Heat stress management in underground mines

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ARTICLE INFO

ABSTRACT

Heat management must be maintained within the mine working environment to minimize stress on equipment and personnel. The issue is a growing concern as mines continue to expand in size, depth and infrastructure. Heat management is a concern as it relates to both heat sensitive equipment and more importantly the health and safety of the workers found within the mine. Proper application of engineering protocols and work practice controls will have a direct impact on the health and safety of workers and increased productivity. Using continuous monitoring stations placed in strategic locations throughout the mine to capture the environmental conditions, various strategies can be used in the planning and prevention of potential hazard exposure. Economic analysis is used to select the most feasible strategy for heat stress control. This paper presents a step by step methodology that may be considered by ventilation specialists to effectively implement a heat management control system. A case study based on a detailed heat management assessment conducted for a potash mine in Saskatchewan, Canada is presented.

1. Introduction

Heat stress can affect individuals with a range of ill effects, compromising the ability for an individual to cool oneself. Factors influencing the severity of heat stress may include the workers age, fitness level and overall health. Additionally, the effects of heat stress can range, in order from least to most dangerous, from heat rashes, heat cramps, heat exhaustion to heat stroke–the latter being the most dangerous with the highest risk of death. Heat stroke occurs when the body's internal temperature rises above 40 °C [1].

There are many different heat sources that contribute to hot environmental conditions underground. These factors may be greatly increased or decreased based on the mine and mining methods used. Some common sources of heat may include auto compression or adiabatic compression, geothermal gradient, blasting, electrical and diesel machinery, human metabolism, oxidization of the orebody or timber, and ground movement [2]. The geothermal gradient with deep mines is often the greatest contributor to the overall hot conditions as the virgin rock temperature increases with depth [3]. The virgin rock temperature surrounding the excavations has a significant role of the ambient air temperature throughout the mine, however electrical and mechanical infrastructure may have varying additional impacts on the condi-

tions spread out across the mine workings. These effects of the heat sources on the environmental conditions ultimately may have substantial impacts in both local excavations and workings found throughout the mine, which must be considered and evaluated.

Heat management is an important factor as mines expand to meet the demand of their growing workforce and extraction rates. The introduction of new equipment and manpower puts additional demands on the ventilation system that is often the primary means of heat control. When mines plan to place additional significant heat sources into the ventilation system, the proper methodology used to monitor, establish and control heat stress with economically viable solutions must be established. The methods used to control environmental conditions within the mine workings need to be both economically viable and feasible. A review of alternatives for cooling ultra-deep mines in Northern Ontario and Quebec, lays out a variety of options that could be implemented within mines experiencing heat stress conditions, which captures capital expenditures and maintenance costs of the systems [4]. Cooling method technologies include ice slurry systems, cooling tower, bulk air cooling, spot coolers, among others. The opportunities and costs of these methods must be thoroughly understood before a mine can implement a heat management program.

This paper presents a step by step methodology for (1) identifying heat sources, (2) establishing a heat monitoring program, (3) calculating heat loads underground, (4) applying heat management strategies and (5) comparing and selecting engineering solutions to heat control.

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A detailed case study, based on a heat stress management study conducted for an underground potash mine, is presented to illustrate application of the proposed strategy.

2. Heat management methodology

A proposed methodology for establishing a heat management program is presented. In the methodology, heat sources are identified, data is collected from environmental monitoring stations and calculated heat loads are assessed using ventilation modeling software. Application of specific management control strategies allows one to control or eliminate heat stress and improve safety.

2.1. Identification of heat sources

All heat sources within the area of interest must be identified and quantified in terms of heat load. The virgin rock temperature is a critical factor in assessing heat loads on the system. The geothermal gradient may provide enough details to accurately describe the surrounding rock temperature. An effective way to measure the virgin rock temperature may be through drill hole data collection [5]. Drill holes are extended a minimum of 10 m into the rock strata at various locations. Thermocouples installed and insulated at depths along the drill hole collect data for analysis. As the temperature levels stabilize with depth, a virgin rock temperature may be determined. To identify heat sources in an area of concern, a survey of the equipment found must be completed. Electrical infrastructure, including power lines and transformers, may be assessed through their resistances and efficiencies to determine heat losses [6,7]. Additionally, stationary equipment and mobile equipment will also have a rated efficiency, which allows for the calculation of heat lost to the atmosphere by identified heat sources.

2.2. Establishment of a heat monitoring program

There is a wide range of environmental monitoring programs that are commonplace throughout the mining industry. Mining regulations typically set minimum standards regarding the monitoring and recording of the environment factors relating to heat found within the underground environment. The basic method frequently employed is the use of handheld monitoring equipment, which is checked and recorded at predetermined locations and on a set schedule. Additional monitoring often only occurs as the result of a change to the ventilation conditions. This type of monitoring often presents a level of accuracy that is sufficient to meet regulatory requirements, but may not provide enough detailed information to account for fluctuating conditions that can range from acute cases to seasonal in nature. When an area within the mine is identified as a potential hazard from heat accumulation, additional monitoring is required. This is done to ensure that the areas the workers are entering are well-managed to minimize heat stress exposure. Additionally, if there is heat sensitive equipment, reducing the environmental heat conditions will often promote equipment function as well as extend equipment life. To capture enough information to accurately describe the conditions found within the subject area of concern a minimum monitor recording frequency must be met based on potential daily and in some cases hourly fluctuations. Currently there are several stand-alone environmental monitors that can be set to monitor conditions at intervals set by the user and placed in the field for real time observation and data collection.

2.3. Calculating heat loads underground

In order to assess the heat load within the underground environment, there are different methodologies that may be employed in order to use the appropriate heat management technique. Heat stress is often considered as a factor of the wet bulb globe temperature when considering the effects of heat on the workers in the mine.

Wet bulb globe temperature (°C) WBGT, can be calculated within the mine environment with the following equation;

$$\text{Web bulb globe temperature} = 0.3t_{gt} \times 0.7t_{wb} \tag{1}$$

where t_{gt} is the globe temperature, °C; and t_{wb} the wet bulb temperature, °C.

To assess the energy that is contained within the air in the underground environment, the enthalpy of the system can be calculated, which considers the moisture content of the air. Additionally, the sigma heat can also be calculated, which considers the energy content less the moisture content. Both methods used to describe the energy contained within the air are considered on a dry basis (kJ/kg dry air).

In order to calculate the enthalpy of the system, the enthalpy of the air (kJ/kg) (h_a) and the enthalpy of the vapour (kJ/kg) (h_v) must be combined [8].

$$h = h_a + h_v = 1.005t_{db} + W(2501.6 + 1.884 \times t_{db}) \tag{2}$$

In order to calculate the apparent specific humidity (kg/kg dry air) the following equation must be used:

$$W = 0.622 \frac{P_s}{P_b - P_v} \tag{3}$$

$$P_S = 0.6105 \exp\left(\frac{17.27 \times t_{db}}{237.15 + t_{db}}\right) \tag{4}$$

$$P_v = P_S - 0.000644 \times P_b(t_{db} - t_{wb}) \tag{5}$$

In the above equations, t_{db} is the dry bulb temperature, °C; P_s the saturation vapour pressure, kPa; P_b the barometric pressure, kPa; and P_v the vapour pressure, kPa.

The enthalpy can then be applied to the mass flow (M_f) to find the heat flow (Watt) (q_f) in the system. The following calculation assumes not change in moisture to the system.

$$q_f = M_f(\Delta h) \tag{6}$$

$$M_f = Q \times w \tag{7}$$

where M_f is the mass flow, kg/s; Δh the sigma heat change, kJ/kg; Q the flow rate, m³/s; and w the air density, kg/m³.

In a ventilation system where there is a change in moisture the heat flow can be found using the sigma heat on a dry basis (S).

$$q_f = M_f(\Delta S + B) \tag{8}$$

$$S = h - 4.187 \times W \times t_{wb} \tag{9}$$

where B is a term which depends on the process involved and on the change in moisture content, °C⁻¹.

Another method of calculating heat loads within the mine environment is by calculating the heat load losses, based on equipment found within the excavation of concern. This method is useful for both reactive heat management planning and predictive heat management. In order to assess the heat losses from equipment, a detailed equipment survey must be conducted on the equipment found within the area of concern. This includes the stationary and mobile equipment, the infrastructure used to power the system, and the utilization of the components within the area. It is advisable to break down the area of concern into smaller segments based on changes in features contained within the excavations, or physical changes in the excavation itself. The strata surrounding the excavation and the changes in moisture content can also have