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# Impacts of Heat in Mining Operations: Review

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***Abstract***
*Different conditions are responsible for emission of heat in mines whether opencast or underground which makes heat an integral part of all mining activities. Working in high temperatures and/or humidities can lead to risky lack of concentration of the miners or to heat collapse and extremely dangerous heat stroke. In this paper, heat is discussed, its source and effects on mine workers; and best procedures to control it via ventilation systems. It targets the impact of heat in mining operations using review method.*

***Keywords:*** *Heat, Humidity, Source, Temperature, Ventilation, Mines, Control, Illness, Symptoms, Workers, Environment.*

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## I. Introduction

Heat causes unprepared fall in efficiency if it malfunctions (see Figure 1 in supplementary materials). Among the old ways of controlling temperature in the underground mines in the 1880's was importing naturally made ice blocks from above the ground which were conveyed in underground ore-cars to cool-off miners. Later, the compression vapour refrigeration which is presently the most popular way of cooling artificially came to light in the 1920's. This was applied in Brazil; Germany and British coal mines (Malcolm, 1990). Subsequent cooling techniques using air gained recognition in mining in the 1930's especially applied in South Africa and India gold mine. Presently, the installed cooling capacity of mine is in vogue which began in the 1960's. Its possesses bogus centralized refrigerators, placed underground; even though it is limited on its ability to reject heat and to send back air which may effectively combine developed energy devices which gives recovery for pipelines of water in shafts to improve cooling(Chao and Xian, 2011). Mine cooling is all about combating geothermal heat and its auto-compression effects in underground mines.

**The Temperature Phenomenon**

Heat transfer in deep mines are caused by situation that are natural and artificial events, mostly human metabolism, geothermal gradient, application of explosives, the self-compression of the rocks matrix, working with diesel equipments and so on. These generators of heat should be controlled for their temperatures and humidity potentials in the mines, especially at the source of production (Maurya et al., 2015); otherwise, an upsurge of temperatures in deep mines produces risks, which may possibly cause turmoil in terrible instances like affectation of the health of workers, safety and on productivity of mine operations (Hatfield and Prueger, 2015). With high temperatures and humidity in deep mines, workers' suffer discomfort, stress, accidents, and drop in productivity. This becomes bigger problems as mining goes deeper from the surface, especially as underground machines gets sophisticated

**Physiological Consequence Faced By Man Due To the Temperature Increase**

The human body metabolism generates heat in order to maintain its temperature balance of closer to 36.9 $^{o}$C; which gives man the sensation of coldness while in contact with the atmospheric temperature (Yesidet al, 2008). The body of man act as black substance (i.e. absorbs heat and radiate it steadily) with respect to exchange of heat with the surrounding. Whenever the human body is unable to maintain its uniform temperature, it becomes unable to liberate the extra heat available in it. In this state, the body is tagged "heat stressed" (Maurya et al., 2015).

**Heat Disorder and Illness**

Operating in elevated temperatures may result into illness of heat, loss of concentration yielding reduced productivity; near-misses (see Figure 2 in supplementary materials) and possibly death (Maurya et al., 2015).. This hazard increases where humidity becomes relatively high (i.e. as the temperatures of the dry bulb (wb) and the wet bulb (db) get nearer, as derived from temperature difference. It is this relative humidity that creates the challenge of body cooling by perspiration due to inhibition (Ryan and Euler, 2017). For instance, 25°C wb/47°C db causes less heat strain than 30°C wb/35°C db. Whenever the wb temperature goes up beyond 27°C, then additional control and working process should be imbibed.

**Heat Stress in Mining**

Heat stress is the heat load on the body from the accumulation of environmental origins, as well as metabolic variation of human body due to burden of work and clothing demands. Like every other industries, underground mining exposes its workers to extreme hot, unproductive and unhealthy situations which leads to heat stresses during work schedules. The sources of heat stress in mining include:

a) Powered facilities which produces huge amount of heat loads to a localized points such as blasting and lighting.

b) Auto-compression which contributes lots of heat load underground (i.e. 10°C per kilometre vertically with depth ((Bardswich, 1965).

c) Ground waters (i.e. static or mobile water) results in the increased moisture in the air depending on the geothermal gradient and the rock characteristics (McPherson, 1993).

d) High atmospheric temperatures cause body heat and reduce the ability of the body to cool off.

e) Restricted air motion limits the ability of the body to dispense heat through perspiration.

f) Poor dressing or clothing materials inhibits the dissipation of heat.

g) High relative humidity makes the surrounding air to gradually lose its capacity of evaporation by sweating through the skin which helps for body cooling (Ryan and Euler, 2017), i.e. mostly at 70 percent minimum (see Figure 8 in supplementary materials).

**Symptoms and Signs:**

The thermo-regulatory system of human attempts to maintain the central temperature of the body to 37°C while working in hot circumstances. This occur by an increased flow of blood to the skin surface, conveying heat away from the centre that results into sweating, which cools the skin and eventually the blood. Lots of physiological symptoms may gradually result whenever the central temperature rises and this control may be lost. Starting effects and symptoms includes:

- Dire need of comfortability and convenience;
- Discouragement to work; and
- Reduced alertness.

These primary symptoms grow into a decreased dexterity and co-ordination which is a pointer to break-down in safety and productivity (Xingxin et al., 2018). These include:

**1. Exhaustion:**

Exhaustion is caused by the inability of blood movement and circulation to consistently take away heat (see Figure 3 in supplementary materials). A reduction in the volume blood results in dehydration which is caused by intake of less fluid. Whenever work rate and environmental heat stress are combined, it causes a rapid heartbeat, in which if the interval of time between successive muscles of heart contractions is not enough to adequately supply blood to the heart; and consequently drops down the circulatory flow rate (2014). Heat stroke happens when the internal temperature of the body increases beyond 40$^{o}$C (Occupational health and safety regulations, 1996). This raises the central temperature of a body to above 37°C. Some of the symptoms of heat exhaustion are: low blood pressure, palpitations, breathlessness, dizziness, thirstiness, tiredness, fainting, headache, blurred vision, nausea, tingling in toes and fingers, numbness, clammy skin, and so on.

**2. Stroke:**

Stroke happens to be the most terrible illness related to heat. It occurs whenever the human body temperature goes beyond 41°C, which critically affect the effective synergy of the involuntary nervous system which caters for the regulation of heat. It also cause irreversible hurt to the brain, liver and kidneys (see Figure 4 in supplementary materials). Medical emergencies should be declared when heat stroke is observed since it bears a strong fatality risk for cardiac arrest or respiratory jerk. Some illness symptoms of heat stroke are similar to heat exhaustion, although its starting point is dramatic and sudden. Further symptoms of heat stroke include: dry coloured and hot skin, sweatlessness, bluishness of lips, expanded pupils, aggression, shivering, glassy eyes, convulsion and coma (Coal MSHA, 2019).

**3. Rash (Prickly Heat):**

Rash results from by prolonged and continuous uncured sweating. This degenerate into sweat ducts blockage and its inflammation producing irritations, sores and tiny reddish blisters (see Figure 5 in supplementary materials). If unchecked, heat rash leads to stronger skin infections which are potentials for heat stroke.

**4. Syncope (Fainting):**

Syncope results from poor and insufficient blood flow and volume in the lower parts of the human body. It produces temporal decrease and drop in blood supply that is made available to the brain; which may degenerate loss of consciousness for a short period (Allsop et al, 2014).

**5. Cramps:**

Cramps are sudden body pains (even though it does not pose a risk to health and life) that occur in the legs, arms or stomach when engaging in strenuous events and tasks. This is caused by the low salt amount in the body (see Figure 6 in supplementary materials). They are strong signals that the body is confronted with difficulty in amending to a rising central temperature (Acuña and Lowndes, 2014).

**6. Sunburn:**

Sunburn is high insolation of the sun causing skin damage. It occurs below the top layer of the causing skin reddishness, fever and blisters that are fluid-filled which degenerates into secondary infection (see Figure 7 in supplementary materials). Skin cancer results if burns prolong (Mathew barnes, 2009). The antidote for this is to squeeze coldness into the sunburned locations and immersing victims in cool and chilled water. The use of butter, ointments, salves should be avoided prevents because they resist escape of heat from the skin. Also, avoid breaking the formed blisters them because it can lead to infections.

**7. Fatigue:**

Fatigue is the indication of inability of to acclimatize or get accustomed to a new environment. Its symptoms include job impairment and performance, especially in tasks that engages adeptness, skilfulness, vigilance and balanced judgment. The best treatment remedy is to remove any victim to a cooler location till he recovers (Labour MSHA, 2012).

**The Hazards of Working in Heat**

Illnesses related to heat results from increased temperatures, humidity, work rate and the physical condition of a person. Thermal exchange between the body and the environment should be at equilibrium for the body to function adequately. This depends on metabolic heat being dispensed to the surrounding through heat transfer of conduction, convection and radiation. The risk factor of heat stress include non-acclimatisation, age, fatigue, dehydration, skin disease, sleep deprivation, overweight/obesity, poor fitness, exposure period, medical conditions and illness. It is basic for every underground miner working in hot conditions to know that high sweating rates combines with excess body fluids loss that causes dehydration and electrolytic instability; which can further grow to cause physical and mental impairment and high risk to health and work productivity (Su et al, 2009).

**Evaluating the Risk of Heat**

So many factors can affect the thermal load body. These include: physical tasks, air temperature, humidity, air movement, radiation heat exchange and the type of clothing worn. Clothing that is thick; impervious hinders heat loss and poses further risk especially when carrying out strenuous tasks. Poor designed Personal Protective Equipment (PPE) such as causes more heat problems in hot environments (Amosu, 2021). A lot of indices have been developed for heat stress integrating these variables to give a unit value which relates the size of heat risk in a given circumstance.

**Controlling the Heat Hazards**

As much as possible, it is best to avoid work events involving high risk of heat illness; otherwise there should be special consideration when there is there no option to work in hot situations. Hence, analysis for risk should be carried out; same for working safety structures designed; and introducing adequate and concise measures of control (design for work and selection of equipment) to the exposure and length of working period. These measures should follow the hierarchy of control which are as follow:

**1. Safe Environment Ventilation**

a) Appropriate selection of machinery (i.e. mobile or fixed plant) which include its impact on both temperature (heat) and humidity (moisture) in the workplace, at the machine operator and in the overall ventilating air.

b) Well-positioned layout of airflow which include the option of extraction and mineral ore development methods, and ventilation pattern for the general and individual mine districts.

c) Precise minimum airflow and temperature standards, which include the accuracy of measuring equipments, locations of measurement, duration and frequency of measurement.

d) Considered seasonal variations of daily temperature and humidity and natural strata radiation heat.

e) Calculated fixed heat loads sources (such as the drives of conveyor) and mobile heat loads sources of the mine (such as the diesel facilities).

f) Application of ventilation flow streams to suck-out gases sources (such as goof gases) and heat sources (such as temperatures from work areas, fixed plant and the airways return ducts.

**2. Engineering Control Method of The Environment**

a) Provision of small climate cooling facilities such as cabins of air-conditioner, cold vests and other ways to cool the working areas.

b) Provision of recovery and rest location and services, which aid to ameliorate the impact of operation of workers in heat; this by helps workers to relax at their break period, i.e. to take meals and chilled drinking water when less stressed thermally.

c) Adequate air working speed impact over the skin.

d) Right moisture which indicates if sweat drips or evaporates from the skin in a workplace.

e) Draining of casual waters to reduce heat flow from the strata into the atmosphere, and to maintain low water moisture content.

f) Provide bulk air cooling intake air into the part or whole mine district; and making available appropriate conditioning cabins and continuous chilled water service in workplaces.

**3. Location and Equipment application**

a) Appropriate selection of facilities for the right job.

b) Consideration of the location of immovable facilities that produces heat should be done before any installation.

c) Continuous activation of machines in order to optimisation benefits of safety and the operational time of mobile facilities.

**4. Water Control To Reduce Humidity**

a) Strategically positioning and maintaining appropriate pump networks for easy access.

b) Eliminating stagnant underground water sources such as strata waters, spillages, excessive sprays, leaks (i.e. from flushing hoses, extension pipes and machines cooling water).

c) Avoiding the permission of puddle or accumulated waters.

**Communication and Training**

Training and education mine workers must cover the following:

a) The right kind of personal protection equipment

b) Their responsibilities and duties to achieve conformity to managing and tackling heat challenges (i.e. emergency alertness, emergency response needs and skills in measuring environmental factors.

c) Observing heat protocols such as pacing and hydration.

d) Recognizing the significance of symptoms, signs and treatment of heat-related illnesses.

e) Getting abreast of the risk and hazards linked with operations in hot and moisty environment.

f) Implementing control measures that ensure workers are safe from heat illnesses.

g) Complying with emergency process and procedures.

h) Engaging in exercises to be physical fit

i) Putting in place due checks on welfare and adequate supervision.

**Monitoring and Procedural Review**

a) Communicating hazards internally by the Health and Safety Management System at the different functions and levels in the mine

b) Continuous improvement through provision, revision and evaluation of heat equipments by the Health and Safety Management System to ensure effectiveness, adequacy and suitability.

c) Documenting information of Heat Stress Development and Management reviews and evaluations gathered at regular periods

**Auditing and Record-Keeping**

a) The heat management system of the mine location must be checked at regular audits in order to continuously maintain improvements and relevance which covers the procedures linked with risk and hazard assessment and records of training.

b) Establishing and maintaining right procedures for identifying and maintaining records (i.e. records of training, results of site monitoring, reviews and audits.

c) Storing and retrieving traceable records of particular activity without damaging, deteriorating or losing them.

**Program of Heat Stress Management**

**Table 1: Heat Stress Events**

| | |
|---|---|
| **Engineering controls** | Improve facilities for minimising high body metabolism such as air-ventilators and refrigerators. |
| **Screening tests** | Exclude the workers with potentials heat stroke risks. |
| **Acclimatization** | Screen the workers with psychological risk factors. |
| **Health and safety medical protocols** | Organise body fitness exercises on regular basis for workers. |

| | |
|---|---|
| **Mandatory water breaks** | Provide individual water-bottles to workers at the onset of every shift. |
| **Personal protective equipment** | Selecting and monitoring correct and appropriately worn clothing. |
| **Education** | Educate workers about the consequence of body heat and its effects. |
| **Work-rest cycles** | Provide the privilege for a rest and a shift. |
| **Work breaks** | Ensure that the central temperature limit of 38°C is not exceeded. |
| **Heat stress index** | Base stress index on local conditions. |
| **Job rotation** | Ensure enough body recovery is achieved during shifts. |

Source: (Tripti et al, 2015).

**Causes of Heat Production and its Transfer in the Mines**

**1. Self-Compression:** This behaves like the compression machine in which the air input flowing into a mine path compresses and heats up, eventually converting potential energy into heat energy. Compression happens adiabatically when there is failure of heat or humidity exchange in the air, consequently raising the temperature, following the law:

$Ts_f/Ts_i = (P_{bf}/P_{bi})^{(y-1)/y}$............................................................................................ (1)

Where Ts is the temperature when dry (°C); $P_b$ is the pressure of the atmosphere (mmHg), and is the ratio of the specific heat of air to volume and constant pressure, and the subscripts " i" and "f" denote the mining front conditions of a path (initial and final).

The variation of the temperature of air by self-compression of rocks ($\Delta th_a$) is mathematically expressed in ° C as presented by (Navarroet al, 2008)

$\Delta th_a = L\sin\emptyset \times 0.0098$........................................................................................... (2)

Where L is the length of the mine road (m.); $\emptyset$ is the inclination angle of the working face of mine.

**2. The Rock Masses:** The transferred heat produced by the rock mass ($dt_r$) in °C, is dependent on so many factors such as:

$\Delta t_r = [(h_1 - h_{tem} \pm sen\alpha) \times P \times \lambda] / [(\lambda \times P \times L + 2000 \times \rho a \times C_e \times Q) \times G_g]$......................... (3)

Where; $h_1$ is Depth (m); $h_{tem}$ is the neutral temperature; P is the perimeter of the path (m); $\lambda$ is the coefficient of heat; $G_g$ is the geothermal gradient (°C); $\rho a$ is the volumetric mass of air (per $m^3$ ); $C_e$ is the specific heat of the air ($Kj/Kg$); $Q$ is the Flow ($m^3/s$) (Navarro-Torres et al, 2008).

3. **Machinery and working Equipment:** The overall consumed energy of underground mining equipments (such as diesel engines, air compressor discharge, and alternate current motors) transfers (a) hot air into the atmosphere; and (b) dissipated power and work produced from friction directly or otherwise. (Hartman et al, 1997).

In diesel engines, the change in the temperature of air by heat transfer, i.e. $\Delta t_d$ (°C), can be calculated as:

$\Delta t_d = (P_d \times q_d \times f_t \times f_m) / (\rho_a \times Ce \text{ x } Q)$.................................................................... (6)

Where $P_d$ is the power of the engine (Kw); $q_d$ is the equivalent heat transferred; $f_t$ and $f_m$ are the mixed energy and mechanical energy factors (Navarro-Torres et al, 2008).

4. **Application of Explosives:** Drilling and blasting are conducted when rocks are bulky and massive; as such explosives are required. Explosives produce and transfers huge quantity of heat into the bulk rock mass and also into underground surrounding. The ventilation Services of mines of United States of America recommended in 2000, how to calculate heat transfer i.e., $\Delta e_x$.

$\Delta e_x = (e_u \times c_e) / (864\,00 \times C_e \times Q \times \rho_a)$...................................................................... (7)

Where $e_u$ is the quantity of explosives ($kg/m^3$); $c_e$ is the specific heat of air released by the Explosive charge ($Kj/Kg$); $Q$ is the Flow ($m^3/s$); and $\rho a$ is the volumetric mass of air (per $m^3$) (Navarro-Torres et al, 2008).

5. **Human Body Metabolism:** The human body continuously reject its residual heat by through the process of thermal transfer which causes a raise in the content of heat impacting mine workers. Using the Colombian instance of underground coal mining, the number of mine workers hired was high because of less availability of machines on ground; hence, the temperature increase produced by human metabolic rates, whose heat transfer is expressed mathematically as $\Delta th_e$.

$\Delta h_e = (n \times q_h) / (Q \times C_e \times \rho_a)$.................................................................................... (8)

Where n is the total number of workers per each work front; $q_h$ is the quantity of heat released by man with respect to the effective temperature (Kw / man); $Q$ is the flow ($m^3/s$); $c_e$ is the heat of air released ($Kj/Kg$) (Hartman et al, 1997). Hartman, portends each man to possess energy of 25 KW (Navarro-Torres et al, 2008).

**The Ventilation (Heat Control) System and Accessories**

Ventilation is specific direction of air flow, its quantity, and control. Even though it provides nothing to operations or production, the lack of it results in (a) reduced efficiency and effectiveness to productivity, (b) high rates of accident, and (c) absent-mindedness. Ventilation helps to move and avail air adequate enough for respiration, and but to mix both physical, biological and chemical pollutants such as dusts, emissions, aerosols, smokes, gas particles, moisture and heat.

Globally, mine ventilation culture is strongly regulated. Provision is created for adequate air pathways into work places from inlet or intake (entry points or down-casts) which allows fresh air to pass into the mine workings to the outlets or exhaust (exit points or up-casts), which permits the air to go out having ventilating the working regions of the mine (Bossard, et al, 1982).. Mine fans are installed on entry airshaft and return airshafts; or both, whether underground or at the surface of mine. History has shows that most mine accidents and occupational diseases are ventilation-related, such as: (a) windblasts, outburst of gases, explosions (dust or gas), smoke emissions and fires outbreaks; and (b) pneumoconiosis, silicosis, asbestosis and other degenerative lung diseases (Rick, 2006).

The relevance of ventilation is recognized by the governments of several countries concerning the safety of deep mines by the imposition of their mining regulations and laws which specifies the minimum conditions for safety and environmental thresholds that a system of ventilation must maintain as limits for its operation, in order to ensure sustenance and acceptably safe work in the environment. This standard helps to deliver enough amount of fresh air for quick dilution of mine contaminants that is below the statutory occupational levels of exposure (Amosu, 2021) and their eventual substitution or elimination. These contaminants include strata gases (such as radon and methane), mineral fumes and dust, and stained air particulates from diesel facilities. Union allows booster fans in coal mines, whereas the United States prohibits them.

To ensure consistent ventilation throughout the mine's life, adequate planning should be conducted which involves: (a) the total volume rate of flow for air needed by the mine, (b) consideration of economic aspects of air flow distribution, and (c) the mine fan(s) pressures.

**A. Mine System And Air Control Devices**

During ventilation system planning, it is imperative to fulfil the necessary volume of air towards all the regulations, and the safety and health standards from the beginning. After this, the appropriate shaft sizes, number of fans and airways are calculated. Uncontaminated air influx the system from the entry airshaft(s) or through other links to the surface, i.e. air flows along into the working regions where the main contaminants (flammable or poisonous gases, radiation, humidity and heat) mix with air. The polluted air reverses via the system along the return airways to the surface through exit airshaft(s) or drifts (level or inclined). By standard, the contaminants are not permitted to exceed compulsory limits of concentration threshold. Ventilation devices (such as mine fans- single or multiple unit installation) are necessary to direct and control air to needed areas of the entire system. Furthermore, several other devices for air control are imperative for the effective distribution of air in underground mines. These include:

**1. Temporary and Permanent Stoppings**

Stoppings are air walls which consist of any materials of concreted blocks, gob walls, masonry, timber blocks (fire-proof), and pre-fabricated alloy steel utilized for channelling the distribution of air-flow effectively (Yuriy et al., 2020). Typical size of stopping and mining entries range from as 4-feet by 20-feet in smaller coal mines to as 30-feet by 40-feet in larger limestone mines.

**Figure 9:** Mine Ventilation Stopping (Source: cdc.gov and researchgate.net)

**2. Undercast/Overcast**

The overcasts are made of bridges of air, made from concrete blocks, masonry or pre-fabricated steel, particularly for the entry and return airways to criss-cross themselves for air flow routing.

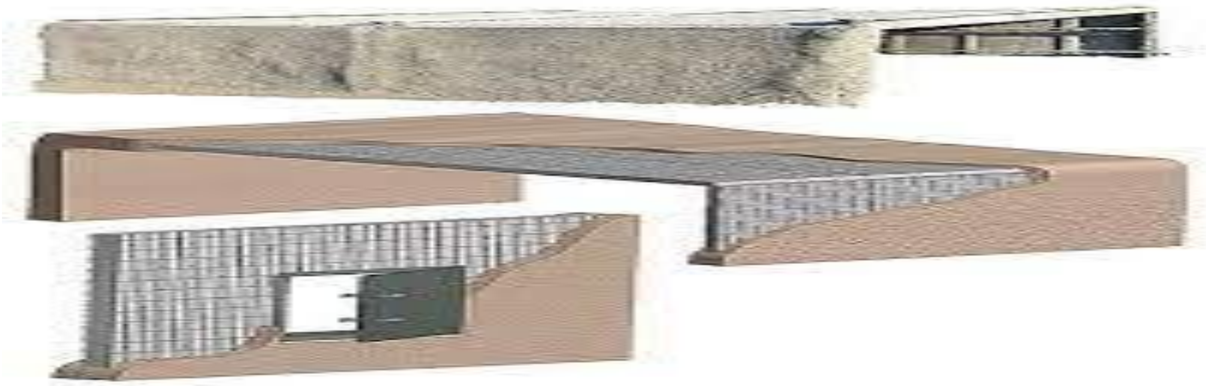

**Figure 10:** Over-cast/Under-cast (Source: gsminerepair.com)

### 3. Mine Regulators

Regulators are desired airflow reducers for controlled pressure differential regulators in the mine section, made of brattice sheet positioned for blocking the airway attached to a sliding shutter in a particular stopping.


**Figure 11: Mine** Regulator (Source: ventsim.com)

### 4. Man-Doors

Man-doors are access doors made of steel that are installed in stoppings between the intake and the return airways.

**Figure 12:** Man-doors (Source: biseeminingandmineral.com)

### 5. Air-Locks

Air-locks are access or man-doors (i.e. two or more units) installed between the intake and the return airways when the pressure differential is high. It helps to prevent short-circuiting of personnel or vehicle passages.

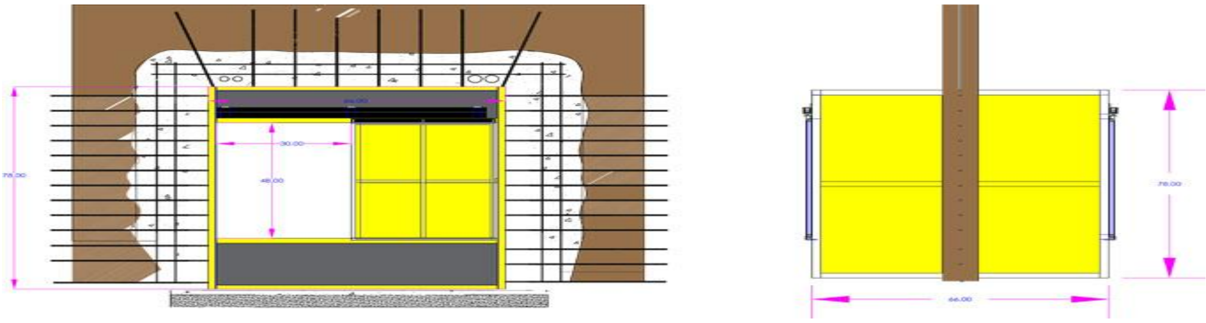

**Figure 13:** Air Locks (Source: minedoor.com)

### 6. Line Brattices/Vent Tubings

The Line Brattices are line brattices (fire-proof) attached to the floor, sides and roof of deep coal mines to provide temporary stoppings and utilized for a short term applications where the differentials of pressure are very low inside and around the working zones. In the same vein, the vent tubings also are usually combined with the auxiliary fans in metal or non-metal mines, inside and around the working zones to direct uncontaminated air (Yesid et al., 2018) unto the faces of operations.

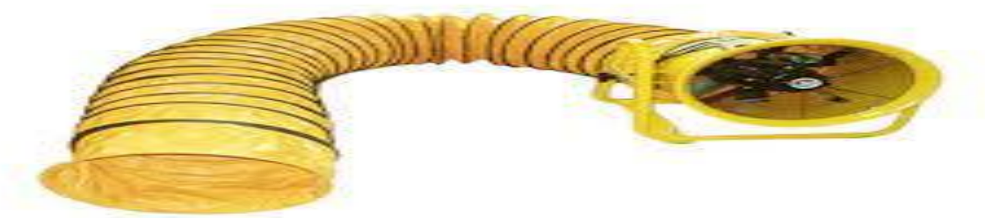

**Figure 13:** Line Brattice/Vent Tubing (Source: amazon.in)

### 7. Booster Fans

The booster fans are utilized to help the flow of air through parts of the mine, i.e. for adjusting flow of air quantity above that which is obtainable in the open system. They also enhance air leakage control without producing unwanted recirculation in situations of normalcy or emergency.

**Figure 14:** Booster Fans (Source: engineerlive.com)

### 8. Scrubbers and Machine-Mounted Water Sprays

The Scrubbers are devices which enhances vacuum cleaning and suppression of dust. The Machine-mounted water sprays are equipments used to help fresh air flow and to re-channel them unto mine faces.

**Figure 15:** Machine-Mounted Water sprays and Scrubbers (Source: Uknowledge.Uky.Edu)

**B. Major Ventilation Systems for Mining:**

**(i) For Stratified Deposits:**

The numbers of deep mines which extract table-like ore-bodies forms (like limestone, coal, salts and potash) usually apply some ventilation methods in mining such as room-and-pillar or longwall. Their designs are the same, even though their layouts vary depending on conditions of geology (Fuller, 1989 and Tien, 1995).

**Figure 16:** Stratified Deposits (Source: srk.com)

**(ii) For Longwall Development**

Two parameters which greatly affect designing the systems of ventilation in longwall mining are the influence in the rate of rock fracturing on longwalls machines that causes the generation of gas, smoke,bdust, moisture and heat ( Uchino and Hirago, 1984; Battino and Mitchell, 1985; Organiscak and Jankowski, 1996; Colinet, et al, 1997; Stokes and Tuck, 1997) and the channelization of methane and other noxious gases which gather in the gob points (den Drijver, et al, 1997; Diamond, 1997; Dziurzynski and Nawrat, 1997; Haake, et al, 1985; Highton, 1980; McPherson, 1993). Setting out ventilation gets complex when mining into seams of coal that are inclined with multiple gas-pocket geological faults. There also has been other type of layouts to accommodate specific geological conditions.

**Figure 17:** Longwall Systems (Source: integratedlearning.net)

**(iii) For Room And Pillar Systems**

The ventilation system in room-and-pillar mining functions uni-directionally allowing air entry through panels centrally by a regulator, and returning it peripherally. Its advantage is that the flow of air spreads at the terminal regions of the panel hereby ventilating wider coverage and proffers high efficiency of air volume at the working face; while its disadvantage is the increased pressure of ventilation which results in leakages of air.

**Figure 18:** Room and Pillar Systems (Source: Britannica.com)

**Mine with Large-Size Entries**

The larger the mine entries, such as practised in the mining of oil shale, salts and limestone, salt, the larger is the volume of air needed for ventilation. Large-sized mines uses air volumes between 350,000 - 500,000 cfm with consideration of the leakage of air through the constructed stoppings, and the recirculation of air, locally (Adam, et al, 1987; Thimons, et al, 1987).

**Recirculation of Air Underground**

For adequate recirculation of air, the major entry and air return paths are not positioned adjacent to each other because it results in the recirculation of exhaust air back into the entry air paths. Mine development should be done with entry and return airways close to one another for appropriate recirculation. Bend in ventilation system should be well-shaped and machined to avoid restricted speed of air flow that can cause shock losses which causes undue humidity, heat or fogginess in the mine.

**Air Tempering For Roof Stability**

Air tempering is the alteration of the specific humidity of rock masses been exposed to conditions of the atmosphere and exchange of, and becoming stable after some period (Haynes, 1975; Anon., 1976; Stateham and Redcliffe, 1978; Cummings, et al., 1983).

Air interacts with the bordering rocks and rapidly attains the temperature of the mine. As the relative humidity of air rises about the rocks (increased or condensed moisture), the temperature of the air drops.

## II. Literature Review

The heat gradient of the earth in underground mines is usually the highest provider of the general hot condition for the increase in temperature of fresh rock varying with depth (McPherson, 1993). A precise way to evaluate the temperature of fresh rock is by collecting data of drilled holes (Duckworth, 1999). The usual heat sources include metabolic rate of man, earth movement, drilling and blasting, burning of mineral ores and forest wood, and machinery (electrical and diesel), auto adiabatic compression, and geothermal gradient (Bardswich, 1965). Due to the depletion and exhaustion of the surface and sub-surface mineral resources, many countries therefore delve into underground mining of deep mineral resources (He and Guo, 2013). Presently, countries like China are confronted with the challenges of elevated temperatures in underground mines, like the Shandong Sun Cun deep mine. This dry, humid and hot working environment critically endangers the health of mine workers and their effective operations (Asghari et al, 2017; Qiu et al, 2018; Laietal et al, 2018; Mahdevari, 2014).

Going by the technical standards of China concerning the development of ventilation System in deep mine, the bottom hole working temperature of air should not surpass 28°C; so, it is of priority and custom to reduce the damage of heat capacity in underground working locations where high temperature and are inherent (Wang, 2013). The technology of water pump is used to recover the leaking and excess heat from the exhaust of the mine (Sun, 2016; Du et al, 2014). Heat stroke happens when the internal temperature of the body increases beyond 40$^{o}$C (Occupational health and safety regulations, 1996). Getting workers to gradually acclimatize to heat stress situations, under a well-managed surrounding proves to be beneficial in hand-full of mines in South Africa (The Mines Regulations, 2003). This harsh surrounding not only decreases the output of the operations of worker', but it also impinge on their health (Gideon et al, 2015). Asearlyas (1919), a South African researched the thermodynamics of the law of airflow in mine, while Jeppe (1939) portends the elementary notion behind the temperature of winds using mathematical model. Lambrechts (1950) analyzed a large data of measured temperature variation in mine shafts using a mean depth of 1258.8metres.

## III. Material And Methods

This study targets the impact of heat in mining operations. The review method was applied in this paper.

**Data Mining and Methodology**

**Data Collection**

Data about the impact of heat in mining operations were extracted from the internet. All data was gotten from journals.

**Data Review and Analysis**

Data were analysed with Microsoft Excel.

**Table 2:** The percentage of accidents due to an increase in air temperature is related to gold mines in South Africa.

| | | | | |
|---|---|---|---|---|
| **Workplace Air Temperature in the (°C)** | 27 | 29 | 31 | 32 |
| **Frequency of accidents (occupation) per thousand workers** | 0 | 150 | 300 | 450 |

**ENVIRONMENTAL UNDERGROUND TEMPERATURE QUALITY STANDARDS**

Overall, the regulations and rules in conjunction with the limit of temperature in the underground mines differ from one country to country (see table 3).

**Table 3**: Permissible temperature limit for different Countries

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

(Source: Yesid et al., 2018)

Millar, 2016 studied underground tunnel for its Sensible and potential heat capacities as seen in table 4 below:

**Table 4**: Sensible and potential heat capacities of underground tunnel

| Depth(m) | Virgin rock temperature (°C) | Dry surface temperature (°C) | Wet surface temperature (°C) |
|---|---|---|---|
| 1500 | 29.3 | 34.7 | 27.9 |
| 2000 | 38 | 35.2 | 28 |
| 2500 | 46.8 | 35.6 | 28.1 |
| 3000 | 55.5 | 36.1 | 28.2 |
| 3500 | 64.3 | 36.5 | 28.3 |
| Equation | y = 0.017x + 3.03 | y = 0.000x + 33.37 | y = 0.000x + 27.6 |
| $R^2$ | 1 | 0.998 | 1 |

Millar, 2016 went further to research on the heat capacities differing wetness factors using thermal conductivity of 4.5 W/(m°C); Density of rock 2700 kg/m$^3$; Capacity of heat 950 J/(kg°C); Air speed taken to be 2 m/s for all openings of tunnels; Geothermal step of 57.1 m/°C and temperature of rock surface 3°C.

**Table 5**: Underground Tunnel Heat Capacities

| Depth(m) | 1500 | 2000 | 2500 | 3000 | 3500 |
|---|---|---|---|---|---|
| Water (kg/s) | 2.779 | 2.921 | 3.062 | 3.204 | 3.346 |
| Heat transferred on tunnel surfaces (kW) | -7538 | -6152 | -3381 | -1977 | -4766 |
| Diesel mobile plant (kW) | 10,800 | 10,800 | 10,800 | 10,800 | 10,800 |
| Electrical mobile plant (kW) | 6700 | 6700 | 6700 | 6700 | 6700 |
| (Wetness fraction 0.25) Latent Heat (kW) | 6771 | 7114 | 7458 | 7802 | 8148 |
| Broken rock Sensible Heat (kW) | 5 | 129 | 254 | 376 | 499 |
| Drills Sensible Heat (kW) | 7 | 7 | 7 | 7 | 7 |
| Pumps Sensible heat (kW) | 100 | 100 | 100 | 100 | 100 |
| Bolters Sensible Heat (kW) | 24 | 24 | 24 | 24 | 24 |
| Lighting Sensible Heat (kW) | 369 | 369 | 369 | 369 | 369 |
| Auxiliary fans Sensible Heat (kW) | 1600 | 1600 | 1600 | 1600 | 1600 |

## IV. Results And Discussion

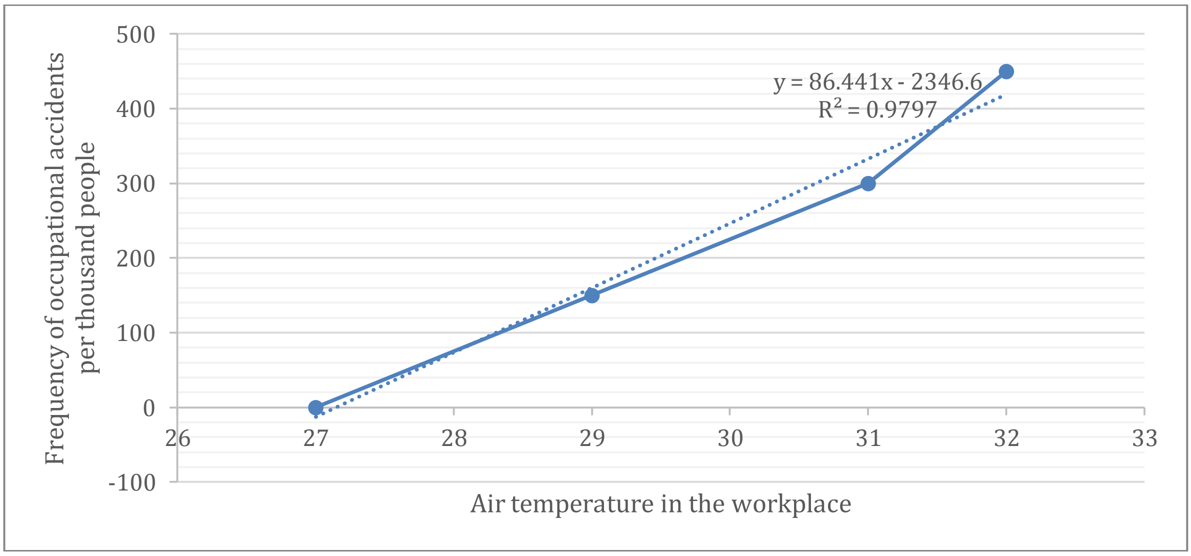


**Figure 1:** Frequency of Occupational accidents per thousand people versus air temperature in the workplace.

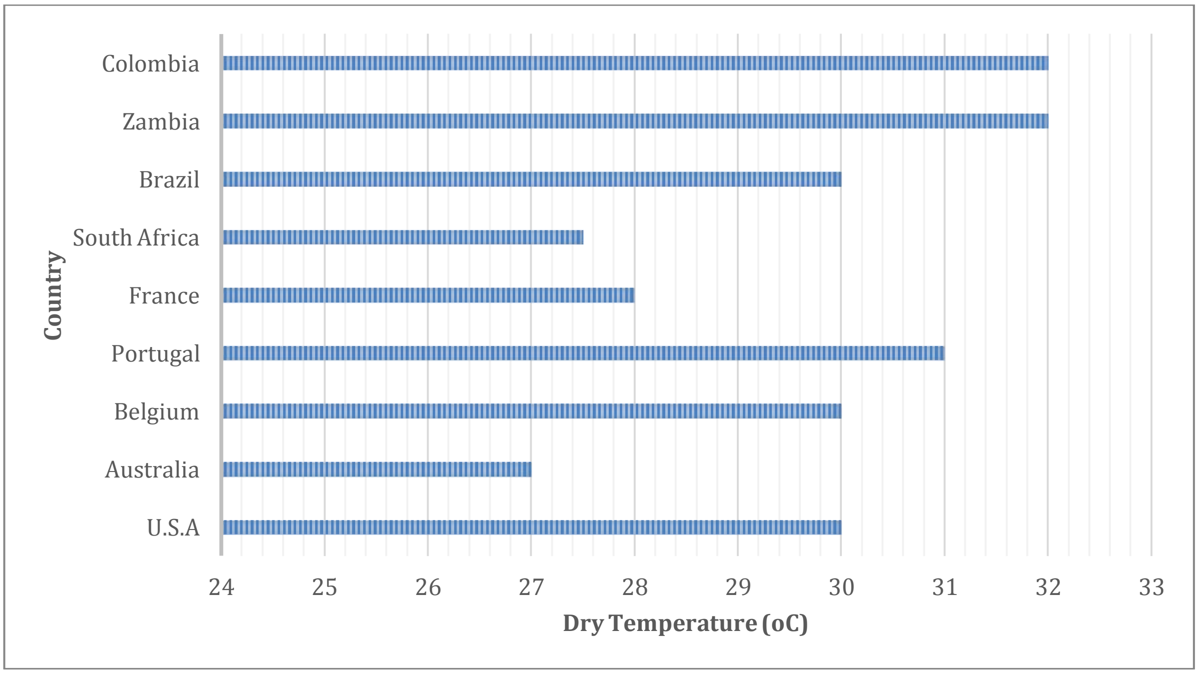


**Figure 2:** Some countries versus their dry temperature

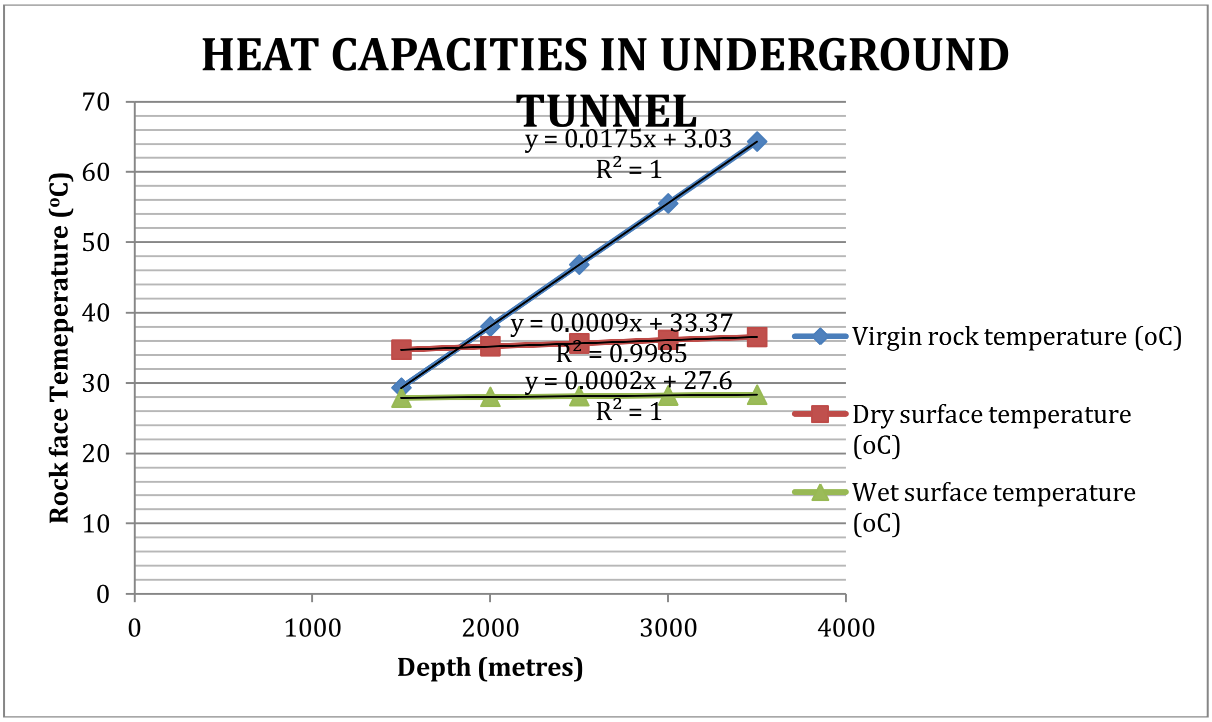


**Figure 3:** Heat Capacities in Underground Tunnel

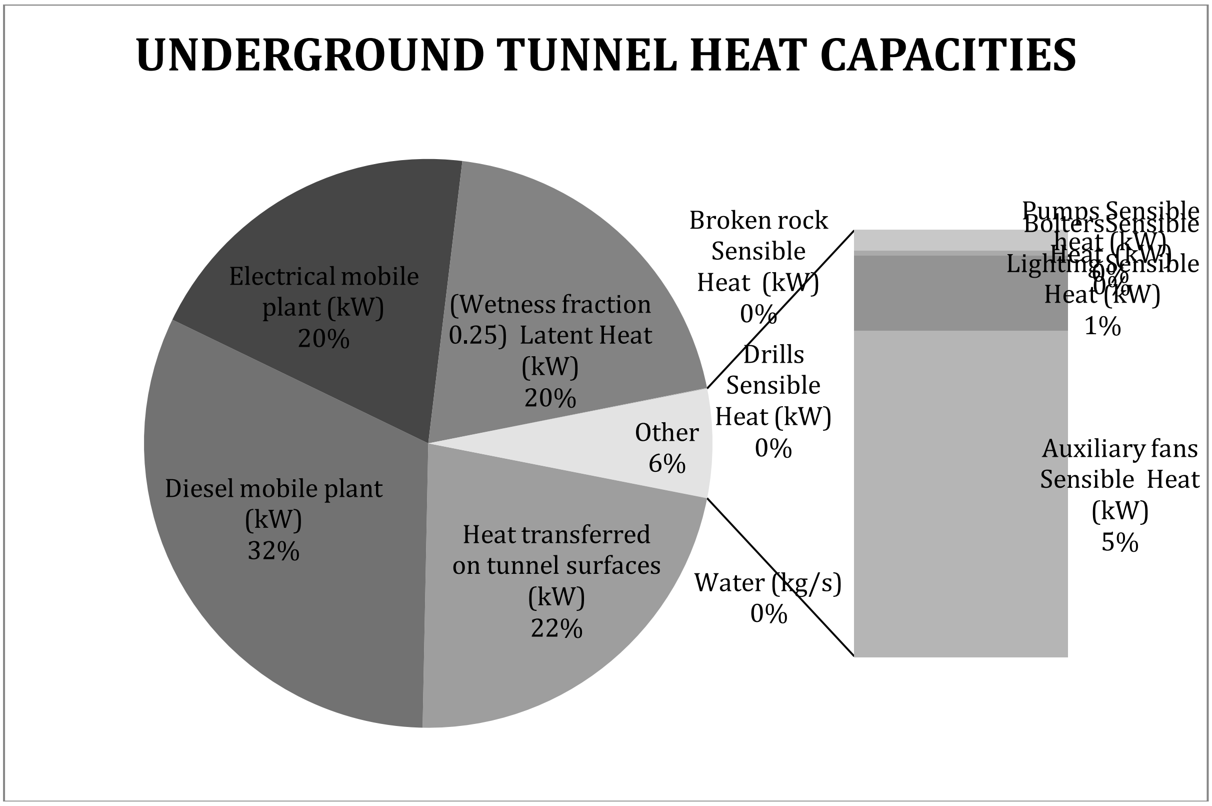


**Figure 4:** Underground Tunnel Heat Capacities

In Figure 1, the percentage of accidents that is due to increase air temperature is related to gold mines in south-Africa. The frequency of occupational accidents is highest at the working air temperature of 32 $^{o}$C with the value of 450 people, i.e. 450 people have the tendencies of having accidents out of an accounted total of 1000 people working in the mines. At the air temperature of 27$^{o}$C, nobody incurs any accident.

In Figure 2, the permissible limit of temperature for some underground mines (with 2 work-hours' time) for workers in some countries were considered. All the countries conforms to the minimum temperature limit, none

the less, the country with the driest and hottest temperature is in Zambia (East Africa, with 32$^{o}$C) and Columbia (South America, with 27$^{o}$C).
In figure 3, the heat capacities in underground tunnel have the highest temperatures, averagely for virgin rocks, from the lowest to the highest depth; followed by the dry surface, with the dry surface rocks as the least.
In figure 4, the diesel mobile plant gave the highest heat, with water, pump, bolter, drill and broken rock estimated to be the least in the tunnel.

## V. Conclusion And Recommendation

Mining activities involves emission of heat. This eventually causes high temperature that affects safety and productivity of the mine. If unchecked, accidents abounds and also heat-related illnesses and risks to work. Control strategies should be engaged such as proper mine designs, work designs and equipment selection. Other options includes setting up safety and health management systems on site, which monitors, reviews, audits and keep records.

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**SUPPLEMENTARY MATERIALS**

**Figure 1:** A typical mine (sigmathermal.com)

**Figure 2:** Heat Stress (Source: cdc.gov)

**Figure 3:** Heat Exhaustion (Source: insider.com)

**Figure 4:** Heat Stroke (Source: healthline.com)

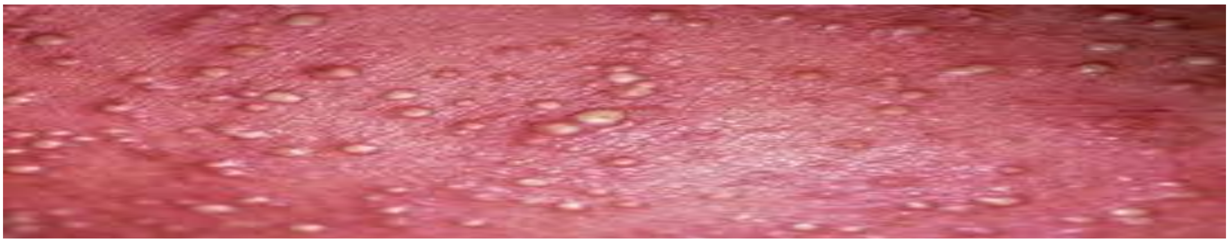

**Figure 5:** Heat Rash (Source: onhealth.com)

**Figure 6:** Heat Cramp (Source: medicienet.com)

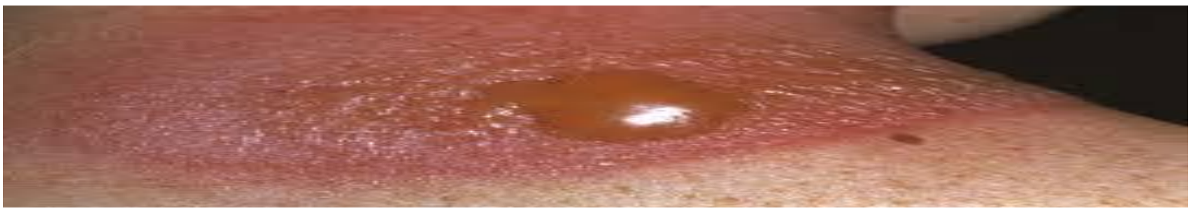

**Figure 7:** Sunburn (Source: msdmanuals.com)

**Figure 8:** Prevention of Heat Illness in Mines (Source: hse.gov.uk)

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