ENERGY POTENTIAL OF MICROWAVE HEATING: PRIOR TO AND IN LEACHING OF LOW GRADE KURU CASSITERIE ORE IN JOS, NIGERIA

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Abstract

The economic potential of dielectric pre-heating of cassiterite ore prior to its leaching was investigated. The recovery of SnO_2 from low grade Cassiterite ore by dielectric pre-treatment was compared with thermal heating method. Increase in SnO_2 recovery by 85 % from the thermal heating method was obtained. The optimum leaching time for the dielectric pre-treated cassiterite was found to be 5 mins while that required for leaching SnO_2 without dielectric pre-heating was 120 mins. The dielectric heating prior to leaching also reduced the processing time by over 90%. The energy consumed for the leaching of cassiterite by the thermal method was found to be about 12.3 times more than that required for the leaching of microwave pre-heated cassiterite. This implied more efficient and energy saving leaching process for the microwave assisted method than the un-assisted one.

Keywords: cassiterite, dielectric, heating, thermal, leaching.

1. Introduction

The distinction between thermal proces microwave processes is in the nature of th source. Over the years, there have continued to be controversies over the effect of microwave on ore minerals. Recently, microwave applications in process metallurgy have been the subject of many studies. Hydrometallurgical extraction of metal from their ore via microwave treatment is potentially lucrative [Onyedika et al., 2013; Hua et al., 2002]. A closer look at the mineral processing industry reveals that enormous quantities of valuable materials are wasted because of the physical and chemical constraints preventing the complete separation of values from gangue. Leaching processes have been proposed for the recovery of tin from ores and low-grade concentrates. Several researchers have proposed different processes which described ways where tin bearing minerals were rendered acid soluble by reduction to SnO_2 which were later stabilized by glass formation and the tin were extracted by leaching the glass in sulfuric acid [Ofor, 1994]. The effects of electrical or thermal temperature heating on the dissolution of a Nigerian cassiterite ore by HCl has been examined [Baba et al., 2009; Funtua et al., 1997], where the kinetic study showed that the reaction rates increased with have been reported whereby thermal heating using the conventional heating methods were utilized [Ogwuegbu et al., 2011; Brocchi and Moura, 2008; Aydogan et al., 2005; Al-Harahsheh and Kingman, 2007]. However, microwave heating has been applied on certain ore minerals to favor leaching for the recovery of several sulfides and oxides and these studies have established the advantage of dielectric irradiation in mineral extraction over the conventional thermal heat. It has been reported also that microwave energy have positive effects on the kinetics of hydrometallurgical extraction processes as supported by recent evidence of increased leaching rate of metals from their ores on the application of microwave technology [Quigyun et al., 2013; Turkmen and Kaya, 2010; Vorster et al., 2001]. They compared the effects of electrical and microwave heating in the leaching of ores and reported a leaching rate of above 95 % by using microwave heating technology. Therefore, this work evaluates the economic potentials derivable in terms of energies utilized in the leaching of cassiterite ore pre-heated by microwave irradiation..

2. Materials and Method

The experimental sample was cassiterite ore obtained from Kuru in Plateau State, Nigeria. The chemical analysis was performed using inductively coupled plasma – optical emission spectrophotometry. Preliminary leaching experiments were performed to obtain the optimum conditions of temperature, concentration, stirring time and particle size.

2.1 Conventional leaching

5.0 g of cassiterite ore of particle size -212 µm was taken in 250 ml 4 M KOH solution. The mixture was stirred at a constant speed of 500 rpm at different temperatures of between 25^o C and 103^o C for 10 minutes. Each leaching experiment was repeated by varying the simple optimization procedures as reported [Onyedika et al., 2013]. The leaching experiments were repeated five times and the average values taken for the energy calculations. The amount of tin (Sn) in the leached liquor was determined by Inductive Coupled Plasma- Optical Emission Spectrophotometer (ICP-OES). The power rating on the heating plate was 1 kW/hr.

2.2 Leaching of Microwave treated Cassiterite

Binatone microwave system of 2.45 GHz of varying heating power (950 W) was used. 20 g of the bulk cassiterite ore was microwaved for 5 minutes, and then crushed to -212 µm. 5.0 g of the microwave treated now called pre-treated cassiterite ore was used for the leaching experiments. The leaching procedure was the same as that utilized in conventional leaching [Onyedika et al., 2013]. In order to optimize the condition, all the optimum conditions of 4 M KOH, temperature of 85^o C and screen size of –212 µm were maintained. Periodic samples of 5 ml aliquots were drawn for chemical analysis.

2.3 Energy Calculation

The analysis was based on the various energy requirements to obtain the individual optimum yields from the two processes. The electrical power consumed is related to the rate of consumption of the energy during both the microwaving of the ore and the leaching process under the conventional method using hot plates. The power rates were calculated from the instrument ratings. The total energies were also derived from power rate multiplied by the optimum time. The energy is calculated from equation;

$$E = \sum_{i=1}^{i=7} p \times t \qquad (1)$$

Where E is the energy utilized in the various processes, p is the power rating of heating mantle or microwave machine, and t is the optimum time obtained from the experimental process. P_T and P_m represents power rating of the thermal heating mantle and power rating of the Binatone microwave system respectively. t_T and t_m are the time taken for the thermal and microwave processes respectively.

3. Results and Discussion

3.1 Chemical Analysis of the Ore

Table 1 is the chemical analysis of the cassiterite ore. The result shows Sn (28 %), Si (5.5 %), Fe (5.16), Mn (0.31 %), Nb (2.53 %), Ti (3.51 %) Al (2.48 %0 and Y (1.06 %). Other trace elements found include U, Ce, K, Na, and Ca. SEM-EDS and XRD analyses of the cassiterite showed the mineralogical components to be mainly cassiterite and quartz with minor presence of ilmenite, almandine, monazite and zircon as reported elsewhere [6].

Table 1: The chemical analysis of Kuru cassiterite ore using ICP-OES

Element	Sn	Si	Fe	Mn	Nb	Ti	Al	Y
% composition	28	5.5	5.16	0.31	2.53	3.51	2.48	1.06

3.2 Effect of microwave heating on ore temperature

Thermo-graphic (temperature profile) representation of cassiterite ore is shown in figure 1. This shows the heating temperature profile of cassiterite with time. The time for maximum temperature was also shown to be within 5 minutes.

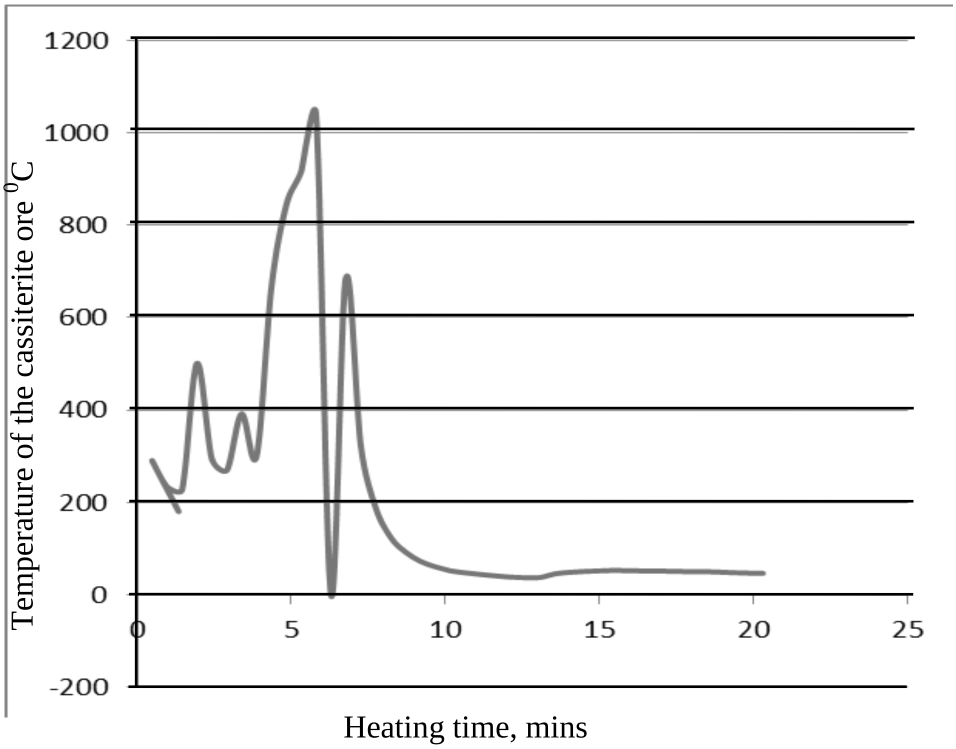

Figure 1: Temperature profile of Kuru cassiterite ore at microwave condition of 950W, 2.45 GHz.

It is suggested that in the initial period of irradiation, microwaves would heat the cassiterite sample from room temperature to temperatures over 1000^0 C and hence promote the twisting of bonds due to polarization in the O-Sn–O, Fe-O and Ti–O molecules found in the ore. Also due to differences in the vibrational energies caused by the irradiation, the internal and external compositions would experience different heating energy and causes frictions. This frictional force then leads to differential stresses at the grain boundaries resulting to cracks within the ore bodies [12]. At this time, crushing will help to liberate and expose the different minerals to KOH attack [13]. Further increase in temperature beyond those for cracking as a result of prolonged irradiation, would cause the bonds in Sn–O, Fe-O and Ti–O to break, leading to the formation of fused O–(Sn–Fe–T)-O_x complexes, which would prevent certain reactions with the various mineral components.

3.3 Leaching of microwave -treated Cassiterite ore vs the leaching of the untreated ore.

Figure 2 is graphical representation of the result of the conventional leaching of cassiterite. It shows that at optimum conditions of temperature, 85^o C and concentration of 4 MKOH solution, the quantity of Sn obtained was 52 % at final operating time of 120 minutes. This indicates a very slow reaction process between the Sn and the KOH solution.

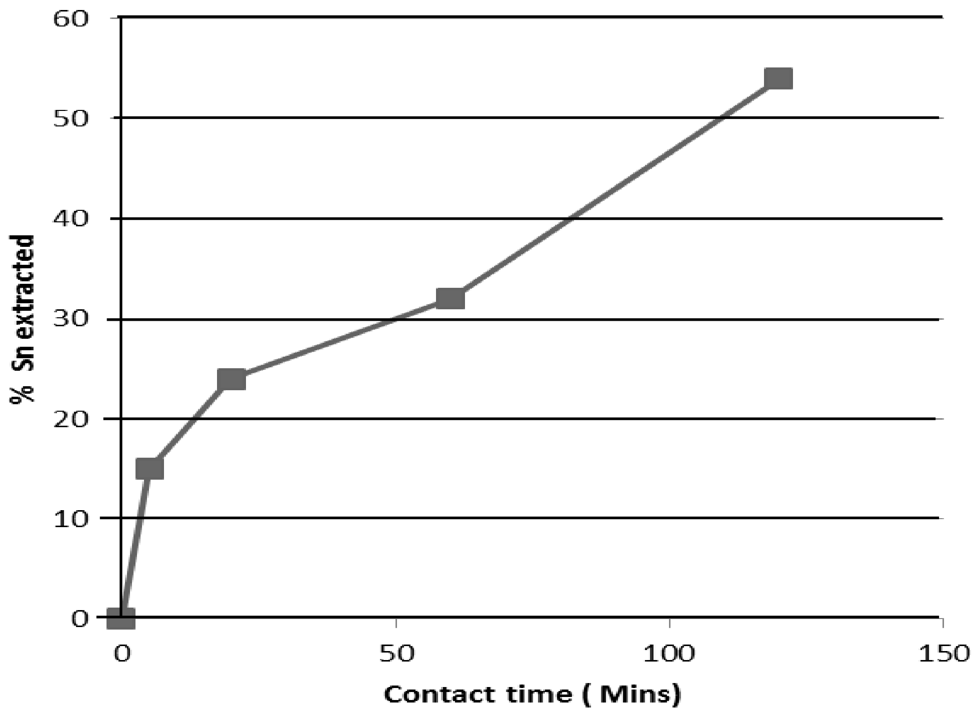

Figure 2: Plot of the conventional leaching cassiterite ore. (Experimental conditions: particle size, -212 µm; agitation speed, 500 rpm; Temperature, 85^{o} C)

Figure 3 is the graphical representation of the result of leaching of microwave treated cassiterite ore under different leaching times. It was observed that the extraction of Sn was high within the first 5 minutes of leaching. A progressive increase in Sn extraction was also observed as time increases from zero to 5 minutes. At 5 mins, about 88 % Sn was obtained. A gradual decrease in the amount of Sn in the solution was observed as time increases. This decrease in Sn yield as leaching time increases may be as a result of co-precipitation of FeOOH, Ti.OH and Sn-(OH)2 in the solution.

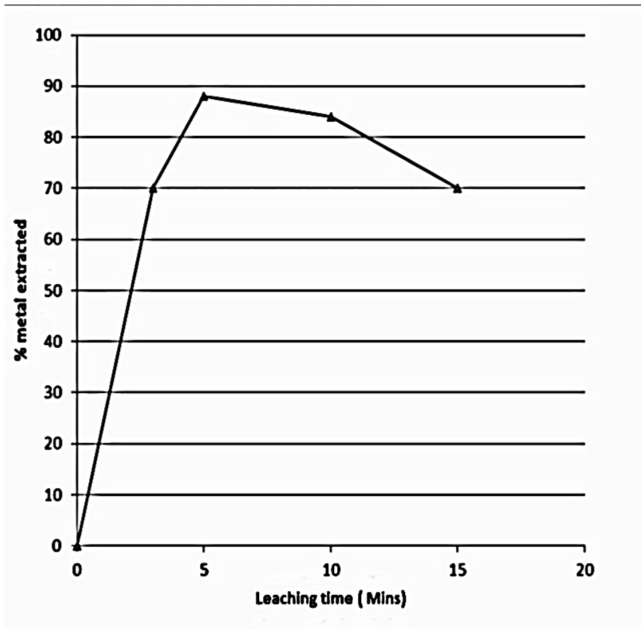

Figure 3 Plot of leaching of microwave treated cassiterite prior to leaching experiment (time; 5 mins, particle size, -212 µm; conc., 4M KOH; Temp., 85^{o} C)

3.4 Economic Analysis of the process

The power rate for the thermal heating mantle was 1.0 kW while the Binatone microwave systemwas 950W;

Energy calculations for the economic analysis of the processes were performed by utilizing the power as in equation 1simplified as:

$$P = \frac{E}{t} \qquad 2$$

E_T is the represents the energy consumed in the thermal heating process; P_T is the power rating for the heating mantle used (1.0 kW); t_T is the optimum time for the process(120 mins),

Energy consumed during leaching of un-microwaved cassiterite ore at optimum time is given by

$$E_T = P_T.\, t_T \quad 3$$

$$= \frac{\mathbf{1\ kw\ .120\ mins}}{\mathbf{60\ mins}} = 2\ kw - hr$$

E_T = the energy for thermal leaching of the microwaved cassiterite ore is 2 kW.

Then energy utilized during microwave treatment of the cassiterite ore is given by;

$$E_M = P_M\ .\ t_M \qquad 4$$

E_M represents the overall energy consumed during the microwave processes; P_M and t_M are the power rating for Binatone microwave (950 W) and time for optimum heat and leach respectively.

E_M is also equal to $E_{M1} + E_{M2}$

E_{M1} is the microwave energy utilized to achieve maximum cracking cassiterite ore by raising ore temperature above 1000 ^{o} C.

$$\frac{\mathbf{0.95\ kw\ .5\ mins}}{\mathbf{60\ mins}} = 0.079\ kw - hr$$

Also, E_{M2} energy utilized during optimum leaching of the microwave treated ore in 5 mins is given by;

$$E_{M2} = \frac{1\ kw\ .5\ mins}{60\ mins} = 0.0833\ Kw - hr$$

Then, E_M becomes (0.079 + 0.0833) *Kw-hr*

$$\text{Ratio of energy consumption} = \frac{E}{(E_{M1} + E_{M2})}$$

$$= \frac{2\ Kw-hr}{0.079+0.0833 Kw-hr}$$

$$=12.3$$

Comparatively, the energy requirement for the microwave assisted beneficiation process is 12.3 times less than the energy utilized for the conventional thermal leaching process. That is to say, that microwave assisted leaching of the cassiterite ore is 12.3 times more energy saving than the conventional process. Notably, the SnO_2 recovery from the microwave assisted process was 53% higher than that obtained from the conventional thermal method, which also adds enormous value to the entire process. It is therefore stated that the economic benefit of microwave treatment of cassiterite ore before leaching have not only led to reduction in leaching energy but also has given rise to increase in the amount of recovery and grade of SnO_2 obtained.

4. Conclusion

The use of microwave pretreatment of cassiterite ore prior to leaching caused improvement in SnO_2 recovery of 85% as compared to that of the thermal method. In terms of selectivity, microwave assisted leaching using 4 M KOH yielded SnO_2 of 52 % in 5 minutes whereas the thermal leaching gave 28% of SnO_2 in 120 minutes which represents about 97% reduction in the processing time. This indicates that the mineralogy of cassiterite ore components was affected by microwave irradiation; that the optimum exposure of cassiterite to microwave heating for utilization in the KOH leaching process was 5 minutes; and that the energy requirement for the microwave assisted beneficiation process of the cassiterite was 12.3 times more energy saving than the untreated cassiterite prior to leaching. Hence, microwave pretreatment of low grade cassiterite ore prior to leaching is of great economic potential.

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