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A parametric analysis of a tunnel climatic prediction and planning model

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Abstract

This paper presents results of a series of detailed parametric studies analysis conducted on a computer based tunnel climatic prediction model developed at the University of Nottingham.

An extensive number of computer simulations have been undertaken using the drivage model. Sensitivity exercises have been undertaken to analyze the effect that variations to the various input and computational parameters have on the predicted climatic conditions. The results of these model sensitivity exercises have been compared against both manually measured and continuously recorded digital climatic survey data collected from within a rapid development drivage of a representative UK coal colliery. The conclusions drawn from these comparative analyses are reported.

The influence of the main climate model variables studied are the rock thermal parameters, the total efficiency of the auxiliary forcing fan, and the electrical equipment utilization (i.e., percentage of power loading given off of sensible heat into airstream). The results of these analyses have identified the range of values that may be taken by these parameters in order that the tunnel climate prediction model satisfactorily reproduces the measured psychrometric conditions.

Keywords: Tunnel ventilation; Mine climate; Climate control

1. Introduction

The extraction of minerals and coal at greater depth, employing higher-powered machinery to increase production levels has imposed an increased burden on ventilation systems to maintain an acceptable working environment. Deterioration in the climate experienced within these workings may also adversely affect the health and safety of the workforce. In the UK, coal extraction is now being practiced at depths of over 1000 m at virgin strata temperatures (VST) in excess of 40 °C. In addition, the adoption of continuous miner and tunnel bolting support methods has permitted improved development rates to be achieved at the cost of increased emissions of dust, gas and heat and humidity. There is a recognized need to improve the efficiency in the design and operation of auxiliary ventilation systems to maintain an adequate underground environment and climate. Any improvement achieved in the quality, quantity and control of the delivered ventilation will assist in the provision of improved gas and dust dilution and climatic control.

The construction of the current computer based climatic prediction tool builds upon earlier research (Ross et al., 1997), which developed a prototype model for short tunnel developments. The current model predicts the psychrometric and thermodynamic conditions within long, rapid development single entry tunnel drivages. The model takes into account the mass and heat transfer between the strata, water, machinery and the ventilation air (Lowndes et al., 2004).

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The physical basis behind the construction of the computational model is briefly reviewed in this paper. The full details of the construction of the model and the initial model correlations against ventilation, climatic and operational data, obtained from a number of rapid tunnel developments within UK deep coal mines may be found in the paper by Lowndes et al. (2004).

This paper presents the results of sensitivity analyses performed on this model that were compared against the continuously measured and recorded climatic survey data conducted over a week at the H272 development drivage of Stillingfleet colliery, UK Coal Ltd. The analysis performed was designed to investigate two specific operational periods within the drivage:

(1) Stage one: parametric studies were conducted using the climatic survey data obtained during a weekend non-production period. During weekend periods the overlap exhaust fan of the ventilation system was switched off and the outlet to the forcing duct was extended to the face end of the tunnel. The maximum set back distance of the force duct from the face end was maintained at 5 m. Consequently during the weekend period, the numbers of potential heat loads to the ventilation air within the drivage associated with production activities were significantly reduced. The remaining major heat sources identified during the weekend period included (i) the heat source/sink effects of the strata; (ii) water pools/floor dampness at head-end; and (iii) the force auxiliary ventilation fan. The collection and analysis of the climatic data together with a comparison with the resultant climate model predictions provided the opportunity to study the heat contributions made to the air stream by the reduced number of potential heat sources and to quantify the range of the parameters that characterize these heat sources. The influences of the main parameters studied were the rock thermal parameters (conductivity and diffusivity) and the total efficiency of the forcing fan.

(2) Stage two: further model sensitivity studies were further conducted to identify the effect of the additional heat loads present during the weekday production periods. In addition to the background heat sources discussed above, the additional heat sources present include: (i) the heat generated by the machinery and associated switchgear, transformers and hydraulic pumps; (ii) the freshly cut roadway rock surfaces; (iii) the heat emitted from conveyed mineral; and (iv) the influence of dust suppression sprays. In addition, during cutting operations the overlap exhaust fan and associated scrubber unit was switched on.

The purpose of the analyses described above was to evaluate the impact produced on the model predictions by a variation in the range of specific model input parameters. The major parameters investigated included the rock thermal parameters, forcing fan efficiency, and the machine heat output. The results of these model calibration exercises allow the range of permissible input parameter values to be identified which enable the validated model to be used to assess the climatic impact of the use of alternative ventilation and/or mining configurations.

2. Aims of the development of the climatic drivage prediction programme

Within many deep, long and highly mechanized underground workings there is a need to investigate the development of a range of efficient and flexible integrated ventilation and refrigeration cooling systems to maintain comfortable climatic conditions. The cyclical nature of mechanized cutting/bolting operations can produce periodic fluctuation in the climatic conditions created within these workings. The existence of this changing work and environmental loading cycle requires the development of sympathetic and adaptable ventilation and cooling system. It is therefore, necessary to consider the optimal location, monitoring and control of these integrated refrigeration and ventilation systems to produce a flexible and cost effective solution.

2.1. Summary of the background to the construction of the tunnel climate model

The psychrometric, climatic and machinery heat source calculations used within the rapid development tunnel model (Lowndes et al., 2004) are based on procedures used within the commercial software CLIMSIM™ initially developed at the University of Nottingham (Gibson, 1976) and now supported by Mine Ventilation Services (MVS) Inc, (1997).

The CLIMSIM™ model was developed to simulate the climatic conditions within a through flow open ended tunnel, in which the ventilation air travels from one end of the tunnel to the other. The computational model divides the tunnel airflow domain into a series of linear interconnected discrete volume elements. The iterative calculation method requires the definition of either the measured or defined inlet airflow and psychrometric conditions for the element at the entry to the defined flow domain. By applying a successive series of calculations, based on the laws of the conservation of mass and energy across each volume element, the thermometric conditions of the airflow at the outlet to each element is determined. The calculations of each volume element are carried out sequentially from inlet of the tunnel to outlet in the direction of the airflow.

In the construction of the computational model for the dead end tunnel drivage model, the airflow domain is also divided into a series of linear interconnected discrete volume elements. However, in addition it is necessary to construct two integrated sets of volume elements, one to represent the air flow in the main body of the tunnel drivage and the other to represent the air flowing within the