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Heat Transfer Generated in an Underground Mining Environment

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Abstract

The article presents the results of the heat transfer analysis that is generated in an underground environment, specifically in coal mines. The objective is to observe the variability of the results, comparing mines with level access and inclined access; Another parameter of comparison has been the variation of the altitude at which the mines are located; The parameters of temperatures, air flow, relative humidity, air density, length of roads, quantity of explosive, number of miners, etc., have been collected in a coal mine located in the city of Cúcuta - Colombia. In order to speed up its use, it has used its own development software, which serves to model comfort and environmental quality underground.

Keywords: Heat transfer, software, thermal impact, underground environment

1 Introduction

The transfer of heat in an underground environment is due to circumstances, natural and introduced elements.

In an underground mine, the heat is generated by the geothermal gradient, the self-compression of the rocks, the use of explosives, diesel equipment and human metabolism, etc. Since any or all of them can be heat generators, it is important to control the temperature and humidity in the mines, both to understand the nature of the heat sources and to calculate or estimate the magnitude of the flow of this. (Hartman et al, 1997) [4].

The increase of the temperature in underground environments generates risks, which can cause tragedies in the worst cases. Two main aspects must be taken into account due to the risk generated by high temperatures: one is the affectation to the corporal health of the workers and the other is the impact on the safety and productivity of the mine. (Su et al, 2009) [9]. When humidity and temperatures are high in an underground environment, workers suffer from a feeling of not comfort, generating stress in them, and this in turn leads to an increase in accidents and a decrease in productivity. As the depth increases and the level of mechanization increases, the high temperatures and the damages produced by the heating, are the biggest problems that the mining safety presents, limiting the activity in the coal mines. (Song and Xie, 2011) [8] (Xie, Z., 2012) [11]

As a referent, in Table I, the percentage of accidents due to an increase in air temperature is related to gold mines in South Africa. (C. Anguo.2004) [1].

Table I. Relationship between accident rate and temperature at the mine

Air temperature in the workplace °C	27	29	31	32
Frequency of occupational accidents per thousand people	0	150	300	450

2 Physiological effects suffered by man due to the increase in temperature

The human metabolism is accompanied by the generation of heat, the temperature of the organism is maintained close to 36.9 ºC; the man, in contact with the surrounding air temperature you may feel a cold or cold sensation.heat, by physiological effects caused by low or high temperatures. (Navarro,V., Da Gama, C. 2005.) [7].

Heat stress can affect people with a variety of effectsharmful,compromising an individual's ability to freshen up. factors that influence the severity of heat stress include the age of the people who are level of physical condition and general health. In addition, the effects of theheat stress may vary, in order of least to greatest danger: eruptions,cramps, heat exhaustion by heat stroke; the latter being the most common.with the greatest risk of death. Stroke occurswhen the body's internal temperature rises above 40°C (.Saskatchewan, 1996)

3. Standards on environmental quality in terms of temperature for underground environments.

In general terms, the norms and regulations, in relation to the temperature limit in the underground environment, vary from one country to another, Table II.

Table II. Permissible temperature limit

Country	U.S.A	Austrália	Belgium	Portugal	France	South Africa	Brazil	Zambia	Colombia
Dry temperature (°C	30	27	30 (Te)	31	28 (Te)	27.5	30	32	32 (Te)

In Colombia, Decree 1886 of 2015, Regulation of Safety in Underground Mining, stipulates in Chapter III the reference to temperature. In article 218, it defines the maximum effective temperature of 31 ° C for a work front, with a dwell time of two-hour workers.

4. Sources of heat in underground mines.

4.1 Self-compression. Similar to a compression device, the air that enters a mine through a path is compressed and heated as it flows. Self-compression occurs when the potential energy is converted into thermal energy. If there is no exchange in the content of heat or humidity of the air, compression occurs adiabatically, with the consequent increase in temperature, according to the law of Equation 1, (Hartman et al, 1997) [4].

$$\frac{Ts2}{Ts1} = \left(\frac{Pb2}{Pb1}\right)^{(y-1)/y} \qquad (1)$$

Where; Ts is the dry temperature (° C), Pb is the atmospheric pressure (mm CH2O), and is the ratio of the specific heat of air to volume and constant pressure, and the subscripts 1 and 2 denote the initial and final conditions of a path or mining front.

In equation 2 the mathematical expression of the variation of air temperature by the self-compression of rocks (Δtha), in ° C, is presented. (Navarro, T. V. et al 2008) [6].

$$\Delta tha = 0.0098 \times L \sin \emptyset \qquad (2)$$

Where; L is the length of the road (m.) And ∅ is the angle of inclination of the mining work.

4.2. The rocky massif. The heat transfer generated by the rocky mass (Δtr) in °C, depends on several variables, as can be seen in equation 3 [6].

$$\Delta \mathrm{tr} = \frac{\lambda * P * L \; (h1 - htem \pm sen\alpha)}{Gg \; (\lambda * P * L + 2000 * \mathrm{pa} * Ce * Q)} \qquad (3)$$

Where; λ is the heat coefficient, Equation 4, P is the perimeter of the path (m), $htem$ Neutral Temperature Depth (m), Gg is the geothermal gradient (°C).

4.2.1. Heat transfer coefficient. λ. It comes as a function of the thermal conductivity K $(W\ /\ m°.C)$, the ratio of Dittus and Boelter Nud (dimensionless), and the diameter d (m), for horizontal and inclined tracks $d\ =\ (A\ +\ B)\ /\ 2$, where B is the base of the section (m) and A corresponds to the height (m).

$$\lambda = \frac{K * Nud}{d} \tag{4}$$

4.2.2. Geothermal Gradient. Gg**.** The surface temperature of the rocks rises constantly with depth, this increase is called a geothermal gradient or change in temperature per unit depth. Equation 5 [4].

$$Gg = \Delta t/\Delta Z \tag{5}$$

4.3. Machinery and Diesel Equipment. In general, the energy consumed by equipment used in underground mining transfers heat to the atmosphere; power losses and work performed generate heat directly or indirectly by friction. The above is true for equipment with electric motors, air compressors, internal combustion engines (diesel), machinery in general; although, compressors generate a cooling effect at the moment of air discharge [4].

The variation in air temperature due to heat transfer from diesel equipment, Δtd (°C), can be calculated from Equation 6 [6]

$$\Delta td = \frac{fm\times ft\times qd\times Pd}{\rho a\ \times Ce\times Q} \tag{6}$$

Where; fm, ft are combined mechanical and energy factors, qd is the equivalent energy of the ACPM y pd is the power of the engine *(Kw)* [6].

4.4. Use of Explosives. The progress of the work by drilling and blasting is common for works where the rocks are massive; the use of explosives generates heat that is transferred to the rocky massif and the air of the underground atmosphere. The "*mine ventilation Services, Inc*". of the USA (2000), recommends the expression of equation 7, to calculate this heat transfer Δex.

$$\Delta ex = \frac{ce \times eu}{86400 \times \rho a \times Ce \times Q} \tag{7}$$

Where, ce is the heat released by the explosive charge (Kj/Kg), eu is the quantity of explosives (kg/day), ce for ANFO is 3900 Kj/Kg, ce for 60% pure dynamite 4030-4650 Kj/Kg, ρa is the volumetric mass of air. (Kg/m^3), Ce is the specific heat of the air (KJ/m. °c) and Q is the Flow (m3/s) [6].

4.5. Human metabolism. The residual heat of the body is continuously rejected by the process of heat transfer. The result is an increase in the heat content experienced by workers, and in that of mine air, in small to moderate amounts [4]. Currently, the rates of assessment of the thermal conditions of the human body in hot and humid environments are widely used, but do not include a complete study of: wet temperature th, dry temperature ts, wet bulb temperature (WBGT), heat stress index, effort and recovery of heart rate, and body temperature [12] [3]. Normally in underground coal mining (Colombian case), the number of workers employed is high due to the low degree of mechanization; therefore, the increase in temperature generated by human metabolism Δthe is relevant [2]. This heat transfer can be expressed by equation 8 [6].

$$\Delta he = \frac{qh * n}{\rho \mathrm{a} * \mathrm{Ce} * \mathrm{Q}} \tag{8}$$

Where, qh (Kw / man), is the heat released by man as a function of the effective temperature; [4] Hartman states, that 0.25 KW of energy corresponds to each man, and n is the total number of workers per work front.

5 Materials and Methods

The work was carried out in two phases, one in the field and the other in the office. Weather parameters (temperatures, relative humidity, volumetric mass of the air) and ventilation (air velocity, flow rates, etc.) were taken from the San José, Carolina and Albaricas coal mines, located on cerro Tasajero in the north of the city of Cucuta, capital of the department of Norte de Santander (Colombia). The equipment used to collect the data was: Psychro Dial electric psychrometer, Extech 45170 thermo-hygrometer, Elcometer 309 Delta T thermo-hygrometer, Testo digital anemometer, KD2PRO resistivity and thermal conductivity meter.

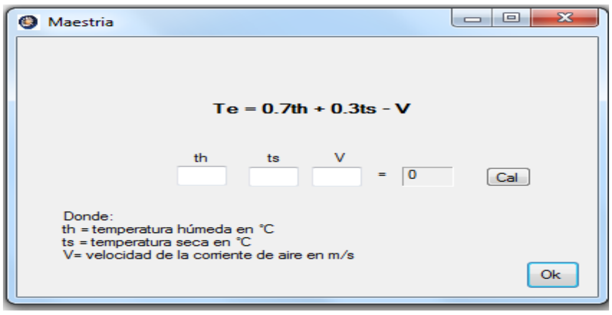
For the programming of the Software, the Visual basic.Net language has been used, which has been fed with the parameters and variables: of the Atkinson theory, of the decree1886 of 2015 [5], and those studied by Hartman et al 1997. Finally, simulations were carried out to verify the degree of accuracy of the software.

6 Results and Discussion

In Figure 2, the Software start window named "Master" is shown, where there is 3 Text box: Te, which is displayed to calculate the effective temperature, Mit that is displayed to calculate the heat transfer generated in the underground environment, and L max, which serves to optimize the length of the duct of an auxiliary ventilation system, from the variation of the diameter of this.

Figure 1. Software Startup Window

For the calculation of the effective temperature, a window is displayed, where there are three dialog boxes, which are fed with the ambient air velocity and temperature parameters, Figure 2. The results are displayed in a box called Label; this TextBox is unchangeable.

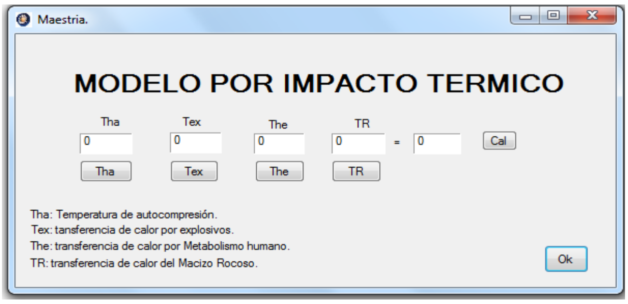


Te = 0.7th + 0.3ts - V

Donde:
th = temperatura húmeda en °C
ts = temperatura seca en °C
V= velocidad de la corriente de aire en m/s

Figure 2. Window for calculating the effective temperature

With the Mit window you can calculate the heat transfer (Thermal Impact), generated by the different natural and introduced elements present in the Underground environment, Figure 3.



Tha: Temperatura de autocompresión.
Tex: tansferencia de calor por explosivos.
The: transferencia de calor por Metabolismo humano.
TR: transferencia de calor del Macizo Rocoso.

Figure 3. Window to calculate the Thermal Impact

Table III shows the results of the limit of the time that mine workers remain in the environment, assuming the effective or dry temperature, according to the regulations of each country. The relative humidity (%RH) is assumed to be constant 90%.

Table III. Results of the permanence limit simulation

Country	USA	Australia	Belgium	Portugal	France	South Africa	Brazil	Zambia	Colombia
dry temperature ts (°C)	33	33	33	33	33	33	33	33	33
wet temperature (°C)	31	31	31	31	31	31	31	31	31
effective temperature (°C)			30.6		30.6				30.6
permanence limit (h)	0	0	2	0	2	0	0	0	2

According to the results of the above table, the countries where the time spent by workers in hot environments, at the effective temperature, is evaluated have a lapsa standard.

Table IV shows the results of the self-compression heat gradient Δtha, varying the length and inclination of the tracks.

Table IV. Results of the simulation of heat transfer by self-compression of rocks

IInclination Track Ø L (m)	**5°**	**10°**	**15°**	**20°**	**25°**	**45°**
100	0,09	0,2	0,26	0,34	0,43	0,8
150	0,13	0,3	0,38	0,51	0,7	1,15
200	0,17	0,34	0,51	0,68	0,9	1,53
250	0,21	0,43	0,64	0,86	1,1	1,92
300	0,27	0,51	0,8	1,02	1,3	2,3
350	0,3	0,60	0,90	1,22	1,5	2,7

According to the results of the previous table, the trend of the temperature gradient is 0.04°C, when the angle of inclination of the road is smooth; but as the dip increases between 10 and 15°, the gradient increases by 0.1°C for every 50 m. of length. If the slope becomes 100% (45°), the gradient increases to an average of 0.4°C for every 50 meters of mining length. Therefore, it can be inferred that there is more heat transfer at higher dipping.

Now, if we have roads with the same length, but their dip varies, respectively; the heat transference has an average tendency of 0.3°C for every 5° of inclination; less than 0.1°C, than the case analyzed in the previous paragraph with 100% slope.

7 Conclusions

The software used for the simulation of heat transfer, is a technological tool of great help for quick decision making.

In several coal mines, measurements have been made of the climatological and physical parameters of the air; With them, simulations have been carried out using software. Taking into account the above, it is possible to deduce that the greatest heat transfer to the environment is generated by the human metabolism, following that generated by the use of explosives.

In several work fronts, blood pressure and body temperature have been taken, to a sample of workers from the mines, obtaining that 50% of them have hypertension and pre-hypertension; the average temperature of the workers has been 38.5 ° C. The above is because there is no comfort environment; and therefore the ventilation service must be improved.

It is possible to conclude that the rock mass generates a greater proportion of heat than the carbon mantles.

The studied mines are found at heights between 700 and 1000 meters above sea level, with a dry tropical climate during most of the year; Due to the above and due to the depths to which the work fronts are located, it is necessary to implement air cooling systems.

For the mining works at the level the heat transferred by the rock mass is directly proportional to the length of advance of the work; while in inclined mining works, the heat generated by the rock mass is greater than that generated in level roads.

In the underground mining of Colombia, little is used equipment with motors of internal combustion type Diesel; Due to the above, the heat transfer gradient to the medium is low, and in many mines it tends to zero.

The main corrective measure to mitigate the thermal impact generated by heat transfer in an underground mine is the implementation of a mechanized main ventilation system; In addition, the auxiliary ventilation system must be optimized, based on: aerodynamic criteria, use of anti-explosion fans and flexible ducts. The simulation of events with software is one of the most used tools in the ventilation of modern mines. With the software product of this investigation, it is possible to simulate the optimization of the length of the duct, varying the diameter of this.

References

[1] C. Anguo, Formation and Harmfulness of Heat Hazard in Mine and its Control Measure, *China Safety Science Journal*, **8** (2004), 3-5.

[2] Y. Castro, Y. Castro, *Comfort and Environmental Quality Assurance Model for Underground Coal Mines*, PhD Tesis, Project in Environmental Engineering. University of Pamplona Colombia. 2013.

[3] Y. Castro, J. Ddelgado, J. Cáceres, Analysis of the thermal impact index generated in an underground environment, *Respuestas*, **19** (2014), no. 2, 32-40.

[4] H. Hartman, J. Mutmansky, R. Ramani, Y. Wang, *Mine Ventilation and Air Conditioning*, Third Edition. A Wiley-Interscience Publication.U.S.A 1997.

[5] Ministry of Mines and Energy of Colombia, 2015. Decree 1886 of 21 September 1886. 82.

[6] V. C. Navarro-Torres, Da Gama and R. Singh, Mathematical modelling of thermal state in underground mining, *Acta Geodyn. Geomater.*, **5** (2008), no. 4 341–349.

[7] V. Navarro Torres, *Underground Environmental Engineering and its Applications to Portuguese and Peruan* Mines, PhD Tesis, Instituto Superior Técnico de la Universidad Técnica de Lisboa. 2005.

[8] X. Song and Z. Xie, Research on Mine Cooling Measures for Zhangshuanglou coal Mine, *Procedia Engineering*, **26** (2011), 1391-1397. https://doi.org/10.1016/j.proeng.2011.11.2316

[9] Z. Su, Z. Jiang and Z. Sun, Study on the heat hazard of deep exploitation in high-temperature mines and its evaluation index, *Procedia Earth and Planetary Science*, **1** (2009), no. 1, 414-419. https://doi.org/10.1016/j.proeps.2009.09.066

[10] S. Wang, T. Ren, T. Zhang, Y. Liang and Z. Xu, Hot environment - estimation of thermal comfort in deep underground mines, *12th Coal Operators' Conference, University of Wollongong & the Australasian Institute of Mining and Metallurgy*, (2012), 241-248.

[11] Z. Xie, Distribution law of high temperature mine's thermal environment parameters and study of heat damage's causes, *Procedia Engineering*, **43** (2012), 588-593. https://doi.org/10.1016/j.proeng.2012.08.104

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