ABSTRACT

One of the underlying assumptions of predicting the climate (climate simulation) in the mine airway is that, for the airway studied, the psychrometric properties of the incoming air remain constant. This assumption can be accepted for the airway at a considerable depth. However, for shallow mine entries (mine shafts, inclines, or declines) which are not too deep, the incoming air properties are influenced by several factors such that the assumptions become unacceptable. These factors include, primarily, the surface climate changes and the cyclic variability in strata temperature in the top 20-25 m of the ground. The conventional climate simulation models cannot find ready applicability in such airway situations. The periodic variations of the surface climate and the upper strata temperatures induce the thermal flywheel effect in the prediction of climate in mine entries that are shallow. The role of the thermal flywheel effect diminishes as the depth of the working increases. The need, therefore, arises to interpret the phenomenon better so that more accurate climate prediction can be achieved in mine intake airways.

In this work, the diurnal changes of psychrometric conditions in a shallow intake incline in a coal mine were investigated. 24-hour studies were conducted in thirteen days spread over thirteen months. These observations, more or less taken at once in a monthly interval, aim to cover the surface climate conditions experienced over the whole year. On each study day, psychrometric observations were made at approximately 2-hour intervals at the top and bottom of a 180 m-long incline of a gradient of 1 in 3. These observations, coupled with airflow measurements and the thermal properties of the surrounding rock, form the basis of the investigation. The studies performed gave the following outcomes:

- Interpretation of the heat exchange behavior between the rock and the air over the entire study period.
- Identification of the factors that influence heat exchange behavior through Kendall's rank correlation analysis.
- Prediction of the direction of heat exchange between the rock and the air using the Multiple Logistic Regression model.
- Development of a transient model for the climatic prediction at the incline bottom based on Duhamel's theorem and validation of the same.

It is observed that the intake air receives sensible heat from the airway during the cooler part of the day, typically from 6 PM to 8 AM. In the remaining part of the day, sensible cooling seems to take place. The latent heat exchange is unidirectional from rock to air, as expected. When daily average heat exchanges are analysed, the higher latent heat transfer is observed in seasons of winter and spring by order of 70% compared to other seasons. The daily average sensible heat exchange is negative in summer and monsoon seasons (air to rock). As a consequence, the average net heat exchange in the airway is lower for summer and monsoon seasons.

The Kendall rank correlation analysis reveals that wet-bulb depression of inlet air is the most important factor for air-to-rock heat transfer. A positive correlation ($\tau = 0.32$) is found between strata heat and wet-bulb depression, i.e., the higher the inlet air wet-bulb depression, the higher the net heat exchange from air to rock. In contrast, the sensible heat of inlet air is dominating factor in explaining rock-to-air heat transfer, but with a negative correlation ($\tau = -0.62$). Thereby, if the incoming air has higher sensible heat, it would lead to diminished net heat exchange from rock to air. The processing of the observations using the multiple logistic regression model results in the optimal cut-off probability of 0.478. Performance evaluation of the proposed model on the testing dataset shows an F-score of 0.8182 and an accuracy of 80%, signifying good classification performance.

A transient model based on Duhamel's theorem is developed in the form of a computer program in order to forecast dry bulb temperature and moisture content at the incline bottom using the common climate simulation input parameters and time history of the psychrometric properties of incoming air. When daily cycles are consistent, a five-day time history for the inlet psychrometric properties improves the prediction compared to a shorter duration. However, if the cycles are inconsistent, as in the case of monsoon, higher numbers of cycles as input would, in fact, lead to a decrease in predictability. Predictions with an error of 1 ºC for dry bulb temperature and 0.5 g/kgda for moisture content are achieved with this model. The sensitivity analysis performed in the model showed that two parameters essentially influence the prediction, these being strata temperature at a depth of 25 m and equivalent wetness of the airway.

At greater depths, the heat transfer between rock and air is unidirectional due to the dependence of strata heat on depth. Numerous literary resources and underground climate prediction models are available for such scenarios. As previously noted, at shallower depths, the exchange of heat between the surrounding strata and the airway depends on surface climatic changes. Regrettably, at present, there are no models available that fully take into account the influence of surface climate variations on underground heat transfer behaviour. Moreover, in today's world, fast urbanization or practical reasons require us to build structures underground. To maintain a comfortable environment in such structures, we must carefully control the temperature and humidity levels. The surface climate can also help in this regard if we understand the thermal flywheel phenomenon better. The study demonstrated the impact of surface climate on underground heat exchange processes at shallow depths and developed a model for predicting the underground climate. This research is significant because it can support the technology of cooling-on-demand to help control the subterranean climate while also being cost-effective.