Determining the Physical and Economic Impact of Environmental Design Criteria for Ultra-deep Mines

Mr RCW Webber

Presented in partial fulfilment of the requirements for the degree

M.ENG. (MINING ENGINEERING)

IN THE FACULTY OF ENGINEERING

DEPARTMENT OF MINING

UNIVERSITY OF PRETORIA

NOVEMBER 2000

ABSTRACT

Ultra-deep mining (to depths of 5 000 m and greater) would be a world first and, accordingly, no previous experience in the determination of acceptable heat stress limits, criteria or indices is wholly applicable. However, some South African gold mines are already operating at depths beyond 3 500 m and much of the knowledge gained in reaching and working at such depths will be helpful in making adequate provision for acceptable environmental control at the greater depths being contemplated. Accordingly, it is necessary to take cognizance of the industry's experience in deep-level mining and of standards and regulations already established in South Africa and elsewhere in order to ensure acceptable working conditions, and standards to control them, that compare favourably and defensibly with those in other mining industries.

The purpose of this project was therefore to investigate the physical and economic impact of environmental design criteria to be used in ultra-deep-level mining. It was necessary to establish a new basis from which the cooling and ventilation requirements for ultra-deep mines could be simulated and evaluated. For this reason it was important to establish in what way these environmental design parameters would affect the productivity of the workforce (physiologically and psychologically) and what economic and environmental constraints would be involved.

Another purpose of this investigation was to establish the basis and application of workplace environmental criteria, standards and limits, both locally and internationally, to determine norms for occupational exposure to various environmental stressors and to evaluate standards for controlling them. The motivation was to ascertain the requirements for providing environmental conditions that would compare favourably and defensibly with those in other mining industries and to ensure the health, safety and productivity of workers, as well as the confidence of potential investors. A further aspect of the work was reviewing the relevant environmental factors in order to identify those that would become more critical at mining depths approaching 5 000 m, including their potential impact on workers and the extent to which they would affect mine designs and planning. The relevant standards and limits pertaining to the factors identified were then evaluated in terms of their

appropriateness and practicability for ultra-deep mining, and their cost implications were analyzed for the mining depths being contemplated.

The local and international use of heat stress limits, criteria and indices were also investigated. These are intended to ensure the health, safety and productivity of workers and, in the case of a heat stress index, to quantify the level of heat stress imposed by the environment. It was necessary to determine to what extent any other indices, limits or criteria would be applicable to South African deep mine conditions. In addition, it was necessary to establish whether there was a single heat stress index that could be used for South African deep mining conditions. Various practitioners from the industry were also consulted with regard to parameters that might influence ultra-deep mining.

Six heat stress indices that satisfied most of the important criteria were identified. The findings detailed in this report indicate that it is likely that an appropriate combination of heat stress indices will be required in planning for and ultimately controlling thermal conditions in ultra-deep mining. The depths being contemplated and the concomitant potential heat hazard present too great a risk for reliance on a single heat stress index, such as the wet-bulb temperature index at present in common use locally. Although this index is expected to be useful in ultra-deep mining, it is likely that it would be more beneficial when used in combination with others, such as wet-kata cooling power and specific or air cooling power (SCP and ACP, respectively). This would allow the use of the index most appropriate for a specific purpose, for example determining ventilation and cooling requirements, specifying minimal cooling power/maximal heat stress limits or monitoring workplace conditions. However, it would be essential to ensure that any inconsistencies among the indices adopted for these various purposes are quantified in order to avoid discrepancies between what is stipulated or planned and what is ultimately achieved. It was found that numerous heat stress indices are currently applied throughout the world's mining industries, and that some countries use a combination of indices as a means of specifying and quantifying heat stress limits.

The need to quantify the costs associated with various levels of wet-bulb temperature and air velocity (the two most important determinants and means of controlling heat stress) was *addressed through an analysis of a model mine operating at a depth of approximately 5 000 m. Several combinations of these two parameters were considered and the costs compared, enabling an assessment to be made of the relative costs involved in limiting environmental heat stress at various levels. It was also found that the ideal situation would be to provide a reject wet-bulb temperature of 25°C or, at least, lower than 27,5°C, to ensure productivity or, alternatively, to control the risk of heat disorders without resorting to formal heat stress management and all that it entails. The decision as to whether to provide a reject wet-bulb temperature of, say, 25°C or 27°C requires incremental quantifications of the decrement in performance and the difference in cost implications between such temperature levels. This would be particularly important for critical mining tasks and should clearly be considered in combination with the results of a detailed analysis of the costs of providing these various levels of wet-bulb temperature.*

From this investigation it was also found that it is possible that the provision of a given level of cooling power at a working depth near 5 000 m would be more cost-effective through increasing refrigeration and reducing the amount of ventilation air. This implies that lower wet-bulb temperatures may be more viable than had previously been expected.

The specific wet-bulb temperatures and stope face air velocities used in this study were adopted for the purpose of comparative cost analyses and should not be regarded as recommended levels. Such levels can only be determined through due consideration of the relevant physiological and work performance criteria, and within the specific design constraints for each mine. It is therefore imperative that the results of this investigation be interpreted with circumspection as the cost implications for environmental control in ultra-deep mining appear to differ significantly from those for current mining depths. However, the major conclusion, namely that reducing the design reject wet-bulb temperature, within limits, does not affect ventilation and cooling costs to the same extent as increasing the total air-flow quantity, appears to be valid for the mining depths being contemplated. In this regard, the simulation results indicate a cost increase of approximately 30% for reducing wet-bulb reject temperatures from 31°C to 25°C, as opposed to an increase of approximately 60% for increasing the stope face air velocity from 0,5 to 1,5 m/s.

Although it is recommended that the required level of environmental cooling power be provided at a minimum total air mass flow rate, it is recognised that practical constraints will dictate the minimum air flow quantity that can be used. Should existing mines be extended to ultra-deep levels, increasing refrigeration capacity may be preferable to increasing air quantities, given the relatively higher costs implied by the latter approach. To further contain the cost of providing a given air velocity at great depth, recommendations are provided on the implementation of controlled recirculation strategies. It must be noted, however, that such an approach could indicate the need to consider reducing emissions at source and/or introducing control measures for major contributors to air pollution in order to control air quality. In this regard, the potential benefits of controlled recirculation, together with the problems that could arise from its inappropriate implementation, formed an integral part of this investigation. An indication of the optimal use of controlled recirculation is also given.

From the various recirculation models for a longwall follow-behind mining layout that were investigated, it was found that global recirculation of air seemed to be the most cost-effective system in planning ventilation requirements at ultra depth. It was also found that a global recirculation percentage of return air of approximately 30% seemed to be the optimum for planning purposes with this type of mining layout. It appears that the application of recirculation strategies will be imperative in future if mining is to be done profitably. A saving of approximately 5% with recirculation was indicated in a comparison with a base-case ultra-deep-level simulation in which there was no recirculation of air. An expected cost figure of $38.9, in terms of dollar/ounce of gold produced, for the cooling and fan requirements for ultra-deep-level mining was calculated. The simulations done were based on conditions for a typical ultra-deep-level mine in the Carletonville area.

Finally, practitioners indicated the need for a multi-disciplinary approach to planning mine environmental control systems, for the establishment of a common virgin rock temperature database and for measures to control air pollutants based on health risk assessments. They also identified the need for research to resolve uncertainties regarding the significance of backfill as a heat source and regarding the control of heat transfer through the effective use of insulation. Practitioners' differing views on issues such as open-circuit vs. closed-circuit *pumping, surface vs. return airway heat rejection, and ice vs. chilled water as a cooling medium may be similarly indicative of additional research needs.*

CONTENTS

Acknowledgements

The author gratefully acknowledges the assistance provided by the following organisations and people:

- The South African Labour Organisation (Mrs Charlene Stepischneck)
- The World Health Organization - South African Branch (Dr W. Shasha)
- The International Labour Organisation
- The Australian Industrial Relations Department
- The German Embassy to South Africa (Pretoria)
- The United States of America Information Services (USAIS)
- The following staff members of the CSIR Division of Mining Technology (Miningtek): Mr Wynand Marx, Mr Mike Franz, Mr Mark Butterworth, Mr Russell Hattingh, Mr Jason Matesa and Mrs Martie van Deventer
- Mr Dirk van Greunen, Chief Environmental Officer on Oryx Mine
- Mr Ken Gudmanz, Department of Minerals and Energy
- Professor Andrè Fourie, University of Pretoria
- The Deepmine Project Team - Co-operative Research Programme
- Bluhm Burton Engineering (Pty) Ltd.
- Diane Nortje (neè Webber) for her typing parts of this document

Nomenclature

°C	Degrees centigrade
ACGIH	American Conference of Governmental Industrial Hygienists
ACP	Air Cooling Power
AIHA	American Industrial Hygiene Association
ASHRAE	American Society for Heating, Refrigerating and Air Conditioning Engineers
BET	Basic Effective Temperature
BP	Barometric pressure
Bpm	Beats per minute
Capex	Capital expenditure
CET	Corrected Effective Temperature
CP	Cooling Power
CRA	Climatic room acclimatisation
DB	Dry bulb
DME	Department of Minerals and Energy
ET	Effective Temperature
FV	Face velocity
h	Hour
HSM	Heat stress management
HTS	Heat tolerance screening
HTT	Heat tolerance testing
ILO	International Labour Organisation
IPE	Index of Physiological Effect
ISO	International Standards Organisation
ITS	Index of Thermal Stress
J	Joule
km	Kilometre
kt	Kiloton
kW	Kilowatt
kWh	Kilowatt-hour
ℓ	Litre
L/M/H	Low/medium/high
M	Mega-
m	Metre
min	Minute
MRC	Medical Research Council
MRT	Mean radiant temperature
NIOSH	National Institute for Occupational Safety and Health
Opex	Operating expenditure
OHSA	Occupational Health and Safety Act
PV	Present value
R	Rand
RH	Relative humidity
RI	Relative importance
s	Second
SCP	Specific cooling power
SCSR	Self-contained self-rescuer

SW_{req}	Required Sweat Rate index
T_{db}	Dry-bulb temperature
T_g or T_r	Globe temperature/radiant temperature
T_{mr} or MRT	Mean radiant temperature
T_{nwb} or T_w	Natural or unventilated wet-bulb temperature
T_{wb}	Psychrometric or ventilated wet-bulb temperature
TLV	Threshold limit value
UDM	Ultra-deep mining
U/G	Underground
UN	United Nations
V or u	Air velocity
VRT	Virgin rock temperature
W	Watt
WB	Wet-bulb
WBGT	Wet-bulb globe temperature
WGT	Wet globe temperature
WHO	World Health Organization

List of Figures

List of Tables

List of Annexures