Personal Cooling in Hot Workings

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ABSTRACT

The number of mines experiencing climatic difficulties worldwide is increasing. In a large number of cases these climatic difficulties are confined to working areas only or to specific locations within working areas. Thus the problem in these mines can be described as highly localised, due to a large extent not to high rock temperatures but due to machine heat loads and low airflow rates. Under such situations conventional means of controlling the climate can be inapplicable and/or uneconomic. One possible means of achieving the required level of climatic control, to ensure worker health and safety whilst achieving economic gains, is to adopt a system of active man cooling. This is the reverse of normal control techniques where the cooling power of the ventilating air is enhanced in some way.

Current methods of active man cooling include ice jackets and various umbilical cord type systems. These have numerous drawbacks, such as limited useful exposure times and limitations to worker mobility. The paper suggests an alternative method of active man cooling than those currently available and reviews the design criteria for such a garment. The range of application of such a garment is discussed, under both normal and emergency situations.

KEYWORDS

Mine Climate, Cooling, Personal, and Active Man Cooling.

INTRODUCTION

In order to function normally the human body needs to maintain a reasonably stable internal temperature. In ambient conditions such as experienced in mining operations it achieves this by balancing the heat gain from the environment and metabolic processes against heat loss by convection, evaporation, radiation and conduction. Where this balance cannot be maintained problems can occur (Tuck and Pickering, 1997).

The number of mines experiencing climatic difficulties worldwide is increasing. The main reasons for this being increased depth, with a consequential rise in virgin rock temperature, increased mechanisation, concentration of production and increased levels of production. However, in an increasing number of cases the geothermal contribution to the heat load is minimal with the majority of the heat load being from machinery. Thus in a large number of cases the heat problem is localised to the production areas of the mine and in some cases poor climatic conditions can be a transient phenomena.

The traditional methods of solving poor climatic conditions in mines involve either increasing the ventilating flow rate and/or the application of refrigeration in order to enhance the cooling power of the ventilation airstream. Whilst this can be effective the question must be posed is it the most cost effective method of providing climate control?

One possible means of achieving the required level of climatic control, to ensure worker health and safety whilst achieving economic gains, is to adopt a system of active man cooling. This is the reverse of normal control techniques where the cooling power of the ventilation air is enhanced in some way. Current methods of active man cooling include ice jackets and various umbilical cord type systems. These have numerous drawbacks, such as limited useful exposure times and limitations to worker mobility. The paper suggests an alternative method of active man cooling than those currently available and reviews the design criteria for such a garment. The range of application of such a garment is discussed, under both normal and emergency situations.

GENERAL PRINCIPLES OF CLIMATE CONTROL IN MINES

The maintenance of satisfactory climatic conditions in mines is of primary importance (Tuck, 1997) and a number of methods can be employed to solve heat problems in underground mines. No general method for solving mine heat problems exists, each situation requires individual attention, however good design practises can be adopted and a logical progression of methods can be defined. In designing a means for solving a mine heat problem the following should always be borne in mind:

1. The method should operate in harmony with the existing mining infrastructure.
2. The method should be flexible.
3. The method should be economic.
4. The method must cope with the need to expand to follow current and future mining activities.

A number of means exist which can be used in isolation or in combination to solve a heat problem, these include:

1. Good ventilation control;
2. Ventilation methods, alteration of the mining method;
3. Reduction or elimination of heat flow at source;
4. Refrigeration;
5. Micro climate cooling;
6. Acclimatisation;
7. Education; and
8. Heat money.

The objective guiding the determination of a climate control method is to produce a thermal environment which both ensures the health and safety of the workforce whilst allowing them to perform tasks to achieve the level of productivity desired. To achieve this it is necessary to effect an improvement in one or more of the main parameters which influence the ability of a human to work in hot and humid conditions. The main parameters influencing the ability of a human to work in hot and humid conditions are:

1. The air dry bulb temperature;
2. The air wet bulb temperature;
3. The air velocity;
4. The work rate required to perform the required task; and
5. The ability of the body to cope with hot humid conditions.

Thus in order to ameliorate the working climate it is necessary to affect an improvement in one or more of the above, the most important parameters to improve are the wet bulb temperature of the air and the air velocity. Therefore three guiding principles for the reduction of the effects of adverse climate are:

1. Reduction of heat load at source;
2. Removal of the man from the source; and
3. The provision of personal protection.

Various solutions using these principles have been applied within the industry and it is usually the first which is applied be it in the form of increasing airflow or the application of cooling. Removing men from the area has received less attention, the main reason that it would involve a radical change to current work practices, although remote operation of mining equipment is becoming more common. However to a certain extent the use of reduced shift lengths is a common method used in hot mining conditions. The third method, personal protection equipment is the subject of this paper.

PERSONAL COOLING SYSTEMS (MICROCLIMATE)

The provision of a microclimate involves intimately providing a worker or small group of workers with a zone of improved climate around them within an envelope of a much worse environment. Usually it involves the cooling of a specific worker or the air around the worker to effect the environmental improvement. However a well used exception to this rule is the use of small fans or compressed air movers aimed at a specific work location in order to locally increase the air velocity. More usual examples of the method are the use of microclimate suits such as ice jackets (Schutte, Keilblock and Marx, 1994) or the provision of a separate cooled environment by practising cab air conditioning on mobile plant or specific items of equipment (Robinson, 1995). The provision of microclimates is still in it's infancy in mining and there is still much development to be undertaken however given the high costs associated with conventional mine refrigeration systems it offers an attractive alternative with distinct economic benefits and the advantage of directly benefiting the worker. Given that mining operations are becoming more and more mechanised with mine workers having a more sedentary work pattern than in the past the requirement to cool a large proportion of mine air is becoming uneconomic in some situations and microclimates a more interesting possibility.

With regard to this paper the subject of microclimate cooling is limited to thermal protective garments. The aim of such garments is to reduce the heat load on the wearer of the garment rather than reducing the heat load at source. Such garments act in one of two ways. They either provide a barrier between the heat source and the body, such as aluminised garments for protection from high radiant heat loads or they remove heat from the immediate vicinity of the wearer.

AVAILABLE COOLING GARMENTS

A number of different cooling garments have been tested in a variety of environments. The methods used can be broadly classified into three groups:

1. Those where the cooling system is integral to the jacket, such as ice jackets.
2. Those where the cooling system is external to the jacket but carried on the body, such as ice or dry ice (solid CO_2) in a back or bely pack.
3. Those where the cooling source is situated away from the body and connected to the body by a tube or umbilical cord.

Ice jackets are well tested under mining conditions (Stydom *et al.*, 1976; Mucke, 1982; Sweetland and Love, 1974; De Rosa and Stein, 1976). Basically they consist of a jacket containing water sewn into pockets either within or on the jacket. The garment is then frozen and then worn by a worker operating in a hot environment. Studies have shown that the garments are effective in allowing the wearers to work significantly longer in hot conditions. However, the weight of the jackets has been shown to significantly increase the energy expenditure of the wearers. Other drawbacks include loss of mobility due to the bulk of the pockets containing the ice and in most cases the jackets did not last a full working shift. Use of dry ice rather than water ice can reduce the weight of the garment and enhance mobility however the cost is greater and there can be a risk of skin damage due to ice burns.

Portable cooling sources rely on heat exchange with a fluid medium, usually water or silicon oil, which is circulated around a network of tubes incorporated into a garment. Such systems can weigh between 5 kg and 13.5 kg. Again the systems are effective at reducing the rate of increase in body core temperature, but not more so than ice jackets. They suffer the same problems as ice jackets in that they are bulky so increase energy expenditure and cause mobility problems (Mucke, 1982; Webbon *et al.*, 1977).

Externally connected cooling systems have been investigated for a number of purposes, notably in aerospace and space industry application. Such systems consist of some type of garment, covering all or only part of the body which has tubes in which a circulating cold fluid is circulated. The cold fluid is pumped from a source external to the wearer via a connecting hose or umbilical cord. The principal advantages of this type of system are that it does not need recharging like the body borne systems and it will not result in a significantly increased load on the body compared to the body borne systems.

Such external cooling systems have been investigated for mining application. Work undertaken by the National Coal Board in the United Kingdom in the 1980's devised such systems for the operators of roadheading machines (Nicholl *et al*, 1985). The systems investigated included a variety of suit designs, including full coverall and limited coverage garments with or without head hood, which were connected to a purpose built water cooler powered from the hydraulic circuit of the heading machine. The results of the study were encouraging in that significant improvements in physiological response were measured. The main problem with such a system is the umbilical cord connection, this can cause mobility problems and was recognised as a potential health and safety hazard.

Thus garments exist which can be applied in the mining industry, however they have not attained a wide application within the industry for a number of reasons. Principally because they have a limited lifespan, restrict mobility, are not comfortable to wear and in some cases are heavy. Having said this ice jackets are used in mines rescue situations where the protection offered far outweighs the problems of such garments.

Ice jackets have also been under constant development, particularly in South Africa. MSA(Africa) have recently introduced an ice jacket called the Ice Chest Cooling Vest (Mine Ventilation Society of South Africa, 1998). This has been tested by CSIR Mining Technology to establish the protective properties of the vest, shown in Figure 1. The tests revealed that cardiovascular strain was reduced whilst wearing the jacket as was the incremental increase in core temperature compared to controlled exposure without the protection. The conclusion of the tests were that the vest provided protection whilst working in heat and could be crucial in preventing heat stroke provided that procedures for wearing the jackets were adhered to and that tolerance times for the vest were observed. Thus whilst the vest is effective and has gone some way to improving the mobility problems associated with previous ice jackets the crucial feature of limited lifespan has not been enhanced substantially.

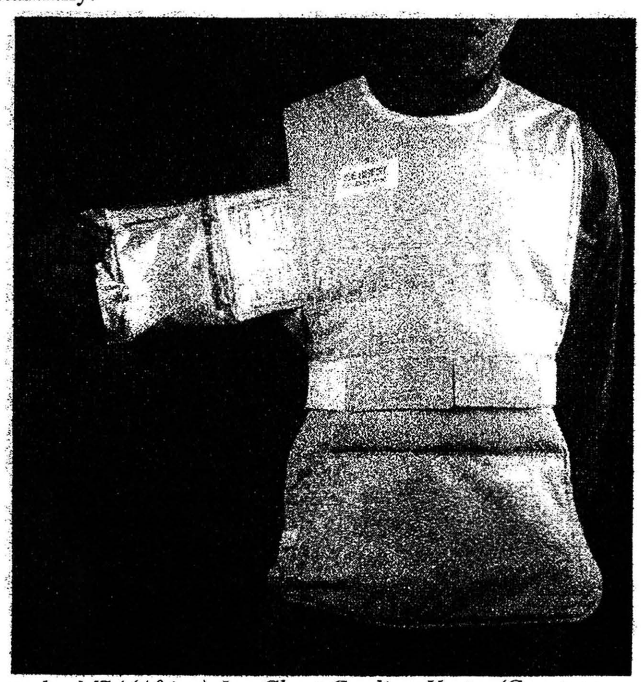

Figure 1. MSA(Africa) Ice Chest Cooling Vest. (Courtesy MSA (Africa), Pty, Ltd).

DESIGN CRITERIA FOR A NEW MICROCLIMATE GARMENT

Existing methods of microclimate cooling garments suffer from three main problems:

1. Limited lifespan, except in the case of umbilical cord systems.
2. Limitations with respect to worker mobility
3. Increased load on the worker due to weight of garment and the cooling medium.

Thus any new garment proposed needs to address the above problems, whilst maintaining the advantages of microclimate cooling garments. As such design criteria for such a garment can be defined, as follows:

1. The garment must be robust enough to withstand the rigors of the environment for which it is intended.
2. It must be lightweight so as not to cause increased load on the wearer.
3. It requires an insulating outer cover to keep the coolth in whilst keeping the heat out from the external environment. In other words the majority of the heat transfer to the coolant must come from the human body not from the external environment.
4. The inner surface of the garment must not be a a temperature which will cause ice burning. The subjective comfort of the wearer is more important to some extent than the benefit obtained by having a colder inner surface temperature. If the garment is too cold to wear, then it is likely that, a worker will not wear it in the correct manner. Wearing the garment over a shirt or other under garment may be a solution to this problem, alternatively correct selection of the internal lining material of the garment may alleviate the problem of the inner surface feeling too cold.
5. The garment must not limit worker mobility. Thus it must not be bulky. Probably the optimum style of garment to ensure complete mobility is a vest style garment.
6. The garment needs a cooling 'charge that is effective for a full shift or that can be recharged simply and quickly during a shift or working period without the need for specialist equipment or tools.
7. The outer surface of the garment needs to be visible in an underground environment.

To satisfy the above the following design of garment is proposed:

1. A vest style garment of minimal thickness to ensure mobility whilst minimising weight.
2. The vest will have a internal lining material which will ensure that the subjective feeling of cold will not be too severe and which will ensure that no friction type injuries can occur from wearing the jacket.
3. The outer surface of the jacket will consist of a insulated skin to minimise heat transfer to the circulating coolant from the ambient environment with a reflecting type surface to minimise radiant heat transfer and to maximise worker visibility to other workers in the area.
4. The cooling effect is to be provided by a circulating gas/vapour. This is to circulate within defined channels/tubes within the vest.
5. The gas is to be provided by a small, re-useable canister of liquid gas worn on the miners lamp belt and connected to the vest by a short length of tubing. The connection between the gas container and the vest connecting tube is to be of a simple design to allow easy replacement of the gas container once empty.
6. Flow of the gas coolant through the vest is provided by a simple differential pressure between the gas container and the release vent within the vest which vents warm gas direct to atmosphere, see Figure 2.
7. Indication of the need to change gas containers can be given via a simple pressure gauge mounted either on the container or at some point within the circulation path.
8. As the gas is to be vented to atmosphere careful selection of the gas used needs to be undertaken. Selection needs to be made on the basis that the gas must not be flammable, carcinogenic, an asphyxiant and that the temperature must be such that no frost or ice burn injuries can occur.
9. Ideally an inert gas would be preferable, however preliminary studies have shown that liquid nitrogen is too cold for such an application.

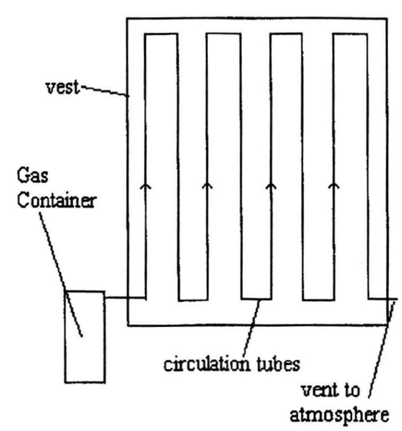

Figure 2. Schematic of proposed cooling garment.

The proposed design is simple, with the advantage of minimal moving parts which should make it robust enough for the task required. The method of circulation of the coolant within the vest relies purely on difference in pressure between the gas container and the ambient environment. The only problems foreseen at this stage in development are in ensuring constant flow of the gas within the vest and that the gas does not discharge too quickly through the system. These problems can be simply rectified by the use of a regulating valve within the system, incorporating a safety pressure relief valve. This should be able to ensure that the residence time of the coolant within the system is long enough. This will ensure that adequate transfer of heat from the body to the vest occurs to enable the temperature of the vented gas to be high enough. Thus ensuring that the amount of released gas is not excessive and to ensure a high enough level of system efficiency.

The proposed design is lightweight and will not add to the workload of the wearer. The method of cooling also allows for simple replacement of the cooling source on demand thus ensuring that full shifts can be worked.

CONCLUSIONS

Microclimate cooling has the potential to be of great benefit to the mining industry enabling the industry to change the ethos of climate control in mines. Currently the industry achieves the desired goals of climate control by either enhancing ventilation flow rates and/or applying air cooling on bulk within mines. Microclimate cooling allows the emphasis to shift from the ventilation to direct cooling of the individuals working in mines. The potential cost savings of shifting to microclimate cooling of the workforce are substantial. Cooling garments are one means by which microclimates can be established within mines.

The aim of this paper was to briefly review the methods currently available with respect to microclimate cooling garments within the mining industry and to suggest a possible new design of a cooling jacket. Design criteria for such a garment were described, as were other aspects of the design. The proposed design satisfy's the needs of the industry. It should be noted that research into the design of the garment is at a very early stage of development.

The potential use of such garments within the mining industry is high, not just within normal production but also in mines rescue applications where normal means of cooling can be inapplicable and the thermal loading can be very high on rescue personnel. The proposed design also is applicable to other industries and activities where heat stress is a potential hazard.

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