# DOUBLING THE CAPACITY OF 50 YEAR OLD CCD CIRCUITS AT LOW COST IN JAMAICA

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**Abstract**

The quality of Jamaican bauxite available to the alumina refineries both in Jamaica and abroad is changing and these changes can effect the settling capacity of red mud thickeners. The changes in quality varies from deposit to deposit but in some cases there is a drop in available alumina and an increase in the goethite content. Both of these factors are presenting new challenges to refineries to maintain their production and cost effectiveness. In the medium term the refineries are carrying out a number of different research projects to develop an understanding of the goethite digestion reactions. In the shorter term the simple solution is to increase the capacity of the mud circuit. The low cost option is to improve settler and washer throughput by upgrading the feedwells using CFD modelling as a guide to performance before installation. This increase in capacity to almost double the previous capacity has been achieved at two plants in Jamaica with a review of a third refinery for similar upgrade underway. In one case this will assist in restoring capacity lost by the deteriorating bauxite quality and will be part of an expansion at reduced capital at another.

A valuable new technology tool easily applied to existing plants with great success.

## 1. Introduction

There are four operating alumina plants on the Island of Jamaica in the West Indies and one export bauxite operation. UC Rusal has a majority interest in three of these operations. The work covered by this paper has been focused on two of these refineries Kirkvine and Ewarton which have a target production of approximately 650,000 tons of alumina per annum. The location of the UC Rusal alumina plants are shown in Figure 1. The bauxite is recovered from the mines using truck and shovel operations with bedrock and pods of limestone being one of the impurities in the deposits and iron oxide the other. All of these alumina refineries are linked to their own coastal ports on the Caribbean Sea by rail lines for the export of their product.

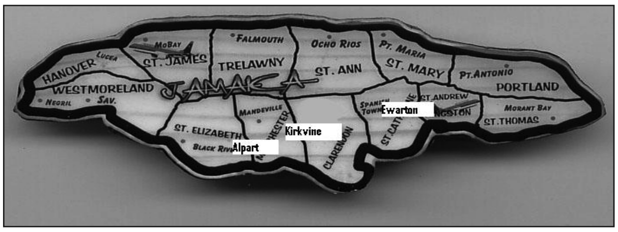


Figure 1. Location of Windalco alumina plants in Jamaica.

The focus of this paper is the residue circuit at Kirkvine plant in Manchester parish, but it also contains some trial results from the Ewarton plant in St. Catherine parish, where the initial trial work started about 5 years ago.

The Kirkvine and Ewarton plants are standard low temperature Bayer digestion alumina plants of old design with large CCD circuits followed by precipitation (batch in Kirkvine, semi-continuous in Ewarton) and rotary alumina kilns. The plants reflect tank design and technology from the 1950's, prior to the advent of synthetic high molecular weight flocculants and of instrumentation technology.

### 1.1 Kirkvine Production Restraints from the CCD Circuit

The work covered in this paper became critical a few years ago because of production restraints in the Kirkvine plant caused by the CCD circuit being unable to control and process the residue generated. The plant and equipment design together with other factors detailed below had caused the production problems.

*1.1.1 Old Plant and Equipment*

The Kirkvine plant was built in the 1950's using the technology of the day. Additionally Jamaican residue is recognised as being difficult to settle compared to other world bauxite deposits. The technology of the fifties was short tank height and large diameter tanks with the main settling agents starch and guar gum. In the 80's and 90's additional tanks were added to the back of the CCD circuit and these were based on the concept of tall tanks with smaller diameters. The tank feedwell designs have been modified over the years as starch has been replaced by higher molecular weight flocculants. The trials covered in this paper are an extension of that development work using modern technology. The object of the feedwell is to mix the flocculant with the slurry particles, reduce the kinetic energy of the stream and allow the discharge of the particles so that they settle in the body of the tank and give clear overflow.

The CCD washer circuit at Kirkvine is set up so that each of 1,2,3 or 4 tanks in each stage are fed from a common head tank by gravity. As the head tank is not equidistant from all the washers it is feeding, the flow is variable and this poor feed distribution makes the control of the washers difficult. The variable split of feed to each washer leads to insufficient underflow capacity in some tanks which in turn causes the mud level to rise in high feed rate tanks even when flocculated adequately. Some inter-stage pumps have been upgraded to reduce the impact of this problem. Most of the pumps newly installed are fitted with variable speed drives, which have the advantage of reducing the wear on the valves and piping, thus increasing the availability of equipment.

*1.1.2 Flocculant Quality*

The Jamaican plants were one of the first adapters of synthetic flocculants as a starch replacement. However, with the increase in demand for flocculant from the increased quantity of poorer settling, residue the flocculant makeup system became inadequate and produced poorer quality product for the CCD circuit.

*1.1.3 Insufficient Instrumentation and Process Control*

Due to high capital cost, some of the instruments that are regarded as standard in newer alumina plants have never been installed. These include slurry flow meters, dilution flow meters and underflow density gauges. Other instruments, however, are of a very high standard, the main one being the mud level probes. Some CCD process control is in place but it is mainly based on controlling flocculant dose rate and rake torque of each individual tank in the front end of the CCD circuit. Controls are less developed in the back end of the circuit.

#### *1.1.4 Rake Design*

Some advances in rake design have been achieved by Windalco in collaboration with equipment suppliers. The main thrust has been reducing the amount of steel surface of the rake to reduce the area available for scaling. This has been done by removing the rake lift mechanism, reducing the torque arm size and having a simple rake arm attached to the centre shaft by cables. The main raking mechanism (ie the blades) have changed very little and are mostly spread evenly along the length of the rake shaft.

### 1.2 Deteriorating Bauxite Quality

To add to the problems associated with an old plant the bauxite quality is also deteriorating. The available alumina has dropped to 43% and the goethite on some deposits has increased by a factor of 4 to about 15%. The available alumina is good by Darling Ranges Australian standards (viz 30% available alumina) but the CCD circuits in these relatively new plants have been designed to handle this volume of residue.

The drop in available alumina to 43% requires higher grinding, digestion and CCD circuit capacity to maintain production. The increase in goethite however generates poorer settling residue and increases digestion and decanter alumina losses.

## 2. Action Plans Initiated by Windalco 2005 to 2007

In order to overcome the continuing production loss from the CCD circuit, a range of plans were developed, addressing the various aspects of the problems. These plans covered a number of areas of development in the CCD circuit. This paper only covers details of a few of the investigations being undertaken. A more complete list is shown briefly here so that an understanding of the sum of these investigations can be obtained.

### 2.1 Plant and Equipment

The first step was to review the plant and equipment and upgrade it using modern technology. This was done by utilising the skills of international specialists in equipment design, surface and reaction chemistry, and basic engineering manpower.

#### *2.1.1 CFD Modelling of Washer and Decanter Feedwells*

A simple way of increasing washer capacity is to improve the feedwell design. A number of initiatives to improve decanter performance at Ewarton had been successfully tested and these were the starting point for the washer improvement at Kirkvine. Once an improved design has been developed then CFD modelling can be used to test if an improvement will be achieved before actually installing the new design in a tank. This can be done by developing designs based on previous knowledge and testing them using computational fluid dynamic modelling. This was initially done at Kirkvine by Windalco process engineers but later with the assistance of Ron Kahane, both of whom used the CSIRO under the AMIRA 266 Thickener Project to carry out the modelling. Feedwells were installed in a number of tanks based on the CFD modelling results.

#### *2.1.2 Flocculant and Rheology*

The upgrading of the flocculant makeup and distribution system was virtually complete (by Windalco engineers) by the middle of 2007 so that constant concentration flocculant at specific dose rates was received by all the CCD circuit. Windalco worked closely with SNF so that new flocculants could be developed to handle the increased goethite residue. A co-operative project was developed with SNF to review current flocculant types and those that would be suitable with the higher goethite bauxite. A study of the ensuing rheology of the underflow of these residues was also undertaken.

#### *2.1.3 Feed Flow Meters and Computer Control*

The CCD circuit washers did not have flow meters installed, so feed distribution relied on operators adjusting the gravity flow by reacting to high rake torque readings, high underflow rates and elevated cloudy or mud bed interfaces. A program was commenced to install feed flow meters on tanks which were to be fitted with trial feedwells.

With the installation of the feed flow meters it was possible to improve the computer control programs so that they operated in the feed forward mode as well as in the feed back mode. It was also possible to set new mud level control targets. When new feedwells and controls are installed on all tanks it will be possible to develop an improved overall control program for the whole CCD circuit.

#### *2.1.4 Reduced Number of Blades Rakes*

A reduced number of rake blades trial was installed in Ewarton in 2002 with the objective of reducing scale growth. Some progress was made in this direction and it was proposed to test a similar design at Kirkvine. More details of this trial are given later in this paper.

## 3. Trial Program – Kirkvine

The initial direction of development by the Kirkvine Windalco Technical Department was to take the successfully tested feedwell design from the decanter ‘C’ at Ewarton and install it in a Kirkvine washer. This was done but the results of the test were not successful. The next step was to involve the CSIRO, by sending the feedwell designs from ‘C’ decanter to them for modelling. The results of the modelling suggested a new design containing a quarter shelf should give the best results. The modified design was installed and Ron Kahane was brought to site to assist with the plant trials focusing initially on the first three stages of washing at current production rates, then on increasing production rates back to the level achieved prior to the introduction of poorer bauxite qualities to the plant. A review of the decanters at Ewarton was also required to determine why success had been achieved on ‘C’ decanter. This work was based on CFD modelling on designs developed in conjunction with and carried out by CSIRO Minerals as a 1 to 1 project under the AMIRA 266 thickener project.

### 3.1 CFD Model

The AMIRA 266 project has been operating for 17 years and has been supported by at least 30 major mineral processing companies during that time. A number of CFD models have been developed during this time with each new model being more accurate than the previous one and capable of delivering more technical information. The backbone of the current model is the two phase turbulent model.

#### *3.1.1 Two Phase CFD Turbulent Model*

The flow in a thickener feedwell is generally turbulent, and the characteristics of turbulence in this region, have a major influence on the size and density of aggregates formed. A quantitative description of turbulence and its effect on the flocculent mixing and particle aggregation processes is therefore required. The transport of suspended solids from the feed inlet to various points in the settling zone is also governed by the hydrodynamics and turbulent mixing within the feedwell. The natural dilution or recycling into the feedwell is also important because of its impact on aggregate properties.

The CFD model incorporates a turbulent, two phase treatment of liquor and solids, using a full two-fluid "Eulerian-Eulerian" technique. Two sets of continuity and momentum equations are coupled by means of common pressure and interphase momentum exchange terms. Turbulence is taken into account using Reynolds averaging so that the flow quantities developed are mean values. The continuity equations contain volume fraction, density and flow velocity of the phases and apply to both the liquid and solid particles. The turbulent diffusivity of the solids phase through the liquor is also incorporated together with the drag force between particles and the liquor and gravitational forces. The pressure force is distributed between phases proportional to the volume fractions and the drag term is calculated using a standard equation for drag coefficient assuming a spherical particle. The effective eddy viscosity is calculated from the laminar viscosity of the liquid and the averaged flow field of the liquor phase using the standard $k-\varepsilon$ turbulence model. The shear production is then calculated from the effective eddy viscosity. The turbulent diffusivity of the solid phase through the liquor reasonably assumes that particles respond perfectly to turbulent eddy motion.

A single aggregate size was assumed in the settling zone of the thickener. Only the part of the thickener above the bed has been simulated. In the thickener model the bed surface acts as a porous boundary where settled aggregates and liquid are incorporated into the bed and removed from the computational domain. The rate at which solids settle into the bed is determined by the settling velocity. The liquid is allowed to leave the domain through the bed surface at an appropriate rate so that mass balance is preserved.

*3.1.2 Flocculant Adsorption and Shear Rate*

The model includes flocculant mixing and adsorption. The two key steps in the flocculation process are mixing the flocculant with the feed and its adsorption onto the surface. These have been modelled using the hydrodynamic model described previously. The mixing between the flocculant and liquor is described by turbulent mixing, with turbulence predicted by *k-e* turbulence model. The rate of adsorption equation shows how well the flocculant is mixed with the feed slurry and how far unadsorbed flocculant molecules travel through the liquor before being taken up by a particle surface. The process is transport limited so the adsorption rate depends on the rate of arrival of polymer molecules at a particle surface.

Shear plays an important role in mixing, aggregation and rupture in the flocculation process. A predictive shear model has been included in the CFD model to give calculated shear rates. This shear rate calculation is quite complex, as the turbulence model does not accurately represent the turbulence in the near wall region. Therefore, the calculated shear rate near the wall is very sensitive to both the distance from the wall and the grid size. A numerical technique has been devised which combines the use of log wall functions and exponentially spaced grid systems. A more complex model was used for some of the CFD runs on the decanter, to give more accurate results. This model incorporates a population balance to account for aggregation kinetics.

### 3.2 Description of Kirkvine Circuit

The circuit at Kirkvine consists of decanters in parallel feeding a CCD circuit that mostly consists of three tanks at each stage with a mix/feed tank between each stage. The last two stages have two high rate thickeners each.

*3.2.1 Tank Design*

The main tank design used in this development work is 30.5metres (100ft) in diameter with a straight wall height of 2.25m (Figure 2) and a feedwell diameter of 3.66m.

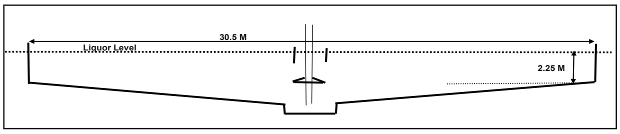


Figure 2. Basic design of 1st and 3rd stage washers

The initial focus has mainly been on the tank design shown in Figure 2, because 73% of the tanks at Kirkvine are this design and improvements to a few of these tanks could easily be rolled out to others of the same design.

The most recently installed feedwells (2005-2006), based on the successful Ewarton decanter design, are shown in Figure 3.

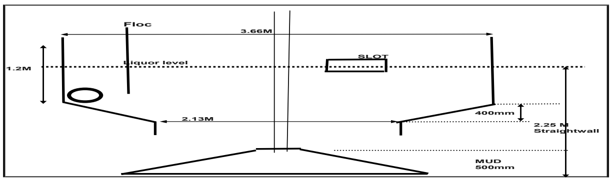


Figure 3. Basic design of feedwell installed in 30.5 meter diameter Kirkvine tanks 2005-2006.

There are a number of basic problems with this design and the short sidewall height of 2.25 metres further exacerbates the poor performance.

- In most cases the feed pipe discharged near the bottom of the feedwell thus allowing short circuiting and reduced contact time between flocculent and slurry.
- The feedwell was not full because it was installed too high up in the tank.
- The presence of slots at the liquor level allowed some of the slurry in the feedwell to escape without being properly flocculated.
- The chinaman's hat was too far below the feedwell to prevent mud re-entrainment into the feedwell.
- The skirt at the bottom of the feedwell added height to the feedwell without contributing much to the flocculation process.
- Control of the CCD washers was difficult because of the poor design of the feedwells and also the lack of instrumentation. This poor control resulted in variable mud inventory and spiking rake torque.

The CSIRO CFD model was used to evaluate a number of feedwell modifications to determine suitable designs for field trials at various feed flow rates and feed percent solids. Most of the runs were carried out at 300m$^3$/hr and 120g/l solids, which at that time was regarded as current plant flows for the lead washers at Kirkvine.

The CFD model was set up for the existing configuration - Figure (3) - to include the tank and closed feedwell, to investigate flow patterns, dilution, solids and velocity distributions, discharge characteristics, shear rate and flocculant absorption. The results from the model identify factors limiting performance, e.g. areas of high velocities and shear rates, regions of poor mixing. The model was then used to explore a total of four design changes to the current feedwell configuration at a liquor S.G. of 1.08. These included changing the location of the chinaman's hat, raising the feed pipe and placing it closer to the wall to better utilize the volume of the feedwell and also installing a part shelf below the feed pipe. Raising the feed pipe and discharge onto a quarter shelf set higher in the feedwell gave the best results, because it gave adequate solids mixing and dispersion high up in the feedwell as well as longer retention time and better energy dissipation (Figure 4).

**Summary of Requirements**

- There is need for a shelf or part shelf to hold up the high solids flow.
- The shelf allows the flocculant to be retained in the feedwell and properly mixed with the slurry.
- The combination of high feed inlet and quarter shelf is effective in creating a dominant swirl, with the feed stream spiralling a few revolutions around the feedwell before exiting.
- The dilution stream is continuous and reaches the free surface recycling low solids liquor back into the feedwell. This also produces more even distribution off the edge of the chinaman's hat.
- Shear rate is similar to the base case.
- At increased feed rates up to 450m$^3$/hr, feedwell operation was satisfactory and only the increased shearing around the feed discharge would have increased particle breakage. Dilution slots on the side of the feedwell were sealed.
- An extra precaution was taken with the first two washers modified, by having recycle dilution available for secondary flocculent addition external to the feedwell.
- The chinaman's hat serves a number of functions. They are: to hold up the flow in the feedwell; to distribute the mud discharged from the feedwell, giving uniform distribution of discharge flow over a wider area; and to prevent mud from the bed being sucked back into the feedwell and interfering with the flocculation process.
- Higher flow rates of 550m$^3$/hr were subsequently modelled on both the decanters and washers. The designs developed are the basis for most of the trial feedwell installations.

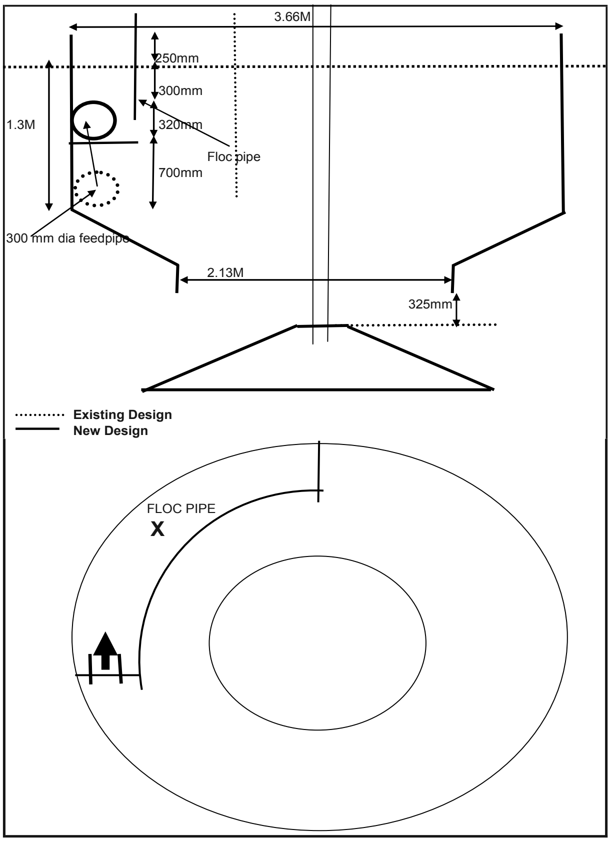


**Figure 4. Showing the initial changes that were made to improve the performance of the tank.**

The main problem with these 30m diameter tanks for the introduction of higher flow rates was the short side wall height of only 2.25m. Added to this was the fact that a chinaman's hat was also required to prevent the cone from receiving too much mud and prevent the mud bed from re-entering the feedwell. Many years ago the tunnels under the tanks had flooded, so the tank underflow pumps were no longer used. Instead the underflow was pumped from a well in the cone, up the sloping side of the cone and into the inlet of the underflow pump.

A simple calculation showed that a 3.66m feedwell would not have sufficient volume to handle the increased flows required to regain the production lost from the lower grade bauxite (except for the 1st stage) and still keep the chinaman's hat at the mud level or above it. The only solution therefore was to model larger diameter feedwells (4.8m) and if the modelling was successful install one as a trial.

### *3.2.1 Basic Feedwell Design Concepts*

Most of the feedwells at Kirkvine that had been installed in the last few years had closed cone bottom designs because the feed residue was a fine size and the cone bottom tended to achieve higher solids from the longer flocculant solids contact time. Based on the assumption that this was a correct strategy all of the subsequent CFD modelling was carried out on the closed feedwell design. The objective, then, of the larger diameter feedwell designs was to improve flocculant slurry mixing, increase momentum dissipation and handle a higher feed flow rate.

The first design modification was to discharge the feedpipe tangentially into the feedwell onto a quarter or half shelf or a full shelf if the feedwell was rotating or onto a new design with an integrated shelf (marked with a K in Table 1). All of these designs were found to be suitable for specific applications. The main criteria for this choice was cost, higher risk of scaling and of course the best design from the CFD modelling. A list of the feedwells modified in 2006 -2007 and based on the CFD model results is shown in Table 1

**Table 1. Tank Feedwells modified 2006-2007**

| Stage | Modification |
|---|---|
| 1st | 16ft K 12ft ¼ shelf 12ft ¼ shelf |
| 2nd | |
| 3rd | 16ft ¼ shelf 16ft K |
| 5th | |
| 6th | |
| 7th | |
| 8th | 17ft K 17ft K |
| 9th | 14ft ¼ shelf |
| 10th | |

The trials were carried out in such a way as to minimise risk to the plant if they were not successful. The initial trials were carried out on the 3rd stages and after proving, successful trials were moved in either direction from there to the 1st stage, 8th stage and the 9th stage.

## 4. Results

Extensive evaluation of the data prior to the feedwell installations and post installation has been carried out. Only a summary of the most outstanding results are shown graphically here.

### 4.1 Third Washer Results

The third washer results clearly show the improvement in performance that has been achieved initially from the new feedwells. A new source of higher grade bauxite was located and used from mid 2007, thus reducing the feed rate to the trial washers. On the other hand, previously all 3 third washers had been in operation. With the new feedwells and the better quality bauxite only 2 tanks are required and the third was a spare until one of the modified tanks could not be restarted after a hurricane that affected the plant. With three tanks in service the decision has been made to blend the good and poor quality bauxite and this is evident in Figure 5, where the total mud tonnage processed by the third washers has increased from 80 tons an hour to as high as 120 tons an hour. The spare tanks that are being generated from these trials may also be used in the future to create an additional washing stage at low cost.

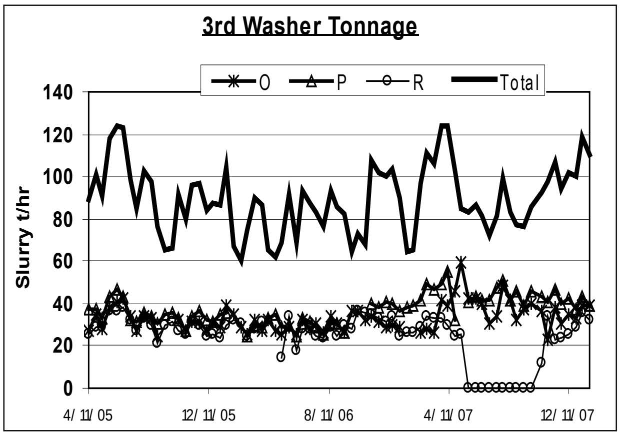


Figure 5. Plot of third washer underflow tank tonnages.

There has been a steady increase in the amount of flocculant on an average gram/tonne basis that has been required to handle the increase in tonnage handled by the third washers (Figure 6). This is to be expected, due to the higher residue tonnage per tank.

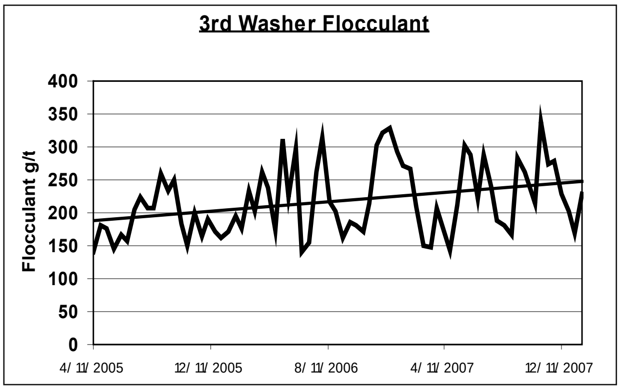


Figure 6. Third washer flocculant consumption.

Another benefit of the feedwell was an improvement in the actual cloudy layer thickness. This can be calculated by subtracting the mud level from the cloudy level and plotting the delta difference. This removes the impact of the high mud bed which can be caused by a high feed rate or insufficient underflow mud capacity. Figure 7 shows that the delta difference of O and P washers has trended to zero since their feedwells were modified, whereas the delta difference of R has always had peaks due to poor flocculation in the feedwell.

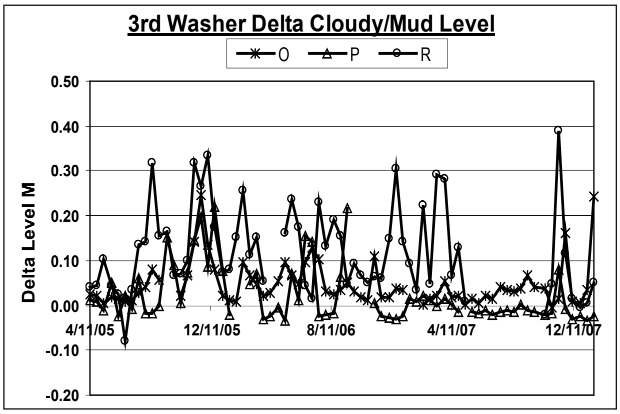


Figure 7. Third washer delta cloudy/ mud level showing the improved performance of O and P after being modified.

## 4.2 First Washer Results

Three first washer tanks have had modifications carried out to their feedwells. The first was the installation of a 16ft Kahane design feedwell in E washer, designed to handle high feed rates (Figure 8).

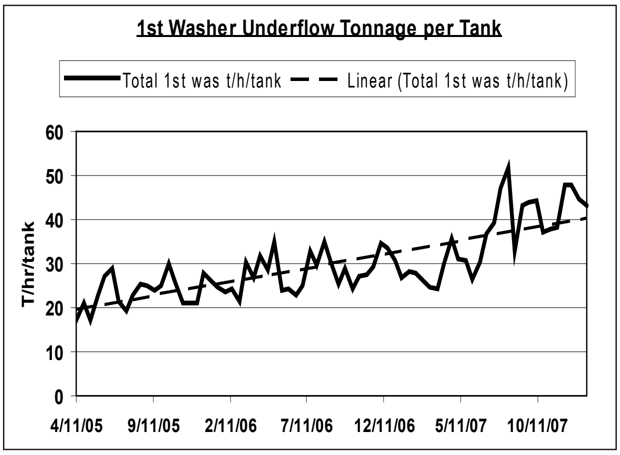


Figure 8 Increasing average tonnage handled by each first washer.

Unfortunately scaling and design of the feed system prevented sufficient feed reaching E washer to initially test the performance at higher feed rates. Some of these problems have been addressed and the average feed flow has increased to the first stage washers. Figure 9 shows the steady increase handled per 1st washer tank from 20 to 40 tonnes per hour.

Under normal conditions a doubling of throughput would be expected to require more than a doubling of the flocculant dose rate per tonne of residue but in this case the average dose rate has actually slightly fallen. Figure 9 shows the flocculant dose rate together with average underflow tonnage. This improvement in flocculant consumption is due to the superior mixing in the new feedwells.

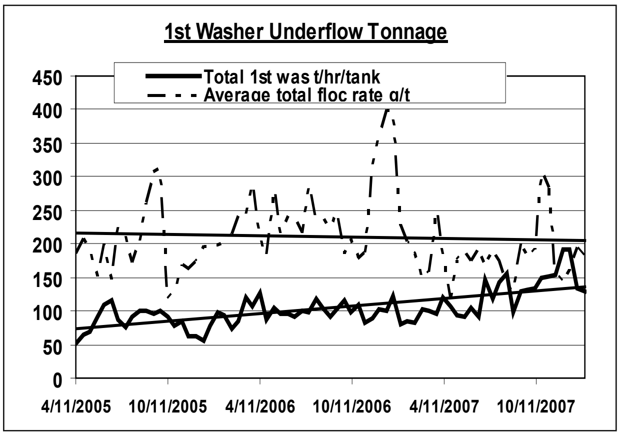


Figure 9. Decreasing flocculant usage and increasing tonnage.

The other factor that has been improved by the new feedwells is the reduction in height of the cloudy layer. This can be calculated by subtracting the mud level from the cloudy level and plotting the delta. This removes the impact of the high mud bed which can be caused by a high feed rate or insufficient underflow mud capacity. Figure 10 shows that the delta of E washer which was traditionally the worst tank to control is trending towards zero since their feedwell was modified.

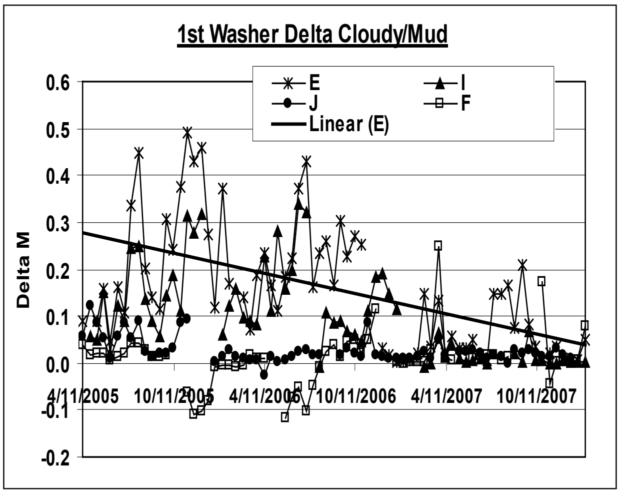


Figure 10. Delta cloudy /mud level.

### 4.3 Other Stages Washer Results

All of the initial work was carried out in the third stage washers followed by the first stage washers to de-bottleneck the front half of the CCD circuit. Once this work had been completed, attention turned to the back half of the CCD circuit. Improvements to the back of the CCD circuit feedwells were only carried out in mid 2007 so changes in performance have not been completely determined at the time of submitting this paper. Preliminary results from the 8th stage suggest that the new feedwells are performing satisfactorily. Results from two deep cone thickeners, 9B (improved feedwell) and 10A (improved pre feedwell flocculant mixing), suggest that some improvement has occurred but that improved controls need to be implemented to achieve the optimum results.

### 4.4 Reduced Blade Rake Results

A reduced blade rake was installed in 1st washer E at Kirkvine (Figure 11) at the same time as the installation of the new design 16 ft feedwell. The number of blades was reduced from 20 to 9 and was based on the same concept as had been adopted at Ewarton plant for their decanters. At Ewarton all the decanters with high capacity feedwells (B, C, D, and E) have had the number of blades reduced to 11 for three arm rakes. This has led, in one case, to the tank service life being extended from 4 months to 9 months. Figure 11 shows a plan of the rake design that was installed in E 1st washer. The results of the first campaign after installation of the rake are clouded by the low feed (30% of design) which may have encouraged scale growth. This problem seems to have been overcome and the next set of results should give a better indication of the rake performance.

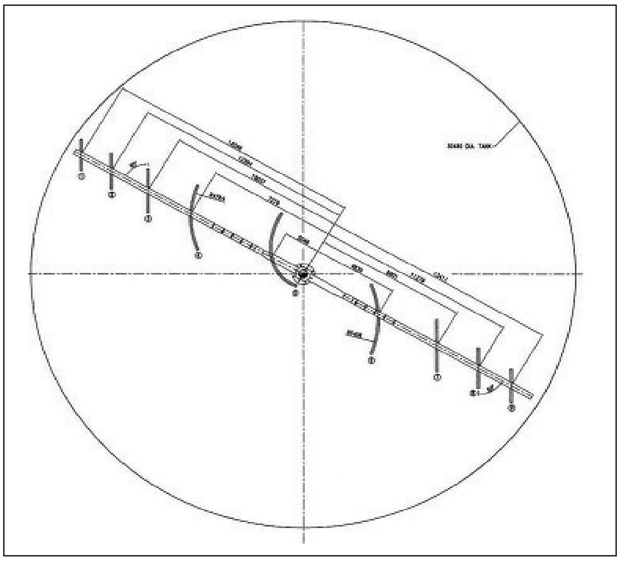

Figure 11. Plan view of reduced rake blade design.

## 5. Conclusions

The Jamaican refineries covered in this paper have met the challenges of deteriorating bauxite quality by using international expertise and modern technology on 50 year old plants. The capacity of tanks in the mud circuit have been doubled by installing new design feedwells based on practical experience and supported by CFD modelling. This has been achieved as a low cost short term option to recover production and allow time to research and develop alternative strategies.

**Acknowledgements**

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