NAMVS 2021 – Tukkaraja (Ed.)

Development of non-regulatory runtime respirable coal and silica dust monitor

C.C. Harb, R.D. Rajapaksha, X. Moya, J. Roberts, P. Hemp, L. Uecker &
T. Rawson
RingIR Inc., Albuquerque, NM, USA

P. Roghanchi
New Mexico Institute of Mining and Technology, Socorro, NM, USA

ABSTRACT: Continuous monitoring of respirable silica dust levels in mining environments is crucial to ensure the safety of mine workers. However, runtime monitoring of elevated silica dust levels is not an easy task. This study introduces the next generation runtime silica dust monitor of elevated silica and coal dust levels in the mining environment. For this development, RingIR will utilize our patented cavity ringdown optical spectroscopy-based technology combined with miniaturized FPGA digital signal processing. The proposed system will continuously pull air from the environment and determine the concentration of silica dust levels via data processing from an on-board computer. These dust levels will be displayed instantly and can send audio and visual alerts if the detected level is higher than the set exposure limit.

1 INTRODUCTION

Since 1970, the coal mine operators and MSHA have used the "coal mine dust personal sampler unit" (CMDSU) to determine the concentration of respirable dust in the mine environment. This unit tests the underground atmosphere by drawing mine air through a filter cassette that collects respirable dust. At the end of a full shift, the cassettes are collected and shipped to a specialized laboratory for analysis. The collected dust on each filter is then weighed under controlled conditions to determine the average concentration of respirable coal dust during the production shifts. An immediate problem with this method is that it takes several days (sometimes weeks) before the mine operators and MSHA receive the results. Another critical problem with this method is that personal sampling for respirable coal mine dust is only performed as an average concentration during a full shift. As a result, high transient/short-term concentrations of respirable coal dust events are not captured through the use of the 10-hour time-weighted-average (TWA) sampling method (NAS, 2018; Colinet et al., 2010).

In the 1990s, NIOSH began conducting research and development to produce a new type of personal dust monitoring unit that could provide readings of dust levels in a near-continuous manner. This new device known as the "continuous personal dust monitor" (CPDM) allows the mine operators to promptly identify and respond to dust concentrations exceeding MSHA requirements. Through near real-time readings, the instrument allows the mine operators to determine dust concentrations, trigger dust control systems, and evaluate the effectiveness of the dust control methods.

Presently, the PDM3700 instrument manufactured by Thermo Fisher Scientific® is used to measure dust concentrations in the production workings in near real-time.

DOI: 10.1201/9781003188476-25

During various MSHA-Industry dust partnership meetings and through NIOSH visits to mine sites, mine operators and mine workers have indicated that a 2nd generation CPDM would need to be designed and manufactured to reduce its size, weight, and operating noise. The construction and the operating features of this unit are still mass-based and filter-based, which means that the instrument uses a particulate filter mounted on an oscillating microbalance to measure dust concentrations. As a result, this instrument can only measure the combined mass of respirable coal dust, plus respirable mineral dust, plus organic matter that is present in the mine air. The total mass of the respirable coal mine dust (RCMD) collected by a respirable personal sampler is assumed to all become the miner's RCMD dose. However, the mass concentration does not necessarily represent the true RCMD dose received by the coal miner, especially for RCMD less than 4 µm. It is critical to identify different constituents of RCMD in order to have a comprehensive understanding of the health effects. Not all of the RCMD inhaled into the miner's respiratory tract will deposit in the lung to become the RCMD dose. A portion of the inhaled RCMD could be exhaled out of the respiratory tract during exhalation without deposition. This phenomenon is especially significant for submicron RCMD (NAS, 2018).

2 TECHNOLOGY DEVELOPMENT

In order to prevent overexposure and enhance the health and safety in mining workplaces, continuous monitoring of respirable dust levels is crucial. Therefore, RingIR's efforts to utilize their patented gas tracking technology (Boyson et al., 2015) for instant monitoring of respirable dust levels in mines to identify elevated dust levels. RingIR collaborates with industry and professional partners to manufacture a simple, miniaturized, low-weight, personal dust monitor for non-regulatory respirable coal and silica dust monitor using quantum cascade laser-based cavity ringdown spectroscopy.

Laser-based spectroscopic techniques are utilized in numerous field portable gas sensors and are proven to be sensitive and efficient due to their accuracy, specificity, and linearity. Further, use of quantum cascade lasers (QCLs) as optical sources has greatly advanced infrared spectrometers (Li et al., 2013; Lin et al., 2017; Michel et al., 2016). We utilized cavity-enhanced direct optical absorption coupled with QCLs for this study. RingIR's patented (Boyson et al., 2015) direct optical absorption technology utilizes broadly tuning mid-infrared QCLs to produce a field-deployable runtime cavity ringdown (rtCRD) spectrometer for gas tracking and leak detection. rtCRD is an emerging technology that has shown its potential in many disciplines such as military, security, environmental and civilian. The systems RingIR has developed reach high parts-per-trillion (ppt) (> 0.1 ppt) sensitivity with low false positives (<0.01%). RingIR has to date developed prototype gas trackers designed for continuous operation over the 7 to 11 µm wavelength range.

3 MATERIALS AND METHODS

RingIR's *Agnoscis* AG-4000 spectrometer (Figure 1) was utilized for this experiment. RingIR's *Agnoscis* AG-4000 is a pulsed-laser, multiplexed rtCRDS-based spectrometer. The laser beams are aligned to the cavity which consists of an input coupling mirror, two high-reflecting mirrors, and an output coupling mirror. The output signal is detected by a single MCT photodetector and passed to a real-time digital signal-processing system for analysis (Figure 2). The AG-4000 measures IR absorption of molecules in the 7-11 µm mid-IR range which has potential in a wide range of applications such as detection of explosives, identification of toxic gases and chemical vapors, terpene profiling, gas leak detection, monitoring of atmospheric pollutants, cannabis analysis, and aerosols analysis from vaping. We utilized the AG-4000 to measure the unique IR absorption profiles of coal dust, silica dust, and 10% silica in coal dust to determine appropriate the discrete wavelengths to develop miniaturized personal dust monitor.

Figure 1. Agnoscis AG-4000 spectrometer.

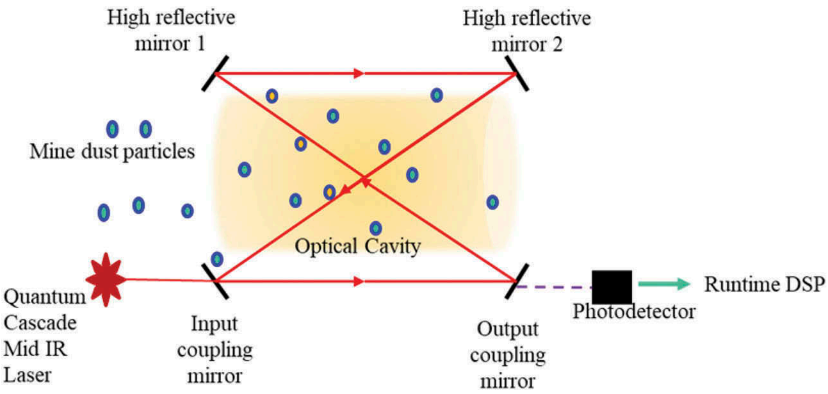

Figure 2. The optical layout of AG-4000 multiplexed.

To achieve this, dust samples of coal, silica, and a mixture of 10% silica in coal dust were tested using a simple plastic jar that allowed the AG-4000 to sample the dust as it was aerated (Figure 3).

Table 1 details the different dust samples tested in the sample jars. The dust sample was placed in the jar, the sample collection hose on the AG-4000 was positioned at the opening of the jar, and the pump was turned on to start the test. The mass flow rate of the AG-4000 was set to 2.2 L per minute.

Further, obtained results were verified using a dust rig which designed to simulate mine environment. The dust rig configuration is shown in Figure 4. For the dust rig study, 3.0 g of coal and silica samples were used with 3.5 ms^{-1} chamber velocity and 2.2 L per minute mass flow rate of AG-4000. The sample inlet hose of AG-4000 was attached to the sample outlet of dust rig.

Figure 3. Experimental setup showing sampling jar attached to the AG-4000.

Figure 4. Dust rig configuration.

Table 1. Dust sample data and experimental method.

Dust Sample	Sample Mass (g)	Total Run Time (min)	Test Method
York Canyon, New Mexico Coal	0.3005	120	Sampling jar
Australia Silica	0.5006	120	Sampling jar

4 RESULTS AND DISCUSSION

The observed mid-IR absorption spectra of coal and silica samples are shown in Figure 5. These preliminary results clearly demonstrate that the capability of simultaneous detection of coal and silica in mine environments using narrow-band lasers. Coal shows strong absorption around 7400-7500 nm which could be used as potential coal detection wavelength using

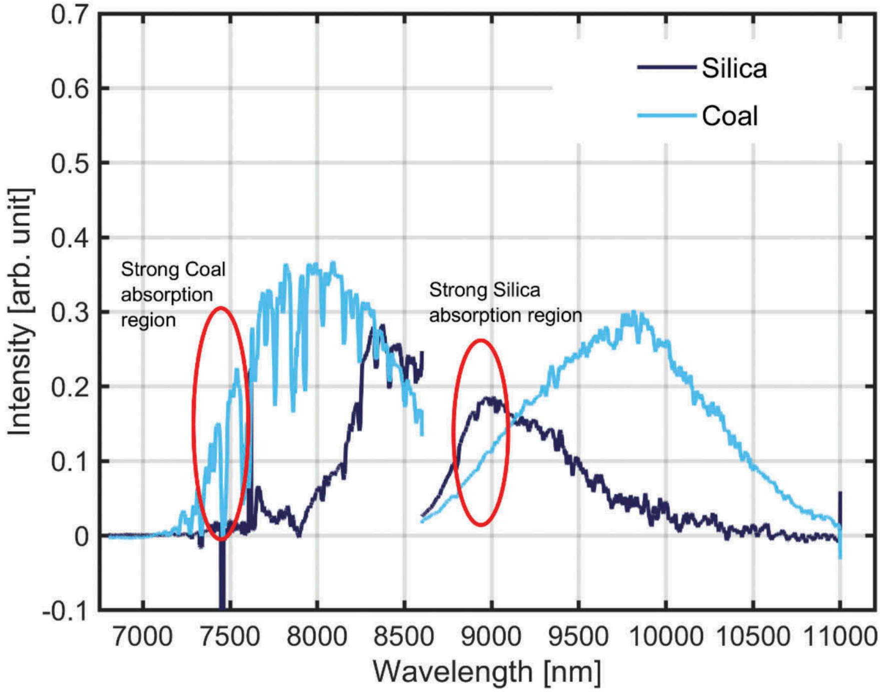

Figure 5. Observed mid-IR spectra for Silica, Coal and 10% Silica in coal dust samples

narrow-band laser. Conversely, silica shows strong absorption around 8500 nm and between 8600-91000 nm. These spectral regions will be used to study the appropriate detection wavelength for silica using narrow-band QCLs.

This initial study demonstrates the potential of developing a rapid dust detection instrument using rtCRDS for simultaneous detection of coal and silica dust. Further, this study is considered as the foundation for future development of personal dust monitor which RingIR is designing for NIOSH for non-regulatory respirable coal and silica dust.

ACKNOWLEDGEMENT

This study is funded by the National Institute for Occupational Safety and Health (NIOSH) [BAA 75D301-20-R-67845].

REFERENCES

Boyson, T. K., Dagdigian, P. J., Pavey, K. D., FitzGerald, N. J., Spence, T. G., Moore, D. S., & Harb, C. C. (2015). Real-time multiplexed digital cavity-enhanced spectroscopy. Optics letters, 40(19), 4560–4562.

Colinet, J., Listak, J. M., Organiscak, J. A., Rider, J. P., & Wolfe, A. L. (2010). Best practices for dust control in coal mining.

Li, J. S., Chen, W., & Fischer, H. (2013). Quantum cascade laser spectrometry techniques: a new trend in atmospheric chemistry. Applied Spectroscopy Reviews, 48(7), 523–559.

Michel, A. P., Miller, D. J., Sun, K., Tao, L., Stanton, L., & Zondlo, M. A. (2016). Long-path quantum cascade laser–based sensor for methane measurements. Journal of Atmospheric and Oceanic Technology, 33(11), 2373–2384.

National Academies of Sciences, Engineering, and Medicine. (2018). Monitoring and Sampling Approaches to Assess Underground Coal Mine Dust Exposures. National Academies Press.

Qing-Yu, L. I. N., & Yi-Xiang, D. U. A. N. (2017). Laser-Induced Breakdown Spectroscopy: From Experimental Platform to Field Instrument. Chinese Journal of Analytical Chemistry, 45(9), 1405–1414.

Phillips, K., Keles, C., Scaggs, M., Johann, V., Rezaee, M., & Sarver, E. (2017). Comparison of Coal vs. Mineral Mass Fractions in Respirable Dust in Appalachian Coal Mines. North American Mine Ventilation Symposium, Golden CO, June 17-22, 2017, pp. 71–79.

PROCEEDINGS OF THE 18TH NORTH AMERICAN MINE VENTILATION SYMPOSIUM (NAMVS 2021), JUNE 12-17, 2021, RAPID CITY, SOUTH DAKOTA, USA

Mine Ventilation

Editor

Purushotham Tukkaraja, Ph.D., QP

Mining Engineering & Management, South Dakota Mines, Rapid City, SD, USA

CRC Press
Taylor & Francis Group
Boca Raton London New York

CRC Press is an imprint of the
Taylor & Francis Group, an **informa** business
A BALKEMA BOOK

CRC Press/Balkema is an imprint of the Taylor & Francis Group, an informa business

Typeset by Integra Software Services Pvt. Ltd., Pondicherry, India

Library of Congress Cataloging-in-Publication Data

A catalog record has been requested for this book

Published by: CRC Press/Balkema
Schipholweg 107C, 2316 XC Leiden, The Netherlands
e-mail: enquiries@taylorandfrancis.com
www.routledge.com – www.taylorandfrancis.com

ISBN: 978-1-032-03679-3 (Hbk)
ISBN: 978-1-032-03681-6 (Pbk)
ISBN: 978-1-003-18847-6 (eBook)
DOI: 10.1201/9781003188476