Available online at www.sciencedirect.com

ScienceDirect

Procedia Earth and Planetary Science 11 (2015) 463 – 468

Procedia
Earth and Planetary Science

Global Challenges, Policy Framework & Sustainable Development for Mining of Mineral and Fossil Energy Resources (GCPF2015)

Potential Sources of Heat in Underground Mines-A Review

Tripti Maurya[a,]* , Kailash Karena[b], Harsha Vardhan[a], M. Aruna[a], M. Govinda Raj[a]

[a] *Dept. of Mining Engineering, NITK Surathkal, Mangalore 575 025,Karnataka, India*
[b]*Shiva Consultancy Group, Sola Science City Road, Sola, Ahmedabad 380 060, Gujarat*

Abstract

Heat is an integral part of all the mining activities. Not only activities but different conditions are also responsible for emission of heat in an underground as well as opencast mine. In opencast mine the heat produced is dissipated in the environment not creating much problem to the working conditions, unlike in underground mines where proper ventilation provisions are made to eliminate the produced heat to improve the working conditions. In this review paper we will discuss the potential sources of heat in underground mines which deeply affects the working condition and ultimately working efficiency of the workers.

Peer-review under responsibility of organizing committee of the Global Challenges, Policy Framework &
Sustainable Development for Mining of Mineral and Fossil Energy Resources.

*Keywords:*Heat; workers health; working condition.

1. Introduction

In simple physics, spontaneous transfer of energy from one body to another, other than by work or transfer of matter is called heat. Heat is said to transfer from hotter body to the comparatively colder body same is the case with hotter medium to colder medium. In opencast working the main source of heat is the sun. Unlike in underground working the heat adds due to various reasons like geothermal gradient, spontaneous heating, autocompression, machinery, blasting, etc.

2. Basic heat transfer mechanism

As shown in figure 1 the mechanism of heat transfer is governed by three basic principles. Namely:

- Conduction: When heat is transferred from one body to other body while they are physically connected to each other.
- Convection: When heat is transferred from one body to another without any physical contact between the bodies.
- Radiation: When the heat is transferred from one body to another through a medium where the medium itself doesn't get heated.

Peer-review under responsibility of organizing committee of the Global Challenges, Policy Framework &
Sustainable Development for Mining of Mineral and Fossil Energy Resources.
doi:10.1016/j.proeps.2015.06.046

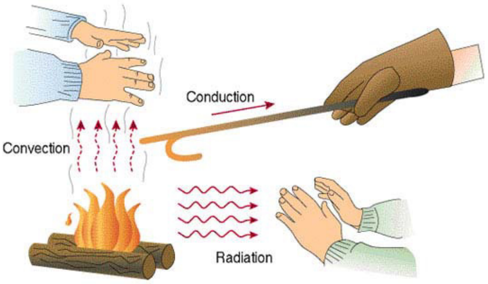

Fig.1. Mechanism of heat transfer

3. Sources of heat in mines

Table 1. Major sources of heat in mines

Opencast mines	Underground mines
Sun light	Geothermal gradient
Working machines	Autocompression
Blasting	Mechanized equipment
Spontaneous heating (in case of coal mining)	Explosives and blasting
	Mechanical processes and light

While in opencast mines the main source of heat is the sun, and the amount of heat generated by other sources is almost negligible as the heat generated by these sources is immediately dissipated in the environment not increasing the surrounding temperature to an uncomfortable level. Unlike in underground mines the heat released gets confined to the working area, if proper care is not taken the temperature of the working area can increase to an uncomfortable level. Below some such sources are discussed in brief.

3.1. Geothermal gradient

The increase in strata temperature with respect to depth is known as geothermal gradient (McPherson 1993). In other words geothermal gradient is the rate of increase in temperature with the increase in depth in the Earth’s interior. Table 1 shows the variation in temperature as we move down the depth.

Table 2.Variation in temperature with increasing depth

Depth	Effect on temperature	Cause
Within 50 m	Almost equal to the temperature of the ambient air	
50m-100m	Variable	Affected by the atmospheric changes and circulating ground water
Below 100m	Almost always increases	Due to tectonic settings and thermal properties of the rock

For dry airways, the flow of heat from the surrounding rock to the ventilation airways is proportional to the difference between the virgin rock temperature and the air temperature. In case of wet airways the heat flow rate from the rock to the air increases.

3.2. Autocompression

When the surface air is sent down the workings, either naturally or through man-made ventilation, it will experience a compression. This means that although the volume of air while going down reduces but, the amount of heat remains the same resulting in hotter air. Thermodynamically, this phenomenon is very similar to the way gas reacts in a compressor, air entering in a mine through shaft is compressed and heated as it flows in a downward direction. If there is no interchange in the heat or moisture content of the air in the shaft, the compression takes place adiabatically, with the attendant temperature rise following the adiabatic law:

$$\frac{T_2}{T_1} = (p_2 - p_1)^{[\frac{\gamma-1}{\gamma}]}$$

Where,

T is absolute dry-bulb temperature, (°Celsius)
p is atmospheric pressure, (Pascal)
γ is the ratio of the specific heats of air at constant volume and pressure, and
1 and 2 denotes the initial and final conditions respectively.

The increase in temperature is a result of potential energy being converted to thermal energy as the air falls through the shaft.When air or any other fluid flows downwards, some of its potential energy is converted to enthalpy producing increase in pressure, internal energy and hence, temperature.

$$H = PV + U$$

Where,

H is enthalpy (J/kg)
P is pressure (pascal)
V is specific volume
U is specific internal energy

The effects of autocompression are virtually independent of airflow. In deep mines, the intake air leaving the bottoms of downcast shafts may already be at a temperature that needs cooling. This is the inevitable result of autocompression.

The reverse effect autodecompression occurs in upcast shafts or ascentional airways. This is usually of less concern as upcast air will have no effect on conditions in the workings. However, the reduction in temperature due to autodecompression in upcast shafts can result in condensation and fogging. The mixture of air and water droplets may then reduce the life of the impellers of exhaust fans sited at the shaft top.

Due to autocompression temperature increases upto 10°C per km vertically downwards, either shaft or decline. As autocompression combines with surface air temperatures resulting in a very significant source of heat as mines go deeper and deeper.

3.3. Mechanized equipment

The operation of all mechanized equipment results in either of the two effects

a. Work is done against gravity, and/or
b. Heat is generated.

Few examples of equipment that work against gravity are:

a. A conveyor transporting material up an incline
b. a shaft hoist
c. a pump

Vehicles operating in level airways, rock-breaking machinery, transformers, lights and fans are all devices that convert an input power, via a useful effect, into heat.

Except the compressed air motors and devices such as liquid nitrogen engines, all other forms of power including electricity and chemical fuels produce thermal pollution that must be removed by the environmental control system in a mine.

3.3.1. Electrical equipment

Figure 2 below shows the fashion in which the power taken by an electrical machine is utilized. In two ways machine efficiency is relevant in this context:

a. First, the total amount of heat produced can be reduced only if the machine is replaced by another machine of greater efficiency to give the same mechanical power output at reduced power consumption.For any given machine, the total heat produced is simply the rate at which power is supplied.
b. Secondly, the efficiency of the machine determines the distribution of the heat produced.

The greater the efficiency, the lower the heat produced at the motor and transmission, and the greater is the heat produced at the pick-point, conveyor rollers, along the machine run or by any other frictional effects caused by the operation of the device.

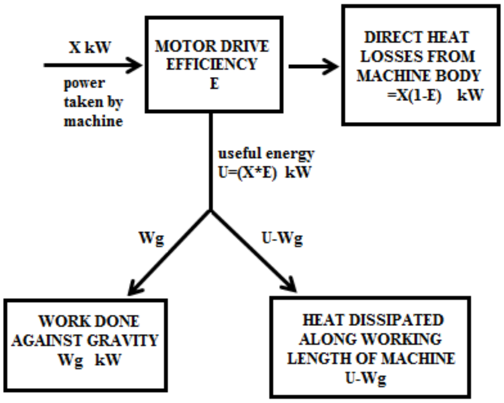

Fig.2. Heat produced by electrical machine

3.3.2. Diesel equipment

Generally, the efficiency of diesel engines is 33%, the remaining 2/3rd are released in the underground environment in the form of heat. Diesel is used in almost all the mining machines like, loaders, trucks, jumbos, explosives transport vehicles, four wheel drive vehicles, etc.

The internal combustion engines of diesel equipment have an overall efficiency only about one-third of that achieved by electrical units. Hence, diesels will produce approximately three times as electrical equipment of the same mechanical work output. This can be demonstrated taking a simple example:

Considering rate of fuel consumption to be 0.31 per rated kW per hour, at a calorific value of 34 000 kJ/l for diesel fuel, the heat produced isof heat emitted for each kilowatt of mechanical output.

$$= \frac{0.3}{60 * 60} \frac{liters}{kW\ output * second} * 34000\ \frac{kJ\ heat}{litre} = 2.83\ \frac{kJ}{s}\ (or\ kWatts)$$

This heat appears in three ways each of which may be of roughly the same magnitude. One-third appears to be heat from the radiator and machine body, one-third as heat in the exhaust gases and the remaining third as useful shaft power which is then converted to heat by frictional processes as the machine performs its task.

As with other types of heat emitting equipment there is little need, in most cases, to consider peak loads. It is sufficient to base design calculations on an average rate of machine utilization. The most accurate method of predicting the heat load is on the basis of average fuel consumption during a shift. The latter is defined as the fraction of full load which if maintained continuously, would use the same amount of fuel as the actual intermittent load on the machine.

A difference between diesel and electrical equipment is that the former produces part of its heat output in the form of latent heat. Each litre of diesel fuel that is consumed produces approximately 1.1 litre of water (liquid equivalent) in the exhaust gases. This may be multiplied several times over by the evaporation of water from cooling system and where water is employed in emission control systems. In situ tests have shown that the factor can vary from 3 to 10 litre of water per litre of fuel depending on the design of the engine, exhaust treatment system and the proficiency of maintenance.

3.3.3. Compressed air

When compressed air is used for drilling or any other purpose then there are two opposing effects that govern the heat load:

a. First, the work output of the machine will result in frictional heat at the pick point or as the machine performs its tasks.
b. Second, the removal of energy from the compressed air will result in the reduction of the temperature of that air at the exhaust ports of the machine.

3.4. Explosives and blasting

It has been estimated that about 90-95% of the energy released during blasting eventually finds its way into the underground environment as heat. It is probable that some of the heat is washed away with the blasting fumes and some gets trapped in the broken rock which may be released during the rock removal. The amount of heat removed by each process is a function of rock fragmentation, the ventilation arrangements and the mining cycle.

3.5. Mechanical processes and lights

The use of electricity and other mechanical devices increases the heat load of a mine. Different mining operations which add to the amount of heat in the mine are operation of fans, hydraulics, compressed air and any friction related heat. The heat produced by light is negligible.

3.6. Underground water

Two types of water sources are found in an underground mine:

a. Groundwater.
b. Mine water.

All groundwater, especially water from hot fissures and natural rock reservoirs, is an inexhaustible source of heat in mine workings. Since, water and heat both are derived from the surrounding rocks or geothermal sources, the water temperature will approach or sometimes it may exceed that of the rock. The water transfers its heat to the mine air mainly by evaporation, increasing the latent heat in the air. Equally large amount of latent heat may be added to the mine air through the evaporation of service water provided for drilling and wetting down and of drainage water from filling operations, also known as mine water, which also gets heated by the rocks.

4. Heat hazards

Due to excessive heat when the human body is not able to dissipate the heat to the environment the core body temperature which generally lies between 98°F to 100°F exceeds and can result to any of the below serious heat related health hazards which can even lead to death.

a. Heat stroke
b. Heat exhaustion
c. Heat syncope
d. Heat cramp
e. Heat rash
f. Transient heat fatigue

Among these hazards heat stroke is the most severe one which can even lead to death.

5. Conclusions

The purpose of this paper is to highlight the major sources of heat in underground mines which affects the working condition and ultimately affects the workers and the productivity of the mine.

Increased utilization and power of mechanization in mines and subsurface facilities has resulted in such equipment joining geothermal effects and autocompression as a major source of heat.

However, in case of machine utilization in many mines, records of fuel consumption by individual machines or even in separate sections of the mine do not seem to be maintained. The ventilation planner often must resort to the type of calculation shown above and using an estimated value for machine utilization.

References

1. Deshmukh, D.J. (2008). “Mine fires and spontaneous heating.” *Elements of Mining Technology Vol.2, Denett& Co.,* India, 4.1-4.33.
2. Donoghue, A.M., Sinclair, M.J. and Bates, G.P. (2013). “Heat exhaustion in a deep underground metalliferous mine.” *Occupational and Environmental Medicine*, 57, 165-174.
3. Epstein, Y and Moran, D.S. (2006). “Thermal comfort and heat stress indices.” *Industrial Health*, 44, 388-398.

4. Golbabaei, F., Monazzam, M. R., Hematjo, R., Hosseini, M., and Dehghan, S. F. (2013). "The assessment of heat stress and heat strain in Pardis Petrochemical Complex, Tehran, Iran." *International Journal of Occupational Hygiene*, 5 (1), 6-11.
5. Hancock, P.A. and Vasmatzidi, I. (1998). "Human occupational and performance limits under stress: The thermal environment as a prototypical example." *Ergonomics,* 41(8), 1169-1191.
6. Hartman, H.L., Muthnansky, J.M., Ramani, R.V. and Wang, Y.J. (1997). "Heat sources and effects in mine." *Mine Ventilation and Air Conditioning, John Wiley and Sons*, U.S.A., 585-617.
7. Hemmatjo, R., Zare, S., Heydarabadi, A.B., Hajivandi, A. and Ghaedi, H. (2013). "Investigation of heat stress in workplace for different work groups according to ISO 7243 standard in Mehr Petrochemical Complex, Assaluyeh, Iran." *Journal of Paramedical Sciences*, 4(2), 97-101.
8. Ismail, A.R., Haniff, M.H.M., and Deros, B.M. (2010). "Influence of wet-bulb globe temperature (WBGT) towards workers' performance: An Annova Analysis." *National Conference in Mechanical Engineering Research and Postgraduate Students*, 435-441.
9. ISO 7243, (1989). "Hot environments- Analytical determination and interpretation of thermal stress using calculation of required sweat rate." *International Organization for Standardization,* Geneva.
10. ISO 7243, (1989). "Hot environments- Estimation of the stress on working man based on the WBGT index." *International Organization for Standardization,* Geneva.
11. ISO 8996, (1990). "Ergonomics- Determination of metabolic heat production." *International Organization for Standardization,* Geneva.
12. Kielblock, A.J. and Schutte, P.C. (1993). "Human heat stress: Basic principles, consequences and its management" *Minesafe International Conference Proceedings, International Conference on Occupational Health and Safety in the Mineral Industry, Perth*, 279-294.
13. Knowlton, K., Miriam, R.E., King, G., Margolis, H.G., Smith, D., Solomon, G., Trent, R. and Paul, E. (2009). "The 2006 California heat wave: Impacts on hospitalization and emergency department visits." *Environmental Health Perspectives*, 117, 61-67.
14. Lahey, J.W. (1984). "What to do when the heat's on." *National Safety News,*130 (3), 60-64.
15. Lin, C.H., Lin, T.P. and Hwang, R.L. (2013). "Thermal comfort for urban parks in subtropics: Understanding visitor's perceptions, behavior and attendance." *Hindawi Publishing Corporation*, 2013, Article ID 640473. http://dx.doi.org/10.1155/2013/640473
16. Malcolm, J. McPherson (1993) "Physiological reactions to climatic conditions." Subsurface ventilation and Environmental Engineering, Chapman & Hall., 2-6 Boundary Row, London SE 8HN, UK,603-650.
17. Miller, V.S. and Bates, G.P. (2007). "The thermal work limit is a simple reliable heat index for the protection of workers in thermally stressful environment." *Annual Occupational Hygiene*, 51(6), 553-561.
18. Misaqi, F. L., Inderberg, J. G., Blumenstein, P. D. and Naiman, T. (1976). "Heat stress in hot U.S. Mines and criteria for standards for mining in hot environments." *Mining Enforcement and Safety Administration, United States Department of the Interior, MESA Report No. 1048,* 1-47.
19. National Institute for Occupational Safety and Health (NIOSH), (1972). "Criteria for a recommended standard- Occupational exposure to hot environments." *NIOSH publication no. 72-10269.* (Cincinnati, OH:NIOSH).
20. National Institute for Occupational Safety and Health (NIOSH), (1986). "Criteria for a recommended standard- Occupational exposure to hot environments." *USDHEW (NIOSH) publication no.86-113.*
21. Olesen, B.W. (1995). "International standards and the ergonomics of the thermal environment." *Applied Ergonomics*, 26(4), 293-302.
22. Parsons, K. (2006). "Heat stress standards ISO 7243 and its global application." *Industrial Health*, 44, 368-379.
23. Payne, T. and Mitra, R. (2008). "A review of heat issues in underground metalliferous mines." *Proceedings of 12th U.S./North American Mine Ventilation Symposium 2008-Wallace (ed),* 197-201.
24. Rowlinson, S., Yunyanjia, A., Li, B. and Chuanjingju, C. (2014). "Management of climatic heat stress risk in construction: A review of practices, methodologies, and future research." *Accident Analysis and Prevention*, 66, 187-198.
25. Sakoi, T and Mochida, T. (2013). "Concept of the equivalent wet bulb globe temperature index for indicating safe thermal occupational environments." *Building and Environment*, 67, 167-178.
26. Schroter, R.C., Marlin, D.J. and Jeffcott, L.B. (1996). "Use of the wet bulb globe temperature (WBGT) index to quantify environmental heat loads during three-day-event competitions." *Equine Veterinary Journal*, 22, 3-6.
27. Singh, C.P. (1978). "Environmental health." *Occupational Safety and Health in Industries and Mines,Nagpur Times Press,* India,496-660.
28. WHO (1969), "Health factors involved in working under conditions of heat stress." *World Health Organisation, Technical Report Series,412, Geneva.*
29. WHO (2003). "Heat waves: Impacts and responses." *Briefing note for the 53rd session of the WHO Regional Committee for Europe, Vienna, Australia.*
30. Yoopat, P., Toicharoen, P., Glinsukon, T., Vanwonterghem, K. and Louhevaara, V. (2013). "Erogonomics in practice: Physical workload and heat stress in Thailand." *International Journal of Occupational Safety and Ergonomics*, 8 (1), 83-93.
31. Zhao-gui, S., Zhong-an, J. and Zhong-qiang, S. (2009). "Study on the hazard of deep exploitation in high-temperature mines and its evaluation index." *Procedia Earth and Planetary Science*, 1, 414-419.

Internet URL'S

32. Anonymous, "Heat stress in mining", http://msha.gov/s&hinfo/heatstress/manual/heatmanual.htm (assessed on 8th August 2013)