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Microwave Energy Aided Mineral Comminution

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Abstract

Mineral liberation during beneficiation is essentially through comminution. However, the fact that the major slice (up to 50 percent) in the pie for total energy requirements during beneficiation is occupied by comminution, dictates us to look into various possibilities to render comminution more energy-efficient.

In the early 1900s, efforts for reduction in the crushing and grinding energies based on the concept, 'thermally assisted liberation' (T A L) were made but could not be commercially exploited. With the advent of microwave energy and applications in different commercial operations based on its property of heat generation in materials encouraged it in utilizing as an aid during comminution. Microwave energy heats individual phases in an ore matrix to different heat levels as per individual microwave absorption characteristics. Exposure to microwave energy over discrete time intervals prior to comminution results in development of micro fractures due to differential heating. Weakening of interspatial bonding in the ore matrix helps in lesser energy requirements. Numerous studies on microwave energy applications in the field of mineral processing and extractive metallurgy are undertaken in many parts of the world in recent years.

With an ambition for implementing microwave technology at the production level in the beneficiation plant operations of Hindusthan Zinc Limited (HZL) as a platform change technology, Central Research and Development Laboratory has included in its road map a project to work on the concept.

The paper is a technical note on the laboratory investigations carried out at CRDL using HZL's Rampura Agucha ore samples. Assistance of M/S SAMEER (Society for Applied Microwave Electronics Engineering & Research), Mumbai, a Govt. of India Laboratory, has been sought for microwave energy facilities. Samples representing grinding circuit feed have been exposed to microwave energy at different intensities and exposure intervals. Laboratory batch mode wet grinding and sieve analysis tests provided a comparative data between microwave- irradiated and non-radiated conditions. Tests have also been conducted under microwave irradiation followed by quenching. Using the Berry and Bruce method of computing relative bond work index, percent energy reduction has been assessed for different time exposure intervals for the same amount of material. Results have been encouraging to progress the work further.

Future work includes design plans for procuring suitable intensity microwave system and installing in one of the Rampura Agucha grinding circuits to monitor microwave energy effects on plant scale. It is also proposed to carry out modeling work to simulate changes in minerals so as to predict the changes. Rigorous laboratory tests have to be undertaken to optimize microwave intensity and exposure requirements.

INTRODUCTION

Mineral, in an extended sense, can be termed as anything of economic value extracted from earth and a mineral deposit can be translated into an ore according to its concentration through geological agencies and development of demand for human use (Wills 1992). Liberation of useful minerals from other materials is very energy-hungry comminution operations. Out of the total beneficiation energy requirements, comminution contributes up to 50%. This trend dictates us to thrive into various possibilities to render comminution more energy-efficient. Situation thus becomes critical in terms of energy requirements in the current and future circumstances for exploring depleting and more complex mineral wealth.

Efforts for improving efficiencies of comminution circuits have been in many folds, like newer machines and comminution modeling/simulation techniques. Since early 1900s, methods towards economize comminution operations through grindability enhancement studies, like 'Thermally Assisted Liberation' (T A L). The constituents of ore typically have different thermal and mechanical properties, for example, thermal expansion coefficients. So, when exposed to heating source, develop stresses of sufficient magnitude to create inter-granular and trans-granular fractures; the effect becoming predominant when quenching is also followed. The presence of phases with high degree of thermal absorption coefficients enhances fracture formation. However, methods based on early concepts of T A L had disadvantages of economics in providing vast amount of energy and/or fuel with the conventional furnaces (Vorster et al 2001).

Late 1900s witnessed microwave energy as the new source for developing heat stresses among mineral assemblies inside the ore and has been found as a unique solution for the economic viability. Microwave is a form of electro magnetic radiation having frequency between 3000 MHz to 3000 GHz. Details of different wave types with their wave length, frequency and energy values are given in Fig 1. Presence of one or two phases within the ore particles that respond well towards microwaves makes the concept work out effectively. The differential absorption capacities of different mineral

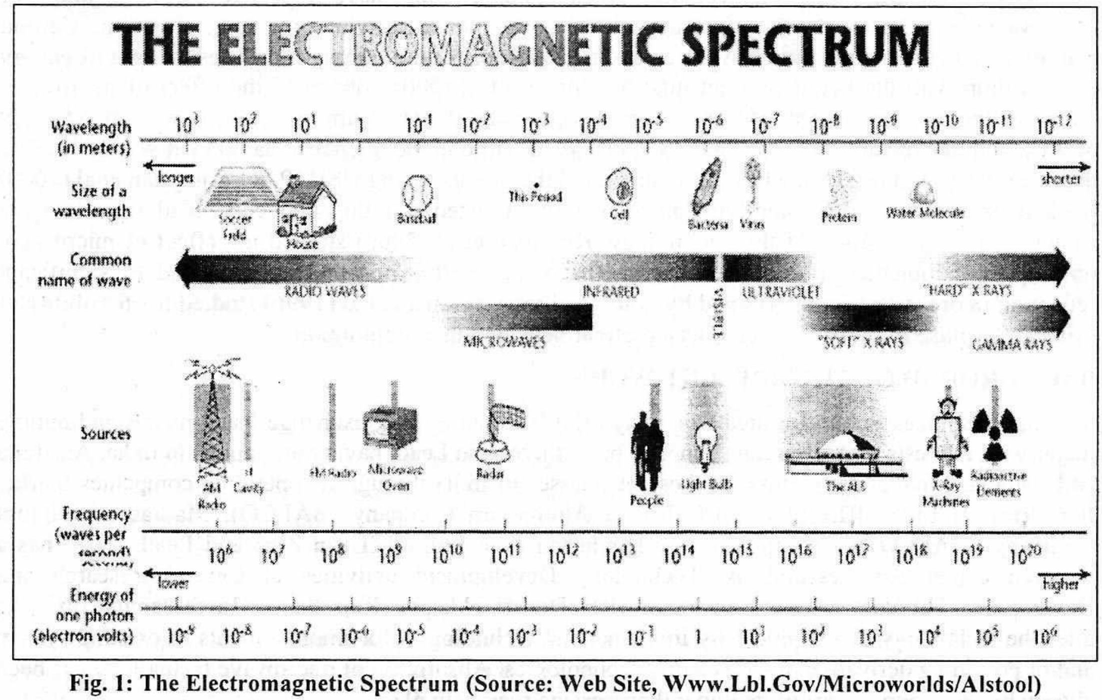

Fig. 1: The Electromagnetic Spectrum (Source: Web Site, Www.Lbl.Gov/Microworlds/Alstool)

constituents cause cracks and micro-fractures development in the ore matrix. For example, presence of sulphides, oxides and graphitic carbon enhances the fracture formation.

BRIEF REVIEW ON MICROWAVE APPLICATIONS

A variety of applications for microwave radiation in the mineral processing and extractive metallurgical industries have been proposed. Some of the early applications include communication, navigation, vulcanization of rubber, medical therapy, drying of food items etc. In the recent past two decades, the remarkable success of microwave was observed in ore comminution, drying, Carbon reactivation, flotation, pressure leaching, roasting and sintering.

The fundamental principle behind all of these applications remains the ability of microwave to heat individual phases within the ore matrix. It was concluded that majority of silicates, carbonates and sulphates were transparent to microwave while most of the sulphides, arsenides, sulphonates and sulphoarsenides heated strongly as they were absorber to the microwave radiation.

Walkiewicz et al (1988) have reported the microwave heating characteristic of selected natural occurring minerals and reagent grade compounds and concluded stress fracturing at mineral grain boundaries in gangue matrix significantly affecting grinding energy requirements and liberation properties. Hwang et al (2002) studied microwave assisted chalcocite leaching with a microwave hydrothermal reactor. The leachability was much better in comparison to conventional one. Agrawal (1999) has worked on microwave sintering of metals. Fe-Ni-C (FN 208) and Fe-Cu-C (FC 208 formed highly sintered bodies with a modulus of rupture (MOR), 60% higher than the conventional sintering product within total time of 90 minutes at temperature range of 1100-1300°C with a soaking time of 5-30 minutes. Kinectrics Inc. (Canadian company formerly Ontario Hydro Technologies) has found microwave as an attractive alternative to conventional heating methods. With calcinations of Alumina and Barium Titanate about 15% electricity at 60% time and 70% electricity, 85% time respectively were saved, while in sintering of Alumina and Zinc Oxide 50% electricity, 60% time and 45% electricity, 50% time respectively was saved. Shuey, 2002 have reported the application of microwaves in various fields of mining like; comminution, drying, roasting, flotation, Carbon reactivation and concluded microwave as an efficient tool for the mining industries in sight of energy conservation with the better product quality. Vorster et al (2001) observed the effect of microwave radiation upon the processing of Neves Corvo Copper ore. A maximum reduction in work bond index of 70% within exposure of 90 seconds was observed while in the quenched samples it was 15% more than the unexposed one. They have also simulated the process using USIMPAC. Kingman et al (2000) worked on influence of mineralogy on microwave assisted grinding and concluded regarding the economic implementation of this technology. Kingman et al (2003) studied the effect of microwave on Copper carbonatite. It has been shown that very short exposure time can lead to significant reduction in ore strength (determined by point load test). Salsman et al (1996) studied the feasibility of using short pulse microwave energy as a pretreatment step in comminution.

BACKGROUND OF THE PRESENT WORK

Vedanta Resources Public Limited Company (plc) is London stock exchange listed metals and mining major with interests in Aluminium, Zinc, Copper, Silver and Lead, having operations in India, Australia and Zambia. It holds its interests in these businesses in India through its operating companies Sterlite Industries (I) Ltd (SIIL) in Copper, Bharat Aluminium Company (BALCO), Madras Aluminium Company (MALCO) in Aluminium and Hindustan Zinc Ltd. (HZL) in Zinc and Lead. HZL has a research center for Research & Technology Development activities at Central Research and Development Laboratory (CRDL), Zinc Smelter, Debari, Udaipur (Rajasthan). The research team looks after the technology development by implementing technologies for improvements in existing system and/or providing derivative or step change technologies. Absorption of microwave technology has been chosen by the group as part of its mineral processing road map plan.

Under the plan, a project has been proposed to be taken up for setting up plant scale facility, on trial basis first, to utilize microwave energy in the grinding operations at Rampura Agucha (R A) beneficiation plant. Details of work presented here are related to lab-scale studies before implementing the technology on site. The typical flow sheet for the beneficiation of lead-zinc ore presently practiced at HZL's R A beneficiation plant is given in Fig 2.

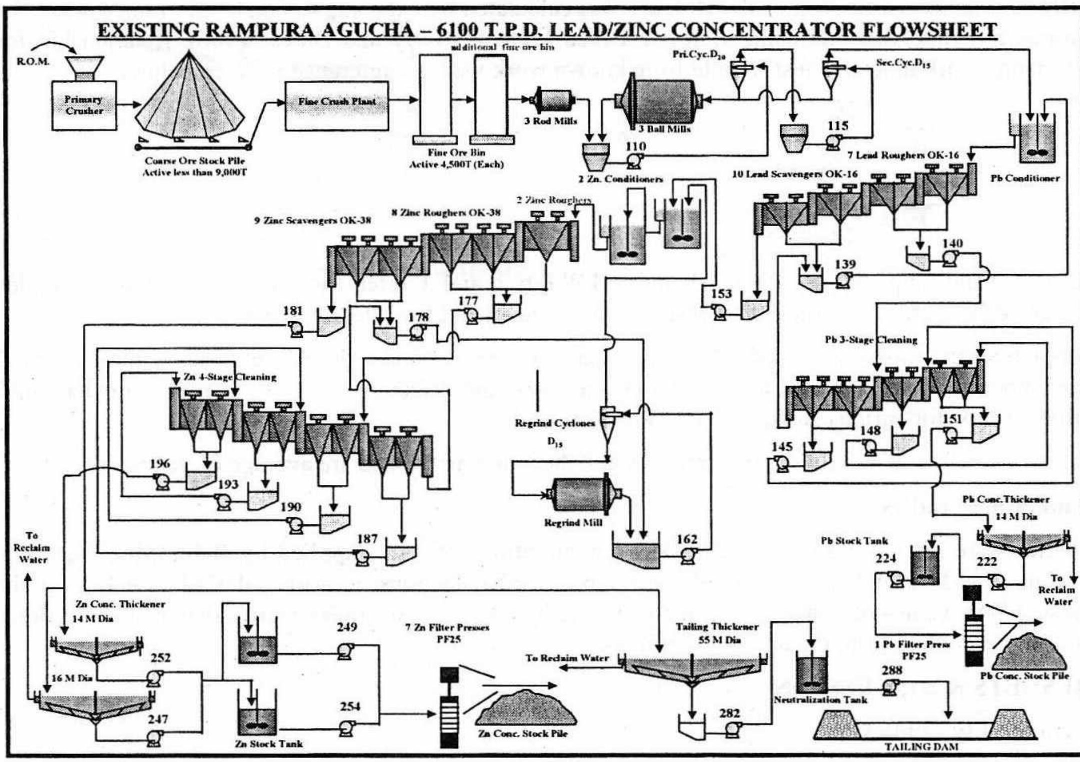

Fig. 2: Schematic Flow Sheet of Rampura Agucha Lead-Zinc Beneficiation Plant

EXPERIMENTATION

Preparation of Sample

With the view to undertake laboratory investigations to study the behavior of Rampura Agucha ore upon microwave irradiation, a few lots of representative rod mill feed sample has been obtained from plant to CRDL. Particle size distribution is ascertained through sieve analysis using 19 mm, 12.5 mm, 6.3 mm, and 2.0 mm sieves. Particles passing 2 mm were discarded. Above sieve fractions were then mixed to get desired amount of samples so that the proportion of each size fraction in -19 mm,-19mm +12.5 mm, -12.5 mm +6.3 mm and -6.3 mm +2 mm fractions was similar to the original sieve fraction available in the rod mill feed. Removal of particles passing 2 mm size were removed from feed in accordance with certain observations from previous works mentioned by authors (Kingman, 2004) that poorest response could be expected from ores containing highly disseminated and fine-grained material through microwave irradiation.

Grindability Studies

The first investigations were carried out to observe the effect of water quenching just after microwave exposure. The 3-kg sample prepared as above was exposed to various power levels of 4.0 kW microwave source available at SAMEER for different time intervals and quenched in water immediately. Further, the samples (unexposed, unquenched exposed, quenched exposed) were ground in batch type laboratory ball mill (12" dia x 12" long) maintaining > 60% (by wt.) pulp density. The ground slurry was analyzed for various sieve fractions (+8, +30, +60, +100, +200, +300, +400, -400 mesh) through wet sieving.

Further, studies were conducted with a batch mode industrial type set up supplied by SAMEER to CRDL. Relative work index of the R A ore was calculated by exposing the material to microwave for various time intervals and using Berry & Bruce Method (Berry and Bruce, 1966). Relationship for estimating work index for test sample from known work index of reference is given below;

$$W_{it} = W_{ir} \frac{\frac{10}{\sqrt{P_r}} - \frac{10}{\sqrt{F_r}}}{\frac{10}{\sqrt{P_t}} - \frac{10}{\sqrt{F_t}}}.$$

In the relationship, Wi is the work index kW.h/t; r and t refer for reference and test samples respectively; P and F refer to 80% passing of the product and feed stream respectively.

Supplementary experiments with the same microwave power and a definite exposure time (observed from previous experiments) were accomplished and the effect of microwave power on ball mill grinding time for various sieve fractions was observed.

All the experiments were done in triplicates and the value mentioned are average of them.

Simulation Studies

Studies were carried out using JKSimMet comminution software supplied by JKSimMet, Australia. The increased throughput was simulated for observed reductions in work index of R A ore for the present P-80 values of beneficiation plant. The reductions in work index were calculated using Berry and Bruce Method from the above experiments.

RESULTS & DISCUSSION

Grindability Studies

Fig 3 indicates that the fine particle fraction generated after microwave exposure under unquenched condition is more or less similar to unexposed ore, while it is substantially higher in case of water quenching after microwave exposure. This reflect that microwave power will be more effective under quenched conditions with respect to unexposed and exposed ore without water quenching. This was due to the extensive intergranular fractures caused by differential heating and subsequent thermal expansion of the microwave responsive grains within the mineral lattice. The reverse holds true for the quenching process. The minerals at higher temperature cool quicker because they have a higher temperature gradient.

Fig 4 reveals a more than 25% reduction in work index for RA ore after microwave treatment. The percentage reduction in work index was calculated from the relative work index values of the microwave exposed ore obtained from the Berry & Bruce method.

Fig 5, 6 & 7 show the effect of microwave under quenched conditions on the ball mill grinding time of the ore. The results have been plotted between cumulative weight percentage passing of 200, 150 & 100-mesh size with respect to different ball mill grinding time. The graphs reflect a constant dominance of fine particles generated in microwave exposed ore under water quenched conditions over the grinding of unexposed ore. The observation reveals that less ball mill grinding time is desired to generate same cumulative percentage passing value (P-80) for every mesh. This signifies that the exposure of ore to microwave results in its decreased *hardness or work index.*

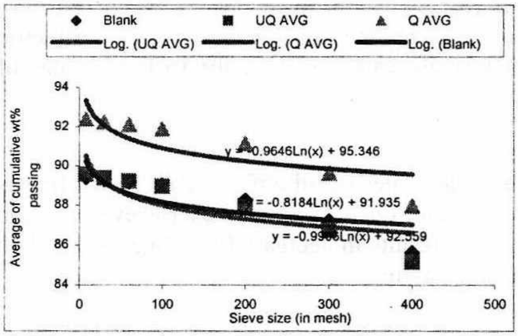

Fig. 3: Trend Line (Semi Log) for Average Particle Size Distribution of Rampura Agucha Samples Under Water Quenched, Unquenched & Unexposed Conditions

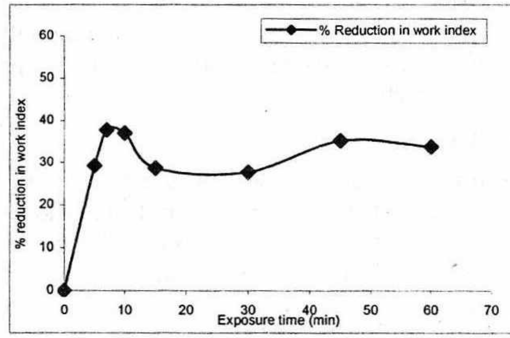

Fig. 4: Effect of Microwave Exposure for Different Time Intervals on Work Index of Ore

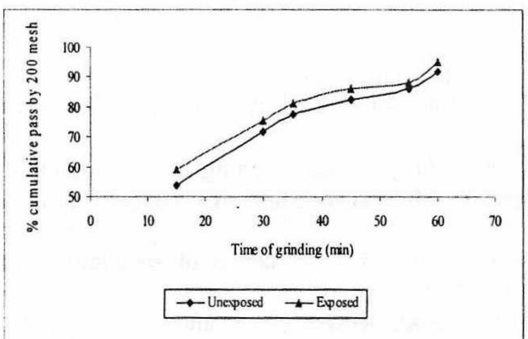

Fig. 5: Effect of Microwave Exposure on Grinding Time of Ball Mill for Percentage Cumulative Passing by 200-Mesh Sieve

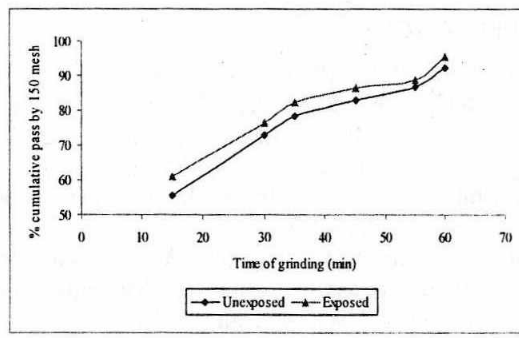

Fig. 6: Effect of Microwave Exposure on Grinding Time of Ball Mill for Percentage Cumulative Passing by 150-Mesh Sieve

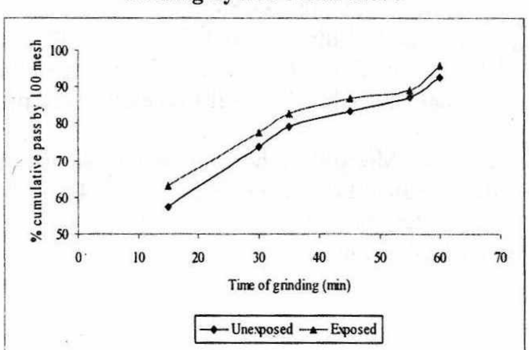

Fig. 7: Effect of Microwave Exposure on Grinding Time of Ball Mill for Percentage Cumulative Passing by 100-Mesh Sieve

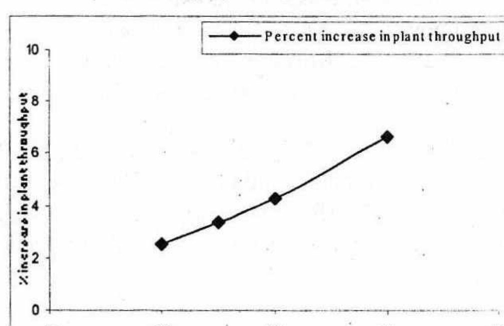

Fig. 8: Simulation Studies to Estimate the Increased Plant Throughput Rate with Percent Reduction in Work Index

Simulation Studies

The data were simulated to analyze the increased throughput rate of the plant due to decreased work index of ore after microwave exposure. As microwave energy aided grinding helps finer grinding, in order not to shift product particle size distribution (for not disturbing downstream flotation), throughput can be increased for an operating mill, resulting in reduction of specific energy per metric ton of ore. Fig 8 shows simulated values of percent increase in throughput for various values of percent reduction in work.

CONCLUSION

From the grindability trials, it is concluded that sphelerite (galena-lead-zinc) ore of R A Mine is responsive to microwave radiation. It was shown that the water quenching after microwave radiation causes substantial reduction in work index of the ore. Thus results in decreased grinding time of ball mill for same cut off value of cumulative weight percentage passing.

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