Minerals Engineering 109 (2017) 169–183

Contents lists available at ScienceDirect

Minerals Engineering

journal homepage: www.elsevier.com/locate/mineng

Towards large scale microwave treatment of ores: Part 1 – Basis of design, construction and commissioning

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ARTICLE INFO

Article history:
Received 8 September 2016
Revised 7 February 2017
Accepted 11 March 2017
Available online 8 April 2017

Keywords:
Microwave
Ore
Copper
Pilot scale
Fracture
Beneficiation

ABSTRACT

Despite over thirty years of work, microwave pre-treatment processes for beneficiation of ores have not progressed much further than laboratory testing. In this paper we present a scaleable pilot-scale system for the microwave treatment of ores capable of operating at throughputs of up to 150 tph. This has been achieved by confining the electric field produced from two 100 kW generators operating at 896 MHz in a gravity fed vertical flow system using circular choking structures yielding power densities of at least 6×10^8 W/m^3 in the heated mineral phases. Measured S_{11} scattering parameters for a quartzite ore (-3.69 ± 0.4 dB) in the as-built applicator correlated well with the simulation (-3.25 dB), thereby validating our design approach. We then show that by fully integrating the applicator with a materials handling system based on the concept of mass flow, we achieve a reliable, continuous process. The system was used to treat a range of porphyry copper ores.

1. Introduction

Microwave treatment of metalliferous ores has long been investigated as a means to enhance the recovery of valuable minerals and reduce the comminution resistance of ores (Chen et al., 1984; Walkiewicz et al., 1988, 1989). The underpinning mechanism and textural characteristics of amenable ores has been described by Batchelor et al., 2015. Selective heating of microwave-absorbent sulphides and metal oxides deported in a microwave-transparent gangue matrix results in differential thermal expansion of the heated phase, yielding micro-fracture around grain margins (Batchelor et al., 2015; Jones et al., 2005, 2007; Kingman et al., 2004a, 2004b, 2000a). Subsequent downstream processing may then yield higher recovery of valuable mineral sulphides and/or lower specific comminution energy, compared to non-microwave treated ore.

Whilst the mechanistic principles are well established, the scientific and engineering challenges of developing a commercial scale system are immense. Typical throughputs of a large copper mine can be in excess of 5000 tph of milled ore (Brininstool, 2015) and a microwave based treatment system would need to handle equivalent throughputs. This is at least an order of magnitude higher than any other microwave process ever built.

The following paper details the design, commissioning and operation of a system which was the culmination of over fifteen years of research and development activity. This resulted in a high power microwave treatment process, capable of operating continuously at throughputs of up to 150 tph, but crucially, scaleable up to several thousand tonnes per hour.

1.1. Microwave processing of ores – Technology development timeline

In Fig. 1, the key early activities which underpinned the development of the pilot-scale system are presented. The earliest work investigated heating rates of different minerals in kitchen microwaves (Chen et al., 1984), supported by measurements of their dielectric properties. The early to mid 90s saw higher power tests conducted in larger industrial multimode cavities. (Standish and Worner, 1991; Yixin and Chunpeng, 1996). The large number of propagating modes characteristic of these types of applicator makes characterising the interaction between the applied microwave energy and the material very difficult, even using the power of modern high performance computers. Whilst the mechanistic principals were beginning to be understood (Kingman et al., 2000a), it was found that reductions in energy inputs (from ≫10 kW h/t to <5kW h/t) and residence times (to yield higher

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http://dx.doi.org/10.1016/j.mineng.2017.03.006
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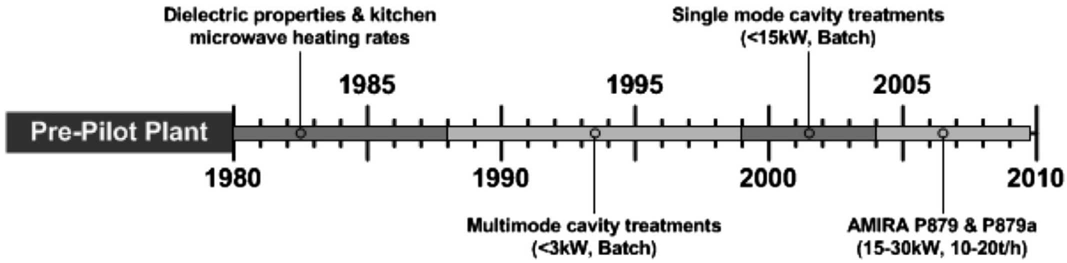

Fig. 1. Early development of microwave processes for the treatment of ores.

throughputs) were required to realise an economically viable process (Kingman and Rowson, 1998).

Focussed work using single mode cavities, post-2000 resulted in reductions in the energy required, greater understanding of the breakage mechanism and also characterisation of the electromagnetic properties of such cavities (Kingman et al., 2004c; Kingman et al., 2000b; Robinson et al., 2010a). This yielded important information regarding the spatial distribution and intensity of electromagnetic energy within them. This enabled optimisation of their configuration, such that a well-defined area of high electric field was supported, sufficient to realise the power densities required. The first continuous belt-based processing systems were trialled under the AMIRA P879a programme around 2006 and were capable of processing ore at throughputs of 10–20 tph and applied powers up to 30 kW. Key learning outputs from this work were: the importance of integrating the materials handling system with the microwave cavity for process stability; and the design of choking structures. These were necessary to confine the electric field within the applicator in open-ended processing systems to prevent gradual warming of the load to optimise the thermal shock based fracture mechanism and achieve compliance with safety standards.

The work which directly supported the development and evaluation of the pilot-scale system is outlined in Fig. 2. This began around 2010 with the development of a vertically aligned capsule which held ore fragments in place as a packed bed. This was moved though the applicator using a belt and pulley system and was effectively a pseudo vertical flow configuration. The key development arising from this work was the design of innovative circular choking structures through which the capsule moved. These confined the electric field in a relatively small zone centred on an open ended applicator. This minimised heat conduction of the heated phases to the bulk ore, thereby maximising stress in the ore matrix and yielding fracture at reasonably low energy inputs. If the circular chokes were not incorporated into the system, then there would exist a gradient in electric field intensity both above and below the vertically aligned applicator, which would introduce a gradual warming of the load at it passed through. Heat conduction to the bulk ore would then lessen the stresses generated through the differential thermal expansion of heated phases confined within a relatively non-heated bulk ore matrix. A detailed account of the mechanistic aspects and ore textures susceptible to such a process has been reported by Batchelor et al. (2015).

The design and testing of these choking structures was considered in detail in Katrib et al. (in preparation). The pre-piloting system was crucial in validating the performance of the circular choking structures, particularly with respect to confinement of the electric field in an essentially open-ended system, in order to meet health and safety and electromagnetic compatibility regulations.

1.2. Aims and objectives

The aim of this work was to design and demonstrate the viability of a pilot-scale system that can be then be further scaled to a commercially relevant system for deployment at a mine site. Specific objectives for the pilot scale system were to:

- Demonstrate that metallurgical effects observed in pre-piloting batch scale testing could be re-produced in continuously flowing ore at pilot scale.
- Evaluate the impact on the system performance and process stability of feed ore presentation in the applicator. Specifically aspects such as particle size; shape; moisture content; voidage; mineralogy and ore texture
- Assess engineering issues such as wear and reliability of the system components
- Produce statistically large volume test samples for subsequent use in proposition analysis

The evaluation of the pilot-scale system addressed the key questions around electromagnetic engineering, materials handling design and optimisation, operability, sample generation/value quantification and techno-economic analysis.

2. Design philosophy of the pilot-scale system

The engineering vision of the pilot-scale system was rooted in the concept of frequency scaling using a single mode cavity surrounding a vertically aligned tube used in pre-piloting studies as described in Section 1.1. Based on flowing ore down a tube passing

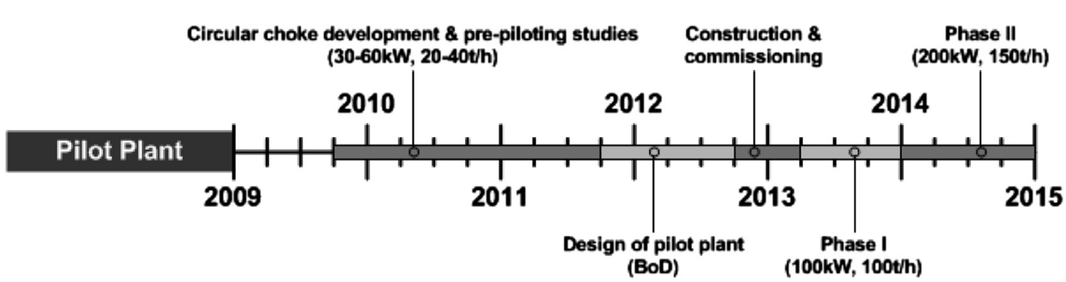

Fig. 2. Key activities in the development and evaluation of the pilot-scale system.