International Journal of Mineral Processing 132 (2014) 26–33

Contents lists available at ScienceDirect

International Journal of Mineral Processing

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

Laser-induced fluorescence images and Raman spectroscopy studies on rapid scanning of rock drillcore samples

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ARTICLE INFO

Article history:
Received 11 November 2013
Accepted 7 September 2014
Available online 16 September 2014

Keywords:
Raman analysis
Laser-induced fluorescence
Drillcore
Image processing
Non-Negative Least Squares

ABSTRACT

There exist many different ways of analysing rock drillcore samples. Here the interest is on the faster exploration activities of mining. A capable, rapid and online measurement technique is presented for analysing the mineral composition of rock drillcore samples. Raman analysis is an accurate but slow method of analysing rock drillcore samples. On the other hand, laser-induced fluorescence (LIF) can be used as a rapid method to produce a colour map of minerals based on their fluorescence. These two methods can be combined by calibrating LIF measurements with Raman results. This paper presents a combination of Raman analysis with LIF image analysis to form a rapid online mineral exploration technique used on the rock drillcore samples. To the best knowledge of the authors, the combination of LIF and Raman in the study of rock drillcore has not been published. The sample set under study is segments of rock drillcore collected from a Ni–Cu multi-metal mine situated in Kevitsa, Finland. Scanning drillcore samples using LIF technique produces images which present a map of colours based on emissions of fluorescent minerals. Some parts of the sample set, based on the exposed colours, are measured through Raman spectroscopy and the minerals are identified using reference spectra from a public source. Identification of minerals through Raman analysis is done using Non-Negative Least Squares (NNLS) method. Results show that colours of LIF images correspond to minerals identified through Raman analysis. The combination of LIF and Raman is then used to produce mineral maps of the drillcore samples and finally an estimation of the mineral abundance per units of drillcore area is developed.

1. Introduction

Drillcore samples are the key source of information in mineral exploration. Custom mineral exploration procedures are rather slow. Geologists log the drillcore samples manually by visual inspection, the samples are then halved and one half of them are sent to laboratories for further analytical measurements. Exact results are obtained in laboratories using slow but precise techniques. This process of sample preparation, drillcore shipment and laboratory analysis is rather expensive, needs a lot of workforce and may cause delays in receiving final analysis results.

Currently available drillcore scanners are used to measure the elemental or mineralogical composition of the samples. X-ray Fluorescence (XRF) analysis which detects elemental contents of the sample (Arkadiev et al., 2006), visible and near-infrared (VNIR) and the short-wave infrared (SWIR) reflectance spectroscopies which detect indications of the minerals in the drillcore (see e.g. (Keeling et al., 2004; Huntington et al., 2006; Tappert et al., 2011)) are the predominant methods for drillcore analysis in the industrial field. There are other spectroscopic and laser-based methods mostly applied in the laboratory but with a high potential for industrial applications, e.g. Laser-Induced Breakdown Spectroscopy (LIBS) which detects elemental contents of the samples (Fortes and Laserna, 2010), Raman spectroscopy for mineral detection already applied in the field (Kauppinen et al., 2013), X-ray Diffraction (XRD) applied for mineral analysis of the pulverised samples in the laboratory (XRD) (Escárate et al., 2009) and Time-Resolved Laser-Induced Fluorescence Spectroscopy (TR-LIFS) for quantitative and qualitative interpretation of luminescent centres (Gaft et al., 2005).

Although results of the spectroscopic methods are usually unfailing since they operate quantitatively or seek distinct patterns in data, the process of measuring and data analysing is slow and far from the goal of rapid analysis. On the other hand, geologists are enthusiastic about the abundance of the minerals as well as mineral map of the drillcore samples. The diameter of the radiation, e.g. laser beam, in most of the point-wise measurement techniques (LIBS, XRD, Raman, TR-LIFS) is about micrometres. Calculating the abundance of the minerals adequate for industrial scales necessitates radiating substantial number of spots to cover broader area of the drillcore surface. Compared to point-wise measurement techniques, XRF analysis enables relatively rapid scanning of the drillcore samples, but it explores the elemental contents of

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http://dx.doi.org/10.1016/j.minpro.2014.09.003
0301-7516/

Table 1
Drillcore samples measured with Raman and LIF from Kevitsa mine.

Drillcore	Start (m)	Length (m)	No. of Raman	LIF
KV386 L2	18.1	0.1	400	Yes
KV291 L4	26.05	0.25	200	Yes
KV357 L34	190.4	0.25	600	Yes
KV386 L16	90.0	0.2	250	No
KV157 L20	116.7	0.15	500	No

the rocks. VNIR and SWIR reflectance spectroscopy using line scanning hyperspectral imaging systems is considerably rapid and whole visible surface of the drillcore can be analysed (Haavisto et al., 2013). However, there are still noticeable number of minerals not detectable by Infrared Reflectance spectroscopy techniques.

Having discussed about the slowness of the spectroscopic techniques, there is a need to develop new techniques which speed up the process of rock and ore drillcore scanning. This paper aims to propose a faster way to determine mineral contents of rock and ore samples. It focuses on scanning of the round-side of the drillcore which is the main sample received during exploration. A new method used for rapid scanning of the drillcore which benefits from both the promptness of laser induced fluorescence (LIF) imaging and advances of digital image processing is presented. On the other hand, different minerals may fluoresce with the same colours under UV light. Moreover, similar fluorescent minerals may fluoresce with dissimilar colours in different mines due to diverse activators (Miller et al., 2005). Consequently, LIF analysis requires a reference which links colours to the minerals. This paper presents calibration of the error-prone but rapid LIF image analysis using the precise but slow Raman spectroscopy technique and eventually shows how Raman can provide complementary information to LIF analysis.

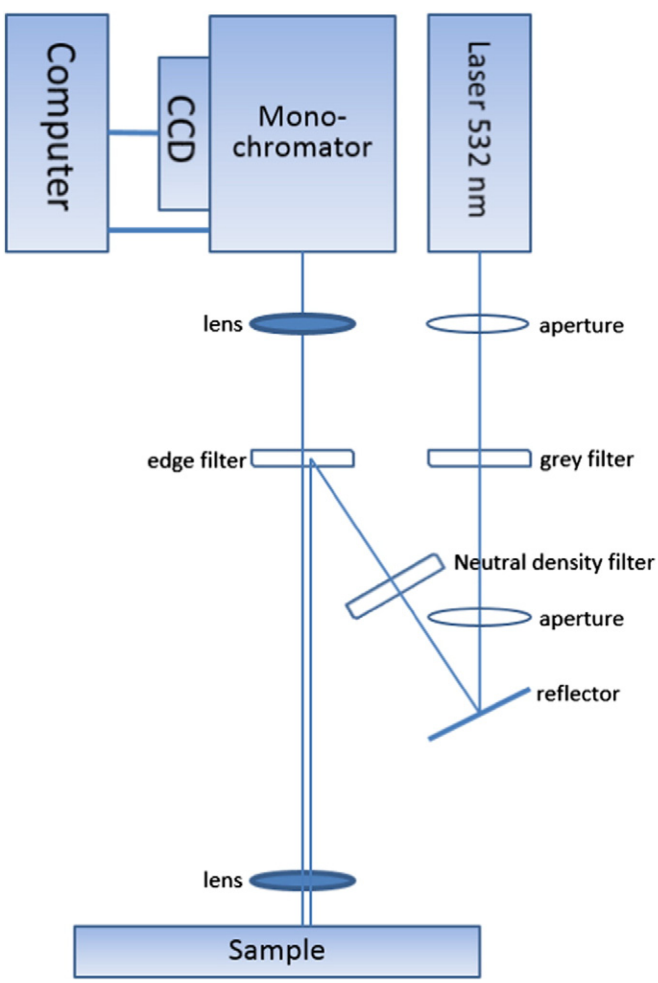

Fig. 1. Measurement apparatus for Raman measurements.

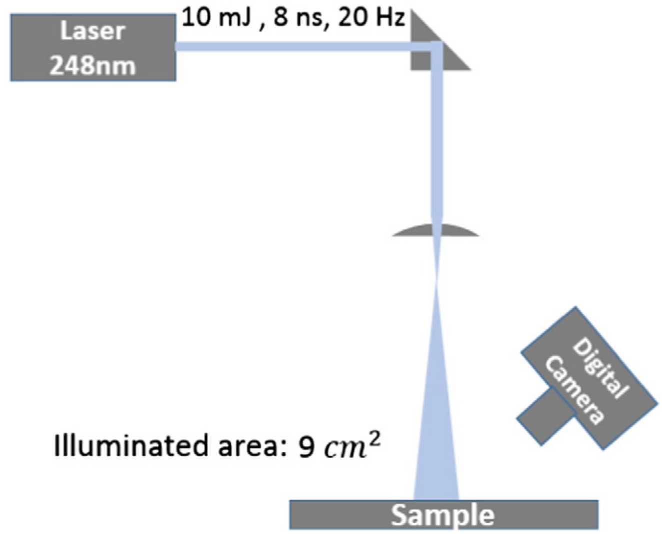

Fig. 2. Schematic diagram of the laser induced fluorescence (LIF) imaging set-up.

2. Materials and methods

2.1. Laser-induced fluorescence

A luminescent mineral is composed of a lattice and luminescent centres called activators. Different activators are the cause of different colour radiations of the luminescent minerals (Gaft et al., 2005). Activators are translated as impurities in minerals and they are mainly transition metals or rare earth element ions (Waychunas, 1988).

Colourful emissions of the fluorescent minerals signify the idea of mineral detection using those colours. Laser-induced fluorescence (LIF) is a sensitive, moderately easy to implement and well-studied measurement technique. Conventional methods of LIF analysis are based on assessing the measured fluorescence spectrum of minerals

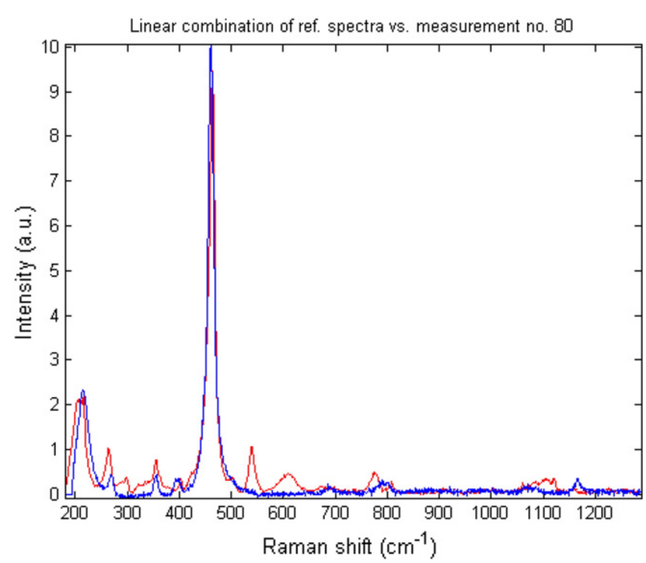

Fig. 3. Measurement no. 80 of the KV357 L34 drillcore. Sample spectrum (blue) and a linear combination of the reference spectra (red).