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Impact of High-Power Microwave Treatment on Comminution and Downstream Processing of Kimberlite Ores

R. Borhan Mehr[1,3*], C.A. Pickles[1*], J. Danoczi[2*], M. McCubbing[2], J. Forster[3], X. Tian[3]

[1] *Queen's University's Robert M. Buchan Department of Mining, Kingston, Canada, *christopher.pickles@queensu.ca*
[2] *Saskatchewan Research Council, Saskatoon, Canada, *jane.danoczi@src.sk.ca*
[3] *Sepro Mineral Systems, Langley, Canada, *ravash.borhanmehr@seprosystems.com*

Introduction

The liberation of diamonds during processing is crucial, as diamond breakage and damage can result in millions of dollars of lost revenue for the mines. Diamond breakage plays a significant role in the assessment of the economic potential of a diamond deposit, affecting grade accuracy, value, and forecasts. Diamond breakage occurs during the recovery process mainly in the comminution stage[1] but also in pumps and ejectors.

Diamond prices increase exponentially with diamond size (PriceScope, 2022). The price per carat of a 1-carat diamond is approximately $7,000, while for a 2-carat diamond it is about $21,000, and for a 3-carat diamond, approximately $41,000. Furthermore, diamonds that incur chips and impact scars from the recovery processes are also devalued, resulting in additional revenue losses for the mines (Rider and Roodt, 2003). Furthermore, the diamond mines evaluate their diamond recoveries based on the size frequency distribution (SFD) curves. These curves monitor both the carats and the number of diamonds in each carat size (Danoczi and Creighton, 2016). Any diamond breakage that results in chips and carat loss, leads to inaccurate predictions and forecasting errors. The main objectives of the current research were to investigate the potential utilization of microwaves for reductions in both the competency of the kimberlites (Forster et al., 2023) and diamond damage.

Mineralogy and Microwave Treatment

The purpose of the current research was to evaluate the microwave treatment of kimberlite. Four kimberlites (Jericho, De Beers, NAM, and PD) were studied at the bench-scale (3.2 kW; 2450 MHz), and the results demonstrated the microwave amenability of the kimberlites. In addition, the Jericho and the De Beers samples were investigated at the pilot-scale (140 kW; 915 MHz). Here, the ability of high-power microwave treatment to reduce the kimberlite's competency with short residence times was studied.

The amounts of the hydroxylated (highlighted in green) and the highly microwave amenable (highlighted in orange) minerals in each of these kimberlites are shown in Table 1. Table 2 shows the relative heating rates according to the residence times in the bench-scale microwave unit. Similar heating behaviours were observed for all four kimberlites. However, in comparison to the other kimberlites, the NAM kimberlite had higher heating rates at lower temperatures, due to its higher initial moisture content. These tests confirmed that the kimberlites were amenable to microwave treatment.

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[1] Finsch mine at Lime Acres, South Africa is an example. The kimberlite was diluted with competent banded iron stone. To crush this ore, a rod mill was used which resulted in numerous chards of broken diamonds.

Mineral, Ideal Formula	**NAM**	**PD**	**Jericho**	**De Beers**
Apatite, $Ca_5(PO_4)_3(OH,Cl,F)$	0.63	0.51	0.12	1.79
Biotite, $K(Mg,Fe)_3AlSi_3O_{10}(OH,F)_2$	3.20	2.76	0.10	0.07
Chlorite $(Mg,Fe)_3(Si,Al)_4O_{10}(OH)_2.(Mg,Fe)_3(OH)_6$	42.55	-	-	-
Fe-oxide, Fe_xO_y	0.19	-	-	0.49
Illite, $K(H_3O)(Al,Mg,Fe)_2(Si,Al)_4O_{10}[(OH)_2,(H_2O)]$	2.91	0.37	-	-
Ilmenite, $FeTiO_3$	0.18	1.71	2.81	2.43
Phlogopite, $KMg_3(AlSi_3O_{10})(OH)_2$	4.69	4.92	0.33	0.67
Talc, $Mg_3Si_4O_{10}(OH)_2$	43.00	-	-	-

Table 1: Hydroxylated (highlited in green) and highly microwave amenable (highlited in orange) minerals content of the kimberlites (wt.%) via QEMSCAN®.

Residence Time (s)	**NAM**	**PD**	**Jericho**	**De Beers**
	Heating Rate (°C/s)			
30	4.77	2.89	1.42	2.13
60	2.23	2.65	3.52	2.03
120	1.52	1.33	1.23	1.75
240	0.73	0.84	0.87	0.82
480	0.25	0.11	0.23	0.20

Table 2: Heating rates of the kimberlites at various times in the bench-scale microwave (3.2 kW; 2450 MHz).

In order to assess the effects of microwave treatment on the comminution and the downstream processing of the kimberlites, high-power pilot-scale microwave studies (140 kW) were performed on the Jericho and the De Beers samples. These microwave treatments were carried out with short residence times (5-12 s) and low energy doses (2-8 kWh/t).

Microwave Treatment and Comminution

The microwave treatment of the kimberlites results in the heating of the constituent minerals. The heating behaviour of a mineral depends on a number of factors such as its permittivities, abundance, grain size, geometry, and distribution within the sample. Each mineral grain experiences its own expansion and contraction in the clay matrix, and this results in thermal stresses and fracturing, which weakens the kimberlite. The rapid evaporation of water and the high pressures generated within pores may also contribute significantly to fracturing and this decreases the competency of the kimberlites.

Figure 1 shows the energy consumption requirements for the De Beers' microwave treated kimberlite (2 kWh/t) and the reference kimberlites after crushing in a jaw crusher, cone crusher, and high-pressure grinding rolls (HPGR). Significant reductions in energy consumption were achieved, with 41.81% in the jaw crusher, 4.53% in the cone crusher, and 17.66% in the HPGR.

Microwave Treatment and Dense Media Separation (DMS)

Microwave treatment of the Jericho and the De Beers samples resulted in average reductions in the DMS yield of 0.2% and 1.8%, respectively. This was attributed to the improved liberation, which results in less misplaced material in the DMS (between the sinks and the floats) and lower yields.

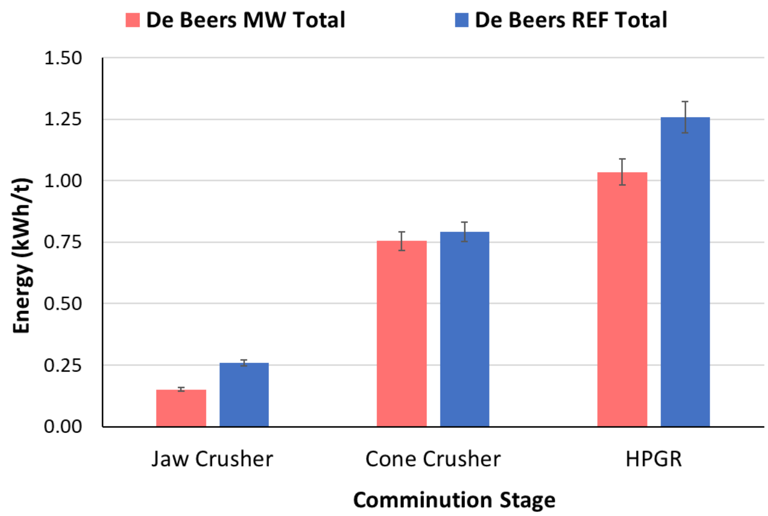

Figure 1: Comminution energy consumptions of the De Beers' microwave treated and reference samples.

Microwave Treatment and Settling

It was found that the particle size distribution (PSD) of the -1 mm size fraction was coarser for the microwave treated kimberlite as compared to the reference kimberlite, specifically for the fine processed kimberlites (<200 μm). Consequently, the settling rate for the microwave treated samples was slightly higher than the reference samples. This was possibly the result of the reduction in comminution energy. A coarser tailings product is easier to settle, requires less flocculant and a smaller thickener unit resulting in less OPEX and CAPEX.

Conclusions and Recommendations

High-power microwave treatment of kimberlites significantly enhanced the comminution efficiency (a total of 15.86%) and improved the mineral liberation. Of particular significance in this approach, is the potential for reduced diamond damage losses that are typically incurred during the comminution process. This could preserve their market value and potentially increasing the revenue (by millions of dollars annually).

It is recommended to install a full-scale demonstration unit at a mine site in order to evaluate the practical benefits and operational impacts of microwave treatment. Ongoing research should aim to optimize the microwave treatment parameters in preparation for the commercialization of this technology.

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