Case Study

A Study of Heat Stress Parameters at Kozlu Coalmine, Turkey

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As mining operations go deeper, working conditions become more severe because of high temperature and moisture. The major heat source in deep mines is geothermal heat from the strata. Apart from the rise in rock temperature occurring as working depths increase, the air in mines is also affected by other heat sources. In modern face workings, for example, outputs of between 1,000 and 2,000 kWh may be installed for face conveyors, ploughs and shearers. This involves not only the heat given off by electrical units but also the heat released when stone and coal are being broken away. The mine climate is also affected by the high moisture content of the air, especially as water is required for dust control and large quantities of water collect in the workings owing to geological conditions^{1, 2}.

Hot environments can produce a strain on the human body that can lead to discomfort, heat stress and death. It should be noted that any environment which causes physical discomfort will involve a decline in standards of care and attention. The potential for accidents and loss of production is thus greater in a mechanized operation where a simple error made by an individual can have serious repercussions. Therefore, failure to create reasonably comfortable working conditions in underground mines will not only put the health and safety of the workforce at risk but also seriously affect productivity and profitability^{3, 4}.

Setting limits for work in hot environments is usually approached in two ways: setting limits for personnel parameters (such as clothing, strenuousness of the activity) and setting limits for the environmental conditions (such as air temperature, humidity)¹. In this paper, mine climate factors which affect mine personnel were examined using linear regression analysis. In order to assess which of the heat stress indices best predicts the miners physiological responses, it was necessary to observe miners who are exposed to high environmental

temperatures. For this purpose, *in-situ* measurements were made at –425 m level in the Kozlu Colliery of Turkish Hardcoal Enterprises in Turkey.

Method

Heat from sources such as the rock, autocompression in the intake airway machinery, the air temperature of the available ventilation and the heat released when coal is broken away contribute to the thermal load of the mine atmosphere in underground coal mining. Water required for dust control collects and together with ground water increases the level of humidity. Methods for the assessment of hot environments can be generally divided into three types. These are direct measurements, empirical methods and rational indices².

The most commonly used heat stress indices, based on direct measurement of climatic parameters, for the assessment of the thermal environment in mines do not consider the personnel parameters “work rate” and “clothing”. The Wet Globe Temperature and the Wet Bulb Globe Temperature (WBGT) are examples of indices used in this type of method^{4, 5}. The climate indices in the second group are based on empirical studies demonstrating a direct correlation between various climatic conditions and the strain they cause. The best known indices in this group are the Effective Temperature Index and the Predicted Four Hour Sweat Rate Index⁵. Rational methods for measuring hot environments are based upon a calculation of the heat exchanges between the human body and the environment.

A physiological heat strain prediction model was developed by McPherson to calculate the inequality between net heat transfer and a known or estimated metabolic rate. A transient period will occur when the body temporarily accumulates or loses heat at a rate Ac (W/m^2), given by equation [1]².

$$Ac = M - (Br + Rad + Con + Evap) \quad [1]$$

Where ;

M : Metabolic energy production, W/m^2

Br : Respiratory heat loss, W/m^2

Rad : Radiant heat loss, W/m^2

Con : Convective heat loss, W/m^2

$Evap$: Evaporative heat loss, W/m^2

$Br + Rad + Con + Evap$ is named Air Cooling Power (ACP) and is used for the determination of the heat transfer between the human body and the environment.

Case Studies

The Kozlu Colliery of Turkish Hardcoal Enterprises has the deepest coal production seams in Turkey and heat stress standards aren't applied to underground miners. A new shaft is also being sunk to –1000 meters, so there will be deeper production seams in coming years and heat-moisture problems will start to arise. Therefore, heat stress standards should be developed and applied to the miners.

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Table 1. Heat stress data

Dry bulb temperature	: 25.3°C	[SD: 0.034]
Wet bulb temperature	: 20.2°C	[SD: 0.069]
Air velocity	: 2.5 m/s	[SD: 0.04]
Pressure	: 106.3 kPa	[SD: 0]
Rock surface temperature	: 25.3°C	
Metabolic heat production	: 245 W/m ² (Moderate manual work)	
Clothing type	: Thin trousers and short sleeved shirt	
Body view factor	: 0.73 (For a walking person)	

Table 2. Convergence of the thermoregulation model towards thermal equilibrium

Iteration	Skin temperature (°C)	Br (W/m ²)	Con (W/m ²)	Rad (W/m ²)	Evap (W/m ²)	Net cooling (W/m ²)
1	32.12	25.94	47.22	12.73	76.49	162.38
2	32.95	25.94	52.92	14.27	87.13	180.26
3	33.6	25.94	57.4	15.48	109.46	208.28
4	33.97	25.94	59.93	16.18	128.03	230.08
5	34.11	25.94	60.96	16.46	136.74	240.1
6	34.16	25.94	61.3	16.55	139.74	243.53
7	34.18	25.94	61.4	16.58	140.65	244.57

In order to determine the heat stress parameters effect on workers detailed surveys were made on the -425 m level. The surveys included measuring dry and wet bulb temperatures, air velocity and pressure, determination of rock surface temperature, and workers' metabolic heat production, clothing type and body view factor, defined as the fraction of radiation emitted by the body and intercepted by rock surface. The view factor has been reported in the range 0.7 to 0.75 for seated, standing or crouching personnel and 0.73 for a walking person²⁾. A whirling psychrometer for the dry and wet bulb temperature measurements, an anemometer for air velocity measurement and a barometer for pressure measurement were used. Ten measurements were made to determinate the dry and wet bulb temperatures, air velocity and pressure. In some circumstances, rock surface temperature may be taken as the dry bulb temperature of the air⁶⁾. The tables given by McPherson were used to select the values of workers' metabolic heat production and clothing type⁶⁾. The heat stress data and standard deviations (SD) of these data are given in Table 1.

From the thermoregulation model, an initial base skin temperature of 32.12°C was established, taking clothing and air velocity into account. A detailed description of this calculation was given by McPherson^{2, 6)}.

The simulated average skin temperature is increased as a function of A_c and the transfer solution process is re-evaluated until A_c is within ± 1 W/m² of zero. Table 2 illustrates the convergence of the model towards

equilibrium when net cooling equals metabolic rate.

The results show that a person will attain an equilibrium skin temperature of 34.18°C after seven iterations. The skin temperature was increased and respiration, convection, radiation and evaporation cooling were recalculated. When the difference between net heat transfer and metabolic heat is within ± 1 W/m² of zero, the iteration procedure will attain an equilibrium skin temperature. Consider a man working at a metabolic rate of 245 W/m², the limiting value of average skin temperature is 34.45°C. Despite this indicating acceptable conditions with small risk of heat strain, especially in deeper levels, working conditions become more severe because of high temperature and moisture. Thus, the mine air causes heat stress on mine workers and reduces their work efficiency.

Consider measurements of 25.3°C dry and 20.2°C wet bulb, the WBGT is 21.73°C. Under these conditions, there is no heat stress problem according to NIOSH, but ISO 7,243 indicates a heat stress problem for workers not acclimatized to heat.

The Effective Temperature (ET) is about 19.86°C according to the Effective Temperature chart and because the Effective Temperature doesn't exceed the reference values a heat stress problem isn't recognized in the work places.

The main problem with the heat stress indices is that they do not take into account all the factors which influence human heat transfer and a direct comparison

between indices is not possible^{7,8}. Indices which account for work rate, for example Air Cooling Power (ACP), are more useful, as particular limiting climates for particular work areas and tasks can be set. It is useful to also employ more than one index of the mine climate to assess climatic conditions, since for a particular climate, one index may not indicate that a problem exists whilst another does⁸.

According to ET, there is no heat stress problem for miners working in the Kozlu Colliery of Turkish Hardcoal Enterprises. On the other hand, WBGT and ACP indicate the danger of heat stress especially for the workers working in levels deeper than -425 m.

All climate indices are implicitly based on a model of the thermophysiological response of humans to climate stresses⁵. The degree of activity or workload (metabolic rate) heavily influences body heat load. Therefore, an index that recognizes this work activity may be considered more appropriate. An example of such an index is the ACP which accounts for the degree of work activity and clothing worn⁹.

There are six factors influencing individual capacity for heat exchange with the environment. These are dry bulb temperature, wet bulb temperature, wall rock temperature (radiant heat), volume flow rate, metabolic heat (work rate) and clothing⁹.

Under these conditions, there is a need to determine the most important factors to be taken into account in a definition of the heat stress. Once they have been found, it can be decided what can be done to protect the miners in underground mines against unacceptable heat stress.

A linear regression analysis was carried out to identify components of the model that are potentially important contributors. If a small change in a parameter results in relatively large changes in the outcomes, the outcomes are said to be sensitive. How does the estimated mean skin temperature change when one of the input variables changes? Using the following steps we carried out the linear regression analysis:

1. Selection of the parameters to be tested (all the above mentioned parameters)
2. Determination of the test range of each parameter (between -40 to 40% with an increments of 10%)
3. For each selected parameter, run the thermoregulation model repeatedly
4. Determination of the most accurate parameters.

Conclusion

1. Setting limits for work in hot environments is usually approached in two ways: setting limits for personnel parameters and setting limits for the environment itself. According to this study, setting limits for personnel parameters is of prime importance in protecting the miners against unacceptable heat stress.
2. The skin temperature is significantly affected by body

activities and by the clothes.

3. The degree of activity and the types of clothing heavily influence body heat load. Therefore, an index that recognizes work activity and clothing is more appropriate.
4. Reducing the effect of metabolic heat can be accomplished by reducing the physical demands of the work. It may be necessary to provide adequate and regular rest periods to minimize heat production.
5. Clothing has great effect on the thermal strain of workers because the cooling effect of sweat relies on adequate air circulation close to the surface of the skin. If the work is hard and the clothing is heavy, then the metabolic heat load on the body is greatly increased, even though the environment may be considered to be moderate.
6. The present standard in Turkey, only gives a range of temperature for work in hot and moist places. This standard should be improved and detailed in such a way that the personnel parameters are included. Therefore, heat stress standards should be developed and applied in mines for safe and comfortable working environments.
7. It should be noted that any environment which causes physical discomfort will involve a decline in standards of care and attention. Therefore, failure to create reasonably comfortable working conditions in underground mining will not only put the health and safety of the worker at risk but can also seriously effect productivity.

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