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Pilot scale microwave sorting of porphyry copper ores: Part 2 – Pilot plant trials

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ABSTRACT

An experimental pilot plant was constructed, commissioned and operated at a major porphyry copper mine to understand the challenges of microwave infrared thermal (MW-IRT) sorting at scale and to compare batch laboratory performance with pilot-scale continuous sortability performance. A method was developed to define the 95% confidence intervals on pilot plant operating windows from experiments on 50–150 fragments performed in a laboratory based replica of the pilot scale microwave treatment system. It appeared that the laboratory testing methodology predicted the sortability of the ores fairly well. For the 11 ore types and three size classes (−76.2 + 50.8 mm, −50.8 + 25.4 mm and −25.4 + 12.7 mm) tested over 233 pilot plant experiments, approximately 42% of the better optimised pilot plant runs predicted copper recovery to within ±5% copper recovery and approximately 84% of the runs to within ±10%. These figures were improved to approximately 50% predicted to within ±5% and approximately 90% to within ±10% if the −25.4 + 12.7 mm size class was omitted. It was demonstrated that laboratory testing better predicted pilot plant sorting performance and provided a narrower operating window when a larger sample size (>50 fragments) was considered due to improved representivity. It is, therefore, fully expected that better predictions would result from larger laboratory sample sizes than those tested during any future testing campaigns. To date, approximately 15,500 tonnes of ore has been processed through the pilot-scale test facility, generating significant engineering know-how and demonstrating MW-IRT sorting at a scale in the order of that required by the mining industry.

1. Introduction

Recent advances in automated sorting technology have seen ore sorting become an increasingly attractive possibility for the mining industry to help reduce energy consumption while maintaining productivity in the forecasted low-grade future. However, sensors that have the resolution to discern grade differences in low-grade ores (typically down to ~0.1 wt%) or have the capacity to process the several thousand tonnes per hour required by the largest operating mines in an economical manner, particularly on a fragment-by-fragment basis, continue to be a limiting factor (Daniel and Lewis-Gray, 2011; Drinkwater et al., 2012; Lessard et al., 2014, 2016; Napier-Munn, 2015; Pokrajcic et al., 2009; Powell and Bye, 2009). Microwave treatment followed by infrared thermal imaging (MW-IRT) has been proposed as an excitation-discrimination technique to facilitate sorting of low-grade ore (Berglund and Forssberg, 1980; Ghosh et al., 2013, 2014; John et al., 2015; Sivamohan and Forssberg, 1991; Van Weert and Kondos, 2007; Van Weert et al., 2009), but until recently has not been demonstrated at scale.

In the first part of this paper, a bespoke, laboratory-based, high throughput and continuous pilot scale microwave treatment system capable of treating up to 100 t/h (instantaneous) of ore in a batch wise fashion was described (Batchelor et al., 2016; Katrib et al., 2016). Utilizing the bespoke system, the fragment-by-fragment thermal response of a variety of porphyry copper ores from different operating conditions was investigated with the aim of determining the effect on sortability performance across conditions likely to be encountered in an industrial environment. It was found that microwave treatment energy was the driving force behind the ultimate temperature rise fragments experienced and that the presence of microwave-heating gangue minerals was the main source of deviation from intrinsic, or ideal, sortability performance.

Subsequent to initial laboratory testing, a decision was taken to commission a pilot-scale test facility at a major porphyry copper mine owned and operated by the project sponsor. The aim of the facility was to understand and develop know-how surrounding the engineering challenges of microwave sorting at scale, to

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compare batch laboratory sortability performance with pilot-scale continuous sorting performance to validate the testing methodology and support project valuation. The pilot plant microwave treatment system had the exact same specification as the laboratory system, apart from utilizing a slightly different microwave frequency (915 MHz) due to the plant being located in a region that uses a different industrial, scientific and medical (ISM) band to the UK (896 MHz) (Meredith, 1998). The major difference was the extensive feed storage and preparation facilities, integration of a commercially available automated sorter, and the associated materials handling, process control, sampling, sample preparation and other facilities that would enable continuous processing for several hours of operation covering a typical working shift. Pilot plant testing was conducted over a period of one and a half years, during which time approximately 300 test runs were completed on 11 different ore types with a total of approximately 15,500 tonnes of material processed.

Table 1
Sample list and number of fragments tested/analysed in the laboratory.

Sample ID	Sample grade[a]	−76.2 + 50.8 mm	−50.8 + 25.4 mm	−25.4 + 12.7 mm
9	Ore	100/50	100/50	150/150
9W	Waste	50/50	50/50	50/50
10	Ore	100/100	100/100	100/100
10W	Waste	100/50	100/50	100/50
11	Ore	100/50	100/50	100/50
11W	Waste	140/140	150/150	150/150
14	Ore	150/150	150/150	150/150
14W	Waste	140/140	150/150	150/150
15W	Waste	150/150	150/150	150/150
16W	Waste	150/150	150/150	150/150
17W	Waste	150/150	150/150	150/150

[a] Sample defined as “ore-grade” or “waste-grade” by host mine.

This second part of the paper presents a comparison of the laboratory and pilot plant sortability performance and further develops the testing methodology to give confidence in the prediction of pilot sortability performance from laboratory testing.

2. Materials and methods

2.1. Ore samples

The porphyry copper ore samples used throughout the piloting investigation were all sourced from the pilot plant host mine. 11 ore types were selected that covered a range of different lithologies with varying copper sulphide grade, copper sulphide to iron sulphide ratio and non-sulphide gangue mineralogy. The ores were also selected on the basis of proportion of future mine plan or otherwise potentially economically valuable material. The ores were supplied in three narrow size classes, namely −76.2 + 50.8 mm, −50.8 + 25.4 mm and −25.4 + 12.7 mm, listed in Table 1, for the reasons outlined in the first part of this paper (Batchelor et al., 2016). Each size class was tested separately to enable optimal separation efficiency from the sorter.

The mine selected an ore-grade and waste-grade (denoted with the suffix “W”) version of four lithologies plus a waste-grade version of three lithologies. Samples #9 and #9W were a quartz-monzonite ore diluted with approximately 10–20 wt% quartzite fragments, which had a consistent texture of well disseminated microwave-heating phases within a speckled microwave-transparent. Samples #10 and #10W were a quartzite ore, which had a fairly consistent texture of well disseminated microwave-heating phases within the microwave-transparent matrix, with some coarser and clustered mineralisation and some sulphide veins. Samples #11 and #11W were a limestone-skarn ore, which

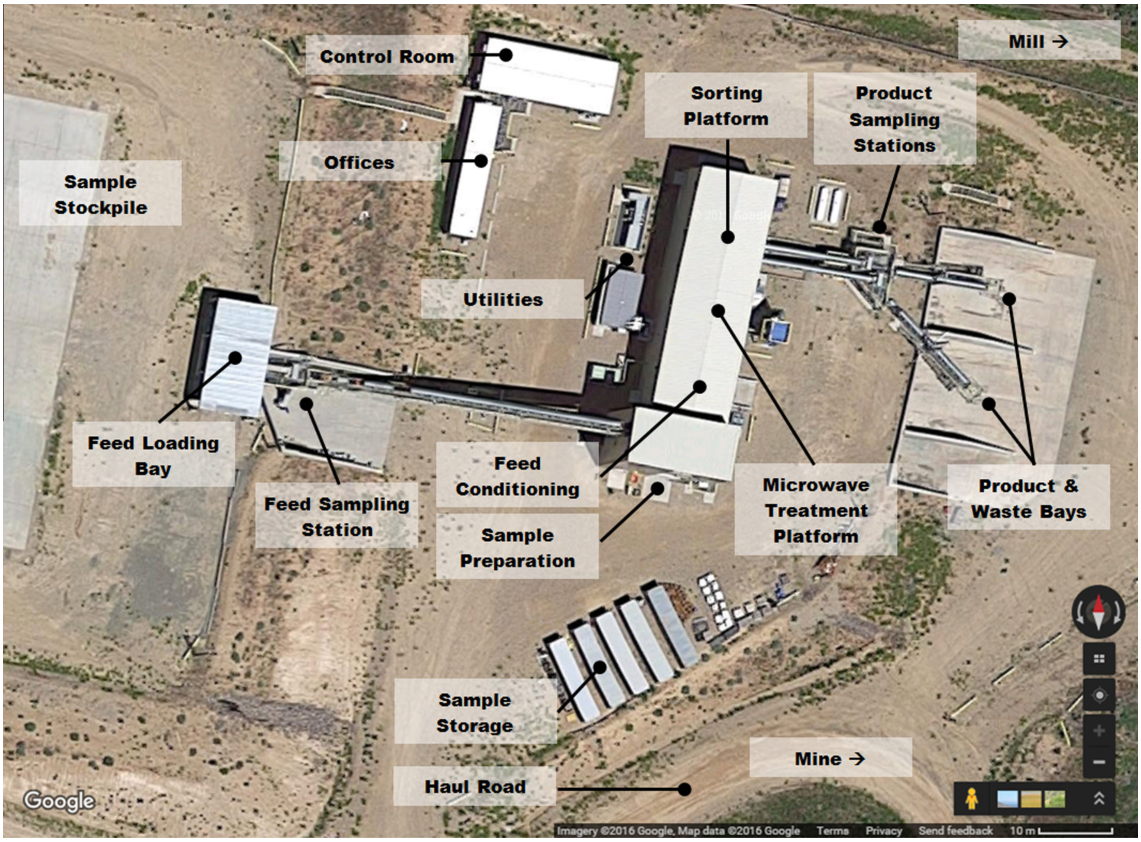

Fig. 1. Pilot plant aerial view.

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