



Magnetic separation of serpentinite mining residue as a precursor to mineral carbonation



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ABSTRACT

Chrysotile mining in Québec has produced about 2 Gt of serpentinite residue. The present study investigates the magnetic separation of serpentinite residue from Québec to produce a non-magnetic feed stock for mineral carbonation. This study also scrutinizes the quality of the magnetic fraction recovered for use as a source of iron ore. The optimum conditions of magnetic separation were obtained with multiple pass approaches; at 40% initial pulp density and 7.5×10^{-3} tesla (T) magnetic intensity with a mean particle size of 75 μm . The process removed about 71% of the iron impurities from the initial feed. The final non-magnetic fraction is rich in magnesium silicates with a low iron oxide concentration of 3.4%. The concentrations of iron oxide and silica in the final recovered magnetic fraction are 79% and 8.6%, respectively.

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1. Introduction

Historically, there have been many chrysotile mines in Québec, but, in recent years, almost all the chrysotile mining activity in the province has been abandoned. Serpentinite Mining Residue (SMR) is the waste generated after chrysotile fiber extraction from the ore. Over the last decades, around 2 Gt of SMR has been accumulated from this mining activity. The main constituents of the residue are lizardite, antigorite, brucite and iron oxides. Magnetic particles such as magnetite are the common associated phase with serpentine formation (Gahlan et al., 2006; Lackner et al., 2008). Also, studies have already reported the presence of magnetite-associated serpentine (lizardite and chrysotile) in the chrysotile mine ores of Québec (Cogulu and Laurent, 1984; O'Hanley and Dyar, 1993; Pronost et al., 2011; Stroink et al., 1985). Since the residues from these mines are also rich in magnesium silicates, they can be a good candidate material for mineral carbonation (IPCC, 2005; O'Connor et al., 2001b). Mineral carbonation is one of the emerging carbon capture and storage technologies in which CO_2 reacts with divalent cations (Ca^{2+} or Mg^{2+}) of natural minerals to form metal carbonates. This carbonation option is promising due to the formation of environmentally benign and geologically stable metal carbonates (IPCC, 2005). However, in an oxidizing atmosphere, the presence of magnetic material, especially oxides of iron, will negatively affect mineral carbonation by forming a passive layer of hematite. This passive layer hinders the diffusion of CO_2 into the reaction site and thus slows down carbonation (Fauth et al., 2000). Therefore, the separation of

magnetic particles from the mineral feedstock has been recommended before mineral carbonation (Huijgen and Comans, 2003).

Gravity and magnetic separation are the commonly used techniques for the separation of magnetic particles from minerals (Kelland, 1973). Gravity separation benefits from the difference in density between the magnetic and non-magnetic fractions, whereas, the magnetic separation technique exploits the magnetic properties of the material (Frangiskos and Gambopoulos, 1975). Magnetic separation was adopted for the present study to obtain a maximum separation of the iron oxide impurity from the feed. The magnetic separation can be either wet or dry, with low or high-energy intensity, depending upon the magnetic susceptibility of the materials to be separated (Bronkala, 1978). The separation process is simple, because, in most cases, conventional grinding before the magnetic separation is sufficient to improve the separation rather than any chemical addition (Environmental Canada, 2009). The technique is commonly used either for the purification of the feed material or the concentration of the magnetic components (Bronkala, 1978; Oberteuffer, 1974). Magnetic separation studies have been extensively carried out and reported for the concentration or purification of chrysotile asbestos ore (Martinez, 1967; Novak, 1953). The present study follows the same approach, with the alternate objective being to produce a better mineral carbonation feedstock from SMR by removing the magnetic impurities.

This is a laboratory scale study with SMR collected from one of the chrysotile mines in Québec. The efficiency of magnetic separation is determined based on the weight recovery of non-magnetic fraction, recovery (the ratio of iron oxide in the magnetic fraction to that in the feed) and the grade of the magnetic fraction (percentage of iron oxide in this fraction) (Bronkala, 1978; Oberteuffer, 1974). The prime goal is to produce a non-magnetic fraction with the minimum quantity of

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iron impurities. This will reduce the chance of iron impurities in final mineral carbonation products and provide a value added magnetic by-product at downstream (O'Connor et al., 2001a, 2001c).

2. Materials and methods

The SMR used for the present study was collected from Black Lake mine (Thetford Mines, QC, Canada). The raw SMR was then ground in a shatter-box (BLEULER-NAEF shatter-box, model M04/06) to liberate more iron bearing components such as magnetite (Kelland, 1973; Lackner et al., 2008). The particle size distribution of the ground material was determined by laser scattered particle size analyzer (HORIBA LA-950). The optimization of the initial pulp density and magnetic intensity was carried out with a single ground raw SMR of mean particle size 412 μm . Further, to understand the influence of size reduction, double ground SMR of mean particle size 75 μm was also used. The size distribution curves for both single and double ground SMR are given in Fig. 1. Magnetic separation tests were also conducted in multiple passes (as shown in Fig. 2a and b) to improve the separation efficiency.

2.1. Experimental set-up

The set-up used for the present study was Wet High Intensity Magnetic Separator (WHIMS -CARPCO model serial no. 221-02). Fig. 3 represents the schematic of magnetic separation. Wet magnetic separation is the commonly used technique for mineral processing (Kelland, 1973; Oberteuffer, 1974) and is suitable for the recovery of fine ferro and diamagnetic mineral (Shao et al., 1996). The quantity of magnetic particle in SMR is comparatively lower; thus a wet separation will provide better separation than dry. The high intensity separator was chosen to have a wide range of magnetic intensity. The device consists of a separation canister packed with a strong ferromagnetic iron ball matrix. An adjustable magnetic field is applied by means of a magnetic coil, and the magnetic field develops on the ball matrix, which helps to trap the magnetic particles. The ball matrix size and sample weight was selected by referring to the operating manual of the device. The

magnetically attracted fraction adhered onto the ball matrix, and the non-attracted fraction was collected downstream. The intensity of the magnetic field developed between the coils was measured by means of a Gauss/Tesla meter (F.W. Bell- model 5080).

2.2. Experimental procedure

Approximately 50 g of ground SMR was made into slurry of desired initial pulp density with distilled water in a 1 L beaker. The prepared slurry was stirred for 1 min with a spatula to give uniform concentration. After passage through magnetic separator, the non-magnetic fraction and fluid were collected downstream. A jet of distilled water was used to ensure that the non-magnetic particles were completely separated from the ball matrix. The trapped magnetic fraction was recovered in distilled water from the ball matrix after shutting down the applied magnetic field. The recovered fractions were filtered and dried at 60 $^{\circ}\text{C}$.

The efficiency of magnetic separation was assessed by considering three response variables:

- a) the mass recovery of the non-magnetic and magnetic fractions (%) (Eq. (1)):

$$\text{mass recovery}(\%) = (\text{mass of fraction} / \text{mass of feed}) \times 100 \quad (1)$$

- b) the iron oxide recovery within the magnetic fraction (Eq. (2)):

$$\begin{aligned} \text{Iron oxide recovery}(\%) & \quad (2) \\ & = \left(\text{concentration of iron oxide in magnetic fraction} \right. \\ & \quad \times \left. \text{mass recovery of magnetic fraction} / \text{concentration of iron oxide in feed} \right) \\ & \quad \times 100 \end{aligned}$$

- c) the grade of the magnetic fraction, determined by comparing the concentrations (in %) of oxides of iron, magnesium and silicon obtained from ICP-AES analysis (the higher the percentage of iron oxide, the higher the grade quality).

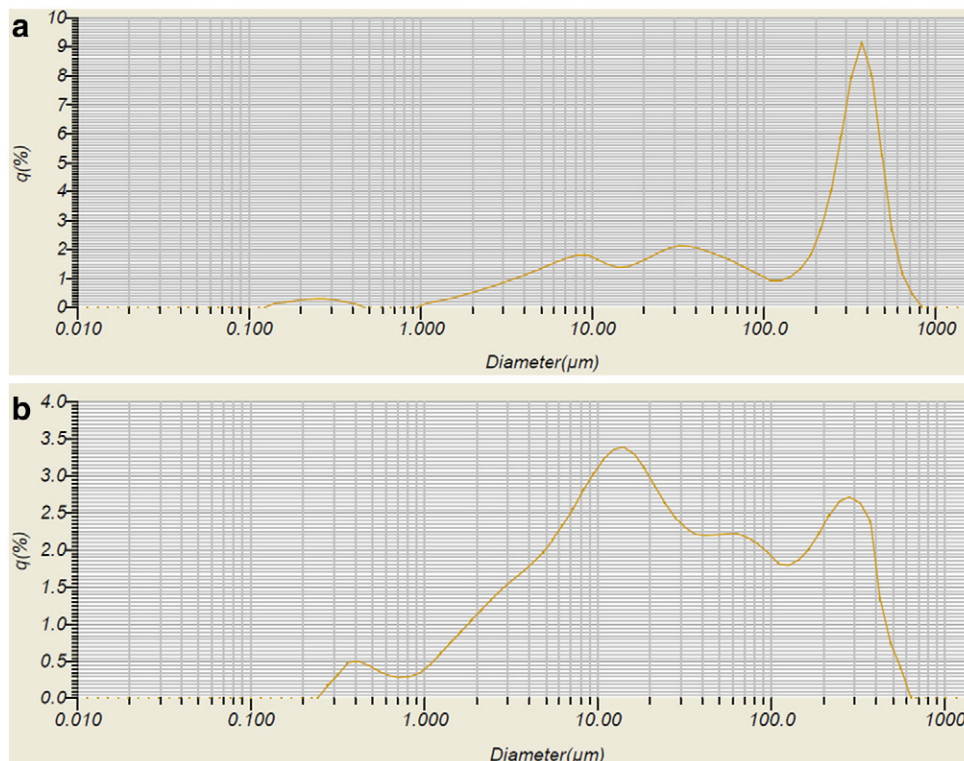


Fig. 1. Particle size distribution curve from laser analyzer for (a) single and (b) double ground SMR.

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