The Importance of Plant Audits

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INTRODUCTION

A processing plant audit is a useful tool for optimizing processing parameters, which often change over the life of a mine. Plant audits are invaluable for assessing the performance of each processing technology: is the process performing to specification and how does each process technology compare to newer technologies?

A processing plant is designed to process a range of ore characteristics that are assumed to be present in a deposit, such as:

- magnetic properties
- hydrophobicity
- density
- size
- luminescence

These properties are exploited using various technologies to concentrate the commodity (valuable component) and to remove the gangue (waste). Most of the ore characteristics are identified at the exploration stage from geological studies on drill samples. However, in practice, this geological information is often overlooked, and the processing plant is designed solely on the characteristics of the commodity without considering the host rock, location or environment.

The effects of geological variations in the ore body, and how geology effects the recovery of a commodity, are often underestimated. Geological variations, such as changes in rock hardness with depth, dilution from country rock, the occurrence of Xenoliths, dykes or sills, can upset recoveries. The effects of geological changes on the recoverability of a commodity can be quantified through a processing plant audit.

Conducting a plant audit when starting up an operation is important for determining the operating parameters for each technology, as well as determining a baseline for measuring the effects of; geological changes, wear and environmental changes on equipment. For instance, in warmer climates, processing plants perform better at night under cooler conditions than during the heat of the day.

At SRC, our experts routinely perform audits in our diamond lab, so we’ve seen first-hand where issues or errors can occur and how to mitigate these. As each plant is unique, we evaluate the individual processes, inspect the equipment to make sure it’s calibrated correctly and review the testing parameters. From the results of an audit, SRC provides suggestions and solutions for where improvements could be made. A successful plant audit takes the whole plant into consideration.

TRACER TESTS AND PARTITION CURVES

Tracer tests offer an ideal method to verify the equipment's settings, reliability and performance. Tracers usually consist of coloured blocks that have a range of values pertaining to the characteristic that the process equipment is measuring, such as:

- density tracers (Figure 1) - these have a range of densities and sizes
- magnetic tracers – these have a range of magnetic susceptibilities and sizes
- luminescence tracers (Figure 1) to evaluate diamond X-ray units - these have a range of luminescence intensities and sizes, some are opaque, and others are translucent
- hydrophobic tracers to evaluate hydrophobicity – the have a range of sizes.

A tracer test is comprised of 10 to 100 tracers for each calibration point. The tracers are then processed, separately or with the feed, by the equipment/technology being evaluated. The number of tracers reporting to the concentrate and tailings fractions are recorded as highlighted in yellow in Table 1.

From the concentrate values, the percentage of tracers reporting to the concentrate fraction for each reference point is determined and plotted, as shown by the red dots in Figure 2.

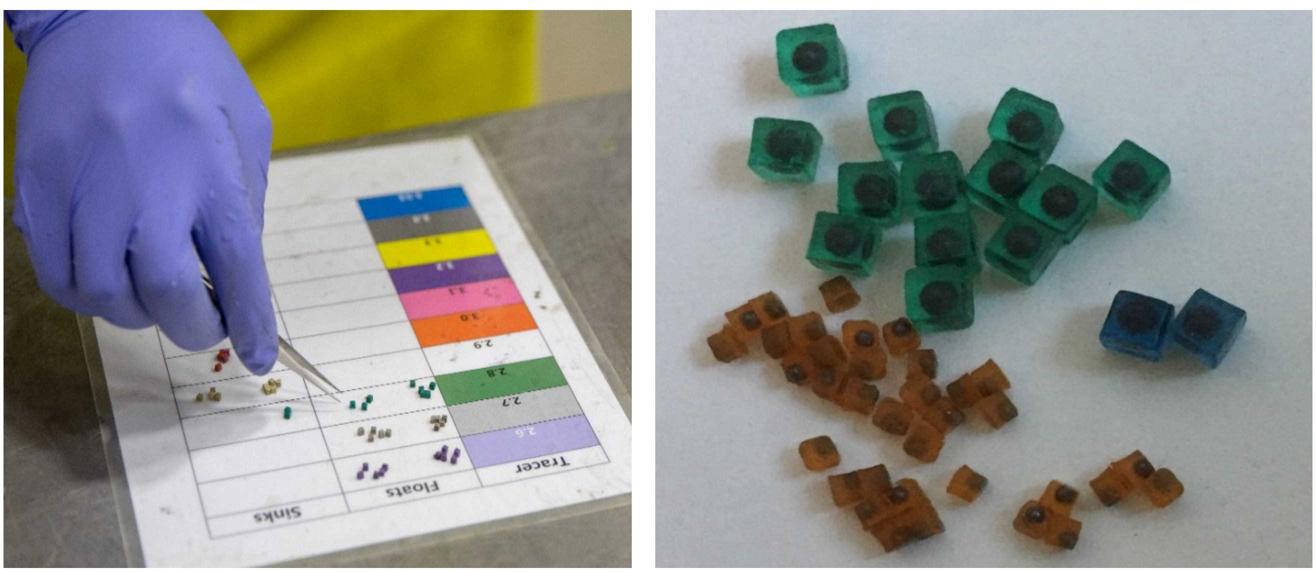

Figure 1: Density tracers on the left and luminescence tracers on the right.

Table 1: The results of a density tracer test conducted on a DMS cyclone

Specific Gravity	Tracers Added	Tails	Concentrate	% to Concentrate
2.60 SG	50	50	0	0.0
2.70 SG	50	46	4	8.0
2.80 SG	50	11	39	78.0
2.90 SG	50	2	48	96.0
3.00 SG	50	0	50	100.0
3.10 SG	50	0	50	100.0
3.20 SG	50	0	50	100.0
3.30 SG	50	0	50	100.0

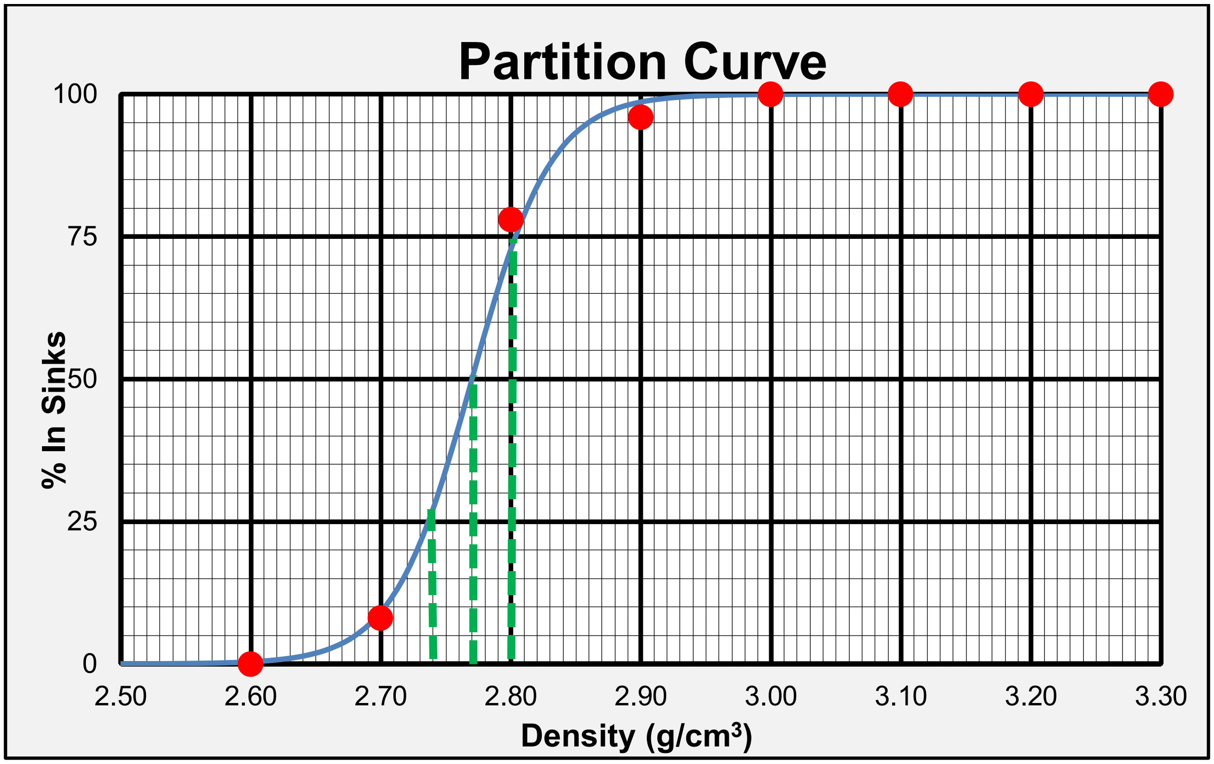

Figure 2: The tracer test results (red dots) and the resulting fitted partition curve (blue) for the data in Table 1.

A **partition curve** is then fitted to the X-axis values (density values in this example) using Equation (1) that best passes through the red dots (tracer tests values). The graph of the derived partition curve is represented by the blue curve in Figure 2.

$$\text{Calculated \%} = \left[\frac{e^{\left(SG \times \frac{Ep}{D50}\right)}}{e^{\left(SG \times \frac{Ep}{D50}\right)} + e^{Ep}}\right] \times 100 \qquad \text{----------} \quad (1)$$

Where: SG = Specific Gravity
Ep = Ecart probable (Equation 2)
D50 = Cut-point (Material density where 50% reports to the concentrate)

The density cut-point (D50) is the density where tracers, or ore, of a specific density are separated with 50% of the tracers reporting to sinks and 50% reporting to floats. The slope of the partition curve at the cut-point is the Ep (Ecart probable) value and is a measure of the steepness (efficiency) of the partition curve at the cut-point as given in Equation (2).

$$\text{Ep} = \frac{(D75 - D25)}{2} \qquad \text{----------} \quad (2)$$

Where: D75 = Material density where 75% reports to the concentrate
D25 = Material density where 25% reports to the concentrate

In this example the parameters of the partition curve are as follows:

D50 = 2.77 SG
D25 = 2.74 SG
D75 = 2.80 SG
Ep = 0.033 SG

Density tracers can be used to evaluate a variety of processing parameters needed for optimizing a process such as; cut-point, pressure, break-a-way size. They can also be used to evaluate a variety of technologies that separate on density, such as Dense Media Separation (DMS) cyclones of different sizes, Tri-flo units, Drum separators, DMS pans and a Drewboy units.

Similarly, tracers with different magnetic susceptibilities are used to evaluate technologies that separate on magnetic properties. Tracers with different luminescence intensities are used to evaluate technologies that sort particles based on their luminescence or fluorescence properties.

AUDITING A MINERAL PROCESSING TECHNOLOGY

In order to determine the effectiveness of a processing plant, all the results from each process are first compared to the mineralogy of the ore. This comparison enables one to determine what percentage of the overall performance is equipment related and what percentage is due to mineral characteristics. Each process is then combined in a sequential manner to provide the overall plant performance.

A process plant audit requires:

1) Inspecting the equipment and verifying that it is functioning correctly.
2) Evaluating the performance of a technology. A tracer test is the easiest.
3) An evaluation of the mineralogy to assess how easily the commodity (concentrate) can be separated from the waste rock (gangue). This is carried out by sampling and analyzing the concentrate and tailings fractions.
4) Evaluating the overall recovery efficiency, which combines both the equipment performance and the mineral recovery characteristics obtained from the sampling exercise.

EVALUATING THE RECOVERABILITY OF THE MINERAL

The commodity in each of the concentrate and tailings fraction is weighed and characterized for the property used in its recovery (i.e., evaluated for density if recovered by a density separator).

The commodity recovered from the concentrate and tailings is then compared to the D50 value obtained in the tracer tests to obtain the following information:

- Total mass of commodity (concentrate + tailings)
- Mass of commodity recovered from concentrate
- Total mass of commodity greater than the D50 value (concentrate + tailings)
- Total mass of concentrate fraction
- Total mass of tailings fraction

EVALUATING THE OVERALL RECOVERY EFFICIENCY OF A PROCESS

The overall effectiveness of a technology when processing an orebody, is a combination (product) of; the equipment performance as given by Equations (3) and the recoverability of the commodity as given by Equation (4). Equation (5) is the product of Equations (3) and (4) while Equation (6) completes the analysis.

$$\text{Equipment Performance at D50 value} = \frac{\textit{Mass of Commodity Recovered}}{\textit{Mass of Commodity Greater than } D50} \quad \text{----------} \quad (3)$$

$$\text{Mineral Recoverability at D50 value} = \frac{\textit{Mass of Commodity Greater than } D50}{\textit{Total Mass of the Commodity}} \quad \text{------------} \quad (4)$$

$$\text{Overall Recovery Efficiency} = \frac{\textit{Mass of Commodity Recovered}}{\textit{Total Mass of the Commodity}} \quad \text{-------------------------} \quad (5)$$

$$\text{Waste Removal} = \frac{\textit{Mass of Waste in Feed} - \textit{Mass of Waste in Concentrate}}{\textit{Mass of Waste in Feed}} \quad \text{------------} \quad (6)$$

AUDITING A MINERAL PROCESSING PLANT

Once all the individual equipment audits are complete, the overall plant recovery can be calculated. Using a Diamond Processing plant as an example, assume we established the following audit results on each technology, by mass on +0.85 mm diamonds, as given in Table 2.

Table 2: The audit results for each process in a diamond processing plant for +0.85 mm diamonds.

Stage	Process	Parameter	Mineral Recoverability	Equipment Performance at D50	Equipment Performance at D75	Comments
1	Liberation	HPGR gap = 2 mm	100.00%	98.50%	98.00%	4% lockup of small ◊
2	Screening	+0.85 mm	100.00%	99.95%	99.90%	Small elongated ◊ loss
3	DMS	3.0 SG	99.60%	99.80%	98.80%	Small ◊ loss
4	Magnetics	$20x10^{-6}$ cm^3/g	98.50%	98.25%	97.80%	Boart ◊ loss
5	X-rays	Threshold = 3.1 V	78.00%	99.90%	99.50%	Low LI$^{\partial}$ ◊ loss
6	SPS* X-rays	Threshold = 2.5 V	100.00%	99.90%	99.70%	Concentrates +3.1 V ◊
7	Scavenger Grease	Water temp = 28^o	99.50%	99.30%	99.00%	Coated ◊ loss
8	Hand sort 1		100.00%	99.30%	99.00%	1st Pass
9	Hand sort 2		100.00%	99.30%	99.00%	2nd Pass

$^{\partial}$ LI = Luminescent Intensity

* SPS = Single Particle Sorter

The overall plant recovery efficiency after each processing stage is then calculated as shown in Table 3.

Table 3: The overall audit results for +0.85 mm diamonds after each consecutive process.

Stage	Process	Mineral Recoverability	Equipment Performance at D50	Equipment Performance at D75	Overall Efficiency at D50	Overall Efficiency at D75
1	Liberation	100.00%	98.50%	98.00%	98.50%	98.00%
2	Screening	100.00%	99.95%	99.90%	98.45%	97.90%
3	DMS	99.60%	99.80%	99.00%	97.86%	96.54%
4	Magnetics	98.50%	98.25%	97.80%	94.71%	93.00%
5	X-rays	78.00%	99.90%	99.50%	73.80%	72.17%
6	SPS X-rays	100.00%	99.90%	99.70%	73.72%	71.96%
7	Scavenger Grease	99.50%	99.30%	99.00%	20.66%	20.22%
	(X-rays + Grease)				94.382%	92.182%
8	Hand sort 1	100.00%	99.30%	99.00%	93.721%	91.260%
9	Tails Hand sort 2	100.00%	99.30%	99.00%	0.656%	0.639%
	(Hand Sort 1+2)				**94.38%**	**91.90%**

CONCLUSIONS FROM PROCESSING PLANT AUDIT

In this example, grease technology is a scavenger technology, treating the X-ray tailings. The recovery efficiency of the grease is calculated as a function of; the X-ray tailings efficiency at Stage 4 (magnetics) and the efficiency of the grease technology. The overall recovery efficiency after grease is the summation of; Stage 6 (overall efficiency after SPS X-rays) and Stage 7 (overall efficiency after Grease).

Also, in this example, the tailings from the SPS X-rays are **not** processed by grease technology. If this was changed and the SPS X-ray tailings were processed by grease technology, then for the D50 value, an additional 0.07% would be added to the overall efficiency at Stage 7, increasing it from 93.44% to 93.51%. And for the D75 value, an additional 0.20% would be added to the overall efficiency at Stage 7 increasing it from 91.86% to 92.06%.

This information allows management to decide if these increases in recovery warrant changing the flow sheet design so that the SPS tailings are also processed by grease technology. In addition, if the X-rays or the SPS fail for some reason, grease technology would recover the diamonds and be a backup for the X-ray section.

Assessing all the technologies indicates that the diamond losses are mainly the smaller diamonds and/or the boart diamonds. **If an audit for the +3 mm (0.3 cts) diamonds is carried out, the plant's recovery efficiency increases to 98.33%.** Also noted is a lower dependency on the grease technology and there is a reduced requirement for a second hand-sort.

CONCLUSION

With the information obtained from a processing plant audit, mine operators can quantify the plant's performance, modify processing parameters to better fit the ore's characteristics, so optimizing the plant's performance, have a reference for comparing alternative technologies, have a reference when exceeding throughput parameters, monitor the effects of changes in the ore body and monitor the effects of equipment wear.

ABOUT THE AUTHOR

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Jane Danoczi, Pr.Sci.Nat, B.Sc. (Physics & Applied Mathematics), M.Sc. (Metallurgy), Engineer Licensee, is part of the Mining and Minerals Division at SRC. She previously served as Manager, Process Design at Shore Gold Inc., as CEO of Danoczi Solutions and as a Senior Research Officer at De Beers.

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