Minerals Engineering 45 (2013) 55–58

Contents lists available at SciVerse ScienceDirect

Minerals Engineering

journal homepage: www.elsevier.com/locate/mineng

A non-invasive technique for sorting of alumina-rich iron ores

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ARTICLE INFO

Article history:
Received 22 August 2012
Accepted 9 December 2012
Available online 27 February 2013

Keywords:
IR thermography
Iron ore
Beneficiation
Ore sorting
Thermal absorptivity

ABSTRACT

This paper describes an Infrared (IR) thermography based technique for sorting of iron ores consisting of alumina-rich particles of relatively low thermal absorptivity as compared to iron-rich particles in the ores. The technique primarily consists of selection of iron ores with Fe compositions ranging from 59 to 69 wt.% and alumina (Al_2O_3) from 0.35 to 8.85 wt.%, crushing the ores up to the particle size range around 10 mm. The iron ore fines are uniformly heated using heat source of wavelength ranging from 10^{-2} to 10^{-6} m for a period of time sufficient to create a difference in infrared emission between the ore particles. The thermal image of the heated ores is captured by IR thermography. The alumina-rich iron ore particles are heated up less as the thermal absorptivity of these ores is less than the ores with high iron content. Thus, the alumina-rich iron ore particles can be identified by observing the temperature profile and/or thermal image of these ores. This technique of ore recognition can be useful in improving the feed quality of iron ore to the blast furnace in iron and steel industries by rejecting the alumina-rich ores through modification in the presently existing processes.

1. Introduction

India has abundant reserves of iron ore which can meet the growing demand of iron and steel industry in the country and also sustain considerable trade. Indian iron ores are rich in iron but usually contain high alumina which reduces the productivity of blast furnace. For an efficient operation of blast furnace, alumina/silica ratio in the feed ore should be less than 1 and alumina present in the ore should be less than 2%. But most of the Indian hematitic iron ores do not satisfy these conditions. The reduction of alumina in blast furnace feed not only increases the productivity but also reduces the rate of coke consumption, slag flowability and increases the digestion of the metal in the blast furnace. For the blast furnace slag to flow freely, it should be above its liquidus temperature. The basicity of the slag expressed as $(CaO + MgO)/(SiO_2 + Al_2O_3)$ determines the slag viscosity above the liquidus and it is progressively lower as the basicity increases. Hence more alumina content naturally increases the viscosity and opposes the slag flowability. The SiO_2 and Al_2O_3, which accept oxygen and form anion complexes in melts are said to be acidic oxides; and those such as CaO, MgO, and FeO which break down the anion complexes are called the basic oxides. With the entry of oxygen ions from metal oxides breaks down the Si–O bonds and Al–O bonds. Al^{3+} can replace Si^{4+} in a slag system of $CaO–MgO–Al_2O_3–SiO_2$. Also, alumina and silica are not equivalent on molar basis in their effect although both increase the viscosity of the melt. Thus alumina: silica ratio <1 is desired to maintain proper basicity of the slag (Singh et al., 2004).

Indian iron ores, in general, contain more than 2% alumina (Pradip, 2006) and hence beneficiation is necessary to reduce the same in the ore before feeding to the blast furnace. Alumina bearing minerals are more or less embedded along with the iron oxide minerals and in general the liberation takes place in the fine size ranges (Singh et al., 2004). Though iron ores are being beneficiated worldwide using several techniques such as spirals, floatex density separators, jigs, multi-gravity separator, low and high intensity magnetic separator, conventional as well as column flotation, selective dispersion–flocculation, in India, the present scheme of iron ore beneficiation and the reduction of alumina broadly comprise crushing the ore to the required size followed by scrubbing and/or wet screening and classification to separate slimes from fines. These techniques have their own inherent limitations and are not effective to reduce alumina below particular limits (Rao et al., 2000). Hence, in order to enhance the competitive edge of Indian iron and steel industry, an efficient alumina removal technology for Indian iron ores is essential.

Ore sorting has been used in mineral processing since the ancient age, with hand sorting being one of the earliest methods of minerals processing. Automatic sensor-based ore sorting (Salter and Wyatt, 1991; De Jong et al., 2004) is a major breakthrough in minerals technology and upfront beneficiation resulting in substantial reduction in downstream costs, improvement of ore quality and exploitation of low grade ore reserves. There are several sensor-based technologies that are found to be potentially useful for sorting applications which include optical sensors,

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http://dx.doi.org/10.1016/j.mineng.2012.12.004

electro-magnetic, infrared, X-ray and laser based sensors (Riedel and Wotruba, 2004). By including a sensor-based sorting system in the mineral beneficiation process would provide numerous benefits in terms of not spending energy on crushing, grinding and treating the barren raw material.

Most of the sorter applications in the mineral industry are the ones with the optical cameras. In general, optical cameras are useful in ore classification only when there is a significant difference in reflection, colour, shape or texture of the ores (Kattentidt et al., 2003). Optical sensors have been used for sorting of gold-bearing rocks in Kloof Gold Mines in South Africa at a gold recovery rate of 70% (Von Ketelhodt, 2009). A laser assisted sorting of limestone is being attempted in Fraunhofer Institute of Laser Technology, Germany for separation of dolomite from limestone on the basis of their MgO content. Sorting according to defined limits has resulted in a classification of 79 wt.% of limestone and 13 wt.% dolomite (Begemann et al., 2010). In 2005, a newly developed DE-XRT sorter has been introduced in the market by CommoDas GmbH of Germany. It is characterised by a sensor resolution of 0.8 mm, effective width up to 1.8 meter and conveying speed of 2–4 m/s. This allows automatic sorting of larger volumes of coal, typically in the order of 5–25 t/h coal per device, or 10–50 t/h mine reject (Von Ketelhodt and Bergmann, 2010). Recently, ORETOME Limited in Ontario, Canada has also started exploring the possibility of separating rocks containing high sulphide and carbonaceous matter by identifying through infrared sensors the radiant heat emitted by these rocks on microwave heating (Weert and Kondos, 2007). The application of electromagnetic techniques for deshaling of coal has been studied at Delft University of Technology, Netherlands in 2003. The efficiency with which an electromagnetic sensor array is able to distinguish density as well as ash content of coal and shale mixtures has been determined experimentally (De Jong et al., 2003). However, to our knowledge, sensor-based sorting techniques have not yet been explored to beneficiate iron ores. Iron ore being the major raw material for the iron and steel industries, presents a unique opportunity to apply sensor-based sorting techniques to improve its quality as these techniques can be applied both in dry as well as wet beneficiation. Therefore, the prime objective of this paper is to show the applicability of IR thermography based technique for identification and rejection of alumina-rich ores taking into consideration the difference in thermal absorptivity of the ores. Further exploration and implementation of this technique in the steel plant will improve the feed quality of blast furnace which in turn will improve the productivity of steel plants.

2. Principles of infrared thermography in mineral beneficiation

Infrared thermal imaging technique converts the invisible radiation pattern of an object into visible images for feature extraction and analysis. The system consists of a thermal camera with detectors, a signal processing unit and an image acquisition system. The thermal imaging technique is being widely used in various fields such as predictive maintenance, non-destructive evaluation, military reconnaissance, medical imaging (Speakman and Ward, 1998). IR based thermal imaging technique has a potential application in automated sorting of ores for mineral beneficiation.

All objects that have surface temperatures above absolute zero emit electromagnetic radiation. When radiation is incident on an object, portion of it is transmitted, some portion absorbed, and some reflected. For thermal equilibrium the total flux (measured in watts) must be constant and is defined as,

$$\Phi_{\mathrm{Transmitted}} + \Phi_{\mathrm{Absorbed}} + \Phi_{\mathrm{Reflected}} = \Phi_{\mathrm{Incident}} \tag{1}$$

For real surfaces, during thermal equilibrium the transmissivity of solid surfaces is equal to zero, therefore (1) can be rewritten as

$$\Phi_{\mathrm{Absorbed}} + \Phi_{\mathrm{Reflected}} = \Phi_{\mathrm{Incident}} \tag{2}$$

In case of ores and minerals in unpolished condition, the amount of heat reflected is very low; hence most of the heat incident on the ores is absorbed by them. The heat radiated by the uniformly heated ores is captured and displayed as thermal image through IR thermography. The ores having low thermal absorptivity are heated up less and can be identified from the thermal images of the ore specimens (Thompson and Dwyer, 1968).

3. Infrared thermography of iron ores

3.1. Methodology

The process for rapid identification and rejection of high alumina iron ore fines consists of selection of iron ores with Fe compositions ranging from 59 to 69 wt.% and alumina (Al_2O_3) from 0.5 to 8.85 wt.% and crushing the ores up to the particle size range around 10 mm. Since this is the first attempt for proof of concept, experiments have been tried with ~10 mm particles. In fact, it is obvious that the experiments on finer particles shall also give similar or better results because the particles in finer size ranges will be in a more liberated state.

Infrared thermography (make FLIR Agema 550) with 0.1 °C resolution is configured to capture the thermal image of the heat radiated by iron ore specimens placed at fixed distance from the IR camera as shown in Fig. 1. The test specimens are heated uniformly using heat source of wavelength ranging from 10^{-2} to 10^{-6} m for a period of time sufficient to create a difference in IR emission between the ore specimens. The radiant heat from the specimens is captured and analyzed using IR thermography. The temperature profile of each of the ores is analyzed to determine the peak temperature. Higher the alumina content, lower is the peak temperature. This is owing to low heating rate of alumina (Al_2O_3) than iron oxide (Fe_2O_3) which can be clearly observed from Table 1. The lower heating rate of alumina is due to its less absorptivity with respect to iron oxide. To improve the feed quality of the ores, alumina-rich iron ores having peak temperature below a threshold value can be now rejected by comparing the peak temperature of the ores with the threshold.

3.2. Experimental and results

3.2.1. Phase I

In the first phase, set of seven iron ore specimens of 10 mm size with different alumina content were selected and were uniformly

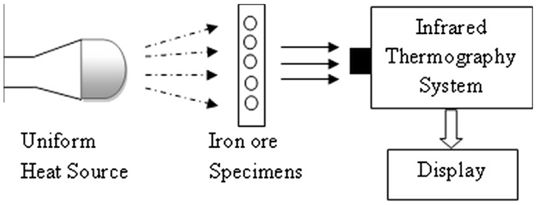

Fig. 1. Schematic of the IR thermography based system for identification of alumina-rich iron ore fines/lumps.

Table 1
Heating behavior of oxides present in iron ore specimens (Wong, 1975; Tinga, 1989).

Category	Minerals	Heating rate in ~°C/min
Easily heated	Fe_2O_3	170
Very little heated	Al_2O_3	80
Inactive	SiO_2	2–5