THE AMIRA P420 GOLD PROCESSING BENCHMARK SURVEYS

By

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ABSTRACT

Benchmarking through industry practice surveys has been a key component of the Amira P420 project throughout its history. These activities can be referenced as four main benchmark survey events: the 1994 Australasian Industry Survey, the 1999 Gold Processing Survey, the 2012 Worldwide Industry Survey and the 2021 Amira P420G Benchmarking Surveys. Those surveys were designed as questionaries to identify gold processing practices amongst the participating sites, and the wider industry. The survey questionnaires were completed by site personnel, with the information received being compiled and anonymised by the Amira P420 Gold Technology Group. The questionaries covered unit processes from milling through to the goldroom.

This paper will present the general trends observed in gravity recovery, leaching and adsorption, and carbon management from the latest 2021 survey, and compares it to data from the previous surveys. The benchmark exercise aimed to identify changes in operational philosophy and improvements.

Keywords: gold, benchmark, processing, gravity, classification, leaching.

INTRODUCTION

The Amira 420 benchmarking has been a tool to identify major changes in the gold industry, as well as to identify best practices. Industry practice surveys have been a key component of the Amira P420 project throughout its history. To date four main benchmark surveys were conducted: the 1994 Australasian Industry Survey, the 1999 Gold Processing Survey, the 2012 Worldwide Industry Survey and the 2021 Amira P420G Benchmarking Surveys.

1994 Industry Survey

As a part of the P420 project gold plant operating practices were surveyed by way of a general questionnaire. The questionnaire contained 452 questions relating to operating conditions, the level of process control used in the circuit, monitoring and sampling practice and a variety of other items covering aspects of the operation from grinding to tailings disposal and storage. The questionnaire was sent to 76 operating gold plants in Australia, New Zealand, Papua New Guinea and France. A total of 66 responses were returned, 30 of which were from companies sponsoring the project. The survey results were manually collated from the questionnaires and summarised in a number of different reports. The survey results were not added to any spreadsheets or databases and the 1994 survey isn't included in this review.

1999 Australasian Industry Survey

The 1999 Gold Processing Survey set, comprised four surveys: an Australasian Industry Survey, an Elution & Electrowinning Survey, a Carbon Management Survey and a Canadian survey.

- **1999 Australasian Industry Survey** – A total of 41 Australian sites completed a detailed plant survey questionnaire. The questionnaire was divided into ten main sections covering various aspects of the plant including types of ore treated, grinding circuit flowsheet, gravity concentration circuits, leach and adsorption circuit configuration and operating conditions, tailings disposal, sampling, carbon management, elution and electrowinning, gold room practices and metallurgical accounting methods.

- **1999 Elution & Electrowinning Survey** – this was a detailed survey questionnaire concerning elution and electrowinning circuits carried out at seventeen sponsors' operations. The questionnaire covered various aspects of elution and electrowinning including typical levels of gold and contaminants found on the carbon, acid washing, elution conditions, details of electrowinning operation, sampling strategies and management issues and cost structure.

- **1999 Carbon Management Survey** - A detailed survey questionnaire of carbon management practices was carried out at fifteen sponsor sites. The questionnaire was divided into five main sections covering various aspects of carbon management including carbon residence time distribution studies, carbon regeneration conditions, carbon concentration determination, carbon movement philosophy and carbon management guidelines.

- **1999 Canadian Survey** - This survey presents general information and operating data collected from eleven Canadian gold plants and assembled by the Mining and Mineral Science Laboratories of CANMET in collaboration with the Centre de Recherches Minérales de Quebec. It is the third such review of operations and it was reciprocally shared with the Amira P420A project in return for the 1999 Australasian Survey data.

2012 Worldwide Industry Survey

Completed in 2014, this Gold Industry Practices Survey had twenty-nine companies covering 77 mining operations for the online survey, with locations in Australia, Asia-Pacific, Africa, Latin America and North America. The survey included 568 questions divided into 15 sections. Twenty-eight of the 77 registered sites completed the survey fully and 21 sites completed less than 10% of the questions with the remaining 28 sites completing between 10 % and 100 % of the questions.

2021 Amira P420G Benchmarking Surveys

The 2021 Amira P420G Benchmark Survey had the participation of a total of 8 gold companies and was completed by 39 sites. It consisted of 12 questionaries Dissolved Oxygen Sensors, Gravity Feed

Screening, Cyclones, Gravity, Leaching & Adsorption, Carbon Management, Flotation, Elution and Electrowinning, Carbon Regeneration, Gravity Concentrate Processing and Goldroom Smelting. The results of this survey are still being processed by the Gold Technology Group. Hence, the results presented the preliminary analysis of the survey data.

This paper focuses on presenting the key data collected in the gold gravity recovery, leaching and adsorption and carbon management benchmark survey in 2021 and comparing it where applicable to the 2012 and 1999 surveys.

SURVEY METHOD

Separate survey questionnaires were created for each area of interest and shared with the participant companies via the P420 website (http://www.goldknowledge.com). Personnel from sponsor companies completed the questionnaires online. Some site personnel also completed spreadsheet questionnaires that were subsequently provided to the P420 project staff who manually transferred the data from the spreadsheets to the online questionnaires.

Survey Questions

The questions for each survey were developed from questions used in industry benchmarking surveys that were conducted during previous P420 projects, new questions that were based on feedback from various sponsors as well as areas of interest for the project researchers.

SURVEY RESULTS

Throughput and Gold Production

Data from the 1999, 2012 and 2021 surveys have been tabulated in Excel. Figure 1 shows the General database is primarily populated with entries from the 1999 and 2012 Surveys, with only 28 of the total 139 (20 %) entries corresponding to the current 2021 Survey. However, in the 1999 survey, only two countries were represented with that number peaking at 14 in the following 2012 Survey.

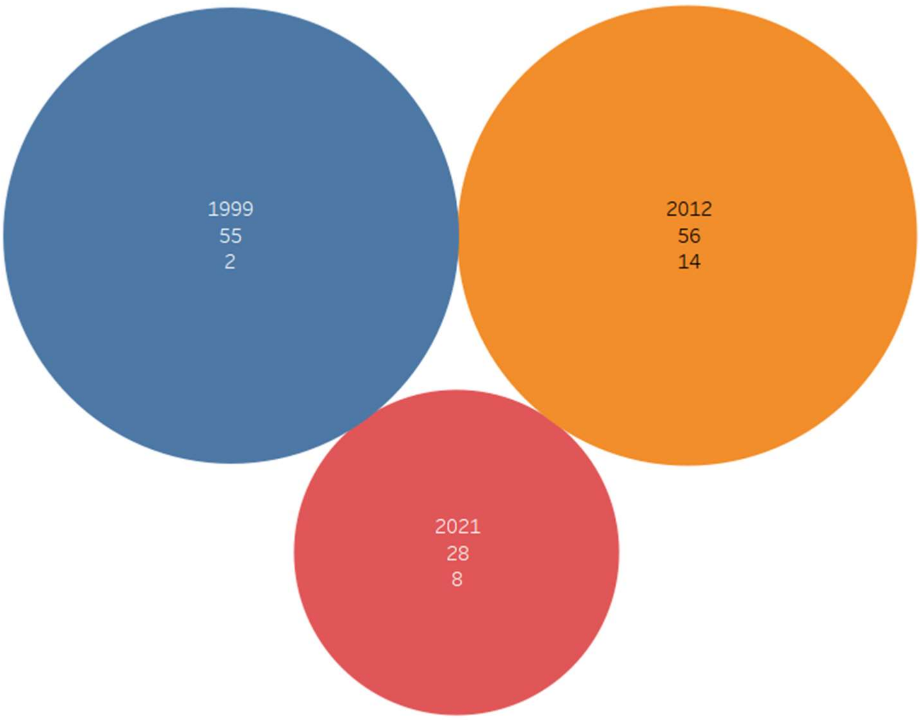

Figure 1: General Survey Database - Year/Number of Entries/Number of Countries [1]

Figure 2 shows the countries participating in each round of the surveys. With only eight countries participating in the 2021 Survey, it is hoped that additional entries will be made from more sites across the world before the end of the Amira P420H project.

Figure 2: Countries Participating in the General Surveys, by Year [1]

Figure 3 shows the annual throughput for sites participating in each of the surveys. This means sites with survey entries for each period will have the unique opportunity to track changes and progress over time. Interestingly, the survey shows an increasing throughput trend of the participant operations.

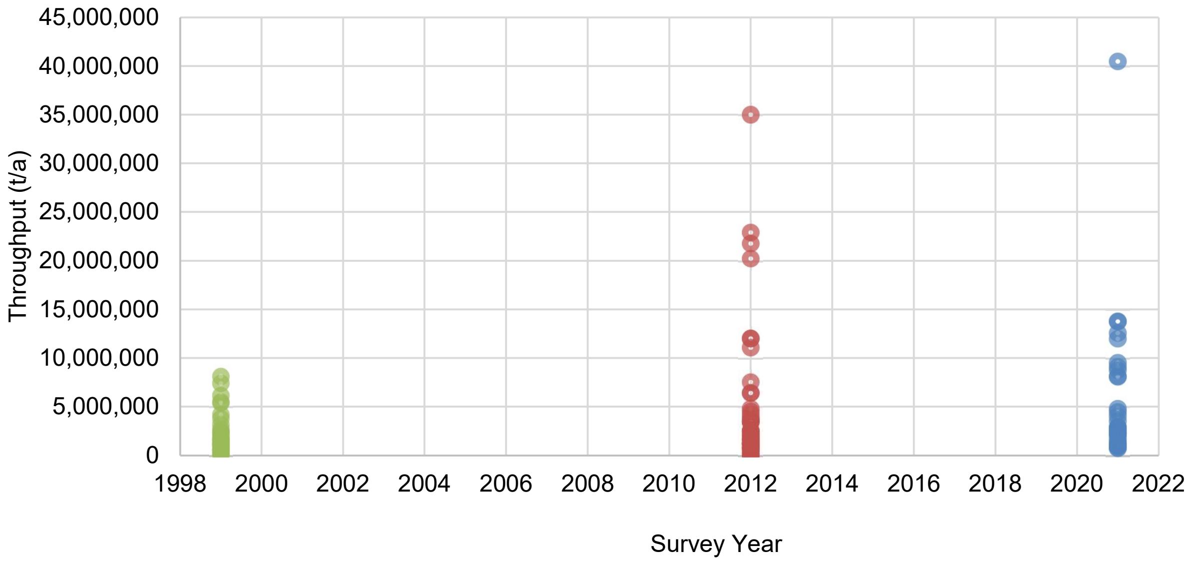

Figure 3: Countries Participating in the General Surveys, by Year

Figure 4 shows the gold production for the years 2012 and 2021. The survey also indicated an increasing trend following the throughput.

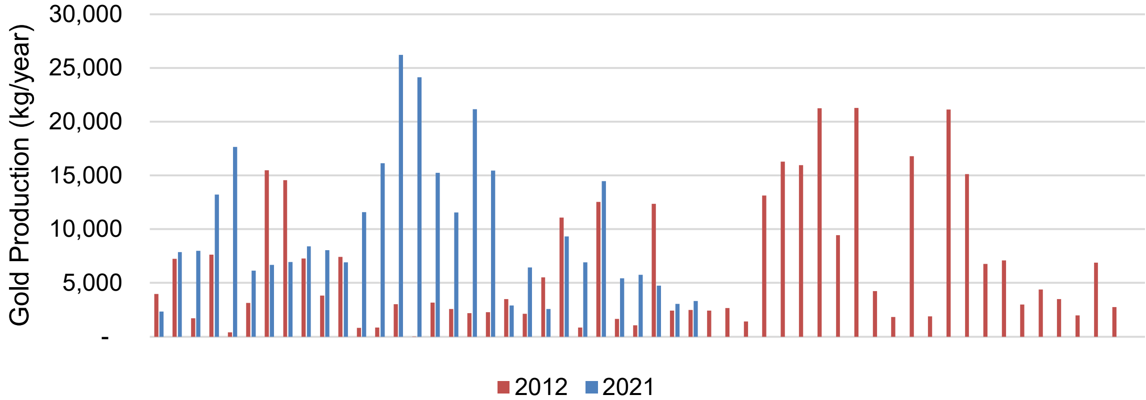

Figure 4: Gold Production in kg/year on the Participant Sites, by Year [1]

Gold Gravity Recovery Circuits

Table 1 shows the proportion of gold recovered by the gravity circuit in the sites surveyed in 2012 and 2021. The average percentage of the total gold recovered from gravity circuits indicated an increase from 2012 to 2021.

Table 1: Gravity Gold Recovery

Gold Gravity Recovery (% of total gold recovery)	2012 Survey	2021 Survey
Average	25	39
Median	15	35
Minimum	1	15
Maximum	80	72

The gravity recovery survey of 2021 covered 37 gravity circuits located in 21 different sites. The type of comminution circuit in which the gravity circuits are installed is compared in Figure 5.

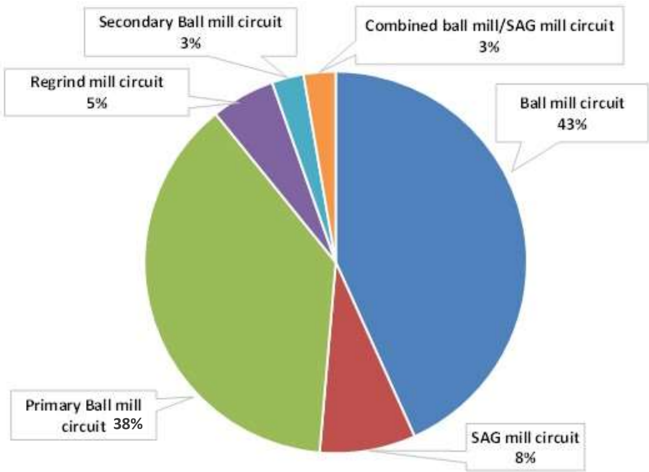

Figure 5: Location of Gravity Circuit

The feed streams for the surveyed gravity circuits are compared in Figure 6**Error! Reference source not found.**. The majority of the gravity circuits in the surveyed plants are treating the cyclone underflow stream.

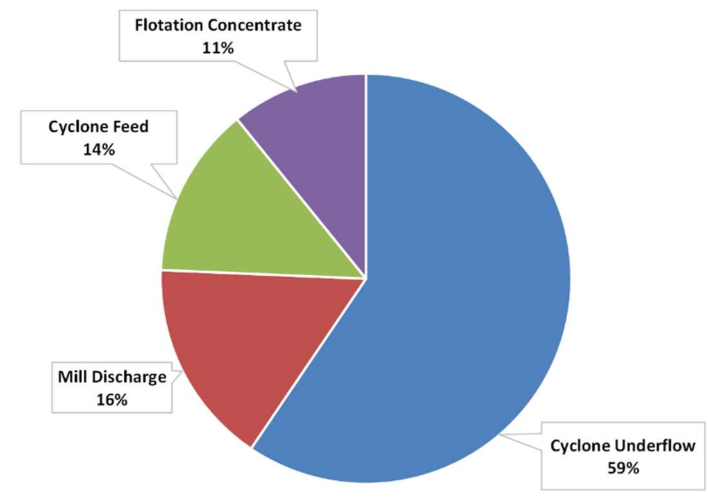

Figure 6: Primary Gravity Recovery – Feed Stream

Figure 7 compares the average proportion of the feed stream reporting to the gravity circuit for the different feed sources. Gravity circuits receiving flotation concentrate treated the entire stream and circuits receiving cyclone underflow processed the lowest proportion of the feed stream.

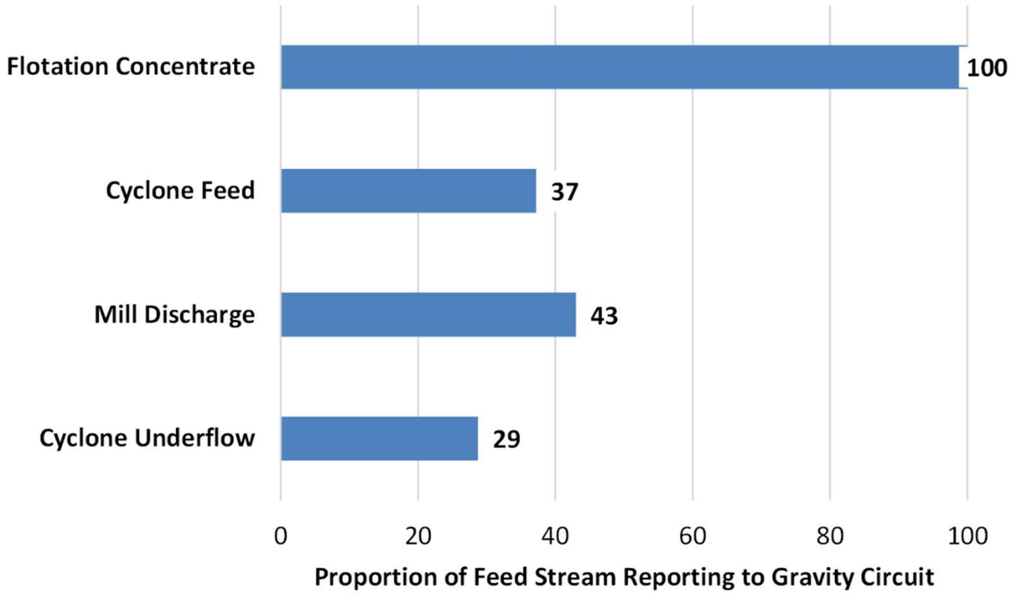

Figure 7: Proportion of Feed Stream Reporting to Gravity

Figure 8 shows the distribution for the number of concentrators installed in each gravity circuit. Nearly two-thirds of the gravity circuits have one concentrator installed and 40% have two concentrators installed.

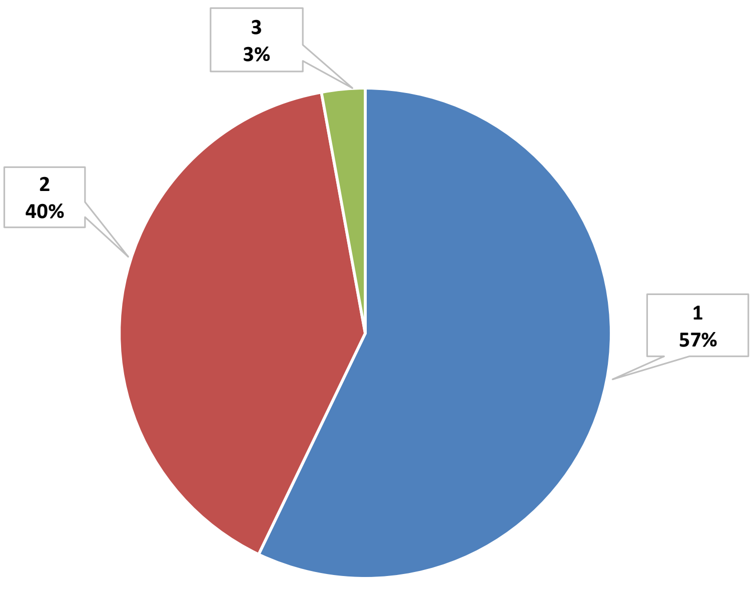

Figure 8: Number of Installed Concentrators in the Circuit

Figure 9 shows the distribution of the operating configuration for gravity circuits with more than one concentrator. Approximately two-thirds of the gravity circuits operate multiple concentrators in parallel.

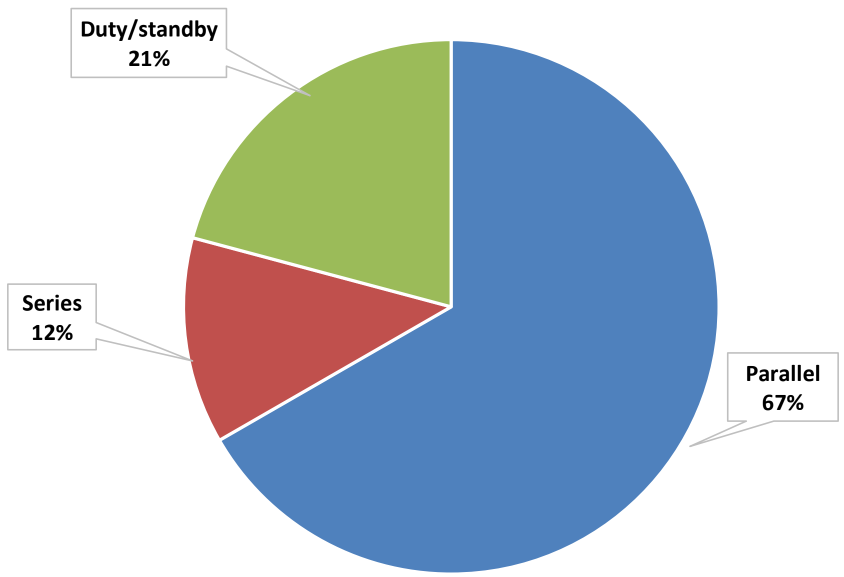

Figure 9: Operating Configuration

Figure 10 shows the distribution of the concentrator feed stream and manufacturer. Knelson concentrators are used to process cyclone underflow, cyclone feed and mill discharge streams. Falcon concentrators are used to process flotation concentrate and cyclone underflow streams.

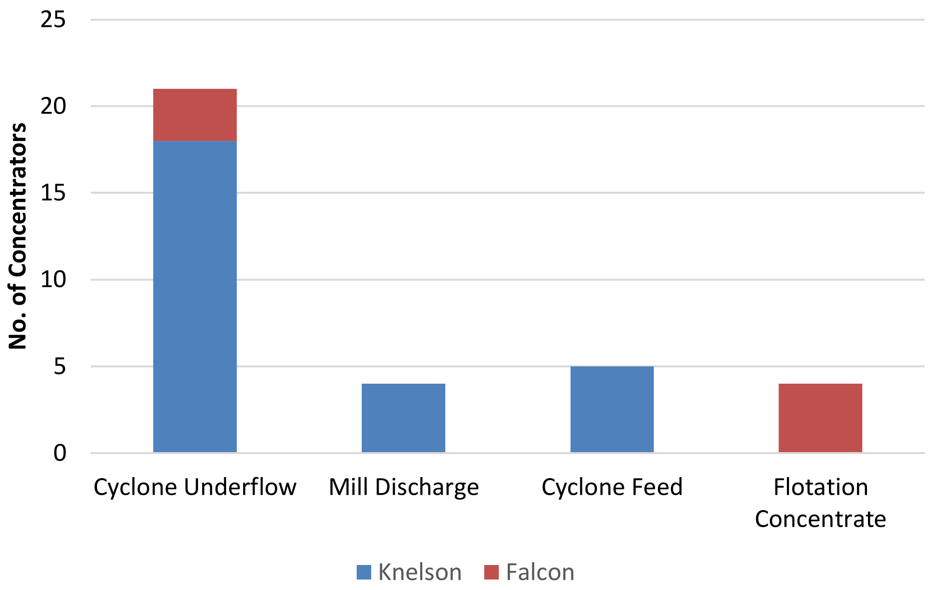

Figure 10: Distribution of Concentrator Feed Stream and Manufacturer

Figure 11 compares the average G-force of the concentrator bowls for the different concentrator manufacturers and feed streams. The Falcon concentrators treating flotation concentrates operated with the highest average G-force and Knelson concentrators processing cyclone feed had the lowest average G-force.

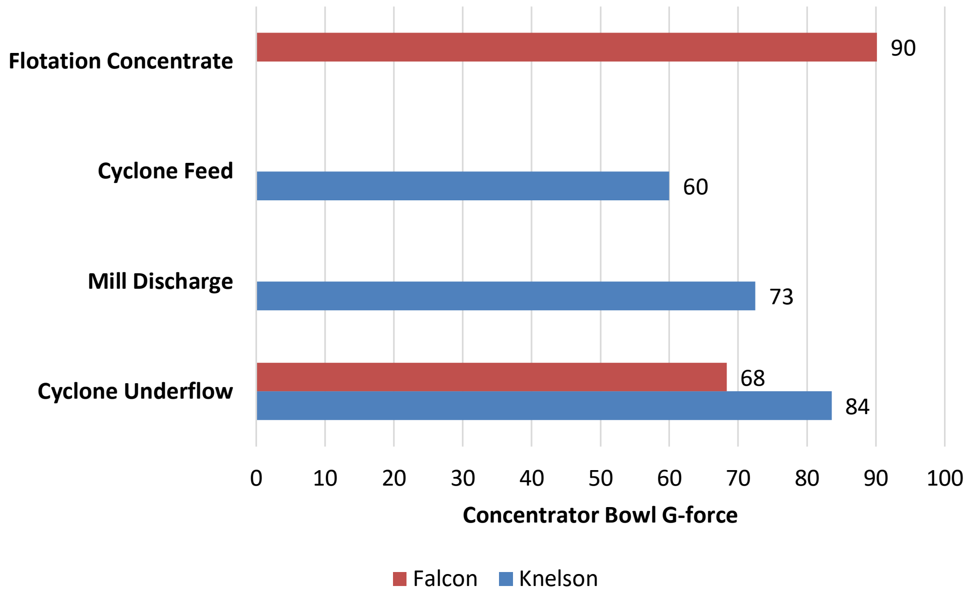

Figure 11: Average Concentrator Bowl G-force Comparison

The distribution of the concentrator cycle times is shown in Figure 12. Except for one site operating with a two-hour cycle time, all of the sites operate the concentrators with cycle times of less than 1 hour.

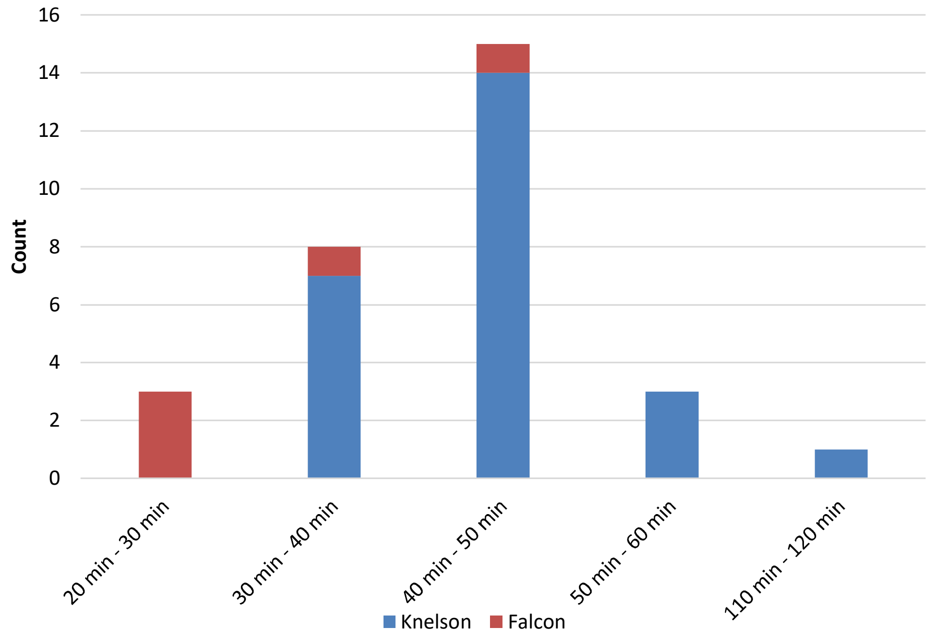

Figure 12: Concentrator Cycle Times

The frequency of bowl inspection for wear is compared in Figure 13. Monthly and weekly inspections make up the majority, accounting for more than two-thirds of the total.

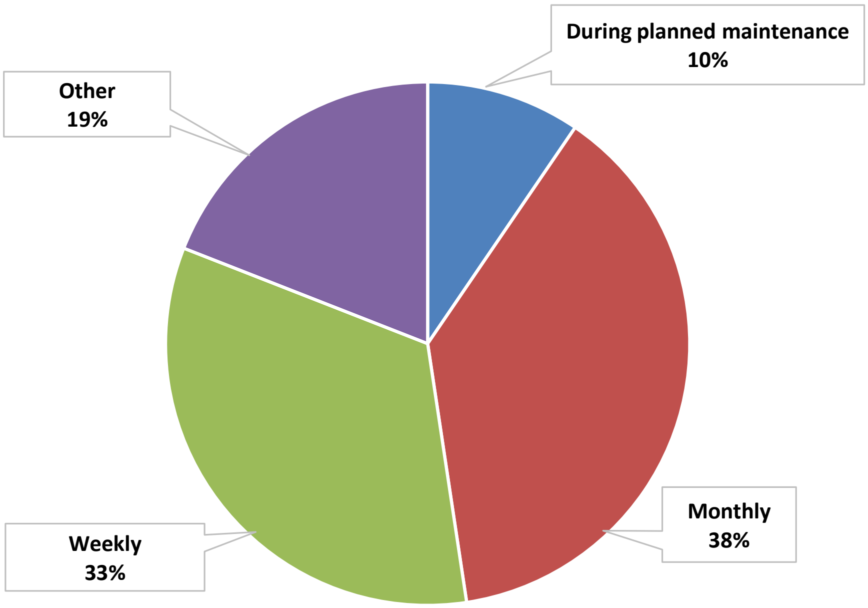

Figure 13: Frequency of Bowl Inspection for Wear

The average concentrator bowl life varied between 3 and 36 months. The frequency distribution for the reported bowl life is shown in Figure 14.

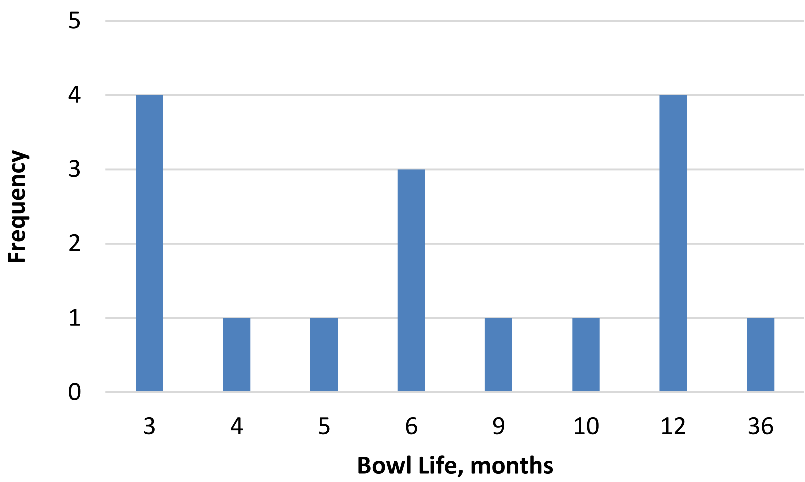

Figure 14: Average Bowl Life

Gold Leaching and Adsorption Circuits

Leaching

The number per site and throughput of the leach circuits varies significantly, from only a single circuit up to three, and from ~250 to +2500 dry tph. Of the 34 responses, CIL is the most common configuration at 56 %, followed by CIP at 35 % and Carousel at 9 %.

As many sites transition to processing more complex ores, including those which contain oxygen consumers, the use of ore-type dependent strategies to ensure sufficient oxygen is present in the leach circuit (and cyanide consumption is minimised) are being more commonly employed. Four sites reported having a dedicated pre-oxidation tank, with dissolved oxygen (DO) levels between 9 ppm and 20 ppm. Seven sites reported adding lead nitrate in the leach circuit. The addition of lead nitrate ranged from 0.03 kg/t to 4.3 kg/t of feed.

Cyanide consumption was tracked in 1999 (Figure 15), 2012 (Figure 16) and 2021 (Table 2) Benchmarking surveys. The trend shows a decrease in cyanide consumption with the automation of cyanide addition in the surveys of 1999 and 2012.

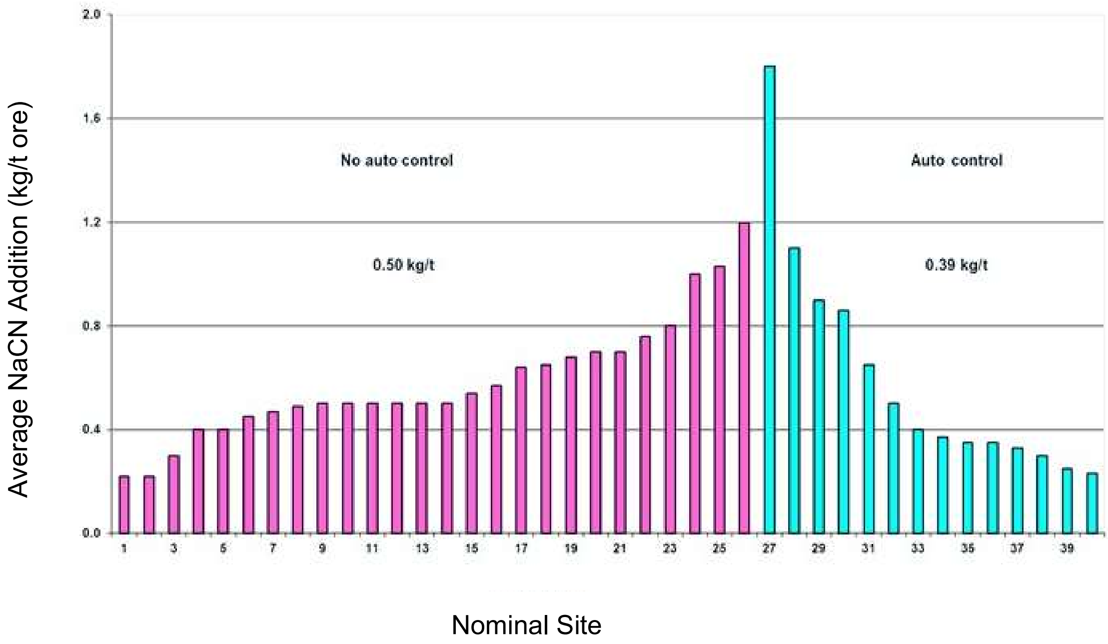

Figure15: Cyanide consumption – P420A Benchmarking survey 1999 [2]

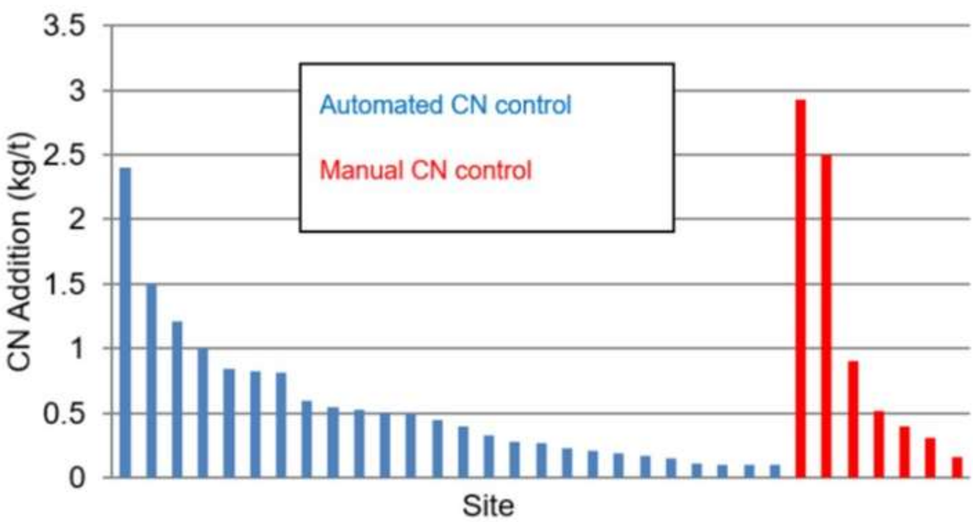

Figure 16: Cyanide consumption – P420D Benchmarking Survey 2012 [3]

The comparisons for cyanide consumption in whole-ore and concentrate leach in the 2021 dataset are given in Table 2.

Table 2: Cyanide Consumption

Cyanide consumption	All Sites Overall Consumption (kg NaCN/t)	Whole Ores Circuits (kg NaCN/t)	Flotation Concentration Circuits (kg NaCN/t)
Average	1.85	0.59	8.77
Median	0.3	0.25	6.8
Minimum	0.12	0.12	0.23
Maximum	17	6.8	17

While it is expected that cyanide consumption for concentrate leaches will be higher than for whole-ore leaches, there are still a surprising number of high cyanide consumers in the whole-ore group. The Gold Technology Group suggests that most of the simple, free-milling ore leaches could be targeting ~0.2 kg NaCN/t so the high numbers seen may be indicative of the data set representing more complex ores (e.g. soluble copper) or lack of cyanide optimisation.

Most sites responding to the 2021 survey are only adding cyanide in a single location, while 36 % are adding cyanide in at least two points within the leach circuit. In theory, multiple addition points should allow for lower cyanide concentrations in the first leach tank with the ability to add cyanide further down the circuit, when and where it is needed for leaching, leading to both lower cyanide consumption and lower WAD/free NaCN in the tails stream, reducing the cost of cyanide destruction where the site has limits on the tailings cyanide concentration.

The cyanide concentration in the leach tanks, according to 2021, is summarised in Table 3.

Table 3: Cyanide Concentration

Minimum Cyanide Concentration	NaCN first tank	NaCN last tank
Average	220	85
Median	120	50
Minimum	10	10
Maximum	1800	600

Six sites reported very low titratable NaCN values of 10 – 40 ppm in the first leach tank and one site reported a very high value of 1800 ppm These results require validation/clarification. The WAD cyanide is monitored at 75% of the responding sites.

In the 2021 survey, all the responding sites reported using automated measurement devices (and manual titration checks), with potentiometric sensors being the most common, having installations at 66 % of sites.

Carbon management

In the 1999 and 2014 surveys, the typical carbon residence time (calculated as = active carbon circuit inventory (t) / elution frequency (t/day) x elution column capacity (t)) was reported as 10-14 days. In the survey of 2021, it was found the average carbon residence time of 16 days, as shown in Table 4.

Table 4: Carbon Residence Time 2021

Residence time	Days
Average	16
Median	13.6
Minimum	3.2
Maximum	70

The maximum residence time of 70 days was observed in a site reporting 2 elutions per week with a significantly high carbon inventory. The minimum carbon residence time was achieved in a site with a high elution frequency and 2 parallel elution columns.

Table 5 shows the typical carbon inventory, in tonnes, at the surveyed circuits in 2012 and 2021.

Table 5: Carbon Inventory

Carbon Inventory (t)	2012 Survey	2021 Survey
Average	83	131
Median	45	113
Minimum	3	25
Maximum	400	368

Longer residence time can lead to very inactive carbon and high gold lock-up in the circuit. Sites with residence times much longer than average generally have a larger inventory than the design criteria. A higher inventory may simply be due to an excess of carbon in the circuit but is more commonly the result of a low carbon activity.

Sites with gold-robbing carbon, or poor carbon activity associated with flotation reagents, may intentionally operate with very low residence times to keep the carbon more active (and loading targets low) to improve circuit performance. Shorter residence times (minimum value of ~3 days noted in each survey) are indicative of low carbon inventory/higher elution frequency and can lead to increased carbon consumption, low gold loading values and higher elution, electrowinning and regeneration costs.

In the previous benchmarking surveys, the median carbon consumption was between 20-30 g/t of ore processed. The 2021 data set (Table 6) has a couple of concentrate leach circuits which have incredibly high carbon consumption which is likely due to the calculation reflecting the very small proportion of the mass treated in the leach circuit (typically only 5-15 % of the mill feed).

Table 6: Carbon Consumption

Carbon Consumption (g C/t of ore)	2012 Survey	2021 Survey
Average	52	139
Median	27	29
Minimum	1	2
Maximum	730	2284

If all reported carbon inventory is taken into consideration, the summary data in Table 6 shows the average would be 139 g/t. The median value of 29 g/t is on the high side of what was considered average from the past two surveys.

Fine carbon is problematic as it can pass through interstage screens and instead of being transferred up the circuit, it will follow the pulp co-currently. Fine carbon, defined as carbon at less than 1.7 mm, can also report to tails carrying appreciable amounts of gold, resulting in gold loss and assay spikes which are challenging during metallurgical accounting. The Gold Technology Group recommends less than 10 % of the carbon inventory should be less than 1.7 mm. In the 2021 benchmark survey, the median bottom size of the carbon fines is reported as 1.18 mm, having a gold grade of 92 g/t.

The Gold Technology Group compile a database of laboratory carbon sizing tests to determine the typical content of fine carbon content, as -1.7+1.18 mm fraction, in circuit carbons (Figure 17). It shows an average of 18 % of fines in the samples tested. This fine carbon (with a bottom size of 1.18 mm) risks wearing finer than the ~800 µm safety screen aperture and being lost to tails.

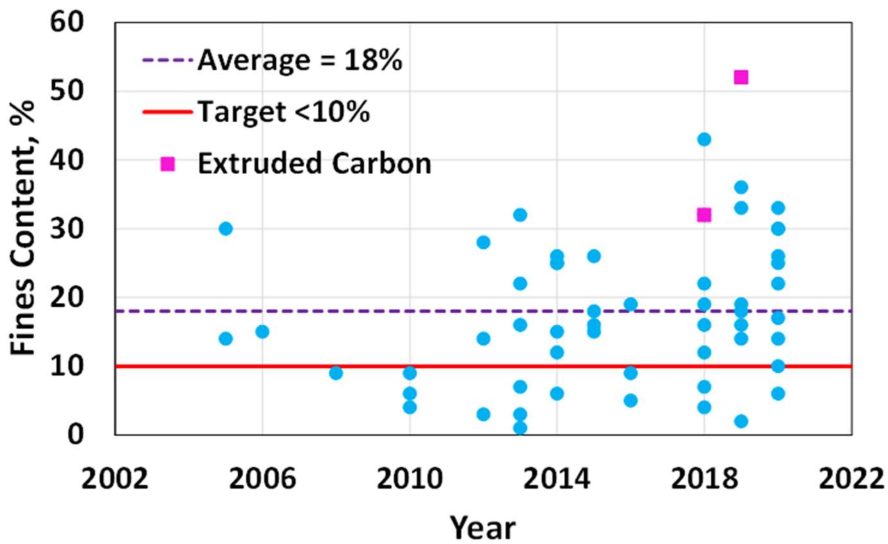

Figure 17: Carbon fines, as – 1.7 mm, content from the Gold Technology Group database (2000-2020) [4]

Solution losses

Since the early days of carbon adsorption circuits, the typical target soluble gold loss for many sites has been 0.01 ppm. In 1999, a wide range of solutions losses was reported with an average of ~0.02 ppm. In 2021, some very high solution losses (~0.3-0.4 ppm) were reported but some very low solution losses were also noted (0.001 ppm). It can be noted that there is concern that these low values may not be accurate as they are likely below the detection limit of the assay method employed. Table 7 shows the average solution loss in 2021 in comparison with 2012. It is still above 0.02 ppm but the median value is closer to the 0.01 ppm target.

Table 7: Solution Losses

Solution loss of Au (ppm)	2021 Survey	2012 Survey
Average	0.023	0.017
Median	0.010	0.011
Minimum	0.001	0.002
Maximum	0.320	0.080

One way to target decreased solution loss is to improve carbon activity and optimise the carbon inventory and distribution throughout the adsorption circuit. Although carbon meters being commercially available to measure carbon concentration in the tanks for many years, only two of the sites reported using the devices in a total of three circuits, with two of those meters only being used to indicate carbon loss through the final interstage screen. All other sites are still relying on manual carbon concentration measurements. Automated carbon measurement has the benefit of not only freeing up the operators' time for more critical duties but also means they may not be required on top of the leach tanks as frequently, minimising HCN exposure.

CONCLUSIONS

This paper summarises the preliminary findings of the Amira P420 G 2021 benchmark surveys and compares the data collected with the surveys from 2012 and 1999. The 2021 survey had a smaller participation of sites, in comparison to the 2012 and 1999. The surveys identified a general increase in throughput and gold production in the sites surveyed. The proportion of gold recovery via gravity also increased in the period observed. In leaching circuits, a significant reduction of cyanide consumption is related to the automation of cyanide addition. The automation of carbon concentration measurement has been reported in two of the sites surveyed. However, the carbon movement sequence has not been reported to be linked to the automated carbon measurement yet. In the Amira P420H project, more work is required to link the data to the previous surveys and correlate survey data to identify the best practices for the operation of gravity and leaching circuits.

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