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Effect of Heat on Underground Mine Workers

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Abstract

Physical stress of any kind may be thermal, noise, vibrations, objective lighting, improper barometric pressure, ionizing radiation, etc. has a considerable effect on human performance. This deleterious effect is gradual in nature in contrast to machine which cause sudden drop in performance if it gets out of order. In other words there is a graceful degradation of human performance on account of stress. The reason behind this is that human being has marked tolerance for both physical and mental stress. Heat stress is also among such causes which reduces one's efficiency to do work. Heat stress is the sum of all the internal and external heat factors which cause the body to become fatigued and distressed. Internal factors that determine the level of heat stress on the body include core body temperature, acclimatization, natural heat tolerance and metabolic heat generated by the workload. External factors include ambient air temperature, radiant heat, air velocity and humidity. This is a very serious issue not only for mining fraternity but for all the civil and construction works also. Ruling this problem out will help us to improve the quality of work, production capacity as well as workers health.

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*Keywords:*physical stress; heat stress; acclimatization; ambient air temperature; heat tolerance; radiant heat; air velocity; humidity.

1. Introduction

The human body acts as black body in terms of heat exchange with environment. Like any black surface it absorbs and radiates heat readily thereby providing the well-established maxim "good absorbs are good radiators and vice-versa". When the body is not able to maintain its constant temperature, i.e., it is not able to dissipate the extra heat to the environment, the body can experience stress physically as well as mentally due to the excessive heat present in the body. In this condition the body is said to be under heat stress.

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1.1. ISO definition of heat stress

A formal definition of heat stress given by ISO 7243 standards is "A person exposed to a hot environment is subjected to heat stress, in particular, is dependent upon the production of heat inside the body as a result of physical activity and the characteristics of the environment governing heat transfer between the atmosphere and the body."

1.2. Heat stress

Heat stress can be defined as the state of a body where it is unable to dissipate the extra heat from the body to the environment. The extent of measures taken by the body (such as vasodilation, increased heart rate and sweating) in response to heat stress depends upon some personal factors like age, gender, degree of obesity, acclimatizing behaviour and individual's sensitivity. In 1969, the World Health Organization (WHO) advised that the internal body temperature should not rise above 38°C (100.4°F) when prolonged daily work is performed in heat.

It is not always necessary that a hot environment will always have an adverse effect on human body, since human body has the ability to respond to environmental heat and acclimatize to it; exposure to extreme heat may overcome the resistant power of the body and may result by harming the health of the person. Heat stress could cause rash, cramp, heat exhaustion, and heat stroke and may exacerbate in serious medical condition, such as heart or lung diseases. Heat related mortality is certified as death from heat stroke or hyperthermia, when body temperature rises above 40°C (104°F).[41]

2. Thermoregulation

Thermoregulation is the body's ability to maintain body core temperature around a set-point temperature of approximately 37°C with a normal range of 36.2° to 37.7°C.[3][23]Temperature regulation is critical to homeostatic function and is linked to thermogenesis (metabolic heat production). The goal of temperature regulation is to maintain this relatively narrow range of homeostatic temperature for optimal physiological function. Heat balance is generally the sum of heat production and heat loss where changes in core temperature are the result of either an increase or a decrease in heat storage.

The heat balance equation for the storage of heat (S) takes into account the heat exchange pathways of metabolic heat production (M), evaporation (E), radiation (R), convection (C), and conduction (K). Additionally, the heat balance equation may incorporate heat production from physical work or exercise (work). The mathematical relation between these variables is represented as:

$$S = Work + M - E \pm R \pm C \pm K$$

Where, positive numbers indicate heat gain and negative numbers indicate heat loss [3].

Heat production is primarily the result of metabolic heat production and physical work or exercise. Heat loss is the movement of heat down the thermal gradient from high to low temperature and primarily occurs by one of more of the following four processes:

a. Evaporation: is heat loss through the conversion of sweat as water on the skin into water vapor gas. This process accounts for approximately 25% of heat loss at rest but becomes a primary means of heat loss under most environmental conditions during exercise.
b. Radiation: accounts for approximately 60% of heat loss and is the indirect movement of heat in the form of infrared rays or electromagnetic waves. Heat may be lost due to skin temperature exceeding air temperature and heat may be gained due to direct exposure to sunlight but varies greatly by environmental condition. However, radiation heat loss is minimal during uncompensable heat grain found with exercise in thermal protective cloths.
c. Convection: is heat loss down the thermal gradient by the transference of heat from an object to surrounding liquid mediums such as moving water, air, and internal body fluids. During exercise, convection occurs as heat produced within the muscle is transferred to the surrounding interstitial fluids.
d. Conduction: is heat loss down the thermal gradient by transference of heat from two objects in direct contact with one another such as feet on the ground surface.

Additionally heat loss is highly dependent of the ambient temperature and humidity of environment.

This complex coordination of thermoregulatory processes is primarily regulated by the preoptic area of the anterior hypothalamus. The preoptic area of the anterior hypothalamus is responsible for generating autonomic, endocrine, motor and behavioral responses to an environmental stimulus.[5]

Hypothermia and hyperthermia manifest whenever the body is unable to maintain normal core temperature due to internal and external factors. Hypothermia is a collection of symptoms resulting from a decrease in core temperature due to the body's inability to increase thermogenesis to counter rapid heat loss. At the other end of the thermal spectrum is hyperthermia. Hyperthermia is the collection of symptoms resulting from an increase in core temperature due to the body's inability to adequately dissipate heat through increased sweating and skin blood flow in the presence of an uncompensable heat gain. Exercise, clothing, and ambient conditions may increase body core temperature exceeding the homeostatic upper limit.

3. Factors governing heat stress

Heat stress is governed by both internal and external factors. Table 1 lists different internal and external factors responsible for heat stress.

Table 1. Factors affecting heat stress on humans

Sr. No.	Internal factors	External factors
1.	Core body temperature	Ambient air temperature
2.	Acclimatization	Radiant heat
3.	Natural heat tolerance	Air velocity
4.	Metabolic heat generated by workload	humidity

4. Effect of heat stress on human body

Most of the heat related illness occurs when a victim is exposed to heat or the person has over-exercised for their age and/or physical condition. When extreme heat is at its most deadly, it can kill by forcing the human body to cool itself down below its capacity, slowing the process by which normal body temperature is maintained. In mining, same as in other cases it has been observed that the exposure of workers to very hot conditions is very unhealthy, inefficient and unproductive.

While working in very hot environment a person can affect his/ her[31]

a. Dexterity and coordination,
b. Ability to remain alert during lengthy and monotonous tasks,
c. Ability to observe irregular, faint optical signs, and
d. Ability to make quick decisions, etc.

5. Heat stress hazards

As described earlier human being is a homeothermal animal. We maintain a constant internal thermal state inspite of varying thermal state. If a person is constantly working in a hot environment then he/she may suffer from following heat related disorders. Table 2 summarizes different heat hazards in increasing order if their severity.

Table 2. Heat hazards in increasing order of their severity level

Sr. No.	Disorder	Symptoms	Causes	Treatment	Prevention
1.	Transient heat fatigue	Reduced performance is seen, particularly in skilled physical work, mental task and those requiring concentration.	Discomfort caused from the heat at a lower level which cannot result in other heat illnesses.	No treatment is necessary unless other signs of heat illness are present.	Acclimatization and training.
2.	Heat rash	"Prickly heat", tiny, raised, blister-like rash.	a. Skin is constantly wet due to sweating. b. Sweat gland ducts become plugged, leading to inflammation.	Keeping skin clean and dry.	Taking shower after working in hot environment. Keeping skin dry.

3.	Heat cramps	Painful muscle spasms in the arms, legs or abdomen during or after working in hot environment.	a. The cause of heat cramp is not very well understood. b. But, it is been assumed that it may occur due to loss of salt from sweating. c. Dehydration may be an important factor.	Resting, drinking water, glucose water and consuming more salt than usual.	Adequate water and salt intake. (Do not use salt tablets).
4.	Heat Syncope	a. Fainting while standing erect and immobile. b. This is a variant of heat exhaustion. c. Symptoms of heat exhaustion may precede fainting.	a. Due to dehydration blood volume decreases. b. Blood pools in dilated blood vessels of the skin and lower body, making less blood available for the brain.	a. Move the victim to a cool place. b. Make the victim rest and drink fluids.	Acclimatization, drinking plenty of water, avoiding stand in one place and intermittent activity to avoid blood pooling.
5.	Heat exhaustion	a. Fatigue, weakness, dizziness, faintness. b. Nausea, headache. c. Moist, clammy skin; pale or flushed. d. High pulse rate. e. Normal or slightly higher body temperature.	Dehydration causes blood volume to decrease.	Victim should be allowed to rest at a cool place and should drink plenty of water.	Acclimatization and drink plenty of water.
6.	Heat stroke	a. Usually hot, dry skin; red, mottled or bluish. b. Sweating may still be present. c. Confusion, loss of consciousness, convulsions. d. Rapid pulse. e. Rectal temperature greater than 104°F.	a. Partial or complete failure of sweating mechanism. b. The body cannot get rid of excess heat.	a. This is a medical emergency. b. Call the doctor and start cooling the victim immediately by taking the victim to a cool place. c. Soak the cloths and skin of the victim with cold water and use a fan to create air circulation. d. Medical treatment is mandatory.	Acclimatization, closely monitoring for signs of heat illness, medical screening and drinking plenty of water.

6. Heat stress indices

We can call heat stress indices as a type of remedial measures taken against the odds that happens due to heat stress. Heat stress indices help us to know better about the heat environment and help us in creating a better place to work. These also help us to reduce the accidents taking place due to the excessive amount of heat in the working environment. From years several investigators have considered different parameters responsible for heat stress and many such indices are developed to fight the odds caused by heat stress. Table 3summarizes different heat stress indices as reported (developed) by various investigators in their respective time period.

Table 3. Proposed systems for rating heat stress and strain (heat stress indices) [10]

Sr. No.	Year	Index	Author (s)
1.	1905	Wet bulb temperature (T_w)	Haldane
2.	1916	Kata thermometer	Hill et al.
3.	1923	Effective temperature (ET)	Houghton & Yaglou
4.	1929	Equivalent temperature (T_{eq})	Dufton
5.	1932	Corrected effective temperature (CET)	Vernon & Warner

6.	1937	Operative temperature (Opt)	Winslow et al.
7.	1945	Thermal acceptance ratio (TAR)	Ionides et al.
8.	1945	Index of physiological effect (E_p)	Robinson et al.
9.	1946	Corrected effective temperature (CET)	Bedford
10.	1947	Predicted 4-h sweat rate (P4SR)	McArdel et al.
11.	1948	Resultant temperature (RT)	Missenard et al.
12.	1950	Craig Index (I)	Craig
13.	1955	Heat stress index (HIS)	Belding & Hatch
14.	1957	Wet bulb globe temperature (WBGT)	Yaglou &Minard
15.	1957	Oxford index (WD)	Lind &hellon
16.	1957	Discomfort index (DI)	Thom
17.	1958	Thermal stress index (TSI)	Lee &Henschel
18.	1959	Discomfort index (DI)	Tennenbaum et al.
19.	1960	Cumulative discomfort index (CumDI)	Tennenbaum et al.
20.	1960	Index of physiological strain (I_s)	Hall &Polte
21.	1962	Index of thermal stress (ITS)	Givoni
22.	1966	Heat strain index (corrected) (HIS)	McKarns& Brief
23.	1966	Prediction of heart rate (HR)	Fuller &Brouha
24.	1967	Effective radiant field (ERF)	Gagge et al.
25.	1970	Predicted mean vote (PMV)	Fanger
		Threshold limit value (TLV)	
26.	1970	Prescriptive zone	Lind
27.	1971	New effective temperature (ET^*)	Gagge et al.
28.	1971	Wet globe temperature (WGT)	Batsford
29.	1971	Humid operative temperature	Nishi &Gagge
30.	1972	Predicted body core temperature	Givoni& Goldman
31.	1972	Skin wittedness	Kerslake
32.	1973	Standard effective temperature (SET)	Gagge et al.
33.	1973	Predicted heart rate	Givoni& Goldman
34.	1978	Skin wittedness	Gonzales et al.
35.	1979	Fighter index of thermal stress (FITS)	Nunneley&Stribley
36.	1981	Effective heat stress index (EHSI)	Hamon& Ryan
37.	1982	Predicted sweat loss (m_{sw})	Shapiro et al.
38.	1985	Required sweating (SW_{req})	ISO 7933
39.	1986	Predicted mean vote (modified) (PMV^*)	Gagge et al.

40.	1996	Cumulative heat strain index (CHSI)	Frank et al.
41.	1998	Physiological strain index (PSI)	Moran et al.
42.	1999	Modified discomfort index (MDI)	Moran et al.
43.	2001	Environmental stress index (ESI)	Moran et al.
44.	2005	Wet bulb dry temperature (WBDT)	Wallance et al.
45.	2005	Relative humidity dry temperature (RHDT)	Wallance et al.

7. Heat stress management program

Every organization where heat stress related problems are encountered must have a plan which deals with such issues and foresees that further these issues are not taking place in the work place. This heat stress management program gives a blueprint of what all things should be considered in a general plan.

7.1. Screening tests

These are based on Body Mass Index (BMI) and aerobic capacity and are designed to exclude people with known risk factors for heat stroke from working in the enterprise mine.

7.2. Work-rest cycles

These have been shown to improve productivity as well as being an adjunct to reducing heat stress. Formal supervision is essential, though, as the cut-off from 100% productivity is relatively sharp in any given environmental climate.

7.3. Mandatory water breaks

These should coincide with work-rest cycles. Water is generally considered to be the best liquid for fluid replacement as loss of salt is not usually severe in normal healthy individuals. It is now common practice to provide workers with personal water bottles at the start of each shift.

7.4. Work breaks

Many countries have adopted this strategy in recent years. To ensure that the core body temperature does not exceed 38°C limits should be set using heat stress indices such as WBGT. Approximately work breaks should be designed around these limits to reduce the level of heat stress.

7.5. Job rotation

This strategy ensures adequate recovery time between shifts after work in very hot environments.

7.6. Engineering controls

Engineering strategies should be based on improving mechanization to minimize high metabolic rates. Robotics and job redesign to counter heat over-exposure, use of shielding, refrigeration and increased air flow.

7.7. Acclimatization

This process has been used for many years as an important method of reducing the risk of heat caused illnesses. Varying protocols have been adopted by mining operations for this purpose, and the current trend of screening workers for physiological risk parameters followed by on-the-job acclimatization.

7.8. Personal protective equipment

It is important that protective clothing does not become a health hazard by forming a barrier to the natural cooling effect of sweat on the body. Selection of appropriate clothing should be monitored and instruction must be provided for the correct wearing of this apparel.

7.9. Heat stress index

The question of, which heat stress index to use should be based on local conditions and made applicable to the particular heat stress management program in place.

7.10. Education

It is important to educate the workforce so that they understand what happens to their bodies when they work in heat and how they can work safely without endangering their health.

7.11. Health and safety medical protocols

These should be conducted at regular intervals to ensure that heat illness is avoided or pricked up at a very early stage and treated. The review of heat stress management protocols are extensive and include many of the issues above. They firmly believe that a successful heat management program will have a major impact on the ongoing success of the mine.

8. Conclusions

Heat stress is a very serious issue in the construction, civil engineering and mining fraternity. Workers working in such hot environment can face serious health problems if the organization is not taking proper care of this issue. Every organization must follow a proper work rest regimen according to the working condition; periodic checkups must be carried out for the workers and their proper records should be maintained; every organization must have a heat stress management program which deals with such issues; a suitable heat index must be adopted to monitor the environment constantly; workers must be encouraged to bring forward such problems so that proper solutions can be drawn.

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