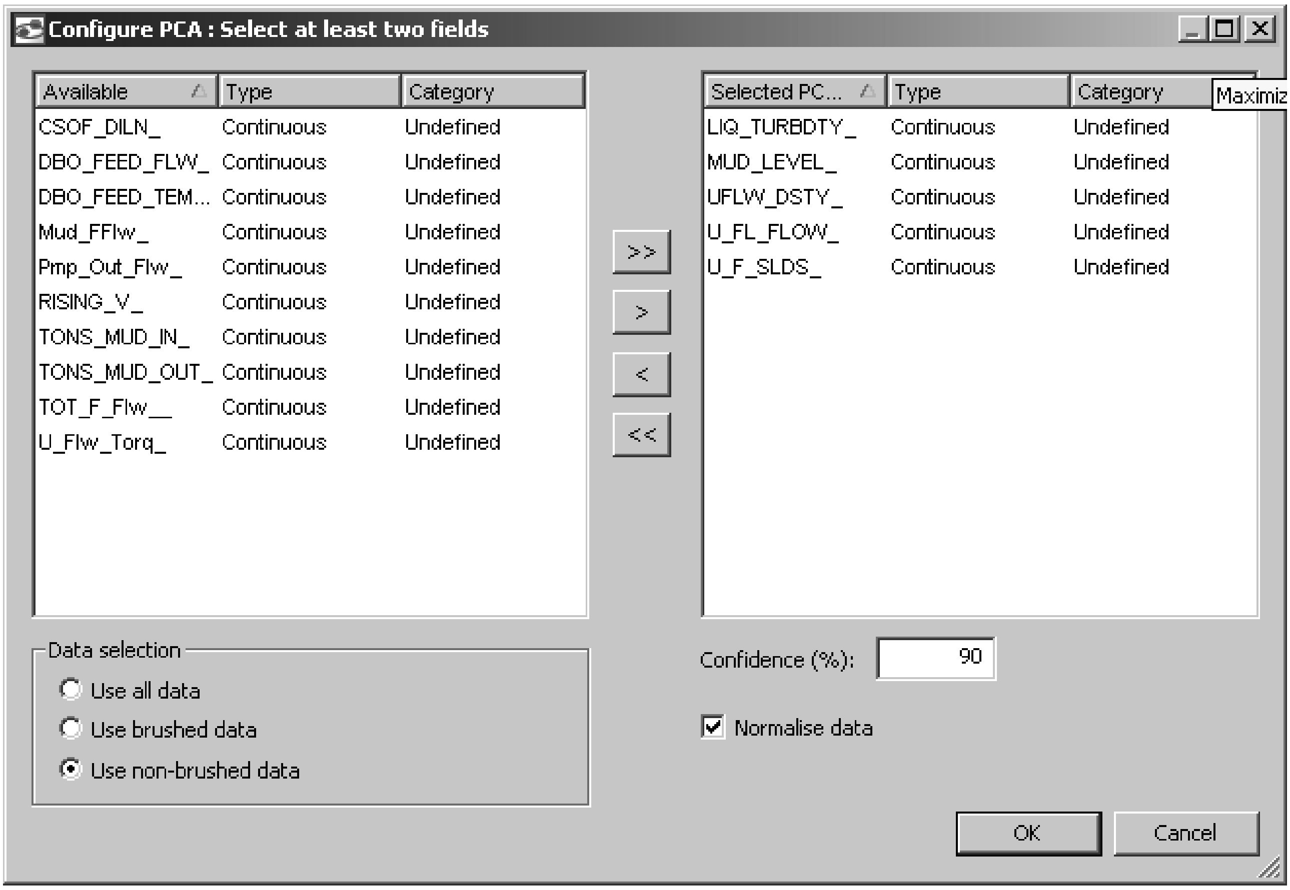

Fig 5. Array of Data (right hand side of table) selected initially for comparison purposes

The specific target variables used for this comparison were:

- Liquor Turbidity
- Mud Level
- Under flow Density
- Underflow Flow
- Underflow Solids

This comparison is based on a Principal Component Analysis (PCA) of the data. This is a simple, non-parametric method of extracting relevant information from confusing data sets. It can provide a roadmap to reduce a complex data set to a lower dimension to reveal the sometimes hidden and simplified structure that often underlies it.

The goal of PCA is to compute the most meaningful basis to re-express a noisy data set. The hope is that this new basis will filter out the noise and reveal hidden structure. This can show which dynamics are important, which are just redundant and which are just noise. It also provides a very useful way of comparing complex data sets.

Figure 6 shows the results of the PCA comparison between the principal components selected as X and Y axes based on the above specific target variables for the operating conditions in Settler 2. The lighter grey data points are for standard operating conditions; the darker grey area within the white outline is for high rate data with the two dashed rings showing that these fall predominantly within the 90% and 95% model confidence limits, i.e. outer and inner dotted circle respectively.

The Squared Prediction Error (SPE) plot shows the error of the X axis's principal component. Again the darker grey area within the white outline shows the high rate data overlaid on the error for the standard operating conditions.

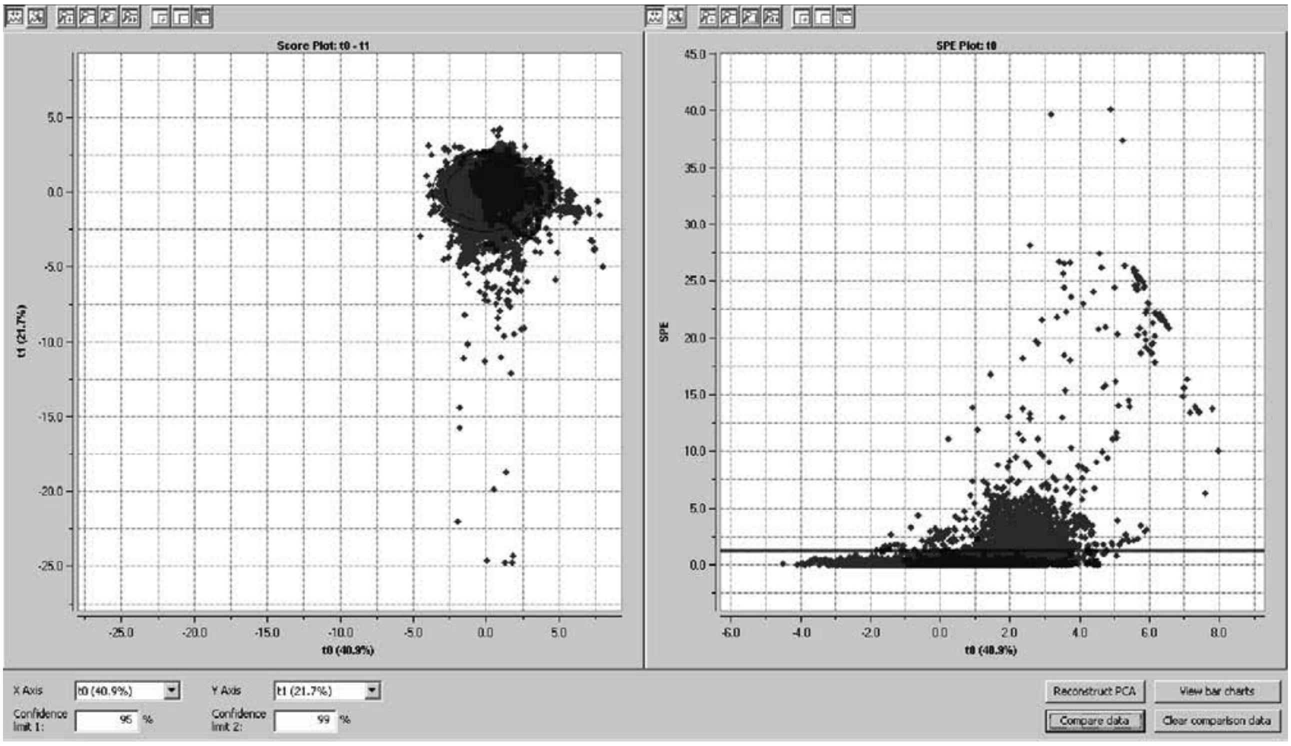

Fig 6. PCA Score Plot and SPE Plot Comparisons for Settler 2. Within the white outline is high rate data

These results showed that the KPI's experienced during Settler high flows and high mud loading fall predominantly within the 90% confidence levels for the whole data spread across the standard Settler operating conditions, and therefore are unlikely to cause significantly poor Settler performance.

4. Assessment of Flocculent Changes

The same basic methodology was used to review the effectiveness of a change in flocculent. It was wished to understand what improvement in the longer term may have accrued from the change of flocculent based on earlier trials with it.

The data analysis revealed two key factors. Trends within the data could be seen but with apparent occasional anomalies. As the data sets were extended to help throw more light on these seeming anomalies it was possible to demonstrate underlying differences in the data sets over time because of changes in operating conditions over two years and between different Settlers even though operating in parallel. This was valuable as it qualified the use of the trend comparisons indicating caution should be applied when seeking to attribute changes purely to the different flocculents.

The data were cleaned by brushing in similar fashion to the earlier work so as to only assess data from operations under normal conditions. A number of trends were developed covering two full years of operation, one year being for the period of operation with each of the two flocculents (viz. 2008 and 2010). On this occasion the purpose of the work was to deploy a rapid analysis tool to vast arrays of data in order to quickly and reliably arrive at an assessment of the apparent efficacy of the flocculent changes under all reasonable Settler operating conditions, including the possible effects of the presence of lime which is added intermittently to the circuit for other liquor control issues. This rapid comparison using multiple trending of parameters did not require the development of PCA models initially but these were developed for the reasons described above. The value of the PCA models developed was not so much their possible use as a control or benefit estimation tool but rather to demonstrate that data relationships (simplified through using PCA) were from different Refinery operating modes. This needs to be adequately addressed if seeking to advance one flocculent over another.

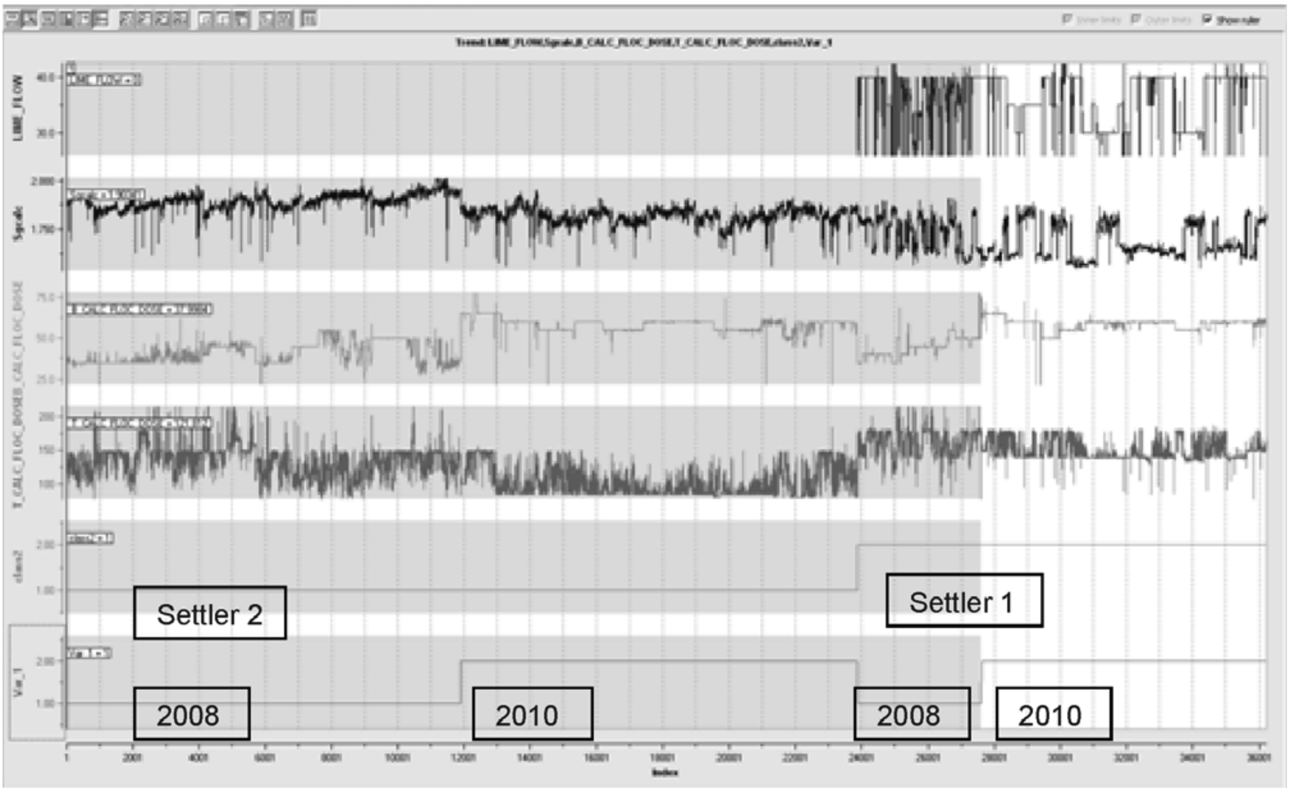

Fig 7. Multiple trends of Lime Rate, U/F Density, Flocculents Addition Rates, Settler Number, and Year

The trends in Figure 7 provide the opportunity to effectively visualise the process relationships. The software does allow for zooming and scrolling to focus on regions of data in more detail than depicted here, to the extent of comparing individual data points if desired. Major trends are apparent, but in each case even with these few parameters plotted, anomalies are apparent even on this scale. For example, whilst U/F Density [Sgcalc] generally decreases when lime is being added, suspected to be due to flocculent deactivation, this is not always the case. Similarly O/F Clarity deteriorated generally with lime addition. It is also noted that for the trends illustrated there is generally less variability within the 2010 data, but the causes are not apparent from the trends. It may be that multivariate analysis of parameters can illuminate this, for example showing tighter control of parameters in 2010 simply because of the trial, or implementation of improved process control algorithms because of the closer scrutiny of the unit process – again because of the trial and higher level technical inputs. It could also be due to non-parametric changes in which case the inability to develop statistically sound models could point to a cause other than what has been attempted to correlate parameters.

The PCA model in Figure 8 actually shows 6 operating modes. 4 are obvious – two separate Settlers over two separate years. The other two modes are within Settler 1 data. This is more clearly seen in lower LH corner data [2010. Flocc 2 Settler 1. +/- Lime] where, on the diagonal, tails can be seen for the lower half of the data cluster. One grouping in this overlapping double cluster has been circled. Similar division exists in upper LH corner for 2008 data. This is attributed to intermittent lime addition. A simpler PSA model using just Settler 1 data over one year in fact delineated these two modes more clearly.

This work is progressing so as to better understand the process complexities apparent from these trend scatter plots and model analyses. One variable that the passage of time will present for possible analysis will be Settler Duty Age.

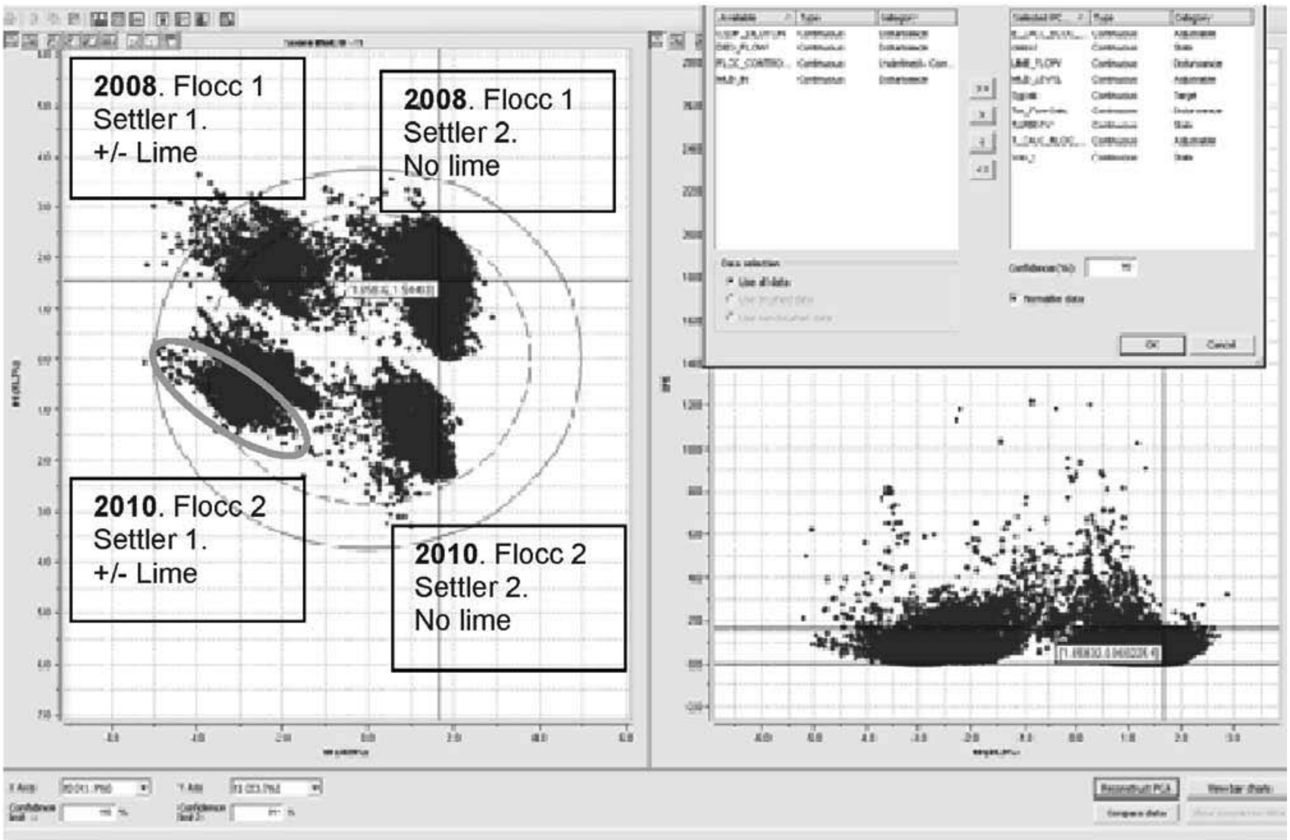

Fig 8. A more complex PCA model illustrating different operating modes for two Settlers

5. Conclusions and/or Recommendations

The data analysis and modelling work for increasing slurry flowrates and mud loadings by some forty percent showed that the performance KPI's experienced during such Settler high flows and high mud loading fell predominantly within the 90% confidence levels for the whole data spread across the standard Settler operating conditions (Fig 6), and therefore would be unlikely to cause significantly poor Settler performance.

The data analysis and modelling work for assessing performance of changed flocculents is ongoing because what was shown was the complexity of operating conditions over the extended period required to compare flocculent performance against performance KPI's. It is apparent the overall operating platform of the Refinery changed and was represented by no less than 6 operational modes (Fig 8) which will need to be more precisely characterised to draw meaningful correlations for a rigorous business case analysis.

Multivariate statistical analysis provides a tool for reducing partiality and bias in data analysis that often arises when using simpler comparisons based on a few parameters (e.g. Fig 7). At the same time it facilitates 'unravelling' or correlation of complex data sets. Rapid visualisation techniques can simplify and speed data interpretation and provide guidance as to which process areas may be amenable to business improvement. This provides the opportunity to focus on more detailed analysis and possible targeted laboratory, pilot or plant trials. The results can provide a rapid directed assessment thereby reducing costs and improving investment outcomes.

With the passage of time and thus more data representing the new operating regimes becoming available, it will be possible to use the Knowledge Extraction and Benefit Estimation components of the software to optimise overall operation of the units.

It will also be possible to replicate the models developed in other areas of Clarification and the Refinery.

This work confirmed the utility of the approach taken. The sea of data collected from many process operations can be overwhelming, and whilst these data can be simply visualised it may not be possible to capture the vital information that is hidden within. Mining such data using Advanced Analytics can bring understanding of data relationships and their bearing on important KPI's [4]. As demonstrated here with increased equipment loading, this fostered increasing the throughput in existing equipment without loss of efficiency. Similar use of the Analytics can demonstrate improved quality, improved use of energy, resources and process chemicals, maximisation of uptimes and improved off-line or real-time knowledge of causes of process variation – all translating to bottom line benefits.

References

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