Powder Technology 339 (2018) 487–496

Contents lists available at ScienceDirect

Powder Technology

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

Design and experimental evaluation of a flooded-bed dust scrubber integrated into a longwall shearer

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ARTICLE INFO

Article history:
Received 14 January 2018
Received in revised form 28 June 2018
Accepted 19 July 2018
Available online 20 July 2018

Keywords:
Dust control
Dust scrubber
Underground mining
Longwall shearer
Flooded-bed scrubber

ABSTRACT

Continuous mining machines operating in U.S. underground coal mines have, for decades, utilized flooded-bed dust scrubbers for capturing and removing respirable dust generated at the production face. However, the application of dust scrubbers to longwall mining systems has not yet been successful. Considering that nearly 60% of U. S. underground coal production is from longwall mines, the successful application of dust scrubbers to longwall mining systems could have a significant impact on miner health. A full-scale mock-up of a longwall shearer was constructed and equipped with a flooded-bed dust scrubber designed to capture dust produced by the headgate cutting drum. The mockup was installed at the National Institute for Occupational Safety and Health (NIOSH) Longwall Dust Gallery and a series of 40 experiments was conducted to evaluate the scrubber's performance. Results show that the scrubber achieved a 56% reduction of respirable dust in the return airway and a 74% reduction of respirable dust in the walkway area near the shearer. Although these tests were conducted under a controlled environment, the results suggest that a similar scrubber design could be very effective at achieving a significant reduction in respirable dust in longwall mining systems.

1. Introduction

Dust is a detrimental, but inherent, consequence of many mining processes. It is particularly problematic in underground coal mining because of its effects on both health and safety of mineworkers. Coal workers' pneumoconiosis (CWP), commonly referred to as *black lung*, is a debilitating and irreversible lung disease, which results from the long-term inhalation and deposition of coal dust in the lungs. Excessive concentrations of respirable dust particles (<10 μm) cause the formation of scar tissue in the alveolar (gas-exchange) regions of the lungs, resulting in massive fibrosis in the advanced stages of the disease. In addition to this health hazard, float coal dust (<75 μm) is a safety hazard because it can settle on the surfaces of mine entries and propagate a mine explosion if the amount of rock dust applied to mine surfaces is not sufficient to render the coal dust/rock dust mixture inert.

Although the prevalence of CWP has steadily declined over the three decades following the Federal Coal Mine Health and Safety Act of 1969 [1], a study by the National Institute for Occupational Safety and Health (NIOSH) indicates that significant health hazards associated with respirable dust still exist within the coal mining industry [2]. According to the NIOSH study, the declining trend in CWP ended around 1999, and its prevalence has since begun to rise, as shown in Fig. 1 [2]. NIOSH claims that, for miners with 25 or more years of experience, the occurrence rate of CWP has nearly doubled since its low point and that the disease is occurring in younger miners. Furthermore, NIOSH states that the disease's progression rate from beginning stages to more advanced stages has accelerated. It is noted that these results are based on mineworkers who voluntarily participated in the NIOSH Coal Workers' Health Surveillance Program (CWHSP), which may not constitute a representative sample of all mineworkers. Nonetheless, the results indicate that CWP still exists and continues to plague the U.S. coal mining industry. In addition, a recent study involving chest x-rays of Australian underground coal miners found 18 out of 248 positives for opacities suggestive of pneumoconiosis [3].

Current dust-control methods include dilution with ventilation airflow, confinement and isolation by water sprays, wetting and capture by water sprays, and wetting and capture by flooded-bed dust scrubbers. Of these methods, dust scrubbing is the most desirable because it removes the dust from the airstream rather than diluting or confining dust as is done with most other dust control methods.

Because of their effectiveness at removing respirable dust, dust scrubbers have been used successfully on continuous miners for decades. However, there has not been much success in the application of dust scrubbing methods to longwall systems. The approaches previously attempted include ventilated drums, ventilated cowls, water-powered scrubbers, and flooded-bed scrubbers. Although each of these methods showed the potential benefits of dust scrubbing, the

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https://doi.org/10.1016/j.powtec.2018.07.072
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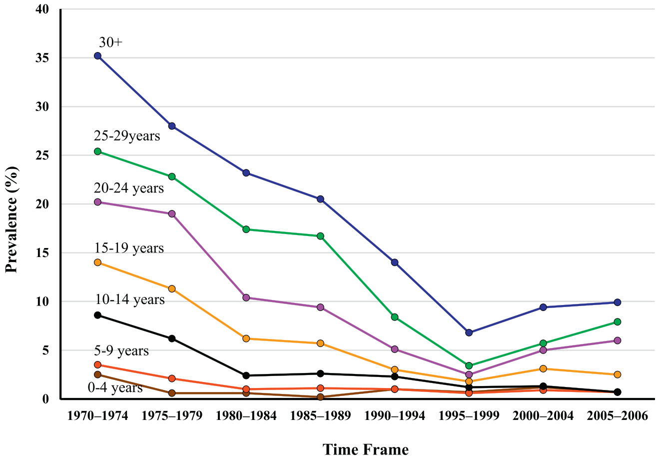

Fig. 1. Prevalence of CWP among examinees employed at underground coalmines [2].

approaches generally had issues with reliability, maintenance, and dust-capture capacity [4–8].

On August 1, 2014, the Mine Safety and Health Administration's (MSHA) new respirable dust rule for U.S. underground coalmines went into effect. Although this rule includes many changes, the most significant ones for longwalls are summarized below.

- The dust concentration limits for respirable coal mine dust has been lowered from 2.0 mg/m^3 at the working face to 1.5 mg/m^3 and from 1.0 mg/m^3 in the intake air to 0.5 mg/m^3, after August 1, 2016 [9].
- The final rule mandates the use of continuous personal dust monitors (CPDMs) to monitor the dust exposure of underground mineworkers in occupations exposed to the highest respirable dust concentration, starting on February 1, 2016. A CPDM is a real-time dust sampler that measures the respirable dust concentration continuously, in real time, and provides a cumulative dust concentration up to the present point in time, a 30-min running average, and the percentage of the permissible exposure limit of the current working shift.
- The term "normal production shift" has been redefined as the production shift that has at least 80% of average production calculated from the 30 most-recent production shifts, as compared with the earlier value of 50% of the average production from the last sampling period. To be considered a valid sample, production for the sampling shift must meet or exceed this 80% average.
- Beginning February 1, 2016, during each calendar quarter, the designated occupation (DO) in each mechanized mining unit (MMU) must be sampled on consecutive normal production shifts until 15 valid representative samples are taken, as compared with the earlier value of five samples collected bimonthly [10].
- The new Rule eliminates using the average of five operator samples for determining compliance, and now requires the use of a single, full-shift operator sample. If the sample exceeds the dust standard, corrective action is required.
- Beginning February 1, 2016, during each calendar quarter, each other designated occupation (ODO) in each mechanized mining unit (MMU) must be sampled on consecutive normal production shifts until 15 valid representative samples are taken [10]. ODO sampling cannot be conducted concurrently with the DO sampling, which extends the total sampling period to a minimum of 30 shifts per quarter.

2. Methods

The objective of this longwall dust scrubber project includes the design, fabrication, and testing of a full-size mockup of a modern longwall shearer with an integrated flooded-bed dust scrubber. Because of the difficulty in developing a scrubber for both cutting drums, the scope of work is limited to a scrubber for capturing dust generated near the headgate drum of the machine. Should this scrubber be shown to be successful, then this technology could be applied to the development of a scrubber for capturing dust generated by the tailgate cutting drum.

2.1. Information gathering and analysis

The research focused on a specific longwall operation to develop the concept and improve the probability of success. Investigators solicited and obtained the cooperation of Alliance Coal, LLC and Joy Global, Inc. (now Komatsu American Corp.) for this initial application. Alliance Coal owns and operates three longwall mines, and the longwall system at its Tunnel Ridge Mine, which includes a Joy 7LS shearer, was used as the test and information-gathering site. The Tunnel Ridge Mine operates in the Pittsburgh coal seam, which has an average seam height of 2.1 m (7 ft).

The research project began with obtaining detailed drawings and specifications of the longwall equipment used at the Tunnel Ridge Mine. Mine visits were made to gather additional information and data. The information included documentation of visual observations of the mining process and dust patterns, with attention being paid to possible scrubber locations on the shearer. Air-quantity and dust measurements were obtained for various locations along the longwall face, and Alliance Coal shared its Mine Ventilation Plan with the research team. Visits were also made to the Joy Global office in Franklin, Pennsylvania and with the NIOSH Dust, Ventilation, and Toxic Substance Branch in Pittsburgh, Pennsylvania. Joy Global provided the research team with detailed dimensional drawings of the 7 LS shearer in electronic format. The obtained data and information from Alliance and Joy were invaluable for constructing computer and physical models of the longwall system.

2.2. Shearer design and construction

2.2.1. Shearer modifications

The research team obtained 2-D and 3-D (.stl files) drawings of the shearer. To create the 3-D model, the shearer was divided into seven parts: main body, headgate drive, tailgate drive, headgate ranging arm, tailgate ranging arm, headgate drum, and tailgate drum. Each part of the shearer model was developed separately, after removing minor details, using the dimensions from the original drawings. The seven parts were then assembled to create a complete shearer model.

Several iterations for the scrubber design were considered before a design was adopted. The final design consisted of the addition of two relatively short modules: a scrubber module located between the headgate module and main body and a fan module located between the main body and tailgate module. An external inlet and duct connecting the scrubber and fan modules and outlet were also included in the design. This integrated design was selected primarily because of height and visibility constraints preventing a scrubber from being added on top of the shearer. Fig. 2 shows the computer model of the modified shearer with the scrubber components shown in blue.

Fig. 2 also shows the shearer-clearer system. The shearer-clearer system consists of a splitter arm that runs from the top corner (walkway side) of the headgate module to approximately 0.46 m (18 in.) beyond the headgate drum. Attached to the splitter arm is a piece of brattice cloth that hangs to the floor. The splitter arm also has a series of spray nozzles attached to it that are directed toward the face. The purpose of this system is to confine the dust generated near the headgate by directing it toward the face, and away from the walkway, where personnel are located. Note that in an operating mine, the passive barrier is composed of heavy mine conveyor belt material rather than brattice cloth. A photo of the shearer-clearer system on the mockup shearer is shown in Fig. 3.