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Infrared thermography: An approach for iron ore gradation

Arpita Ghosh [a], A.K. Sharma [b], B. Nayak [a], S. Palit Sagar [a,*]

[a] CSIR-National Metallurgical Laboratory, Jamshedpur, India
[b] National Institute of Technology, Tiruchirapalli, India

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ABSTRACT

There are insufficient high-grade iron ores currently being mined to meet world demand for steel production. In order to meet raw material demand in India, lower grade ores with high alumina contents are being crushed and beneficiated, mainly by gravity techniques requiring water. However, the scarcity of water in the mining areas warrants the development of some dry gradation techniques for iron ores so that the inferior ore specimens can be rejected in order to improve the grade of the concentrate. The present gradation of ores by mineralogical/chemical methods is time-consuming and cumbersome. This paper presents an Infrared (IR) thermography-based non-invasive technique for the faster gradation of iron ores, taking into account the variation in thermal absorptivity of the ore constituents. Iron ore samples from the Joda, Noamundi and Barsua mines, with Fe contents ranging from 52 to 67 wt.%, were selected and crushed to around 10 mm particle size. The crushed iron ores were uniformly heated using a microwave oven, for a time period sufficient to create a difference between the ore particles in the extent of their respective infrared emissions. The thermal images of the heated particles were captured by IR thermography and the peak temperature of each ore particle was obtained from the thermal profile. A computer program was developed for ore gradation based on the peak temperature of each ore particle which corresponds to its iron content. A threshold was selected through chemical verification of the ores and accordingly the ores were categorized as high-, medium- and low-grade.

1. Introduction

The quality of ores is an important facet for blast furnaces in iron and steel industries, which use iron ore as one of their key raw materials. The overall productivity and in turn the profitability of the steel plants in part depends on the quality of iron ore fed to the blast furnace. For efficient blast furnace operation, the alumina/silica ratio in the feed ore should be less than 1 and alumina present in the ore should be less than 2% (Singh et al., 2004). Minor variations in these parameters can drastically affect the performance of a plant. The reduction of alumina in the blast furnace feed not only increases the productivity but also reduces the rate of coke consumption, slag viscosity and increases the reduction of the metal in the blast furnace (Rao et al., 2000).

Generally, Indian iron ores contain more than 2% alumina (Pradip, 2006) and hence beneficiation is necessary to reduce the alumina content in the ore before it can be used in the blast furnace. Alumina bearing minerals are intimately intergrown with the iron oxide minerals and in general their separation and liberation takes place in the finer size ranges and thus requires fine grinding (Singh et al., 2004). Iron ores are currently being beneficiated worldwide using several techniques such as: spirals, floatex density separators, jigs, multi-gravity separators, low and high intensity magnetic separation, conventional as well as column flotation and selective dispersion–flocculation. In India, the present method for iron ore beneficiation and the reduction of an ore's alumina content broadly comprises crushing the ore to the required particle size range, followed by scrubbing and/or wet-screening and finally classification to separate the slimes (particles below 0.15 mm) from fines (Rao et al., 2000). However, the scarcity of water in many of the mining areas necessitates the development of some dry gradation techniques for iron ores so that the inferior ore specimens can be rejected in order to improve the grade of the concentrate.

In mineral processing industries, ore-gradation plays a crucial role at different stages of the extraction process, ranging from the design of the mine to mineral grading and plant control (Chatterjee et al., 2010b). Usually, mineralogists or geologists grade and characterize the ores through visual inspection. However, less subjective and advanced methods are also available for mineral identification and ore grading. The general procedure for ore quality assessment in the mineral processing industries is to collect different representative ore specimens from the mines and then chemically analyze them by means of suitable techniques such as X-ray fluorescence (XRF) and neutron-activation on-line analysis (Oestreich et al., 1995). The present process of ore gradation by

* Corresponding author.
E-mail address: sarmi@nmlindia.org (S.P. Sagar).

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sampling and chemical analysis is time-consuming and burdensome. Due to the time-lag between collecting the samples and receiving the chemical analysis data, it is not possible to perform online ore gradation. This absence of real-time online analysis data handicaps plant operators and quality assurance managers. Moreover, online cross-belt analysers are capital intensive and their performance in iron ore applications with respect to minor constituents such as alumina, are not adequately established. Therefore, a relatively capital inexpensive, reliable online sensing system, which is also faster than the ore gradation by sampling and chemical analysis method currently in use, is desirable for the gradation of iron ores.

In recent years, some initiatives have been taken for the development of automatic systems for the measurement of mineral composition and texture. The early attempts used image analysis for obtaining quantitative mineralogical information from optical microscope images. The identification of and discrimination between the different mineral constituents of iron ores was based on their differing light reflectance in polished section. Although the technique was found to be relatively cheap and fast, the optical properties of many minerals overlapped, thus making discrimination between them impossible by grey level thresholding alone (Sutherland and Gottlieb, 1991). However, this problem can be largely overcome by RGB thresholding which is usually done for mineral liberation analysis by de-agglomeration and segmentation of images obtained through back scattered electron signals from scanning electron microscope (Gu, 2003; Gu et al., 2012). Oestreich et al. (1995) utilized a color sensor system based on color vector angle to estimate the composition of a mixture of two minerals, chalcopyrite and molybdenite. Ferruginous manganese ores were studied via histogram analysis in the RGB color space and a textural analysis, along with an edge detection technique, was used for the discrimination of alumina-bearing lump ore particles and to distinguish different ore types (Singh and Rao, 2006). The studies presented by Chatterjee et al. (2010a,b) analyzed limestone lump ore particles by selecting a segmentation algorithm from several tests and then applying morphological, textural and color feature extraction steps. Finally, principal component analysis was used to reduce the feature vector and a neural network was used for classification of the ore particles.

Most of the sensing systems available for ore gradation take into consideration the color, mineralogy, texture and optical properties of the ore particles. This paper presents an Infrared (IR) thermography based non-invasive technique for faster gradation of iron ores, taking into account the variation in thermal absorptivity of the ore constituents. Implementation of this technique in the beneficiation process in the mines would lead to more systematic and improved decision making for effective blend planning and impurity reduction. Additionally, real time analysis of feed grade would help plant operators with effective plant operation in order to achieve their targeted output in terms of alumina percentage and yield.

2. Principles of infrared thermography in mineral beneficiation

The infrared thermal imaging technique converts the invisible radiation pattern of an object into visible images for feature extraction and analysis. The system consists of an infrared 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 and medical imaging. (Speakman and Ward, 1998). The IR based thermal imaging technique has a potential application for the 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, some 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,

$$\Phi_{Transmitted} + \Phi_{Absorbed} + \Phi_{Reflected} = \Phi_{Incident} \quad (1)$$

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

$$\Phi_{Absorbed} + \Phi_{Reflected} = \Phi_{Incident} \quad (2)$$

In the 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 a thermal image through IR thermography. Ore particles with lower thermal absorptivity can be identified from the thermal images of the ore specimens (Thompson and Dwyer, 1968).

3. Steps to ore gradation

3.1. Methodology

In this investigation, iron ores with Fe content in the range of 52 to 67 wt.% and alumina (Al_2O_3) from 0.5 to 8.85 wt.% were collected from Joda, Noamundi and Barsua mines in India. These ores were crushed to a particle size of approximately 10 mm and some particles were then chosen as test specimens. The test specimens

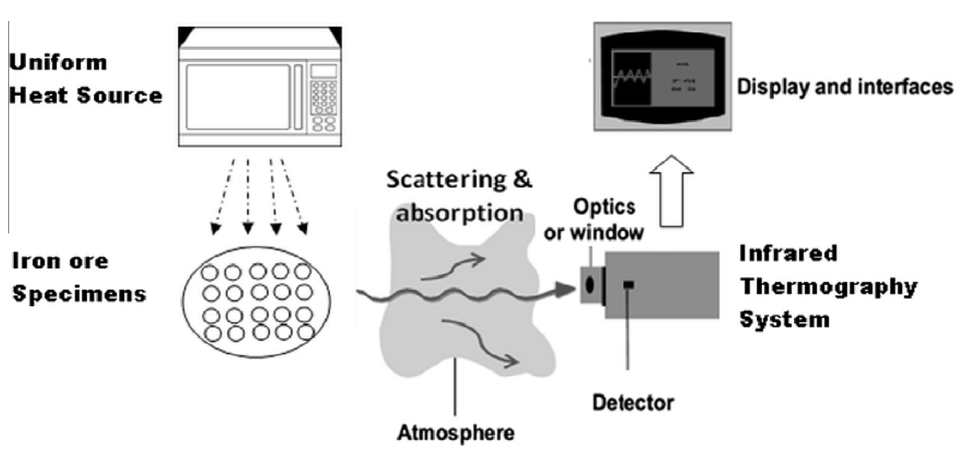

Fig. 1. Schematic diagram of the IR thermography based system for gradation of iron ores.