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Life-cycle carbon footprint analysis of magnesia products

Jing An*, Xiangxin Xue

Shool of Metallurgy, Liaoning Province Key Laboratory of Metallurgical Resources Recycling Science, Northeastern University, Shenyang, 110819, Liaoning, China

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ABSTRACT

Liaoning Province in China contains significant magnesite deposits and thus has become the country's largest production and export base for the magnesia raw materials and refractories. Unfortunately, the processing of such materials and refractories contributes significantly to the carbon emissions of the magnesite industry. In the present study, the carbon footprints associated with magnesia production processes were analyzed and compared using the life cycle assessment method of cradle-to-gate in order to provide a theoretical basis for improving the production processes, optimizing the product structure and for the formulation of energy conservation and emission reduction measures. In order to show the results against changes in key parameters, the sensitivity analysis was carried out. The results show that the total carbon footprints of light calcined magnesia and fused magnesia are the lowest and highest, respectively. In addition, one-step calcination method with the material of magnesite was found to be cleaner than the two-step calcination method with the material of light calcined magnesia. The direct carbon footprints resulting from the magnesite decomposition processes in the making of all magnesia products are very similar, while the emissions resulting from fuel combustion to produce sintered magnesia are high, especially in the case of two-step calcination. To reduce the total carbon footprints of light calcined magnesia and sintered magnesia, emphasis should be placed on the direct carbon footprints resulting from the production processes. In the case of fused magnesia, the key to reducing the carbon footprint is to decrease electricity consumption by improving the thermal efficiency of heating furnaces. CO_2 emissions from the magnesite decomposition process can best be managed through capture and reuse. Overall, it is recommended that various enterprises should take action to implement CO_2 recycling.

1. Introduction

China is rich in magnesite deposits and, in fact, holds the world's largest reserves of this mineral—35.64×10^8 t—accounting for 28.7% of the total worldwide deposits (Quan et al., 2008). The majority of this magnesite, 85% of the total Chinese deposits, is found in Liaoning province. In addition, approximately 40% of the magnesite in this location has a MgO content of more than 46% and is located in shallow zones that are readily mined (Quan et al., 2008). Liaoning thus has a long history of magnesite utilization and is well known as the center where the greatest amount of magnesia materials and refractories are produced and exported. At present, nearly 500 companies and 160 thousand employees are associated with the local magnesite industry (Xu, 2013). The output of magnesite ore was 1.6×10^7 t and the output of magnesite-based product was 1.4×10^7 t in Liaoning Province in 2014 (The Association of China Refractories Industry, 2015). It is estimated that the products made by Liaoning's magnesite industry account for more than 90% of the domestic market and 60% of the international market, and the products are exported to the United States, Holland, Japan, South Korea and other countries (Huang, 2015).

The main products of the Liaoning magnesite industry include magnesia, magnesia brick and unshaped refractory products (Quan et al., 2008). The most important primary products and the main raw materials are light calcined magnesia, sintered magnesia and fused magnesia. The total output of this series of magnesia products in 2014 was 8.7×10^6 t, accounting for 63% of the total refractory products (The Association of China Refractories Industry, 2015). Magnesia is produced using reverberatory kilns, shaft kilns and electric furnaces, and so significant quantity of coal, heavy oil and electricity are consumed during the production process, resulting in copious direct or indirect carbon emissions. In addition, magnesite is a carbonate mineral primarily having the chemical composition $MgCO_3$ (Quan et al., 2008), and so a certain amount of CO_2 is

* Corresponding author.
E-mail address: anj@smm.neu.edu.cn (J. An).

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released in the course of ore decomposition. Therefore the series of magnesia products contribute significantly to the magnesite industry carbon emissions, as the most important primary products and the main raw materials to produce other refractory products.

Greenhouse gas emissions are produced from a wide variety of industrial activities. The main emission sources are releases from industrial processes that chemically or physically transform materials (IPCC, 2006a). The global warming caused by GHG emissions has become a focus of worldwide attention. Just before the Copenhagen Climate Change Conference, China made a commitment to the world: by 2020, China's carbon dioxide emission per unit of GDP will have dropped by 40%–45% compared to that in 2005. Thus, many industries are actively pursuing the reduction of carbon emissions. Such emissions can result from various production processes and therefore studying the emissions associated with these processes is a very important component of promoting low carbon development of China.

Some previous studies have focused on the energy consumption and environmental impact of magnesium production and magnesium alloy production with the method of life cycle assessment (LCA) (Tamakrishnan and Koltum, 2004; Kwon et al., 2015; Gao et al., 2009; Du et al., 2010). In China, magnesium is primarily obtained from the smelting of dolomite, while magnesia and magnesia brick are produced with magnesite. Some researchers and enterprises have done many works concerning the energy conservation of the production of magnesia refractory materials, especially the production of fused magnesia (Yuan et al., 2009; Tong, 2010; Jiang, 2011; Tong et al., 2011). But only limited study has been performed concerning the environmental impact of the magnesite industry, including investigations of soil contamination by magnesite dusts (Wu, 2007; Yang et al., 2009), groundwater contamination by magnesite mining (Bajtoš, 2004) and cleaner production of a magnesia refractory material plant (Li et al., 2015b). In recent years some studies concerning GHG emission have been done and they studied the theory and technology of CO_2 recovery from the magnesia production process (Pan, 2010; Zhao et al., 2015). However, the above studies were all conducted from the production process of a single factory. As an efficient tool, LCA has been widely used to evaluate the environmental impacts of various products or processes (Dufour et al., 2009; Burchart-Korol, 2013; Allegrini et al., 2015; Höglmeier et al., 2015). But only fused magnesia process associated with magnesite industry has been assessed and compared using the methodology of LCA (Li et al., 2015a). In their study, moreover, only CO_2 and dust were taken into the consideration of the emissions to air in the inventory of the fused magnesia production stage, while other greenhouse gases were not considered. Related research on other products associate with magnesite industry is almost blank.

There is no waste water produced and the air pollutants are predominant during the production of various magnesia. And that global warming potential resulted from carbon emissions is the most important environmental impact according to the reference (Li et al., 2015a). So the aim of the present study was to analyze and compare the carbon emission characteristics of the various magnesia products with the methodology of cradle-to-gate LCA, so as to provide a theoretical basis for improving the production processes, optimizing the product structure and for the formulation of energy conservation and emission reduction measures of Liaoning's magnesite industry.

2. Materials and methods

The concept of a carbon footprint originated in Britain and was rapidly adopted by academia, nongovernmental organizations and the media. Although this idea was derived from the pre-existing concept of an ecological footprint, the majority of researchers believe that carbon footprint should be expressed in units of mass rather than area (Wiedmann and Minx, 2008; Hammond, 2007). There are also different views concerning the calculation of the carbon footprint. Some contend that such calculations should include solely CO_2 emissions, while others think that the footprint should include all GHGs expressed as their CO_2 equivalents (Druckman and Jackson, 2009; Hertwich and Peters, 2009). Input-output analysis and process analysis are two common methods used to calculate environmental footprint. Tan et al. have done several works with the method of fuzzy input-output (Tan et al., 2012; Aviso et al., 2011). The method of process analysis was used in this study. Life cycle inventory analysis is a key step for the method of process analysis combining LCA, which has been used widely during the carbon footprint calculation of some products (Pattara et al., 2016; Scholz et al., 2015). And this study was conducted based on carbon footprint definition and life cycle framework of ISO (ISO, 2013, 2006).

2.1. System definition

Magnesia can be subdivided into light calcined magnesia, sintered magnesia and fused magnesia. Sintered magnesia, moreover, can be subdivided into ordinary sintered magnesia, middle grade magnesia and high purity magnesia according to its magnesia content. Light calcined magnesia can be used to produce middle grade magnesia, high purity magnesia and fused magnesia and is also an important raw material for the synthesis of many chemical products as well as certain building materials. It is produced from magnesite through calcination, cooling, screening and grinding. At present, calcination in the Liaoning region is generally carried out in reverberatory kilns.

Sintered magnesia is the material used to make magnesia brick as well as unshaped refractory products. Ordinary sintered magnesia is produced from magnesite using a shaft kiln, typically with a volume in the range of 20–50 m^3 and at temperature above 1600 °C. Middle grade magnesia and high purity magnesia are produced via a two-step calcination method. High grade magnesite is initially processed into light calcined magnesia in a reverberatory kiln, after which the light calcined magnesia is processed with a Raymond mill. The resulting powdered light calcined magnesia is pressed and then calcined in a shaft kiln. In the production of middle grade magnesia, light calcined magnesia powder is pressed using semi dry pressing and treated in a coal-fired shaft kiln. In contrast, high grade magnesia is obtained by dry pressing of light calcined magnesia powder followed by treatment in a shaft kiln fueled by heavy oil.

Fused magnesia is composed of large grained crystals and is quite compact. For this reason, it is the best raw material for the production of the magnesia carbon brick used in steel converters, electric furnaces and other devices. The production of fused magnesia can occur through one or two processes. In one method, magnesite or purified magnesite powder is smelted in an arc furnace above 2750 °C. In the other, the magnesite is initially calcined to light calcined magnesia using fossil fuel combustion, after which the resulting light calcined magnesia granules are smelted in an arc furnace.

The complete life cycle for magnesia products include raw materials production, background energy production, magnesia products production, refractory products production, products application, waste products disposal and recycling. The LCA method of cradle-to-gate was applied due to the complexity of the complete life cycle system and the limitation of data. Many studies have also used this method (Nhu et al., 2016; Chan et al., 2015). The corresponding evaluation scope of this study is summarized in Fig. 1. Here, 1 t of magnesia product (it is not 100% pure MgO and