An Approach for Disc Filter Debottlenecking and Flotation Plant Improvements

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Abstract

This paper presents an approach that can be applied for Plant optimization and debottlenecking. Hence, it will emphasize methodology and experimental description rather than end results, although this project was successful and created value for the client. A capacity increase program was initiated which was divided into multiple study Phases to reduce complexity thereby maximizing the probability of success. The were two major bottlenecks addressed subsequently with the respective objectives of 1) understanding, identifying and solving the filter cloth blinding problem and 2) identifying the Flotation Plant bottlenecks and recommend solution for immediate improvements. The developed approach was based on an R&D project model that included: internal and external literature review, development of an ARENA model of the Plant, Process Performance Assessment to establish the base case process KPI’s, historical and in-plant DOE for process parameters optimization, mechanical and process equipment Audits to bring equipment back to original equipment manufacturer design, as well as the use of advanced microscopic characterization techniques that enabled the identification of the cause of the filter cloths blinding and the proposal of practical solutions to be tested in-Plant. Process Performance Assessment combined with Design of Experiment resulted in recommended parameter changes/adjustments for optimal/improved filtering efficiency for a possible filtering rate capacity increase of 5 to 10 %. The Flotation Plant performance Audit established the current flotation circuit capacity and identified the bottlenecks for capacity increase, resulting in a list of recommendations for process control improvements. Finally, literature review generated some additional benefits. New flotation reagents have been identified and tested at the laboratory scale and might lead to Flotation Plant efficiency improvements while lowering the cost of reagents by 30 to 50%.

1. Introduction

The extraction of minerals from earth requires ore beneficiation as a first stage of refinement. The primary concentrate can then undergo a second stage of refinement that requires regrinding to release the remaining gangue which is followed by a separation/flotation process to increase the concentrate grade. The higher grade Flotation Concentrate slurry then needs to be dewatered by a filtering process/media. Maintaining the filtering rate and filter efficiency constant as a function of time can be challenging due to the progressive filtering efficiency loss. The efficiency loss can be attributed to two different phenomena that are additive: 1) natural filtering media wearing and degradation that will results in a progressive efficiency loss over a period of 6 to 8 weeks (depending on the industry type) and 2) the progressive filter cloth blinding that usually occurs over a short period of time resulting in process upsets that have a significant impact on the Plant OPEX as well as its capacity.
The current case study will be focusing on the blinding issue that was severe and occurred during a period of 7 to 10 days of operation for a specific product grade. During these production runs, filters usually experience a constant loss of efficiency over a period of 9-10 days down to a point where the filtering rate is so low that a change in product grade has to be made to mitigate production loss. The Process Performance Assessment calculations show that the average filter rate loss to be -1% per day with maximum/peak value at -3% per day; i.e., an average productivity loss of 10% and up to 30% over a production period of 10 days as shown in Figure 1. In the case of this specific study, the disc filters were identified as the primary Plant bottleneck followed by the Flotation Plant; both being in the critical path for the Plant capacity increase program.

![Disc Filter Throughput as Function of Time](image)

Figure 1: Example of filtering rate loss over a period of 10 days. This case represents one of the worst case scenarios at a loss of approximately -3% per day.

This paper will be emphasizing the description of the approach and methodology, and, to a lesser extent, the results, that were applied in the framework of this study. The proposed approach/methodology enables identification of the causes/nature of the problem and proposal of solutions to mitigate the blinding of the disc filters, which would improve/optimize both filtering and mineral separation (flotation circuit) efficiencies. It is believed that this methodology could be applied to help solve different industrial process related problems in a variety of fields and industries.

2. Project Objectives

2.1 Capacity Increase Program

The capacity increase Program was initiated with the following main objectives as guidelines:

- Bring existing equipment to (and sustain at) design capacity;
- Creep existing equipment capacity as much as possible;
- Add additional capacity where required.
2.2 Case Study Objectives
The current paper will

- Identify and solve main Plant Bottlenecks:
  - Disc Filters:
    - Identify nature of the blinding (What?);
    - Understand the mechanism by which blinding occurs (Why?);
    - Propose and test solutions to solve the disc filter cloth blinding problem (How?);
    - Optimize Filter Process Parameters.
  - Flotation Circuit:
    - Determine circuit capacity;
    - Identify the bottlenecks;
    - Propose solution for immediate improvements.

3. Approach Description

3.1 Methodology
The developed approach was based on an R&D project model that includes 4 different phases:

- Phase 1:
  - Literature Review – internal and external;
    - Prepare report and presentation
  - Develop the Plant Arena Model.
- Phase 2:
  - Perform Process Performance Assessment (process gap analysis);
  - Arena Model calibration/validation.
- Establish experimental plan (scope of work - SOW):
  - Identify Plant major bottlenecks;
  - Prioritize and prepare action plan/SOW;
  - Present SOW and obtain buy-in.
- Work included in different manageable phases (3-4-5...):
  - Item a: Perform ARENA modeling to estimate project benefits and establish best project timeline;
  - Item b: Perform historical Design of Experiment (DOE) on filter performance;
- Item c: Perform mechanical and process disc filter Audit;
- Item d: Perform Flotation Plant performance Audit;
- Item e: Perform microscopic characterization of filter cloth using different techniques;
- Item f: In-plant testing of the proposed solutions;
- Item g: Reporting and results presentation.

3.2 Experimental Method

**Literature Review and Scope of Work**

An exhaustive literature review was performed that included both internal and external literature/reports. This phase can be seen as the study incubation/preparation phase where fundamental information is collected which is essential for the preparation of a sound SOW. This clerical phase took 2-3 months of work collecting articles, gathering technical data and interpreting/criticising reported results. A literature review report was prepared and presented to key client personnel.

Allowing some time to perform a literature review is generally not easily accepted by the client. In this case study, it proved to be essential for preparing a sound SOW that was based on the latest industry findings as well as on a relatively good understanding of the process fundamentals behind disc filtering, blinding/clogging and flotation processes. It is essential that the SOW be discussed and then accepted (buy-in) by all of the client key process and operation personal.

**ARENA modeling**

Dynamic simulation is the preferred methodology for evaluating complex systems because, unlike spreadsheet models or linear programs, it captures the dynamic effects of system interactions, process variation, random failures, competition for resources, logistical constraints, process constraints, and other phenomena observed in real systems and quantifies the cumulative capacity losses associated with them. This allows for a realistic assessment of the type of production performance that can be expected. What-if experimentation with different modes of operation is easily carried out, allowing the best plant configurations and operating strategies to be worked out before actual operation begins. This is especially true of operations where production delays tend to lead to a chain reaction of delays due to the tightly coupled nature of the operation. Quantifying the amount of lost production is not at all readily carried out by simple calculation, trial on an existing system, or by comparison of one shop with another. Computer simulation is often the most practical way of quantifying the effects of the various system disruptions on productivity and in identifying the bottlenecks limiting production. The purpose of the model is to determine production capabilities and identify bottlenecks that limit pellet plant throughput for each of the proposed what-if scenarios. The model will be used to quantify the benefits of replacement/improvement projects in order to rank them according to their expected costs and benefits. The simulation model explicitly considers the operational and logistical aspects of the system, e.g. product flow, production scheduling, operating strategy, etc. Many metallurgical aspects such as composition based yields are explicitly modeled to ensure the model is as useful as possible to evaluate different improvement scenarios.
**Process Performance Assessment**

A complete Process Performance Assessment (PPA) was carried out to establish the base case Key Performance Indicators (KPI’s) of the Plant. This step was the starting point of this optimization/debottlenecking program since established the reference base case for future process improvements to meet the Corporate targeted yearly production; i.e., it determined the gap between actual productivity and future required productivity for each of the Plant sectors and equipment. The PPA mainly consists of data mining and statistical calculations/correlations using the MiniTab Software. It is interesting to note that the PPA exercise was performed by establishing the performance of each of the Plant sectors and then, drilling to each of the individual equipment performances composing these sectors. The time frame that was used for this analysis covered a full production year, extracted from the PI data archive, to capture the typical operational interferences such as the planned/unplanned downtimes, annual shutdown, typical process transition and upsets conditions. The main KPI’s were the following: %Availability, %Utilisation, %Downtime (planned and unplanned), %Efficiency, Nominal Throughput (/8760 h), Real Throughput (while operating) and Maximum Demonstrated Rate over a period of 7 days (MDR_7).

**Historical Design of Experiment (DOE)**

A historical DOE was performed based on 2 years of operating data. The objective of such an analysis should be to investigate the influence of selected parameters on the equipment performance for different products or set of conditions as well as to establish a quantifiable relationship (transfer function) between the process parameters value and the equipment throughput. All process parameters are to be listed into a C&E matrix (causes & effects) for which measurements could be obtained were included in the preliminary analysis which should be performed with the involvement of the Plant operators and process engineers. All parameters for which measurements were not available or which were too infrequent had to be discarded. This desktop analysis was performed using the PI data to identify the important process parameters that have an impact of the filter performance. This filtered the parameters and focused only on the significant ones for the in-plant testing as a second step of the DOE exercise. Parameters for the in plant DOE must be selected carefully, as each additional parameter increases the number of runs required exponentially. Parameters that were significant in the historical DOE were considered and prioritized according to the DOE results and the experience of plant personnel. Selected parameters also must be practical to test, as a certain amount of control is required to set the parameter within the desired testing limits. The Minitab Statistical Software was used for the data filtering and DOE statistical calculations/correlations. It is important to note that data filtering is critical for this type of exercise. Data coming from process upset conditions and flyers must be discarded from the analysis. The key process parameters investigated were the following: temperature, density, size distribution (Mesh & Blaine), Vacuum, rotational speed and % additives.

**Disc Filter Audit**

Special attention was given to the filter sector since it was identified as the primary Plant bottleneck. Therefore, discussion with operations combined with the review of the original equipment manufacturer (OEM) drawings and specifications showed that some of the equipment parts have been changed through the years and that there was no background/documentation available as to why these changes were made and what were the effects on equipment performance: improved or impaired? Some of the changes/differences appear to go against the current trends and were believed not to be optimal. Consequently, as part of the plan to bring back the equipment performance back up to OEM specifications, an Audit program was put together involving original equipment manufacturers as well as field experts. The objectives of the Audit were to identify detrimental design changes and provide insights to bring filters to original equipment
manufacturer (OEM) design, propose possible improvements based on new technologies for revamping/improving the actual filters and identify possible process control improvements. It was expected that the latter insights for improvements should be a complement to the internal projects/work being carried out to bring filters to the required capacity to meet the production target.

**Flotation Plant Performance Audit**

Special attention was given to the Flotation sector since it was identified as the second Plant bottleneck. Consequently, an in-Plant testing campaign was performed to assess plant performance at different throughputs. As such, the plant feed rate was intentionally kept at lower rates for a few hours at the time and then incrementally increased when upstream and downstream conditions permitted, whilst a series of samples were collected at different key points to establish the mass balance and cell-to-cell recovery/separation efficiency. The objectives of this task were the following: determine current trends in the circuit and then, evaluate requirements for the targeted capacity increase.

**Advanced Microscopic Characterization**

The filter cloth microscopic characterization was using advanced techniques with the objective of imaging and identifying the cause of the cloth blinding. Consequently, techniques such as FEG-SEM coupled with x-ray EDS, Auger Microscopy, IFTR, XPS, and XRD available at the Centre for Materials Microscopic Characterization-(CM)² located at Ecole Polytechnique de Montreal. FACT-Sage Software (CRCT-Polytechnique) was also used for thermochemical calculations. It is interesting to note that an innovative sample preparation was developed for the observation of the filter cloth. A series of 1 cm² cloth samples were juxtaposed and embedded into epoxy under vacuum. Then, the resulting epoxy puck containing all the embedded cloths was polished down to submicron diamond surface finish enabling the Scanning Electron Microscope observations and x-ray analysis of the polymer cloth mesh cross section.

4. **Results**

4.1 **ARENA Modeling**

ARENA modeling of the Plant established two main bottlenecks as well as the gap that will have to be filled for each of these bottlenecks to reach the targeted capacity. Consequently, sectors that were in the critical pathway were prioritized and an action plan was established to identify work items and projects that will allow to debottleneck these sectors and increase the Plant Capacity. Based on the established projects portfolio and work items, a series of dynamic simulations were carried out to identify the possible Roadmaps to reach the targeted Program capacity increase as seen in Figure 2. It is important to understand that there is an optimal project sequence that will maximize the benefit as a function of time; i.e., ARENA enabled the identification of the project sequence and combination that will bring the highest capacity increase the earliest in the program schedule, which impacts the Program cash flow and NPV.
4.2 Process Performance Assessment

As an example, data mining and statistics showed that there were substantial differences in individual module performance as seen in Figure 3 (Real module throughput). According to the table feeder measurements module 3 was the best performing module; hence not all modules performed equally and that there is potential for increased throughput here, if all the modules could be made to perform at the level of module 3. This fact has been corroborated by the observations of operators that reported that some modules appear to perform better than others. This was also in accordance with the MDR\textsuperscript{7} that showed the highest rate maintained for 7 consecutive days by each module. Again, for MDR\textsuperscript{7}, not all modules performed equally and there are no reasons as to why, because they are all fed with the same material and are of the same technology/manufacturer. Consequently, this exercise enabled application of sound numbers/statistics and then establishment of the basis for future improvement steps and target. Therefore, the optimization/improvement target could be for all lines to reach the MDR\textsuperscript{7} of line 1, or to be more ambitious, module 3 or module 7. There is potential for increased throughput here, if all the modules could be made to perform at the level of module 3. Since one module is already capable of this higher throughput, there is no reason why the others should not be able to perform similarly. Consequently, in the future, line 1 could become the benchmark. It is important to outline that this statistical approach can be applied to any Plant sector or to a specific equipment to establish its base case reference performance allowing preparation of a specific action for further improvement to meet the required productivity target.
4.3 Historical Design of Experiment (DOE)

It has been determined by the Arena model simulations that the filters section was the main bottleneck and the one that needs to be addressed first. The performance of this area is affected by many variables. This historical design of experiment (DOE) focuses on the effects of process parameters on the modules throughput. Figure 4 shows an example of a typical Main Effect plots resulting from such statistical analysis. As seen, it is interesting to note the process parameters effect on the equipment performance and that they tend to pass through an optimal point. Such analysis also allows generation of transfer function which calculates a weighing coefficient for each of the parameters whilst taking into account the process parameter interaction. The end result of this analysis is a predictive equation for the equipment throughput/performance as a function of the key process parameters. Consequently, an in-plant DOE was carried out to validate the results of the historical DOE and confirm the anticipated throughput increase. It was anticipated that 2 to 4% capacity increase can be obtained by tuning/adjusting and then controlling the key process filtering parameters at their optimal set points.
4.4 Flotation Plant Performance Audit

The Flotation Plant Performance Audit established the current flotation circuit mass balance, the cell-to-cell % recovery, the circuit maximum capacity and identified the bottlenecks in the pathway for further throughput increase. The results showed that the final concentrate grade can mainly be affected by the ore type, residence time, reagent addition rates, feed grade and solid concentration. Figures 5 and 6 show typical examples of the results that can be obtained following a Performance Audit, beside the complete mass balance. These results can be used to plan/optimize future flotation operation or as a design criteria for future modifications/improvements. Moreover, the Audit also can identify a series of possible modifications to improve process control and Flotation performance that can be implemented rapidly; i.e., a quick hits list.

In addition, the literature review enabled identification of new flotation reagents that were not commercially available when the Flotation Plant process was developed for this specific type of mineral. Consequently, interesting reagents prospects were identified and the test at the laboratory scale for validation. Results proved to be very encouraging justifying in-plant testing/validation which might lead to flotation efficiency improvements with less reagents addition (also interesting for the environmental perspective) while lowering the yearly cost of reagents by 30 to 50%.

Figure 5: Gangue recovery to final concentrate as a function of throughput
4.5 Advanced Microscopic Characterization

The filter cloth consists of a regular knitting of Nylon cord. Each of these cords are composed of a given number of individual relatively well aligned Nylon fibers. Cloth knit appeared tight, relatively free of dust as well as of foreign particulates. Fibers appeared to be free of each other; no adherence between them as seen in Figure 7.

Figure 7: SEM micrographs on initial / as received Nylon filter cloth. View of the filter cloth back (surface in contact with the backing cloth)

Figure 8-A shows a SEM micrograph of a used filter cloth. As seen, the cloth in severely blinded as agglomerated filled the spaces between the fibers. Figure 8-B shows material adherent and covering and the cloth fiber surface. This is believed to be scaling that forms progressively during filter operation.
Figure 8: A = SEM micrograph of a used filter cloth. Spaces between fibers are all filled/blinded with agglomerated particulates. B = Typical micrograph showing scaled material that is coating the Nylon fibers.

Figure 9 shows a typical micrograph obtained from the polished epoxy embedded filter cloth which allowed preservation of the phase that is coating the Nylon fibers. This phase is also believed to bind the particles together slowly filling the space in-between the fibers resulting in cloth blinding resulting in disc filter efficiency loss. Following the microscopic characterization and the identification of the compound responsible for filter cloth blinding, a mechanism explaining the formation of this compound was proposed followed by a series of recommendations to solve this problem. This led to in-plant testing of the recommended solutions. It was anticipated that a 5 to 8% filtering capacity can be obtained by solving/mitigating the blinding issue in addition to the reduction in OPEX attributable to the longer filter cloth campaign.

Figure 9: SEM micrograph showing scale that is covering a Nylon fiber
4.6 Additional Benefits

The presentation and diffusion of the results within the organization is of critical importance and sometimes underestimated in term of benefit. For this case study, process and operations representatives from different Plant sectors that were not initially affected by the current work were invited for the study results presentation. Amazingly, a link was made with another problematic sector of the Plant where, in that case, the screens were experiencing a similar blinding/clogging problem causing them to be this sector’s prime bottleneck which was known to have a significant impact on this sector capacity and OPEX. Consequently, used screen samples were microscopically characterized as seen in Figure 10-A. Interestingly, solutions recommended for the filter cloth blinding can be applied to solve this scaling problem. In addition, characterization highlighted a flaw in the screen design that once corrected with the manufacturer might lead to improved screen efficiency and longer campaign before blinding; increased capacity and lower OPEX. Figure 10-B shows the polymer screen design flaw that is causing a funnel effect which is believed to promote particle capture and progressive screen openings blinding.

Figure 10: SEM micrographs; A = used screen; B = transversal cut of the screen. As seen, presence of agglomerated material bridging on top of one of the screen mesh and the funnel effect with higher risk of clogging by larger particles that may enter but cannot exit; i.e., particles will be trapped between fibers.
5. Conclusions

This paper presented an approach that was successfully applied in the framework of a Plant optimization and debottlenecking study. Figure 11 presents an overview of this approach that can be applied to any type of optimization and debottlenecking study. Usually, consulting firms are asked to prepare a SOW to debottleneck the plant with limited knowledge of the process and operation and, then, upon approval proceed accordingly. The current methodology promotes a stepwise approach that will be easier to manage by both the client and the consultant that is believed to maximize the probability of success. Therefore, the first Phase of the Study should begin with the literature review carried out concurrently with the development of the ARENA model of the Plant. Once literature review and model basis completed, it is suggested to initiate the Process Performance Assessment and gap analysis to gain a deeper knowledge of the process and flow sheet. Plant sectors and equipment performance statistics will already enable identification of possible improvement work items in the different Plant sectors covered by the Study. It will also bring up a rough idea of the gap that will have to be filled in term of productivity/efficiency to meet the Program capacity target. However, it is to point out that the most reliable gap value will come form the ARENA simulations results that take into account the dynamics (synergies and interferences between the Plant sectors and individual equipment). Furthermore, the data and statistics generated by the Process Performance Assessment will also need to be calibrated and validated in the Arena Model. Then, the model functional description and results have to be accepted by the client; only then, the identified bottlenecks can be frozen/agreed upon; which will enable the preparation of the Study SOW and prioritization with the client key representatives. It is then recommended to proceed into different phases keeping their scope/objectives as simple as possible; i.e., if possible address only one major bottleneck at the time. Once this bottleneck solved, then move on to the next Study Phase until all major bottlenecks are solved and equipment improvements are completed as well as their anticipated benefit validated. The final reporting and presentation of the results steps are very important since they ensure results are archived for future reference, while presentations ensure that the essential of the results are communicated to the key peoples within the organization. Moreover, extending the attendees to key process peoples from other Plant sectors may prove to be highly beneficial as it was the case for the current work. Finally, the key factors that are believed to have played an important role in the success of the presented case capacity increase program study are the following:

- The stepwise Phase by Phase approach;
- Dedicated client representatives for the different sectors to be debottlenecked;
- Proper coordination with the Plant parallel activities to avoid overlap:
  - Reliability Centered Maintenance (RCM);
  - Process R & D program;
  - Continuous improvement program;
  - Operational excellency program.
- Weekly progress meeting (teleconference) involving operation, maintenance, process and upper management (VP technology executive).
Phase 1:
- Internal and external literature review
- Plant ARENA Model

Phase 2:
- Process Performance Assessment/gap analysis
- ARENA model calibration/validation

SOW – Optimization & Capacity Increase Program
- Establish SOW to address Plant bottlenecks and continuous improvement work items
- Prioritized activity as a function of the subsequent project phases

Phase 3:
- Address and solve bottleneck 1 (e.g., filters in the current case study)

Phase 4:
- Address and solve bottleneck 2 (e.g., Flotation Plant in the current case study)

Study ends
- Reporting and presentation of results

Parallel activities
- Reliability Centered Maintenance (RCM)
- Process R&D Program
- Continuous Improvement Program
- Operation Excellency Program

Presentation and buy-in of the model by the client: management, maintenance, process and operation

Clear mandate definition and objectives that will be the guidelines

Audience/attendees selection is critical to generate spin-off

Figure 11: Summary of the followed approach for the presented case study