24-029

Digital One Enterprise Expert Operating System on Production Line at Doe Run's Buick Mill—Expert-Control of Flotation, Grinding and Things (EOT)

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ABSTRACT

The Doe Run Company (Doe Run), a global supplier of lead (Pb), copper (Cu) and zinc (Zn) concentrates, and lead metal alloys, installed an enterprise expert control system—termed as Digital One—on the company's Pb, Cu and Zn circuits at its Buick Mill in December 2022. Digital One was developed with Metso and deploys Metso's product, VisioFroth™. This automated system is now running and optimizing the flotation processes for all three circuits (Pb, Zn and Cu), all plant air and methyl isobutyl carbinol (MIBC). In addition, Digital One also controls a second, newly built, modern flotation reagent system. Digital One also paves the way for automation and expert control of the entire mill, integrating grinding, thickening and filtration. Digital One is digitally immersed in a universal distributed control system (DCS); therefore, today's mineral processing plants may be upgraded to it or designed around it. This presentation will explore the plant design and operation of this technology at the Doe Run Buick Mill.

INTRODUCTION

Doe Run's Buick Mill processes complex ores containing Pb, Zn, and Cu with dolomite, pyrite, and marcasite gangue materials. These ores are processed using a traditional sulfide flotation scheme including a bulk Pb/Cu float, a float to separate Cu from Pb, and a Zn float to separate Zn from the bulk tails. This process has been the core of Buick Mill's operations since its creation.

In recent history, Buick Mill primarily relied on operator-set automatic controls for most of the milling process, including darts on float cells, air flow to float cells, and chemical reagent dosing. This is managed by a tried, tested, and thoroughly proven DCS. This system is well suited to handle the typical ores which Buick Mill receives but struggles with some complex ores such as marcasite rich ores.

To expand Buick Mill's capacity to handle increasingly complex ores such as these marcasite ores, a secondary additional reagent system was added. These reagents are potent, and their usage is indicated by changes in the mill feed and concentrates that are typically rapidly evolving. This includes anything from rapid changes in feed grade to sudden spikes in marcasite content, both of which have significant repercussions on the stability of the flotation process.

While these potent reagents can be directly controlled by a human operator, it has been found that these reagents require nearly constant attention to attain the best performance. It is exceedingly easy to overdose these reagents, so it is vital to turn them off once they are not required. Incorporating this dosing control into an expert control system is thus one of the requirements for this reagent system to be maximally effective.

Based on preliminary work at Doe Run's Brushy Creek Mill, and with considerable testing to understand the reagent system itself, it was determined that the VisioFroth™ system developed by Metso should be able to provide this functionality and more to enable a step-change improvement in Buick Mill's flotation capabilities.

Most importantly, Metso's OCS-4D© software powers both VisioFroth™ and Metso's advanced process control (APC) on crushing and grinding. Doe Run could use OCS-4D© to develop and apply expert flotation, expert grinding and the much-needed integrated expert flotation and grinding to process its regular and complex ores in the most efficient way possible.

As such, the major upgrade project of introducing state of the art expert control to Buick Mill began with the introduction of the VisioFroth™ system. OCS-4D© proved to be the ideal platform for the enterprise expert control and operating system at Buick Mill.

VISIOFROTH™ SYSTEM

Doe Run introduced Metso VisioFroth™, a machine vision system, first piloted at its Brushy Creek mill with two VisioFroth™ cameras on the zinc rougher line, then installed at Buick Mill. It is applied in the flotation circuit for incorporating with process control to provide more consistent monitoring and quantitative determination of froth properties. VisioFroth™, a product by Metso, is an image analysis system for on-line measurement of flotation froth properties and gives quantitative measures of the same (Runge et al., 2007). It calculates various parameters associated with the froth phase, which are:

- Froth velocity—the speed of froth moves towards the launder, often used to correlate to mass pull and recovery.
- Bubble size, bubble count distribution—the size/counts of surface bubble. This can be used to determine reagent dosing for reagents which strongly impact bubble size or count.
- Froth texture—a method of determining repeating patterns of froth types, mostly utilized to correlate the effectiveness of mineral loading with the reagents and concentrate quality.
- Collapse rate—an indicator of the superficial surface bubble bursting rate.
- Stability—refer to the similarity between two successive frames, recently studied can be used to determine pulping cells.
- Bubble load—indirect measurement of mineral load attached to bubbles.
- Color—three major color outputs which are RGB, HSV, and LAB. The most common used is LAB, Luminance (brown color pixel, Ax (green to red), and Bx (blue to yellow).

The VisioFroth™ system runs in the OCS-4D© software package. The OCS-4D© software forms the heart of the system by processing images and quantifying froth properties which then are used for process control to maximize and optimize the flotation circuit. The OCS-4D© software has a graphical user interface, navigator module, data miner module, image miner module, and variables module. The navigator module is for the user to configure logic control. It is essentially an animated control decision tree which makes it easy for the user to understand the overall control schematic/logic. The data miner module gives the user the ability to create charts (line plot, histogram, xy plot, variogram, and radar) and acts as a statistical module. The image miner module allows the user to store images which are collected from the video stream thus the user can correlate images, froth properties parameters, and plant process variables. The variables module enables the system to connect (inputs/outputs) to other systems (e.g., Distributed Control System (DCS), Programmable Logic Controller (PLC), SQL server, etc.), creates status, flags, equations, and logical functions. OCS-4D© includes fuzzy expert control, modelling modules, optimizer modules, model predictive control modules, and a PID module.

It is particularly worth noting that between Buick Mill and Brushy Creek Mill the VisioFroth™ system and OCS-4D©, along with the subsequent development of the Digital One expert system, were successfully integrated with both Rockwell DCS and Emerson DeltaV DCS systems. OCS-4D© allowed for seamless interfacing and automation with both DCS systems in either configuration.

Doe Run Buick Mill installed 19 VisioFroth™ cameras in the lead, zinc, and copper circuits at the Buick Concentrator (Figure 1).

The first phase of the project included installation of 7 VisioFroth™ cameras for Zn rougher and cleaner circuits distributed as 4 VisioFroth™ cameras for 4 rougher banks at the first cell of each bank and 3 VisioFroth™ cameras for the 3 cleaner stages at the first cell of each stage.

The second phase of the project included installation of 5 VisioFroth™ cameras for Cu rougher and cleaner circuits with arrangement of 1 VisioFroth™ camera for the rougher first cell and 4 VisioFroth™ cameras for the first cell of each cleaner stage.

The final phase of the project included installation of 7 VisioFroth™ cameras for the Pb circuit with 4 VisioFroth™ cameras installed for the first cell of each of the 4 rougher

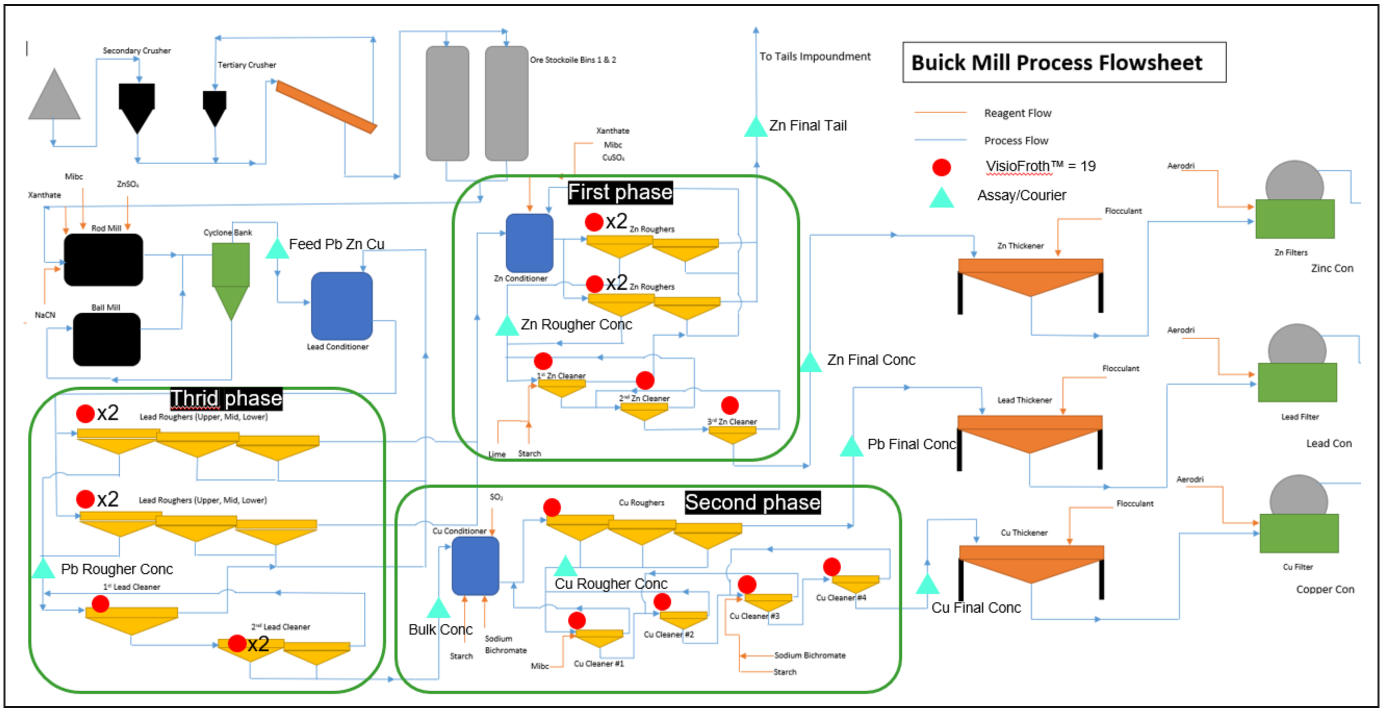


Figure 1. Buick Mill Process Flowsheet

banks, and 1 VisioFroth™ camera installed for the first cell of the first cleaner, and 2 VisioFroth™ cameras installed for the first cell of each secondary cleaner.

EXPERT FLOTATION FROM VISIOFROTH™ TO ENTERPRISE DIGITAL ONE ON PRODUCTION LINE

Mill control room operators operate flotation cells, relying on the visual observation of complex and changing froth appearances and online XRF assay readings to detect any disturbance in the plant. If there is any variance of the production target, then the operator identifies the causes, and, based on their knowledge and experiences, they react. They will adjust cell operating conditions and reagents to drive production back to target.

To expert control complex flotation processes, VisioFroth™ needs to consolidate operators' diverse empirical references, often unreliable, into its quantitative bubble parameters and characteristics, first and foremost the froth velocity. This is a foundation to build expert flotation control and extend it to the mill enterprise expert control and operating system, termed Digital One on Production Line, the goal set to achieve.

Given that Doe Run's Buick Mine operation has so many varieties of ores processing in the mill, the interrelated variables (feed grade, mineralogy, flotation thermodynamics and kinetics, reagents, and operational conditions) contribute to instability of flotation, the ores change and delay in assay reading also add to lost opportunity for improving recovery.

Advanced automatic flotation expert control therefore needs to operate the essences of floatation such as flotation reagents, bulk and in particular Buick Mill's 2nd modern reagent system of powerful selective collectors and depressants. This is another foundation and coincides with introduction and implementation of VisioFroth™ and development and applications of Digital One enterprise mill expert control and operating system.

Air and frother are critical in generating acceptable air and froth bubbles, both of which are always changing and varying, and even more critical in imparting desirable bubble characteristics for flotation. Digital One needs to include and adjust air and MIBC dynamically and in real time to optimize froth characteristics and flotation performance.

Heretofore, mill operators using and interacting with Digital One can automatically adjust the level of flotation cells and reagents including air and MIBC to get a desired mass pull out of the cells, and with the confirmation of XRF online assay readings (which are delayed about 15 to 20 minutes) to achieve grade and recovery targets.

VisioFroth™, froth velocity, has a strong correlation with concentrate tonnage flow (mass pull) from flotation cells (Runge et al., 2007). The data from the cameras is used to automatically control the mass pull to achieve optimal recoveries while maintaining operational constraints such as saleable concentrate grades.

In addition, the Digital One expert system can also adjust, automatically, the flotation reagents by utilizing VisioFroth™ camera information.

The VisioFroth™ system commissioning process included gathering, observing, and reviewing plant and process variables, information and VisioFroth™ parameters. The visualization of ore variabilities was reflected in froth velocity measurement when level setpoint persisted (Figure 2). This situation may not be anticipated by the control room operator, and this may also correct by itself. However, this causes less mass pull which leads to lost opportunity for recovery and, thus, lost plant revenue.

The above trend was fit into a histogram chart (Figure 3). The average froth velocity was 4.14 cm/s with standard deviation 1.3344. It was clearly shown that there were two operating situations, which may be due to ore variability.

The initial froth velocity control was configured to maintain froth velocity at a setpoint by manipulating the level setpoint. In Figure 4, the Expert Control was turned on at around 07:00, illustrating how the level setpoint was changed to maintain froth velocity at setpoint. Due to ore variability, froth velocity was low (decreased), and Expert Control's reaction was to decrease the level setpoint (make the froth depth shallower) in order to increase froth velocity. In general, the control philosophy for froth velocity is:

- if froth velocity is fast, then level setpoint should increase.
- if froth velocity is low, then level setpoint should decrease.

The idea of controlling the mass pull is to: 1. maximize recovery when ore is good (high grade); and 2. to optimize

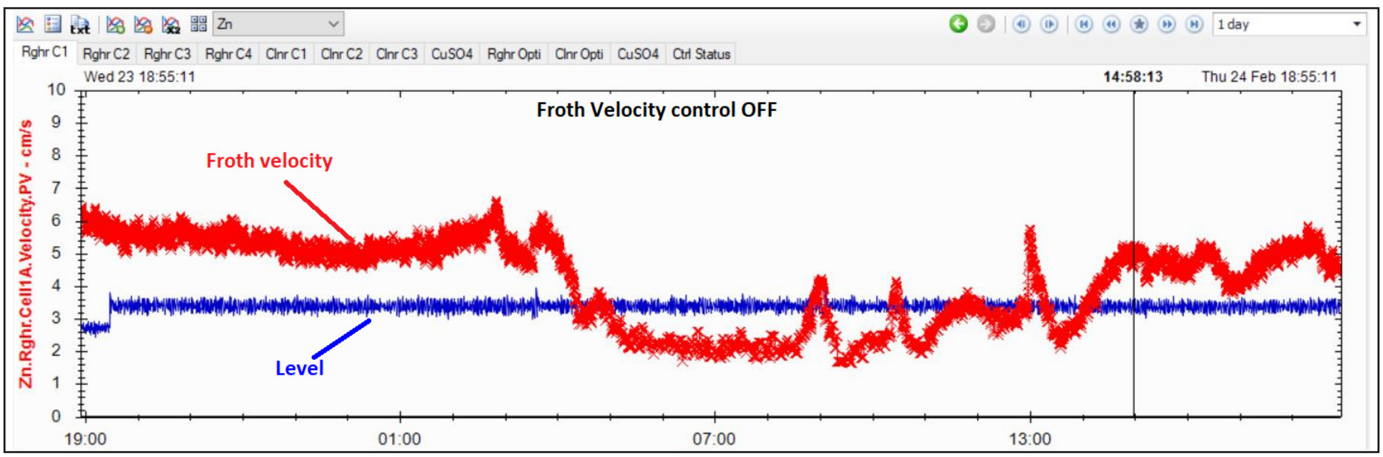


Figure 2. Froth Velocity without Expert Control System line plot

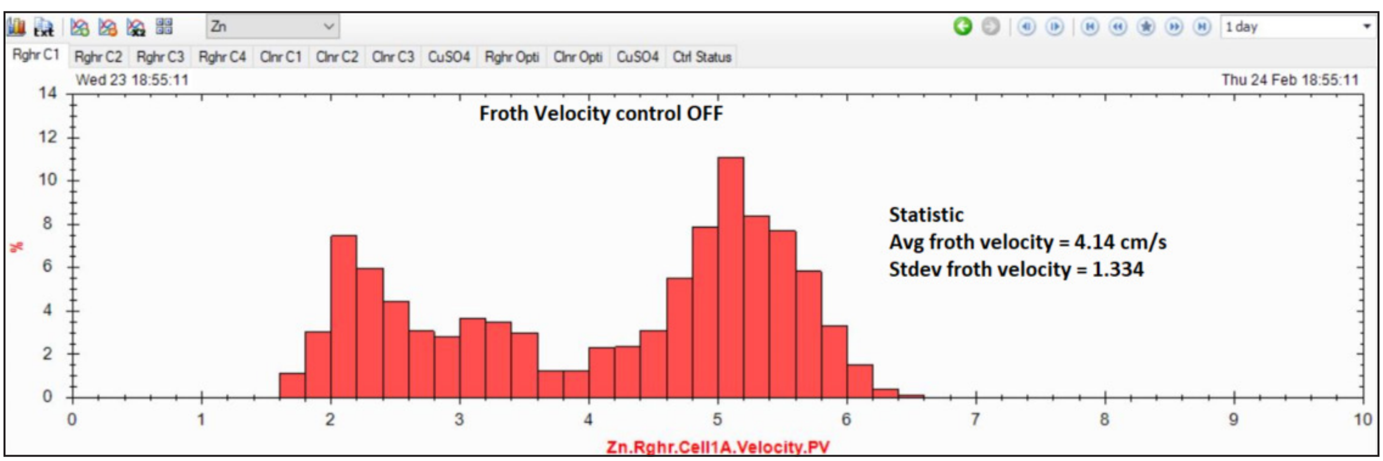


Figure 3. Froth Velocity without Expert Control System histogram plot

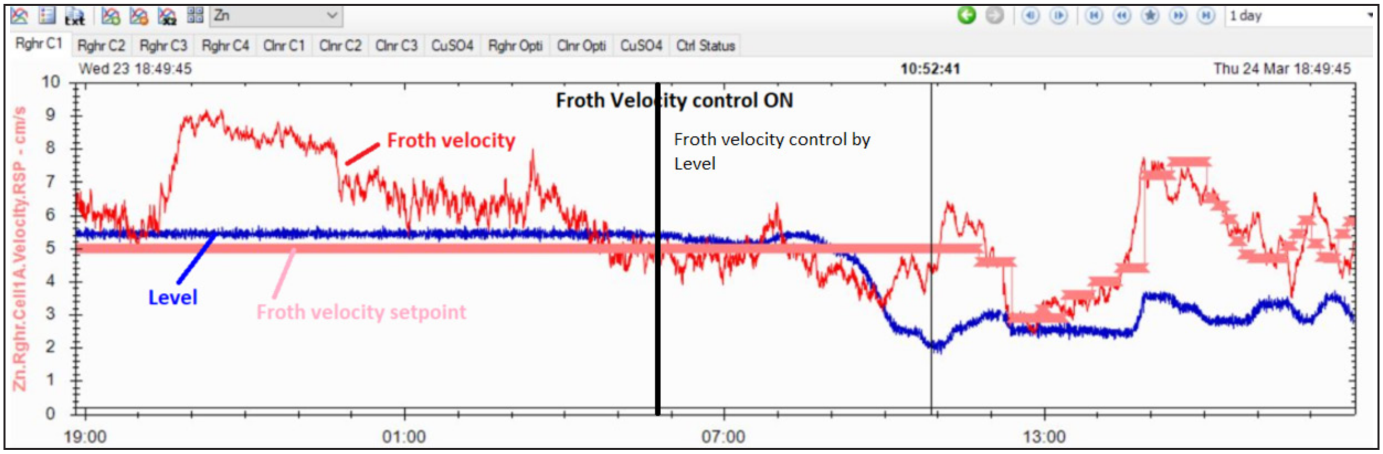


Figure 4. Froth Velocity with Expert Control System line plot.

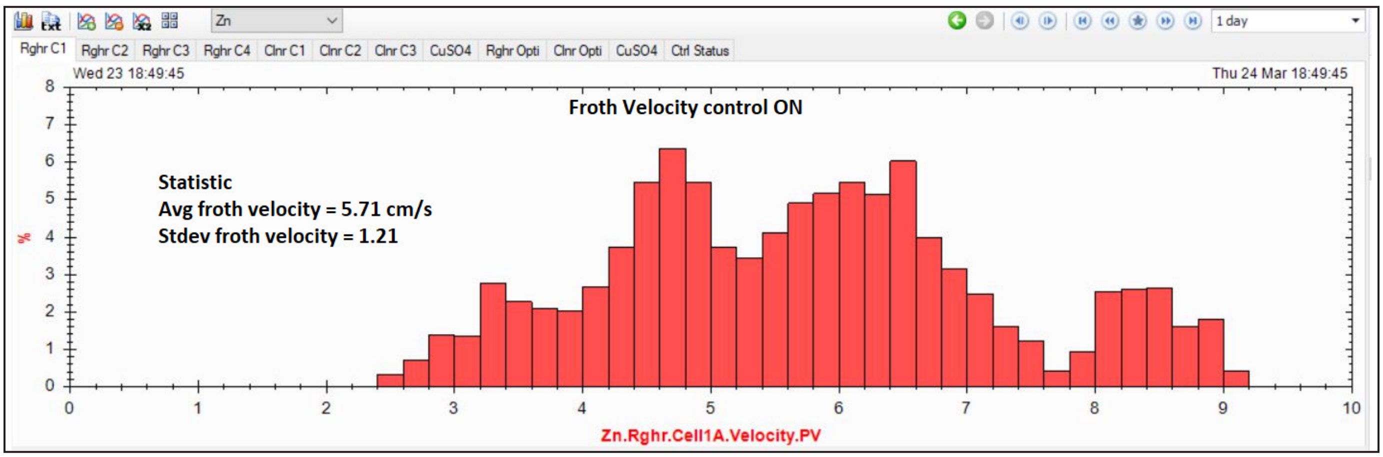


Figure 5. Froth Velocity with Expert Control System histogram plot

grade when ore is bad (low grade). Therefore, the target of rougher and cleaner (final) concentrate grade is targeted in the Expert Control and named optimization control. Initial optimization control (Figure 4) was configured and tested. The average froth velocity (Figure 5) was shown as a potential for improvement due to process variability.

Thus, the goal is grade and then recovery, optimization control (grade control) is configured to modify froth velocity setpoint and reagents adjustment. The operators are now targeting grade in Expert Control System. Figure 6 shows hierarchy Expert Control System. The reagents control is part of optimization control. The grade control is changing froth velocity setpoint to maintain grade on target.

- if grade is high, then the froth velocity setpoint will increase.
- if grade is low, then the froth velocity setpoint will decrease.

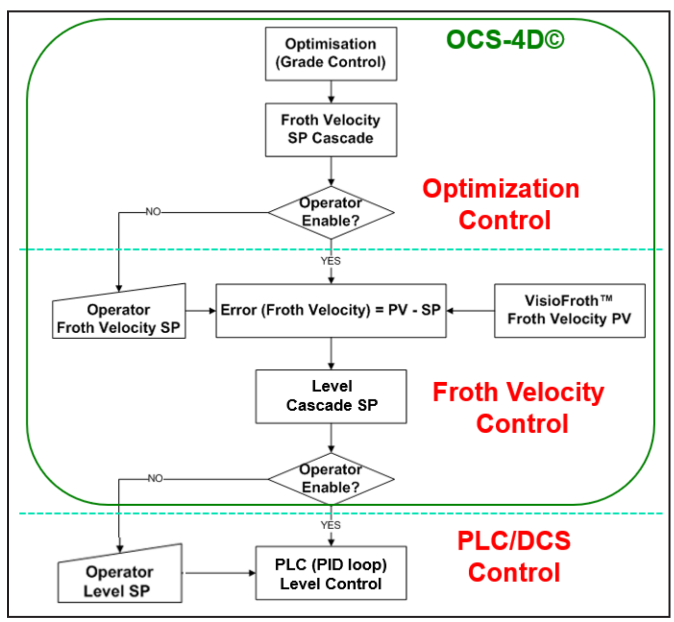
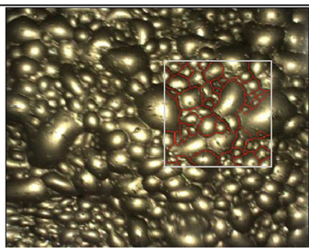
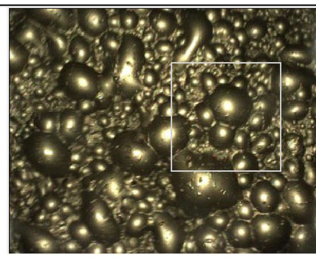
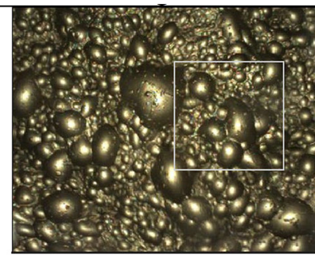
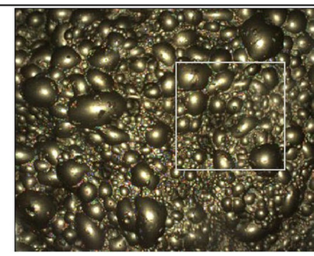
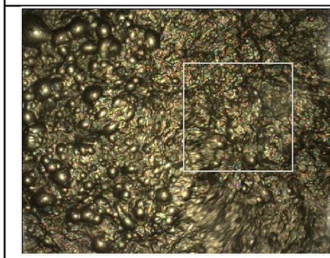
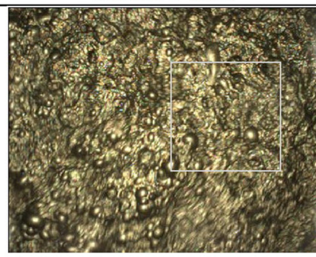
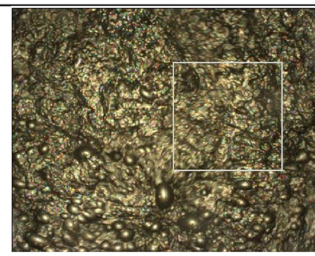
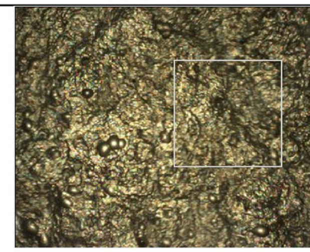


Figure 6. Hierarchy Expert Control System

Table 1. Froth texture of Cu Rougher

 Texture 1.07	 Texture 0.95	 Texture 0.88	 Texture 0.80
 Texture 0.70	 Texture 0.60	 Texture 0.54	 Texture 0.50

As the OCS-4D© has a data miner module, it enables the visualization and association of the ore variabilities and froth parameters. This data can be used to develop process correlations, which can then be used to handle process disturbances. The Expert Control System basically mimics the best operator experience and knowledge. Therefore, the system is enhanced so it can operate and optimize production 24/7.

The correlation of ore variability is learned and observed, and the relative effect of a change in mill feed grade upon froth velocity becomes obvious. Thus, modifying froth velocity setpoint and reagents quickly are key to disturbance handling (ore change). Then, the relative change of Cu, Pb, and Zn mill feed grade are used to determine fast or slow response of froth velocity setpoint which then effectively adjusts level setpoint and reagents setpoints.

The Doe Run flotation cells do not have individual airflow. Rather, the airflow control is by a single control valve to each circuit (i.e., Zn rougher circuit has one airflow control). The control of airflow for each circuit is controlled by:

- the average froth velocity of circuit
  - If average froth velocity is high, then the airflow setpoint is decreased.
  - If average froth velocity is low, then the airflow setpoint is increased.
- froth texture and concentrate grade (i.e., Cu assay in final Pb concentrate). Operators often use this as a barometer of concentrate quality or as an indicator of the need for a reagent.

Thanks to the image miner module that allows storing images along with data, it was possible to correlate images with plant process variables and froth parameters.

Table 1 gives the idea of the numeric reading of froth texture parameter. It suggests that with a high froth texture (> 0.80) that airflow should be increased since it needs more bubbles to recover mineral, while with low froth texture (< 0.6), that airflow should be decreased because it may float gangue mineral. The hypothesis is that froth texture may have a correlation to Cu grade in final concentrate Pb, and therefore froth texture and concentrate quality are used for controlling airflow as well.

ZN CIRCUIT REAGENTS

Plant operators monitor froth (bubble size) flotation regularly then adjust $CuSO_4$ consumption. The rule of thumb is when the bubble size is too big then increase $CuSO_4$ and when the bubble size is too small then decrease $CuSO_4$. This activity has been practiced manually over the years.

Bubble size and bubble count as one of the outputs from VisioFroth™ provide a quantitative number. Hence, combining operator knowledge and bubble size information, a best-practice control of $CuSO_4$ reagent was developed.

It was obvious that the consumption of $CuSO_4$ and ore variabilities change the bubble size and bubble count (Figure 7). The thermodynamics of the flotation process are also affected by mill feed Zn head grade. Thus, these two parameters were used for controlling $CuSO_4$.

A relative change in mill feed Zn is used for controlling $CuSO_4$. The bubble size and bubble count are used for constraint control. $CuSO_4$ logic is as detailed below:

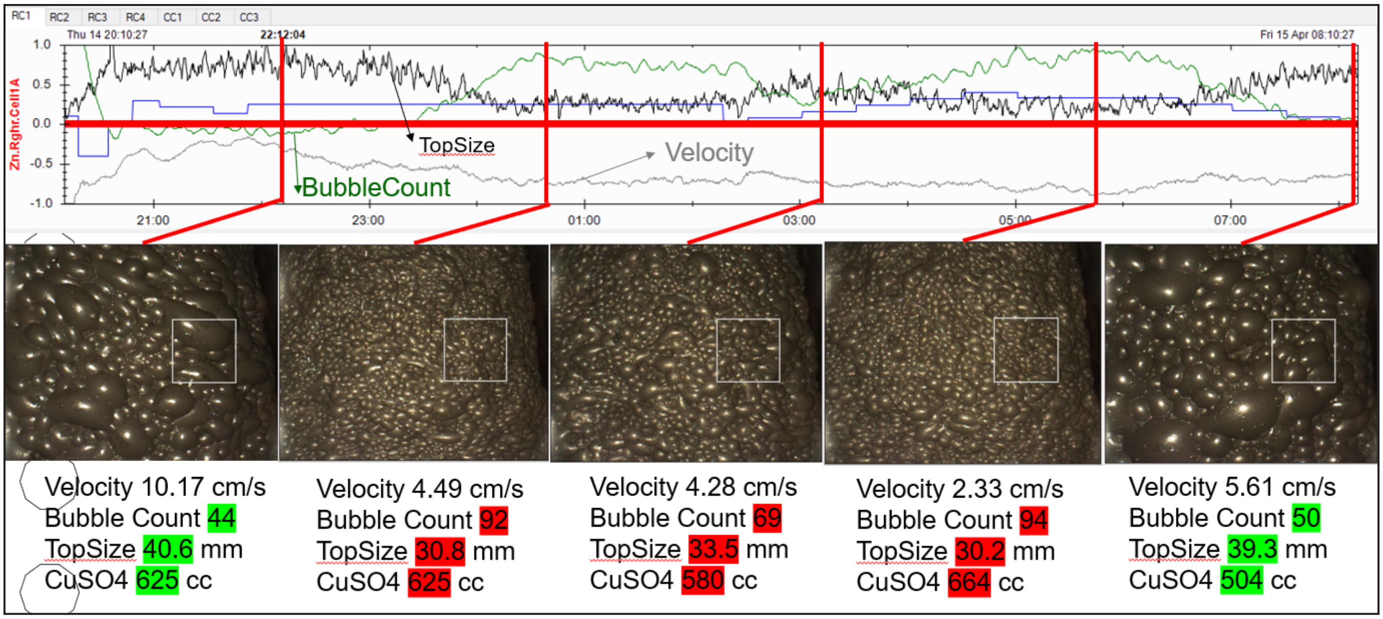


Figure 7. The correlation of Image miner to process variables

- $CuSO_4$ is increased when mill feed Zn decreases.
- Until bubble size becomes too small, or
- Until bubble count is too high, or
- Until final concentrate Zn drops below target
- $CuSO_4$ is decreased when mill feed Zn increases.

Dosing of MIBC (frother) is modified to control rougher concentrate Zn. The frother dosage rate is increased when rougher concentrate Zn increases, and the dosage rate is decreased when rougher concentrate Zn decreases.

Lime reagent is controlled by final concentrate Zn. The lime addition is increased when final concentrate Zn decreases, and the lime addition is decreased when final concentrate Zn increases.

CU CIRCUIT REAGENTS

Sodium dichromate (rougher and cleaner) is controlled by mill feed Pb. It increases when mill feed Pb increases, and it decreases when mill feed Pb decreases.

If Pb in final concentrate Cu is high (>5) then starch and sodium dichromate are increased. If Cu in final concentrate Pb is high (>1) then starch and sodium dichromate are decreased.

MIBC reagent is modified to control rougher concentrate Cu. MIBC is increased when rougher concentrate Cu increases, and MIBC is decreased when rougher concentrate Cu decreases.

PB CIRCUIT REAGENTS

MIBC reagent is modified to control final concentrate Pb. MIBC addition is increased when final concentrate Pb increases, and MIBC addition is decreased when final concentrate Pb decreases.

SPECIAL REAGENTS CONTROL

There are 5 special reagents (Table 2) addition to flotation: Pb collector, Zn Collector, Cu Collector, Fe Depressant, and Pb Depressant.

For each reagent there are 2 modes for operator to run.

1. Basic mode: controls reagent at LL (Low Limit) operator set.
2. Advanced mode: controls reagent at ratio of assay reading, with exponential feedback control to increase and decrease reagent dosing when the process variable is far from the target.

Whether the reagents are in basic or advanced mode, if the assay reading is below the threshold limit, then reagent setpoint will be set to zero, then it will automatically run again if assay reading returns within the operational range.

As part of the learning and observation, operators can monitor online the VisioFroth™ video from WebView. This live stream can also be used for camera maintenance, (i.e., camera gets dirty, camera disconnected, and camera malfunction).

Table 2. Special reagents limits

Solvay Reagents Automatic						
				Chemical Dosing; cc/minute		
Chemical On	Chemical Off	Where		Basic Mode	Advanced Mode	
When >=	When <=	XRF Readings	OCS-4D tags Local	LL	LL	HL
4	3	Pb% in Zinc_Concentrate	Courier.Final.Conc.Zn.Pb	20	20	30
0.15	0.1	Zn% in Zinc_Tailings	Courier.Final.Tails.Zn.Zn	25	25	60
1.2	0.9	Cu% in Lead_Concentrate	Courier.Final.Conc.Pb.Cu	20	20	40
3	2.5	Fe% in Zinc_Concentrate	Courier.Final.Conc.Zn.Fe	20	20	40
4.5	4	Pb% in Copper_Concentrate	Courier.Final.Conc.Cu.Pb	20	20	40
These limits set in OCS-4D				These limits set in Scada		

Results

Since the implementation of the VisioFroth™ cameras and the Digital One expert control system starting in October 2022, the system has remained on the production line. The Expert Control system is designed for robustness and based on key fundamental principles in flotation to meet the requirements for such a system to continue to exist in an operational production environment.

Overall, the system has achieved acceptance by the operators and has most notably allowed for the processing of previously less- or un-economical marcasite lead\copper ores into saleable concentrates. One particular accomplishment is that over 200,000 tons of high-grade Pb and Cu ore with high marcasite content have now been processed. Moreover, processing this ore has been transformed into a routine operation at Buick Mill which in some cases may not even require operator intervention at all.

Throughout this entire process of developing Digital One, one of the key principles was that the expert system provided by Metso was at fault by default. Any issues during operations were attributed to it unless clearly separable from it, and therefore its development involved holding it to the highest standard of being without fault or limitations.

The OCS-4D© software provides a powerful integration layer between the existing DCS, the froth cameras and VisioFroth™ system, and the Digital One expert control as described here. The integration layer is sufficiently abstract that it has been almost routine to adapt procedures developed in one circuit or in one mill and transfer them to another circuit or reimplement them for another mill's specific setup. At the same time, it is concrete enough to directly reason about each little step of automation implemented for any reagent, any cell level, any velocity set point, or even more abstract soft sensors such as dynamic constraints or optimization routines.

OCS-4D© was continuously stretched to find the limits of its control capabilities. However, it was found to be very capable of providing the various control schemes we needed for air, MIBC, the specialty reagents, and now even taking over much of the bulk reagent dosing completely. There have been no bottlenecks or limitations to the control system imposed by the OCS-4D© software. The functionality available to the Digital One system has been more than sufficient to take over as the digital operator of the flotation circuit at Buick Mill and has opened new opportunities and frontiers.

In addition to the VisioFroth™ system's original scope of controlling the froth levels and the more advanced controls developed since, Digital One has been able to incorporate knowledge and experienced operators' best practices into automatic controls on the mill. This essentially forms an automatic digital encyclopedia of how to operate the mill, which can in turn be used to help raise the mill's performance baseline.

CONCLUSIONS

The combination of the different levels of control all combine to complete the Digital One on Production Line processes at Doe Run's Buick Mill. The mining industry is moving towards more intelligent instrumentation and more analysis to have a fully functional control system that can maintain and increase recovery and reproduce concentrate grade and quality. With Metso's VisioFroth™ and the optimization logics of expert system all integrated in OCS-4D©, Doe Run Buick Mill's Digital One platform is sustainable, expandable and highly competitive in the mining industry.

Digital One expert control can operate the entire Buick Mill's flotation plant consisting of lead, zinc and copper flotation circuits. The impact of Digital One enterprise expert system has had far reaching effects on future plans for Buick Mill. This system also paves the way for additional improvements in areas throughout the entire mill, from grinding to filtration. A key highlight is that the Digital One Expert

System is completely digital, sees no boundaries in DCS, and can use data from anywhere in the mill to adjust operational parameters anywhere else in the mill.

The process of integrating the VisioFroth™ system and its control software OCS-4D© with Buick Mill's specific requirements to create the Digital One expert system highlights the flexibility, modularity, and robustness of the setup and will help pave the way for further improvements.

It has already been shown with Buick Mill and Brushy Creek Mill that VisioFroth™ and Digital One can interface effectively with both Rockwell DCS and Emerson DeltaV DCS, the two most dominant DCS systems in the mining industry. Digital One provides a universal digital expert control system at each of the Doe Run mill sites. Digital One can be a powerful enterprise expert control and operating system with considerable flexibility for milling and flotation mineral processing plants in the mining industry.

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24-030

Efficiency of Carbon Sorbents in Removing Zinc from Mine Water: A Comparative Case Study of the Rothschönberger Stolln Water

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Nils Hoth
Marlies Grimmer
Festus Animah

ABSTRACT

One of the challenges of mining is the concentration of heavy metals it releases into the environment through a phenomenon called Acid Mine Drainage. Freiberg is no exception due to its long mining activities. The European Union proposes that all rivers and streams must be in a good ecological status by the year 2027 but this would be difficult for large water sources as it would be economically unviable. Consequently, the approach of treating these waters at point sources would be of immense help and hence this column experiment on mine water treatment with carbon sorbents to remove zinc form the Rothschönberger Stolln. For this experiment three resins namely, APTsorb, activated coke, charred fermentation residues (which was produced by the Freiberg University of Mining and Technology) were analyzed through a simple column experiment to determine their sorption capacities. Through their sorption capacity as this experiment seeks to ascertain: we are able to make suggestions scientifically on the best material among the three for the future design of a treatment plant for the RSS. After the experiment whereby a 10 ml peri glass column was used, material A: APTsorb showed the least adsorption capacity (0.01 meq/g) and this could be attributed to the fact that the resin works well under pre-determined parameters such as pH and surface area. Material B: Activated coke showed a better sorption capacity (0.53 meq/g) in comparison to the basis value used for this experiment. Material C: charred fermentation residue which was produced by the University showed the most efficient capacity of (1.69 meq/g). This in comparison with the value used as the basis for this experiment showed that material C (charred fermentation residue) is very efficient for zinc sorption. pH values measured at the effluent of all the experiment were slightly higher than the pH measured in the initiating water.

INTRODUCTION

The Freiberg ore deposit is a zinc–lead–silver vein deposit. The geology of the Freiberg mining district is such that it is located in the central part of the Freiberg ore deposit and includes largely medieval mine works. These medieval mining activities have led to the metal concentrations in outflows of dewatering galleries and the Rothschönberger Stolln is no exception. In some top soil areas of the Freiberg area, even concentrations of some heavy metals can be located (Bayer, 1998). The European Union's 2002 Water Framework Directive indicates unequivocally that all flowing waters must be brought to an ecologically good to a very good status by 2027. This goal has become a far-fetched goal due to the economic difficulty in treating large rivers.

Nevertheless, "Grief 2013" indicates that another approach to the treatment of large water bodies is to treat it at point sources. Heavy metals generated through old mining activities could have low concentrations but upon accumulation could amount to tones of concentrations and hence becoming harmful. The aim of this work is therefore to test with different carbon-based materials for their ability to take up zinc from highly concentrated solutions by means of sorption processes using the RSS waters. The

Rothschönberger Stolln is a drainage channel which reaches a length of about 30 km from the Sächsische Brand Erbisdorf via the Freiberg mining district to Halsbrücke and from there to the mouth hole at the Triebisch near Rothschönberg. Construction of the tunnel began in