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How relevant are engineering samples in the management of personal dust exposure?

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A R T I C L E I N F O

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A B S T R A C T

A directive, legislated by the South African Department of Minerals and Energy (DME) in 1997, was introduced to reduce the dust exposures of continuous miner (CM) operators to below 5 mg/m^3, when measured at the operator's cab position. The focus of this paper is to review the effectiveness of observing this rule for almost two decades and discuss industry perceptions arising from the application of this rule. The results have demonstrated that the engineering sample cannot predict the personal shift dust exposure of a CM operator. Therefore, it is recommended that the engineering sampling, as currently practiced, should be reviewed with the objective to discontinue and replace it by the approved PDM3700 real-time dust monitor.

1. Introduction

Major hazards in an underground coal mine include methane and coal dust explosions and personal exposure to dust. Based on the first ever recorded coal mine explosion in Southern Africa in Natal in 1891, it can be inferred that underground coal mines have been operational for over 125 years [1]. Considering where the global coal mining industry is positioned today and the arduous efforts that have resulted in improved public perceptions of the coal industry. Fig. 1 demonstrates the success of various initiatives in reducing fatalities resulting from underground gas and dust explosions.

The statistics shown in Fig. 1 include events from early 1900s to 2015 from USA, South African and Australian coal mines. Coal mining in South Africa has matured over the decades in both safety and health management with a unified approach towards management of risks. The reduction in explosions is factual evidence of the coal mining industry taking responsibility and being proactive in preventing such major incidents with innovative technologies, technical leadership and being eternally vigilant in dealing with multiple hazards in the workplace.

Understanding the risk of exposure to respirable dust was pioneered in South Africa in the early part of the 20th century with initial dust sampling techniques employing the konimeter, the use of the real-time Hund Tyndallometer, and later the introduction of gravimetric sampling in the mid-1990s, despite the USA and the rest of the world adopting it in the early 1970s. Increasing concern about coal dust related lung diseases, together with the Leon Commission Report, caused the DME to review the legislation aimed at protecting the health and safety of mine employees [2]. One of the milestones in dust management in coal mines was a DME Directive B7, effectively termed as "the 12 m rule", introduced in 1997 [3,4]. In addition, during this period, South Africa became the first country in the world to adopt the new size-selective respirable dust curve for monitoring dust as opposed to the original Johannesburg size-selective curve of the 1960s [5,6].

Directive B7, titled "*A Guideline for the Ventilating of Mechanical Miner Sections*" was issued by the DME to the South African coal mining industry. This directive stipulated that one daily dust sample, termed "a CM engineering sample" was to be taken at every CM with an acceptable limit of 5 mg/m^3. The sampling pumps were to be positioned on the CM at the operator's position or at a position where the CM operator would be seated if on board the machine. Analysis of the results indicated that mere application of 12 m rule on its own does not solve the dust problems, but rather that it is achieved by the meticulous application of available state-of-the-art dust control technologies, and the regular maintenance of installed systems to ensure that they work at all times [7]. This paper reviews the origin of the CM engineering sample, its application and shortcomings and its current interpretation after two decades of implementation in South African coal mines.

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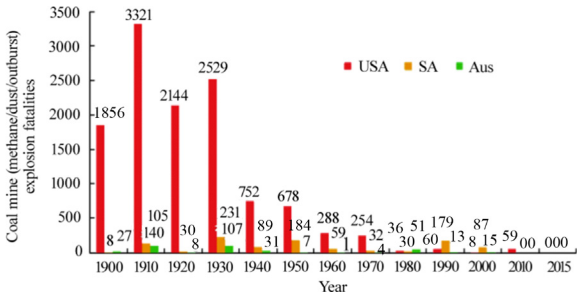

Fig. 1. USA-SA-Australian coal mine explosion fatality statistics over the decades.

2. Dust monitoring in South African collieries

This section of the paper summarises the history of dust exposure monitoring and the changes that have taken place in the last two decades. Exposure monitoring and assessment is a complex system that requires clear understanding of the coal mining operation, monitoring practices, engineering controls, ventilation system and dust generation dynamics. It is therefore increasingly necessary to measure the dust levels as accurately as practicable to assess the exposure, by using effective sampling techniques. Historically, the assessment of workers' dust exposure in South African coal mines was done by using various air samplers such as the Casella 10 mm cyclone, Gilian cyclones, GME008 Higgins-Dewell type South African cyclones, MSA cyclones, and CIP10 samplers. All these dust monitoring units were approved by the DME and operated at a conventional flow rate of 1.9 L/min, except for CIP-10, where the flow rate is 10.0 L/min. Due to its inherent measurement shortcomings, CIP10 samplers are no longer used in South African mines following an instruction by the DME. Currently South African coal mines must perform two types of dust sampling. In terms of the DME guideline for the assessment of personal exposure to airborne pollutants, the results of the personal exposure sampling programme are to be submitted to the inspectorate quarterly [8]. In terms of the *DME Guideline for a Code of Practice for the Ventilating of Mechanical Miner Sections in Coal Mines* in terms of Section 34(1) of the Minerals Act 1991, the results of gravimetric sampling performed daily at all operating CM sites, termed "environmental samples" in the Directive in 1997, but commonly referred to as 'engineering sampling' must be submitted to the Directorate within four days. Prior to 1998, dust samplers at all South African underground mines were operated in agreement with the BMRC respirable convention [9]. However, according to the new ISO/CEN/ACGIH respirable dust curve with a 50% cut point (d50) of 4 μm, the recommended flow rate is 2.2 L/min [10]. The dust samples are weighed on completion of the working shift and the procedure for determining the dust mass is followed according to DME guidelines [11].

3. Sampling definitions

This section of the paper provides background to various sampling definitions that are used in the mining industry. Occupational health exposure assessment refers to various sampling strategies over the years and relevant definitions of the sampling methods are summarized below [12].

Personal sampling is a method of sample collection whereby the dust sample collected is in the breathing zone of a mine worker while performing occupational duties during a work shift. In this sampling method, the worker wears the sampling train (cyclone, pump, tube, sample filter) for the entire work shift. Personal sampling results are most commonly used as the exposure or dose element in the development of dose-response relationships.

Area or environmental sampling is a method of sample collection whereby the dust sample taken at a fixed location at the workplace in an environment or area of interest that is not mobile. The dust sample reflects the average concentration in the area of interest and does not reflect the exposure of any worker in that area. The guideline for a code of practice for the ventilating of mechanical miner sections in coal mines in 1997 noted that the sampler is to be placed in a stationary position inside the cab of the mechanical miner and referred to as environmental sampling. Area sampling should not be confused with the engineering sampling suggested in the Directive in 1997 and the term "environmental" for the purpose of B7 is not correct.

Occupational sampling: an occupational sample is the dust sample taken during a work shift on individual workers who perform duties in a designated occupation and the terminology is used in US coal mines. This method of sampling measures the dust exposure for defined occupations as if one person performed the duties in that occupation for the whole working shift.

Engineering sampling: an engineering sample is the dust sample taken at the CM operator's position, which is not defined in the original DME directive [3,4]. An engineering sample is the dust sample taken to characterise the emission source or suppression effectiveness of ventilation and dust control measures. The engineering sampler is switched on at the face area at the beginning of the shift while the cutting machine is standing and is switched off before leaving the face area at the end of the shift. It aims at evaluating both the management (administrative effectiveness) of the dust control system as well as effectiveness of the dust control system (engineering). An engineering sample (sample collected during the sampling period only) is the dust sample taken at the CM operator's position (Fig. 2). The engineering sample is collected only while the engineering activity is taking place (in this case CM operation in a shift).

What is of importance in the current context is that when the directive was instituted and promulgated during the late 1990 s, the CM operator was on-board the machine. Currently, the majority or almost 90% of CM operations are done remotely where the operator is in fresh intake air. In addition, there was no guidance, in the B7 directive on the exact location of sampling with respect of the CM cab geometry other than "front of the CM cabin", as should be specified in evaluations of various engineering dust control systems.

Fig. 3 shows the position of the instrument used to obtain a CM engineering sample, (i.e., location '1' in Fig. 3) as per Directive B7 that applied in Mine Health and Safety Council (MHSC) studies [13]. The choice of location-1 provides an indication of dust rollback at the CM operator's position and the effectiveness of directional sprays and the ventilation system and of the CM dust control system when the CM is operated with an on-board scrubber and auxiliary ventilation system. Operating CMs 'remotely' as is common now allows the CM operator to be located in the fresh intake air (location R in Fig. 3). With the switch over to remote operation and the operation of larger CMs, the position of the sampling device was also moved away to other locations towards the back of the CM (Locations 3, 4 and 5 in Fig. 3). This has resulted in failure

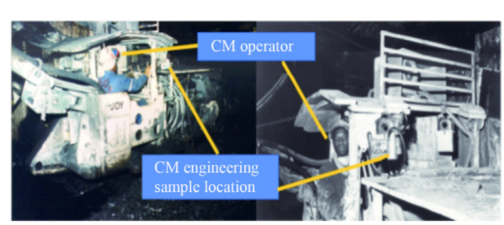

Fig. 2. Position of samplers at the CM operator's position.