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Enhancing mineral liberation of a Canadian rare earth ore with microwave pretreatment☆

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ABSTRACT

Liberation, as an attribute of mineralogy characteristic, whose impacts on finely disseminated Canadian rare earth ore was studied with microwave pretreatment. Samples of a light rare earth ore along with mostly ankerite and biotite as dominant gangue minerals as well as bastnaesite, strontianite and goethite as dominated minerals were exposed to further comminution by ball mill and microwave pretreatment fragmentation. Mineralogical characteristics were analyzed by using a mineral liberation analyzer (MLA). The results indicated that tight association mutually penetrates among dominated minerals in the range size of $-300+212$ μm and $-212+150$ μm and gangue minerals in the form of adjacent type, fine vein type, shell type and packing type. Temperature in the ore samples pre-treated by microwave can rapidly rise to 250 °C with microwave power of 0–1.5 kW and microwave time of 0–2 min. Applying the microwave pretreatment merely reduces the hardness of the ore causing the fracture of rare earth ore, but this does not transform or change the original mineralogy characteristics of the ore samples. On the basis of above study, the liberation value of bastnaesite, strontianite and goethite with microwave pretreatment is greater than with conventional comminution when the liberation class is above 75%. The distribution of particle size of rare earth ore samples is better with microwave pretreatment than with conventional comminution for particle size of 7.4×10^{-5} m. With microwave pretreatment, the theoretical grade–recovery of bastnaesite, strontianite and goethite in the rare earth ore attains better results than with conventional comminution at a given grade.

1. Introduction

Mineralogy concentrates on investigating morphology, chemical composition, physical properties, impurities and internal mineral structure of ore.[1] The rare earth ore is analyzed by applying the mineral liberation analyzer (MLA) that involves BSE image analysis and X-ray mineral identification to automatically quantitatively analyze mineral characterization of the ore in most bene ficiation.[2] The information on mineralogical parameters of ore was achieved to provide the theoretical basis for the downstream of mineral processing.[3]

As is known, approximately 70% of the rare earth production might be from bastnaesite which is proven to have an enormous reserve in the world.[4–7] Despite its great reserves, yield of rare earth minerals will not satisfy market demands because of the limitation of processing technology and the gradually reduced reserve of the rare earth ores that can be enriched or separated readily.[8] Therefore, the large majority of low grade rare earth ores have to be utilized. Also new technologies of processing rare earth ores should be improved as innovatively as possible.[9]

Conventional comminution, for fragmentation through grinding, has continued to need a high level of energy consumption. As an important sector of processing technology, this constraints future development of the mineral industry chain and compromises the profitability of beneficiation.[10] Hence, the consumption of energy has to be declined, and novel ways of energy saving must be urgently developed in the areas of physical technologies such as piston-die compression,[11] high voltage pulses electricity[12] and microwave heating[13] as the auxiliary force to be applied to the ore to improve the ore comminution efficiency. Microwave is a new resource that is safe, environmentally friendly and abundant. It has some

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characteristic of low energy consumption, and there have been the process duration improvements, rapid and controlled heating, peculiar temperature and selectivity of energy deposition.[14,15] In the view of the above mentioned advantages, microwave have already been applied to many fields such as agriculture, petroleum and chemical engineering and so on. Especially in the area of mineral processing, the minerals in the ore adsorb microwave, which improves the efficiency in the beneficiation. Either Amankwah et al.[16] or Kingman et al.[17] researched the grinding energy needed of ore pretreatment with microwave, the results showed the microwave heating could reduce the energy consumption needed for grinding. The research on the effect of liberation on carbonate ore from South Africa with microwave was carried out by Scott et al.,[18] the results showed that microwave can improve the liberation of ores. Hence, the microwave pretreatment has emerged as an alternative to current mechanical comminution techniques.[19] The method on microwave heating to ore is that it is pre-treated by microwave and grinding.[20] Ore in the coarser size is capable of achieving the intergranular breakage with microwave pretreatment from local difference in temperature.[21] Moreover, fracture is generated along the grain boundary causing the liberation increment.[22,23]

Rare earth samples selected from Canada, are of low grade ore, which have complicated structure, are of various species, gray and high hardness in physical properties. They comprise bastnaesite, strontianite, and goethite as main minerals as well as ankerite and biotite as dominant gangue minerals. The current processing techniques to recover rare earths are mainly through crushing and grinding processing methods, which makes the treatment process simple and easy to achieve in the industry. However, rare earth ores from Canada, are of low grade, are of complex mineral composition and are high in hardness. This leads to a large loss of energy consumption, consequently, increasing greatly in the cost of rare earth mineral processing.

We studied mineralogy characteristic using MLA, X-ray diffraction (XRD), X-ray fluorescence (XRF) and scanning electronic microscopy (SEM). We compared the effects of rare earth ore with microwave pretreatment and conventional comminution on the ore samples from Canada in this research, which expects to realize the occurrence character, varieties of rare earth ore, embedded character, packed relationship, particle size distribution, occurrence character of other valuable elements in the rare earth ore as well as kinds and content of gangue minerals. Mineralogy characteristic, as a theoretic basis, provides a standard parameter for scientific economical evaluation, the technique of reasonable beneficiation. The pre-heating microwave technique can be applied to exploiting rare earth ore in the area of Canada. This reasonably priced beneficiation and recovery method of valuable elements will greatly benefit the industry.

2. Materials

2.1. Feed materials

The rare earth ore samples selected for this study were a dominant rare earth elements-bearing ore, which came from Canada. The feed size of rare earth ores was crushed to <1 mm for all the test work as the precision of the MLA was optimum around 500 μm. The chemical component of rare earth samples was analyzed by XRF as shown in Table 1. Table 1 lists the rare earth samples that primarily contained Ce_2O_3, La_2O_3, SrO and a good deal of Fe-bearing elements. The varieties and content of minerals could be bastnaesite, strontianite and goethite in the rare earth ore reported by MLA in Table 2. The rare earth ores were abundant in bastnaesite of 8.35% with a tiny amount of monazite as dominant purpose minerals, strontianite of 3.24% as well as goethite of 25.76% must be regarded as the valuable minerals. The gangue minerals occurred as ankerite, biotite and ferrosilite and so forth.

The ability of minerals to absorb microwave in the rare earth ore is presented in Table 3. The listed strontianite and biotite were not capable of absorbing the microwave because of existing carbonate. Bastnaesite, goethite, ankerite and ferrosilite had weak microwave absorption ability. Pyrite has strong microwave absorption ability because of Fe-bearing elements and sulfide.[24]

2.2. Characteristics

The rare earth samples, obtained from the microwave chamber, were used for quantifying the phase transformation, the intergrowth phase was analyzed quantitatively by XRD ($2\theta = 0–100°$) in the rare earth samples. The micro-structures of minerals are shown with microwave pretreatment and then without microwave pretreatment by SEM. Their mineralogy attributes were analyzed using MLA.

2.3. Methods

2.3.1. Regular treatment

The rare earth samples were pre-treated with ball mill (EMERSON Model: S60AAW-6118 in the USA) so that 10 g of the grain size of <1 mm particles were obtained. The particles were placed in process vessel, which was filled with distilled water. The process attained the grinding concentration of 60% while setting the grinding time to 75 s. After ground, the rare earth slurry was filtered through Separatory Funnel with acetone washing preventing the agglomerates. Finally, the rare earth ores were dried with a vacuum oven at a temperature of 70 °C.

2.3.2. Microwave treatment

The quantity of 100 g rare earth samples below the particle size of <1 mm were fed to a quartz crucible with microwave pretreatment and they then placed in microwave oven, with the frequency of 2.4 GHz and the power adjusted in the range of 0–9 kW. The rare earth ore was pre-treated with the microwave power of 1.5 kW and the microwave heating time of 2 min. Afterward, the rare earth samples pre-treated were ground by ball mill with water in the same procedure as above.

2.4. Mineral liberation analyzer (MLA)

The MLA employs various measurement methods to analyze the grain sizes, liberation, intergrowth relationship, packed relationship, and associated relationship of ore. It utilizes backscattered electron to qualitatively analyze the distinct phase boundary of particles, combined with energy dispersive X-ray analysis (EDX) to analyze elemental composition of minerals to determine the varieties of rare earth minerals. MLA can perform accurate and precise grain pattern and quantitative data results. Liberation is capable of

Table 1
Primary chemical element analysis results of rare earth ore by XRF.

Component	Ce_2O_3	La_2O_3	SrO	Fe_2O_3	CaO	BaO	MgO	MnO	Al_2O_3	SiO_2	TiO_2	SO_2	K_2O	Nb_2O_5
Content (wt%)	2.67	1.21	4.41	45.08	26.97	3.4	3.54	4.98	0.66	4.98	0.42	0.3	1	0.38